

**SATURATION
SYSTEMS INC.**
SAN DIEGO, CALIFORNIA

**VOLUME
2**

**MIXED-GAS
DIVING**



U S NAVY DIVING MANUAL
NAVSHIPS 0994-001-9010

VOLUME

2

MIXED-GAS DIVING

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SEPTEMBER 1973

Navy Department
Washington, D. C. 20350



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

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

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FOREWORD

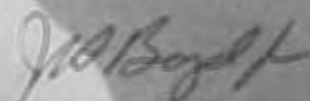
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The U.S. Navy Diving Manual (NAVSHIPS 0004-001-9010 September 1973) supercedes the U.S. Navy Diving Manual of March 1970.

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

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



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

PREFACE

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

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

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

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

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

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

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

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



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Captain, U. S. Navy
Supervisor of Diving

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CHAPTER NINE

MIXED-GAS DIVING THEORY

The term, "mixed-gas diving," refers to diving operations conducted using any breathing medium other than air. This medium might consist of nitrogen and oxygen in proportions other than those found in the atmosphere, or it might consist of a mixture of other inert gases with oxygen. The breathing gas might also be 100% oxygen itself, which is not technically a "mixed" gas but which requires similar knowledge and training for safe use. Mixed-gas operations do not exclude the use of air, however, as air may be used in some phase of a mixed-gas dive.

Mixed-gas diving is generally a complex undertaking. A mixed-gas operation requires detailed planning, the use of specialized and advanced equipment, and extensive surface support personnel and facilities. Because of the very nature of mixed-gas operations—often conducted at great depth or for extended periods of time—hazards to personnel and to the success of the operation are greatly increased. For these reasons there can be no such thing as a "casual" mixed-gas dive.

The U.S. Navy Diving Manual, Volume One, is a comprehensive introduction to the theory and practice of diving with surface-supplied air, or with SCUBA using compressed air as the breathing medium. Any diver approaching the study of mixed-gas diving must first be qualified in air diving operations, and a thorough familiarity with the contents of Volume One is presupposed in the material presented in Volume Two.

This chapter presents information on the development and employment of mixed-gas diving equipment and techniques, and also serves to orient the diver to important aspects of underwater physics and physiology as they particularly apply to mixed-gas diving. Additionally, planning factors unique to mixed-gas operations are considered.

HISTORIC DEVELOPMENT OF MIXED-GAS DIVING 9.1

Oxygen Diving 9.1.1 Diving equipment which had been developed through the mid-nineteenth century greatly limited a diver's freedom of movement because of the requirement for surface-supplied air. Early attempts to supply self-contained compressed

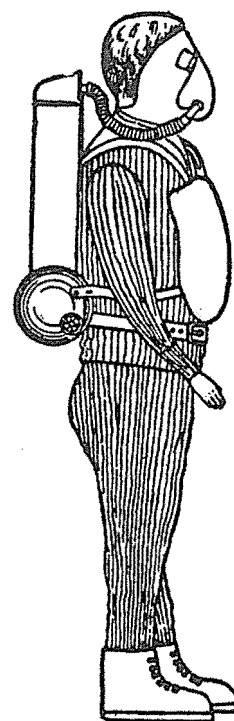


Figure 9-1 Fleuss Apparatus; the first oxygen recirculating breathing apparatus.

air for use by divers were not successful, due to the limitations of both pumps and containers to package air at sufficiently high pressures.

In 1876, Henry Fleuss began development of an oxygen rebreathing device which freed the diver of dependence upon surface support. The Fleuss device used a watertight rubber face mask connected by breathing tubes with a copper tank of oxygen charged to 450 psi and a breathing bag. The diver would inhale pure oxygen. His exhaled breath would pass into the breathing bag and there be drawn through rope yarn which has been soaked in a solution of caustic potash. This chemical absorbed the carbon dioxide, and allowed the unused portion of oxygen to be re-circulated through the face mask. In the early models of this apparatus, the make-up feed of fresh oxygen was controlled by the diver with a hand valve.

Fleuss successfully tested his apparatus in 1879, first in a tank of water where he remained for about an hour, and then by walking along a creek bed at a depth of eighteen feet. During this dive Fleuss, who had an insatiable curiosity, wondered what might happen if he turned off his oxygen feed. He soon became unconscious and suffered gas embolism as he was hauled to the surface by his tenders. A few weeks

after his recovery, Fleuss made arrangements with Augustus Siebe's diving equipment company to put his re-circulating design in commercial production. Somewhat refined, and with the addition of a demand-regulator to replace the need for hand valving of the oxygen, the Fleuss SCUBA became the direct ancestor of a wide ranging family of respirators, submarine escape devices and combat swimmer breathing units.

Respirators—such as the Navy Oxygen Breathing Apparatus (OBA)—are used for rescue and fire-fighting in smoke filled environments. Submarine escape devices have been largely superseded by free-escape techniques, which have been tested to depths of 500 feet. In the U. S. Navy, the recommended free-escape method utilizes the "Steinke Hood," which is not a breathing device but, rather, a simple head-and-shoulder hood with a faceplate window. The hood contains some of the swimmer's exhaled breath and exhaust from the life jacket during ascent; it also keeps water away from his face and permits vision. This provides significant psychological support to the swimmer which is particularly needed during an emergency escape. For escapes from greater depths, rescue devices, such as the McCann-Erickson Chamber and the Deep Submergence Rescue Vehicle (DSRV), must be employed.

Combat swimmer breathing units were widely used in World War II, particularly by the British, Italians and Japanese. The swimmers used various modes of attack—some rode diver-guided "chariot" torpedos, some were carried to the scene of action in midget submarines from which they placed explosive charges under the hulls of enemy ships. Several notable successes were achieved, including the sinking of several battleships, cruisers, and a number of merchant ships.

In 1936, the Italian Navy tested a chariot torpedo system in which the driver-divers used a descendant of the Fleuss SCUBA. This was the "Davis Lung" designed originally as a submarine escape device, and later manufactured in Italy under a license from the English patent holders.

The British began their chariot program in 1942 using the Davis Lung and also exposure suits. Experience soon brought improvements. Swimmers using the MK

I Chariot Dress quickly discovered that the steel oxygen bottles adversely affected the compass of the chariot torpedo. Aluminum bottles were not available as an item of supply in England, but German aircraft used aluminum oxygen cylinders. The aircraft cylinders were almost the same size as those aboard the MK I and were easily salvaged in sufficient numbers from downed enemy bombers to correct the problem.



Figure 9-2 The original Davis Submerged Escape Apparatus consisted of a breathing bag, relief valve, CO₂ absorbent canister, emergency O₂ capsule, main O₂ cylinder and valve, non-return valve and flexible tube for charging the breathing bag and a corrugated tube leading to the mouthpiece.

Other changes, through the MK II and MK III Dress, involved improvements in valving, faceplate design and arrangement of components. After the war, the MK III became the standard Royal Navy Shallow Water Diving Dress. The MK IV Dress, used toward the end of the war, had one major difference from the MK III. The MK IV 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 independent freedom of movement away from the chariot torpedo.

The Japanese not only used diver-guided torpedos (the **Kaiten**) with some success, but also developed what may well be considered the most unusual sub-surface combat force of the war. This was the **Fukuryi**

volunteer group made up of underwater sentries who were assigned to patrol by walking along the sea bottom just offshore from the home islands. Their mission was to stop incoming enemy landing craft. They wore rubber suits and helmets equipped with oxygen rebreathers; and, for a weapon, were equipped with a contact mine on the end of a long pole. Theoretically, they would be expected to thrust the mine up against the bottom of a landing craft as it passed overhead. In a test, one officer walked an 8-hour patrol at a depth of 27 feet. The Fukuryi did not see combat, since the war ended before an invasion of Japan became necessary.

U. S. combat swimmers in World War II were of two different groups. Naval beach reconnaissance units did not normally use any breathing device, although several models existed. Other groups of U. S. operational swimmers, under the Office of Strategic Services, developed and applied advanced methods for true self-contained diver-submersible operations. They employed a rebreather invented by Dr. C. J. Lambertsen, the Lambertsen Amphibious Respiratory Unit (LARU). The LARU was a closed-circuit oxygen SCUBA for use in clandestine operations where a complete absence of exhaust bubbles was necessary. The standard unit now in use by USN combat swimmers is the Emerson-Lambertsen oxygen rebreather derived from the WW II LARU. However, for most work, open or semiclosed units are usually preferred because of greater depth capabilities and the decreased possibility of oxygen poisoning.

The problem of oxygen toxicity was unknown to Fleuss and was apparently not encountered in early shallow water experiments with his apparatus. The danger of oxygen poisoning had actually been discovered prior to 1878 by Paul Bert (the same physiologist who first proposed controlled decompression as a solution to the problem of the bends). In experiments with laboratory animals, Bert demonstrated that breathing oxygen under pressure could lead to convulsions and death. In 1899, another researcher found that breathing oxygen over prolonged periods of time, even at pressures not sufficient to cause convulsions, could lead to serious lung irritation.

The results of these experiments were not widely nor quickly known, and for many years divers were not



Figure 9-3 Lambertsen Amphibious Respiratory Unit (LARU).



Figure 9-4 Emerson-Lambertsen Oxygen Rebreather.

aware of the dangers of oxygen poisoning. In fact, not until large numbers of combat swimmers were being trained in the early years of World War II did the true seriousness of the problem become apparent. After a number of oxygen-poisoning accidents, the British established an operational depth limit of 33 feet. In recent years, this has been reduced to a working-depth of 25 feet. The subject of oxygen toxicity is discussed in more detail in Section 9.3.2.

Non-Saturation Mixed-Gas Diving 9.1.2. The practical limit for air diving operations was established in 1915 when the U S S F-4 was salvaged from 304 feet. The Navy divers were able to work at that depth—but just barely. The decompression requirement, combined with the effects of nitrogen narcosis, limited bottom time for each dive to about 10 minutes.

A few years later, a prolific inventor named Elihu Thomson theorized that helium might be an appropri-

ate substitute for nitrogen in a diver's breathing supply, and he estimated at least a 50% gain in working depth by the use of helium. In 1919, he suggested that the U. S. Bureau of Mines investigate this possibility. Thomson directed his suggestion at the Bureau of Mines, rather than the Navy Department, since the Bureau held a virtual world monopoly on the marketing and distribution of helium.

In 1924, the Bureau of Mines and the Navy joined to sponsor a series of experiments in the use of helium-oxygen mixtures. The initial work was done at the Bureau of Mines Experimental Station in Pittsburgh, Pennsylvania. In 1927 the Navy shifted the operations of its own Experimental Diving Unit (EDU) from Pittsburgh to Washington, D. C. where the work continued.

The first tests showed no detrimental effects on animals or humans from breathing a helium-oxygen mixture. The principal physiological effects noted by all divers when using helium-oxygen were the increased sensation of cold caused by the high thermal conductivity of helium and the "Donald Duck" effect on human speech that resulted from the acoustic properties of the gas.

The depth advantage to be gained from the use of helium was soon well established. In 1937, at the EDU, a diver wearing deep-sea diving dress with a helium-oxygen breathing supply was compressed to a simulated depth of 500 feet in a chamber. He was not told the depth, and when asked to make his own estimate he reported that it felt like 100 feet. During decompression, at the 300 foot mark, his breathing mixture was switched to air, and he 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 feet.

In 1940 Lambertsen proposed that mixtures of nitrogen or helium with oxygen be used in SCUBA to limit both oxygen toxicity and the problem of bends. This proposal led to his development of the mixed-gas rebreathing apparatus from which the current Navy Mk 6 was derived after WW II.

Through all of this period, the U. S. Navy was the acknowledged world leader in helium-oxygen diving



Figure 9-5 Recovery of the SQUALUS; the first U.S.N. Operation using He-O₂.

technology. However, Navy divers were not the only divers working with mixed gases or with helium. In 1937, a civilian engineer named 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 (who designed the lightweight diving mask which bears his name) made a simulated helium-oxygen dive of 550 feet. Later, in 1948, a British Navy diver set an open-sea record of 540 feet while using war-surplus helium originally provided by the United States.

In other 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 4% oxygen. At the surface this percentage of oxygen would not be sufficient to sustain life. However, at 100 feet, the oxygen partial pressure would be the equivalent of 16% oxygen at the surface. Zetterstrom devised a simple method for making the transition from air to hydrogen-oxygen without exceeding the 4% oxygen limit. At the 100 foot level, he replaced his breathing air with a mixture of 96% nitrogen and 4% oxygen, and 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, a misunderstanding on the part of his topside support personnel resulted in a too-rapid return to the surface. Zetterstrom did not have time to enrich his

breathing mixture or to adequately decompress. He was killed by the effects of the ascent. Experimentation with hydrogen as a component of breathing gas has continued sporadically, but without significant results.

A young diving enthusiast from Switzerland, Hannes Keller, was later to study Zetterstrom's work (among others') and to evolve his own breathing mixture which, depending upon the depth of the dive, involved changing proportions of nine different gases. In 1962 (with partial support from the U. S. Navy) he reached an open sea depth of more than 1000 feet off the California coast. This exceptional dive was also marked with tragedy: Keller's companion was killed by decompression sickness.

In recent years, to match basic operational requirements and capabilities, the U. S. Navy has generally divided mixed-gas diving into two basic categories: non-saturation diving without a pressurized bell to a maximum depth of 300 feet and saturation diving for deeper depth or extended bottom-time missions. The 300 foot limit is not primarily based upon equipment or diver limitations, but rather upon the basic assumption that any Navy diving mission at greater depth will necessarily be a long-term operation. Examples of such missions include submarine rescue and salvage, sea-bed implantments and 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.

Two major U. S. Navy contributions to mixed-gas diving have been the development of suitable equipment and the development of standard mixed-gas diving decompression tables.

EQUIPMENT 9.1.2.1 The Navy helium-oxygen helmet has been the standard rig for most mixed-gas diving, and only in the past few years has equipment been designed which will eventually replace this unit. The helium-oxygen (He-O₂) helmet is essentially a Mk V deep-sea helmet which has been modified by the addition of a system for conserving the gas supply by recirculating the breathing mixture through a carbon dioxide removal device. Because of this feature, the volume of gas required is about one-fifth of that which would be required in a comparable dive in an



Figure 9-6 Experimental Diving Unit chamber complex.



Figure 9-7 Recirculating hard-hat diver training in the Potomac River.

open-circuit mode. However, the helmet weighs more than 100 pounds and imposes an awkward burden on the diver. This has led to the development of several newer types of mixed-gas equipment for both surface-supplied and SCUBA operations. These not only increase diver efficiency, but also widen the range of operations in which the diver may function successfully. Specific equipment includes—

- MK 6**—a semiclosed mixed-gas SCUBA which is the standard U.S. Navy combat swimmer apparatus. It has a maximum depth capability of 200 feet and an endurance time of 30 minutes to 3 hours depending upon water temperature and diver activity. The breathing mixture may be either helium-oxygen or nitrogen-oxygen, but the latter is most frequently used for reasons of economy and diver comfort. However, the nitrogen-oxygen mixture is not compressed air, and the percentage of oxygen in the mixture must be greater than that of air to avoid hypoxia.
- MK 8 and MK 9**—semiclosed SCUBA developed primarily for use in saturation diving and now superseded by more effective apparatus.
- MK 11**—a semiclosed SCUBA designed for use in conjunction with personnel transfer capsules for saturation diving. The diver is connected to the PTC by a life-support umbilical through which breathing gas, heat and communications are provided.
- MK 10**—a closed-circuit mixed-gas SCUBA. The supply of oxygen to the breathing mixture is controlled by electronic sensors which monitor the oxygen level in the circulating gas and admit oxygen to replace that which has been consumed by the diver. The MK 10 is of particular value to combat swimmers by providing great depth capability, high endurance, and no telltale exhaust. It is also used in saturation diving from personnel transfer capsules.
- A multi-purpose unit**, currently under development, is composed of compatible mod-



Figure 9-8 MK 12 lightweight hard-hat prototype.



Figure 9-9 U. S. Navy diver wearing a Diver's Mask U.S.N. MK 1.

ules which may be varied to suit operational requirements. The basic dress consists of a lightweight fiberglass helmet, a neck seal and a wet or dry suit. The design will permit the use of surface-supplied air or, through the addition of a scrubber backpack, recirculating mixed gas. Designated the MK 12 apparatus, it should become the equipment of choice for most deep-diving operations.

- Auxiliary support equipment** is another area of continuing U.S. Navy design and development effort. This activity includes various diver vehicles (such as small submersibles and personnel transfer capsules) and a modern version of the diving bell. The latter affords the surface-supplied, mixed-gas diver protection from the environment and a place to rest. This unit is designed to furnish heat, gas and communications and is used in operations employing the MK 1 diver's mask.

MIXED-GAS DIVING TABLES 9.1.2.2 Mixed-gas diving tables were originally developed by the Navy and have been regularly up-dated as a result of experimentation and experience. Because the process of up-dating is continuous, divers preparing for mixed-gas operations must verify that the latest edition of the diving tables is on hand.

Saturation Diving 9.1.3 True scientific impetus was first given to the saturation concept in 1957 when a Navy diving medical officer, George F. Bond, theorized that the tissues of the body would eventually become saturated with inert gas if exposure time was long enough. Once a diver was saturated, further extension of bottom time would impose no additional decompression time requirement. Captain Bond (then a Commander, and Director of the Submarine Medical Center at New London, Connecticut) supervised a series of experiments, first with animals and then with humans, that proved the theory.

The first practical open-sea demonstrations were undertaken in 1962 with the "Man-in-Sea I" program of E. A. Link (one man breathing helium-oxygen at 200 feet for 24 hours), and "Conshelf One" of Captain Jacques-Yves Cousteau (six men breathing nitrogen-oxygen at 35 feet for 7 days). These pioneers extended both depth and duration during 1964. In that year Link and Lambertsen conducted a two-day exposure of two men at 430 feet, and Cousteau's "Conshelf Two" experiment maintained a group of seven men for 30 days at 36 and 90 feet with excursion dives to much greater depths.



Figure 9-10 E. A. Link's "Man-In-The-Sea" Program.

The best-known U. S. Navy experimental effort in saturation diving has been the SEALAB program. SEALAB I (1964), under the direction of Captain Bond, kept four men underwater for a total of 11 days at an average depth of 193 feet. SEALAB II, a year later, put three teams of 10 men each in a habitat at 205 feet. Each team spent 15 days at depth, and one man remained for 30 days. Later experiments have taken divers to 38 feet for 2 months (TEKTITE 1, 1969—conducted under the joint sponsorship of the USN, Dept. of Interior, and NASA) and 520 feet for 5 days (1970).



Figure 9-11 U. S. Navy SEA-LAB habitat.

Saturation diving has been conducted with any of several breathing media—ranging from air (in shallow water operations) to helium-oxygen in a dry chamber test to 2,000 feet. Detailed information on the use of various breathing gases will be found in Chapter Fourteen.

Two basic concepts of saturation diving technique have evolved. In one, the divers actually live underwater for the duration of the dive and are supported in a large submerged habitat. The habitat contains appropriate systems for diver safety and comfort and is designed to operate in pressure balance at depth. The habitat is not normally a pressure chamber, so some arrangement must be made for appropriate decompression at the end of the operation. In the other basic saturation technique, the divers are regularly cycled in a personnel transfer capsule (PTC) between the underwater work site and a surface chamber, where they are maintained in a saturated condition but under more comfortable (and less hazardous) living conditions than in a habitat.

Using compatible equipment, several deep diving systems (DDS) have evolved in recent years which can be used for both saturation and short-term diving. The principal advantage of such a diving system in non-saturation diving is to eliminate the need for long periods of in-water decompression, thereby increasing diver comfort and safety. With the support of a diving system, the working diver is never far from a dry refuge. The standby diver can also be on scene at all times, monitoring the progress of the work from the capsule and ready to provide assistance when needed.

For the Navy, deep diving systems (DDS) are ideally suited to the requirement of fleet diving. They have been designed for transport by air or sea and as permanent installations aboard specially configured ships. A DDS provides wide margins of safety, flexibility and economy in operations.

The portable DDS MK I will support two 2-man teams through a 14-day mission by alternating the teams be-

tween the surface chamber and the work site. The DDS MK II, a larger system designed particularly for long-term saturation diving, will support two 4-man teams for an extended mission profile. The MK II system is being installed as part of the basic equipment of the ASR-21 class of submarine rescue ships. The MK I diver's mask and MK 10 and MK 11 apparatus are employed from PTC's to provide the diver's breathing medium, communications and heat.

In July, 1972, successful deployment of the DDS MK 2 MOD 0 to a depth of 1010 feet demonstrated the Navy's capability to conduct open sea saturation diving operations. Research and development continues to extend this limit.

Saturation-Excursion Diving 9.1.4 Many diving operations require that work be accomplished at several different levels in the water column or at separate points on an irregular bottom. A saturated diver working out of a habitat or capsule at mid-depth can move to a lower depth for reasonable periods of time and return to the saturation depth without difficulty. This possibility was first demonstrated in Cousteau's "Conshelf Two" (1969), when the divers established an underwater base camp at 31 feet with a deeper chamber set at 87 feet. Divers at the base camp (breathing air with an oxygen partial pressure of 302 mmHg) made excursion dives to 165 feet. Divers in the deeper habitat breathed 50% air-50% helium and made excursion dives as deep as 330 feet using open-circuit SCUBA.

Since that time experimental investigation has shown that the latitude for no-decompression excursion dives is quite wide. For example, a saturated diver working from a 300-foot depth could descend an additional 150 feet for an hour without imposing any interim decompression requirement to interfere with his safe return to the 300-foot level. From a starting point of 400 feet, the diver could descend to 500 feet and remain for an hour.

It is standard USN practice to limit the depth and duration of excursion dives to preclude the need for in-water decompression. In an emergency exceeding these limits, however, the capsule can be pressurized to a greater depth for safe transfer of the diver. Under no circumstances should an excursion be made to a



Figure 9-12 Deep Diving System MK I.



Figure 9-13 Divers starting excursion dives from the DDS-2 PTC during Sealab experiments.

depth shallower than saturation level. Bubble formation and decompression sickness are possible if the diver ascends to a level above the saturation depth. Safe ascent limits have not been systematically studied.

MIXED-GAS PHYSICS 9.2

The fundamental laws and concepts of underwater physics presented in Volume I are basic to a proper understanding of mixed-gas diving techniques. The air diver, functioning with a fixed composition breathing media, seldom needs to perform many calculations requiring the use of the various gas laws. In mixed-gas diving, however, such calculations are vital to safe diving.

A thorough working knowledge of the application of the gas laws is mandatory for the mixed-gas diver, and consequently, a review of the Gas Laws is presented in the following sections.

MIXED-GAS DIVING THEORY

Boyle's Law 9.2.1 At constant temperature the absolute pressure and the volume of a gas are inversely proportional. As pressure is increased volume is reduced; as pressure is reduced volume is increased.

Expressed as a formula—

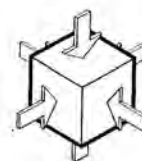
$$P = \frac{1}{V} C$$

$$\text{or } PV = C$$

Where: P = absolute pressure

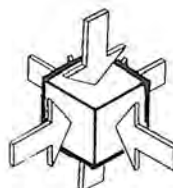
V = volume

C = a constant



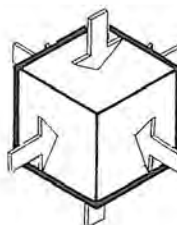
$V_1 = 1.0 \text{ CU FT}$

$P_1 = 1 \text{ ATM}$



$V_2 = 0.5 \text{ CU FT}$

$P_2 = 2 \text{ ATA}$



$V_3 = 2.0 \text{ CU FT}$

$P_3 = 0.5 \text{ ATA}$

Figure 9-14 Boyle's Law—These figures illustrate the changes in volume due to changes in pressure.

Example No. 1

Problem—The average gas flow requirement of a diver using a Mk I mask and doing moderate work is 1.4 cu ft/min when measured at the depth of the diver. What will be the gas requirement, expressed in volume/minute at surface conditions, for a diver working at 132 feet?—231 feet?—297 feet?

Solution—Since $PV = C$, then (using subscript 1 for surface conditions and subscript 2 for depth conditions),

$$P_1 V_1 = P_2 V_2$$

at the surface

$$P_1 = 1 \text{ ata}$$

$$V_1 = \text{unknown}$$

at 132 feet

$$P_2 = \frac{132 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 5 \text{ ata}$$

$$V_2 = 1.4 \text{ cu ft/min}$$

the gas flow (measured at surface conditions) required to support diving at 132 feet is then,

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

$$V_1 = \frac{5 \text{ ata} \times 1.4 \text{ cu ft/min}}{1 \text{ ata}}$$

$$V_1 = 7.0 \text{ cu ft/min}$$

at 231 feet

$$P_2 = \frac{231 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 8 \text{ ata}$$

therefore;

$$V_1 = \frac{8 \text{ ata} \times 1.4 \text{ cu ft/min}}{1 \text{ ata}}$$

$$V_1 = 11.2 \text{ cu ft/min}$$

at 297 feet

$$P_2 = \frac{297 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 10 \text{ ata}$$

therefore;

$$V_1 = \frac{10 \text{ ata} \times 1.4 \text{ cu ft/min}}{1 \text{ ata}}$$

$$V_1 = 14.0 \text{ cu ft/min}$$

Example No. 2

Problem—An open diving bell of 100 ft³ internal volume is to be used to support a diver at 198 feet. What volume of helium-oxygen (measured at surface conditions) must be added to the original 1 atmosphere of air in the bell to balance the water pressure at

depth? If the bell is lowered to 297 feet after pressurization to 198 feet and no more gas is added, what will be the gas volume in the bell?

Solution—To determine the volume of He-O₂ required to pressurize the bell to 198 feet (V_1)—

$$P_1 = 1 \text{ ata}$$

$$V_1 = \text{unknown}$$

$$P_2 = \frac{198 \text{ ft}}{33 \text{ ft/atm}} = 6 \text{ ata}$$

$$V_2 = 100 \text{ cu ft}$$

$$V_1 = \frac{P_2 V_2}{P_1} = \frac{6 \text{ ata} \times 100 \text{ ft}^3}{1 \text{ ata}} = 600 \text{ cu ft}$$

To determine the volume of gas in the bell at 297 feet (V_3)—

$$P_2 = \frac{198 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 7 \text{ ata}$$

$$V_2 = 100 \text{ cu ft}; P_3 = \frac{297 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 10 \text{ ata}$$

$$V_3 = \text{unknown gas}$$

$$V_3 = \frac{P_2 V_2}{P_3}$$

$$V_3 = \frac{7 \text{ ata} \times 100 \text{ cu ft}}{10 \text{ ata}} = 70 \text{ cu ft}$$

Charles' Law 9.2.2 At constant pressure the volume of a gas is directly proportional to the change in the absolute temperature. If the pressure is kept constant and the absolute temperature is doubled, the volume will double. If temperature decreases, so does volume. Also if volume rather than pressure is kept constant, as by heating gas in a rigid container, then the absolute pressure will change in proportion to the absolute temperature.

Expressed as a formula (constant pressure)—

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

Expressed as a formula (constant volume);

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

Where:

P_1 = initial absolute pressure

P_2 = final absolute pressure

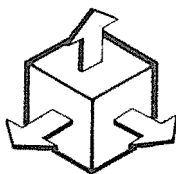
V_1 = initial volume

V_2 = final volume

T_1 = initial absolute temperature

T_2 = final absolute temperature

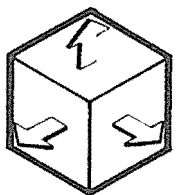
A



$V_1 = 1 \text{ CU FT}$

$T_1 = 300^\circ\text{K}$

$P_1 = 1 \text{ ATA}$

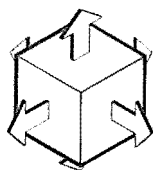


$V_2 = 2 \text{ CU FT}$

$T_2 = 600^\circ\text{K}$

$P_1 = 1 \text{ ATA}$

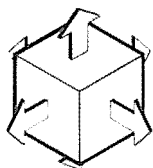
B



$V_1 = 1 \text{ CU FT}$

$T_1 = 300^\circ\text{K}$

$P_1 = 1 \text{ ATA}$



$V_2 = 1 \text{ CU FT}$

$T_2 = 600^\circ\text{K}$

$P_2 = 2 \text{ ATA}$

Figure 9-15 Charles' Law—

A If the pressure is held constant the volume varies with changes in the absolute temperature.

B If the volume is constant the pressure varies with changes in absolute temperature.

Example No. 1

Problem—The onboard gas supply of a PTC is charged on deck to 3,000 psig in an ambient temperature of 32°C. The capsule is deployed to a depth of 850 feet at which the water temperature is 8°C. What will be the pressure in the supply at the new temperature?

Solution—In this example volume is constant, only pressure and temperature change. Using subscripts 1 for original conditions and 2 for final conditions—

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

Converting to absolute temperature values (metric system)—

$$T_1 = 32^\circ\text{C} + 273 = 305^\circ\text{K}$$

$$T_2 = 7^\circ\text{C} + 273 = 280^\circ\text{K}$$

Converting P_1 to absolute pressure—

$$P_1 = \frac{3,000 \text{ psig}}{14.7 \text{ psi/atm}} + 1 \text{ atm} = 205 \text{ ata}$$

Substituting—

$$P_2 = \frac{P_1 T_2}{T_1} = \frac{205 \text{ ata} \times 280^\circ\text{K}}{305^\circ\text{K}} = 188 \text{ ata}$$

Converting to gage pressure—

$$P_2 = (188 \text{ ata} - 1 \text{ ata}) (14.7 \text{ psi/atm}) = 2,750 \text{ psig}$$

Example No. 2

Problem—A habitat is deployed to a depth of 627 feet at which the water temperature is 40°F. It is pressurized from the surface to bottom pressure, and due to heat of compression the internal temperature rises to 110°F. The entrance hatch is open and the divers begin their work routine. During the next few hours the habitat atmosphere cools down to the surrounding seawater temperature because of malfunction in the internal heating system. If no additional gas was added to the habitat, what percentage of the internal volume would be flooded by seawater?

Solution—In this example pressure is constant, only volume and temperature change.

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

Converting to absolute temperature values (English system)—

$$T_1 = 110^\circ\text{F} + 460 = 570^\circ\text{R}$$

$$T_2 = 40^\circ\text{F} + 460 = 500^\circ\text{R}$$

Substituting—

$$V_2 = \frac{V_1 T_2}{T_1} = V_1 \times \frac{500^\circ\text{R}}{570^\circ\text{R}} = 0.88 V_1$$

Changing to Percent—

$$V_2 = (0.88 V_1) (100\%) = 88\% V_1$$

$$\text{Flooded Volume} = 100\% - 88\% = 12\%$$

The General Gas Law 9.2.3 The General Gas Law is a combination of Boyle's and Charles' laws which relates pressure, volume, and temperature.

Expressed as a formula—

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

Where—

P_1 = initial pressure (absolute)

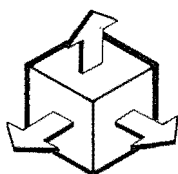
V_1 = initial volume

T_1 = initial temperature (absolute)

P_2 = final pressure (absolute)

V_2 = final volume

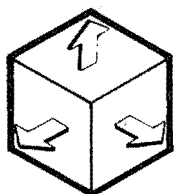
T_2 = final temperature (absolute)



$$V_1 = 2 \text{ CU FT}$$

$$T_1 = 300^\circ\text{K}$$

$$P_1 = 2 \text{ ATA}$$



$$V_2 = 1 \text{ CU FT}$$

$$T_2 = 600^\circ\text{K}$$

$$P_2 = 8 \text{ ATA}$$

Figure 9-16 General Gas Law—relates temperature, pressure and volume changes of gases.

The following should be noted in using the General Gas Law—

1. There can be only one unknown.
2. If it is known that a value remains unchanged (such as the volume of a tank) or that the change in one of the variables will be of little consequence, cancel the value out of both sides of the equation to simplify the computations.

Example No. 1

Problem—A bank of cylinders having an internal volume of 20 cubic feet is to be charged with helium and oxygen to a final pressure of 2,200 psig to provide mixed gas for a dive. The cylinders are rapidly charged from a large premixed supply, and the gas temperature in the cylinders rises to 160°F by the time final pressure is reached. The temperature in the cylinder bank compartment is 75°F.

A. What will be the final cylinder pressure when the cylinders have cooled to ambient temperature?

B. How many cubic feet of gas at normal temperature and pressure (NTP = 70°F, 14.7 psia) will the bank contain?

C. How much gas at NTP would have been stored if the bank was charged slowly to 2,200 psig and the gas temperature had remained at 75°F?

Solution—

A. To determine the final cylinder pressure when the gas has cooled—

$$P_1 = 2,200 \text{ psig} + 14.7 \text{ psi} = 2,214.7 \text{ psia}$$

$$T_1 = 160^\circ\text{F} + 460 = 620^\circ\text{R}$$

$$T_2 = 75^\circ\text{F} + 460 = 535^\circ\text{R}$$

$$P_2 = \text{unknown} \quad V_1 = V_2 = \text{constant}$$

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

Cancelling V on both sides of the equation and rearranging—

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

Substituting—

$$P_2 = \frac{2,214.7 \text{ psia} \times 535^\circ\text{R}}{620^\circ\text{R}} = 1,911.0 \text{ psia} = 1,896.3 \text{ psig}$$

B. To determine the volume of gas at NTP resulting from the rapid charging—

$$\begin{aligned} P_1 &= 2,214.7 \text{ psia} \\ T_1 &= 620^\circ\text{F} \\ V_1 &= 20 \text{ ft}^3 \\ P_2 &= 14.7 \text{ psia} \\ T_2 &= 70^\circ\text{F} + 460 = 530^\circ\text{R} \\ V_2 &= \text{unknown} \end{aligned}$$

Rearranging—

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

Substituting—

$$V_2 = \frac{2,214.7 \text{ psia} \times 20 \text{ ft}^3 \times 530^\circ\text{R}}{14.7 \text{ psia} \times 620^\circ\text{R}} = 2,576 \text{ cu ft NTP}$$

C. To determine the volume of gas at NTP resulting from the slow charging—

$$\begin{aligned} P_1 &= 2,214.7 \text{ psia} \\ T_1 &= 535^\circ\text{R} \\ V_1 &= 20 \text{ ft}^3 \\ P_2 &= 14.7 \text{ psia} \\ T_2 &= 530^\circ\text{R} \\ V_2 &= \text{unknown} \end{aligned}$$

Substituting—

$$\begin{aligned} V_2 &= \frac{P_1 V_1 T_2}{P_2 T_1} \\ V_2 &= \frac{2,214.7 \text{ psia} \times 20 \text{ ft}^3 \times 530^\circ\text{R}}{14.7 \text{ psia} \times 535^\circ\text{R}} = 2,985 \text{ cu ft NTP} \end{aligned}$$

Example No. 2

Problem—A 100 cubic foot salvage bag is to be used to lift a 3,200 pound torpedo from the seafloor at a depth of 231 feet. An air compressor with a suction of 120 cubic feet/min. at 60°F and a discharge temperature of 140°F is to be used to inflate the bag. Water temperature at depth is 55°F. Neglecting torpedo dis-

placement, breakout forces, compressor efficiency and the weight of the salvage bag, how long will it be before the torpedo starts to rise?

Solution—Displacement of bag to lift torpedo =

$$\frac{3,200 \text{ lb}}{64 \text{ lb/ft}^3} = 50 \text{ ft}^3$$

$V_1 = \text{unknown}$

$P_1 = 1 \text{ ata}$

$T_1 = 60^\circ\text{F} + 460 = 520^\circ\text{R}$

$V_2 = 50 \text{ ft}^3$

$P_2 = \frac{231 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 8 \text{ ata}$

$T_2 = 55^\circ\text{F} + 460 = 515^\circ\text{R}$

Rearranging and Substituting—

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

$$V_1 = \frac{8 \text{ ata} \times 50 \text{ ft}^3 \times 520^\circ\text{R}}{1 \text{ ata} \times 515^\circ\text{R}} = 403.8 \text{ ft}^3$$

$$\text{Time} = \frac{\text{Volume Required}}{\text{Compressor Displacement}} =$$

$$\frac{403.8 \text{ ft}^3}{120 \text{ ft}^3/\text{min}} = 3.4 \text{ min}$$

(Note that the 140°F compressor discharge temperature is an intermediate temperature and does not enter into the problem.)

Dalton's Law 9.2.4 The total pressure exerted by a mixture of gases is equal to the sum of the pressures of the different gases making up the mixture—each gas acting as if it alone were present and occupied the total volume. The pressure contributed by any gas in the mixture is proportional to the number of molecules of that gas in the total volume. The pressure of that gas is called its **partial pressure (pp)**, meaning its part of the whole.

Expressed as a formula—

$$P (\text{Total}) = \text{pp}(\text{A}) + \text{pp}(\text{B}) + \text{pp}(\text{C}) + \dots$$

Consequently—

$$\text{pp}(\text{A}) = P (\text{Total}) \times \frac{\% \text{Vol} (\text{A})}{100\%}$$

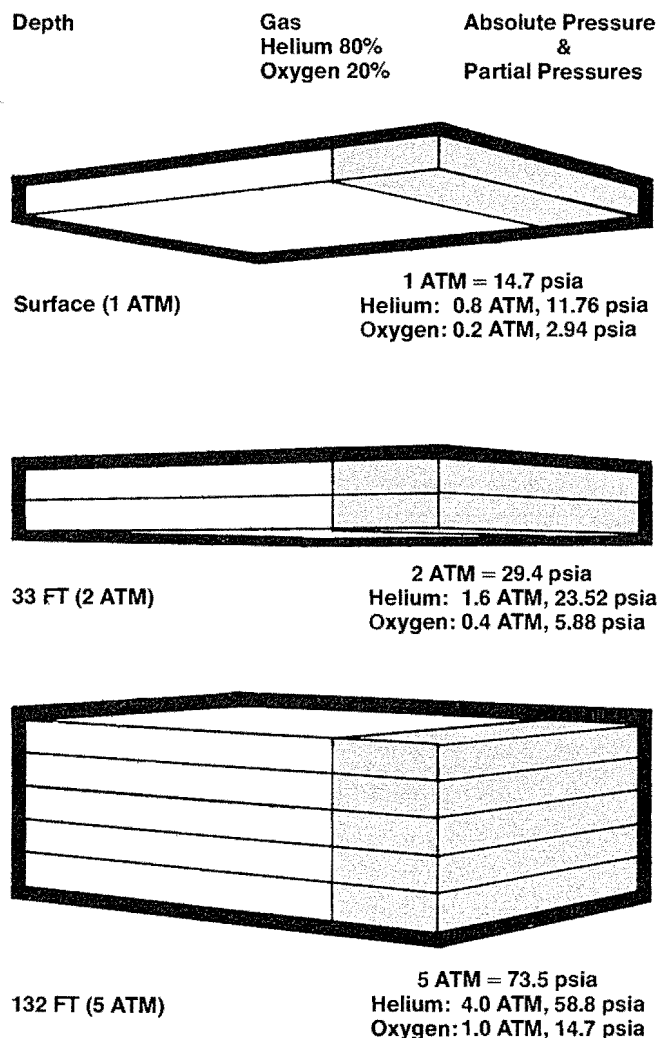


Figure 9-17 Dalton's Law (The Law of Partial Pressures)

Example No. 1

Problem—A helium-oxygen mixture is to be prepared which will provide an oxygen partial pressure of 1.2 ata at a depth of 231 feet. What should be the oxygen percentage in the mix?

Solution—Convert depth to atmospheres absolute—

$$D = \frac{231 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 8 \text{ ata}$$

Since—

$$pp(A) = P(\text{Total}) \times \frac{\%Vol(A)}{100\%}$$

Rearranging—

$$\%Vol(A) = \frac{pp(A)}{P(\text{Total})} \times 100\%$$

$$\%Vol(A) = \frac{1.2 \text{ ata}}{8 \text{ ata}} \times 100\% = 15\% \text{ oxygen}$$

Example No. 2

Problem—A 30-minute bottom time dive is to be conducted in 264 feet of seawater. The maximum safe oxygen partial pressure for a 30-minute exposure under normal operating conditions is 1.6 ata (Chapter 14). Two premixed supplies of He-O₂ are aboard—16% O₂ and 22% O₂. Are either of these mixtures safe for the intended dive?

Solution—Convert depth to atmospheres absolute—

$$D = \frac{264 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 9 \text{ ata}$$

The maximum allowable O₂ percentage is found as follows—

$$\%Vol(A) = \frac{pp(A)}{P(\text{Total})} \times 100\%$$

$$\%Vol O_2 = \frac{1.6 \text{ ata}}{9 \text{ ata}} \times 100\% = 17.8\% O_2$$

Result—

The 16% mix is safe to use; the 22% mix is unsafe.

$$\text{The pp of the 16\% mix} = 9 \text{ ata} \times \frac{16\%}{100\%} = 1.44 \text{ ata } O_2$$

and 1.44 ata O₂ is less than the maximum allowable.

$$\text{The pp of the 22\% mix} = 9 \text{ ata} \times \frac{22\%}{100\%} = 1.98 \text{ ata } O_2$$

and use of this mixture would result in a significant risk of oxygen toxicity developing.

Example No. 3

Problem—The gas cylinders aboard a PTC are to be charged with an He-O₂ mixture. The mixture should provide an oxygen partial pressure of 0.9 ata to the diver using a MK I mask at a saturation depth of 660 fsw. What should be the oxygen percentage in the charging gas? If the diver makes an excursion from

saturation depth to 726 fsw what will be the oxygen partial pressure of his breathing gas?

Solution—Convert depth to atmospheres absolute—

$$D = \frac{660 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 21 \text{ ata}$$

The O_2 content of the charging mix is found as follows—

$$\%Vol O_2 = \frac{0.9 \text{ ata}}{21 \text{ ata}} \times 100\% = 4.3\%O_2$$

Convert excursion depth to atmospheres absolute—

$$D = \frac{726 \text{ ft}}{33 \text{ ft/atm}} + 1 \text{ atm} = 23 \text{ ata}$$

The O_2 partial pressure at excursion depth is found as follows—

$$pp O_2 = 23 \text{ ata} \times \frac{4.3\%O_2}{100\%} = 0.99 \text{ ata}$$

Henry's Law 9.2.5 The amount of gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas. If one unit of gas is dissolved at one atmosphere partial pressure, then two units will be dissolved at two atmospheres, etc.

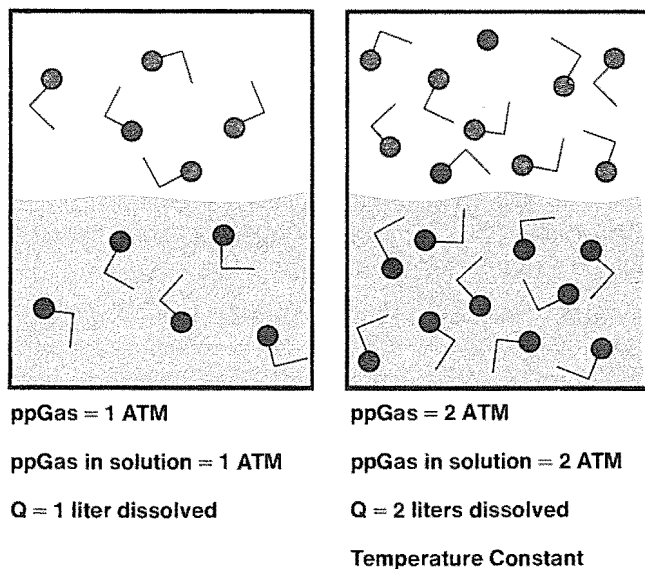


Figure 9-18 Henry's Law—the example shown is at equilibrium (solution saturated)

MIXED-GAS DIVING PHYSIOLOGY 9.3

Mixed-gas operations often involve great depths, lengthy exposures to unusual breathing mixtures, and low temperatures. Any of these can seriously impair a diver's working effectiveness and pose continuing problems of health and safety.

The fundamental principles of diving physiology were discussed in **Volume I** and form the foundation for understanding the hyperbaric effects of mixed gas. In this type of diving, however, certain physiological considerations assume added importance and other effects, not previously discussed, are encountered. These concerns are discussed in this section and include—

- Ventilation, breathing resistance and gas transport.
- Oxygen toxicity.
- Use of oxygen in decompression.
- Body heat loss and temperature balance.
- Distortion of speech.
- Other physiological concerns such as compression arthralgia and the high pressure nervous syndrome (HPNS).

Ventilation, Breathing Resistance and Gas Transport 9.3.1

The ability of the cardio-vascular system to circulate blood to various parts of the body determines a man's capacity to do heavy work at the surface. At great depth, work capacity is more directly determined by the effectiveness of pulmonary ventilation. The factor tending to limit thorough ventilation at depth is that the density of the breathing mixture causes increased resistance to gas movement.

Experiments have demonstrated that men can perform moderate work to depths greater than 1,000 feet while breathing helium-oxygen in a dry chamber. The density of the helium-oxygen at 1,000 feet is 4.3 times that of air at the surface or about the same as air breathed at 110 feet.

Figure No. 9-19 illustrates the effect of increased gas density upon pulmonary ventilation. Maximum voluntary ventilation (MVV) is the maximum gas volume that can be breathed per minute by voluntary effort. The minute respiratory volume measured during max-

imum exercise is always less than the MVV. As will be noted in the illustration, the MVV decreases at greater gas densities as the depth is increased. Deterioration in pulmonary ventilation is particularly pronounced as the diver descends from the surface to 1,000 feet. Actual measurements have been made to 1,600 feet and greater depths have been simulated with breathing gases denser than helium. Therefore, this curve graphically illustrates the reduction in maximum exercise levels that can be expected of divers in dry chambers at these depths. Immersed divers, because of UBA breathing resistance and effects of immersion, are further limited.

EFFECT ON MAXIMUM VOLUNTARY VENTILATION OF INCREASED ATMOSPHERIC PRESSURE

% Decrement In MVV

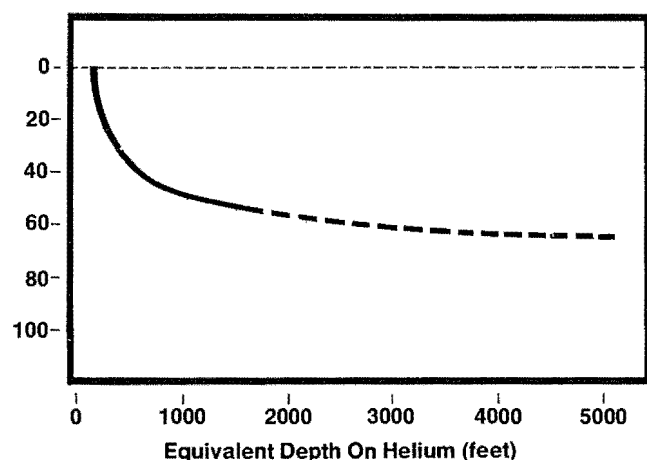


Figure 9-19 Curve of Maximum Voluntary Ventilation vs. Depth.

The ultimate hydrostatic pressure levels under which man may function have not yet been determined. In dry chamber experiments with various breathing mixtures, helium has been successfully tested to 2,000 feet, neon to 1,000 feet, and nitrogen-oxygen below 300 feet. Helium produced no noticeable effects, and presumably, actual saturation diving using helium will eventually prove feasible at least to that test level. Neon seems to impose no mental or physiological limitations, but because it is more dense than helium,

problems of pulmonary ventilation may impose a working limit below some depth (estimated to be 700 feet). Saturation exposures with nitrogen have not been conducted below 100 feet, although there is no reason to assume that they are not possible. The limiting factor with nitrogen rather than respiratory functions will be the narcotic effect at increased pressure. The limiting factor with air is the inevitability of lung damage from prolonged exposure to elevated oxygen partial pressures (see Section 9.3.2.2).

An additional consideration with both nitrogen-oxygen mixtures and air is the greater density (compared with helium mixtures) which interferes with pulmonary ventilation. At any given depth ventilation will be superior with a less dense gas, and in some operations (such as when using mixed-gas SCUBA which includes the additional factors of equipment-related breathing resistance and dead space) the difference in breathing effectiveness can be significant. The retention of carbon dioxide because of inadequate ventilation will not only limit the diver's capacity for work but may facilitate the onset of other problems, most notably oxygen poisoning.

Oxygen Toxicity 9.3.2 In contrast with air operations, it is an inherent capability in mixed-gas diving to be able to vary the oxygen level of the diver's breathing medium. This flexibility introduces the hazard of accidental oxygen toxicity.

There are two major expressions of oxygen poisoning — one that involves effects of oxygen upon the central nervous system (and often results in a convulsion similar to that of an epileptic seizure), and the other which leads to severe irritation of the lung.

Central nervous system poisoning is dependent upon the partial pressure of the inspired oxygen and the duration of exposure. **Pulmonary oxygen poisoning** and accompanying lung damage is also specifically related to the duration of exposure to higher-than-normal levels of oxygen. Pulmonary oxygen toxicity is rarely a problem in surface-supplied diving operations due to the short exposure time. However, because of the extended bottom times encountered in mixed-gas (particularly saturation) diving, the possibility of pulmonary involvement is greatly increased.

CENTRAL NERVOUS SYSTEM (CNS) OXYGEN POISONING 9.3.2.1

Central nervous system oxygen poisoning becomes a distinct possibility when the partial pressure of inspired oxygen reaches 1.6 atmospheres. The percentage of oxygen in the breathing mixture is not in itself the significant factor. A diver breathing 100% oxygen at 20 feet or air at 220 feet breathes an oxygen partial pressure level of 1.6 atmospheres. Most divers can tolerate an oxygen partial pressure of 2.0 atmospheres for many hours at rest, and some divers can exceed that level without apparent difficulty related to CNS O₂ toxicity. In addition to individual differences in the ability to withstand such exposure, the length of time before symptoms appear is influenced by other factors—

—The level of exertion. Experimentally, most men at complete rest in a dry chamber can breathe pure oxygen for as long as 2 hours at a simulated depth of 60 feet. However, at that depth and doing even light work, symptoms may begin to be experienced within 15 minutes.

—Carbon dioxide retention resulting from resistance in the breathing apparatus, inadequate ventilation of the diver's lungs or excess CO₂ in the inspired mixed gas. The resultant buildup of carbon dioxide speeds the onset of oxygen poisoning symptoms.

—Intermittent exposure to high oxygen partial pressures. If the level of oxygen in the breathing mixture is alternated between a high value and a low one, the diver can be exposed to a higher total amount of oxygen before the development of symptoms of poisoning. Also, if the partial pressure of oxygen is reduced at the first signs or symptoms of poisoning, the condition will be reversed if it has not already entered a progressive stage. These factors are important when oxygen is used in decompression or in any therapeutic application.

As a result of extensive experimentation and years of field experience, oxygen partial pressure/exposure time limits have been established for the conduct of mixed-gas working dives. These limits, given in Figure No. 9-20, should not be exceeded in operating situations except as required in certain standard decompression procedures when the diver is at rest. The limits apply to nitrogen-oxygen SCUBA diving and helium oxygen surface-supplied diving where carbon

OXYGEN PARTIAL PRESSURE LIMITS TABLE

Exposure Time (min.)	Maximum Oxygen Partial Pressure (atmospheres)
-------------------------	--

NORMAL EXPOSURES

30	1.6
40	1.5
50	1.4
60	1.3
80	1.2
120	1.1
240	1.0

EXCEPTIONAL EXPOSURES

30	2.0
40	1.9
60	1.8
80	1.7
100	1.6
120	1.5
180	1.4
240	1.3

Figure 9-20 Oxygen partial pressure limits for nitrogen-oxygen SCUBA and surface-supplied helium-oxygen mixed-gas diving.

dioxide retention or very heavy work is anticipated. Helium-oxygen SCUBA limits allow greater exposure.

The warning symptoms of central nervous system oxygen poisoning may vary, not all possible symptoms are likely to occur in each instance, and in some cases there may even be an absence of warning symptoms entirely. Some of the symptoms may easily be the result of other physiological problems and some may even reflect the approach of **hypoxia**—a condition resulting from an inadequate supply of oxygen rather than an overabundance.

The most common symptoms may be remembered by the acronym **V-E-N-T-I-D**—

- Vision. Any abnormality, such as “tunnel vision” (a contraction of the normal field of vision as if looking through a tube.)
- Ears. Any abnormality of hearing.
- Nausea. This may be intermittent.
- Twitching. Usually appears first in the lips or other facial muscles, but may affect any muscle. This is the most frequent and clearest warning of oxygen poisoning.

- Irritability.** Any change in behavior including anxiety, confusion, unusual fatigue.
- Dizziness.**

Additional symptoms may include difficulty in taking a full breath, an apparent increase in breathing resistance, noticeable clumsiness or incoordination.

When the poisoning reaches an acute level, the victim will suffer convulsive seizure. The entire body is seized in a violent spasm which soon changes to a series of jerking movements of the limbs, trunk, head and face. Frothy saliva (which may be mixed with blood if the tongue or cheek has been bitten) is blown from the lips. After a minute or two, the jerking will decrease and eventually cease. At this point the victim may be in a deep coma from which he will slowly regain consciousness (perhaps exhibiting some irrationality). After a period which may vary from 15 minutes to an hour, he will be generally recovered, will usually feel exhausted and may have a headache. He will probably not remember many details of the episode. If the level of oxygen is not reduced, the convulsion cycle may repeat with increasingly serious consequences.

The convulsion itself is not particularly dangerous to the victim, although some physical damage—such as collapsed vertebrae or a badly chewed tongue—may occur. The principal dangers arise from the loss of control while in the diving environment. In a deep sea diving dress the convulsion could precipitate a blowup or squeeze and might conceivably result in a gas embolism if the diver is brought too quickly to the surface. With SCUBA the main danger is that of drowning.

Central nervous system oxygen poisoning can largely be prevented by observance of the following guidelines—

- Never exceed the depth/time limits prescribed for each type of apparatus and breathing mixture.
- Never use oxygen in any concentration except as designated in the decompression tables and operating instructions for the apparatus. (For example, never use oxygen in an open-circuit SCUBA.)
- Ensure that the breathing apparatus is in good order.
- Observe safety precautions.
- Avoid excessive exertion.
- Heed any abnormal symptoms, however slight.

If symptoms are observed, a prompt lowering of the oxygen partial pressure will usually avert the onset of convulsions. However, even if the diver suffers from a convulsion and the level of oxygen is not changed, the convulsion will usually complete its cycle and the diver's condition will return to near-normal. The level must be reduced as soon as practical to prevent further seizures.

A diver who is suffering from a convulsion should be prevented from injuring himself. A buddy diver is the best insurance against drowning in a SCUBA operation. If the seizure should occur while in a recompression chamber, the tender should keep the victim from thrashing against hard objects, but complete restraint of movement is neither necessary nor desirable. The use of a mouth bit (such as several tongue depressors wrapped in tape) will help avoid damage to the victim's tongue or cheeks. Ordinarily a man will suffer no lasting effects of a seizure, and there is no evidence that he will be any more or less susceptible to oxygen poisoning in the future.

PULMONARY OXYGEN POISONING 9.3.2.2 Pulmonary oxygen poisoning, with irritation or damage to the lungs, results from prolonged exposures to oxygen at partial pressures above 0.5 atmospheres. At higher partial pressure (approximately 2.0 to 3.0 atmospheres), central nervous system poisoning will likely occur before lung damage becomes apparent. The length of exposure time required to produce symptoms varies with the partial pressure of inspired oxygen, as well as with individual tolerances. Pulmonary toxicity develops more rapidly at higher oxygen partial pressures. Figure No. 9-21 illustrates the time/partial pressure relationships. The symptoms of pulmonary oxygen poisoning are not as dramatic as those of central nervous system toxicity, and the onset of lung damage is insidious and progressive.

The first symptoms, related to inflammation of the lining of the air passages, are likely to be painful breathing

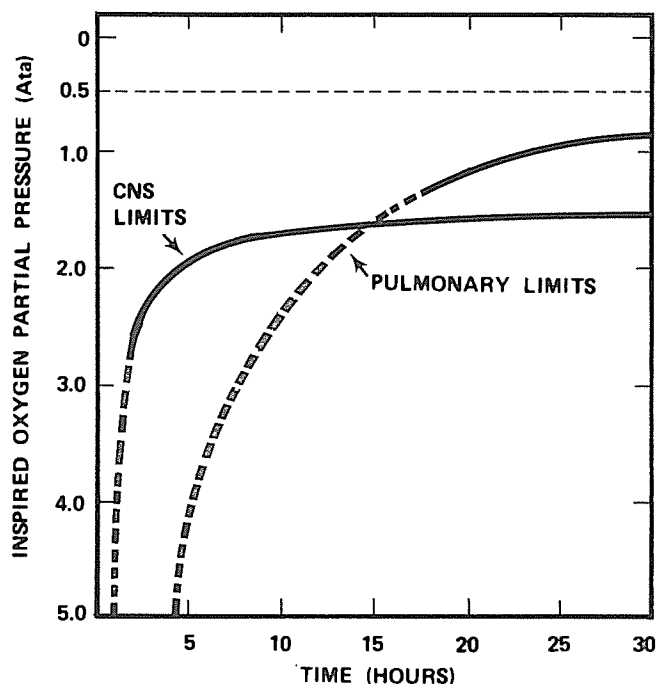


Figure 9-21 Time/O₂ partial pressure relationships.

(especially deep breathing) and intermittent coughing. As the damage progresses these symptoms become more severe and the coughing may become uncontrollable.

The alveoli and lung capillaries become affected, and the lungs eventually lose the ability to handle the movement of oxygen from the airways to the blood. Thus, in fatal cases, death is actually due to hypoxia of the vital organs even though the cause of the problem is an excess of oxygen in the lungs.

In the early stages of pulmonary oxygen poisoning the damage is completely reversible after the exposure ceases. This permits the use of oxygen at elevated pressures when the exposure is carefully controlled. When used to aid decompression, the level should be kept below that which produces any detectable lung damage. However, in using oxygen to treat a disease, the medical officer in charge may elect to accept mild or even moderate lung damage that is reversible in order to better treat a more serious problem.

Pulmonary oxygen poisoning can arise in non-saturation diving (whether on air, mixed gas or oxygen), but

the exposure is usually not long enough to produce any symptoms or detectable damage. The primary hazard occurs in saturation diving and prolonged decompression. The lower level of inspired oxygen partial pressure which will cause no toxicity for very long exposures is not known with certainty. Experimentally, 0.5 atmospheres have been tolerated.

Use of Oxygen and Other Gases in Decompression

9.3.3 At all stages of decompression, the rate of elimination of an inert gas can be increased by a reduction in the partial pressure of that gas in the breathing mixture while maintaining the total pressure. This will increase the outward pressure. This will increase the outward pressure gradient, and can be accomplished by the substitution of another inert gas or by increasing the proportion of oxygen in the breathing mixture. As a consequence, decompression time can be shortened at the expense of increased procedural complexity.

The use of multiple inert gases during decompression is still in the experimental stage. It is not unusual, however, to use air or nitrogen-oxygen during decompression following an He-O₂ dive. Some of the nitrogen will be absorbed by body tissues, but helium will be more rapidly eliminated and the overall effect may be a reduction in the total inert gas loading in the body. One side effect of this type of procedure is the eventual development of skin itch if the exposure is long enough. At depths greater than 100 feet, if the body is surrounded by a helium-oxygen mixture (as in a PTC) and the diver is breathing nitrogen-oxygen through a mask, gas gradients can develop through the skin, resulting in severe itching similar to skin bends, due to the formation of bubbles in the skin tissues.

One hundred percent oxygen is commonly used for breathing during various phases of decompression from mixed-gas dives. Since oxygen is consumed by the body, it does not contribute to the gas loading which must be reduced to provide safe decompression. Maintenance of the total pressure by pure oxygen deters inert gas bubble formation and resulting decompression sickness while permitting high outward inert gas gradients to exist. This procedure, however, can only be used during the shallower portions

of the decompression profile because of the toxicity hazards previously discussed. Furnished to the diver at specified points in the decompression cycle, this additional oxygen accelerates the release of inert gas from the body tissues. Despite its advantages in decompression, oxygen should not be used indiscriminately.

Body Heat Loss and Temperature Balance 9.3.4

Maintenance of acceptable body temperature is a problem in virtually all diving operations. However, any diving operation involving helium-oxygen mixtures will pose more serious temperature control problems; and if the dive is in deep, cold water, active measures must be taken to protect the diver and conserve his body heat as much as possible. An additional factor, which further complicates maintenance of uniform body temperatures, is introduced by the widely varying levels of work (and therefore heat production) experienced in both saturation and non-saturation dives.

The high thermal conductivity of helium (approximately 6 times that of air) draws heat away from the diver at a great rate; and the colder the environment, the more severe the problem. Providing the diver with insulating clothing will help, but the high pressures encountered in deep-diving reduce the effectiveness of insulating clothing by compressing the material. The effectiveness is further reduced in a helium atmosphere since helium tends to replace whatever gas is trapped in the "air spaces" of the material. At a depth of 600 feet, for example, a $\frac{3}{16}$ -inch neoprene wet suit in a helium environment would have one-fourth its normal surface-insulating value.

In deep-diving operations of today it is recognized that some form of external heat must be provided to the diver in an effort to maintain a thermal balance and prevent chilling or hypothermia. Several methods for providing heat to the diver have been tested and some are operational. The most successful (to date) has been through the use of suits provided with circulating hot water from the surface or from a PTC. The power required to compensate for heat loss for a diver at 600 feet breathing helium-oxygen would be approximately 3,000 watts when at rest and between 500 watts and 1,000 watts when working.

Respiratory heat loss is also increased in deep-diving to the point where, at 600 feet, a diver may lose more heat through breathing than his body can generate even if working and provided with a hot-water suit. With a cold breathing gas (assumed to be equal to ambient water temperature) the diver can suffer from respiratory distress in the form of incapacitating shivering, chest pains, nasal and tracheo-bronchial secretions, and difficult and labored breathing. In deep, cold water operations the limiting temperature for the onset of symptoms increases with increasing depth.

In order to compensate for the increased heat capacity of gases (and associated respiratory heat loss) at great depths, it is essential that diver breathing gas be heated to avoid breathing distress. Figure No. 9-22, **U. S. Navy Standard Minimum Inspired Gas Temperatures**, provides the minimum allowable temperatures for breathing gas when all other steps have been taken to keep the diver warm. Inspired gas temperatures higher than the standard should be provided in all situations involving cold water diving.

When operating in a habitat or a PTC, the range of temperature in which a diver will feel reasonably comfortable will vary with depth. For example, using helium-oxygen at a depth of 400 feet, the average diver will accept a temperature range of about 3°C— from 28.5°C to 31.5°C. At 1,200 feet the range is reduced to 1°C and the comfort level has shifted upward so that the low limit is now 32.5°C. Clearly, small changes in ambient temperature produce major changes in comfort for the diver.

Distortion of Speech 9.3.5 One other physiological problem encountered in mixed-gas diving when using helium mixtures is the so-called "Donald Duck" effect upon human speech. The exact reasons for this effect are not fully understood and may involve both the vocal chords and the resonant passages of chest, throat and head. With experience, divers and tenders can learn to overcome some of the communications interference imposed by the distorted speech. Electronic speech "unscramblers" offer a definite benefit. The speech impairment is temporary and without lasting effect on the diver and will markedly improve when other breathing mixtures are substituted for

FSW	°C	°F	FSW	°C	°F
600	-1.0	30.1	850	9.4	48.9
650	1.7	35.0	900	10.8	51.5
700	4.0	39.2	950	12.1	53.8
750	6.0	42.9	1000	13.3	55.9
800	7.8	46.1			

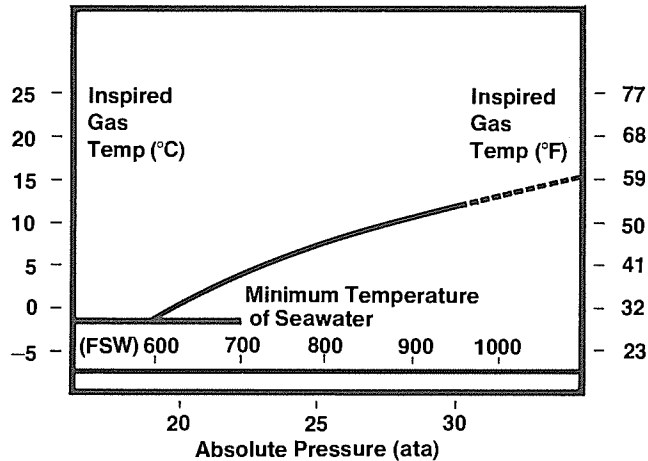


Figure 9-22 Minimum safe inspired gas temperature limits

helium. The principal hazard with distorted speech is that vital communications from the diver might not be understood.

Other Physiological Concerns 9.3.6 Certain physiological phenomena have been observed in both dry chamber pressure tests and in actual deep-diving operations which may be linked to a variety of factors: high ambient pressure, high rates of change in pressure, changes in the composition of the breathing mixture or, possibly, to the constituent gases in the breathing mixture. The exact causes are not yet clear. These phenomena include—

- Joint pains may be experienced during compression or may appear at some point in time after arriving at maximum depth. These pains tend to improve after a few hours or days. The pains are not debilitating but may pose a handicap to the normal conduct of operations. Experimentally, the joint pains seem to be precipitated by rapid and large pressure changes.
- High Pressure Nervous Syndrome (HPNS) includes certain diverse general symptoms which have been clinically described. Muscular tremors

(sometimes called “Helium Tremor”) have been observed in experimental exposures of exceptional depth. The cause is unknown.

Other symptoms including dizziness, nausea, decreased alertness, a desire to sleep and electroencephalograph (EEG) changes have also been noted. A high rate of compression is thought to be a contributing (although not an exclusive) factor in production of these symptoms.

OPERATIONS PLANNING 9.4

Mixed-gas diving operations are complex, require close coordination and constant support, and (as a consequence of extended decompression obligations) can be hazardous if improperly planned or executed. If a problem should arise it must be handled as an emergency, and there will be little time to search through manuals or operations orders seeking an approved course of action.

The planning for a mixed-gas operation must be thorough, correct, and involve all support units and personnel as well as the diving team itself. Planning is necessarily more extensive than with air diving. For example, special equipment and specially trained personnel are required. Among others, a recompression chamber (properly configured for mixed-gas operations) and a diving medical officer must be at the diving site. Requirements for surface support are greatly increased and are usually dependent upon the availability of appropriately equipped support vessels. Gas supply factors are critical and must be determined far enough in advance to ensure that adequate quantities of the correct gas mixtures will be on station.

If the operation includes saturation dives, the planning effort will be even more complicated. For example, a saturation dive requires 24-hour topside support, day in and day out, with a fully qualified team on station at all times. Thus, keeping two men at the work site in a saturation dive could require at least three times the number of topside personnel as would a non-saturation dive. Additionally, surface support vessels assigned to the operation must be able to physically handle habitats and/or personnel transfer capsules, have sufficient space for the installation of deck decompression chambers, and be able to provide the

submerged divers with heat and power for the duration of the operation.

Volume I, Chapter Four (Operations Planning) is a comprehensive introduction to the planning of diving operations using surface-supplied air or open-circuit SCUBA. The material presented in that chapter is applicable to mixed-gas operations as well, although specific aspects of such operations are not directly covered. These aspects will be discussed in the following sections which are organized to follow the general format of Volume I, Chapter Four. This manner of presentation will serve also as a brief review of the overall subject of dive planning.

The basic planning steps which will be described are—

- Define objectives.
- Collect and analyze data.
- Establish operational tasks.
- Select diving technique.
- Select and assemble the diving team.
- Brief the diving team.
- Make final preparations and check all safety precautions.

Define Objectives 9.4.1 Why is the operation being undertaken, and what is to be accomplished?

Factors which will influence the choice of mixed gas, rather than air diving or no diving at all, will include the depth of the work site, the estimated length of time required to complete the job and the availability of specialized equipment. In general—

- For deep dives of short duration or for shallower dives where absolute mental acuity and physical dexterity are required, surface-supplied mixed gas may be the method of choice.
- For dives below 300 feet or for dives in shallower levels where extensive underwater times are indicated, saturation diving is the technique of choice.
- A habitat is best suited to operations requiring close and constant observation of a single work area, as in scientific investigation. For other types of operations the safety and

comfort of the divers in a saturation dive will be better supported with the use of personnel transfer capsules and deck decompression chambers. In general, a habitat requires greater levels of surface support and greatly limits the mobility and flexibility of the support units.

Collect and Analyze Data 9.4.2 This data will include information about environmental conditions at the dive site (bottom conditions, tides and currents, weather), specific information about the resources available for the conduct of the operation including the availability of logistic and emergency assistance. Analysis of such data will aid in the selection of the dive technique and divers, in the identification of potential hazards, and in making allowances for contingencies which might arise.

Establish Operational Tasks 9.4.3 Tasks embracing the entire operation from the planning stage to final post-dive activities must be established. Prepare a basic outline for the operation and ensure that all phases will be properly coordinated and that all identifiable tasks are assigned to responsible units or individuals.

Select Diving Technique 9.4.4 As with air diving operations the principal factors influencing the choice of technique are—

- depth and planned duration of the dive.
- qualifications of personnel.
- type of work and degree of mobility required.
- environmental considerations (temperature, visibility, type of bottom, current, pollution, etc.).

In mixed-gas diving the importance of some of these factors is increased, and additional factors are imposed—

- Since most mixed-gas diving is deep diving (See Table No. 9-1 for Depth Limits), the divers must be prepared to work at low temperatures and at a distance—in both time and space—from the surface. For such reasons, SCUBA would be generally inappropriate unless employed in conjunction with a personnel transfer capsule (tethered mode) or habitat.

- Mixed-gas SCUBA, except when used from a PTC, is currently limited to use by combat swimmers.
- Oxygen SCUBA, intended for shallow clandestine operations involving maximum freedom from detection, is not to be used in fleet diving operations. Use of this equipment is restricted to combat swimmers specially qualified by training in its use and hazards.
- The use of lightweight gear(MK1) and the open bell finds particular application in situations which necessitate mobility in the water column. Deep-sea recirculating gear provides the diver comfort and security demanded by particularly adverse environmental conditions and obstructions, such as in deep salvage or repair operations.
- Operations below 300 feet, whether saturation or non-saturation, imply the need for DDS equipment. Decompression obligations below this depth impose such physical demands upon the diver that in-water decompression is impractical. Use of a bell system for diver transport and subsequent decompression on deck offers a significant margin of diver safety and support ship flexibility for non-saturation diving in deep and/or adverse environments.
- Surface support and logistic requirements are complex. Large specially-configured ships or diving barges are generally required; the normal small craft used in air diving are usually not appropriate. Currently the only standard fleet vessels equipped to support mixed-gas diving are the ASR (auxiliary submarine rescue) and ATS (auxiliary tug salvage) classes. Since certain other mixed-gas support vessels are unique—such as ships of the ASR-21 class equipped with DDS MK 2—the operations planning may have to include advance inputs to scheduling programs.
- The use of a habitat greatly reduces support flexibility since the topside vessels and other units are literally tied to the work site. The habitat, although on the bottom, is therefore indirectly subject to the sea-keeping problems caused by weather and wave action.



- The level of planning itself may place a significant workload on non-diving administrative personnel.
- All equipment used in mixed-gas and oxygen diving must be U.S. Navy-approved for such service. A list of approved equipment will be found in Appendix II D.

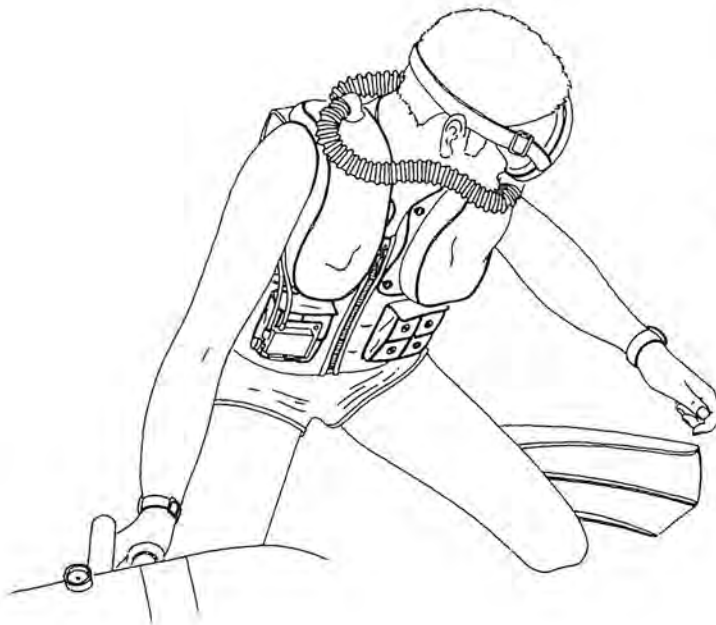
TABLE 9-1 – DEPTH LIMITS—TECHNIQUE & APPARATUS

DEPTH IN FEET METERS		LIMIT FOR	NOTES
25	7.62	Breathing 100 percent oxygen while working or swimming.	(1)
130	39.6	Nitrogen-oxygen mixed-gas SCUBA; normal working limit.	(2, 3)
170	51.8	Nitrogen-oxygen mixed gas SCUBA; exceptional exposure limit.	(3)
200	61.0	Helium-oxygen mixed-gas SCUBA; maximum working limit.	(3)
300	91.5	Surface-supplied, deep-sea, helium-oxygen diving; maximum working limit.	(3, 4)
300	91.5	Surface-supplied MK 1 lightweight gear with open bell, helium-oxygen diving; maximum working limit.	(3, 4)
Below 300 Feet		Surface-supplied helium-oxygen diving is not to exceed 300-foot depth limit without the direct authorization of the CNO in accordance with OPNAV 9940.1E	
1,000	304.8	Deep diving systems used within certification limits of systems and breathing apparatus.	(5)

Notes:

- (1) For time limit at 25 feet and for other depth-time relationships, see Chapter 13.
- (2) Certain operational swimmers (EOD, UDT, SEAL) are authorized to dive to depths listed for use with helium-oxygen SCUBA when required, provided they have been qualified through approved training.
- (3) These limits are based on a practical consideration of working time versus decompression time and oxygen tolerance limits. In the use of nitrogen-oxygen mixed-gas SCUBA and surface-supplied helium, the normal oxygen partial pressure limits will not be exceeded except for exceptional situations.
- (4) A diving medical officer and a recompression chamber are required on the scene for all dives using surface-supplied helium-oxygen equipment.
- (5) A diving medical officer is required on the scene for all DDS operations. All diving personnel must be saturation qualified. Current certification limits for respective equipment are as follows—
 - DDS-MK 1, Mod 0—850 feet
 - DDS-MK 2, Mod 0—850 feet
 - DDS-MK 2, Mod 1—850 feet
 - SDS 450—450 feet
 - MK 10, Mod 4 Apparatus—850 feet
 - MK 11, Mod 0 Apparatus—850 feet
 - MK 1 Diver's Mask—850 feet

OXYGEN DIVING GENERAL CHARACTERISTICS



Minimum Equipment—

- UDT-type life jacket
- Depth gage
- Facemask
- Swim fins
- Knife
- Wristwatch

Principle Applications—

- Shallow search and inspection
- Clandestine operations

MIXED-GAS DIVING THEORY



Figure 9-23 Oxygen rebreather (rear view).

Advantages—

- No surface bubbles
- Long duration
- Good mobility
- Rapid deployment
- Portability
- Minimum support

Disadvantages—

- Limited to shallow depths
(O₂ Toxicity Hazard)
- No voice communications
- Limited physical protection
- Influenced by current

Restrictions—

- Work limits—
 - Normal 25 feet/75 minutes
 - Maximum 40 feet/10 minutes
 - Current—1 knot maximum
- Diving team—
 - One diver—minimum 4 men
 - Two divers—fleet minimum 6 men
 - EOD/UDT/SEAL minimum 4 men

Operational Considerations—

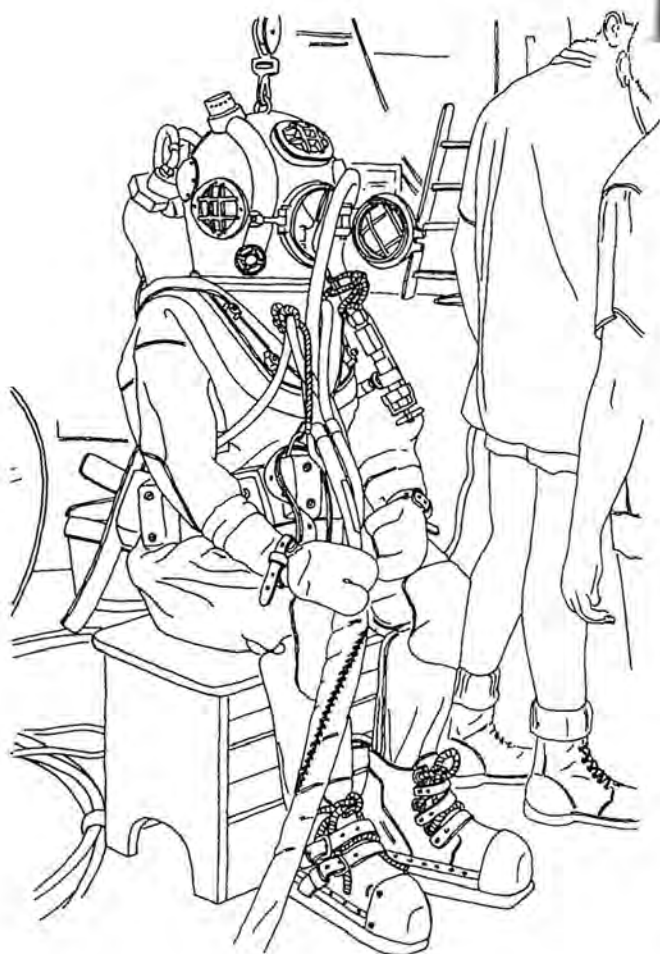
- Buddy and stand-by diver required*
- Small boat required for diver recovery
- Avoid use in areas of coral and jagged rock
- Moderate to good visibility preferred

*Requirement may be waived by EOD/UDT/SEAL diving officer

RECIRCULATING DEEP-SEA DIVING GENERAL CHARACTERISTICS



Figure 9-24 Recirculating Deep-Sea Diving



Minimum Equipment—

- Recirculating helmet and breastplate
- Diving dress
- Thermal underwear
- Weight belt
- Weighted shoes (heavy)
- Knife
- Gloves
- Surface umbilical
- Pneumofathometer

Principle Applications—

- Deep diving operations
- Submarine Rescue
- Heavy salvage and repair
- Underwater construction

Advantages—

- Unlimited by gas supply
- Maximum physical and thermal protection
- Voice and line-pull communications
- Variable buoyancy

Disadvantages—

- Slow deployment
- Poor mobility
- Large support craft and surface crew

Restrictions—

- Work limits—
 - Normal 290 feet/30 minutes
 - Maximum 300 feet/100 minutes
- Current—2.5 knots maximum
- Diving team—minimum 10 men

Operational Considerations—

- Adequate mixed-gas supply
- Stand-by diver required
- Diving medical officer and recompression chamber required
- Exceptional exposures require approval of commanding officer or higher authority

LIGHTWEIGHT MIXED-GAS DIVING GENERAL CHARACTERISTICS

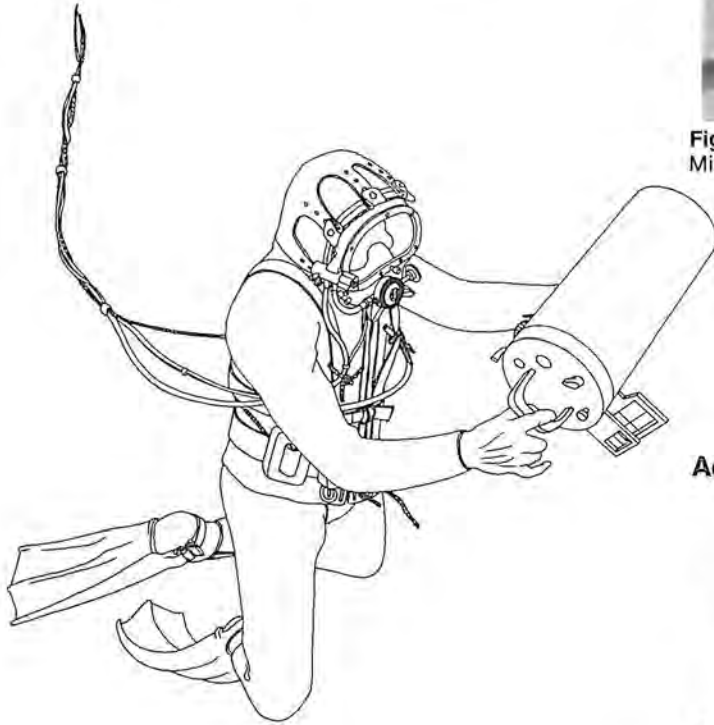


Figure 9-25 Open Bell and Lightweight Surface-Supplied Mixed-Gas Diver.

Minimum Equipment—

- Diver's Mask USN MK I
- Unisuit
- Weight belt
- Knife
- Swim fins or shoes
- Open bell with surface umbilical
- Umbilical from open bell
- Come-home bottle

Principle Applications—

- Deep water search, inspection and repair
- Light salvage

Advantages—

- Unlimited by gas supply
- Good horizontal mobility
- Voice and line-pull communications
- Fast deployment
- Protection of open bell during descent and ascent
- Safety provided by open bell at worksite

Disadvantages—

- Mobility limited by umbilical
- Large support craft required
- Limited physical protection when working outside of bell

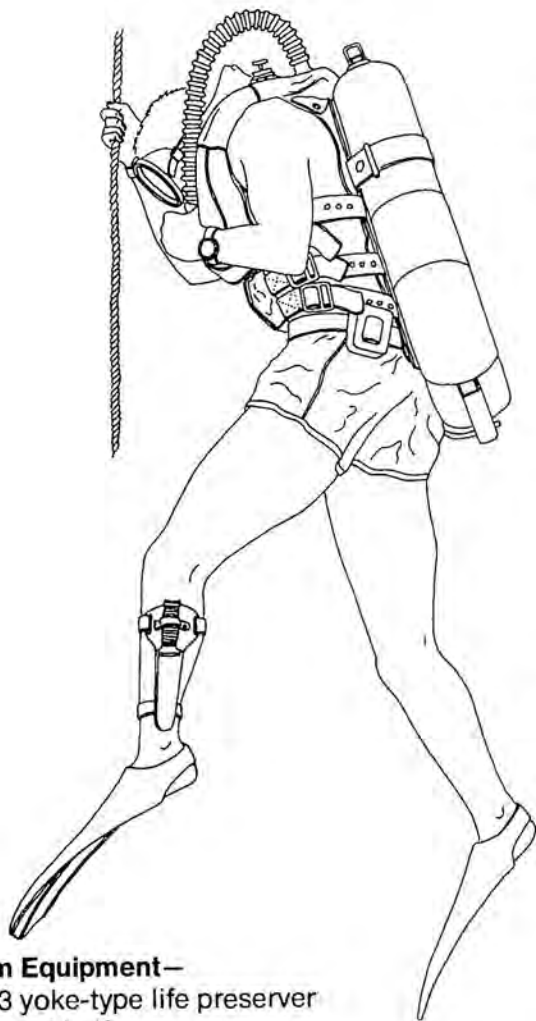
Restrictions—

- Work limits—
 - Normal 290 feet/30 minutes
 - Maximum 300 feet/100 minutes
- Current—2.5 knots maximum
- Diving team—minimum 10 men

Operational Considerations—

- Open bell required
- Adequate mixed-gas supply
- Stand-by diver required
- Diving medical officer and recompression chamber required
- Exceptional exposures require approval of commanding officer or higher authority

MK 6 SEMICLOSED-CIRCUIT DIVING GENERAL CHARACTERISTICS



Minimum Equipment—

- MK 3 yoke-type life preserver
- Belt and knife
- Swim fins
- Facemask
- MK 6 SCUBA
- Wristwatch

Principle Applications—

- Deep search and inspection
- Light repair and recovery
- Clandestine operations



Figure 9-26 MK 6 SCUBA

Advantages—

- Efficient utilization of mixed-gas supply
- Reduced surface bubbles
- Rapid deployment
- Portability
- Excellent mobility
- Minimum support
- Minimum bottom disturbances

Disadvantages—

- Limited endurance
- Breathing resistance
- Limited physical and thermal protection
- Lack of voice communications
- Influenced by current

Restrictions—

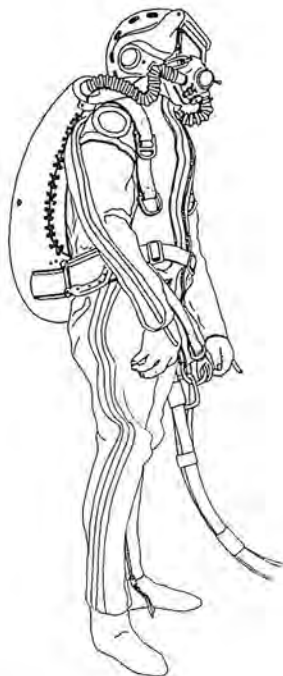
- Work limits—Helium-Oxygen—
 - Normal 170 feet/35 minutes
 - Maximum 200 feet/30 minutes
- Work limits—Nitrogen-Oxygen—
 - Normal 130 feet/30 minutes
 - Maximum 170 feet/30 minutes
- Current—1 knot maximum
- Diving team
 - One diver—minimum 4 men
 - Two divers—fleet minimum 6 men
 - EOD/UDT/SEAL minimum 4 men

Operational Considerations—

- Buddy and standby diver required*
- Diving medical officer and recompression chamber required*
- Small boat required for diver recovery
- Avoid use in areas of coral and jagged rock
- Moderate to good visibility preferred

*Requirement may be waived by EOD/UDT/SEAL diving officer

DEEP DIVING SYSTEMS GENERAL CHARACTERISTICS



Minimum Equipment—

As specified by the system being used, but to include—

Deck decompression chamber
Entrance lock

Personnel transfer capsule

Control console

Life support system

Handling system

Diver's lockout apparatus, either—

Diver's Mask USN MK 1

MK 10 MOD 4

MK 11 MOD 0

Principle Applications—

Deep observation

Deep, short duration, search, salvage and repair

Saturation diving for projects requiring extensive bottom time



Figure 9-27 DDS MK I

Advantages—

Maximum diver safety
Efficient utilization of bottom time
Maximum comfort
Continuous personnel monitoring

Disadvantages—

Slow deployment non-pressurized pre-dive inspections
Large support craft and crew
Limited mobility

Restrictions—

Work limits—

DDS MK 1 MOD 0—1000 feet

DDS MK 2 MOD 0—1000 feet

DDS MK 2 MOD 1—1500 feet

SDS 450—450 feet

MK 10 MOD 4—1500 feet

MK 11 MOD 0—850 feet

MK 1 Mask—1000 feet

Diving team—

DDS MK 1—16* **

DDS MK 2—16-17* **

SDS 450—11*

Operational Considerations—

Large gas supply required

Surface-supplied stand-by diver(s) needed for each diver out of PTC

All diving personnel must be saturation qualified

Diving medical officer required

Operationally limited by the capability of the handling system

Supply of hot water required for cold water lockouts

Selection of diver's apparatus governed by lockout depth and duration

*plus handling crew

**based on single watch, saturation-mode

Select and Assemble the Diving Team 9.4.5

The typical mixed-gas team will include the following personnel—

- Diving Officer.** In charge of training and all diving operations.
- Diving Supervisor.** Assists the diving officer in the planning phases, ensures that all preparations are properly made, and when diving commences is directly in charge at the diving station.
- Diving Medical Officer.** Responsible for the medical and physiological aspects of the dive, including pre and post-dive evaluation of diver condition, and medical emergencies encountered throughout the dive.
- Diver.** Must be qualified for both the depth of operation and the mixed-gas diving technique to be used.
- Standby Diver.** Same qualifications as the diver; prepared to enter the water immediately to assist the diver in an emergency.
- Tender.** Qualified diver. Dresses and assists the diver while on the surface; tends the diver's lines and hoses during the dive, and maintains frequent communications with the diver while monitoring the diver's location, condition and progress.
- Timekeeper/Recorder.** Qualified diver. Maintains the diving log. Records bottom and decompression time. Maintains voice communications with the diver and monitors depth with the pneumofathometer.
- Rack Operator.** Qualified diver. Responsible for providing adequate and correct breathing gas to the diver.

When a deep diving system (DDS) is employed, typical additional personnel—each qualified in the DDS being used—are required as follows—

- Control Van Operator.** Qualified diver. Conducts detailed pre-dive check of all systems and components (control van, personnel transfer capsule, deck decompression chamber, etc). Maintains proper atmosphere and pressure in the DDC. Maintains communications

with the divers. Decompresses divers according to established schedule.

- Winch/Tugger Operator.** Qualified diver. Conducts pre-dive inspection of all elements of PTC handling systems (cranes, winches, umbilicals and cables). Operates the umbilical or lift wire winch during launch and retrieval of the PTC; supervises and coordinates deck crane handling of the PTC. Supervises handling and storage of umbilical or cable.
- Hose/Cable Handler.** Qualified diver. Mates umbilical bundle to the PTC lift wire. Ensures free flow of umbilical/cable during deployment and retrieval of PTC. Maintains running inspection of umbilical/cable, watching for potential defects.
- Extra Man.** Qualified diver. Trained in the duties of various members of the team; available for relief as necessary.

Table No. 9-2 contains manning levels for specific types of mixed-gas operations and equipment. Appendix E (Vol. I) lists qualifications for mixed-gas diving personnel.

Brief the Diving Team 9.4.6 With the larger teams and increased complexities of mixed-gas operations, comprehensive briefings of all hands are extremely important. While the operation is in progress, divers returning to the surface (or to the PTC or habitat) should be promptly de-briefed so that topside personnel can be kept advised on the progress of the work and will have the information necessary for making modifications to the dive plan when appropriate.

Make Final Preparations and Check All Safety Precautions 9.4.7

Mixed-gas diving operations share the common elements of preparedness and safety of air diving discussed in Volume I. There are, however, three vital considerations in mixed-gas diving which must be recognized and evaluated prior to commencement of operations. Because of their importance, these factors—gas supply, hyperbaric flammability, and chamber contamination—are separately discussed in the following section.

TABLE 9-2 – PERSONNEL REQUIREMENT CHART

DESIGNATION	MIXED-GAS SCUBA Surface Crew			
	Optimum		Minimum	
	One Diver	Two Divers	One Diver	Two Divers (D)
Diving Officer	(C)	(C)	(C)	(C)
Diving Supervisor	1	1	1	1
Diver	1	2	1	2
Standby Diver	1	1	1	1
Tender	1	2(A)	1(A,B)	2(A,B)
Timekeeper/Recorder	1	1		
Total Men Required	5	7	4	6

DESIGNATION	SURFACE-SUPPLIED MIXED-GAS			Deep Diving System (E)	
	Deep-Sea Recirculating Rig		Lightweight (MK 1) & Open Bell	SDS 450	DDS —1,2 (G)
	One Diver	Two Divers			
Diving Officer	1	1	1	1	1
Diving Medical Officer (Required)	1	1	1	1	1
Diving Supervisor	1	1	1	1	1
Diver	1	2	1	2	2
Standby Diver	1	1	1	2	2
Tender	3	4	2		
Timekeeper/Recorder	1	1	1	1	1
Rack Operator	1	1	1		
Control Van Operator				1	1
Winch/Tugger Operator			1(F)	1	2
Hose/Cable Handler				1	2
Extra Men					3
Total Men Required	10	12	10	11	16

NOTES:

- | | |
|--|---|
| <p>A. One Tender/Diver required when Divers are surface tended; if using Buddy System one Tender required for each Buddy pair.</p> <p>B. Tender also acts as Timekeeper.</p> <p>C. EOD Diving Officer required on scene for all EOD operations.</p> | <p>D. Four-man EOD team authorized to use two Divers.</p> <p>E. Assistance in handling PTC (SDC) required from ship's crew, this manpower not shown. Levels for non-saturation diving only.</p> <p>F. Ascent/Descent control of open bell.</p> <p>G. MK 2, Manning cited for use of one DDC only.</p> |
|--|---|

GAS SUPPLY 9.5

In air diving the breathing mixture is readily available, although operational limitations may be imposed by the capacities of pumps and compressors or the availability of back-up systems. In mixed-gas diving there is the one obvious prior requirement: adequate quantities of the appropriate gases must have been ordered and placed in stock before the operation may begin.

This is obviously a basic requirement. Perhaps too basic, because some otherwise well-planned operations have been failures because the support units had left port for remote operations carrying the wrong gas mixtures. In part these problems arise from the fact that many diving units are not equipped to work with "pure" gases and must use pre-mixed standard percentages—for instance, 16% oxygen and 84% helium or 20% oxygen and 80% helium. The gas mixture must be correct for each planned dive (based upon depth and apparatus to be used)—and must be determined far enough in advance of the operation to permit orderly procurement. If the operation is to be conducted in some area remote from the nearest point of re-supply, the initial determinations are critical.

Additionally, the gas supply must be adequate—in both quantity and content—for all phases of the operation from descent to decompression, and it must include a substantial reserve.

The procedures for determining the gas and CO₂ absorbent requirements of various types of breathing apparatus are shown in Table No. 9-3. The gas storage volume of various apparatus is shown in Table No. 9-4. When DDS-type of equipment is to be employed, additional substantial quantities of gas must be included for DDC and PTC charging and for replacing losses due to leakage, transfer trunk and medical lock usage and scrubber cycling. Required standards of purity, methods of gas analysis, and mixing procedures will be found in Appendix No. II A.

ASR He-O₂ Supply System 9.5.1 Although the use of mixed gas is not restricted to diving from submarine-rescue vessels, ASR's do constitute the largest category of suitably equipped ships in the USN fleet. Even though the precise design of gas supplies

aboard other vessels may vary from that aboard the ASR, the principles of other systems should be analogous. Consequently, the functioning of the ASR system is discussed in detail. It should be noted, however, that all members of the diving team assigned to a ship or unit equipped to conduct mixed-gas operations should be completely familiar with the **specific system** being used and the operation of automatic gas mixers, if installed.

The ASR helium-oxygen system consists of a helium-oxygen and oxygen cylinder stowage rack; diving station supply manifolds; and associated volume tanks, valves, gages, and piping as shown in Figure No. 9-28. The system is designed so that one of three breathing media—helium-oxygen, oxygen, or compressed air—can be supplied to the diver as required. The installations in different submarine-rescue vessels vary in detail of design, but in general they all provide for stowage of approximately 100 gas cylinders and for diving 2 divers from each of 2 separate stations.

The cylinders containing the helium-oxygen and oxygen gases are arranged in banks (Figure No. 9-29). They are arranged so that each helium-oxygen bank is loaded with a mixture containing a definite percentage of oxygen. The cylinder valves are opened, and gas to be supplied to the diver can then be controlled by valves on each bank. The oxygen cylinders are arranged in their own banks. The stowage is so designed that cylinders in an exhausted bank can be replaced without interrupting gas supply to the diver.

Helium-oxygen from the cylinder stowage rack passes through a high-pressure strainer and, in the installation shown in Figure No. 9-30 and Figure No. 9-31, through a pressure regulator to the volume tanks. These volume tanks number two for helium-oxygen and one or two for oxygen. Oxygen from the cylinder stowage rack passes through the oxygen pressure regulator before entering its volume tank(s). These piping systems include suitable valves, gages, and bypass arrangements. The volume tanks are tested to a pressure of 1,000 psi.

Gas from the volume tanks then goes to the diving stations where pressure-regulating valves for con-

TABLE 9-3—AVERAGE MIXED-GAS BREATHING APPARATUS GAS CONSUMPTION RATES AND CO₂ ABSORBENT USAGE

EQUIPMENT	GAS CONSUMPTION RATES		
	DEMAND		RECIRCULATING
	Light Work	Heavy Work	Heavy work Swimming
Diver's Mask USN MK 1	0.6 acfm 15.8 lpm	1.5 acfm 39.4 lpm	NA
Deep-Sea Recirculating Helmet	NA	NA	0.5 scfm 13.3 lpm
MK 6 & MK 11 60% O ₂ , 40% N ₂	NA	NA	0.28 scfm 6.9 slpm
40% O ₂ , 60% N ₂	NA	NA	0.42 scfm 11.0 slpm
32.5% O ₂ , 67.5% N ₂	NA	NA	0.74 scfm 19.5 slpm
32% O ₂ , 68% He	NA	NA	0.65 scfm 17.1 slpm
40% O ₂ , 60% He	NA	NA	0.39 scfm 10.5 slpm
Emerson Rebreather	NA	NA	0.053 scfm 1.4 slpm
MK 10 Mod 4	NA	NA	0.053 scfm 1.4 slpm

EQUIPMENT	CAPACITY (POUNDS BARALYME)	CO ₂ ABSORBENT USAGE			
		DURATION (HOURS)			
		LIGHT WORK		HEAVY WORK	
		Seawater 40°F	Temperature 70°F	Seawater 40°F	Temperature 70°F
Diver's Mask USN MK 1	NA	NA	NA	NA	NA
Deep-Sea Recirculating Helmet	6	0.8	6.0	0.34	2.7
MK 6	6	0.8	6.0	0.34	2.7
MK 11	10	1.3	10	0.58	4.6
Emerson Rebreather	6	0.8	6.0	0.34	2.7
MK 10 Mod 4	7	0.9	7.0	0.4	3.2

TABLE 9-4—CAPACITY OF MIXED-GAS APPARATUS CYLINDERS

EQUIPMENT	Rated Pressure PSIG	Water Volume Cubic Inches	Gas Capacity		Recommended Minimum Reserve	
			Surface Volume Feet ³	Liters	Pressure PSIG	Gas Content
Closed-Circuit O ₂ (EMERSON)	2000	152	12.7	360	500	O ₂
MK 6 Semiclosed-Circuit	3000	725	77	2380	600	He-O ₂
MK 10 Closed-Circuit-O ₂	3000	150	18	510	600	O ₂
MK 10 Closed-Circuit-Diluent	3000	150	16	453	600	He
MK 11 Semiclosed-Circuit (2 Cylinders)	3000	330	35	991	2700	He-O ₂

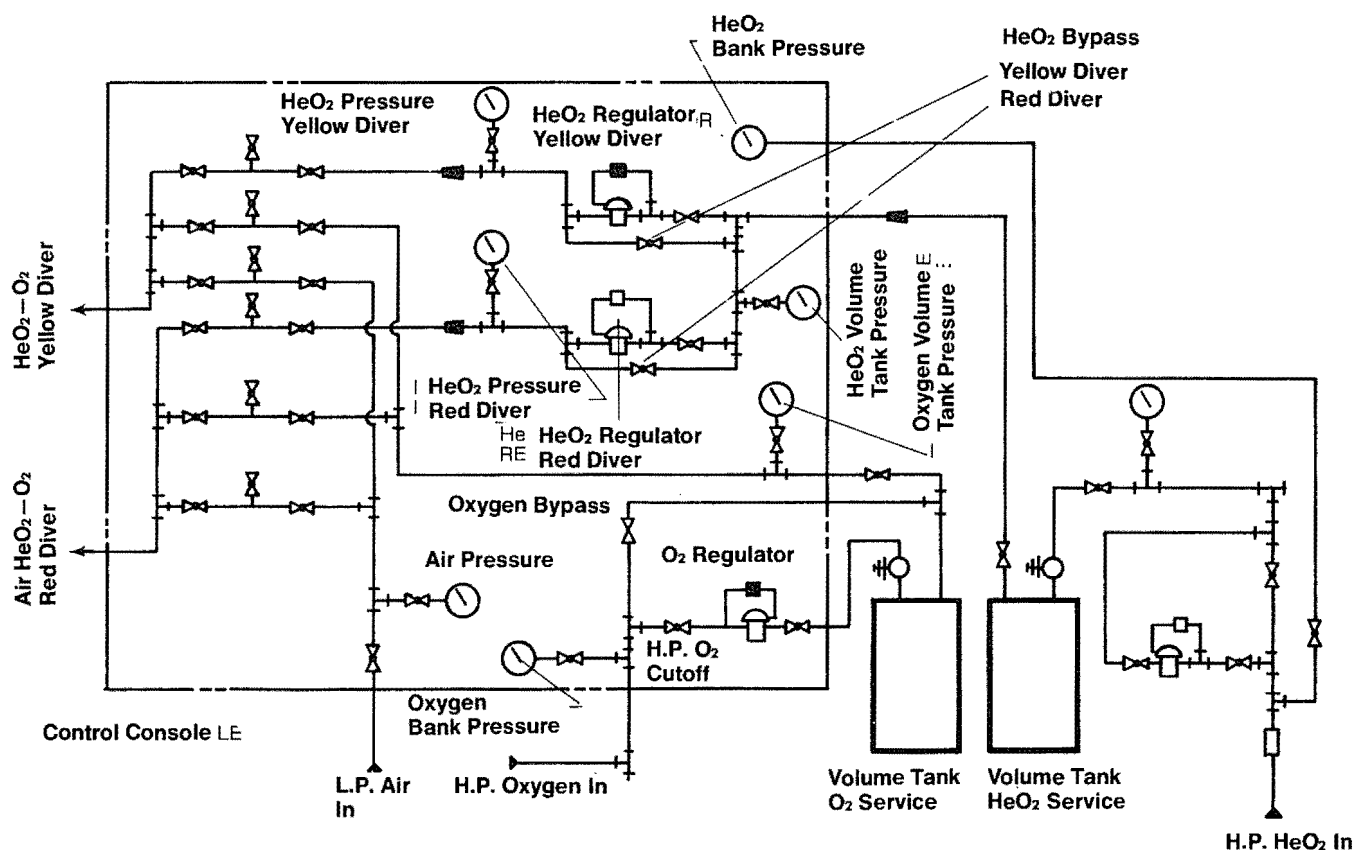


Figure 9-28 ASR Gas Supply Schematic

trolling the pressure of helium-oxygen or oxygen supplied to the divers are located (Figure No. 9-32). Each of these diving station manifolds provides necessary piping, valves, and gages to supply either helium-oxygen, oxygen, or air to one or two divers. It should be remembered that pressure regulation of the compressed air is at the source and not at the manifold.

The pressure-regulating valves (Figure No.'s 9-31A and 9-31B) with their dome loaders are used to regulate the pressure of helium-oxygen gas mixtures to that required by the diver. The valves are similar in construction to other diaphragm-operated regulators except that, instead of controlling the discharge pressure by means of spring pressure against the diaphragm, a dome over the diaphragm is charged to a suitable pressure by the dome loader. In case the pressure regulator does not operate correctly it can be cut out of the system by cutout valves and the pressure controlled by means of a bypass valve. The pressure delivered by the regulator must be carefully adjusted to the correct over-bottom pressure for the diver. This adjustment requires continuous changing of the dome loader setting while the diver is going down or coming up. The most likely causes of derangement of the regulator are failure of the diaphragm and worn or damaged valve parts.



Figure 9-30 He-O₂ and O₂ Volume Tanks.



Figure 9-29 ASR Gas Banks.



Figure 9-31 He-O₂ high pressure regulating station.





A



B

Figure 9-32 Diving station manifolds—
A ASR-21 class console
B ATS-1 class console

HYPERBARIC FLAMMABILITY 9.6

Recompression and deck decompression chambers (for saturation diving) are routinely used in support of mixed-gas diving. Because extensive oxygen breathing by mask in surface chambers is common practice, and in saturation procedures it is possible to vary the chamber oxygen content, the hazard of chamber fire assumes significant proportions.

It is often difficult or impossible to remove with absolute certainty any of the three conditions that can result in a fire from a closed-chamber atmosphere. For this reason operating personnel must be aware of the hazards and potential sources of chamber fires. The conditions necessary for a fire include: (1) an atmosphere capable of supporting combustion, (2) a source of ignition, and (3) a fuel. Every effort must be made to reduce or eliminate all materials and equipment from the chamber atmosphere which could contribute to a fire under pressure.

The oxygen percentage primarily determines the extent to which a given atmosphere will support combustion. Studies of oxygen-nitrogen mixtures have shown that many materials that would not burn in an atmosphere containing 21 percent oxygen will ignite and burn readily in an atmosphere containing 31 percent oxygen. In addition, it has been determined that at a higher total pressure ignition of certain materials will occur where no ignition was possible at lower pressures. Substitution of helium for nitrogen in the atmosphere reduces the tendency for ignition, but once ignited, materials burn at a faster rate. Subsequent studies have indicated that an atmosphere containing 6 percent oxygen or less at any pressure will not support combustion of most common materials.

Generally, the oxygen concentration in the chamber atmosphere for deep dives is maintained at low levels to avoid oxygen toxicity. This decrease in the oxygen percentage may also render the atmosphere incapable of supporting combustion under certain carefully defined conditions. Four zones representing complete combustion, incomplete combustion, slight combustion and no combustion are shown in Figure No. 9-33.

As a safety precaution, the oxygen partial pressure and absolute concentration within the chamber should

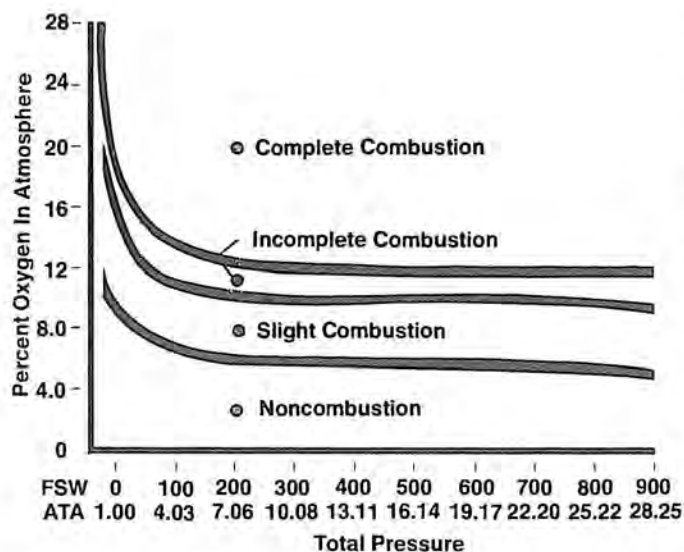


Figure 9-33 Hyperbaric Flammability Chart.

be held to an absolute minimum consistent with the physiological requirements of the occupants.

Considerable effort is being expended to develop suitable non-flammable clothing and bedding materials for chamber use. Until such time that satisfactory items are available, the quantity of flammable materials and potential ignition sources must be kept to an absolute minimum within the chamber.

CHAMBER ATMOSPHERE CONTAMINATION 9.7

The residence time which mixed-gas divers may spend in surface chambers can be extensive, particularly in saturation operations. With increased exposure time to the chamber atmosphere, the possible hazards to health presented by minor quantities of toxic impurities in the environment increases.

Toxic or noxious contaminants can be introduced into a chamber atmosphere in many obvious and often insidious ways. Items including paint, mastic, glue, cleaning solvents, wiring insulation, and rubber and plastic coatings can emit gaseous components which may cause injury to occupants in a high-pressure, closed atmosphere. Other sources of contaminants that could cause discomfort to chamber occupants include the diver himself, the diver's waste materials,

machinery or equipment failures. The toxic effects and limits of most contaminants have not been established for high pressure atmospheres. Contaminant limits are available for submarines based on a 1-atmosphere environment. However, great care should be taken before interpreting these limits for use in high pressure chamber atmospheres. Factors which must be taken into consideration in determining if a hazardous condition exists include—concentration of a contaminant, whether the effects are cumulative, the frequency with which contamination occurs, and the duration of such periods.

The capability for removal of gaseous contaminants in high pressure chambers or capsules of DDS systems is extremely limited. Contamination control at present is limited to (1) carbon dioxide removal with lithium hydroxide, Baralyme, or Sodasorb; and (2) trace contaminant removal, particularly odor-causing compounds, with Purafil. It must be remembered that scrubbers or absorbent materials will not remove all possible contaminants and that they are capable of selective absorption.

Caution must be exercised to eliminate or reduce the use of materials which will contaminate the atmos-



Figure 9-34 Baralyme, a CO₂ absorbent, is supplied in 40, 7 and 2 pound containers and in 4 pound disposable cartridges.



Figure 9-35 The DDS MK 1 Life Support Package controls the atmosphere inside the deck decompression chambers.

phere when repairing or overhauling equipment in a chamber. The use of cleaning solvents, glues, paints, or lubricants which would off-gas sufficient amounts of toxic materials to contaminate the atmosphere must be minimized. All chambers should be adequately ventilated and sufficient time allowed for curing, drying, etc., after any repair work involving any equipment, materials, or processes which might cause contamination of the chamber atmosphere during diving operations.

While on the surface, any chamber must be ventilated before and during any occupancy for the purpose of re-establishing consumables, repairing, or replacing equipment. In saturation diving after a PTC is depressurized following transfer of personnel to a chamber or a chamber lock is depressurized, the percentage of oxygen in the atmosphere may not be sufficient to support life on the surface. The chamber must be ventilated. ■

MIXED-GAS UNDERWATER BREATHING APPARATUS

Mixed-gas underwater breathing apparatus (UBA) encompasses that group of diver breathing equipment which employs a lightweight, diver-worn gas recirculation system to remove carbon dioxide and either an integral or PTC-provided mixed-gas supply. This class of equipment provides the operational mobility of the free or lightweight-equipped diver with the depth advantages of mixed gas and the extension of underwater duration and/or gas supply inherent in recirculating the diver's breathing gas. Some UBA's permit completely autonomous diver operations and therefore can be referred to as mixed-gas SCUBA; other apparatus of similar type receive their primary gas supply (via umbilical) from a PTC and consequently are not true SCUBA. Both types of equipment are grouped together in this chapter under the "UBA" designation because of their similarities in construction, operation, and use.

Although the world-wide development of mixed-gas UBA dates from 1912, its use in the USN is quite recent. Following WWII the MK 5 SCUBA was developed to provide greater depth capability, underwater duration, and minimum bubble and sound production for combat swimmers and Explosive Ordnance Disposal divers. The MK 5 is the direct ancestor of the current MK 6 apparatus which is widely used in free swimmer applications by UDT, SEAL and EOD divers (Figure No. 10-1).

In the 1960's, increased depth and duration capabilities provided by the introduction of deep diving systems (DDS) and saturation diving techniques brought about the need for improved diver breathing apparatus. The current generation of UBA for PTC diving operation, developed to meet these increased demands, share a common technology with mixed-gas SCUBA and oxygen rebreathers (Chapter Thirteen). The basic difference lies in the required umbilical to the PTC. The diver tether (essential to safe operations in DDS diving), while somewhat limiting diver mobility, provides several advantages to the PTC diver not afforded the free mixed-gas SCUBA swimmer. The umbilical can provide hard-wire two-way voice communications, heat to make up for respiratory and body surface losses, and a gas supply which is not limited to that which can be carried by the diver.



Figure 10-1 U. S. Navy Diving Team wearing the Mark 6 UBA

In modern diving there is no wider group of equipment than that of the UBA. Numerous manufacturers have made and are currently producing a great variety of mixed-gas recirculating apparatus for the underwater swimmer in both tethered and untethered modes. Many models can be used in either mode.

Although the number of types and specific features of UBA are extensive, the majority employ one of two types of operating principles—semiclosed-circuit or closed-circuit. It is the intent of this chapter to explain the nature of these two fundamental systems and describe in detail the specific UBA currently in USN service.

PRINCIPLES OF OPERATION 10.1

With open-circuit SCUBA, diving depth and duration are sharply restricted by the low efficiency of gas utilization resulting from complete discharge of each exhalation. The efficiency of gas utilization, with open-circuit apparatus based upon consumption of available oxygen, is approximately 5 per cent near the surface and decreases with increasing depth. In order

to conserve the gas supply and extend underwater duration, it is essential to improve the efficiency of gas utilization. This is accomplished in the UBA by diver-worn systems which recirculate the diver's breathing medium for reuse, remove carbon dioxide produced by metabolic action in the body, and control the oxygen concentration in the inspired gas within physiologically safe limits.

Recirculation and CO₂ Removal 10.1.1 The diver's breathing medium is recirculated in the UBA to remove carbon dioxide from the gas stream and permit reuse of the inert diluent component of the mixture. The basic recirculation system, as shown in Figure No. 10-2, consists of a closed loop incorporating inhalation and exhalation hoses and associated check valves; a mouthpiece, full facemask, or lightweight helmet; a carbon dioxide removal unit; and one or two breathing bags.

Movement of recirculating gas through the circuit is normally accomplished by the natural inhalation-exhalation action of the diver's lungs. Since the lungs are only capable of producing small pressure differences, the entire circuit must be designed for minimum flow restriction.

The connection device between the diver's breathing passages and the circuit must be of minimum volume to preclude deadspace and associated rebreathing of local, CO₂-rich gas. This is accomplished in full-face masks and lightweight helmets by using an integral oral-nasal mask or mouthpiece. Similarly, inhalation and exhalation check valves used to ensure unidirectional flow of gas through the circuit must be in close proximity to the diver's breathing passages to minimize deadspace. All connecting hoses in the system must be of relatively large diameter (usually 1½" diameter) to minimize pressure drop.

CARBON DIOXIDE SCRUBBER 10.1.1.1 Carbon dioxide is normally removed from the breathing circuit in a watertight canister of CO₂ absorbent material located in the backpack of the UBA. Certain absorbents, e.g., shell natron (sodium hydroxide) and lithium hydroxide, strongly react with water to produce caustic fumes and cannot be used in UBA's. The canister assembly is usually filled with granular Baralyme, an efficient CO₂ absorbent which, if in-

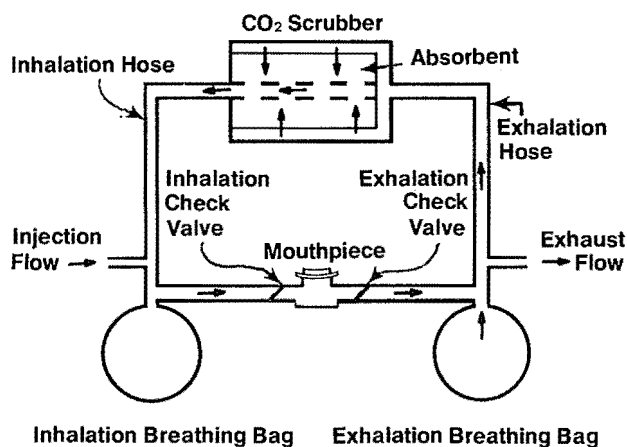


Figure 10-2 Schematic of the basic UBA recirculating loop.

advertently wetted, produces a minimum of caustic fumes. Water produced by the reaction between the CO₂ and the Baralyme, and by the diver himself, is sometimes removed by a chemical absorbent or water absorbent material in the canister. CO₂ absorption capacity of the scrubber bed is strongly influenced by temperature. Capacity may be reduced as much as 80% when operating temperature drops from 70°F to 40°F. In UBA's designed for use from PTC's, it is common practice to heat the backpack with hot water to maintain permissible inspired gas temperatures and to improve canister duration in cold water operations.

The canister design must provide low flow resistance and maximum contact between the gas and the absorbent. Flow resistance is usually minimized by employing a canister housing which provides an annular space around the absorbent bed to reduce the gas flow distance through the Baralyme. The absorbent may be provided in a throw-away cartridge or be bulk-filled into a canister. If improperly bulk-

filled, channels may be formed in the bed by bridging of the absorbent granules which permit gas to bypass the absorbent and retain carbon dioxide. As a consequence, care must be taken during bulk filling operations to thoroughly settle the bed by gentle tapping of the canister. Fine material which passes through the canister screen must be blown free from the system before use to avoid dust inhalation.

BREATHING BAGS 10.1.1.2 One or two breathing bags are used in all UBA to permit free breathing in the circuit. The need for such devices can be readily demonstrated by attempting to exhale and inhale into an empty soda pop bottle. The bottle, analogous to the recirculation system without bags, is unyielding and presents extreme back pressure. In order to compensate for this phenomenon, extensible gas accumulators or reservoirs must be placed in the UBA circuit. A flexible diaphragm or breathing bag(s) is located in parallel or series in the breathing circuit and has a maximum displacement equal to the combined volume of both lungs.

Neutral buoyancy is inherent in the system since the gas reservoir is designed to act counter to normal lung action (sometimes such bags are referred to as "counter lungs"), and consequently, constant volume is maintained. During exhalation, and associated reduction in body displacement and buoyancy due to diminished lung volume, the reservoir expands and displaces an equal water volume to maintain neutral diver buoyancy. On inhalation the situation is reversed. This cycle is shown in (Figure No. 10-3).

The flexible gas reservoir must be physically located as close to the diver's lungs as possible to minimize any hydrostatic pressure difference between the lungs and the reservoir as the diver changes attitude in the water. This is accomplished in twin-bag UBA's by locating the bags on the upper portion of the body trunk to the left and right of the head either in the front attached to a vest or in the rear within the backpack.

Single bag UBA's usually have the reservoir built into the backpack assembly and located at the centroid of the lungs.

The use of a single bag or diaphragm located within the backpack is mechanically simpler and affords

minimum encumbrance to the diver and maximum protection for the reservoir. However, because of the variation in flowrate experienced during each breathing cycle, greater breathing resistance is encountered during peak flow in the single bag system than in a two-bag system. The twin-bag UBA permits gas to be accumulated on both sides of the scrubber and tends to average the flowrate through the system to minimize pressure drop.

RECIRCULATION SYSTEM FAILURE 10.1.1.3

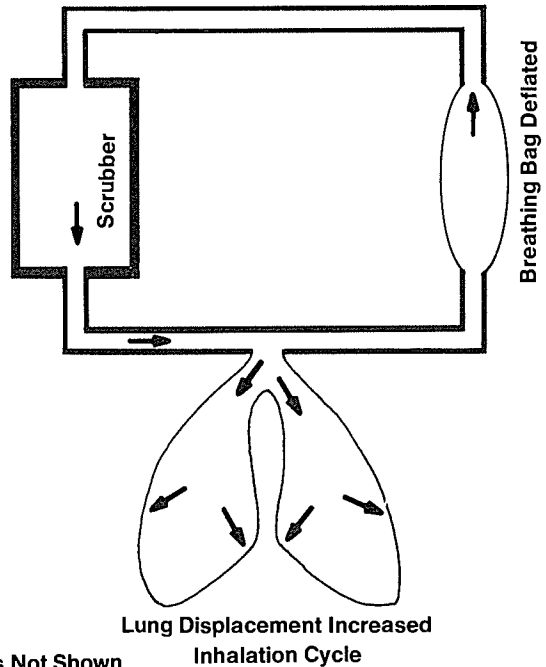
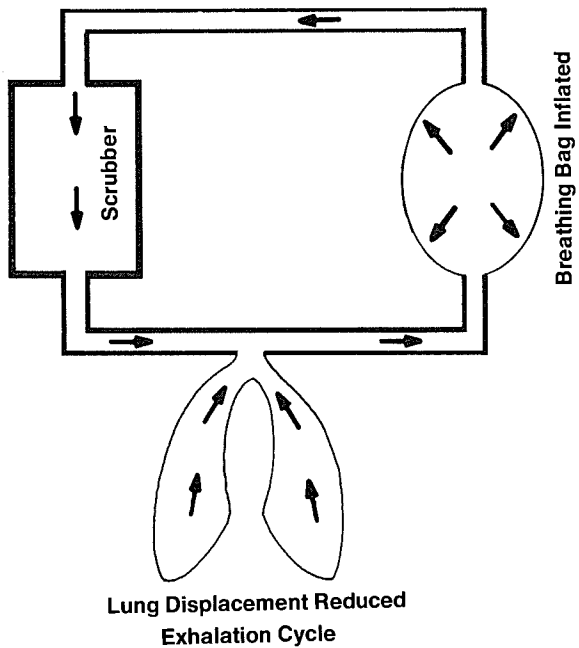
Reliable functioning of the recirculation system is vital to the safety of the UBA-equipped diver. Any factor which reduces the efficiency of CO₂ removal increases the hazard of carbon dioxide poisoning. Properly maintained equipment filled with fresh, well-packed Baralyme; avoidance of partial water flooding due to improper assembly, testing, or technique; and careful attention to limiting underwater duration to safe canister capacity at the operating temperature are all essential to diver safety.

Gas Addition, Exhaust and Monitoring 10.1.2

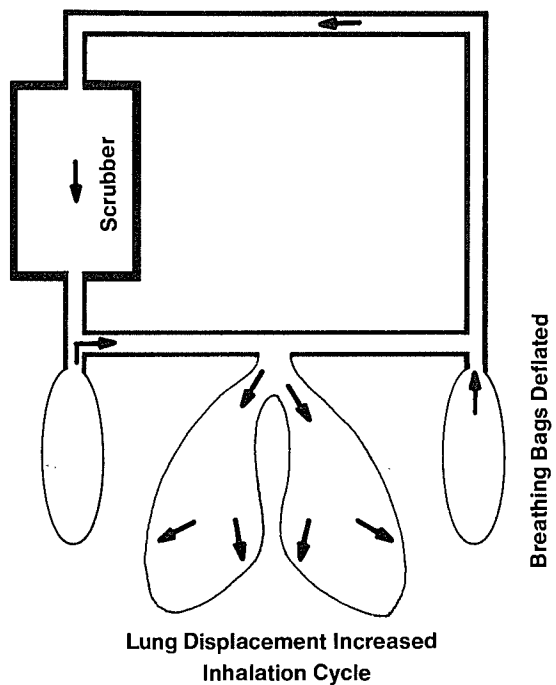
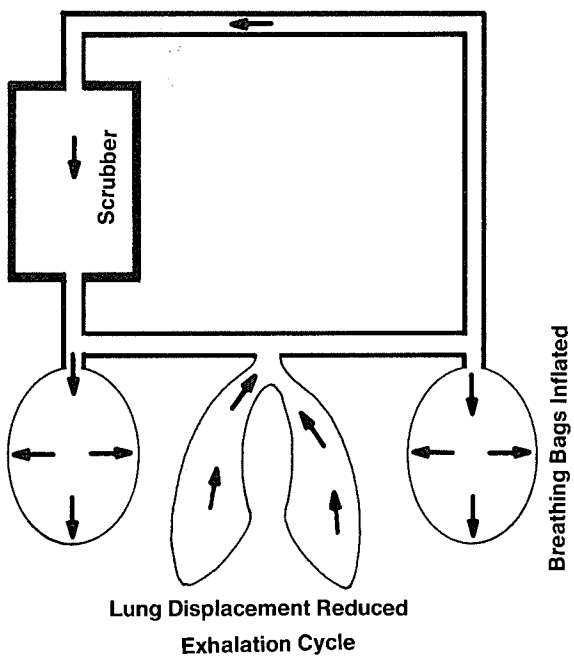
In addition to the hazard of carbon dioxide poisoning, the UBA diver encounters two additional hazards—hypoxia and oxygen toxicity. For safe operation it is essential that the UBA reliably control the oxygen partial pressure in the breathing medium within narrow limits to avoid these hazards.

Hypoxia can occur whenever sufficient oxygen is not being added to the recirculation circuit to meet metabolic requirements. If oxygen or an oxygen-rich mixed gas is not added to the re-breathing circuit, it is apparent that the oxygen in the loop will be gradually consumed until a point is reached at which the mixture is incapable of sustaining life.

Oxygen toxicity, as described in Chapter Nine, can occur whenever the oxygen partial pressure in the diver's breathing medium exceeds specified concentration and exposure time limits. Consequently, in addition to the proper pre-dive selection of the correct oxygen partial pressure for the depth and duration of the dive, the UBA must function to limit the maximum oxygen level to the required value at the anticipated work rate.



Single Gas Reservoir—Check Valves Not Shown



Twin Bag Gas Reservoir—Check Valves Not Shown

Figure 10-3 UBA breathing bags act to maintain the divers' neutral buoyancy by responding counter to lung displacement.

The method used to maintain the oxygen concentration in the breathing medium within the required upper and lower limits in the UBA varies depending upon the principles of operation—semiclosed-circuit or closed-circuit.

SEMICLOSED-CIRCUIT 10.1.2.1 The semiclosed-circuit apparatus employs the continuous injection of a small fixed flowrate of oxygen-rich mixed gas into the system to satisfy metabolic requirements. The oxygen-rich injection gas is mixed with the recirculating mixed gas in the UBA on the inhalation side of the apparatus to maintain the average oxygen partial pressure in the circulating gas stream at the required level. Assuming constant depth operation, a somewhat lesser flowrate (due to oxygen consumption) of recirculating gas from the exhalation side of the apparatus is exhausted to the surrounding water.

The semiclosed UBA employs a **constant mass flow-rate system**. Since oxygen consumption by the body at any given work rate is a mass (not volume) related function, continuous injection of a sufficient mass of oxygen to just balance the body's requirements results in maintenance of a constant partial pressure of oxygen in the recirculating gas stream at any given depth. Constant mass injection of an oxygen-rich (relative to the recirculating stream composition) mixed gas is employed, rather than injection of 100% oxygen, to minimize apparatus complexity. For adequate diver safety under operating conditions involving various work rates and depths, UBAs employing pure oxygen injection require redundant oxygen analysis and control circuits. Such systems are discussed in Section 10.1.2.2. Constant mass injection systems also eliminate the need for automatic or manual variation in volume flow as depth varies throughout the dive.

A. LIMITATIONS—Since semiclosed UBA's use a preset mass flow principle, they are subject to certain operational limitations. The **bag oxygen percentage**, or "bag level," (average O_2 level in the system) must be predetermined based upon the anticipated work rate of the diver and maximum allowable oxygen partial pressure at depth. These considerations establish the flowrate setting and oxygen percentage in the supply mix. The O_2 percentage in the mix is governed

by the maximum partial pressure at depth that may be safely breathed if the recirculation system must be bypassed and supply gas used for direct breathing. Flowrate setting is based upon the percentage of oxygen in the supply mix and the anticipated work rate or oxygen utilization rate of the diver.

The preset conditions result in limits which cannot be altered during the dive if the underwater situation changes. As an example, depth cannot be increased without danger of oxygen toxicity resulting from use of the premixed gas at higher pressure. A UBA flowrate set for minimum exertion and noise propagation level in defusing a mine may be insufficient for an extended swim and produce hypoxia due to over consumption of available oxygen.

The depth range over which a semiclosed UBA can be employed is also limited by injection gas considerations. A free diver deploying from the surface must have a minimum bag oxygen level of 16% at 1.0 atmosphere to avoid hypoxia. Oxygen concentration in the supply mix and flowrate considerations for the surface condition will obviously govern maximum depth due to partial pressure limits.

Semiclosed UBA's adjusted for excursion diving from PTC's at great depth use leaner oxygen supply mixtures and are operationally safe only within a given depth range. An ascent to the surface with a semiclosed apparatus being used from a PTC at 600 feet, even if practical from the standpoint of decompression, would result in hypoxia. Conversely, use of a UBA set for diving from the surface could result in oxygen toxicity if employed from the PTC at 600 feet.

In practice the maximum depth that the highest percentage oxygen mixture can be breathed is the depth at which the partial pressure of oxygen equals 1.6 ata (N_2 - O_2 diving) and 2.0 ata (He - O_2 diving). As previously discussed, the oxygen percentage of the supply mix must not exceed the allowable oxygen partial pressure limits. The bag oxygen level will always be lower than that of the supply due to metabolic consumption. Maximum oxygen supply percentage or maximum depth on a given supply oxygen level can be determined by solving the following appropriate formula—

$$\%O_2 \text{ max} = \frac{ppO_2 \text{ max} \times 33 \text{ ft/ata} \times 100\%}{D \text{ max} + 33 \text{ ft.}}$$

$$D \text{ max} = \frac{ppO_2 \text{ max} \times 33 \text{ ft/ata} \times 100\%}{\%O_2 \text{ sup}} - 33 \text{ ft}$$

Where—

$\%O_2 \text{ max}$ = Maximum permissible oxygen concentration in supply mixture, percent

$D \text{ max}$ = Maximum depth of dive on available mixture, feet of seawater

$ppO_2 \text{ max}$ = Maximum permissible oxygen partial pressure,
1.6 ata for nitrogen-oxygen mixtures
2.0 ata for helium-oxygen mixtures

$\%O_2 \text{ sup}$ = Maximum permissible oxygen concentration in supply mixture, percent

Example—

Problem—

A. Determine the maximum allowable $\%O_2$ in the supply mixture for a N_2 - O_2 dive to 143 fsw.

B. Determine the maximum allowable dive depth using a supply mixture containing 32% oxygen and 68% helium.

Solution—

Substituting—

A.

$$\%O_2 \text{ max} = \frac{1.6 \text{ ata} \times 33 \text{ ft/ata} \times 100\%}{143 \text{ fsw} + 33 \text{ fsw}} = 30\%$$

B.

$$D \text{ max} = \frac{2.0 \text{ ata} \times 33 \text{ ft/ata} \times 100\%}{32\%} - 33 \text{ fsw} \\ = 173 \text{ fsw}$$

For any rate of oxygen utilization by the diver, the bag oxygen percentage can be accurately predicted if the cylinder gas composition and the rate of gas inflow are known. Diver oxygen consumption is normally considered to be 0.5 liters/min at rest and 3.0 liters/min maximum during heavy underwater work. The constant mass flow of gas is usually expressed as liters/min (STPD) because this unit is readily measured during predive adjustment using a variable area flowmeter. The breathing bag (inspired) oxygen and inert gas concentrations during

rest and heavy work can be determined using the following formulas—

$$\%O_2 \text{ bag} = \frac{(O_2 \text{ in} \times G \text{ in}) - O_2 \text{ con}}{G \text{ in} - O_2 \text{ con}} \times 100$$

Where—

$\%O_2 \text{ bag}$ = Bag oxygen level, percent

$O_2 \text{ in}$ = Oxygen level in supply gas, decimal percent

$G \text{ in}$ = Total mixed-gas inflow, liters per minute

$O_2 \text{ con}$ = Oxygen consumed, liters per minute

Example—

Problem—

Determine the bag gas composition for a diver at rest and performing heavy work using a UBA with 60% O_2 /40% N_2 supply mix and an injection gas inflow of 8 liters/min (STPD).

Solution—

Substituting—

$\%O_2 \text{ BAG at Rest}$

$$= 100\% \frac{(.60 \times 8 \text{ liters/min.}) - 0.5 \text{ liters/min.}}{8 \text{ liters/min.} - 0.5 \text{ liters/min.}}$$

$$= 100\% \frac{4.8 \text{ liters/min.} - 0.5 \text{ liters/min.}}{7.5 \text{ liters/min.}}$$

$$= 100\% \frac{4.3 \text{ liters/min.}}{7.5 \text{ liters/min.}} = 57.3\% O_2$$

$\%N_2 \text{ In Bag at Rest} = 100\% - 57.3\% O_2 = 42.7\% N_2$

$\%O_2 \text{ BAG During Work}$

$$= 100\% \frac{(.60 \times 8 \text{ liters/min.}) - 3.0 \text{ liters/min.}}{8 \text{ liters/min.} - 3.0 \text{ liters/min.}}$$

$$= 100\% \frac{4.8 \text{ liters/min.} - 3.0 \text{ liters/min.}}{5.0 \text{ liters/min.}}$$

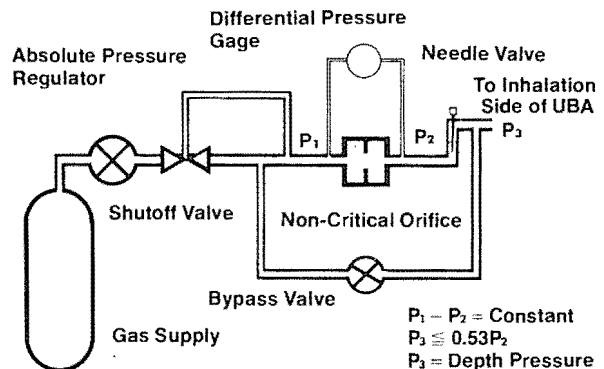
$$= 100\% \frac{1.8 \text{ liters/min.}}{5.0 \text{ liters/min.}} = 36.0\% O_2$$

$\%N_2 \text{ In Bag During Work} = 100\% - 36\% = 64\% N_2$

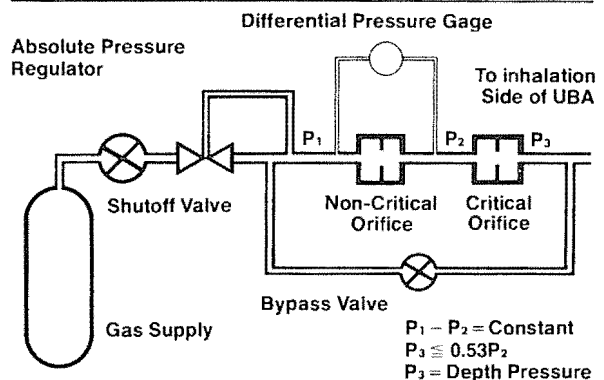
From this example it can be seen that the bag oxygen level will vary from 57.3% at rest to 36.0% during heavy activity. During these fluctuations, the gas entering the bag from the supply remains fixed at 8 liters per minute with a 60% O₂/40% N₂ composition.

B. MASS FLOW CONTROL—The constant mass inflow of gas to the recirculation loop of the semiclosed UBA is controlled by an absolute pressure regulator and a preset flow restrictor. The absolute regulator reduces the high pressure supply gas to a constant delivery pressure regardless of depth. The restrictor must operate at critical flow (sonic velocity) to insure that mass flow into the system will remain constant regardless of diving depth. For a fixed orifice, this condition occurs when the absolute upstream pressure (regulator delivery pressure) to the orifice is more than twice the value of the downstream pressure (dive depth in a UBA). As long as the constant upstream pressure from the regulator exceeds maximum depth pressure by a factor of two, mass flow will remain constant at all shallower depths. If the regulator is improperly set or the orifice improperly sized for the required pressure and flow conditions and the ratio of upstream to downstream pressure becomes less than two, mass flow will change with depth. Some types of restrictors are more efficient than the orifice and can maintain critical flow conditions until the back pressure (dive depth) approaches 75% of the absolute pressure from the regulator.

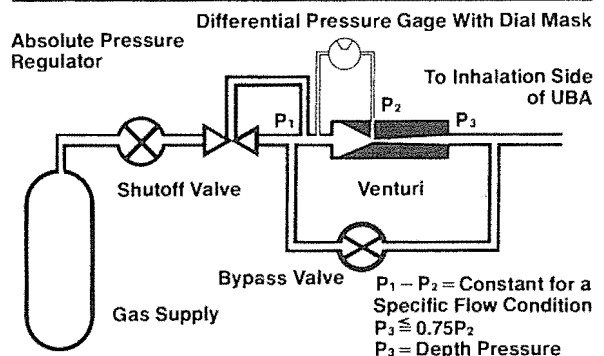
Examples of mass-flow control systems are shown in Figure No. 10-4. Some semiclosed underwater breathing apparatus, particularly early models, employ a replaceable fixed orifice (available in various sizes) to provide a specific flow with a given gas composition and regulator setting. Other units use a needle valve which can be adjusted and locked for given regulator pressures to provide desired flow. Still others use a venturi nozzle and require no adjustment other than supply pressure because of the venturi's wide flow range. This latter system employs another characteristic of critical flow; namely that critical mass flow through a given flow restrictor is directly proportional to upstream pressure. If the delivery pressure of the regulator is doubled, the mass flow through the restriction will double.



Replaceable Orifice-Needle Valve Type—The non-critical orifice is selected and installed to give a constant differential pressure reading at the desired mass flow. Needle valve is used for setting desired mass flow.



Double Replaceable Orifices Type—The non-critical orifice is selected, installed and used as above. A separate critical orifice is selected and installed for the desired mass flow.



Venturi Type—Desired mass flow rate is set by adjusting regulator to specific delivery pressure (P₁). Differential pressure reading will vary depending on specific mass flow selected. Dial mask is rotated to show needle at correct P for selected mass flow.

Figure 10-4 Typical systems used to provide constant mass flow and flow indication in semiclosed-circuit UBA's.

The absolute pressure regulator maintains a constant pressure output to the restrictor by automatically compensating for depth changes, using a housing sealed at one atmosphere (or vacuum to avoid temperature effects) which resists hydrostatic pressure or a combination of these elements. The regulator is precisely set at the surface with a test gage for the particular restrictor or restrictor setting required to achieve desired mass flow. This setting is maintained throughout the dive.

C. MASS FLOW INDICATION—If the injection gas flow into the recirculation system is partially or totally restricted (usually due to blockage in the critical flow device), hypoxia can result. Consequently for safety, some form of injection flow indication must be available to the diver.

Flow indication is accomplished in a variety of ways (as shown in Figure No. 10-4) including differential pressure gages installed across flow devices and whistles. Proper oxygen concentration can also be determined by use of galvanic oxygen partial pressure sensors with signal lights or audible alarms. Such mechanical or electronic systems are supplemented by diver observation of gas flow from the exhaust valve. At constant depth, gas will be exhausted from the apparatus as long as there is an injection flow into the system.

The use of a differential pressure gage for flow monitoring is the most common technique. The gage cannot be placed across the critical flow restrictor because if the restrictor becomes plugged the gage will continue to read the difference between regulator delivery pressure (upstream) and depth pressure (downstream) even though flow has ceased. Pressure difference must be monitored across a device with independent flow characteristics. Typical of this arrangement is the use of a separate flow restrictor in the MK 6 apparatus which is preselected and installed in the control block to give a 3 psi differential pressure at the desired flowrate. A gage attached to the front of the vest is connected by two hoses across the restrictor, and the gage needle remains centered as long as proper flow is passing through the critical orifice (needle valve) downstream in the system. Use of the apparatus at other flow conditions requires installation of a different restrictor in the line calibrated

at the new flow to produce the same 3 psi pressure drop.

A small inline venturi can also be used for flow indication. Pressure taps at the convergent and divergent portions of the venturi provide a differential pressure reading to the gage proportional to flow through the nozzle. By use of a locking mask on the gage face, the safe flow range for a given setting of the regulator is indicated to the diver by the gage needle showing in the mask aperture. This type of system permits the use of a single flow indicator element for different desired flowrates; associated gage readings are accommodated by changing the position of the gage mask.

D. EXHAUST—Since a semiclosed UBA has a continuous inflow of mixed gas into the breathing circuit, there is an associated exhaust to the surrounding water at constant depth conditions. Although inflow is continuous, actual exhaust flow tends to occur cyclically every two or three breaths due to seating and unseating pressures of the exhaust valve. The exhaust valve is located either on the exhalation bag on the diver's vest or in the backpack assembly. The valve is normally adjustable from 0.25 psi to 1.0 psi. The exhaust system pressure adjustment controls the degree to which the breathing bags are filled. The exhaust valve is adjusted so that the breathing bags stay filled with enough gas for a full breath, but not so full that the diver must exhale into completely inflated bags. A diaphragm in the exhaust valve senses the water pressure to maintain the required differential pressure at constant depth and during ascent. The valve may also be equipped with a manual override for bag deflation and a muffler-diffuser to minimize telltale bubbles and noise propagation in clandestine operations.

E. GAS SUPPLY—Most semiclosed UBA's have integral gas supplies in the form of high pressure cylinders carried in the backpack assembly. Semiclosed SCUBA's are equipped with two manifolded cylinders containing the supply mix for compactness (rather than a single larger cylinder). Occasionally the supply cylinders are complemented with a smaller third cylinder filled with pure oxygen for use during in-water oxygen decompression. The mixed gas supply furnishes the required injection gas at constant

depth and also, through a manual bypass valve in the control block or a demand regulator, provides makeup gas to the system during descent. The bypass is also used for purging the system if a malfunction is suspected.

Semiclosed UBA for use from a PTC also carry cylinders in the backpack containing premixed helium-oxygen which is physiologically safe for direct breathing at the operating depth. The difference, however, is that these cylinders are reserved for emergency use in the event that the primary gas supply through the umbilical from the PTC is lost. The diver's gas supply is normally drawn from a separate group of cylinders which are a part of the onboard PTC supply. Transfer from PTC to integral supply is accomplished by a switchover valve on the apparatus. Sufficient gas is carried in the diver's backpack to permit return to the safety of the PTC.

F. COMPONENT ARRANGEMENT—Major components of the semiclosed UBA are mounted on a rigid frame backpack which is contoured and supported on the diver for minimum interference during swimming. The backpack contains the two gas supply cylinders, scrubber system, pressure regulator and often provides a mounting for one or two breathing bags and the flow control system (Figure No. 10-5). Some models have the breathing bags attached to the front of an apparatus supporting vest, and some also have a control block containing the flow control, bypass and pressure gage mounted in one module attached to the vest for convenience.

Most UBA have a streamlined, readily detachable cover over the backpack assembly to minimize snagging.

CLOSED-CIRCUIT 10.1.2.2 To extend underwater endurance of mixed-gas UBA without increasing the gas supply, it is necessary to employ a completely closed system in which oxygen concentration in the system is directly controlled, rather than by the indirect method of using a preset mass flow. While perhaps functionally simpler in principle, the closed-circuit mixed-gas UBA tends to be more complex than the semiclosed because of the oxygen analysis and control circuits required. Offsetting this complexity, however, are several inherent advantages:



Figure 10-5 Typical component layout of a semiclosed-circuit UBA.

1. Aside from mixed or diluent gas addition during descent, the only gas required at depth is oxygen to make up for metabolic consumption. Consequently, duration is essentially independent of operating depth.
2. Since the partial pressure of oxygen in the system is automatically controlled throughout the dive to a preset value, dives may be made from the surface to great depths. Additionally, no adjustment is required during a dive for variations in depth and work rate.
3. Since no inert gas leaves the system except by accident or during ascent, the closed-circuit UBA is bubble-free and thus well-suited for clandestine operations.
4. No parts need be changed in the apparatus during pre-dive calibration.

A. OXYGEN ANALYSIS AND CONTROL—An oxygen analysis and control system monitors the partial pressure of oxygen in the recirculation system of the closed-circuit mixed-gas UBA. As oxygen is consumed from the recirculating gas, the system senses the ppO_2 , compares it with the desired preset reference value, and admits pure oxygen to the recirculating gas through an electronically-controlled valve until the desired partial pressure is restored. In this manner the only gas added to the system at constant depth is oxygen required for metabolic makeup.

Oxygen concentration in the recirculation system is measured by sensors which provide an electrical output through the galvanic reaction of oxygen coming in contact with a sensing electrode. Sensors are calibrated and control set points adjusted prior to the dive using resistors in the electronic module of the backpack. The sensors monitor the oxygen partial pressure and send a signal to the electronic module which is directly proportional to the ppO_2 . The module (powered from a battery pack) amplifies the signal strength, compares the actual ppO_2 value with the setpoint value, and controls the electric solenoid valve on the oxygen supply. A partial pressure value less than the setpoint automatically causes the valve to intermittently open and admit oxygen to the recirculation loop. When the desired ppO_2 is restored, the valve remains closed.

The galvanic oxygen sensors (Figure No. 10-6) used in the UBA achieve necessary system safety through redundancy. The use of three sensors permits a differential diagnosis of malfunction in any one element. One sensor functions independently of the electronics module and sends its signal directly to an oxygen partial pressure meter in the diver's wrist display. An alarm circuit compares the output signals of the other two sensors and initiates a light signal on the chest display if there is a significant difference. Through the use of a selector switch on the chest display, the output signal of each sensor can be read on the meter to isolate the malfunctioning sensor. The selector switch is also used to set the system for operation in a high or low oxygen partial pressure range and turn the oxygen control circuit off. The dual range capability permits diving at a normal ppO_2 level and switching to a higher oxygen level during decompression to shorten the process. Normally, an alarm circuit (wrist display) and meter readout (chest display) is also provided to indicate the condition of the battery pack.

The oxygen control function is performed on a timed sequence and discrete batch-basis rather than continuously. This mode of operation eliminates the need for more complex proportional control in which an oxygen flow control valve would change its flow range in proportion to the difference between the setpoint and actual ppO_2 value. Every few seconds (usually 2)

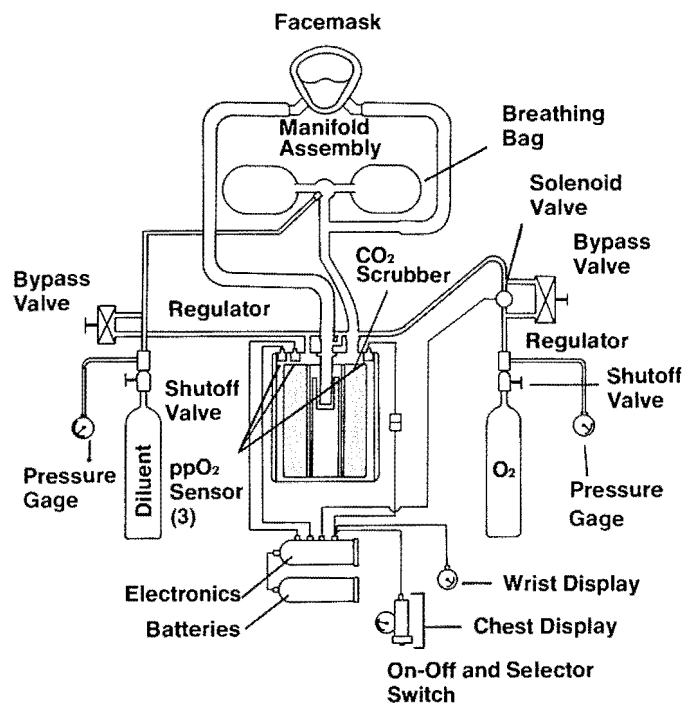


Figure 10-6 Flow diagram of a typical closed-circuit UBA.

the control circuit compares the actual and setpoint values and, if oxygen is needed, it signals the solenoid valve to open for two-tenths of a second. The result is the periodic introduction of fixed pulses of oxygen as needed. The delay time in the circuit permits a period for adequate mixing of oxygen with the recirculating mixed gas and response of the sensors to the new oxygen partial pressure to avoid the introduction of an excessive quantity of O_2 .

B. RECIRCULATION SYSTEM—The gas recirculation system of the closed-circuit UBA is essentially the same as that described for the semiclosed. Makeup oxygen is added to the system in the scrubber (usually split between the inhalation and exhalation side) to assure thorough mixing with the recirculating gas. The three oxygen sensors are normally positioned in the discharge from the scrubber to provide rapid response to changes in ppO_2 incurred by the addition of makeup oxygen. This type of arrangement minimizes the hazard of inhalation of temporarily oxygen-rich gas.

C. GAS SUPPLY AND EXHAUST—The closed-circuit apparatus usually has one cylinder of oxygen and



Figure 10-7 Components of a closed-circuit UBA.

another of diluent gas. Both are equipped with pressure regulators, and bypass valves are installed for manual operation in emergencies. The diluent gas, usually helium-oxygen mixed to provide a safe ppO_2 at maximum depth, is normally used only to pressurize the system during descent. Closed-circuit UBA are generally equipped with pressure-sensing valves which automatically add diluent gas to the apparatus as depth is increased. An exhaust valve, similar to that used in semiclosed-circuit equipment, vents the rebreathing unit during ascent.

D. PTC APPLICATIONS—When used from a PTC in deep diving applications, the closed-circuit-equipped diver employs an umbilical for safety. The umbilical provides a safety tether, hot water for body and respiratory heating, emergency breathing gas, and permits voice communications with capsule occupants and topside. Although the diluent cylinder can be used for demand breathing in the event of malfunction of the UBA, its endurance in this mode is very limited. The independent emergency gas supply is a desirable safety factor, particularly when deep excursions are to be performed.

E. COMPONENT ARRANGEMENT—As with the semiclosed apparatus, the closed-circuit UBA has all major system components mounted in a backpack enclosed by a removable cover (Figure No. 10-7). The separate chest and wrist displays are connected to the backpack by multi-conductor cables.

U. S. NAVY UBA 10.2

At the present time there are three models of mixed-gas underwater breathing apparatus approved for use in Navy diving. These units, designated the MK 6, MK 10 and MK 11, have been rigorously tested under laboratory and field conditions to insure the reliability, durability and safety required of USN diving equipment.

All mixed-gas UBA are mechanically more complex than more commonly encountered surface-supplied and air SCUBA equipment. Consequently, adequate diving safety is only achieved when the diver has been thoroughly trained with the particular model of apparatus to be used, the equipment has been properly calibrated for the specific diving conditions to be encountered, and the dive is conducted within the associated depth and duration constraints.

The following sections of this chapter provide detailed information on each apparatus. Included is a description of the equipment, principles of operation, calibration and adjustment, predive checkout, underwater procedures, and postdive checks. The information presented, combined with suitable training, provides the basis for safe underwater use of the apparatus. The reader is referred to the instruction and maintenance manuals for each model of equipment for detailed information concerning trouble-shooting, maintenance and repair.

The three models of UBA included in the manual are—

MK 6 MOD 0—Semiclosed-Circuit UBA

Application—combat swimming and EOD operations

Depth—to 200 feet

Duration—4 hours @ 70°F, 30 minutes @ 40°F

MK 10 MOD 4—Closed-Circuit UBA

Application—PTC diving (tethered)

Depth—to 1,500 feet

Duration—4 hours

MK 11 MOD 0—Semiclosed-Circuit UBA

Application—PTC diving (tethered)

Depth—to 1,000 feet

Duration—4 hours

MK 6 MOD 0 MIXED-GAS UBA 10.3

The MK 6 (Figure No. 10-8) apparatus is a semiclosed-circuit UBA designed for combat swimmer and EOD SCUBA applications at moderate depth (to 200 feet). It consists of a backpack containing a self-contained gas supply, scrubber, and injection gas regulation system. The backpack is supported on a vest to which is attached two front-worn breathing bags. The addition of system pressurization gas is manually controlled. Injection flow indication is by means of a constant reading, differential pressure gage worn on the vest. The MK 6 is occasionally fitted with an additional cylinder containing oxygen for use during decompression.



Figure 10-8 U. S. Navy Diver outfitted with the MK 6 UBA.

Breathing Circuit 10.3.1 An initial understanding of the apparatus can best be achieved by tracing the flow of gas through the system (Figure No. 10-9).

1. When the diver takes a breath, a one-way inhalation valve in the right side of the mouthpiece opens, admitting gas (through the inhalation hose) from the inhalation breathing bag.
2. Upon exhalation, the carbon dioxide-laden gas is directed through the one-way exhaust valve on the left side of the mouthpiece through the exhalation hose into the exhalation breathing bag. This incoming volume of gas forces the gas already in the breathing bag through the left breathing hose and down through the outer shell of the scrubber assembly.
3. The inner shell of the scrubber, or canister, contains granular Baralyme. As the exhaled gas filters through the Baralyme pellets, the carbon dioxide is removed.
4. As the now-purified gas reaches the top of the canister, it is mixed with a pre-determined quantity of fresh gas from the cylinders, and this mixture is passed through the right breathing hose into the inhalation breathing bag where it mixes with the recirculating gas.

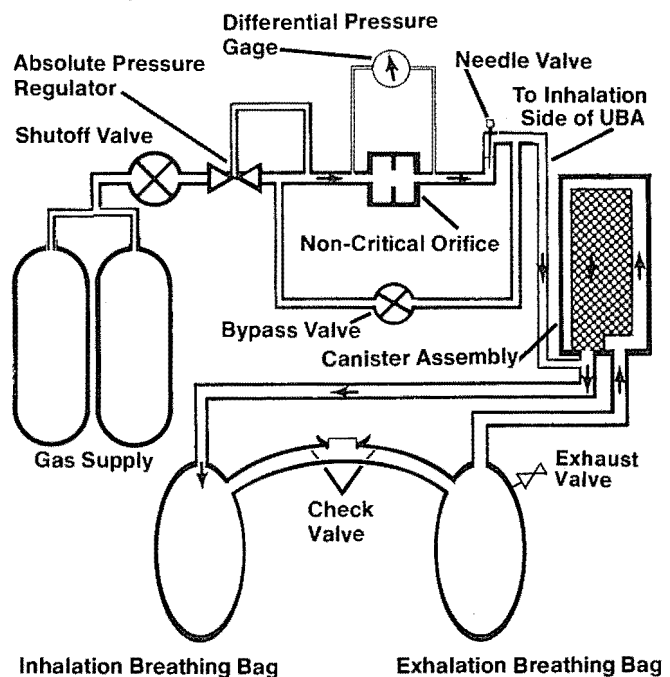


Figure 10-9 MK 6 UBA schematic.

5. The injection gas is metered through an absolute pressure regulator, flow indicating orifice and needle valve at a pre-set mass flowrate. Prior to the dive, the diver installs an orifice of the appropriate size for proper flow indication and sets the needle valve to provide a flow of mixed gas sufficient to replace the oxygen which he will be consuming at the anticipated work rate. The absolute pressure regulator automatically maintains injection gas pressure at a set value regardless of depth change.

6. Because there is a constant mass of mixed gas entering the system and only the oxygen in this gas is consumed, a volume of recirculating gas must discharge from the system into the water. This discharge occurs at the end of every few exhalation cycles as the exhalation breathing bag is refilled. An exhaust valve, mounted on the breathing bag, opens when the pressure in the bag reaches a pre-determined level (which can be adjusted by the diver). If at any time the system fails to maintain a degree of exhaust, it is probable that the inflow of fresh gas from the supply cylinders has been decreased. This condition should be regarded as a warning signal.

Description of Components 10.3.2 The MK 6 apparatus is made up of the following specific components—

1. The backplate carries the cylinders, attached manifold and valve assemblies, and the canister assembly. The backplate is secured to the vest assembly by a toggle pin at the top and three pairs of retaining straps at the sides.

2. The twin gas cylinders are connected with a manifold valve assembly at the top and secured by a spreader bar at the bottom to form a single unit for handling and charging. The aluminum cylinders are hydrostatically tested to 5,000 psi and have a combined capacity of 84 cubic feet of gas at standard conditions when fully charged to 3,000 psi. A stud at the bottom of each cylinder accommodates the spreader bar. The manifold valve assembly is mounted on the cylinders through a pair of elbow fittings which are sealed to the neck of each cylinder with a preformed packing. One of the elbows contains a safety disk which is preset to rupture in the range of 3,375-3,750 psi. The manifold itself contains a



Figure 10-10 Diver fully outfitted with the MK 6.

shutoff valve and has a fitting for the attachment of the regulator valve assembly. The cylinders are charged through this same fitting by using a special charging line assembly.

3. The regulator assembly is attached to the manifold and has a fitting for the attachment of the control block assembly (see Item 4, below). The regulator is a pressure compensated control valve which ensures delivery of mixed gas at approximately the same pressure regardless of depth. The regulator employs a sealed bellows containing a spring and a diaphragm assembly which responds to ambient and upstream orifice pressure. A valve, attached to the diaphragm, responds to changes in diaphragm position to throttle supply flow and maintain a constant pressure upstream of the needle valve.

4. The control block assembly contains a fixed orifice (with filter), the size of which is selected in advance of the dive to provide a 3 psi pressure drop at the computed flow requirements of the diver. The orifice comes in three sizes: 8, 12 and 21 liters per minute. Outlets are located downstream and upstream of the orifice with fittings which connect with a differential pressure gage. This gage is used to monitor injection gas flow in the SCUBA during a dive. A needle valve is located downstream of the orifice to provide an adjustment of the rate of gas flow into the system.

The needle valve, when properly positioned, is locked in place by a jam nut. Other units of the control block assembly include an **on-off valve**, a **by-pass valve** (to permit unrestricted flow of gas from the regulator assembly for apparatus pressurization during descent) and a **check valve** (to prevent by-pass flow from entering the rest of the assembly).

5. The scrubber assembly is composed of two units. The **inner shell**, which holds approximately 6½ pounds of Baralyme, is fitted with a screen at each end. A spring unit at the bottom serves to hold the inner shell firmly in position within the outer shell. The **outer shell** is a water tight unit which provides a channel (between the walls of the inner and outer shell) through which the exhaled breath is directed to the bottom of the canister. The top of the outer shell has fittings for two hoses: the **left breathing hose** from the exhalation breathing bag, and the **right breathing hose** leading from the inner shell to the inhalation breathing bag. A **gas inlet block** mounted at the right-hose fitting serves to admit replenishment gas as metered through the regulator and control block.

6. The vest covers the diver's chest. It is secured in front by a zipper and attached to the backplate by three pairs of straps. The vest serves two purposes: to provide a comfortable means of wearing the backplate and tank units and to hold the **breathing bags**. These bags each hold about 4 liters of gas when fully inflated and are attached to the vest with six common-sense fasteners. Each breathing bag is fitted with two hose connectors—one for the hose leading to or from the mouthpiece, and one for the hose leading to or from the canister assembly. Each bag also has a drain plug to facilitate post-dive cleaning and drying. The exhalation bag (on the left) carries the **exhaust valve assembly**. This is an adjustable spring-loaded relief valve which may be set to maintain a system pressure between 0.25 psi and 1.0 psi over ambient. The proper system pressure is determined by the diver himself, and the valve should be set so that a small quantity of gas is vented with each breath—or, at least, with every third breath. Adjustment of the exhaust valve also permits the diver to make small changes in buoyancy to control trim. The exhaust valve can be manually opened by a "pull grip" for quick release of excess pressure.



Figure 10-11 MK 6 UBA Note: cylinders, manifold and regulator.



Figure 10-12 MK 6 Regulator assembly.



Figure 10-13 MK 6 Control Block assembly.



Figure 10-14 MK 6 canister assembly (between cylinders).

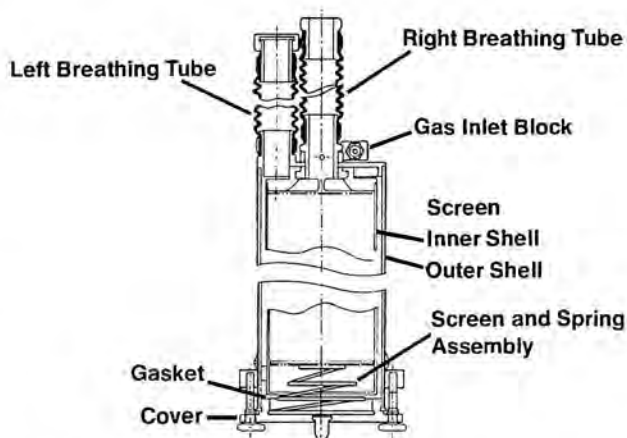


Figure 10-15 Cross section of the MK 6 canister.



Figure 10-16 Flow adjustment procedure for the MK 6.



Figure 10-17 MK 6 Vest.



Figure 10-18 MK 6 mouthpiece assembly.

7. The final unit of the MK 6 is the mouthpiece-T tube assembly and the attached inhalation and exhalation hoses. The mouthpiece assembly contains two one-way check valves (for inhalation and exhalation) and a shutoff valve which is manually set to either the surface or diving position. In the "surface" position, this valve prevents entry of water into the breathing system.

Pre-Dive Preparations 10.3.3 Prior to the start of any dive, the equipment must be thoroughly inspected and the canister must be filled with a fresh supply of Baralyme.

A vital part of pre-dive preparation is to determine the appropriate gas mixture for the dive and to adjust the apparatus to provide the proper flow of that mixture. There are three settings which must be made—

1. An orifice of the proper size must be selected and installed (to accommodate a maximum flow requirement of 8, 12 or 21 liters per minute).
2. The regulator assembly must be adjusted for the supply pressure required for the installed orifice. These pressures are 80 psi for 8 lpm, 140 psi for 12 lpm, and 180 psi for 21 lpm. Pressure setting is determined with a test gage.
3. The control block metering valve must be set for the pre-determined flow rate using a calibrated flow meter.

A comprehensive Pre-Dive Equipment Preparation Checklist is contained in Appendix II-E. The breathing mixture must be selected to provide adequate levels of oxygen in the system at operating depth. As a practical matter, to assist in decompression and to minimize the possibility of decompression sickness, the breathing mixture should contain the highest concentration of oxygen that will not result in oxygen poisoning. The metering valve setting must be adjusted, in consonance with the breathing mixture in use, to provide sufficient oxygen to replace that which is being consumed by the diver.

The lowest permissible level of oxygen in the inhalation bag is 16 percent. In underwater swimming, the highest sustainable rate of oxygen consumption is approximately 3.0 liters per minute. Therefore, the minimum permissible inflow of any gas mixture will be that which would maintain a 16 percent oxygen level in the inhalation bag at an oxygen consumption rate of 3.0 liters per minute. Table 10-1 lists the mixed-gas supply flow rates required to maintain this condition. The table lists both actual and measured flow rates in liters per minute. The actual flow rate is that measured by a flow meter calibrated for the gas being measured. The flow meter supplied with the MK 6 test kit is calibrated using air, and consequently the flow

TABLE 10-1—MIXED-GAS FLOW RATE TABLE; MK 6 MOD 0 SCUBA

Inert gas	Maximum Oxygen percent	Type of exercise	Actual flow, liters per minute	Measured flow, liters per minute	Maximum depth,* feet
Nitrogen	60	Swimming	8	8	55
	40	Swimming	12	12	97
	32.5	Swimming	21	21	129
Helium.....	40	Swimming	11	8	80
	32	Swimming	18.5	12.5	180

*Maximum depths noted are non-exceptional exposure limits

meter readings (measured flow) must be referenced to Table 10-1 to determine the actual flowrate of mixed gas.

The maximum permissible level of oxygen in the bag will be that which, at the maximum operating depth of the dive, does not exceed a partial pressure of 1.6 ata (N₂-O₂) or 2.0 ata (He-O₂). To introduce a safety factor into the computation of this level, the percent of oxygen in the mixed-gas supply is used. The actual concentration of oxygen in the breathing bag will always be somewhat lower than in the supply because of dilution by recirculating gas in the system. Maximum allowable oxygen percentage in the supply mix can be determined using the formulas in Section 10.1.2.1.

Once the required surface flow rate has been determined, the gas-supply duration may be calculated. In making this calculation, an allowance of 10 percent of the supply for volumetric requirements on descent and 10 percent for a safety factor is ample for most situations. The combined 20 percent is taken into consideration by using a cylinder low-pressure safety limit of 20 percent of the cylinder pressure rating. The gas supply duration is calculated using the following formula—

$$t = \frac{V(p - s)}{14.7(f)}$$

Where—

- t = Gas supply duration, minutes
- V = Total cylinder volume, liters
- p = Initial charging pressure, psi
- s = Low-pressure safety limit, psi
- f = Surface flow rate, lpm

EXAMPLE—

PROBLEM—A diver equipped with a MK6 apparatus set for 21 lpm injection flowrate and cylinders charged to 2,800 psi is to make a dive to 130 feet. What is the maximum allowable dive duration?

SOLUTION—The two cylinders of the MK6 have an internal volume of 12 liters. The low pressure safety limit is 20% of 3,000 psi (maximum charging pressure) or 600 psi.

Substituting—

$$t = \frac{V(p - s)}{14.7(f)} = \frac{12 \text{ liters } (2,800 \text{ psi} - 600 \text{ psi})}{14.7 \text{ psi/atm } (21 \text{ lpm})}$$

$$= \frac{12(2,200)}{14.7(21)} = 85 \text{ minutes}$$

Diving Procedures 10.3.4 Standard SCUBA diving procedures, as discussed in Chapter Five, Volume I, including safety precautions and communications, are used when diving with the MK6. The following special instructions, however, must also be followed—

1. During descent, manually actuate the bypass valve to keep the breathing bags properly inflated (about $\frac{2}{3}$ capacity). If pressure balance is not maintained, breathing effort will increase, and gas starvation and squeeze may occur.
2. Upon reaching the desired depth, readjust the exhaust valve setting to maintain the proper bag inflation.
3. At depth, work normally. Avoid extreme exertion unless the gas flow was originally set for heavy work.
4. Continuously monitor the differential pressure gage reading and the operation of the exhaust valve.

Unless the exhaust is constant and regular (at least every third breath) and the gage needle remains in the safe zone, a failure of the injection gas supply system must be assumed, and emergency procedures must be initiated.

5. If malfunction of the mass-flow system or carbon dioxide scrubber is suspected, purge the UBA with supply gas and abort the dive.

6. Prior to ascent, flush the breathing bags by using the following procedure—

- Assume a position such that the exhaust valve is above the bag.
- Take several deep breaths and exhale normally.
- Open the exhaust valve using the pull grip and let the water pressure flatten the bag.
- Release the pull grip.
- Open the bypass and fill the bag to the normal level. Do not exhaust any gas from the system.

7. If the bags should become over-inflated—as during ascent, or if the exhaust valve is not properly set—manually pull the exhaust valve “pull grip” to dump the excess pressure.

8. For quick inflation of the bags, as for example to aid in an emergency ascent, manually actuate the bypass valve. Care should be taken, however, to avoid over-inflation to the point of bursting the bags during ascent.

9. When ascending from a dive that does not require decompression, stop at 30 feet and purge the breathing bags before completing the ascent.

10. When using a MK 6 without an auxiliary oxygen supply, the breathing bags should be flushed with the gas mixture in use at each decompression stop. Even if the first stop is above 30 feet, the bag must first be purged when the diver reaches 30 feet.

11. Some units of the MK 6 SCUBA have been equipped with an auxiliary oxygen supply for use during decompression. This modification uses a standard oxygen cylinder and regulator from the US Navy closed-circuit oxygen apparatus and provides for input of oxygen into the system through the drain valve of the inhalation breathing bag. If the MK 6 unit in use is equipped with this oxygen supply, follow these procedures—

—Ascend to the first decompression stop. If this is deeper than 30 feet, purge the breathing bags with the gas mixture in use and complete the decompression stops as required. Purge the breathing bags upon arrival at each stop until reaching 30 feet.

—Upon arrival at the first oxygen stop (20 or 30 feet), turn off the mixed-gas supply and turn on the oxygen supply. Purge the breathing bags three times with oxygen, then complete the required decompression using oxygen.

—The shift to oxygen must take place at 30 feet even if the first decompression stop is scheduled for 20 feet.

Post-Dive Maintenance and Troubleshooting

10.3.5 Upon completing a dive with the MK 6 SCUBA, the following post-dive procedures should be conducted—

1. Close the manifold shutoff valve and the mouth-piece valve.

2. Thoroughly rinse the breathing apparatus in clean fresh water. Clean all breathing passages with fresh water and medicated soap.

3. Remove the drain plugs from breathing bags and allow the bags to completely dry.

4. Remove used Baralyme pellets from the canister assembly, and thoroughly rinse the assembly.

5. Tag out cylinders as being empty.

6. Inspect the regulator assembly, safety rupture disc, and exhaust valve assembly for any contamination or damage. Check the regulator flow. If it has varied more than 10% from pre-dive readings, closely examine the assembly for malfunction.

7. To prepare the MK 6 for storage—

- Unlatch the cylinder straps.
- Close the manifold valve assembly.
- Actuate the bypass valve ring several times.
- Back off the regulator spring button.
- Remove fabric components and preserve.
- Use a specified preservative on all rigid parts and fittings.
- Store in protective boxes in a cool, dry place.

Troubleshooting procedures for the MK 6 MOD 0 are tabulated in Appendix II-E.

MK 10, MOD 4—MIXED-GAS UBA 10.4

The MK 10 apparatus is closed-circuit UBA intended for use in diving from PTC's to depths of 1,500 ft. The apparatus includes a backpack assembly, a wrist-worn alarm unit, a chest-worn control-display unit, an umbilical to the PTC, and a physiometer. The backpack contains a diluent gas supply cylinder for system pressurization, an oxygen cylinder for metabolic makeup, scrubber, one breathing bag assembly, a rechargeable battery pack, and an electronic control module and associated sensors and control valve for oxygen addition. The wrist display employs warning lights for indication of normal/abnormal functioning of the oxygen control system. The chest display permits meter read out of oxygen partial pressure in the system, selection of sensor read out battery condition monitoring and system on/off function. The umbilical from the PTC provides emergency gas to the UBA, hot water to a bag surrounding backpack components. Oxygen partial pressure is controlled to either a high or low setpoint. System pressurization gas is automatically controlled by a regulator.

Operating Modes 10.4.1 The MK 10 MOD 4 UBA performs five basic functions—

1. Senses and maintains the oxygen partial pressure in the breathing gas at a preselected value.
2. Removes carbon-dioxide exhaled by the diver from the breathing gas.
3. Maintains the breathing gas at a pressure equal to the surrounding water pressure.
4. Maintains the breathing gas at a physiologically acceptable temperature.
5. Provides topside with UBA function measurements.

The MK 10 utilizes a dual gas supply: one cylinder of oxygen and one cylinder of diluent gas (which may be air, some other mixture, or pure inert gas). A pressure-sensing valve admits diluent gas to maintain the system pressure equal to that of the surrounding water. The make-up feed of oxygen is controlled either automatically or manually, depending upon the mode of operation.

The MK 10 may be operated in one of three modes—**Automatic mode**—whereby galvanic sensors moni-



Figure 10-19 MK 10 Mod 4 (shown without back cover).

tor the partial pressure of oxygen in the system and a solenoid valve controls the entry of fresh oxygen into the system to maintain the partial pressure at a predetermined level. This is the normal mode of operation.

Manual mode—in which bypass controls are used to admit oxygen or diluent gas as necessary, in the event of malfunction of the automatic oxygen make-up feed or the diluent add valve. A malfunction of the automatic oxygen system will be signalled by a red warning light on the wrist display unit. A diver forced to switch over to the manual mode for oxygen supply should immediately return to the PTC. Manual addition of diluent gas may be required during descent if the diluent add valve is not functioning properly, but this does not necessarily indicate an emergency situation.

Emergency mode—used in the event of a complete failure of the oxygen system or exhaustion of the oxygen supply. In this mode, the MK 10 is used as an open-circuit SCUBA by direct inhalation of mixed diluent gas. Endurance in this mode is quite limited, especially at greater depths.

Breathing Circuit 10.4.2 The breathing circuit consists of a facemask assembly with shutoff valve and check valves (Figure No. 10-20), a flexible exhalation hose to the inlet of the scrubber, a flexible hose from the scrubber outlet to a tee which directs the breathing gases to the inhalation hose and the total pressure control assembly, and a flexible inhalation hose from the tee to the facemask assembly. Threaded hose connections are provided at the ends of the flexible inhalation and exhalation hoses to permit quick removal for cleaning. Male and female type threads are utilized to prevent mismatching the

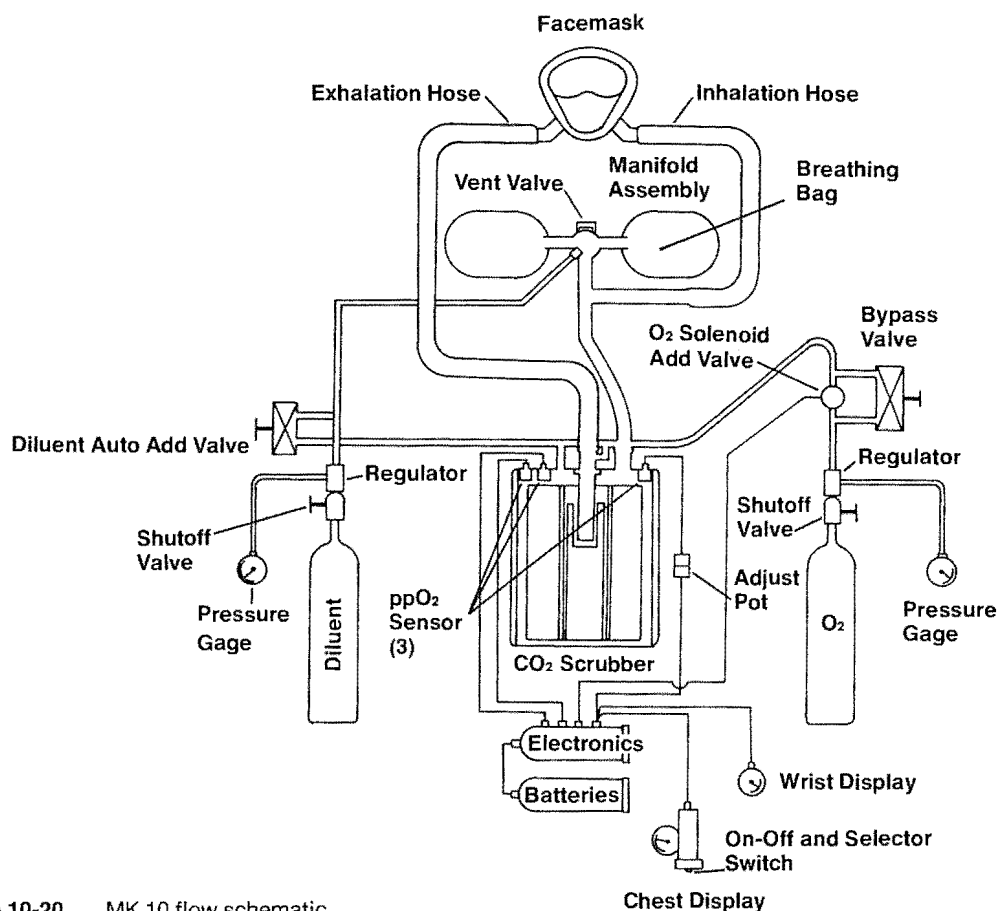


Figure 10-20 MK 10 flow schematic.

hoses. The following is a sequential description of operation of the MK 10 in the automatic mode—

1. The diver's exhaled breath flows through a one-way check valve, through a flexible neoprene exhalation hose, and into the scrubber unit which removes carbon dioxide and excess moisture. In the scrubber, the exhaled breath first passes through a water absorber, to remove water that has developed from condensation in the exhalation hose or entered the system from leaks around the diver's mask. The gas next flows through the carbon-dioxide absorbent and then through another water absorber, to remove condensed moisture which has been generated from the chemical action of the carbon-dioxide absorbent. The two water absorbers, the carbon-dioxide absorbent, and associated filters and baffles are all contained in a disposable cartridge installed in a stainless steel canister.

2. Three independent galvanic sensors, mounted in the top of the canister, monitor the partial pressure of oxygen in the gas leaving the scrubber. Two of these sensors (each serving as back-up for the other) are connected to the electronic module. Every 2 seconds, this unit compares the signal from the sensors with a reference level which has been pre-set prior to the dive. (The unit actually operates with two levels, either of which may be selected by the diver. The low level is used for normal diving, and the high level is used for accelerated decompression.) If the partial pressure of oxygen is below the reference level, a solenoid valve at the oxygen cylinder opens for two-tenths of a second, admitting oxygen to the canister. The third sensor is connected to a wrist display unit which gives warning if the oxygen level should fall and not be replenished by the automatic system.

3. The gas next passes to a manifold connecting a pair of neoprene breathing bags which act as a single accumulator. Two valves are mounted on the manifold housing. One, the **diluent add valve**, is essentially a second-stage demand regulator which opens to admit diluent gas to the system whenever the outside water pressure exceeds the system pressure by a value equivalent to 4 inches of water. Under normal conditions, diluent will be added as the diver descends. The other valve is a spring-loaded vent valve which is normally set to open when internal pressure exceeds external water pressure by a value equivalent to 6 inches of water. The setting of this valve is adjustable through a range of pressure differentials from 4 to 8 inches of water. This valve can be held shut for the purpose of manually pressure checking the breathing circuit prior to a dive.

4. When the diver takes a breath, gas is drawn from the breathing bags, through the **inhalation breathing hose** and through a **one-way check valve** into his mask.

Description of Components 10.4.3 The basic components of the MK 10 UBA are the gas cylinders, the electronic control system (which includes the electronic module, the battery module, the sensors, the chest display and control unit, the wrist display, and necessary cables and connectors), the carbon dioxide removal assembly, and the total pressure control assembly (consisting of the breathing bags, manifold, and diluent add and vent valves). All of these components except the chest and wrist displays are mounted on a structural back-pack frame enclosed in a thermal control bag and covered by a one-piece plastic cover. The lower portion of the thermal control bag is mounted between the structural frame and the internal components. The upper portion of this bag snaps inside the plastic protective cover and fastens to the lower portion by means of a zipper.

GAS CYLINDERS 10.4.3.1 The gas cylinders used in the MK 10 are 150 cubic-inch volume steel cylinders coated on the outside with poly-vinyl chloride to prevent corrosion in seawater. At the design pressure of 3,000 psi these tanks will hold 18.8 cubic feet (532 liters) STP of oxygen and 15.6 cubic



Figure 10-21 MK 10 General Components.



Figure 10-22 MK 10 gas cylinders.



Figure 10-23 MK 10 backpack

feet (442 liters) STP of helium, or slightly different quantities of various gas mixtures. Each cylinder is fitted with a shut-off valve and a safety disc which will rupture in the pressure range of 4,500-5,000 psi. The valves are essentially identical, but are provided in right-hand and left-hand versions to prevent inadvertent interchanging of the oxygen and diluent cylinders. Each cylinder is also fitted with a first stage regulator set to maintain an outlet pressure of 115 psig above the ambient water pressure. The solenoid valve, which controls the flow of oxygen, is mounted downstream from the regulator and is paired with a manual bypass valve. (A manual bypass valve is also installed in the diluent gas feed line but is considered to be part of the total pressure control system.)

ELECTRONIC CONTROL SYSTEM 10.4.3.2 The electronic control system automatically monitors and controls the partial pressure of oxygen in the breathing gas. Power is supplied by 20 rechargeable nickel-cadmium batteries housed in a watertight battery module. The tolerance range for line voltage in the system is from 22.5 vdc to 29.0 vdc. The batteries may be recharged through 250 operational cycles after which they must be replaced. For recharging, the battery module may be left in place on the mounting frame or it may be removed.

Three sensors are mounted in the discharge end of the absorbent canister where they monitor the partial pressure of oxygen in the breathing gas every 2 seconds. These sensors provide an electrical output through the galvanic reaction of oxygen coming in contact with a sensing electrode. The output signal is directly proportional to the partial pressure of oxygen in the gas mixture.

The signal from two of the sensors is sent to the electronics module where it is amplified and compared with a pre-set reference voltage which has been calculated to correspond with the desired oxygen partial pressure. The module compares the signals from both sensors. If the value from the highest-reading sensor is less than the reference voltage, an electronic switch provides power to open the oxygen valve for two-tenths of a second. The electronics module also contains four variable resistors used for calibration. One pair is used to calibrate



Figure 10-24 MK 10 chest display (above) and wrist display (below).



Figure 10-25 MK 10 electronic control system.

Sensors 1 and 2; the other pair is used to set the values for the LOW and HIGH oxygen levels (for normal diving and accelerated decompression, respectively). The available range for the LOW setting is between 0.2 and 1.0 atmospheres absolute of oxygen, and for the HIGH setting, between 0.95 and 1.25 ata.

The chest display unit is the control center for the automatic system. This unit includes a display meter and a selector switch. The meter has two scales: one calibrated to present the partial pressure of oxygen in atmospheres, and the other is calibrated in volts dc and marked to show the 22.5 to 29.0 vdc tolerance range of the apparatus. The meter scales and needle are marked with radium paint to enhance visibility.

The selector switch is used to set the system for operation in the HIGH or LOW oxygen range, or to turn it off. Within each range, there are settings for reading the output of Sensors 1 and 2, for reading the battery voltage, and for checking the reference level of oxygen. While the switch is at any setting within either range, the automatic control system will monitor and maintain the oxygen level as pre-determined for that range. To prevent inadvertent switching between the HIGH and LOW circuits, or to prevent the diver from accidentally turning the switch to the "off" position, stop-detents are installed between the two scales and at the "off" setting. The diver must physically pull the switch knob out from the display housing to override this detent.

The chest display is normally attached to the right shoulder harness strap with a D-ring. When the diver wants to read the display or change the setting of the switch, he removes it from the strap so that he can see the face of the unit.

The signal from Sensor 3 is not fed through the electronic module, but is sent directly through a separate calibration trimpot, and then to a meter in the wrist display unit. This meter, with radium painted dial, indicates the oxygen partial pressure. Because this sensor operates independently of the electronic module, it is not affected by malfunction or disconnection of that unit.

Signals from Sensors 1 and 2 are also sent to the wrist display unit as part of an alarm circuit. This circuit monitors the following functions—

- the output of Sensor 1 compared with the reference voltage.
- the output of Sensor 2 compared with the reference voltage.
- the output voltage of the battery module. The output of the alarm circuit is fed to one of two indicator lamps in the wrist display unit. If all of the above functions are within normal tolerance levels, the amber ("safe") lamp will glow. However if the red ("danger") lamp is lighted, it is an indication that one or more of the following out-of-tolerance conditions exist—
 - the output of Sensor 1 is 25% above or below the reference voltage.

- the output of Sensor 2 is 25% above or below the reference voltage.
- the battery voltage is less than 22.5 vdc.

The red lamp on the wrist display will warn the diver of a potentially dangerous condition. By use of the chest display unit, he can isolate the cause of the warning signal and determine if immediate corrective action is necessary. In this regard, the chest display is used as a **diagnostic center**. By rotating the display selector knob, the diver can independently check the outputs of Sensors 1 and 2 and the battery module to determine which of these is not functioning properly. If the problem is not low battery voltage, the output of the two sensors should be compared with the reading provided on the wrist display by Sensor 3.

As a general rule, if the red indicator light remains "on," the diver must switch to manual oxygen control and terminate the dive. (Manual control is initiated by turning the selector switch to the "off" position and using the oxygen bypass valve.) There are, however, some conditions where the red light may come on even though the automatic control system is functioning normally. These conditions are all associated with partial pressures of oxygen which are more than 25% above the pre-determined operating level and will occur in one of two ways—

1. A sudden increase of oxygen may momentarily raise the indicated partial pressure, since the fresh gas enters the system at the same point that the sensors take their reading. This condition is more common at greater depths.
2. During a rapid descent, when air is used as the diluent gas, the amount of diluent added to the system to compensate for increasing pressure may also add enough oxygen to increase the partial pressure beyond the 25% level.

In both of these cases all three sensors would indicate the same increased oxygen level, and the level would soon decrease as the oxygen is consumed. However, if a continued high level of oxygen remains in the system, the oxygen cylinder valve **must be closed** until the partial pressure drops to within the normal operating range. The valve must then be manually controlled to maintain proper oxygen levels while the diver returns to the PTC.

The particular malfunction which causes this condition is rare, although the diver must be aware of the possibility and be prepared to take the proper corrective action. More common problems which require mandatory dive termination are—

- Different readings by two or more sensors (0.05 atm or greater).
- All sensors reading the same but 25% or more below the desired operating level.
- Battery voltage less than 22.5 vdc.

Additionally, the dive must be terminated if both indicator lights are on or off at the same time.

CARBON DIOXIDE REMOVAL ASSEMBLY 10.4.3.3

The carbon dioxide removal assembly consists of a stainless steel outer canister and a disposable inner cartridge which contains the carbon dioxide and water absorbents. The top of the outer canister is fitted with inlet and outlet connections for the breathing gas and an inlet connection for the oxygen feed. This connection also admits diluent gas when the diluent bypass valve is actuated. (See schematic diagram, Figure 10-18.) The three oxygen sensors are also mounted in the top of the outer canister; however, as discussed, they are part of the electronic control system.

The disposable cartridge is inserted into the lower end of the canister (which is completely open) and is held firmly in place by four latches, with a gasket around the rear cover of the cartridge forming a seal with the rolled edge of the canister. A fresh cartridge must be inserted in the canister prior to each dive. Failure to do so may result in dangerously high levels of carbon dioxide in the breathing circuit. To prevent inadvertent installation of a used cartridge, the word "USED" is painted on the outside of the cartridge rear cover where it is visible when the cartridge is in place in the canister. On a fresh cartridge, this label is concealed by a water-soluble cover. Once in the water, this cover will dissolve within one minute, exposing the "USED" label.

TOTAL PRESSURE CONTROL ASSEMBLY 10.4.3.4

The total pressure control assembly includes the breathing bag assembly, the manifold, and the diluent add and vent valves. The breathing bags are made of



Figure 10-26 MK 10 CO₂ removal assembly.



Figure 10-27 MK 10 breathing bag assembly (cover removed).

neoprene, and each has a fully inflated volume of approximately 3.2 liters. The bags are attached to the manifold on the inhalation side of the circuit by a special adapter and are easily removed for cleaning or replacement.

The manifold includes fittings for attachment of the breathing bags, the diluent add valve, the vent valve, and the hose through which breathing gas enters and exits the assembly. The manifold is also equipped with a pair of bag inlet extensions which protrude into the neck of each breathing bag to keep the passage open.

The total pressure control assembly is housed in a molded plastic container which provides a mounting point for the manifold and protection for the bags.

BACKPACK ASSEMBLY 10.4.3.5 All components of the MK 10 apparatus—with the exception of the wrist and chest display units—are mounted on the backpack assembly. This consists of a tubular steel frame, laced with nylon webbing to provide a cushion against the diver's back, a plastic tray for mounting the various units, and a streamlined plastic cover for protection and reduced drag. The total assembly is secured to the diver by a vest assembly. This is a tailored nylon fabrication which attaches to a plate assembly welded to the frame of the backpack. Support flanges, also attached to the frame, provide adjustment straps which interface with buckles sewn to the vest. Doffing and donning of the UBA is simplified by means of a full length nylon zipper on the front of the vest.

Supplemental hardware is sewn to the vest. A small D-ring on either side of the vest interfaces with the straps from the bag box. These straps are adjustable and can be positioned by the wearer to insure that the vent valve is worn tightly against the back to minimize static breathing resistance. Two larger D-rings are available, one on each side of the vest, to accommodate the chest display clip. The ring on the right side (as worn) is used when the unit is in operation, while that on the left serves as a storage position for the chest display to minimize damage as a result of inadvertent droppage. An additional locking snap provides the same function for the wrist display. It too is mounted on the left side of the vest.

THERMAL BAG ASSEMBLY 10.4.3.6 To enhance system performance in cold environments, a thermal bag assembly is provided with the MK 10 MOD 4. The bag assembly surrounds the backpack components and breathing hoses. The internal volume of the bag is continuously flooded with hot water to maintain the components and recirculating gas at a higher temperature than the surrounding seawater. Operation of the MK 10 with the heating jacket assures—

1. Operation of regulators and other components at temperatures which provide good performance.
2. Efficient scrubbing reaction for maximum canister duration.
3. Physiologically safe breathing gas temperatures.

This system is designed to be used in conjunction with an open-circuit hot water suit and a portion of

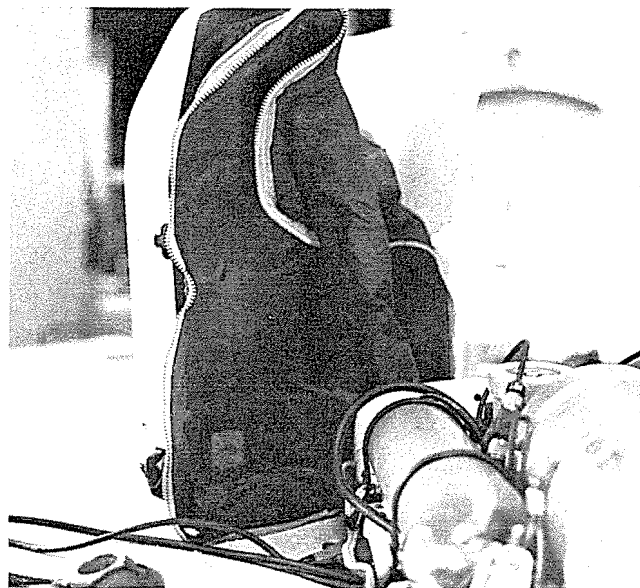


Figure 10-28 MK 10 thermal bag.

the hot water supplied to the diver is diverted to flow through the thermal bag.

The bag itself consists of a base piece of nylon-coated neoprene hard mounted between the tray and frame. This piece is designed to remain assembled to the breathing apparatus even when auxiliary thermal support is not required.

The upper portion of the bag, fabricated from the same material as the base, contains a nylon zipper for attachment to the base. This upper part snaps to the inside of the outer plastic protective cover and, when zippered, encloses the entire breathing apparatus. Tube-like projections surround the breathing hoses and the hot water exits through these tubes to minimize thermal loss in the hoses. Appropriately located cutouts afford accessibility to the bottle shut-off valves.

These cutouts are undersized and made in a flexible neoprene patch sewn to the bag. This assures a tight interface which minimizes hot water leakage. Pockets are provided in the vicinity of the bypass valve handles so that the valves can be located and depressed.

The hot water interface is located at the lower portion of the bag over the scrubber canister. A mounting plate located within the bag attaches to a potted fit-

ting which penetrates the outer cover and the bag. A "tee" which taps water from the suit umbilical couples directly to this fitting.

The upper portion of the bag is easily removed should the thermal system not be required. Hot water flow of 1 GPM at 90°F will maintain a He-O₂ gas temperature to the diver's mask of 64°F in 28°F water at 1,000 foot depth. The temperature of the scrubber canister will be maintained above 70°F if these input conditions are maintained.

Pre-Dive Procedures 10.4.4 Prior to the start of any dive, the equipment must be thoroughly inspected, calibrated and tested. A fresh absorbent cartridge must be installed, the batteries must be charged, and the oxygen and diluent gas cylinders must be charged and installed. Appendix II-F, a detailed pre-dive checklist, outlines these necessary procedures.

An important part of pre-dive planning is the selection of the diluent gas, and the computation of gas consumption rates for oxygen and the diluent.

The diluent gas may be any inert gas which is appropriate for the maximum planned depth of the dive. However, as a safety factor, the diluent should be a mixture of inert gas and oxygen. Oxygen in the diluent permits breathing the diluent in an emergency operating mode.

The recommended diluent gas mixtures are presented in Table 10-2. The basic guidelines call for the use of air or a mixture of 80% helium and 20% oxygen for dives not exceeding 130 feet. Below 130 feet, the mixture should be of helium and oxygen in the proportions noted in the table for the maximum planned depth.

Table 10-3 gives the endurance to be expected from the oxygen supply, starting with two variables: the initial cylinder pressure, and the depth of the dive. (A constant oxygen consumption rate of 1.5 liters per minute has been assumed in the preparation of this table.) This table has not been computed with a reserve safety factor, and this factor should be taken into account during pre-dive planning.

Diluent gas is added to the breathing system to maintain a system pressure equivalent to that of the



Figure 10-29 Diver mask used with the MK 10.

surrounding water. During descent, diluent will be transferred from the cylinder to the breathing system. During constant depth operations, no change in diluent level should take place either in the system or in the cylinder. During ascent, diluent will be vented to the water from the system; the quantity of the gas in the cylinder will not change.

However, if a second descent follows an ascent, more diluent will be taken from the cylinder to replace that which was vented to the water. If the dive plan calls for a series of depth changes, exhaustion of the diluent supply is possible and must be anticipated. The consumption of diluent is a factor of depth change, and is not related to time. Table 10-4 describes the losses of diluent to be anticipated from changes in depth. An additional factor in diluent loss is the volume of gas required for mask-clearing. Although each such instance does not result in a significant loss of gas, repeated occurrence could become significant. For example, if operating at a depth of 1,000 feet, the loss of one liter of diluent due to mask clearing would by itself represent a decrease in diluent cylinder pressure of 215 psi.

In computing probable diluent loss during the dive, a reserve safety factor, commensurate with the depth of operations, must be considered. Also as a safety factor, if the dive profile indicates that the diluent supply will be almost depleted, the dive plan must be organized in such a manner that during the final stage of the dive the diver will be ascending to the PTC rather than descending. As noted above, no diluent is drawn from the cylinder during an ascent.

TABLE 10-2—PERCENTAGE OF OXYGEN IN DILUENT GAS MIXTURE AS A FUNCTION OF DEPTH; MK 10 MOD 4 UBA.

- A. Select maximum operating depth and move vertically to Curve I.
- B. Move horizontally to the left to read maximum percentage (by volume) of oxygen.
- C. Read vertically downward from intersection with Curve II to find minimum depth at which mixtures with this oxygen percentage may be breathed.

Example—For a dive to a maximum depth of 1,000 feet, the diluent cylinder should contain a mixture of 3% oxygen, 97% helium by volume. The maximum ascent that can be made in the emergency operating mode is to 200 feet.

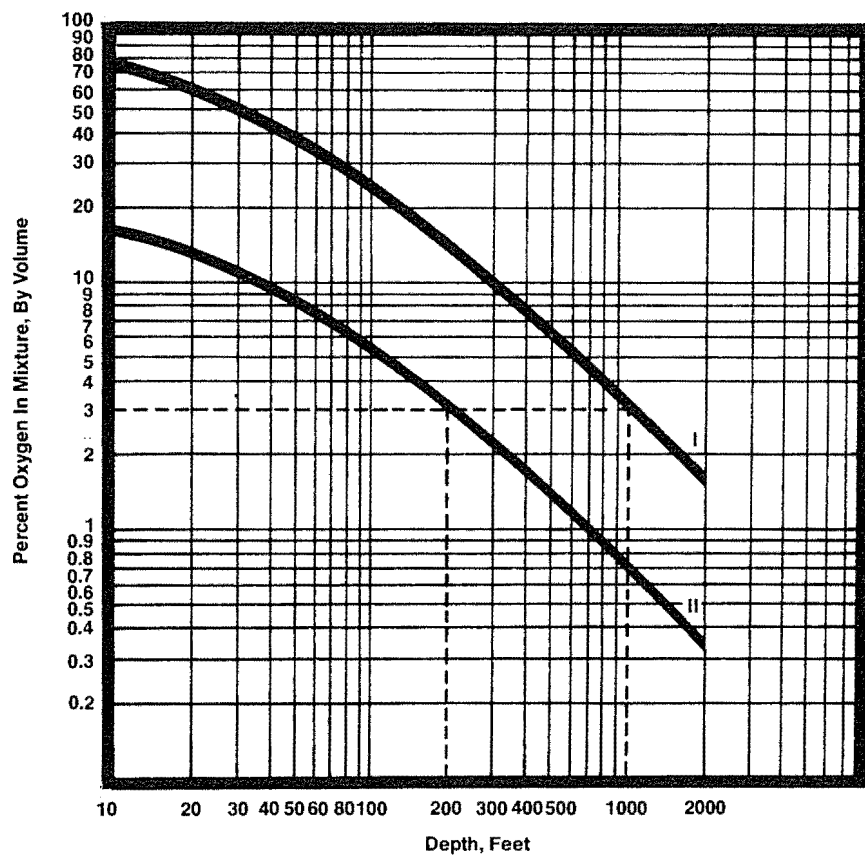


TABLE 10-3 OXYGEN CYLINDER PRESSURE DROP VERSUS TIME; MK 10 MOD 4 UBA

- A. Enter table at the oxygen cylinder pressure and follow slanted line to the dive depth.
- B. Move vertically downward from this intersection to read the duration of time for which oxygen can be breathed from the cylinder. (Note: This time does not include any safety factor. A suggested factor of 20% of the maximum duration should be planned into the dive.)

Example— For a pre-dive oxygen cylinder pressure of 2,800 psi and a maximum dive depth of 500 feet, the duration of the oxygen supply is approximately 4½ hours. A 20% safety factor would be approximately 1 hour. The O₂ cylinder pressure required for a dive to 500 feet for 1 hour is about 850 psi. The diver should terminate the dive when the O₂ cylinder pressure reaches 850 psi.

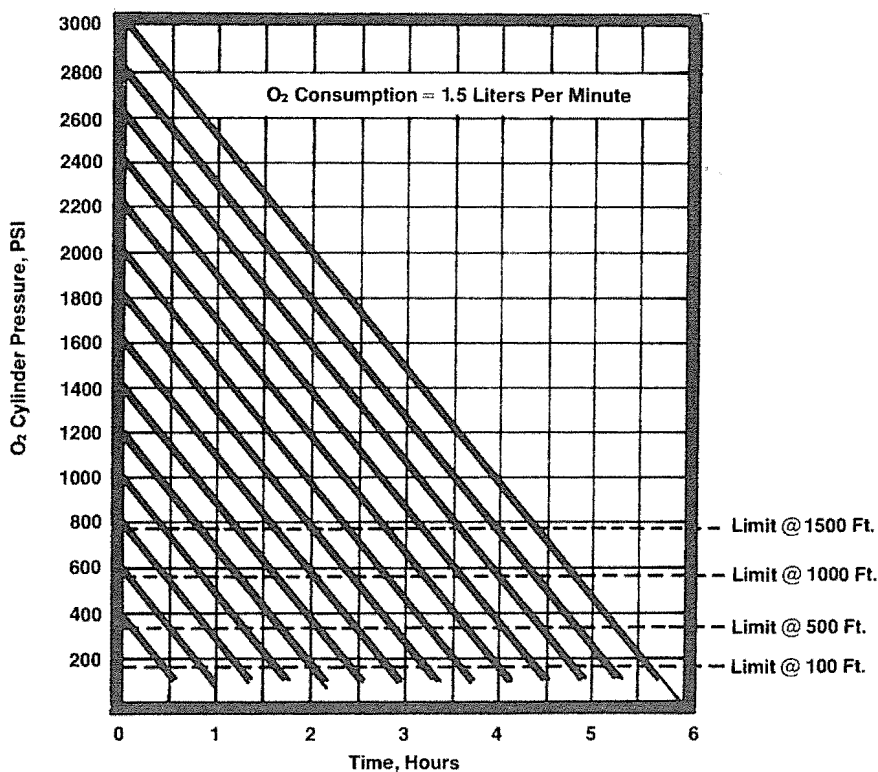


TABLE 10-4—DILUENT CYLINDER PRESSURE DROP VERSUS DEPTH; MK 10 MOD 4 UBA

- A. Enter the appropriate table (either air or He-O₂) at the diluent cylinder pressure and follow the slanted line to the dive depth.
- B. Move horizontally to the left to read the existing cylinder pressure.
- C. The horizontal dashed lines indicate the pressures at which the diluent cylinder is essentially empty. That is, diluent will no longer flow out of the cylinder unless the diver ascends. Do not dive below these limits.

Example—Assume the use of helium-oxygen as the diluent gas, the pre-dive diluent cylinder pressure is 1,800 psi, the dive will start from a PTC located at a depth of 500 feet and the planned dive consists of the following excursions—

1. Leave PTC and dive to 700 feet
2. Return to PTC
3. Descend to 700 feet
4. Return to PTC
5. Descend to 600 feet
6. Return to PTC

Point 1 on Table 10-4b represents the starting point in the PTC at 500 feet, with the pressure in the diluent cylinder at 1,800 psi. The descent to 700 feet represents a depth change of 200 feet and is shown on the Table from Point 1 to Point 2. The ascent to the PTC is represented from Point 2 to Point 3. The descent from 500 feet to 700 feet is a change of 200 feet and is represented from Point 3 to Point 4. The return to the PTC is represented from Point 4 to Point 5. The descent to 600 feet is represented from Point 5 to Point 6 and the return to the PTC is represented from Point 6 to Point 7. At the point of return to the PTC the diluent cylinder pressure is 575 psi.

There are several important observations to be made from this example—

1. The diver could not have descended to 700 feet on the last dive from the PTC (Point 5 to Point 8) because there would not have been sufficient gas in the diluent cylinder. The dashed horizontal limit lines show the "cylinder empty" pressure for various depths. Point 8 is below the limit line for an excursion to 700 feet,

and consequently the diver is prohibited from descending to this depth.

2. When operating near the diluent gas supply, the dive must be planned in such a manner that the diver must be ascending to the PTC instead of descending. Gas is not used from the cylinder during an ascent but it is used during any descent.

3. As in the case of planning a safety margin for the oxygen supply based upon a minimum pressure, a minimum diluent pressure must also be selected at which time the dive must be terminated. This margin becomes increasingly significant when other diluent losses are considered.

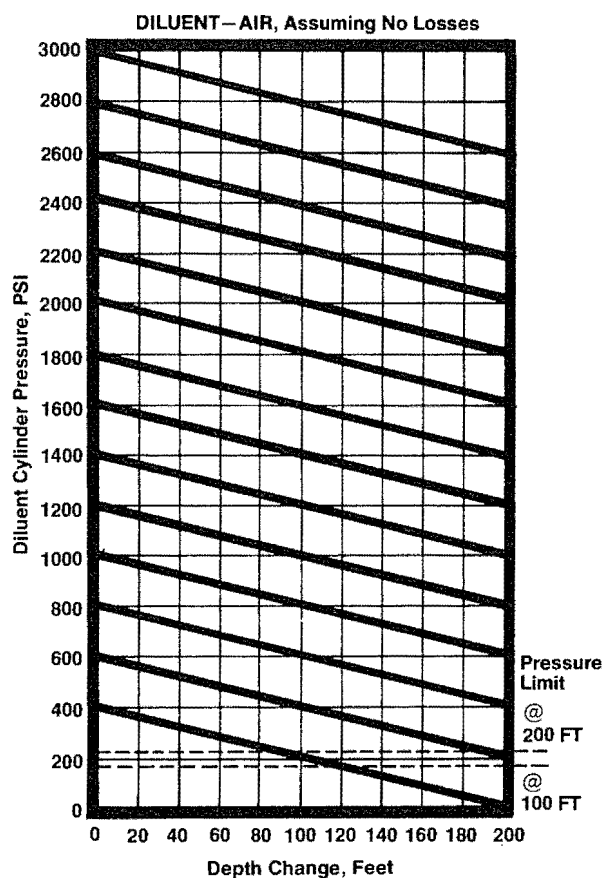


TABLE 10-4a—AIR DILUENT

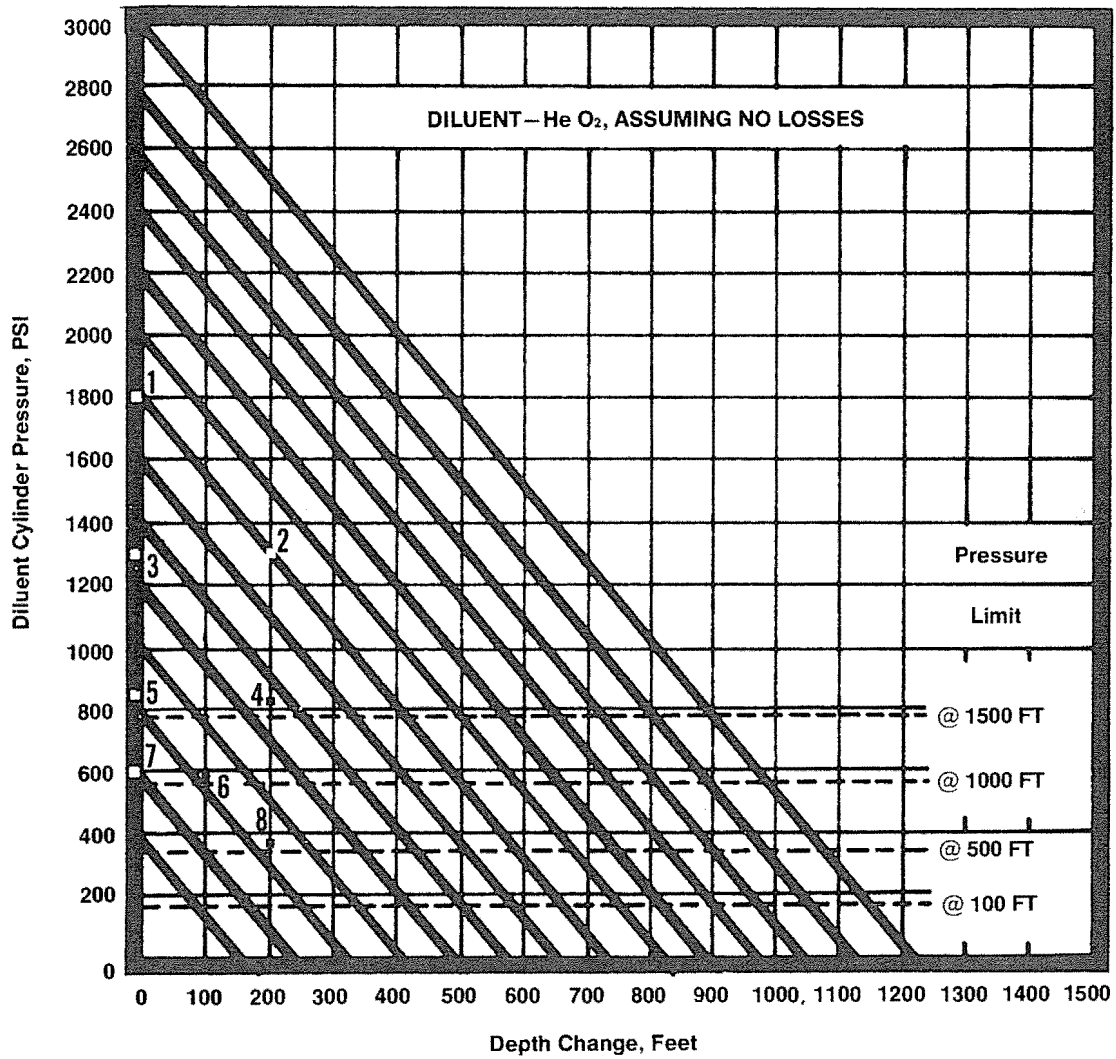


TABLE 10-4b – DILUENT – He O₂, Assuming No Losses

Underwater Procedures 10.4.5 Standard operating procedures and safety precautions which apply to the use of any SCUBA also apply to the use of the MK 10, MOD 4. Certain additional procedures which must be followed include—

1. The normal mode of operation is the automatic mode. When functioning normally, the amber light in the wrist display will be lit.

2. If the red light comes on, the diver must take appropriate steps (see 10.4.3.2—Electronic Control System) to determine the cause. If the light remains on for an extended period of time, or if both the red and amber lights are on or off at the same time, the diver must turn the selector switch to the “off” position, operate in the manual mode, and terminate the dive.

3. The diver should constantly be alert for the symptoms of oxygen poisoning (as remembered from the acronym **V-E-N-T-I-D**—vision, ears, nausea, twitching, irritability, dizziness). If such symptoms occur, the unit should be switched to manual operation and the partial pressure of oxygen immediately lowered by manual addition of diluent gas. The dive must then be terminated.

4. For U.S. Navy operations, the MK 10 MOD 4 will only be used in a tethered configuration, linked to a PTC. A physiometer must be employed which provides topside personnel with a read out of oxygen partial pressure and inspired gas temperature in the UBA. This tether will provide a means for heating the diving dress and preheating the inspired gas and will also ensure constant communications with the stand-by diver in the PTC. In the event of an emergency involving malfunction or loss of the MK 10 breathing circuit, the stand-by diver will be able to provide the primary diver with a fully-rigged MK 1 diving mask, supplied with breathing gas from the PTC. In such event, there is no interface or connection between the MK 1 mask and the MK 10 apparatus.

Post-Dive Procedures and Maintenance 10.4.6

Immediately following a dive, the apparatus must be inspected, cleaned and tested in accordance with the steps outlined in Appendix II-F. Field maintenance of the MK 10 is limited to these steps and to the re-

placement of any malfunctioning module. These replaceable units include the electronics module, the chest and wrist display units, and the battery module. **Field repair of these modules is not authorized.**

Further operational and technical information about the MK 10 is contained in NAVSHIPS 0994-004-7020.

MARK 11 MOD 0 MIXED-GAS UBA 10.5

The MK 11 apparatus is a semiclosed-circuit UBA employed for diving from PTC's to depths of 850 feet. The system includes a backpack assembly, an umbilical and an apparatus monitoring panel in the PTC. The backpack assembly includes emergency gas and switchover valving, scrubber, two breathing bags, injection gas regulation system, and oxygen partial pressure sensor. Injection and system pressurization gas is fed to the apparatus through the umbilical from the PTC as is hot water for heating the backpack. The output signal from the oxygen partial pressure sensor is transmitted through the umbilical to a dual-diver monitoring/alarm panel in the PTC. Audio communication is also provided. System pressurization gas is manually controlled.

Operating Modes 10.5.1 The MK 11 is not a completely “self-contained” apparatus (except when used in an emergency mode) and must be used in a tethered configuration in conjunction with a PTC.

The MK 11 MOD 0 UBA has four modes of operation—

1. **Semiclosed-circuit, umbilical-supplied.** This is the normal mode of operation. The MK 11 has an endurance of 4 hours which is established by the capacity of the carbon dioxide removal unit.

2. **Open-circuit, umbilical-supplied.** Endurance is dependent upon the gas supply from the PTC.

3. **Semiclosed-circuit, emergency cylinder-supplied.** Endurance is 15 minutes at 600 feet, or 10 minutes at 1,000 feet.

4. **Open-circuit, emergency cylinder-supplied.** Endurance is approximately 12 breaths at 600 feet, approximately 8 breaths at 1,000 feet.

Breathing Circuit 10.5.2 The MK 11 UBA contains components which regulate injection gas feed,

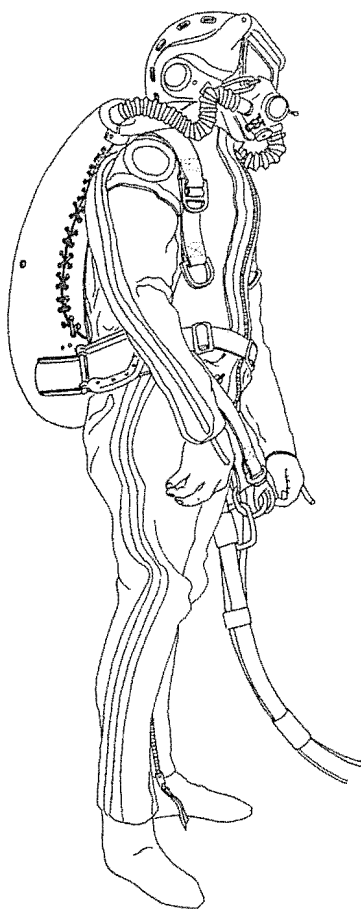


Figure 10-30 Diver fully outfitted with the MK 11 UBA.

remove carbon dioxide, recirculate breathing gas, supply emergency gas, monitor oxygen partial pressure, fill and purge the apparatus and exhaust excess gas. The following is a sequential description of how these components function in the MK 11 during normal operation—

1. Upon exhalation, the diver's breath flows from the oral-nasal mask through the exhalation check valve and hose into the exhalation breathing bag in the backpack. An attitude-sensitive (cardioid) exhaust valve at the exhalation bag vents any excess gas from the system. The recirculating gas passes into a water-warmed carbon-dioxide removal canister which is bulk filled with 10 pounds of Baralyme. Recirculating gas passes from the scrubber into an inhalation breathing bag in the backpack where it is mixed with fresh supply gas from the umbilical.
2. Umbilical supply gas feeds two regulator assemblies and a critical flow (sonic) orifice in the backpack. The absolute pressure regulator block (APRB) contains the flow control orifice which is supplied gas directly from the umbilical. It also contains the constant absolute pressure regulator (CAP) which allows emergency gas from the backpack cylinders to

flow at constant pressure to the orifice if the umbilical supply is lost. The constant differential pressure regulator (CDP) receives umbilical gas from the APRB (or the CAP in an emergency mode) and maintains a constant differential pressure, relative to depth, to supply the system fill/purge valve and a second-stage regulator on the facemask for demand breathing and mask clearing.

The orifice (pre-selected for the dive) meters the gas flow into the inhalation bag. This orifice is designed to provide a constant mass-flow of gas proportional to the supply pressure. In operation, both the choice of orifice and the umbilical supply pressure are important to ensure adequate flow of gas into the system.

3. At the inhalation bag, a galvanic sensor assembly measures the partial pressure of oxygen in the gas and provides a signal to the dual-diver monitor in the PTC. (If the partial pressure of oxygen falls below a pre-determined level, an alarm will sound to alert support personnel to the problem. Using voice communications with the diver, they may instruct him to operate the manual purge valve, to shift the mode of operation, or to return to the facility.)

4. From the inhalation bag, the gas moves through the inhalation hose to the inhalation check valve in the face mask, and then to the oral-nasal mask unit.

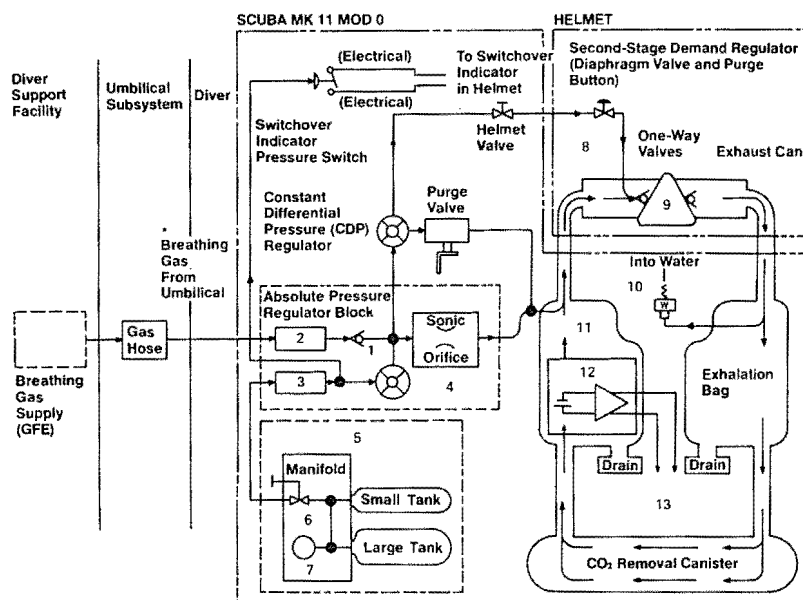
Description of Components 10.5.3 The basic components of the MK 11 UBA are the gas regulation and supply system, carbon dioxide removal assembly, the electrical system (which includes the oxygen sensor, PTC diver monitor panel, audio communications, and supply switchover alarm), and the umbilical. All of these components are mounted on a contoured, structural backpack enclosed in a thermal control bag and covered by a one-piece plastic cover. The CO₂ removal canister is located inside the bottom of the backpack shell adjacent to the small of the diver's back. The heavy items, such as cylinders and regulators are placed as close as possible to the center of buoyancy of the gas bags.

GAS REGULATION AND SUPPLY SYSTEM 10.5.3.1 The absolute pressure regulating block (APRB) supplies injection gas from the umbilical to the inhalation breathing bag through a replaceable fixed

- | | |
|--|---|
| 1 Check Valve | 9 Oral-Nasal Mask |
| 2 Filter | 10 Cardiod Exhaust Valve |
| 3 Filter | 11 Inhalation Bag |
| 4 Constant Absolute Pressure (CAP) Regulator | 12 PO ₂ Amplifier |
| 5 Manifold Assembly (Emergency Gas Supply) | 13 PO ₂ to Umbilical Electrical Cable (Electrical) |
| 6 On-Off Valve | |
| 7 Safety Disc | |
| 8 Demand Regulator Can and Intake Assembly | |

*HEAVY LINE INDICATES GAS FLOW IN SEMICLOSED-CIRCUIT, UMBILICAL-SUPPLIED MODE

Figure 10-31 MK 11 Flow schematic.



orifice. The APRB also contains the constant absolute pressure regulator (CAP) which supplies the flow control orifice from the emergency cylinders if the umbilical supply is lost. The CAP is preadjusted to deliver a pressure equal to twice the maximum depth plus 40 psi. The APRB also supplies umbilical gas to the constant differential pressure regulator (CDP). This regulator, preadjusted to deliver 125 psi above ambient, also receives gas from the CAP if the primary supply is lost. It supplies gas to the system purge valve for manual pressurization of the system during shallow diving descent (injection flow is normally sufficient in deep diving) and permits system purging in the event of flooding or malfunction. It also supplies gas to a second-stage regulator on the facemask through a shutoff valve on the mask to permit mask purging and demand breathing.

During normal operation, the supply gas from the PTC, regulated to the pressure indicated in Table 10-5, enters the APRB where it flows through a filter, check valve, and sonic orifice into the recirculation system. The CAP regulator maintains constant pressure gas to the flow control orifice regardless of depth whenever the pressure drops to an unsafe level in the umbilical gas supply. Umbilical gas pressure builds up at the outlet port of the CAP regulator and on the underside of the regulator bellows assembly. The sealed aneroid-type bellows assembly contains a helical spring and is attached to a valve assembly in the inlet chamber.

As pressure increases at the outlet port of the regulator the bellows moves upward, compressing the helical spring, and closing the valve when the regulator set pressure has been reached. Conversely, as pressure at the discharge port of the regulator (and underside of the bellows) decreases, the helical spring moves the valve stem away from the seat and allows gas to flow.

When the CAP regulator admits gas to the system from the emergency supply cylinders, the MK 11 operates as a semiclosed-circuit SCUBA with a limited duration. A warning system, consisting of a pressure switch and a facemask indicator lamp, alerts the diver when the reserve gas supply pressure, measured at the cylinder manifold has dropped approximately 300 psi. At that point, the diver must return to the PTC.

The CDP regulator consists of a pressure sensing diaphragm, a filter and a spring system. In operation, gas passes through the filter into the inlet chamber building up pressure at the outlet port and on the underside of the sensing diaphragm. This pressure causes the sensing diaphragm to move upward against the helical spring, closing the valve. When the downstream flow ceases, the valve stem is pressed fully upward against the seat, closing the orifice. As water pressure on the topside of the diaphragm increases or pressure on the underside of the sensing diaphragm decreases, the helical spring moves the valve stem away from the seat.

ELECTRICAL SYSTEM 10.5.3.2 The electrical subsystem contains several units, each of which perform functions independent of each other. These are—

- Two-way, hands-off voice communications between the diver and the PTC and diver-to-diver. A microphone and earphone set are installed in the face mask, and a pre-amplifier assembly to boost the microphone signal is mounted in the backpack.
- Switchover indicator system, which informs the diver when the emergency gas supply has been depleted enough to have resulted in a pressure drop of 300 psi at the cylinder manifold. This indicator system consists of a pressure switch, an indicating light assembly (with a pair of light-emitting diodes wired in parallel for redundancy), and connecting cables.
- Oxygen partial pressure monitoring system which consists of a ppO₂ sensor, sensor amplifier and dual-diver monitor. The sensor produces a voltage that is proportional to the ppO₂ in the inhalation bag. This voltage is amplified and sent through the umbilical electrical cable to the dual-diver monitor. Upper and lower limit alarms in the monitor, set before the dive, provide an audible signal when the ppO₂ in the inhalation bag is too high or too low.

All units of the electrical system are connected to the umbilical by the electrical whip. This cable assembly serves both to carry signals and to provide 28 VDC which is converted from 115 VAC by a pair of converters in the dual-diver monitor unit in the PTC.

UMBILICAL 10.5.3.3 The umbilical consists of a water hose, gas hose, and electrical cable taped together and having suitable connectors at each end.

The gas hose, which consists of an inner tube, polyester braided reinforcement, and outer cover, provides a flow of breathing gas from the PTC to the diver at up to 1,050 psi supply pressure through the 3/8 inch I.D. inner tube. The hose burst pressure is 10,000 psi. The gas hose is fitted with a quick disconnect fitting at the diver-end and is connected semi-permanently to the PTC by an O-ring union tailpiece and nut which is screwed onto the PTC union male fitting.

The rayon braid-reinforced, natural-rubber water hose delivers 2-gpm of 110°F water to the diver at 51 psi

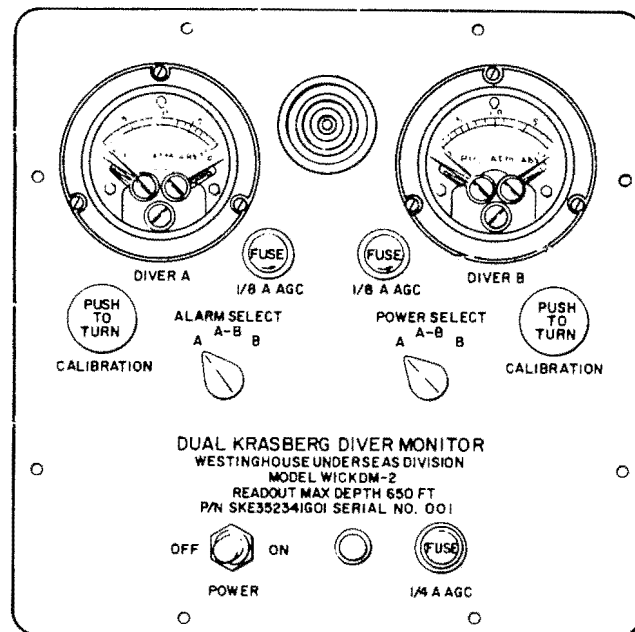


Figure 10-34 MK 11 Dual-Diver Monitor Unit.

supply pressure through a 1/2 inch internal diameter. The hose consists of 50 foot segments that are spliced together with 1/2 inch inner diameter nylon hose barbs and stainless-steel bands. The water hose is fitted with a quick disconnect coupler at the diver end and is connected to the PTC by an O-ring union tailpiece and nut similar to that previously described.

The two hoses and electrical cable are taped together with 2 inch tape at 18-inch intervals. A D-ring is lashed to each end of the umbilical for connector strain relief.

Pre-Dive Procedures 10.5.4 Prior to any dive, the equipment must be thoroughly inspected, calibrated, and tested. The carbon dioxide removal canister must be filled with fresh Baralyme, and the emergency gas supply cylinders must be charged.

Table 10-5 presents data for the selection of the breathing gas mixture for both umbilical supply and emergency supply for operation at various depths. The table also contains information about gas flow rates (in surface liters per minute) and supply pressure, and notes the correct orifice size which must be installed in the automatic pressure regulating block.

The MK 11 is provided with a Field Test Kit and a Maintenance Kit, containing various adapters, gages and special tools necessary for carrying out both pre-dive and post-dive operations. Table 10-6 contains a list of the components of the Field Test and Maintenance Kit, and the purpose for which each is used. Appendix II G is a comprehensive Pre-Dive Checklist for the MK 11 apparatus.

TABLE 10-5—MIXTURE, FLOW RATE, AND ORIFICE SELECTION DATA FOR MK 11 MOD 0 UBA

Depth Range (Ft)	Gas Supply Operating Mode	Gas Mix (Percent)		Minimum Flow (SLPM)	Max. Depth (Ft)	Min. Pressure (PSIA)	Orifice No.	Actual Flow (SLPM)	Actual Pressure (PSIA)
Surface to 95	umbilical-primary	60	40	16	95	365	8	17.8	365
	tank-emergency	50	50	10		265		11.4	265
80 to 230	umbilical-primary	80	20	22	230	365	7	25.7	365
	tank-emergency	76	24	16		265		17.7	265
135 to 300	umbilical-primary	85	15	30	300	436	6	35	440
	tank-emergency	80	20	20		336		24	340
200 to 400	umbilical-primary	88	12	36	400	525	7	40	535
	tank-emergency	85	15	28		425		28	435
235 to 500	umbilical-primary	90	10	40	500	614	8	42	615
	tank-emergency	88	12	30		514		34	515
300 to 625	umbilical-primary	92	08	50	625	726	8	50	730
	tank-emergency	90	10	40		626		43	630
500 to 800	umbilical-primary	94	06	60	800	881	9	61	885
	tank-emergency	92	08	50		781		51	785
625 to 950	umbilical-primary	95	05	70	950	1016	9	75	1020
	tank-emergency	94	06	60		916		63	920
800 to 1000	umbilical-primary	96	04	82	1000	1060	9	82	1120
	tank-emergency	95	05	58		960		68	960
800 to 1250	umbilical-primary	96	04	85	1250	1284	9	94	1285
	tank-emergency	95	05	70		1184		84	1185

Underwater Procedures 10.5.5 Standard operating procedures and safety precautions for SCUBA and DDS operations apply to use of the MK 11 MOD 0. Certain additional procedures which must be followed include—

1. The normal mode of operation is semiclosed-circuit, umbilical supplied. In the event of an interruption of the umbilical gas supply, reserve gas will automatically be fed into the system from the self-contained emergency cylinders. If the interruption persists long enough for the emergency supply pressure to drop 300 psi, a warning light in the face mask will alert the diver to return to the PTC.

2. To ensure that the reserve gas supply has not been accidentally closed off, the diver should periodically check the manifold on-off handle for correct position.

3. If the apparatus becomes flooded, the diver must open the face mask valve, close the inhalation valve, and go on open-circuit.

4. If flooding and loss of umbilical pressure occur at the same time, the diver must make certain that the manifold valve is open, then open the face mask valve, close off the inhalation valve, and go on open-circuit breathing from the emergency gas supply. Duration in this mode is limited to approximately 10 breaths at 600 feet and 8 breaths at 1,000 feet, and the diver must quickly return to the PTC.

5. A fogged face plate may be cleared by lowering the head below breathing bag level and admitting a small amount of water to the face mask by pressing the water purge button. A small amount of water should be left in the face mask for use in rinsing fog off the mask.

6. While at work, the diver should adjust the hot water bypass valve and front and rear flow control valves for maximum comfort.

7. If symptoms of inadequate ventilation develop, the system should be immediately purged by actuation of the purge valve.

8. If the diver alarm on the dual-diver monitor unit indicates that the partial pressure of oxygen in the breathing system has fallen below the calibrated level, support personnel must so notify the diver by

voice communications and advise him to purge the system, go on open-circuit, or return to the PTC.

Post-Dive Procedures and Maintenance 10.5.6

Appendix II G is a comprehensive Post-Dive Checklist for inspection, repair and stowage of the MK 11 apparatus.

Particular attention must be given to Table 10-7 which outlines special decompression procedures for the equipment. If not properly prepared for decompression, or if correct decompression procedures are not followed, the equipment may be damaged.

Additional operational and technical information for the MK 11 is contained in NAVSHIPS 0994-005-2010.

TABLE 10-6 FIELD TEST AND MAINTENANCE KIT COMPONENTS—MK 11 MOD 0

Field Test Kit—

1. Low-pressure hose assemblies necessary to connect the gasometer to the MK 11 to measure the metered flow of gas into the breathing circuit.
2. A flowmeter, valve, connecting tubing and calibration cover to calibrate the pO_2 sensor separately from the rig.
3. A helmet adapter and gage assembly to check the low-pressure leaktight integrity and cardioid exhaust valve settings.
4. A switchover warning indicator test gage and adapter to check out and adjust the switchover indicator pressure switch.
5. A regulator plug gage and adapter assembly to adjust the CAP regulator in the APRB.
6. Adjustment keys for the CAP and CDP regulators.
7. A pin straightener for the pO_2 Sensor electrical connector pins.
8. Sonic orifice assemblies for the APRB.
9. A BIB umbilical adapter for the CAP regulator sonic flowrate adjustment.

Maintenance Kit—

1. Charging assembly used to charge the back-pack manifold assemblies.
2. An adapter and valve assembly used to test the pO_2 level of the charged manifold assemblies.
3. A CDP regulator output pressure test adapter used to adjust the CDP regulator pressure.
4. A manifold pressure test adapter assembly used to check the pressure of the charged manifolds.
5. Two manifold test fixtures used for maintenance testing.
6. Two 3-foot maintenance and calibration whips.
7. A CDP regulator pressure cap for maintenance tests.
8. A helmet valve adapter for maintenance testing.
9. A hydro test plug for maintenance testing of the manifold assembly.
10. Special tools for the assembly and disassembly of the CDP regulator and the APRB.

TABLE 10-7 DECOMPRESSION REQUIREMENTS MK 11 MOD 0 UBA

Component	Recommended Decompression Rate Limit	Disassembly Before Decompression	Decompression Procedure	Effect of Rapid Decompression
Thermal Protection Subsystem				
Suit Boots Gloves	Same as Divers	None	<ol style="list-style-type: none"> 1. Decompress with divers 2. Allow room for expansion of material 3. Inspect seams and tubing for weakness or damage after decompression and repair as necessary. 	<ol style="list-style-type: none"> 1. Suit expands in all dimensions after helium exposure and decompression. Suit then gradually returns to normal size. 2. Immersion in water after helium compression causes suit to form a leathery texture retained after decompression.
SCUBA MK 11 MOD 0				
All Except ppO₂ Sensor Amplifier Assembly And Canister	500 Ft/Min	Remove ppO ₂ Sensor Amplifier Assembly	After Rapid Decompression: <ol style="list-style-type: none"> 1. Inspect materials for cracks or bubbles. 2. Check O-ring and gasket seals and replace as required. 3. Conduct complete operational checkout and leak test. 	Bubbles form in preamplifier in communications cable causing intermittent communication failure
ppO₂ Sensor Amplifier Assembly	2.0 Ft/Min with 60-min stop at 60 ft or same as divers	Remove from SCUBA MK11 MOD 0	Decompress with divers	Bubbles form under sensor membrane, causing inaccuracy
Canister		Loosen end cap		Gasket expands and deforms canister end.
Helmet, NW4-C	None	None	After rapid decompression, inspect for cracks, surface chips, or bubbles.	None

TABLE 10-7 DECOMPRESSION REQUIREMENTS—MK 11 MOD 0 (cont'd)

Component	Recommended Decompression Rate Limit	Disassembly Before Decompression	Decompression Procedure	Effect of Rapid Decompression
Switchover Indicator	None	None	Check for damage and ensure operability after rapid decompression. Replace if necessary.	None
Umbilical Subsystem				
Gas Hose, Water Hose, Electrical Umbilical, Bib Whip, Predive Checkout Electrical Whip	None	None	Avoid storage in high-pressure helium environment. Store in water while at operating pressure and during decompression, if possible.	Surface bubbles may form after storage in high-pressure helium environment.
Electrical Subsystem				
Microphone	None	None	No special procedure required.	None
Earphones	Same as divers	Remove from helmet	Decompress with divers.	Bubble may form under covering. Bubble disappears after 5 to 10 days.
Diver Monitor	(Not tested for hyperbaric operation)			
Accessory Subsystem				
Knife, Flippers, Shoes, Slate and Stylus	None	None	No special procedure required. Inspect for surface cracks or tears after rapid decompression.	None
Depth Gage	Same as diver	None	Decompress with diver	Inaccuracy, leakage
Compass	Same as diver	None— Note: Remove filler plug if more rapid decompression is required.	Decompress with diver or remove filler plug for more rapid decompression.	Leakage

TABLE 10-7 DECOMPRESSION REQUIREMENTS—MK 11 MOD 0 (cont'd)

Component	Recommended Decompression Rate Limit	Disassembly Before Decompression	Decompression Procedure	Effect of Rapid Decompression
Field Test Kit and Maintenance Kit				
All	200 Ft/Min (Case closed) 500 Ft/Min (Case open)	Remove all plugs and dust covers from components.	Decompress with case open.	Case could crack or burst if closed.

SURFACE-SUPPLIED MIXED-GAS DIVING OPERATIONS



Figure 11-1 Diver wearing He-O₂ recirculating deep-sea outfit

Surface-supplied, mixed-gas diving involves those forms of diving in which a breathing mixture other than air is supplied from the surface to the diver by a flexible hose. This method of mixed-gas diving is particularly suited for operations beyond the depth limits of air diving yet of sufficiently short decompression time as to preclude the need for a Deep Diving System. Surface-supplied mixed-gas diving is also applicable in the deeper air diving range when the operation demands freedom from narcosis to permit maximum mental acuity and manual dexterity.

As with surface-supplied air diving, the mixed-gas diver has a choice of two basic outfits—**heavyweight** and **lightweight**. The factors which influence the choice of equipment are much the same as for air diving: nature of the work to be accomplished, diver comfort and protection, environmental considerations, and availability of support facilities.

The heavyweight outfit, usually known as the "Heliox" deep-sea rig, and the lightweight outfit, employing the Diver's Mask USN MK 1 from an open bell, will be described in detail. Other material covered in this chapter includes the operation of mixed-gas supply systems, diver communications, and underwater techniques and procedures which are unique to mixed-gas operations.

DIVING EQUIPMENT 11.1

Deep-Sea Mixed-Gas (He-O₂) Outfit 11.1.1 The heavyweight mixed-gas outfit is a modified standard deep-sea air outfit. The diving dress, umbilical and accessories are identical in most respects; but the helmet has been re-worked to provide for the installation of a gas recirculating system. This helps to conserve the breathing mixture by passing it through a carbon dioxide absorbent and thus reduces the need for large volumes of fresh mixture for ventilation of the helmet.

Conservation of gas is important primarily because of the expense and supply problems involved in obtaining and handling helium-oxygen mixtures. Early experiments with these mixtures, conducted with standard deep-sea helmets, demonstrated the feasibility of helium-oxygen diving. However, adequate ventilation of the helmet and dress required a constant flow of at least three cubic feet per minute measured at the depth of the diver. At a depth of 297 feet (10 atm abs), for example, the necessary flow measured at the surface is 10 x 3 or 30 cubic feet per minute. At that rate an average cylinder of gas would only last about 7 minutes.



Figure 11-2 Rear view of diver wearing a recirculating deep-sea outfit



Figure 11-4 Recirculating helmet; front view



Figure 11-5 Recirculating helmet; rear view

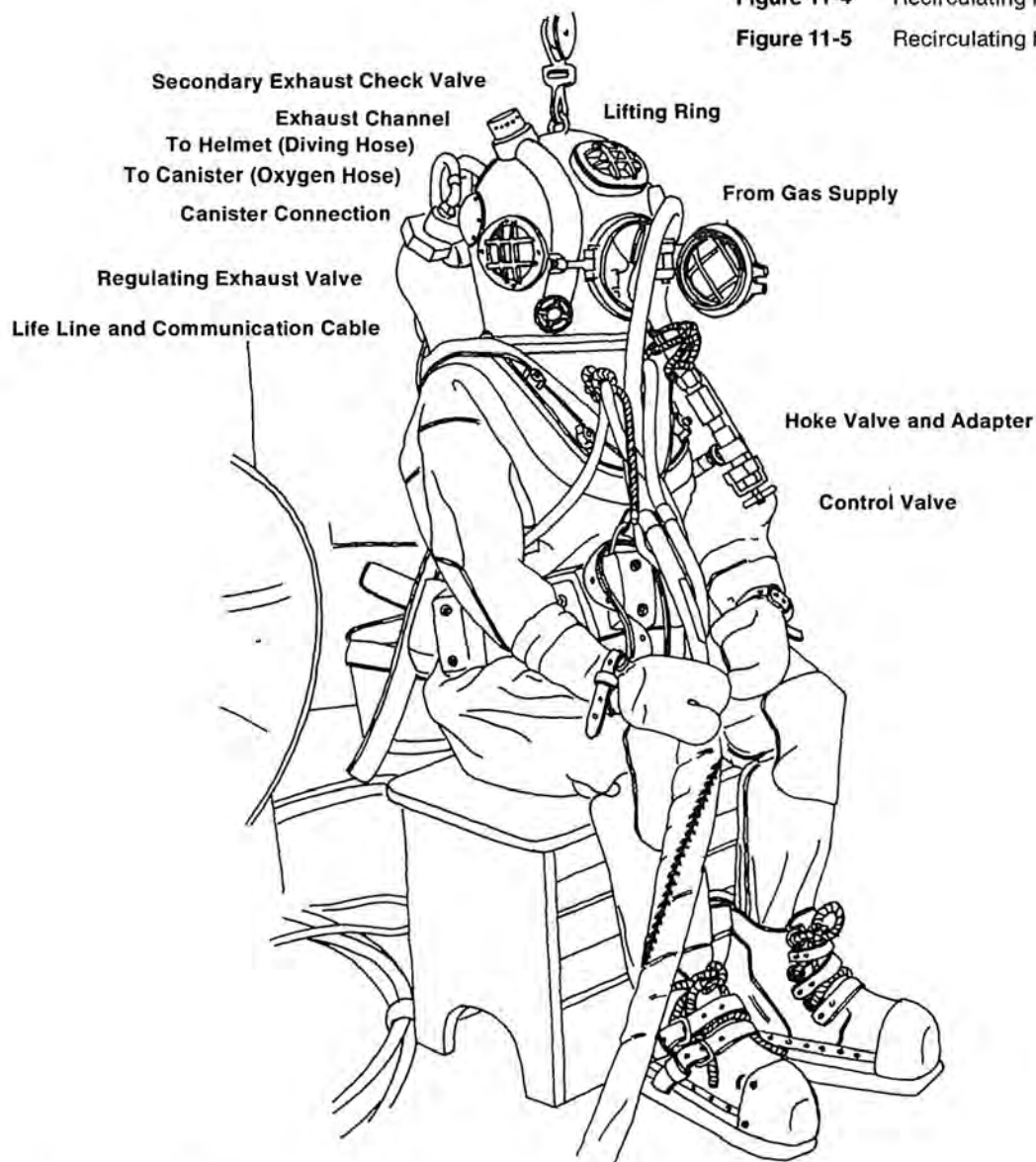


Figure 11-3 Recirculating deep-sea diving outfit

A working diver on the bottom actually needs only about 0.5 cubic foot of make-up gas (measured at depth). After some experimentation with various apparatus, most of which proved to be too clumsy or inconvenient to use, the design evolved to a simple modification of the Mark V helmet which has proven to be both safe and efficient. This modification is described in detail in Section 11.1.1.1.

For purposes of discussion and comparison with standard deep-sea equipment, the components of the **heavyweight mixed-gas outfit** are divided into the analogous three groups—

Helmet Group—which includes the helmet, breastplate, recirculating system, and associated valves and fittings.

Diving Dress Group—which includes the basic dress, underwear, chaffing pants, helmet cushion, gloves, shoes, weight belt and diver's knife.

Hose Group—which includes the gas hose and fittings, the control valve, the lifeline and amplifier cable, and the pneumofathometer.

THE HELMET GROUP 11.1.1.1 The He-O₂ helmet is a modified standard Mark V air helmet; it is constructed of the same materials and is similar in most respects with the following exceptions—

- two large goosenecks have been installed on the rear of the helmet. These provide the connections for the recirculating device and carbon dioxide absorbent canister.
- a smaller gooseneck is located at top rear center of the helmet. This connection originally permitted the use of a set of electrically-heated underwear which is no longer employed. The gooseneck is now sealed.
- a secondary exhaust check valve has been installed on the exhaust channel to prevent accidental flooding.
- a special internal duct leading from the canister discharge opening provides improved gas circulation within the helmet.
- because the canister fits up against the rear neck portion of the helmet, the safety lock (dumbbell) has been relocated to the position formerly occupied by the spitcock. The spitcock itself has been re-

moved as an additional safeguard against the loss of breathing mixture and flooding.

- the breastplate has been modified for the change in position of the dumbbell safety lock; otherwise, it is unchanged.

The modified helmet with breastplate and canister weighs approximately 103 pounds. This compares with 56 pounds for the standard helmet and breastplate and obviously poses an extra burden on the diver and tenders. As an aid in handling the unit, a lifting ring has been attached at the top of the helmet. The ring is used in conjunction with a small block and tackle, and it is of particular value when lowering the helmet over the diver's head and holding the weight off his shoulders during the dressing process.

The recirculating system consists of a gas supply, a circulating device which operates on the venturi principle, and a canister of carbon dioxide absorbent.

The gas supply is taken from the main supply hose just ahead of the control valve. A Hoke needle valve is installed on a special adapter on the inlet side of the control valve. When the Hoke valve is open, gas is passed through a 54-inch section of standard oxygen hose and into the recirculating device installed in the right-hand canister gooseneck. The Hoke valve and the main control valve operate independently of each other—either or both may be used at any given time. In normal operation the Hoke valve is never closed unless the recirculator malfunctions or the supply hose breaks or becomes disconnected. The control valve is usually kept closed except under the following conditions—

- to build up the pressure and volume of gas in the suit during descent.
- whenever the diver needs a sudden increase in gas in the suit to regulate buoyancy.
- to supply breathing mixture to the helmet in a conventional "open-circuit" mode in the event the recirculating device should fail.
- to ventilate the dress by flushing out the gas with a fresh supply.

These procedures are described in Section 11.3.1.3.

The recirculating device, or aspirator, contains a high-pressure injector nozzle of a size calculated to pro-

vide, at 100 psi pressure differential, a volume of gas that contains sufficient oxygen to replace that consumed by the diver. This jet of incoming gas also performs the work of recirculating the gas within the helmet through the absorbent canister. Recirculation is accomplished by a well-known principle (Venturi's) by which a rapidly moving jet of gas tends to drag surrounding gases along with it and thus create a suction-pump effect. The Venturi nozzle draws 11 times its own input volume (1/2 cu. ft./min. at the pressure of the dive) of "used" gas through a passage from the interior of the helmet. This carbon dioxide laden gas, now combined with incoming fresh gas, passes through the chemical absorbent in the canister and the carbon dioxide is removed. The mixed gases then pass into the helmet; any excess gas pressure that builds up is released through the exhaust valve.

The aspirator assembly includes a screen retainer assembly, a high-pressure nozzle, an aspirator body with a passage from the interior of the helmet, and a Venturi discharge nozzle (Fig. No. 11-6).

The screen retainer assembly holds a 100-mesh bronze screen which prevents the high-pressure nozzle from becoming plugged by foreign matter which may be blown through the hoses. This screen must be regularly inspected and cleaned. The screen retainer assembly screws directly into the high-pressure nozzle fitting. The nozzle fitting screws directly into the aspirator body with a metal-to-metal seal in which no packing is used. The nozzle fitting may be removed for cleaning with a 3/4-inch wrench.

The nozzles are machined to close tolerances and must be handled very carefully. A nearly invisible scratch or a small bit of foreign matter will alter the flow of gas and may result in inadequate ventilation of the helmet. The nozzles should be regularly inspected before and after each use.

The high-pressure injector nozzle should be cleaned and checked for proper size by first blowing filtered high-pressure air through the nozzle, and then by running a wooden or plastic rod, the size of a No. 72 drill, through the nozzle from the high-pressure side. In normal practice the shank of a No. 72 drill (held inverted in a pin vise) is often used; however, the drill-

end must never be used since this would scratch the nozzle surfaces.

The Venturi discharge nozzle is screwed into the lower side of the aspirator body and projects down into the canister. It can be removed with a 7/8-inch wrench.

The carbon dioxide absorbent used in the canister is an essentially noncaustic compound composed of hydrated barium hydroxide and calcium and potassium hydroxides. Known commercially as Granular Baralyme, this absorbent has replaced the highly-caustic Shell Natron which was formerly used to fill the canister. Canister packing procedures are described in Section 11.3.1.1.

The discharge end of the canister is fitted with another 100-mesh screen to prevent particles of the absorbent from being carried into the helmet. The canister itself is secured to the two goosenecks with 3-inch lock nuts containing Koroseal or neoprene washers to ensure a watertight connection. Water leaking into the canister seriously reduces the effectiveness of the Baralyme.

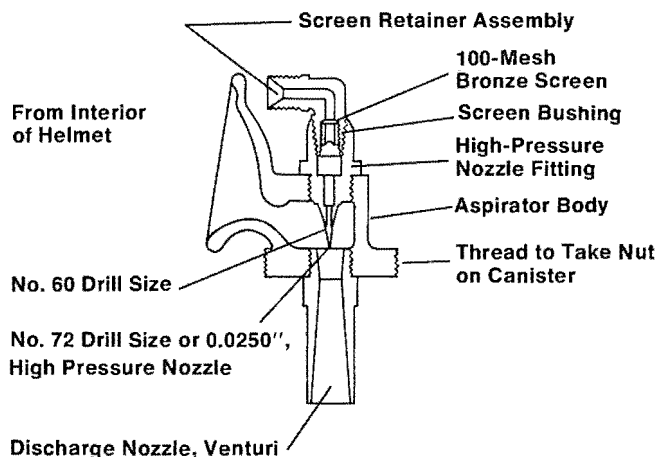


Figure 11-6 Recirculating device

A fully-packed canister, which holds approximately 6 pounds of Baralyme, has a maximum duration of 3 hours (with a 200-percent safety factor) under average diving conditions. When diving in cold water conditions (40°F or less), however, the chemical reaction is not as effective and duration may be reduced to as low as 35 minutes. Additional operational procedures which must be followed when using Baralyme are—

- maintain a 100-psi overbottom mixed-gas pressure for all working dives.
- special periods of manual ventilation should be a regular part of working procedure.

WARNING

The Baralyme contains an “indicator” chemical intended to demonstrate the extent of absorption by a color change. This is an inaccurate indicator and should be disregarded.

Three valves are installed on the helmet. These are the safety gas non-return valve, the gas-regulating

exhaust valve, and the secondary exhaust check valve. The non-return valve may be of either the cartridge/O-ring or spring stem type; and, as in air diving equipment, it is mounted on the inlet gooseneck. The presence of this valve is mandatory, and proper functioning must always be checked prior to each dive. The exhaust valve is the same unit used in air diving with the exception that the valve is adjusted so that the initial setting has the spring follower disk in contact with the sleeve when the adjusting wheel is 2 1/2 turns short of the fully closed position. (This compares with a setting at 1/8 turn for air diving operations.)

The secondary exhaust valve, which is not part of the standard Mark V outfit, is a double-check valve installed at the end of the exterior exhaust channel to guard against the possibility of accidental flooding. This valve should be disassembled prior to each dive and inspected for tightness and cleanliness. Disassembly is accomplished by removing the two threaded rings from the top of the valve: the upper ring is loosened or set by hand, and the lower ring is installed or removed with the use of a special wrench.

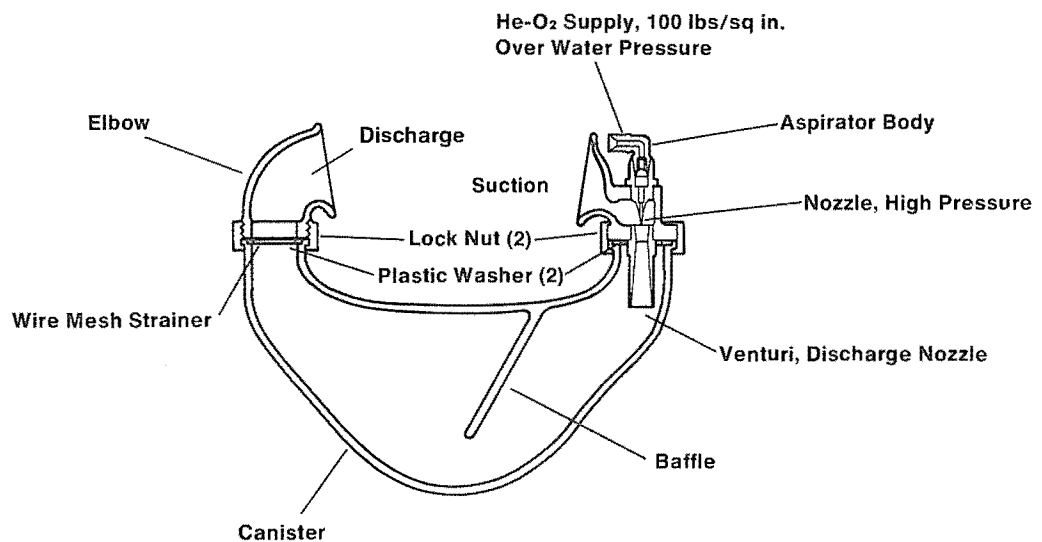


Figure 11-7 Canister assembly; sectional view

THE DIVING DRESS GROUP 11.1.1.2 The diving dress used in mixed-gas diving is virtually identical to that used in air diving. The only basic difference is in the shoes which are special 40-pound models. Diving gloves are always worn to guard against gas leakage.

THE HOSE GROUP 11.1.1.3 The basic hose group is essentially identical to that used in air diving. The primary difference is that a special adapter is fitted to the air control valve to permit attachment of the Hoke valve and special length of hose leading to the aspirator.

Lightweight Mixed-Gas Diving Outfit (MK 1) 11.1.2

There are two approved lightweight diving masks in use in the U. S. Navy—the standard (or “Jack Browne”) and the Diver’s Mask USN MK 1. The standard model is used for air diving only. The MK 1 is an improved version of the standard mask which permits two-way diver communications and operation in a demand mode and has also been adapted for use in mixed-gas operations.



Figure 11-8 Diver dressed in lightweight mixed-gas diving outfit

The principal difference between the air and mixed-gas versions of the MK 1 is in the size of the side valve orifice—a larger orifice is installed for mixed-gas use.

Employment of the lightweight outfit for mixed-gas diving offers the advantages (over the heavyweight outfit) of ease of operation, reduced weight, a higher degree of mobility and flexibility, and economy. General disadvantages (for some types of operations) are that it lacks the stability and diver protection offered by the heavyweight outfit. The surface-supplied lightweight outfit may only be used for mixed-gas diving when employed with an open bell. The bell provides a local habitat and backup facilities which significantly add to diver safety. Because of the additional protection afforded the diver during in-water decompression, the lightweight/open bell mode of diving may be conducted to depths of 300 feet.

The basic components of the **lightweight outfit** are—

Mask Group—which includes all valving, and the emergency gas supply cylinder.

Diving Dress Group—which includes the diving dress (standard UNISUIT, optional wet suit or optional hot water suit) and gloves, shoes or fins, chaffing pants, and knife.

Hose Group—which includes the gas hose and fittings, lifeline, communications cable, and pneumofathometer.

Open Bell—which includes the umbilical to the bell, manifolds and communications system.

With the exception of the modified MK 1 mask and open bell, these items of equipment may be identical with those used for lightweight air diving and are described in detail in Chapter Six, Volume I. For convenience a brief description and review of operating procedures is presented in the following pages.

DIVER'S MASK USN MK 1 11.1.2.1 The mask is built around a molded fiberglass frame upon which is mounted a rubber face seal, a head harness and a faceplate made of 1/4" acrylic plastic. A moveable nose pad on the interior of the mask can be used by the diver as an aid in equalizing the pressure in his ears and sinuses. A communications connector provides a watertight electrical path through the mask for



Figure 11-9 Prototype diver's mask USN MK 1 (shown without bail-out bottle connected).

the connection between the communications cable to the bell and a microphone/earphone assembly worn by the diver.

The other components of the mask group, all of which are involved in the supply of breathing gas, are—

- the **side valve assembly** which controls the flow of gas into the mask in either a free-flow mode or through the demand regulator. A nonreturn valve is installed as part of the side valve assembly.
- the **demand regulator** is a second stage demand regulator modified from a standard SCUBA regulator which permits the flow of gas into the mask to be controlled by the diver's breathing rate. Through the use of a manual purge button, the diver can also select a free-flow of gas through the regulator.
- an **emergency gas supply** fitting permits the attachment and use of a 72 cu. ft. back-up supply cylinder of breathing gas for use in emergency situations when the normal supply is lost.
- the **main exhaust assembly**, located under the demand regulator, also serves as a purge valve to remove water from the mask.
- a special **oral-nasal mask unit** is mounted inside the main body of the mask and fits over the diver's nose and mouth. The oral-nasal unit reduces the respiratory dead space to which the diver is exposed. This feature reduces the possibility of carbon dioxide buildup and minimizes the need for manual ventilation of the mask.

The diver can choose between two modes of mask operation and between two sources of breathing gas. With the side valve open the gas will free flow into the side of the mask and through a check valve into the

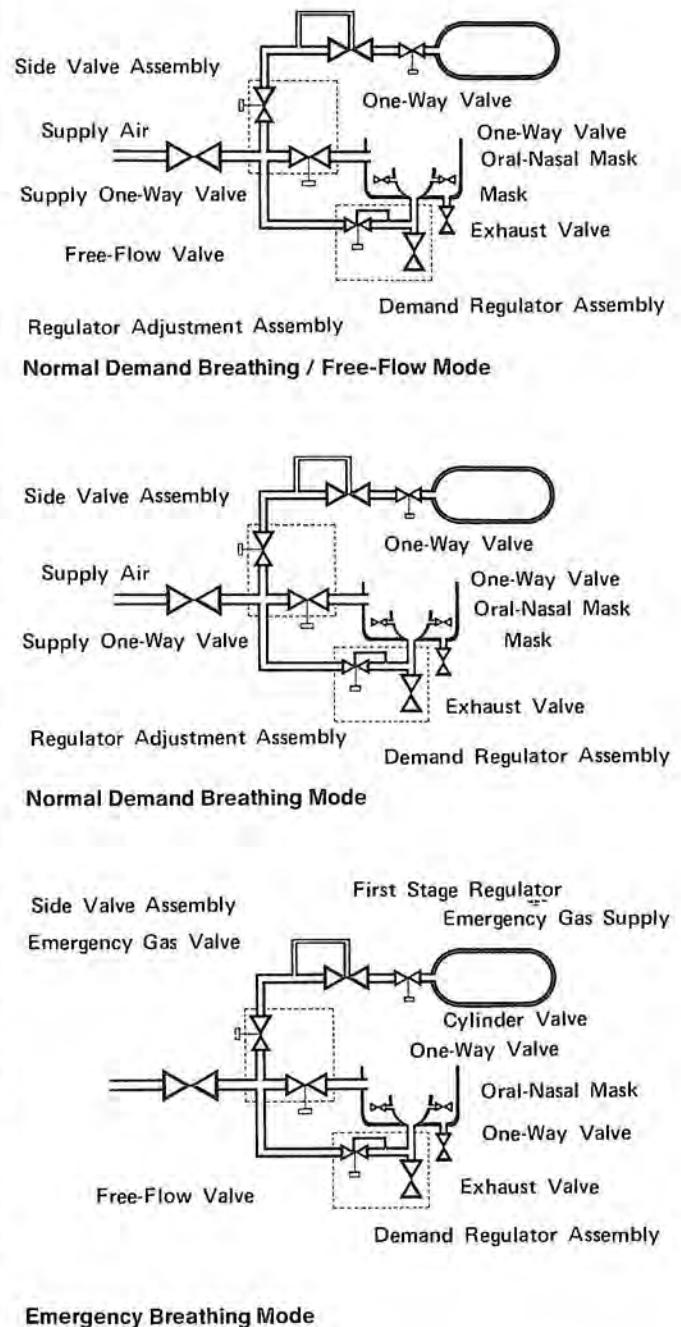


Figure 11-10 Flow schematic, Diver's Mask USN MK 1

oral-nasal mask. The diver's exhaled breath will pass out through the regulator (which, as in a SCUBA, also functions as an exhaust valve). The excess incoming gas will pass out through the main exhaust valve. With the side valve closed the breathing gas will be directed through the demand regulator. This is the normal mode of operation for mixed-gas diving.

An emergency "bail-out" bottle must be worn on all mixed-gas dives employing lightweight equipment. This is a single 72 cubic foot SCUBA cylinder and first stage regulator attached to a vest. Pockets on the front of the vest enclose weights as required for buoyancy control.

In an emergency, such as a loss of surface-supplied gas to the bell, the diver can switch to the "bail-out" bottle by turning the emergency selector knob 1/4 turn clockwise. Mixed gas from the first stage regulator on the 72 cubic foot cylinder will pass directly into the side valve assembly. The emergency gas may be used in a free-flow or demand-breathing mode by changing the position of the side valve knob as in normal operation.

OPEN BELL 11.1.2.2 The open bell (also referred to as a "roving" or "pickup" bell) acts as a diving stage, simple habitat, and supply point for the mixed-gas diver using lightweight equipment. Its concept is analogous to that of the early diving bells which provided a "captured bubble" of air for skin divers, but in modern form the open bell provides numerous features unimagined by the early pioneers in diving.

A typical bell, as shown in Fig. No. 11-11, resembles a conventional steel diving stage 7 feet high and 4 feet in diameter. The upper 2 1/2 feet of the bell is enclosed in sheet metal to provide an open bottom, gas-tight compartment. The upper structure normally contains four circular viewing ports which permit the diver(s) to observe the surrounding area during transit and while on the ocean floor. A lift wire and umbilical line connect the bell with the surface. The umbilical provides breathing gas, hardwire communications, depth measurement (pneumofathometer) and hot water for suit heating (if required) to outlets within the bell to which the individual diver's lines and hoses are connected (see Fig. No. 11-12).



Figure 11-11 Typical open bell used in lightweight mixed-gas diving operations.

In operation the bell is deployed from the surface ship with from one to three divers aboard. They ride the bell in a vertical position with their head and shoulders inside the upper compartment. During descent the divers, who wear full lightweight diving equipment connected to the utility outlets, maintain a continuous flow of mixed gas into the compartment to balance the increasing water pressure. Upon arrival at the bottom one or two divers slip out from under the bottom skirt of the compartment and swim to the worksite while trailing their diving umbilicals from the bell.

Upon completion of their work the divers return to the bell and stow the excess length of their umbilicals aboard. The topside crew is advised to initiate ascent, and the bell is returned to the surface following the prescribed staged decompression procedure dictated by depth, gas mixture and bottom time.

The open bell provides several advantages which enhance diver safety and permit the use of lightweight diving techniques for deep, mixed-gas, surface-supplied diving. Advantages include—

- **Simple Deployment**—Virtually any naval ship that has suitable equipment to support mixed-gas diving can be used as a surface platform. The need for a large deck area, heavy lift capability, and an extensive topside crew associated with DDS-type operations is eliminated. If the ship can support conventional surface-supplied recirculating He-O₂ helmet diving, it can provide suitable facilities to support lightweight-equipped mixed-gas divers.
- **Diver Mobility**—The lightweight mode of mixed-gas diving permits maximum diver mobility in horizontal and vertical attitudes as previously discussed.

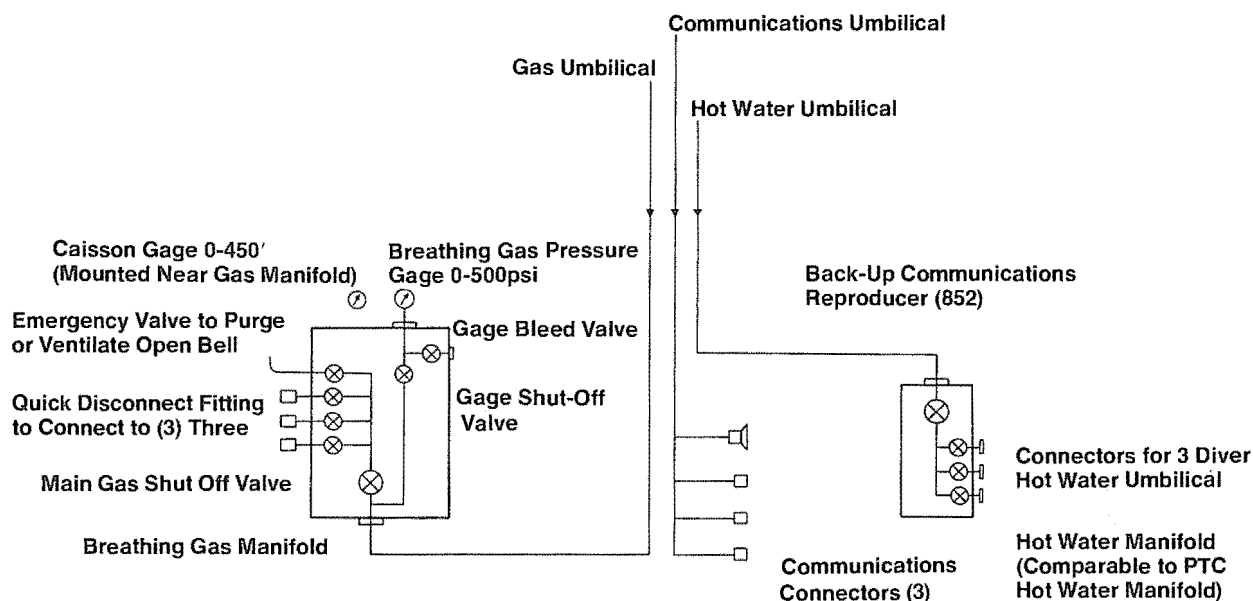


Figure 11-12 Piping and wiring schematic for the Open Bell

- **Minimum Hose Drag** — Drag forces on the umbilical due to currents and sea conditions affecting the surface ship are not transmitted to the diver. The only drag forces directly affecting the diver are those associated with potential bottom currents which act on his short umbilical to the bell.
- **Refuge and Comfort** — In the event of equipment malfunction or injury, the diver is never more than the short distance of his umbilical from the safety of a breathable atmosphere. The dry environment surrounding his head and shoulders also provides the diver a measure of comfort during the decompression phase of the dive.
- **Alternate Communications** — In the event of a malfunction of the communications set within the MK 1 mask, the diver may remove the mask within the compartment and communicate with the surface via the reproducer in the bell.
- **Auxiliary Equipment** — The open bell provides a light weight platform convenient to the worksite for

storage of tools, lights and other equipment required to conduct various tasks.

- **Emergency Gas Supply** — A spare mask is installed in the bell for emergency backup of the diver's primary mixed-gas supply.

Accessory Equipment for Mixed-Gas Diving 11.1.3

For the most part, the accessory equipment used in deep-sea and lightweight air diving operations is appropriate for use in comparable mixed-gas operations. Environmental factors (such as the colder waters normally encountered in deep diving and the additional temperature problems caused by the high thermal conductivity of helium mixtures) will frequently determine the specific choice of accessory equipment. Additionally, because mixed-gas operations are more complex and require greater levels of surface support, the types and quantities of accessory equipment required must be carefully considered during the planning phase of the operation.



Figure 11-13 Hot water suit

HOT WATER SUIT 11.1.3.1 Surface-supplied, mixed-gas diving employing lightweight equipment often requires that supplementary heat be supplied to the diver. Cold water diving and protracted in-water decompression from deep and/or long bottom time exposures causes a loss of more heat to the surrounding water than the body can generate. Reduction in body temperature and associated chilling effects can occur even with the improved passive insulating characteristics of the Unisuit. In order to compensate for heat loss in demanding circumstances, a hot water suit is used.

The suit, shown in Fig. No. 11-13, consists of a nylon lined cellular neoprene wet suit to which has been added perforated hoses along the limbs, chest, and backbone areas. Hot water, supplied by hose from the surface, enters the suit through a control manifold at the diver's waist. Valves in the manifold permit control of the total water flow to the diver and, if desired, the split between front and back flow to suit the comfort needs of the diver. The water is discharged in the areas of greatest thermal need and then flows within the suit to provide a balanced temperature. The water discharges around the gloves and face and partially through the zippers. This type of thermal protection eliminates the problems associated with local hot spots and broken electrodes found with electrically heated suits.

For surface-supplied diving, hot water is normally generated by a diesel oil-fired boiler (Fig. No. 11-15) on the support ship. Seawater is provided to the hot water generator by a self-contained pump. As it passes through the boiler it is heated to 140°F to 180°F, depending upon the generator model and thermal demand of the divers, and pumped through spe-

cial thick-walled (0.5 in ID or 0.75 in ID) hoses to the divers.

The heat lost in the transport of water through the hose is influenced by numerous factors including composition of the hose material, rate of flow, and the temperature and circulation characteristics of the seawater surrounding the hose. Fig. No. 11-16 provides charts which permit estimation of the required discharge temperature (hose inlet) from the hot water generator under various flow and hose length conditions to deliver 100°F water to a diver submerged in relatively still 43°F seawater.

The boiler systems are available in several models to simultaneously support from 2 to 6 divers. The latest types of diving ships, such as the ASR 21-class, are equipped with steam-seawater heat exchangers of sufficient capacity to meet the hot water requirements of divers without the need for boilers.

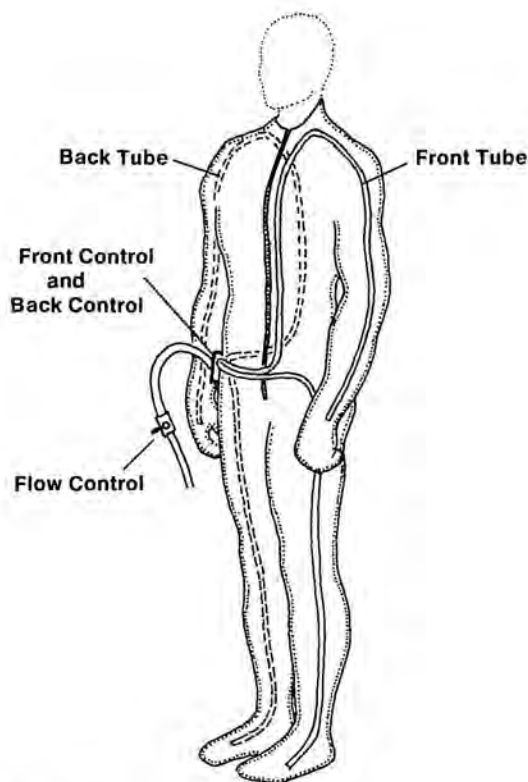


Figure 11-14 Flow schematic, hot water suit



Figure 11-15 Clayton Boiler

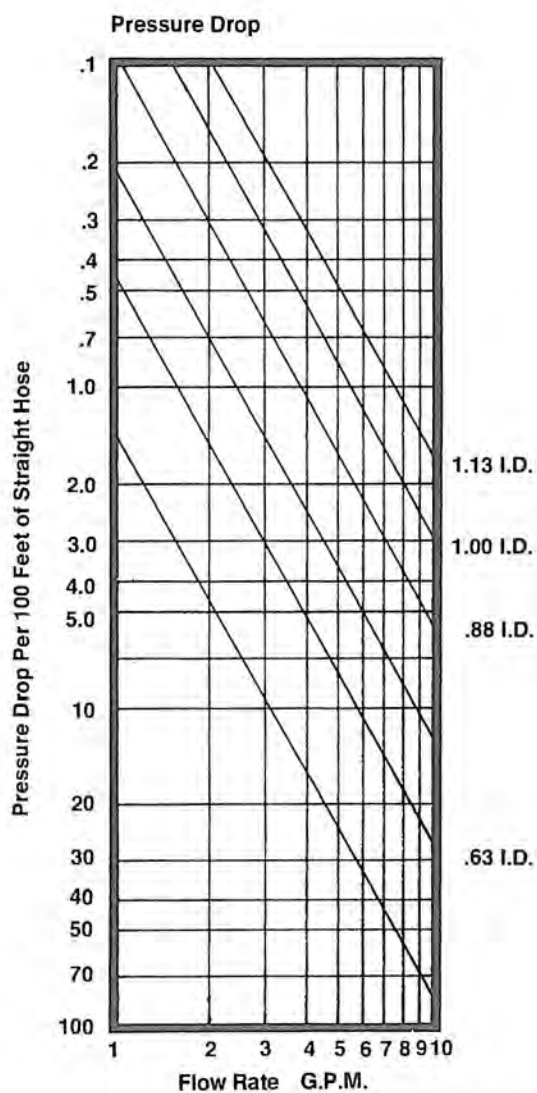
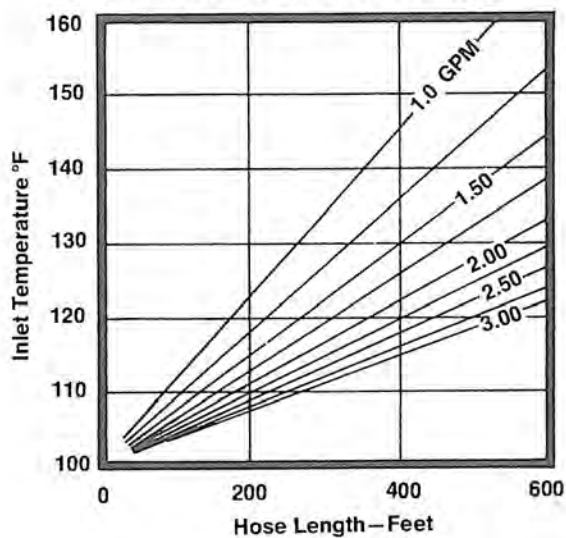
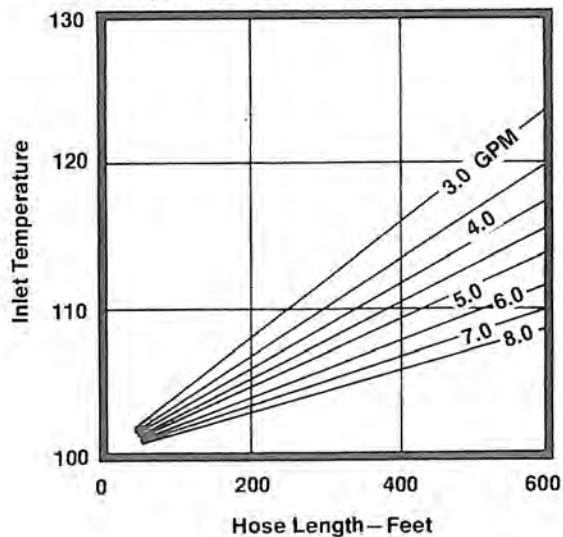


Figure 11-16 Performance curves showing required hot water surface temperature to supply 100°F water to diver in 43°F water

Inlet vs. Outlet Temperature
Unlimited Hot Water Hose 1.25 x .50 I.D.



Inlet vs. Outlet Temperature
Unlimited Hot Water Hose 1.63 x .75 I.D.



MAINTENANCE TOOLS AND SPARE PARTS 11.1.3.2

Although the majority of mixed-gas diving equipment, like that used in air diving, can be serviced and maintained with commonly available handtools, the He-O₂ deep-sea outfit requires special tools. These tools must be available at the operations site and include such items as special wrenches for the secondary exhaust valve on the hard hat and No. 72 drill-sized rods (or drills) for checking the aspirator nozzle. Spare parts such as spare washers and 100-mesh screens for the aspirator and canister must also be available. A list of such items is contained in Table No. 11-1.

Communications 11.1.4 For surface-supplied mixed-gas diving, there are two available means of

communication between the diver and the surface. These are standard line-pull signals (augmented with two unique mixed-gas signals as described in Section 11.3.1.3) and/or voice communications established through one of the regular diving inter-communications systems.

These systems are—

- Model 1 used with the heavyweight outfit.
- Model 2 used with either the heavyweight outfit or the MK 1 mask.
- Mini-communicator used with the MK 1 mask.

A description of these units and a discussion of correct operating procedures will be found in Section 6.3, Volume I of this Manual.

TABLE 11-1 — MIXED-GAS EQUIPMENT TOOLS, MAINTENANCE ITEMS AND SPARE PARTS

COMPONENT	QUANTITY	COMPONENT	QUANTITY
Tools		Spare Parts (cont.)	
Box, tool and spare parts	2	Gasket, secondary exhaust valve	3
Die, rethreading ½ in.-12	2	Glass, helmet, face window	6
Die, rethreading 1 ½ in.-17	2	Glass, helmet, side window	6
Tap, rethreading ½ in.-12 N	2	Glass, helmet, top window	6
Tap, rethreading 1 ½ in.-17 NS	2	Light bulb 1,000 watt	6
Wrench, nonreturn valve	4	Nozzle, discharge, venturi	3
Wrench, open end, gas hose	6	Nozzle, high pressure	3
Wrench, open end, amplifier & lifeline coupling	6	Nut, wing, breastplate (large)	15
Wrench, spanner, diving cable	6	Nut, wing, breastplate (small)	30
Wrench, T-slot, helmet	6	Screw, machine, brass 8-32 NC x ¾ in., gross	1
Maintenance Items		Screws, rubber valves	6
Cement, rubber, quarts	12	Springs, exhaust valve, pair	12
Cloth, patching diver's dress, yards	4	Stud, breastplate (long)	6
Halyard, single, cord, cotton, feet	20	Stud, breastplate (short)	18
Packing, air control, flax, feet	100	Valve, exhaust, secondary	1
Sealing compound, beeswax, pounds	10	Valve, Hoke	5
Tubing, elastic, yards	20	Valve, rubber	6
Spare Parts		Washer, amplifier	50
Drill, No. 72	3	Washer, copper, for breastplate straps	50
Gasket, faceplate	6	Washer, nonreturn valve seat	20
Gasket, helmet, leather	10	Vice, pin, No. 72 drill	1

Communications in mixed-gas diving are usually more difficult than in air diving for two reasons—

- If the dive is at great depth, line-pull signals are likely to be dampened out by the length and catenary of the hose and lifeline cable. This puts an extra burden on the tender to keep slack to a minimum.
- In the helium-oxygen medium, the diver's voice loses clarity (the "Donald Duck" effect previously described). This happens so quickly, in fact, that the voice change is an excellent and reliable means for verifying changes in the breathing mixture when shifting between helium-oxygen and air or oxygen. With practice and care, both the diver and the tender can learn to overcome much of the difficulty in speaking and understanding. Care must also be taken to keep external factors—such as background machinery noise—to a minimum.

HELLE VOICE UNSCRAMBLER 11.1.4.1 For operating situations in which minimum voice distortion must be achieved, the Helle unscrambler communications system may be used (Fig. No. 11-17). This specially designed intercommunications unit incorporates electronic circuitry which removes the majority of voice distortion associated with helium-oxygen diving.

The Helle unscrambler is similar in function to the Model 1 diving intercommunications set. However, it has an additional control knob (graduated from 0 to 1,000) on the right front of the panel. This is adjusted by the tender to achieve minimum voice distortion. The unit employs two wires to each diver to permit three-way conversation between the surface and two divers. A built-in speaker-microphone is used for tender voice transmission and monitoring of diver conversations. A reproducer (speaker-microphone) in the diver's headgear is used for diver communications, and the Helle system will accommodate reproducers with impedances from 3 to 16 ohms.

Power is provided by an internal 12 volt lantern battery (25 hr. life), an external 12 VDC power source, or (in some models) an internal nickel-cadmium battery which can be recharged from a 120 VAC, 60 Hz source.

To operate the system, the tender volume control switch is turned to the ON position, and the diver's



Figure 11-17 Helle Helium-voice unscrambler

and tender's volume knobs are adjusted to the desired level. The operator must hold the "press-to-talk" lever down while talking and release it when listening. He may listen or talk to both divers simultaneously by turning the "divers' speakers switch" to the BOTH position. To talk to one diver alone, he selects the appropriate position for diver one or diver two. When one diver would like to talk to the other diver, he must tell the operator who then presses the appropriate cross-talk switch. These are momentary switches which must be alternately held down by the operator while the divers are conversing. The tender volume control knob controls the volume between the two divers when the cross-talk switches are being used. The operator can hear the complete conversation at all times, and he may interrupt at any time by using the "press-to-talk" lever.

MIXED-GAS SUPPLY 11.2

The basic mixed-gas supply system (rack), as installed on ASR-type vessels, was described in Chapter Nine. Units may vary in design and some details from one installation to another, but each serves the same purpose: to provide the diver with appropriate breathing media (including mixed gas, air and oxygen) as needed during the dive and decompression profile. Operation of the gas rack requires special training. Under no circumstances should inexperienced personnel be allowed to operate the rack during preparation for, or execution of, a dive.

Specific sequential details for operation of the gas rack to supply the diver(s) will be found in Appendix II F, Surface-Supplied Mixed-Gas Diving Checklist, and the diving procedures which follow this section. Appendix II A, Diving Gases, provides necessary data on purity standards, mixing procedures and gas analysis and Appendix II C discusses safety precautions

which should be thoroughly understood by all diving personnel engaged in mixed-gas operations. Prior to commencement of operations, however, the following general items should be verified—

Alternate Supplies—Two independent mixed-gas supplies of an appropriate mixture for the dive to be undertaken should be available at the diving station for immediate switchover in the event of failure of one supply.

Other Gases—Breathing air for emergency use during the dive (Chapter Fourteen) and oxygen for use during decompression should be available at the diving station and supplied to the manifold in such a manner as to permit immediate transfer of the diver to the alternate breathing medium.

Gas Quantity—Sufficient mixed gas must be stored in the primary supply to—

- A. satisfy the apparatus demand of the working diver throughout the bottom and decompression phases of the dive,
- B. support the standby diver in an emergency,
- C. provide a reasonable contingency.

The alternate supply must be capable of supporting a diver and standby diver during the total decompression phase of the dive. Additional gas must also be available to supply breathing and ventilation requirements in the recompression chamber for treatment of decompression sickness.

Oxygen Percentage—The oxygen content of the mixed gas must be carefully selected and specified for the depth and bottom time of the dives to be undertaken. Oxygen percentage must be within normal tolerance limits to preclude the hazard of oxygen poisoning (Chapter Fourteen). Whether procured as specific mixes from the supply system or mixed by diving personnel, all cylinders of mixed gas must be analyzed for O₂ content prior to use (Appendix II A).

DIVING PROCEDURES 11.3

Thorough planning and careful preparation is vital in all diving; however, surface-supplied mixed-gas operations, because of their increased complexity and hazards, additionally require absolute adherence to prescribed standards and procedures. Each person involved in the operation must be well trained, and

his experience should be augmented by frequent exercises and emergency drills.

The comprehensive checklist presented in Appendix II F should be used as a basis for preparation of a similar operational checklist which is specifically suited to local conditions or unit mission parameters.

Prior to initiation of diver dressing activities, whether deep-sea or lightweight gear is to be used, the Diving Supervisor must—

1. Ensure that all equipment has been inspected and laid out including back-up and accessory gear.
2. Verify that the gas supply is correct in all respects including composition, supply pressure and flow. The primary and secondary gas supply and the standby air supply must be activated as follows:
 - A. Connect hoses to the appropriate manifolds and control stations with oil separators installed at all hose connections.
 - B. Start the compressors for the standby air supply, charge the air supply volume tank, and set the system to operate at a pressure 100 psig over the maximum operating depth pressure for the scheduled dive.
 - C. Select and tag the primary and secondary oxygen banks. Charge the oxygen volume tank to 125 psig. Gage and record the pressure on both banks.
 - D. Select and tag the primary and secondary He-O₂ banks. Verify the proper gas percentage in both banks; check and record the pressures.
 - E. Activate the mixed-gas control rack. Check percentages and pressures. Charge the He-O₂ volume tank to 54 psig for deep-sea diving; 100 psig for lightweight diving. This is the pressure at which the divers will initially be fed the gas mixture.

Deep-Sea He-O₂ Diving 11.3.1 Since the deep-sea He-O₂ outfit is virtually the same as the standard deep-sea outfit, many of the operating procedures are quite similar. Two dressing stations, with teams of experienced tenders, are required. Two divers should always be dressed. In contrast with air diving, both

the primary and standby divers must be completely dressed including helmet installation. Since the He-O₂ helmet cannot be installed on the breastplate with the canister attached, time delay associated with proper helmet and canister placement is too long for standby safety. Consequently, the standby diver must wear the helmet with the faceplate open and be ventilated with compressed air while on deck.

CANISTER FILLING 11.3.1.1 The helmet canisters should be properly filled and be ready for installation prior to dressing the divers. The correct procedure for filling a canister is as follows—

- 1 Place the empty canister in the special filling rack.
- 2 Wash the interior of the canister with hot fresh water, paying particular attention to the canister unions, and blow dry with oil-free compressed air. Water and air hoses for this purpose should be rigged to the diving station.
- 3 Select a container of fresh Granular Baralyme and wipe the exterior thoroughly to remove any dirt or grease before opening the container.
- 4 Pour the Baralyme directly from the container into the canister, filling the canister from both sides. A light flow of air blown over the Baralyme as it is being poured will help keep some of the Baralyme dust out of the canister.
- 5 **DO NOT USE THE LAST TWO INCHES OF BARALYME IN THE CONTAINER** as any dust will have settled to the bottom.
- 6 Fill the left side of the canister level with the screen rim.
- 7 Fill the right (Venturi) side to within 3 inches of the canister rim.
- 8 Tap the canister gently on deck. **DO NOT SHAKE OR POUND THE CANISTER.** A properly filled canister should hold approximately 6 pounds of Baralyme.

DRESSING THE DIVER 11.3.1.2 The Diving Supervisor should ensure that only trained personnel will assist in dressing the divers. Inexperienced personnel, however well-meaning, can hamper the dressing procedure and possibly cause injury to the diver. Dressing procedures for He-O₂ deep-sea diving are illustrated in Figure No. 11-18.



A The helmet, suspended by a small block and tackle, is carefully lowered over the diver's head.



B While one tender firmly holds the breastplate the other turns the helmet until it is securely mated to the breastplate.



C The dumbbell safety lock is turned down into the breastplate recess and secured by the latch and cotter pin.

Note: Test the communications system.

Figure 11-18 Fully dressed except for helmet, the special mixed-gas dressing sequence begins:



D The life-line/communications cable and diving hose are positioned and secured; the control valve assembly is mated with the Hoke valve adapter. The pneumofathometer is positioned with the discharge at waist level.



F A Koroseal or neoprene washer is placed in the right-hand canister nut and a 20 mesh screen (flush side up) and Koroseal or neoprene washer placed in the left hand nut.



G The canister is positioned and the canister nuts are nano tightened. Using special wrenches, the tenders evenly and firmly tighten the nuts.



E The recirculating device is set into the right-hand canister gooseneck and screwed down hand tight.



H Fully dressed diver ready for pre-dive check procedures.
Note: The Diving Supervisor should verify that the canister is properly installed and check all other connections. When satisfied, he calls for "gas on diver" and the Rack Operator sends He-O₂ to the diver at the pre-set pressure of 54 psig.



I A tender puts his hand inside the helmet to deflect the initial gas flow and the Hoke valve is fully opened to blow baralyme dust out of the canister.

Note: When the gas passing through the canister remains clean, the faceplate is closed and the diver breathes deeply for a few seconds. The faceplate is opened, and the diver counts out loud. If his voice exhibits the "Donald Duck" effect, this verifies that he is receiving He-O₂.



J Faceplate closed, the diver is pressurized using the main control valve until the secondary exhaust valve just lifts. Close the control valve.

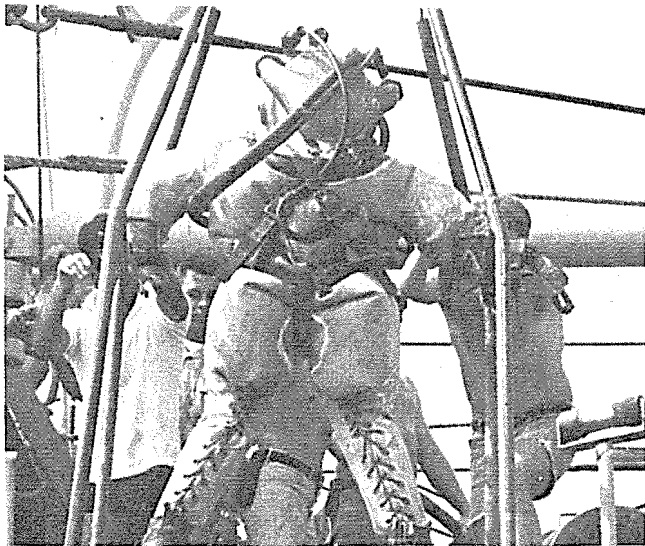


K Tenders soap all suit connections and seams from top to bottom of the diver to detect any leaks.

Note: The diver should personally check the setting and operation of all valves and should fully ventilate. When satisfied that his equipment is operating properly he signals his readiness for the dive to the tenders by both the communications system and hand signal.



L The tenders make a final check of the equipment and pat the top of the helmet.



M Assisted by tenders, the diver moves onto the diving stage and is ready to be lowered into the water.

IN-WATER PROCEDURES 11.3.1.3 The basic in-water procedures used in hard-hat diving with air are also followed in mixed-gas diving. As previously discussed, environmental factors are likely to be more pronounced, and the diver must be prepared—both physically and psychologically—to cope with these factors.

The basic difference in underwater procedures between air and He-O₂ deep-sea diving is that the diver may elect to receive his breathing mixture on “open-circuit,” as with the standard outfit, or he may use the recirculating system to conserve the gas supply. The latter is the normal mode of operation of He-O₂ diving, but in order to ensure adequate ventilation in the diving dress, the diver must change modes from time to time. Two special hand signals have been established by which the diver can be directed to switch, and by which he can inform topside personnel of his status in the event of a failure of phone communications. These signals are—

3 and 2 pulls: “Ventilate” or “Go on open circuit.”

4 and 3 pulls: “Circulate.”

Gas Flow Control

To ventilate, the diver opens his control valve about one-quarter turn and holds the chin valve open. He should ventilate whenever directed to do so, whenever he is not satisfied with the efficiency of the recirculating system, and whenever he wants to completely flush out and renew the atmosphere in the diving dress. When performing heavy work, the diver should ventilate at regular intervals to compensate for his increased production of carbon dioxide and to ensure that he will receive ample quantities of oxygen to support his level of effort. Ventilation is also used to facilitate the change-over from mixed gas to oxygen during decompression.

To circulate, the diver closes his control valve and releases the chin button. The breathing mixture will

then pass through the Hoke valve, and the recirculating system will be in operation.

To “go on open-circuit,” the diver opens the control valve and the exhaust valve and closes the Hoke valve. Open-circuit operation must be used if the recirculating system fails either through some malfunction or by hose failure. The best immediate indication that the diver will have of such a problem is from the change in sound of the gas passing through the aspirator jet. When on open-circuit, the supply system will function in the same manner as that of the standard deep-sea air outfit.

Descent

The diver is lowered into the water, and, with the order “COME TO 100 OVER,” the gas supply pressure is brought to 100 psig over his present depth pressure. A final check is made for leaks and for proper functioning of the valves.

During decent the diver uses his control valve to keep the dress properly inflated. At the same time, the Rack Operator “leads” the descent by keeping the supply pressure 10 feet greater than the 100 psig over the diver’s depth as a precaution against a too rapid descent.

On The Bottom

Upon reaching bottom, the diver thoroughly ventilates his dress and closes the control valve thus allowing the recirculating system to handle his supply requirements. Buoyancy will normally be controlled through the use of the chin button. The diver can open the control valve if he needs a more rapid inflation of his dress, as when moving over obstacles. The gas supply should be maintained at a constant over-bottom pressure of 100 psig.

In air diving, a fogged faceplate is considered a danger sign of potentially inadequate ventilation and associated carbon dioxide buildup in the helmet. With the recirculating helmet using mixed gas, however, the situation is reversed. Water is a natural by-product of the Baralyme/carbon dioxide chemical reaction, and some fogging of the faceplate can be taken as an indication that the system is working properly. However, if the diver notices a milky-white spray or liquid in the helmet, he must go on open-circuit and abort

the dive. This is an indication of water leaking into the recirculating system and wet Baralyme.

Ascent

Preparations for ascent are the same as for air operations. Particular care must be exercised in the choice of decompression tables. The time of ascent to the first stop, time at the stops, and the depth of the first oxygen stop are all specified in the helium-oxygen partial pressure tables. An ascent rate of 60 feet per minute should be used between stops.

The gas supply pressure should be maintained at 100 psig over ambient pressure until the first oxygen stop is reached. This stop will occur at either 40 or 50 feet depending upon the decompression schedule in use. At this stop, the gas supply is shifted to oxygen and the diver is ventilated with 25 standard cubic feet of oxygen. This measurement is readily determined by monitoring the pressure drop at the oxygen bank. A quantity of 25 scf equals a 225 psig drop from one standard oxygen bottle, a 112.5 psig drop from two bottles, a 75 psig drop from three bottles, etc. During this ventilation, the pressure at the oxygen volume tank should be maintained at 125 psig. Following ventilation, the pressure should be maintained at 75 psig throughout the remainder of decompression to the surface.

A more comprehensive discussion of decompression procedures—including those cases in which the diver must be decompressed using air or using He-O₂ throughout—is contained in Chapter Fourteen.

When the diver reaches the surface, the supply is immediately shifted to air and the hose is flushed out for at least one minute. In the meantime, the diver is helped to the dressing bench. The faceplate is opened, the canister removed, the lines and hoses along with the control valve are unfastened from the breastplate, and the helmet is removed.

Lightweight He-O₂ Diving 11.3.2 Surface-supplied mixed-gas diving using lightweight gear may only be conducted with an open bell. Dressing and underwater procedures for using the Diver's Mask USN MK 1 for mixed gas diving are essentially the same as those for lightweight air diving discussed in Chapter Six of Volume I. Primary differences in tech-

nique are found in the more common usage of hot water suits and rigging and deploying the bell. A fully outfitted deep-sea diver should be used as a safety standby for lightweight mixed-gas operations.

RIGGING AND CHECKING THE BELL 11.3.2.1

The open bell has an unballasted weight of approximately 1,700 pounds and a water displacement of 2,350 pounds (37 cu. ft.). It must be deployed in a negative mode which requires the addition of approximately 1,000 pounds of ballast weight to the lower part of the bell to achieve a 350 pound negative buoyancy. A greater quantity of ballast may be required in heavy seas to speed entry through the air-water interface. Under minimum ballast conditions, the lifting load imposed upon the boom, crane, or davit used for deployment will be approximately 3,350 pounds with three divers aboard the bell. The capacity of the lifting system and wire size must be verified to insure that they are adequate for the static and dynamic loads which may be imposed during deployment in heavy seas. Lifting speed must be a minimum of 60 feet/minute. Following confirmation of the characteristics of the lift system, the bell is moved to its deployment position and the following procedure is employed—

- 1 Shackle the bell to the lift wire using a 4-point bridle to the lifting points on the bell. Safety wire all shackle pins.
- 2 Coil the bell umbilical on deck with bell-end coils up, utility ends down.
- 3 Connect the bell-end of the umbilical to matching hot water, gas, communications, and pneumofathometer fittings on the bell. Connect the utility-end of the umbilical to the hot water generator, supply gas manifold, intercommunications set, and pneumofathometer readout.
- 4 Connect the diver's umbilicals (usually consisting of a 50 foot length of communications cable, gas hose, hot water hose and pneumofathometer hose seized at 18-inch intervals with marlin) to the appropriate bell connections.
- 5 Coil and stow the umbilicals on the bell.
- 6 Activate the utility supplies and check each diver umbilical. Connect a spare MK 1 mask and check

the gas flow, O₂ percentage and communications of each supply. Perform a communications check of the reproducer in the bell. If applicable, open each hot water connection to check for adequate flow.

- 7 Install the emergency umbilical and mask and check the operation of its gas supply and communication system.
- 8 Lift the bell and return it to the deck to insure proper functioning of the lifting system.
- 9 Insure that additional tools and equipment which are to be carried on the bell to the job site are aboard and thoroughly secured.

DRESSING DIVERS AND DEPLOYING THE BELL

11.3.2.2 Only the MK 1 mask is to be used for light-weight mixed-gas diving. Water temperature and in-water exposure time will govern the choice of exposure suit. In general, if the water temperature is below 50°F or if the dive duration will exceed two hours, a hot water suit should be worn. These zip-front suits are generally supplied in medium size which fit 85% of all diving personnel; other sizes must be specially ordered. A diver-carried emergency gas supply (bail-out bottle) is required for all light-weight mixed-gas diving. The emergency supply is a standard 72 cubic foot SCUBA bottle equipped with a 1st stage SCUBA regulator attached by hose to the emergency connection on the MK 1 mask. The divers are dressed and deployed in the following sequence—

- 1 Charge the bail-out bottle to 2,250 psig with the mixed gas to be used during the dive. Analyze the bottle for O₂% after it has been filled.
- 2 Each diver dons his exposure suit and bail out bottle. Dressing procedures for the hot water suit are discussed in Appendix 11E and for the Unisuit in Section 6.4.1 of Volume 1.
- 3 The divers board the bell, and MK 1 masks and hot water suits are connected to the umbilicals.
- 4 A final briefing of the divers is conducted.
- 5 Gas supply to the bell should be adjusted to 100 psig.
- 6 Individual mask supply valves are opened, masks are donned, and the umbilicals are secured to the harness D-ring at the divers' waist by a snap ring.

Diving gloves and swim fins or shoes are donned.

- 7 Gas flow in demand, free-flow and emergency modes as well as the voice communication circuit for each diver is checked for proper function.
- 8 The breathing gas pressure gage on the bell is checked.
- 9 After a final visual check of the equipment of all divers on the bell by the Diving Supervisor, the divers signal their readiness to dive and lifting of the bell is initiated.
- 10 During lifting and over-the-side deployment, the divers on the bell must grip the inside hand rail with both hands. All portions of their bodies and equipment must be within the structure of the bell to prevent possible injury should the bell impact with the ship during deployment.



Figure 11-19 An open bell being deployed over the side of the USNS FLORIKAN.

- 11 During descent, the rack operator maintains the gas pressure at 100 psig greater than the bell depth. Descent rate should be approximately 75 feet per minute. Tending personnel must smoothly deploy the bell umbilical over a bulwark roller to match the speed of descent of the bell.

- 12 While descending, the divers maintain a constant flow of mixed gas into the bell compartment with the manifold valve to offset the increasing water pressure. Gas is added at a rate which maintains the water level at the base of the compartment and allows a small amount to bubble past the lip.
- 13 During descent, if applicable, the divers open their individual hot water supply valves and adjust their waist valves for the desired comfort level.
- 14 Communications between divers and topside is continuously maintained during descent. Topside is advised to slow the descent as the bottom or worksite (if mid-depth) is approached. Approximately 10 feet above the final bell position, descent is ordered to be stopped. Any lateral positioning instructions are given, and the bell is slowly lowered to position.

ON THE BOTTOM 11.3.2.3 The bell can be used to support one to three divers depending upon the the job requirements. When two divers are used, each is normally a working diver. When three are used, two are working divers and the third remains aboard the bell and acts as a tender. When the final bell position is reached, the following procedure is used by the divers—

- 1 Recheck the gas flow and pressure, communications, and hot water supplies. If a third diver is not included in the operation, secure the valve providing gas to the bell compartment.
- 2 Have topside slacken the lift wire and bell umbilical (if bell is on the bottom) to prevent ship motion from affecting the bell.
- 3 Lay the umbilicals in loose coils on the floor of the bell to permit unrestricted deployment.
- 4 The working divers slip out from under the bell compartment and, trailing their umbilicals, swim to the worksite.

ASCENT 11.3.2.4 Upon completion of their tasks, the working divers return to the bell, and preparations are made for a stage decompression ascent as follows—

- 1 Securely stow all tools used on the job aboard the bell.

- 2 Bring the divers' umbilicals inboard and stow.
- 3 Advise topside to begin the ascent.
- 4 Topside personnel raise the bell to the first decompression stop as required by the schedule being used. Depth indication is read from the pneumofathometer and checked by the divers with the caisson gage on the bell.
- 5 The rack operator should reduce the gas supply pressure to maintain a 100 psig difference over the bell depth pressure.
- 6 Ascent continues following the prescribed schedule with a shift to oxygen during the final phase of decompression.
- 7 During ascent, tending personnel must coil the bell's umbilical on deck.
- 8 Since the bell is self-depressurizing (gas will escape under the lip of the compartment as it expands), no action is required by the divers aboard the bell unless it is necessary to use the gas space as a breathing source during an emergency. Whenever the gas in the compartment is to be used for continuous breathing (descent, on bottom, or ascent), the compartment must be ventilated with mixed gas to prevent CO₂ buildup. In this situation continuously ventilate with 2 cubic feet/min (measured at depth pressure) of mixed gas for each diver aboard the bell—even if only one is breathing from the gas space and the rest are using the MK 1 mask. (Procedures for calculating the flow of gas versus pressure drop of the gas supply are discussed in Section 8.4.3.4 of Volume 1 of this manual.)
- 9 As the surface is approached, the divers aboard the bell should once again insure that their bodies and equipment are inboard of the bell structure to prevent injury.
- 10 The bell is lifted onto the deck, the divers are debriefed, and the equipment is readied for future use.

POST DIVE PROCEDURES AND MAINTENANCE 11.4

As with any type of dive, the divers should be immediately de-briefed so that work progress can be as-

sessed and any necessary changes to the dive plan can be incorporated. Additionally, the physical condition of the divers should be monitored to ensure that no problems have developed—or are likely to develop. The divers must remain in the vicinity of the recompression chamber for at least 6 hours following a mixed-gas dive and should not leave the general vicinity of the diving unit for at least 24 hours. Under no circumstances should a diver make a trip in an airplane for the same period; and, if emergency evacuation of a diver by helicopter should become necessary, it should be conducted at the lowest possible altitude.

Maintenance and record-keeping procedures are the same for mixed-gas diving as for air diving; except that some additional records (e.g., gas usage log) are required. (Re Appendix I.B.)

Following completion of deep-sea mixed-gas diving, clean and inspect washers, nozzles and fittings associated with the helmet recirculating system. These items should always be washed with fresh water and stored in a clean, dry condition. Rubber valve diaphragms in the secondary exhaust valve should be dusted with talc if they are to be stored for any period of time. One final, but important, action is to thoroughly blow all hoses clear with fresh air to ensure that no residue or oxygen remains. ■

DEEP DIVING SYSTEMS

Although open, pressure-balanced diving bells have been in use for several centuries, it was not until 1928 that a bell appeared which was capable of retaining internal pressure when raised to the surface. In that year Sir Robert H. Davis, the British pioneer in diving equipment, designed the Davis Submersible Decompression Chamber (SDC). The vessel was conceived as a method of reducing the time a diver would be required to remain in the water during a lengthy decompression.

The Davis SDC consisted of a steel cylinder with two inward opening hatches, one on top and one on the bottom, capable of holding two men. In operation the surface-supplied diver was deployed over the side in the normal mode, and the bell was lowered with a tender inside to a depth of 60 feet with the lower hatch open. Surface-supplied air was used to ventilate the bell and to prevent flooding. The diver's deep decompression stops were taken in the water, and upon arrival at 60 feet he was assisted into the bell by the tender. 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. The diver and tender in the bell were subsequently decompressed within the safety and relative comfort of the bell.

The increased decompression times associated with mixed-gas diving and the need for added diver comfort resulted in the design of an improved bell system in 1931. Davis designed a three-compartment deck-decompression chamber (DDC) to which the SDC could be mechanically mated to permit transfer-under-pressure of the diver. The DDC provided additional space, a bunk, and food and clothing for the diver's comfort during the 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 the concept 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 experiment. Link used the SDC for both transportation of the diver to the sea floor and subsequent decompression on deck. In later ex-



Figure 12-1 Davis Submersible Decompression Chamber

periments a DDC was used for improved diver comfort. American diving had entered the era of the deep diving system (DDS), and from that time onward advances and application of the concept grew at a phenomenal rate in both military and commercial diving.

U. S. NAVY DEEP DIVING SYSTEMS 12.1

The U. S. Navy currently has three basic models of deep diving systems in operational use. They are—

Salvage Diving System—SDS 450

Deep Diving System—MK 1

Deep Diving System—MK 2

The U. S. Navy's first DDS, SDS-450, was placed in Fleet Service by Harbor Clearance Unit One in 1967 and was followed by improved versions designated DDS MK 1 in 1970 and DDS MK 2 in 1972. Experience with these systems and advances in diving technology have resulted in a continuous program of development, application, and improvement of Navy deep diving systems.

The basic concept and application of the DDS has changed very little since the time of Davis, although the equipment itself reflects the significant advances made in materials, instrumentation, and life support equipment during the subsequent period. Deep diving systems are used for both saturation and non-



Figure 12-2 Link's aluminum SDC

saturation diving, and may be used in both observation (1 atmosphere internal pressure) and pressurized modes of operation.

Although most SDC's today are still capable of being used for diver decompression without the use of a DDC, the vast majority of systems employ a multi-lock DDC and transfer the diver for greater comfort and safety. Some SDC's (now more properly referred to as "PTC's"—Personnel Transfer Capsules) used only in support of saturation diving have single inward opening hatches which require a pressurized mode of diving and cannot be used in a hydrostatic mode for observation. DDS used for non-saturation diving tend to be more compact and mechanically simpler than those associated with saturation diving. The long residence times associated with saturation diving necessitate systems which provide more space in the DDC, have more extensive life support equipment, and more complex instrumentation and controls.

Of the three current types of Navy systems, the SDS-450 is only employed for non-saturation and observation diving, whereas the DDS MK 1 and MK 2 can be used in all diving modes. The basic difference between the MK 1 and MK 2 is found in their deployment characteristics and capacity to support numbers of divers—the MK 1 is designed to be air transportable and to be used from ships of opportunity, while the larger MK 2 is designed for installation only on specially configured rescue and salvage ships and barges.



Figure 12-3 DDS MK 1 Personnel Transfer Capsule being deployed over the side of the USNS GEAR

General data on each USN system is contained in sections 12.6, 12.7 and 12.8 of this chapter. It should be noted that certain DDS models have been built with improvements not originally installed in the prototypes. As a consequence, for detailed information on a specific DDS the reader is directed to the respective operating manual for the model and modification number of the system.

APPLICATIONS OF DEEP DIVING SYSTEMS 12.2

Each of the three modes of PTC operations—hydrostatic observation, nonsaturation diving and saturation diving—has application in various types of missions. Often the modes are combined, such as initial use of the PTC as a hydrostat to study the work area and minimize bottom time in a subsequent non-saturation dive. The DDS is a versatile tool in diving, and application of this type of equipment is extensive. Typical uses include, but are not limited to, the following—

Hydrostatic Mode 12.2.1

1. Observation can be made of the placement or alignment of objects on the seafloor or parts of structures in the water column. This type of operation

often involves providing voice instructions to a top-side handling crew and has the advantage of permitting non-diving personnel to observe and direct the operation from the PTC.

2. The PTC can be used within the lateral limits of the handling system and the ship's mooring system to conduct bottom searches for lost objects.
3. In one-atmosphere comfort diving personnel can study a repair, salvage, or construction project and determine requirements for specialized tools or equipment necessitated by unexpected conditions without incurring a decompression obligation.
4. Scientific or technical visual observations can be made from the comfort and security of the PTC.

Non-Saturation Diving 12.2.2

1. Deep, short term (bottom times usually less than one hour) dives for limited repair, construction, or recovery projects requiring extensive decompression time can be conducted. This mode of operation limits the diver's in-water exposure to that of the actual excursion time from the bell and provides the safety and comfort of the PTC and DDC for the subsequent lengthy decompression and access for medical treatment. Without deep diving systems many dives routinely conducted today would be beyond the limits of human endurance if they were to be attempted with in-water decompression.
2. Short term dives conducted under particularly adverse environmental conditions can be conducted. The short length of the diver's umbilical results in minimum drag in high current situations for dives which are within surface-supplied diving depth but would otherwise be technically impossible.

Saturation Diving 12.2.3

1. Underwater projects which demand extensive bottom worktime (large construction, submarine rescue and salvage) are best conducted with a DDS used in the saturation mode. Multiple diving crews can be cycled between the easily provisioned and controlled DDC and the worksite to permit continuous diving operations. Operations may be readily discontinued and later resumed if adverse weather threatens the moorings of the surface platform. All

equipment necessary to conduct saturation operations is carried by the support ship and may be readied and deployed in minimum time.

2. Bottom habitats used for saturation diving (except those in depths shallower than 30 feet and those capable of maintaining bottom pressure when raised to the surface) require DDS equipment for transport and final decompression of the aquanauts.
3. Deep underwater projects which require moderate bottom work time or diver activities involving work at various depths are conducted in the saturation mode with excursion dives. The PTC and DDC are pressurized to a saturation depth up to 150 feet shallower than the deepest work site, and the divers make no-decompression excursion dives from the PTC. This procedure minimizes final decompression time.

Other Uses 12.2.4

1. The DDC portion of the DDS may be used in place of a recompression chamber for support of routine diving operations.
2. The DDC's of MK 2 systems may be used for decompression of submarine crews pressurized as a result of damage control procedures. Rescue of the crew from the sunken submarine is accomplished by a DSRV or McCann bell which is mated to the DDC with a special adapter for personnel transfer.

MAJOR COMPONENTS OF A DDS 12.3

The configuration and specific equipment which compose a deep diving system varies greatly with the primary type of mission for which it was designed. All modern systems, however, have similar major components, as shown in Figure No. 12-4, which perform analogous functions regardless of their actual complexity.

Personnel Transfer Capsule 12.3.1 Personnel transfer capsules (PTC's) are either spherical or cylindrical submersible steel pressure vessels equipped with a hatch opening in the bottom for the entrance and exit of the divers. Capacity generally varies from two to a maximum of four divers. Early PTC's occasionally consisted of two separate compartments to permit their use for diver decompression

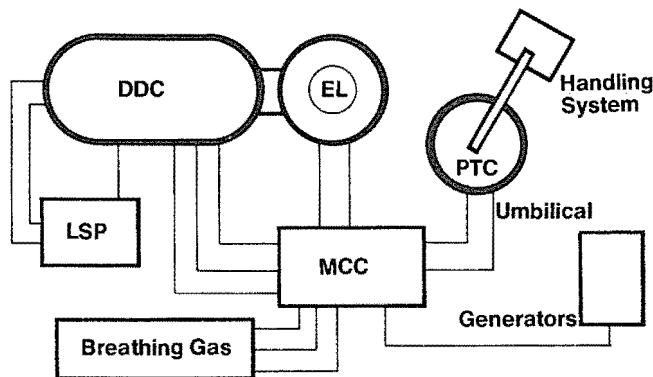


Figure 12-4 DDS major component arrangement

without a DDC or to allow a non-pressurized observer or tender to accompany the diver. In modern practice PTC's are single compartment capsules to reduce complexity and minimize weight for easier handling. They retain the control capability, however, to decompress the capsule occupants in the emergency circumstance of being unable to employ the DDC.

PTC's are designed to be inherently buoyant with all personnel and equipment aboard. When the intrinsic design of the pressure vessel will not permit positively buoyant operation, syntactic foam (a plastic matrix of pressure resistant glass spheres) attached to the PTC is used to achieve proper buoyancy characteristics. This safety feature permits buoyant ascent under emergency conditions and necessitates some form of ballast or downhaul mechanism to permit normal deployment to the seabed. The simplest systems employ jettisonable ballast which results in uncontrolled ascent in an emergency. Other systems use either a passive winch on the PTC (connected with a weight) which is used for controlled emergency ascent or, in the most advanced equipment, a submersible electric winch on the PTC which is used in normal operations for positive downhaul and ascent against a weight in addition to emergency ascent.

All PTC's carry emergency supplies of mixed gas and oxygen in pressure vessels mounted on the outside of the pressure shell. The emergency gas supply provides metabolic oxygen for the capsule occupants and mixed gas for divers or additional bell pressurization in the event of loss of surface-supplied

gas or other casualty. On some systems pure helium is carried for bell pressurization, and occasionally an internal emergency supply of oxygen is installed. PTC's generally do not carry sufficient gas aboard to pressurize the interior to full depth rating and supply diving needs because of the associated weight and volume of the required cylinders. Some PTC's used for saturation diving, however, use the onboard gas supply to meet the requirements of the divers' breathing apparatus. This practice eliminates the need for a gas hose from the surface; the PTC is pressurized on deck to operating depth prior to descent.

Umbilicals and underwater breathing apparatus (UBA) for two or more divers are stored inside the PTC (either on the floor or on wall racks). The umbilicals consist of a gas supply hose and a communications cable, which also serves as a lifeline, or a separate lifeline. These two elements of the umbilical are often supplemented by the addition of a hot water supply hose for suit and respiratory gas heating for cold water exposures. Although interior stowage of umbilicals and UBA's is space consuming, this disadvantage is offset by the convenience of more rapid donning, doffing, and stowage of equipment and easier tending of the diver(s) by PTC standby personnel.

In addition to the bottom hatchway for diver egress and ingress, some PTC's also incorporate an additional hatchway on the side for horizontal mating to a DDC. Hatchways are equipped with mating locking flanges for pressure-tight connection to companion units on the DDC for personnel transfer. All PTC's have an inward opening, pressure-sealing hatch over the lower hatchway to retain internal gas pressure during recovery from the bottom and, in saturation diving, during deployment from the surface. The interior hatch usually covers a short cylindrical entrance trunk. The trunk acts as a small floodable volume when divers leave the PTC underwater and, consequently, minimizes flooding of the capsule interior. An external opening, pressure-sealing hatch is employed over hatchways when capsules are used as hydrostats.

The minimum life support equipment for a PTC includes a CO₂ scrubber consisting of a blower and associated canister of CO₂ absorbent and a gas

supply to provide metabolic oxygen. This basic requirement is often supplemented with an analyzer for measurement of the partial pressure of oxygen in the capsule atmosphere. Advanced systems employ CO₂ analyzers and heating of the PTC interior by electrical resistance heaters or hot water heat exchangers.

Controls and instruments aboard PTC's vary greatly in complexity. Basic internal valving and piping control PTC pressurization and depressurization, emergency breathing gases, and gas flow to the diver(s). Normal design practice requires stop valves at the internal hull surface, and penetrators are normally located only in the lower half of the pressure shell as further precaution against accidental flooding in the event of piping/valving failure. Depth indicators are provided for internal and external pressure measurement. Minimum communications consist of a two-way hardwire voice system. The minimum system is often supplemented with a sonar-type underwater communication set (UQC) and closed-circuit television. Electrical systems vary from the simplest battery pack to power the scrubber and internal lighting to the comprehensive multiple-voltage distribution system used on the MK 1 and MK 2 for heating, internal and external lighting, instrumentation and communications.

Certain other characteristics are commonly found in PTC designs. The PTC pressure shell usually incorporates a number of viewports for use by capsule occupants and surface-support crew. One or more bumper rings around the shell protect the pressure vessel and outside-mounted equipment from impact damage during handling. Many PTC designs incorporate a built-in stand for sitting on the seafloor and simplified servicing on deck whereas others, in order to simplify mating procedures, utilize a separate deck cradle.

Deck Decompression Chamber 12.3.2 The deck decompression chamber (DDC) is a multi-compartment, horizontal steel pressure vessel mounted on the surface support platform. DDC's generally include a minimum of two locks (compartments), and may incorporate three or more in systems designed to accommodate operations involving several diving crews. Modular construction (single locks or units



Figure 12-5 DDS MK 1 Entrance Lock

bolted together to form the deck complex) is sometimes employed to simplify transportation and add arrangement flexibility.

The two-compartment DDC provides an entrance lock (EL) which permits personnel transfer and mating facilities for the PTC and a larger lock used as a living/decompression area by chamber occupants. In some systems, e.g., MK 1, the term "DDC" only refers to the larger living compartment. A few systems, e.g., MK 2, have the PTC transfer hatch in the inner or living lock (IL) of the DDC because of special spacial considerations on the support ship.

The entrance lock has one or more hatchways to the exterior of the vessel which are equipped with inward opening, pressure-sealing hatches. Occasionally pressure-resisting external hatches are used because of internal space limitations. The hatchway(s) permits lock-in, lock-out of attending personnel and divers and usually has the mating flange and locking device for securing the PTC. A hatchway is also provided through the bulkhead to the living compartment for personnel entrance and egress. For regular two-compartment DDC's, this hatchway is closed by a single inward-swinging, pressure-sealing door in the living compartment since in no operational sequence is it desirable to pressurize the EL above living compartment pressure. For modular systems in which the entrance lock may service two or more compartments at different pressures, additional pressure-

sealing doors are fitted on the EL-side of the bulkhead hatchways.

Entrance locks usually contain a minimum of equipment since normal personnel residence time in this area is short. They are designed to be as small as practical to conserve gas used in pressure cycling. The EL tends to be a wet area because this location is used for the removal and storage of exposure suits and other equipment by divers returning from operations. Since this area can be segregated from the primary living area, it is often used as the location for the sanitary facilities in addition to gear storage.

Basic sanitary needs may be served by a simple bucket or portable head but many DDS incorporate a hot water shower (particularly useful for rewarming divers), a wash basin and water-flush head. Such sanitary water supplies and drainage systems must maintain a controlled differential water supply pressure over chamber conditions. In addition they must be equipped with safety interlocks to preclude accidental personnel exposure to the pressure differential of atmospheric conditions.

The main lock of the DDC must be large enough to prevent occupants from being forced to adopt a cramped position during decompression. Systems used for saturation diving must be much larger, and at least some portion of the facility should have full standing head height. A small lock is built into the side or end head of the compartment for the passage of food, medical supplies or other articles between the diving crew in the chamber and outside personnel. Viewports built into the sides and end of the pressure shell permit the visual monitoring of occupants and are often used for illumination of the lock interior by externally-mounted lights. Bunks are usually installed for the comfort of the diving crew.

The basic control and piping system of a DDC is similar to that of a recompression chamber and includes internal valving and a caisson gage. Control valves on the exterior of the shell are normally used to control all gas flow into and out of the chamber complex. In many DDS deck complexes, however, control of the DDC environment is performed from a separate central control panel located at a distance from the chambers and connected via cables and

hoses (or hard piping). In this type of design, valving on the chamber is used as a backup mode of operation. Separation of the control function from the chambers often permits greater flexibility in location of the DDC aboard ship, reduction in unit volume for shipping, and environmental protection for chamber operators.

Fire in the closed environment of the DDC presents a significant hazard. As a consequence, DDC's should have some type of fire fighting provisions. Equipment ranges from simple sand and water buckets to fire hoses with external, pressurized water supplies to, in the most advanced systems, water deluge nozzles actuated manually or automatically by flame sensors. As in recompression chambers which have a similar hyperbaric flammability hazard, all ignition sources are eliminated and the use of combustible materials is minimized. Mask systems are installed in all locks for emergency breathing in contaminated atmospheres as well as normal administration of oxygen during decompression. PTC's do not usually have firefighting equipment because they are operated in a depth range in which the oxygen concentration in the gaseous environment will not support combustion (See Chapter Nine).

Life support for a DDC used in non-saturation diving for shallow operations may only consist of the capability to adequately ventilate the locks with air. In most systems, however, a CO₂ scrubbing capability and O₂ monitor are provided. The precise control of environmental conditions demanded in saturation diving necessitates the addition of temperature, humidity and impurities controls and monitoring of the carbon dioxide concentration. The equipment necessary to maintain desired conditions is usually located outside the pressure vessels with associated sensors and ducting inside.

Minimum communications in the DDC consist of an open-circuit, two-way audio communications set to permit chamber operators to monitor the diving crew. Helium unscramblers are routinely installed to improve speech clarity. A sound-powered phone system is often installed as a backup for voice communications, and closed-circuit television (CCTV) cameras are commonly employed for visual monitoring of chamber occupants.

Life Support Systems 12.3.3 Major components of the life support system (LSS) are normally located external to the DDC. They may be wholly or partly mounted on the outside of the pressure shell to minimize piping, or be grouped in a separate module.

Heating and cooling units employing circulating water are used in saturation systems and also in some non-saturation systems when DDC's are subjected to extreme environmental temperatures. The circulating water feeds one or more heat exchangers located either inside the DDC locks or within external combination scrubbers which circulate the lock atmosphere. When humidity control is employed to increase comfort and minimize skin problems, a cold water exchanger is used for condensing water from the chamber atmosphere, and a hot water exchanger is used for reheating the gas.

Carbon dioxide scrubbers located outside the DDC are usually housed within groups of pressure vessels which function at chamber pressure. This type of design minimizes the size and power requirements of the explosion-proof recirculating blower installed in the assembly. A minimum of two pressure vessels arranged and piped in parallel are used to permit depressurization and changeover of the Baralyme canister via a quick-opening hatch while maintaining one scrubber on-line.

The life support package (LSP) often contains the supply/receiver equipment for a flush-water sanitary system. This type of system includes water pressurization pumps (or a pressurization tank for batch systems), water heaters, sewage holding tanks and associated piping and controls. Some LSP's also include a mascerator and sewage pump to transfer wastes to the ship's sewage system.

Controls for operation of the life support systems are normally an integral part of the equipment and are locally operated. Various chamber monitoring analyzers and malfunction indicators at the central control console provide information on system performance and the possible need for corrective operator action.

Control Console 12.3.4 A main control console (MCC), located near the DDC in a weather-proof van or below deck, provides operating controls and moni-

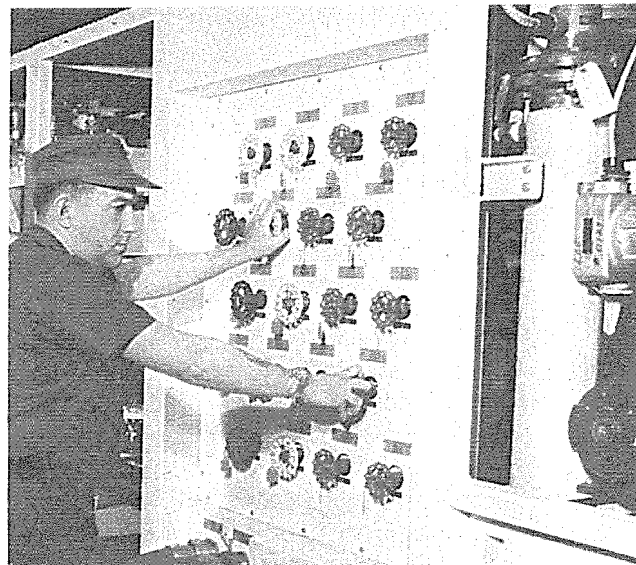


Figure 12-6 DDS MK 1 Life Support Package (Shown with panels removed).

toring devices to ensure safe operation of the DDC, EL, and PTC. Electrical power distribution (sometimes as a separate console), metabolic gas, pressurization, vent and decompression, lighting, communications, and system monitoring are usually all controlled from the console. When the control console is housed in a van, the module usually contains a window for observation of the exterior of the DDC, lighting, heating and air-conditioning for the operators.

The gas section of the console provides control of the various gas supplies and operating pressures in the DDC and EL. The console operator controls pure oxygen, one or more helium-oxygen mixtures, helium and compressed air delivery to the chambers. Additional valving is provided for decompression control which is normally performed manually because of its singular importance. Occasionally, however, DDS control consoles are fitted with automatic decompression controllers. Separate valving is provided for control of surface-supplied gas to the PTC and/or the charging of the onboard PTC gas supply flasks. Pressure readouts on the console monitor the internal condition in the DDC locks and PTC as well as PTC depth.

An oxygen partial pressure analyzer readout for the DDC (and PTC in advanced systems) is usually located on the MCC and also a CO₂ partial pressure readout for saturation systems.

All communications systems in the DDC and PTC are controlled from this location. The operator may direct voice communications between divers, PTC, DDC and control console as required. The intercom system is often supplemented with a helium voice unscrambler, a tape recorder for monitoring conversations, a radio tuner for entertainment of off-duty DDC occupants, and CCTV monitors connected with cameras installed on the DDC, EL, and PTC.

For all but the simplest deep diving systems, electrical power requirements are substantial. Power control components are usually grouped in the main control console or are separately housed in the immediate vicinity to simplify coordinated overall control of the DDS. Primary power is supplied by the ship; a backup supply for critical systems is always provided. Backup may take the form of emergency batteries and an inverter, a separate auxiliary generator, or the ship's auxiliary system. The power control console (PCC) or panel contains the required circuit breakers, transformers, battery chargers, and power transfer gear required to protect and monitor the electrical supply to all systems.

PTC Umbilical 12.3.5 The PTC is connected with the surface platform via an umbilical cable. The configuration of the umbilical is dependent upon the design of the PTC, and whether it is primarily intended for saturation or non-saturation diving.

For some saturation systems, such as the MK 2, sufficient gas is carried aboard the PTC to supply the divers' breathing apparatus and the capsule is pressurized prior to descent. Since additional gas from the surface is not required, this type of system employs a single composite cable which performs three primary functions (strength-power-communications cable-SPCC). The SPCC acts as a strength member to raise and lower the PTC (even if flooded) and conducts electric power, wired communications, and coaxial transmission (CCTV signals) between the MCC and the PTC. The SPCC terminates in a mechanical breakout which is secured to a lifting eye on top of the PTC.



Figure 12-7 SPCC winch and controls for DDS MK 1.

Saturation systems which employ diver breathing apparatus having a large gas demand, e.g., MK 1 mask, usually require supplemental gas supplied from the surface. Such systems usually have an umbilical consisting of two hoses (one for gas supply, one for a pneumofathometer and supply backup), a communications cable, a power cable, and a lifting cable. In practice hoses, communications and power cables are normally married together to form a single umbilical which may be fastened to the lift wire during PTC deployment. The umbilical is unfastened, coiled and stowed during PTC ascent. A similar arrangement is used for a PTC employed in nonsaturation diving.

When hot water is used for diver heating, an additional hose must be added to the umbilical. When an SPCC is used, the hot water hose may be temporarily fastened to the cable as previously described; when a composite hose/cable bundle is used, it is included as an integral part of the bundle.

The use of a single umbilical cable rather than separate hoses and cables minimizes current effects and simplifies handling. The SPCC-approach simplifies deck operations but necessitates large deck equipment to maintain the minimum bending radius of the cable and presents operational repair problems because of its special construction. The composite system, while minimizing repair problems and lifting machinery size, necessitates additional deck personnel for fastening/removal and stowage operations.

PTC Handling Systems 12.3.6 Of all elements of deep diving systems, none are more varied than PTC handling systems. Launch and retrieval of the PTC through the air-sea interface and mating with the DDC present significant hazards to the divers aboard during heavy weather and is a major factor in the configuration and operation of the handling system. Further variability is introduced as a consequence of the differences in the configuration of the various surface platforms used and the placement of DDC's.

All handling systems, however, have certain common characteristics. The system should—

A. Be designed and well maintained to withstand the shock loads imposed by heavy weather.

B. Have the ability to pass the PTC through the air-sea interface at sufficient speed to avoid excessive wave action.

C. Keep the PTC well clear of the superstructure of the surface-support platform to avoid impact damage.

D. Have a winch of sufficient power to permit fast retrieval of the PTC to match decompression ascent rates for non-saturation diving. The winch must also be of sufficient size to store all cable required while maintaining a safe minimum cable bending radius. Controls and brakes which permit precision control for PTC mating and approach to the seafloor are essential.

E. Include a translation system to move the suspended PTC to and from the launch/retrieval position astern, athwartship or amidship to the DDC.

F. Have a method to restrain PTC movement during mating to the DDC.

The simplest handling systems are those which are an integral part of the DDC complex. Such packaged systems employ a hydraulically inclined A-frame equipped with a sheave over which the PTC lift wire passes to a winch on the DDC frame. The location of the DDC package aboard ship is critical since it must be in close proximity to the gunnel of the surface platform to provide sufficient outboard deployment of the PTC.

Other handling systems, particularly for smaller PTC's, employ separate A-frames, cranes, booms, or davits to provide sufficient outreach over the side or through wells for safe PTC deployment. Such systems, commonly used on ships of opportunity, usually employ manually or tugger-winch restrained tag lines temporarily attached to the PTC during deck movement.

Larger PTC's, such as those used in the USN's MK 1 and MK 2 systems, require special handling provisions. The MK 2 PTC is deployed through the center well of salvage and rescue ships (IX-501, ASR-21 class) with a gantry crane. A special capture basket, which surrounds the upper portion of the PTC, is used underwater in the launch and retrieval process to minimize surface wave effects. The MK 1 PTC has been handled using the McMahon twin-boom system, a special articulated crane, and the Whirley crane of



Figure 12-8 PTC handling system aboard the ASR 21

the ATS. Both the MK 1 and MK 2 systems employ a large deck winch to provide lifting force to the SPCC and through slip ring assemblies transmit electrical power and communications to the PTC. The other lifting equipment aboard ship is primarily employed for translation of lifting forces and movement of the PTC to the DDC for mating.

Underwater Breathing Apparatus 12.3.7 Divers working from a PTC are always tethered as a safety precaution. Even when completely self-contained breathing apparatus is employed, a safety line between diver and PTC is essential to preclude the significant hazard posed by the diver being unable to find and return to the safety of the capsule. Voice communications between the diver, PTC tending personnel, topside, and other divers is also a requisite for safe operations.

A wide variety of breathing apparatus are being used from PTC's. Demand masks, lightweight recirculating helmets, semiclosed and closed-circuit apparatus, and pumping units which circulate the PTC atmos-

phere to the diver are all successfully used. The choice of apparatus is governed by operational considerations including required bottom time, gas logistics, personnel training, checkout and servicing time, and maintenance requirements.

Demand masks, such as the USN MK 1, and lightweight demand helmets are commonly used in operating situations in which gas logistics do not present a problem or in non-saturation diving when bottom time is short. Occasionally the MK 1 mask is used as an emergency backup rig for closed or semi-closed apparatus. The simplicity of construction and operation, and compactness of this type of apparatus offer distinct operational advantages which in certain types of operations offset the greater gas consumption.

Operations involving extensive bottom time, e.g., saturation diving, and/or great depths normally require the use of a recirculating breathing apparatus to minimize gas consumption. Both the MK 10 closed-circuit rig and MK 11 semiclosed-circuit rig are used by the USN for this purpose. These apparatus, always used in a tethered mode for diver safety, are equipped with special hot water jackets for gas and canister heating. Lightweight helmets equipped with recirculating systems are also used in some deep diving systems.

One of the newest breathing systems employs a compressor-depressor system to pump the PTC atmosphere to the diver and back to the PTC. Inspiratory and expiratory gas flow through a two-hose umbilical is controlled by two regulators on the diver's mask. This type of system employs the PTC life support system to purify and control the diver's breathing medium, and consequently eliminates the bulk and complexity of a diver-worn recirculating apparatus.

DEEP DIVING SYSTEM OPERATIONS 12.4

Detailed operating instructions for installation, deployment, retrieval, mating and decompression vary significantly from one diving system to another. Instructions for use of advanced DDS, such as the USN MK 1 and 2, are extensive and beyond the scope of this manual. Such detailed information is essential for the safe operational use of the subject DDS, and the reader is referred to the appropriate operating man-

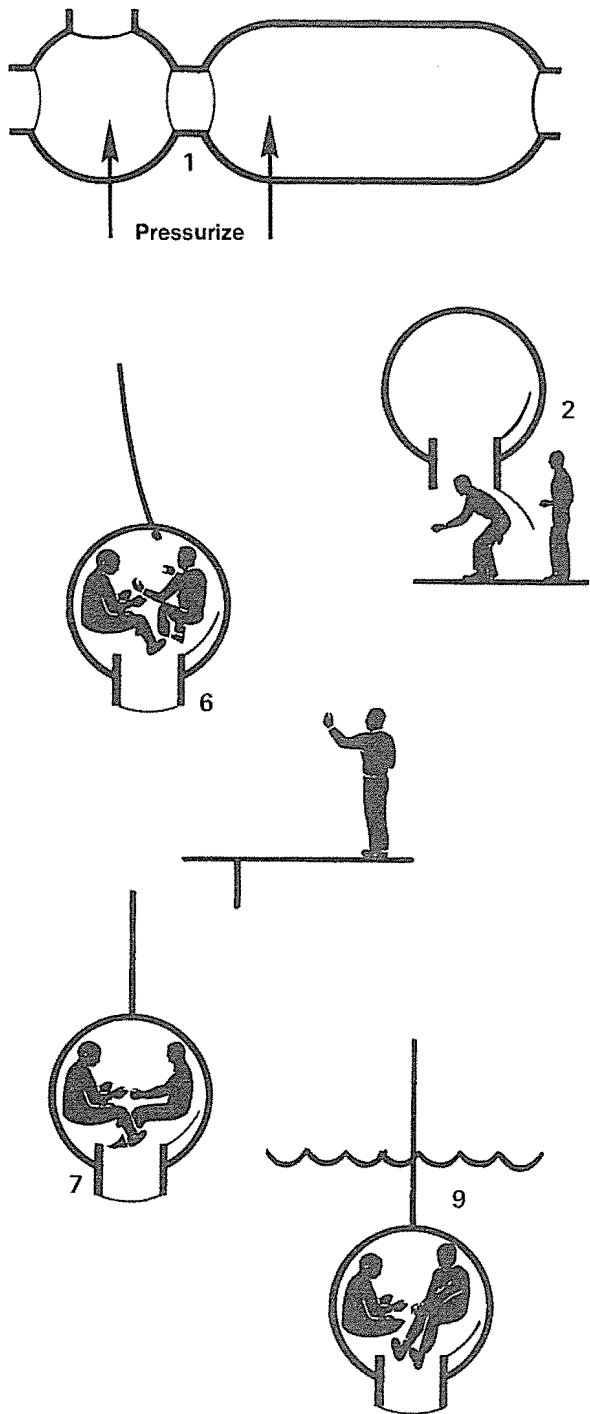
uals. General pre-dive and post-dive checkout procedures will be found in Appendix II-I.

General Criteria 12.4.1 This section of the Diving Manual details the operating principles and sequence common to most deep diving systems used in the three major modes—hydrostatic, non-saturation, and saturation diving. Prior to initiating actual DDS operations, the following criteria must be met for the specific system in use—

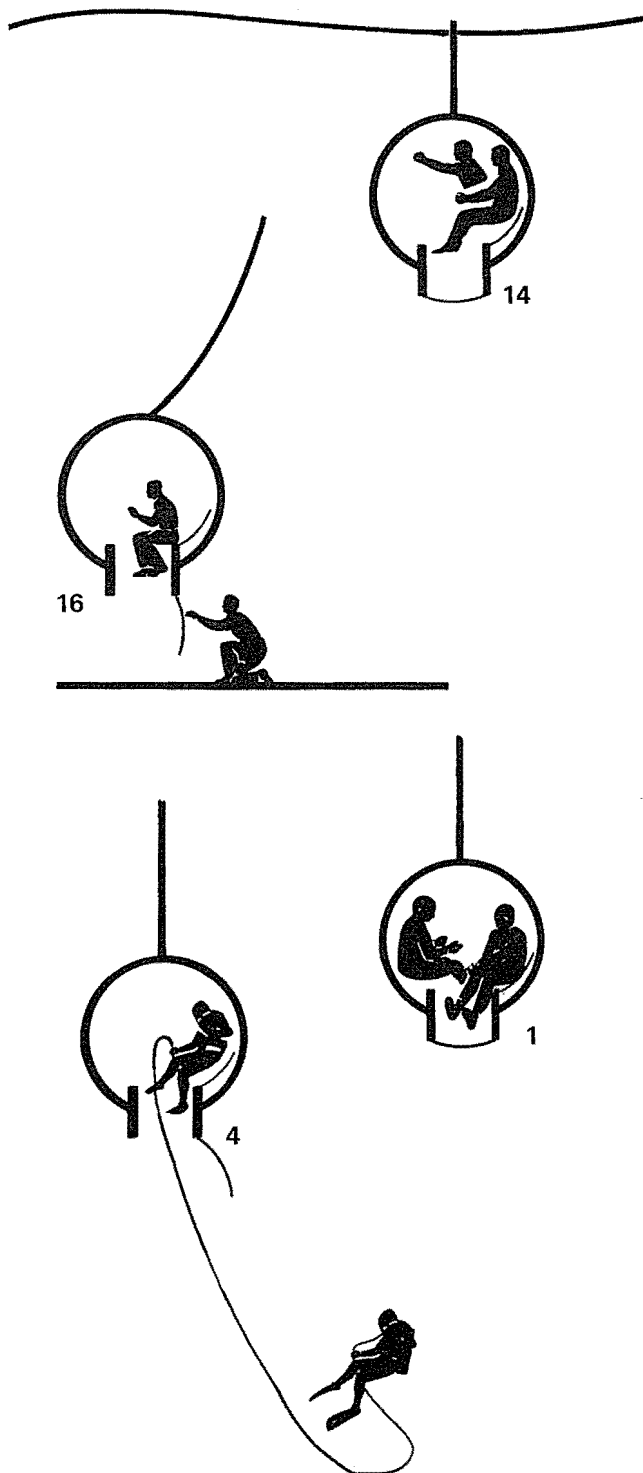
- A.** The DDS must be installed, operated, and maintained in complete accordance with the system's operating instructions.
- B.** All support and diving personnel must be trained and qualified for the DDS being used.
- C.** All stations must be manned in accordance with written instructions.
- D.** All diving personnel must be qualified with the specific UBA to be used.
- E.** The support ship must be securely moored, and all ship's systems relating to support of the DDS must be fully operational.
- F.** All team personnel must be thoroughly familiar with emergency procedures for the DDS. All systems, subsystems, components and backup facilities related to the safety of the DDS and occupants must be functioning properly.

Hydrostatic Diving 12.4.2 The following operating procedure is used in conducting a hydrostatic (non-pressurized observation) dive—

- 1.** Pressurize the DDC to the maximum operating depth to be encountered by the PTC. This is done as an emergency precaution to ensure that the DDC is operational in the event that the PTC must be pressurized in an emergency and occupants require decompression.
- 2.** PTC occupants board the capsule on deck. They perform a pre-dive checkout and activate gas, electrical, communications, life support and ballast systems aboard the PTC. All pressurization capabilities must be functional.
- 3.** The external trunk hatch is closed and dogged by PTC personnel. The DDS MK 2 requires installation of the removable external hatch prior to use of the PTC in the hydrostatic mode.



4. Carbon dioxide removal and oxygen monitoring/control systems are checked for proper operation.
5. Slack is taken up on the lift cable and PTC hold-downs are removed. Steadying (tag) lines are attached to the PTC (when required) and tensioned.
6. PTC occupants brace themselves for transit and advise the Main Deck Supervisor of their preparedness.
7. The PTC is lifted by the handling system, moved across the deck, and positioned over the side or centerwell.
8. If the PTC is to be used in a free descent, negatively buoyant mode with a clump, it is now ready for deployment. If it is to be used in a positively buoyant mode, the downhaul winch on the PTC is allowed to unspool cable until the clump reaches bottom. If a taut guidewire system is to be used for PTC positioning, the PTC guiding is secured around the cable.
9. The PTC is lowered through the air/water interface as rapidly as possible to obtain a hatch seal and transit this potentially hazardous zone.
10. If steadying lines have been used, they are removed by ship's divers. If a separate cable and winch are used to raise and lower the PTC after it is underwater, the main lift wire is also removed at this time.
11. The PTC is lowered to the observation site under the voice direction of PTC personnel. If the PTC is designed to be surface-supplied with gas, the umbilical is continuously secured to the lift wire by chain binders attached by deck personnel during PTC descent. This procedure ensures that a PTC pressurization capability is always available for emergency use. When a PTC downhaul winch is used, PTC personnel control the winch but close coordination is required with the deck winch operator.
12. While in the observation mode, PTC occupants must monitor the oxygen partial pressure and scrubber operation and add O₂ as required to



maintain a life sustaining environment inside the PTC.

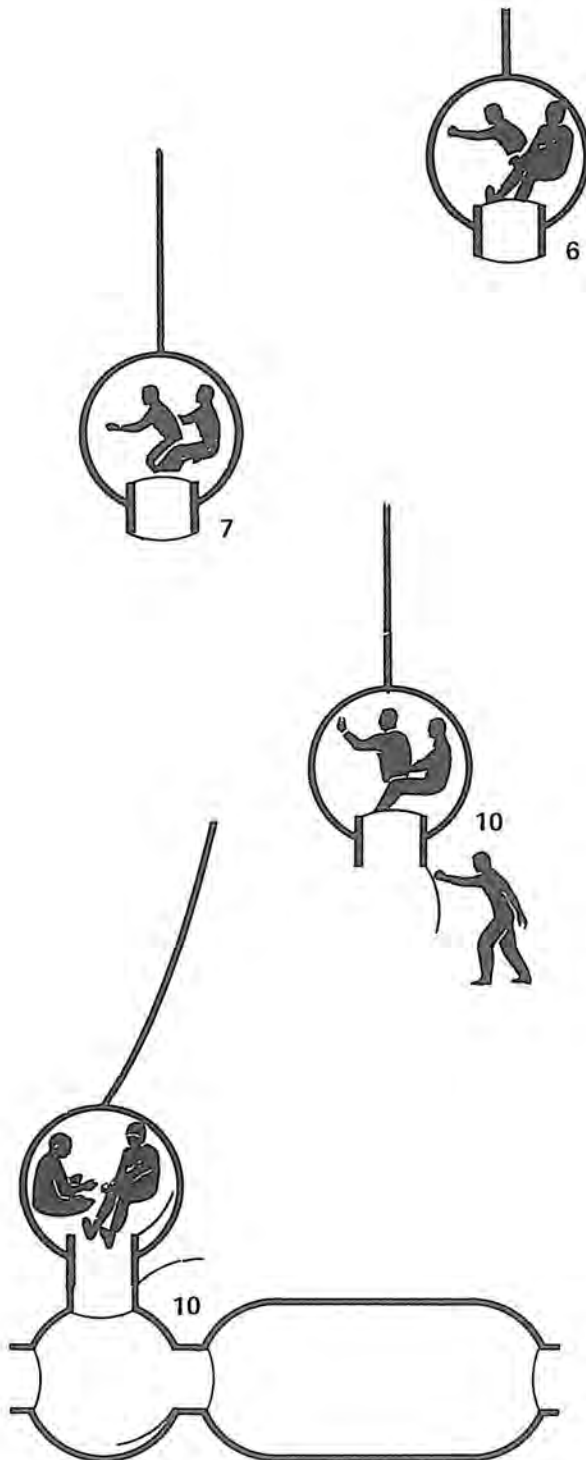
13. Upon completion of the task, PTC personnel advise topside that they are ready for ascent.
14. The PTC is lifted to just below the air/water interface and held there while divers attach steadying lines and the main lift wire (if required).
15. The PTC is rapidly lifted aboard the ship and secured in its stowage position.
16. The lift line is slackened, the lower hatch is opened, and PTC personnel exit from the capsule.
17. A postdive checkout of the DDS is conducted and the system is secured or readied for further operations.

Non-Saturation Diving 12.4.3 Non-saturation diving is conducted with a DDS to meet operational requirements and in the training of saturation divers. This mode of diving is usually conducted using the observation technique initially, followed by pressurization of the PTC on the bottom to minimize bottom time. Preparatory procedures are similar to those in Section 12.4.2 with the additional requirement that the UBA and other diver equipment must be thoroughly checked prior to descent. Upon reaching the work site the following procedures are used—

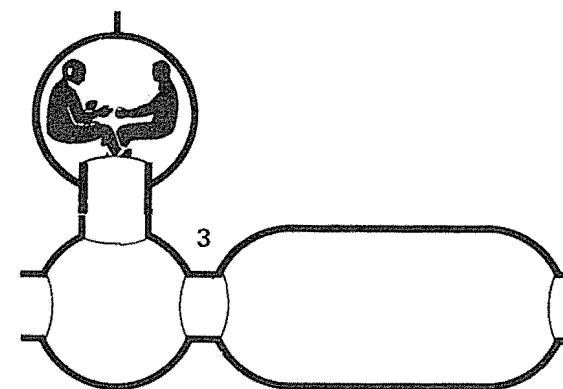
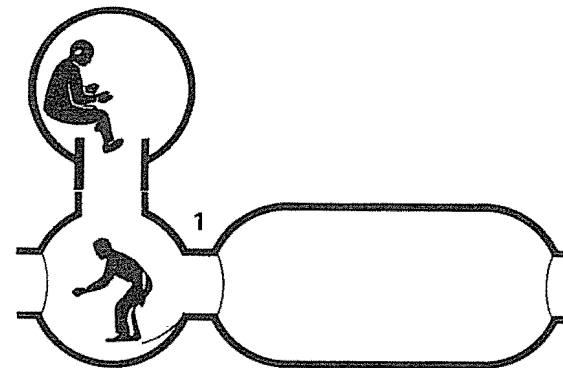
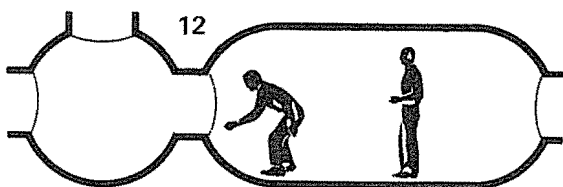
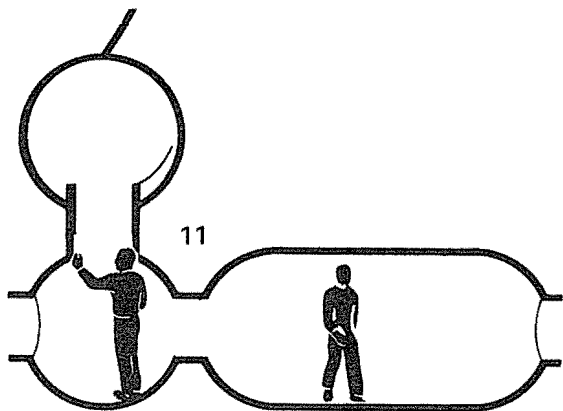
1. The working diver(s) dons his UBA and prepares his umbilical for deployment.
2. The external hatch is undogged and the PTC is pressurized by the divers using either surface-supplied or PTC-supplied gas (depending upon the PTC design and depth) until the internal gas pressure equals the external water pressure. Bottom time begins as soon as pressurization commences.
3. The lower hatch is opened when internal and external pressures are balanced. The diver checks his breathing apparatus and turns on the hot water supply to his suit (if used).
4. He enters the water, takes his bearings on the job site, and swims to the site trailing his umbilical behind. The umbilical is tended by the diver inside the PTC and continuous voice communications are maintained.



Figure 12-9 Diver locking out of the DDS MK 1 PTC



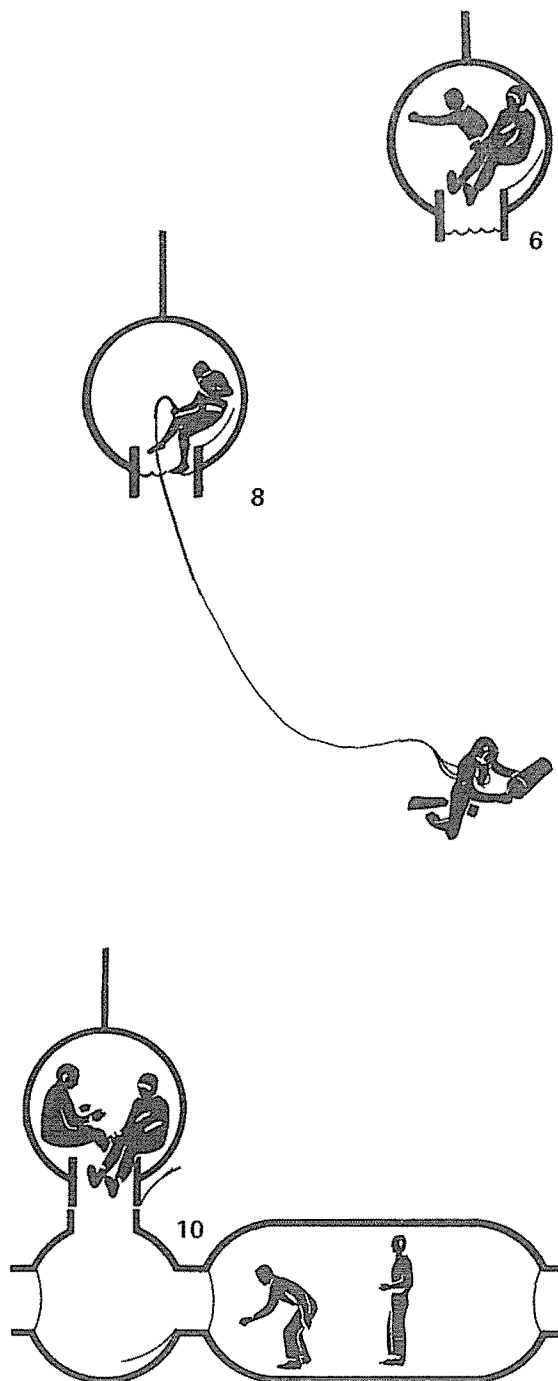
5. When completed with the task, the diver returns to the PTC and removes his diving gear. If additional underwater work is required, the other diver(s) dons his gear, swims out from the PTC, completes his work and returns.
6. When ready to come up, the divers close and dog the internal and external (if installed) hatches. Although the inside hatch will maintain internal PTC pressure during ascent and transfer to the DDC, the outside hatch is closed as a safety precaution. If a failure in the lifting system should drop the PTC to a hydrostatic pressure greater than the internal pressure, flooding of the capsule would result. Gas trapped in the trunk will escape past the lip of the outside hatch during ascent.
7. The divers signal the Main Deck Supervisor of their preparedness to ascend. The PTC is lifted to just below the air/water interface at an ascent rate greater than 60 feet per minute. During initial ascent from the bottom, the divers must ensure that the internal hatch is properly sealed and that no gas from the PTC is being unintentionally lost. This is done by monitoring the PTC caisson gage. Loss of internal PTC pressure requires a halt in ascent until the situation can be corrected.
8. Decompression time may begin as soon as the PTC leaves the bottom. During PTC ascent, the divers reduce the internal pressure of the capsule by exhausting gas to the sea to match the decompression schedule being used (Surface-supplied mixed gas or air tables).
9. The PTC is lifted aboard ship after the attachment of steadying lines and lift wire (if required). The DDC is depressurized to match the internal pressure of the PTC.
10. The deck crew undogs the external PTC hatch and secures it away from the entrance trunk. The PTC is mated and locked to the DDC. The divers are advised to undog the inside PTC hatch.



11. The PTC trunk space and matching transfer trunk on the DDC are pressurized to equal the PTC and DDC pressure. The divers open the internal PTC hatch and the DDC hatch and transfer to the DDC. The DDC hatch is closed by the divers.
12. The divers transfer to the main lock of the DDC and close the entrance lock hatch behind them. The PTC is depressurized by the deck crew. The entrance lock of the DDC is maintained at main lock pressure as an emergency escape area for chamber occupants in the event of fire or atmospheric contamination.
13. Decompression of the divers in the DDC is continued following the selected schedule.
14. The PTC is removed from the entrance lock, moved to its stowage position, and serviced for future use.
15. Transfer of food and other supplies to the divers in the main lock is accomplished using the DDC medical lock. Transfer of personnel into and out of the main lock is performed using the entrance lock.

Saturation Diving 12.4.4 In saturation operations PTC deployment, swim out, retrieval and mating procedures are similar to those previously described except that the divers are maintained at constant bottom pressure until final decompression. Modification in procedures for saturation diving include—

1. For initial pressurization the PTC (with internal hatch open) is locked onto the DDC, and divers enter the DDC and secure the hatches.
2. The DDC and divers are slowly pressurized to bottom depth following procedures given in Section 14.6.
3. The PTC is pressurized to bottom depth. The divers transfer to the PTC from the DDC and close and dog the DDC hatch behind them. They then close the PTC internal hatch.
4. The PTC/DDC trunk space is vented to atmospheric conditions. The PTC is unlocked from the DDC and deployed as previously described.



5. The PTC is lowered to working depth. When seawater and internal PTC pressures are equal (observed by PTC gages), the internal hatch is opened.
6. Gas is added to the PTC to displace seawater in the trunk. Diving equipment is donned and checked and the diver(s) swims out of the PTC to accomplish the underwater task.
7. Saturation divers should not ascend above the level of the PTC. Such action results in an outward gas pressure gradient across the body tissues which could result in decompression sickness.
8. Divers may work as deep as 25 feet below saturation depth for unlimited periods and return directly to the PTC. Deeper excursion dives must be performed within the no-decompression obligation in returning to the PTC.
9. Upon return to the PTC and stowage of gear, the divers secure the inside hatch and advise the surface to initiate ascent. Particular care must be exercised by the divers to ensure a complete hatch seal since even minor pressure reductions in the PTC atmosphere impose an unprogrammed decompression of saturated body tissues.
10. The PTC is raised, mated, and the divers are transferred to the DDC. If two teams of divers are being used with one DDC complex, the second team transfers to the PTC after the capsule and diving apparatus is serviced.
11. The divers rotate between periods of living in the DDC and work on the bottom from the PTC until time for decompression.
12. The divers are decompressed in the DDC following procedures in Section 14.6. Saturation decompression employs continuous linear decompression rates which are fastest (10 ft/hr) in the deep portion of the dive profile and slowest (3 ft/hr) as the surface is approached. Decompression is halted twice during each 24-hour period. The constant pressure hold periods of the daily routine are an integral part of the decompression procedure for tissue gas elimination.

DEEP DIVING SYSTEM EMERGENCY OPERATIONS 12.5

As has been discussed, the use of a DDS significantly adds to diver safety for deep water operations by minimizing in-water exposure time and providing a local refuge for the diver at the work site. Certain dangers exist in DDS operations, however, which may or may not have a counterpart in conventional diving.

General Criteria 12.5.1 In the design of a well-engineered DDS, potential operating hazards are evaluated and features are built into the equipment or redundant subsystems are employed to reduce potential dangers. In certain instances hazards are an integral aspect of the operation and must be overcome by carefully prepared and executed operating procedures. Typical of design safety features are the inherent buoyancy of the PTC, redundant life support components, and mask breathing systems. Procedural approaches to safety are noted in the prohibition of ignition sources and flammable substances inside the DDC.

Few DDS emergency systems operate automatically; the actuation of the majority of such systems and execution of proper emergency procedures require timely, correct action by the DDS crew. Such action demands a well-trained operating crew who have practiced emergency drills and are thoroughly familiar with all aspects of operation of the specific system being used.

It is impossible to list all the types of emergency circumstances which may occur in DDS operation. As an example, the maintenance of saturation pressure is of critical importance and may be affected by the malfunction, damage or improper operation of numerous components which results in an emergency situation. The following emergencies and associated corrective procedures are considered to be those which may be most generally encountered. Detailed operator action for a specific DDS will be found in the respective operating manual for the system.

DDC Emergencies 12.5.2 Of the several types of emergency situations which may develop in the DDC, the most serious are the uncontrolled loss of pressure and fire. Failure of the life support, power, and com-

munications also pose hazards but are generally of lesser consequence.

FIRE IN THE DDC 12.5.2.1 Two types of fire may occur under hyperbaric conditions—the flash fire and the slow burning fire. Of the two, the flash fire is the most serious and must be combatted within seconds of initiation. A slow burning fire, e.g., wire insulation, which is not promptly extinguished may initiate a flash fire depending upon available fuel, oxygen concentration and type of inert gas in the chamber atmosphere. In addition to the dangers posed to chamber occupants from heat and scorching, products of combustion may rapidly contaminate the atmosphere. The emergency procedure is as follows—

1. The MCC operator secures all electrical power to the DDC and turns on DDC emergency lights.
2. Standby diver wakes all divers.
3. Divers vacate the lock, if possible, and secure the bulkhead hatch.
4. Lock occupants go on mask breathing (BIB system).
5. Transfer personnel to PTC, if possible, demate and move PTC to safe location.
6. Secure all gas supplies, ventilation and LSS to the lock containing the fire.
7. Depressurize the DDC and fight the fire with external personnel.
8. When the DDC is serviceable, return to depth, reactivate LSS and transfer personnel from the PTC.

If the location of the fire prevents the escape of personnel to another lock or the PTC, they must immediately don breathing masks and fight the fire using the lock's fire fighting equipment.

PRESSURE LOSS OR INCREASE IN THE DDC 12.5.2.2 Pressure in the DDC, particularly in saturation diving, must be controlled at all times within narrow limits. An unplanned increase or decrease in pressure is an indication of some failure or malfunction in the system. Changes in pressure must be detected promptly by MCC operators and corrective action taken. In saturation diving the pressure should

not be allowed to change more than one atmosphere (33 feet) at depth. In the event of pressure loss—

1. Alert divers.
2. Maintain lock pressure by adding gas. If ppO_2 level drops, divers use BIBS.
3. Divers vacate lock, secure bulkhead hatch and transfer to the PTC. They close the trunk and PTC hatches.
4. The source of leakage is determined by sequential isolation of locks, LSS, DDC valving and other chamber penetrations. Leak testing is facilitated by use of a helium leak detector or soap solution.
5. The source of leakage is corrected, pressure and ppO_2 level restored, LSS reactivated and personnel transferred back to the DDC.

Pressure increase can result from either a malfunction in the LSS which allows temperature to rise or by the bleeding in of gas. In either case pressure level is maintained by venting excess gas. Corrective action then proceeds while the ppO_2 level is monitored. The LSS units are alternated or gas inflow lines are sequentially secured until the pressure increase ceases.

OTHER DDC EMERGENCIES 12.5.2.3 Failure of the life support system can result in loss of control of temperature, ventilation, humidity, CO_2 and ppO_2 . Redundant life support systems are mandatory for saturation diving systems and desirable for non-saturation diving. Failure of the on-line system requires switching to the alternate while repairs are made. Loss of the recirculating blower in the system is particularly serious because a lack of circulating chamber gas will result in an inability to maintain temperature, humidity and CO_2 levels. Failure of the primary ppO_2 control (or monitor) necessitates switching to an alternate automatic system or manual analyzer backup. In situations involving a DDS with only one LSS or failure of the backup unit, it is necessary to purge the chamber with $He-O_2$ to maintain a physiologically safe $ppCO_2$ level or have the divers use the BIBS until the system can be returned to service. Gas purging may also be required if primary power is lost to the LSS and emergency power is unavailable.

A failure of electronic communications between the DDC and the MCC is not serious since signals can

be relayed visually using one of the viewports. During a communications failure, a man is stationed at a viewport to relay messages to the MCC operator while the system is being repaired. Detailed or lengthy written messages can be exchanged through the medical lock.

PTC Emergencies 12.5.3 Because of the isolation of the PTC while engaged in underwater operations, many emergency situations involving the PTC necessitate prompt corrective action by the divers themselves. This is particularly true at depths which are unreachable by divers from the surface.

Malfunction of PTC systems or supportive handling equipment are invariably serious situations. The loss of pressure integrity or the ability to raise the PTC to the surface can have grave consequences unless effective emergency procedures are implemented.

PTC ENTANGLEMENT 12.5.3.1 The PTC may become entangled at work depth by cables, obstructions at the work site, fouling of the downhaul winch due to cable spooling, and the umbilical fouling in the PTC structure. Four possible methods of correction are available, and regardless of the technique used, continuous communications with topside are required to ensure proper supportive action on the part of the surface crew. A major consideration is the duration of life support available to the PTC divers.

1. The simplest circumstance is one in which the PTC divers alone (or with the assistance of support divers) can exit the PTC and eliminate the obstruction. The PTC is then raised in its normal mode.

2. If the degree of entanglement is not judged to be too severe as to break the lifting cable, a positive lift may be made with the SPCC winch. The PTC hatch is secured and the downhaul winch is braked. The support ship is moved up-current in the moor while paying out cable. This is a safety precaution in the event that the downhaul cable or clump are lost and result in a buoyant PTC ascent. The SPCC winch lifts the PTC in a negative mode.

3. A hopeless degree of entanglement or inadequate onboard life support duration (surface-supplied gas PTC's can be purged to extend limits) necessitate the use of a second PTC to rescue the divers. Great



Figure 12-10 DDS MK 1 PTC during buoyant ascent tests.

care must be exercised by the surface crew to deploy the second PTC close enough to the stranded capsule to permit divers to swim over while precluding the possibility of entanglement of the second capsule in the umbilical of the first or the initial obstruction.

4. A buoyant free ascent may be employed in situations when the umbilical or SPCC is hopelessly entangled. This procedure requires the severing of the umbilical and liftwire or SPCC. The support ship must be moved as previously described while paying out lift cable. For PTC's having a lift wire/umbilical system, the PTC divers must cut the connections at the PTC. Communications with the surface are maintained by UQC operating on emergency power. The hatch is secured and divers strap down and don protective headgear. For SPCC-equipped PTC's, the divers activate and detonate the explosive cable cutter to sever the SPCC. Buoyant ascent is initiated by controlled payout of cable from the passive PTC winch (on units so equipped) or by explosive severing of the downhaul cable. Upon surfacing, the ship's crew secures a lifting line to the PTC and transfers it to the DDC for mating. If the SPCC (MK 1, 2) is not entangled, a buoyant ascent (not free) may be made by severing only the downhaul cable.

PTC PRESSURE LOSS AND FLOODING 12.5.3.2

PTC flooding may result from any loss in gastight integrity (leaking hull penetrations or viewports) or tipping while submerged with the hatch open. Flooding from tipping, usually caused by current effects, is generally not serious since the SPCC can be employed for righting the capsule, divers can use the BIBS, and excess water can be discharged by adding gas to the bell. Loss of gas (and water) integrity, however, constitutes a serious casualty. Actual flooding under this condition is of far less concern than the loss of pres-

sure-holding capability. This type of situation is particularly serious in saturation diving.

Any loss in internal PTC pressure during deck handling or flooding during descent is immediate cause for aborting the dive and transfer of personnel to the DDC while the PTC is being repaired. Addition of gas to the PTC is used to counteract the loss and minimize flooding.

If the PTC is flooding (water level rising) while at depth or during ascent, the following procedure is employed—

1. Recover divers (if at depth) and add gas to stabilize flooding.
2. Investigate the source of leakage and advise topside of the extent of the leak.
3. Pressure loss can result from—
 - a. Exhaust valves not fully shut.
 - b. Leaking hull penetrators and cable glands.
 - c. Foreign objects between hatch and sealing surface.
 - d. Damaged or defective hatch gasket.
 - e. Sprung or maladjusted hatch.
 - f. Cracked or non-sealing viewport.
4. Topside must determine whether to recover the PTC or transfer divers to another PTC (if available). Consideration must be given to—
 - a. Nature of the leak and rate of pressure loss.
 - b. Capability of maintaining gas pressure and duration using the onboard PTC supply, or surface supply if used, until the PTC can be mated.
 - c. Time required to deploy a second PTC.
5. If the pressure loss occurs on ascent, lowering the PTC may reduce the loss while the situation is corrected. Any leakage of gas from the PTC will probably increase during ascent (lower hydrostatic pressure, greater pressure differential) unless corrective measures are employed.
6. The PTC divers (with assistance from support divers if practical) should attempt to correct the leak. Inspect the hatch seal and fit of the hatch. Check hull penetrations and tighten. If the pressure loss cannot be corrected and would be too rapid to permit a safe

ascent (maximum allowable pressure drop for saturation diving is 33 feet), a second PTC must be employed.

OTHER PTC EMERGENCIES 12.5.3.3 Loss of electrical power in the PTC is readily handled by switching to the onboard emergency battery supply. This system is sufficient to power the life support system and analyzers but is insufficient to power an electrical downhaul winch (if used). Submersible winches are designed to automatically brake if primary power is lost and necessitate a negative mode lift by the deck equipment. Internal short circuits can be isolated by sequential actuation of onboard circuit breakers. PTC divers go on BIB system as a safeguard against atmospheric contamination. A short circuit in the SPCC requires that the dive be aborted.

Two-way communications between the MCC and PTC are vital. A partial communications failure involving the helium unscrambler and intercom dictates that the dive be routinely aborted. A total loss of communications demands a prearranged procedure to be followed by topside and PTC personnel as follows—

1. Recover divers and secure hatch.
2. If a downhaul winch is used, it is placed in the BRAKE position. The PTC will be lifted in the negative mode.
3. When communications are initially lost, the Diving Officer will allow 15 minutes to give the PTC operator time to recover divers.
4. The Diving Officer will set off two light underwater explosive charges to notify divers that a 15-minute standby period has begun and broadcast on the UQC.
5. One minute prior to raising the PTC, the Diving Officer will set off a single explosive charge.
6. After the one-minute warning, PTC recovery will begin.

A saturation diver who has exceeded the no-decompression excursion time limits specified in Section 14.6 cannot return to the original saturation depth of the PTC. He has incurred a decompression obligation relative to saturation depth. Topside should be advised, the PTC must be lowered to the depth of the diver while adding gas, and the DDC must be increased in pressure to the new saturation depth.

SALVAGE DIVING SYSTEM 450 12.6

Personnel Transfer Capsule 12.6.1

GENERAL 12.6.1.1 The Personnel Transfer Capsule (PTC), shown in Figure No. 12-11, is a submersible capsule capable of transferring two divers in full diving dress, with necessary work tools and associated operating equipment, from the deck of a ship to a maximum working depth of 450 feet while maintaining the required pressurized environment. The PTC consists of a spherical hull with an ingress and egress trunk with hatches, support frame, gas system, electrical system, visual and audio communications system, passive ascent winch, and anchor. The PTC is designed to operate with an internal pressure of 200 psi when fully charged. It is also capable of withstanding the full differential pressure externally, and can therefore be used as a hydrostat at maximum working

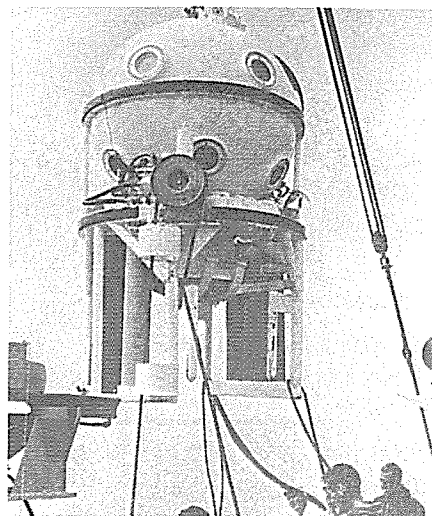


Figure 12-11 SDS 450—Personnel Transfer Capsule

depth with an internal pressure of one atmosphere. In this mode the PTC is used only for observation with divers and/or observers remaining inside the capsule. The PTC may be pressurized aboard ship before commencing a mission, during descent, or upon reaching working depth. When properly pressurized, the diver may then leave the PTC through the trunk and hatches located at the bottom of the hull. Attaching "hookah" life support lines permits exploration at distances up to 100 feet from the capsule.

Salvage Diving System 450

GENERAL CHARACTERISTICS

Designation—

U. S. Navy Salvage Diving System (SDS) 450*

Operating Depth—

450 FSW

Divers Supported and Duration—

Two each, two-man teams for non-saturation diving

Personnel Capacity (PTC)—

2 Men

Personnel Required (Minimum)

11 Men (including divers)

Modes of Use and

Normal Submerged Endurance—

Observation (30 man-hours)
Non-Saturation Diving

Construction—

Modular construction, air transportable

Applicable Support Ships and Barges—

ARS, other ships of opportunity

PTC Utilities—

Surface-supplied gas using umbilical with separate lift cable
Communications and power via umbilical
Onboard emergency gas and power supply
No PTC heating

PTC Downhaul Winch—

Passive, hydraulic type, PTC-installed
Can be made active by use of hoses and surface-supplied hydraulic power

Special Features—

Not equipped for saturation diving

Operating Manuals: Ocean Systems, Inc.,
Advanced Diving System IV

*Formerly ADS-IV



Figure 12-12 SDS 450

Major Components and Overall Size—

Personnel Transfer Capsule—One Each

—Height—126 in.
—Width—70 in.
—Volume—80 cu. ft.
—Weight—7,000 lbs.

Deck Decompression Chamber—Two Each

—Length—111 in.
—Height—66 in.
—Width—54 in.
—Volume—95 cu. ft.
—Weight—6,000 lbs.

Entrance Lock—One Each

—Length—63 in.
—Height—52 in.
—Width—66 in.
—Volume—54 cu. ft.
—Weight—6,000 lbs.

Main Control Console (Van)—One Each

—Length—96 in.
—Height—78 in.
—Width—48 in.
—Weight—4,000 lbs.

HULL 12.6.1.2 The PTC spherical hull is fabricated of welded SA-212B steel and has an outside diameter of 65 inches. A 24½-inch diameter cylindrical trunk, welded to the bottom of the sphere, provides for ingress and egress of personnel and equipment. Its lower flange is the mating flange between the PTC and Entrance Lock (EL). The hull is reinforced locally to provide for fifteen view ports and a lifting eye. Individual hull penetrations are located in the lower hemisphere to accommodate various electrical and gas lines. Two protective bumper rings (one around the equator of the sphere, and the other at the top of the support frame) protect utility connections and the pressure shell from impact damage. A portable exterior light and portable underwater television camera are secured to the television support bracket at one of the lower view ports. The hull is mechanically mated to a support frame by four links. The interior of the hull is equipped with controls for the operation of electrical and life support systems and the PTC emergency ascent winch. A lifting eye installed on the interior overhead permits divers to use a block and tackle to haul objects into the PTC through the trunk. The deck assembly is located just above the internal hatch. Hookah hose, audio and gas connections are located inside the hull.

HATCHES 12.6.1.3 The access trunk is fitted with an internal and an external hatch.

- Internal hatch—located at the top of the trunk, opens inward and seals with internal pressure. No hatch dogs are used; the initial seal is achieved by the weight of the hatch. The hatch may be latched in the open position.
- External hatch—located at the bottom of the trunk, opens outward and seals with external pressure. It is counterbalanced and equipped with dogs for initial sealing.

SUPPORT FRAME 12.6.1.4 The non-flooding support frame is constructed of tubular steel and supports the PTC on a level surface with sufficient clearance under the hull so that the external hatch can be opened and the crew can enter or leave. Loose pin connectors are installed at four points between the support ring and the PTC hull in the event of failure of one or more of the attaching links. Two groups of

auxiliary gas supply cylinders are mounted vertically on the support frame. Each group consists of one 1.5 cubic-foot and two 0.9 cubic-foot cylinders. Also mounted on the support frame are an emergency power unit, a transformer-rectifier unit, a passive hydraulic ascent winch and anchor, two general underwater lights, a television camera and associated special underwater light.

ASCENT WINCH AND ANCHOR 12.6.1.5 The PTC emergency ascent winch is a closed-circuit, variable speed hydraulic unit. The winch has a cable dog release mechanism actuated by a gas/hydraulic ram. The winch is mounted on the support frame adjacent to the trunk. The 1,000-pound anchor rides in a guide bracket directly below the winch when not in use. The anchor cable is 1,200 feet in length. With a payload of two divers and associated equipment the PTC is 300 pounds positive. With the 1,000-pound anchor the PTC is 700 pounds negative—its normal mode of deployment. The winch may be used to regulate the distance from the ocean bottom to the PTC in addition to emergency ascent by release of the cable dog and controlled unspooling of the cable. By providing a hydraulic pump topside and running hoses to the PTC, the winch may be converted to an active mode. The winch may then be used to haul the PTC down to the bottom (positively buoyant mode).

GAS SYSTEM 12.6.1.6 The PTC receives surface-supplied gas through a hose in the umbilical for normal pressurization of the capsule and diver supply. An emergency gas supply containing helium, oxygen and helium-oxygen is carried in cylinders on the support frame. Internal pressure, gas-supply pressures, and PTC depth are monitored during PTC pressurization, steady-state operation, and depressurization. The system contains metabolic oxygen addition and a carbon dioxide scrubber system which are used by the crew to control the breathing atmosphere.

- Control equipment—Color-coded and labeled valves at internal and external locations on the PTC provide for control of all gas system functions.
- Oxygen system—The PTC oxygen system consists of one 0.9 cubic foot externally-mounted cylinder and associated valves, piping and fittings. The oxygen cylinder provides oxygen makeup inside the

PTC for two divers for a maximum duration of 37 hours.

- Helium system**—The PTC helium system consists of one 0.9 cubic foot externally-mounted cylinder and associated valves, piping and fittings. The helium system furnishes pure helium to purge the CO₂ scrubber blower motor in order to reduce the fire hazard.
- Helium-oxygen mix system**—The mix system consists of two 1.5 cubic foot and two 0.9 cubic foot cylinders and associated valves, piping and fittings. The mix system may be used in an emergency to add gas to the PTC, to provide breathing gas to the divers, or to activate the ascent winch dog. There is sufficient gas for 35 minutes for one diver at 450 feet using the MK 1 mask.
- Vent and environmental monitoring system**—The system consists of a combination of gages and valves to control and regulate internal pressure of the PTC. A manual vent valve prevents over-presurization of the PTC and can be used for flow-through ventilation. An external valve is provided for control of depressurization on deck. A sea-pressure gage, calibrated in feet of seawater, monitors PTC depth. A pneumofathometer hose provides readout depth, and the main supply hose provides readout of PTC internal pressure to the Main Control Console. A caisson gage, calibrated in feet of seawater, provides monitoring control during depressurization.
- Carbon dioxide scrubber system**—A blower and a canister containing enough Baralyme to remove 70-manhours of carbon dioxide is provided. PTC atmosphere is forced through the canister by the blower, CO₂ is absorbed, and scrubbed gas is emitted. The blower drive motor is helium-purged.
- Instrumentation**—PTC instrumentation is designed to ensure safe conditions for the divers at all times. The instrumentation monitors oxygen partial pressure (ppO₂) for manual control, and pressure in the PTC and emergency gas supplies.

ELECTRICAL SYSTEMS 12.6.1.7

- Primary electrical system**—Surface-supplied power for normal operation is transmitted to the PTC

through a multi-conductor power cable in the umbilical at 115 volts, 60 Hertz. A harness directs the power wires to external lights and an AC-to-DC power supply package on the PTC support frame. In the power supply the 115 volt AC power is converted to 28 volt and 12 volt DC by a transformer/rectifier unit and supplied to the interior of the PTC. The 28 volt DC power is supplied to two interior lights and the CO₂ scrubber. The 12 volt DC power is supplied to two gage lights and the UQC. A special magnetic reed switch inside the PTC is used to turn primary power on and off through a relay in the power supply.

- Secondary electrical system (emergency)**—Four 13.5 volt nickel-cadmium batteries in the power supply package provide secondary power for emergency use in the event of the loss of primary power. The four batteries, two in series, two in parallel, are maintained at full power by a trickle charger in the supply package whenever primary power is on. An automatic transfer switch in the package switches to battery supply whenever primary power is lost. The secondary supply will power the CO₂ scrubber for 8 hours.

COMMUNICATIONS (AUDIO AND VISUAL) 12.6.1.8

The PTC has three individual communications systems with the MCC to ensure efficient operation under a variety of conditions.

- Hard-wire intercom system**—The 3-wire intercom system is an amplified voice system providing communications between MCC, divers, and PTC crew.
- Underwater mobile sound communication set**—The UQC system is an emergency unit providing voice communications between the PTC and the underwater telephone system of the attending vessel. It is used in event of failure or disconnection of the power/communications cable.
- Closed-circuit television**—The CCTV system consists of a video channel from the PTC to the MCC which provides continuous observation of personnel during descent and ascent of the PTC. In addition, the underwater camera may be removed from the PTC at the work site and used as a portable unit to explore working areas to monitor work being performed. The camera is capable of deployment to

100 feet from the PTC. The CCTV is equipped with a special portable 1,000 watt mercury vapor lamp for underwater illumination.

Umbilical Cable and Lift Wire 12.6.2

UMBILICAL 12.6.2.1 A 1,200-foot composite umbilical cable connects the PTC with the MCC. The umbilical is a non-load bearing grouping of gas hoses, power and communications cables secured together at 2-foot intervals with plastic tape. Two ½-inch diameter neoprene hoses, with a working pressure of 800 psi, are in the umbilical. One hose is used to supply gas at 100 psi above bottom pressure for PTC pressurization and diver breathing. The other hose is used as a pneumofathometer but may also be employed as a secondary gas supply and to vent the PTC. The primary power cable contains four No. 10 AWG neoprene-covered conductors. The audio communications cable is composed of six No. 12 shielded conductors. It provides two separate audio channels. The CCTV has a separate power cable for its associated light and a single composite coaxial and control cable.

LIFT WIRE 12.6.2.2 A 1-inch diameter, non-rotating wire rope is used for lowering and lifting the PTC. A formed zinc wire rope socket is fitted to one end of the cable for attachment to the PTC. At 50-foot intervals a 1-inch tool clip or halyard snap is attached to the umbilical with ¼-inch braided nylon. During deployment of the PTC, a chain stopper, consisting of a 30-inch diameter circle of ⅝-inch galvanized chain, is passed around the lift line and through itself twice and placed every 50 feet on the lift wire. The umbilical is snapped to it.

Deck Decompression Chambers and Entrance Lock 12.6.3

GENERAL 12.6.3.1 The deck decompression chambers, Figure Nos. 12-13 and 12-14, provide a pressurized environment for decompression at the termination of a dive. Each chamber is equipped with the necessary living and rest facilities for two men. When two diving teams are employed, they may be maintained at the same or different pressures. Normally, two deck decompression chambers are connected to the entrance lock. A single DDC may be



Figure 12-13 SDS 450—Deck Decompression Chamber

used when only one team is engaged in non-saturation diving. The EL acts as the primary entrance to the deck decompression chambers, and as an equalizing pressure chamber for transferring diving teams between the decompression chambers and the PTC. The entrance lock also serves as a pressurizing chamber, enabling outside medical or technical personnel to enter either deck decompression chamber without affecting the pressurization level of the complex.

DECK DECOMPRESSION CHAMBER (DDC) 12.6.3.2

—Chamber construction—Each DDC pressure chamber consists of a welded cylindrical section, two ellipsoidal heads, two flanged end trunks, and individual nozzles for gas, electrical, and liquid penetrations. Each chamber is equipped with three viewports for internal lighting, visual observation, and CCTV observation. A medical lock provides for the transfer of medical supplies, food, or other necessary articles between diving crews in the chambers and outside support personnel. Pressure-sealing hatches are mounted on the inner face of each trunk for affecting the internal chamber pressure seal. The outside end of the trunk provides a flange

for bolting the chamber to the EL or to another DDC. If only one trunk is employed, the other may provide easy access to the chamber for removing an injured diver.

- Living accommodations**—No bunks or installed sanitary facilities are provided because of space limitations and low occupancy time.



Figure 12-14 SDS 450—Entrance Lock (EL).

- Gas systems**—The DDC gas systems provide oxygen, helium-oxygen mixture, helium, and air for pressurization and life support of the divers. An inlet line pressurizes the chamber interior by supplying helium-oxygen or air. An interrelated vent and decompression system provides equalization between chambers, protection against over-pressurization, and decompression. An oxygen/air/mixed-gas breathing mask manifold accommodates four emergency masks. Pressurizing or depressurizing of the DDC is normally done from the MCC. A CO₂ scrubber, containing sufficient Baralyme for 70-manhours, is internally mounted in the DDC. The scrubber is equipped with a heat exchanger coil through which is passed heated or chilled water from an external air conditioning/heating unit to maintain desired environmental temperature. A means of sampling the internal atmosphere is provided for monitoring oxygen partial pressure. A caisson gage is provided for pressure monitoring

by chamber occupants, and external pressure gages are located at the MCC and outside the chamber.

- Liquid systems**—Each DDC has a manually operated fire suppression system. A 45-gallon water tank is mounted externally on the DDC support frame. The water is pressurized with 250 psi air supplied from the MCC. Fittings are provided to fill and vent each tank. Water is piped into the DDC to a ball valve. A length of rubber hose with nozzle is attached to the valve. Operation of the valve provides a high flow of water for approximately 30 seconds to extinguish a fire.
- Communications**—Communications to the MCC and/or a tender stationed outside the DDC are provided by a 2-wire audio system. A speaker/microphone is used in the DDC which is always open to the MCC. A jack on the outside of the DDC permits a phone set to be plugged into the intercom for tender use. The CCTV camera may be attached at the 3-inch port for visual surveillance of chamber occupants.

ENTRANCE LOCK 12.6.3.3

- Chamber structure**—The EL is a short horizontal, cylindrical pressure chamber with three flanged trunks and individual penetrations for utilities. Two viewports are provided for internal lighting and observation. Three 28-inch diameter pressure-sealing hatches are mounted internally on the trunks for achieving the internal chamber pressure seal and are equipped with gas equalization valves. The upper hatch is counterbalanced. The vertical trunk is equipped with a power closure to provide mating of the PTC and the EL.
- Gas systems**—The EL has the same basic gas systems as the two deck decompression chambers with the following exceptions: temperature is not controlled in the EL and a CO₂ scrubber is not provided. Ventilation is accomplished by flow-through of gas.
- Liquid systems**—No liquid systems other than a drain plug are fitted.
- Communications**—Communications for the EL are identical to the DDC.



Figure 12-15 SDS 450—Control Van

Control Console 12.6.4

GENERAL 12.6.4.1 The prime function of the control console, Figure Nos. 12-15, 12-16, and 12-17, is to provide operating controls and monitoring devices to ensure safe operation of the DDC, EL and PTC. Electrical power, metabolic gas, pressurization, vent and decompression, lighting, communications, and systems monitoring are all controlled from the main control console. The MCC is housed in a separate aluminum van which contains interior lighting, air conditioning and heating, and a window which permits observation of all pressure chamber exteriors.

MAIN CONTROL CONSOLE 12.6.4.2 The MCC has two separate gas sections for control of the various gas supplies and operating pressures. One section, located at the back of the van, controls the PTC. The other, located at the front of the van, controls the DDC and EL. Supply gases to the MCC and gas flow to and from respective chambers is conveyed by high pressure hoses. The operator controls pure oxygen, one helium-oxygen mixture, high and low pressure air, and from the return side of the gas section manually controls the decompression process. In addition, the operator monitors oxygen partial pressure in the DDC and PTC depth and internal pressure. The MCC controls the communication system in the DDC and all communications, including that with the PTC, are directed to the console, or the console may permit conversation with other parts of the system.

POWER CONTROL PANEL 12.6.4.3 The power control panel, located in the control van, contains all power control components for the PTC, DDC and EL. Included are circuit breakers, an inverter, transformers and a rectifier. High voltage power (115-volt, single phase, 60-Hertz) is supplied to the electrical system



Figure 12-16 SDC 450—SDC control panel in the control van.



Figure 12-17 SDS 450—DDC/EL control panel in the control van.

from the attending ship. The PTC is supplied 115-VAC split into two circuit breaker-protected circuits, one for the PTC main power and one for the PTC external lights. DDC and EL lighting is supplied by separate 26-VAC step-down transformers. A rectifier power supply provides 24 to 28-VDC to the CO₂ scrubbers in the DDC. This DC supply also powers the CCTV system through an inverter to provide closely regulated 115-volt, 60 Hertz electricity. The CCTV light is on a separate, direct 115-VAC circuit. Two 12-volt, rechargeable wet cell batteries in the control van, which operate through an automatic transfer switch, power the DDC scrubbers in the event of failure of primary power.

Life Support 12.6.5 The life support system for the DDC consists of internally-mounted CO₂ scrubbers with heat exchanger coils and an external closed-circuit hot/chilled water supply unit previously described.

Operational Data 12.6.6

PERSONNEL TRANSFER CAPSULE

Manufacturer Ocean Systems, Inc./
Superior Tank

Material SA-212B Steel

Construction Welded

Dimensions—

—Outside diameter at
equator 65 in.

—Total height with support
frame 126 in.

—Inside height
(including trunk) 92 in.

—Trunk diameter 24½ in.

—Trunk length 27¼ in.

Gas flasks—

—Helium (He):

Quantity 1

Volume (cubic feet
water volume) 0.9 CFWV

Pressure 2,250 psig

—Helium-oxygen mix (He-O₂):

Quantity 4

Volume (cubic feet
water volume) 2-1.5 CFWV,
2-0.9 CFWV

Pressure 2,250 psig

—Oxygen (O₂):

Quantity 1

Volume (cubic feet
water volume) 0.9 CFWV

Pressure 2,250 psig

—Operating temperatures:

In air 20°F to 120°F

In water 29°F to 90°F

Anchor—

—Type Lead
—Weight 1,000 lbs.

Maximum operating pressure—

—Internal 200 psig

—External (450 feet depth) 200 psig

Electrical power—

—Surface supplied
(through SPCC) 115v, 1 ϕ , 60Hz

—Emergency (on-board
batteries) 24v, DC

CO₂ scrubber—

—Type Baralyme

—Capacity 70 manhours at 3.8
mmHg ppCO₂

Diving apparatus—

—Quantity 2

—Type USN MK 1 Mask

—Hose length 100 ft.

Emergency Mask Breathing system (BIBS)—

—Quantity 2

—Type USN MK 1 Mask

—Helium-oxygen duration 0.6-manhours @
max depth

Ascent Winch—

—Manufacturer Marco

—Type passive, closed-
circuit hydraulic

UMBILICAL and LIFT WIRE

Umbilical—

—Manufacturer Ocean Systems, Inc.

—Type Construction Independent ele-
ments, tape-bound

—Length 1,200 ft.

—Gas Hoses 2 ea., ½-in. ID,
800 psi WP

—Power Cable 1 ea. composite, 4
No. 10AWG
conductors

—Communications Cable 1 ea. composite, 6
No. 12AWG shield-
ed conductors

—CCTV Cable 1 ea. composite, 1
RG-59 coax, 5 No.
18AWG, 2 No.
16AWG

—CCTV Light Cable 1 ea., 2 No. 10AWG
conductors

Lift Wire—

—Manufacturer Roebling

—Type Construction Royal Blue 18 x 7
non-rotating

—Diameter 1 in.

—Breaking Strength 42.2 tons

—Rec. Sheave Size 34 in. dia.

DEEP DIVING SYSTEM MK 1 12.7

Personnel Transfer Capsule 12.7.1

GENERAL 12.7.1.1 The Personnel Transfer Capsule (PTC), shown in Figure Nos. 12-18 and 12-19, is a submersible capsule capable of transferring two divers in full dress, with necessary work tools and associated operating equipment, from the deck of a ship to a maximum working depth of 850 feet while maintaining the required pressurized environment. The PTC consists of a spherical hull with an ingress and egress trunk with hatches, support frame, gas system, electrical system, visual and audio communications system, submersible downhaul winch, and anchor. The PTC is designed to operate with an internal pressure of 378 psi when fully charged. It is also capable of withstanding the full differential pressure externally, and can therefore be used as a hydrostat at maximum working depth with an internal pressure of one atmosphere. In this mode the PTC is used only for observation with divers and/or observers remaining inside the capsule. The PTC may be pressurized aboard ship before commencing a mission, during descent, or upon reaching working depth. When properly pressurized, the diver may then leave the PTC through the trunk and hatches located at the bottom of the hull. Attaching "hookah" life support lines permits exploration at distances up to 100 feet from the capsule.

HULL 12.7.1.2 The PTC spherical hull is fabricated of welded HY80 steel and has an outside diameter of 79 inches. A 30-inch diameter cylindrical trunk, welded to the bottom of the sphere, provides for ingress and egress of personnel and equipment. Its lower flange is the mating flange between the PTC and Entrance Lock (EL). The hull is reinforced locally to provide for ten viewports and a lifting eye. Also, two penetration plates are located 180 degrees apart at the equator of the sphere to accommodate the various electrical and gas penetrations. A protective bumper and buoyancy blocks circle the hull horizontally to protect the electrical and gas connections. A portable exterior light and portable underwater television camera are secured to the television support bracket at one of the lower viewports. The hull is mechanically mated to a support ring in the support frame by four links. The interior of the hull is equipped



Figure 12-18 DDS MK 1—PTC interior

with control panels and mechanical controls for the operation of electrical and life support systems and PTC downhaul winch. A lifting eye installed on the interior overhead permits divers to use a pulley to haul objects into the PTC through the trunk. The deck assembly is located just above the internal hatch. The outboard sections of the deck are bolted to the hull bulkhead, and the inboard sections are bolted to the hatch. Tiedown rings are provided on the deck for securing tools or equipment during a mission. Hookah hose, outlets, and electrical connections are located inside and outside of the hull.



Figure 12-19 DDS MK 1—Personnel Transfer Capsule

DEEP DIVING SYSTEM MK 1 MOD 0 GENERAL CHARACTERISTICS

Designation—

U.S. Navy Deep Diving System (DDS) MK 1
MOD 0

Operating Depth (Max)—

850 FSW

Divers Supported and Duration—

Two each, two-man teams for 14 days (max.
depth) plus decompression time

Personnel Capacity (PTC)—

2 Men

Personnel Required (Minimum)

16 Men (including divers) plus PTC handling
crew

Modes of Use and

Normal Submerged Endurance—

Observation (30-manhours)
Non-Saturation Diving
Saturation Diving (6-manhours @ max. depth)

Construction—

Modular construction, air transportable

Applicable Support Ships and Barges—

ATS, YDT-16, other ships of opportunity

PTC Utilities:

Self-contained gas supply,
Self-pressurizing to 850 FSW,
Power and communications via SPCC
Onboard emergency gas and power supply
Electrical heating of PTC interior

PTC Downhaul Winch—

Active, electrically powered, PTC-installed sub-
mersible winch

Special Features—

None

Operating Manuals—

NAVSHIPS 0994-004-9010
Mark 1 Deep Dive System (3 Vols.)

Training Manuals—

None available



Figure 12-20 DDS MK 1

Major Components and Overall Size—

Personnel Transfer Capsule—One Each

—Height—144 in.
—Width—79 in.
—Volume—148 cu. ft.
—Weight—19,000 lbs.

Deck Decompression Chamber—Two Each

—Length—162 in.
—Height—92 in.
—Width—92 in.
—Volume—320 cu. ft.
—Weight—17,225 lbs.

Entrance Lock—One Each

—Length—92 in.
—Height—109 in.
—Width—118 in.
—Volume—148 cu. ft.
—Weight—13,000 lbs.

Main Control Console (Van)—One Each

—Length—168 in.
—Height—90 in.
—Width—69 in.
—Weight—7,125 lbs.

Power Control Console (Van)—One Each

—Length—90 in.
—Height—90 in.
—Width—69 in.
—Weight—4,925 lbs.

Life Support Package—One Each

—Length—170 in.
—Height—89 in.
—Width—50 in.
—Weight—8,275 lbs.

SPCC Winch—One Each

—Length—154 in.
—Height—96 in.
—Width—110 in.
—Weight—32,300 lbs.

HATCHES 12.7.1.3 The access trunk is fitted with an internal and an external hatch.

- Internal hatch**—The internal hatch, located at the top of the trunk opens inward and seals with internal pressure. It is counterbalanced for easy operation. Latches are operable from inside or outside the PTC, and are set so that a 5 psi back pressure causes the hatch seals to relieve. A manually controlled valve is located in the hatch to equalize internal PTC pressure and trunk pressure, when required. The hatch may be latched in the open position.
- External hatch**—The external hatch, located at the bottom of the trunk, opens outward and seals with external pressure. It is also counterbalanced, and latches and seals operate the same as the internal hatch.

SUPPORT FRAME 12.7.1.4 The free-flooding support frame is constructed of tubular steel and supports the PTC on a level surface with sufficient clearance under the hull so that the external hatch can be opened and the crew can enter or leave. Loose pin connectors are installed at four points between the support ring and the PTC hull in the event of failure of one or more of the attaching links. Three 10-cubic-foot and one 4.0-cubic-foot gas flasks are mounted horizontally on the support frame. Bolted retainers protect the flasks from damage and allow for their removal. Also mounted on the support frame are an emergency power unit, junction box, a transformer/rectifier unit, a power control unit, a downhaul winch and anchor, lights, and television camera.

SUBMERSIBLE WINCH AND ANCHOR 12.7.1.5 The PTC downhaul winch is a submersible, all electric, two-speed drive winch. The winch is mounted on the support frame adjacent to the trunk, between the two pairs of gas flasks. The 2,090-pound anchor rides in a guide bracket directly below the winch when not in use. The anchor cable is 1,200 feet in length. The winch has a load capacity of 2,500 pounds at 40 fpm or 13 fpm. An automatic brake engages when motor power is off. A two-speed reversible motor controller with overload relays protects the winch motor against stall damage. Four separate controls in the PTC con-

trol the following: power to the motor, forward-reverse action, speed selection, and brake release for free-spooling. The winch may be free-spooled at a maximum rate of 8 fpm with a drag force of 600 to 700 pounds.

GAS SYSTEM 12.7.1.6 The self-supporting PTC gas system consists of all the gas handling and monitoring components (flasks, piping, gages, valves, etc.) required to independently sustain two divers for a normal eight hour mission (30 hours in an emergency). Helium, oxygen, and helium-oxygen mix are supplied by four PTC support frame-mounted flasks and one internally-mounted emergency oxygen flask. Internal pressure, gas-supply pressures, and PTC depth are monitored continuously. The system provides for metabolic oxygen addition and includes a carbon-dioxide scrubber system to control breathing atmosphere.

- Control equipment**—Color-coded valves at internal and external locations on the PTC provide for control of all gas system functions.
- Oxygen system**—The PTC oxygen system consists of one 4.0-cubic-foot-volume externally-mounted flask, one .072-cubic-foot-volume internally-mounted flask, and associated valves, piping, and fittings. The externally-mounted oxygen flask provides oxygen makeup inside the PTC for two divers for a maximum duration of 30 hours. The smaller internally-mounted flask is used to supply emergency makeup oxygen to the PTC interior for 1.5 hours per man in the event of failure of the externally-mounted flask.
- Helium system**—The PTC helium system consists of two 10-cubic-foot-volume externally-mounted flasks, and associated valves, piping, and fittings. The helium system is designed to self-pressurize the PTC and purge oxygen from all PTC electrical units to alleviate any fire hazard. The system contains sufficient helium to charge the PTC interior from one atmosphere to 378 psi (850 feet) without affecting mission capabilities.
- Helium-oxygen mix system**—The mix system consists of one 10-cubic-foot-volume helium-oxygen mix flask, an internal mask breathing system (BIBS), and associated valves, piping, and fittings. The mix

system also supplies breathing gas (helium-oxygen mixture) to the hookah units for use outside the PTC. In addition, breathing mix is supplied to the BIBS in the event of contamination of the internal atmosphere. There is sufficient gas for two hours per man, plus a one hour per man reserve, at 850 feet, using the MK 11 UBA.

- **Vent and environmental monitoring system**—The system consists of a combination of gages and valves to control and regulate internal pressure of the PTC. A relief valve, set at 385 psi, and a manual vent valve prevent over-pressurization of the PTC in the event of a line rupture causing full flask discharge into the PTC. A needle valve is employed to control depressurization. A sea-pressure gage, calibrated in feet of seawater, monitors PTC depth. A transducer provides readout of depth and PTC internal pressure to the Main Control Console (MCC). A 0 to 100 psig differential gage, calibrated in feet of seawater, provides pressure monitoring during depressurization.
- **Carbon-dioxide scrubber system**—The scrubber system consists of two blowers and a canister containing enough Baralyme to remove 24-manhours of carbon-dioxide. A spare canister permits CO₂ scrubbing for a total of 48-manhours. One of the blowers forces the PTC atmosphere through the canister where CO₂ and odors are absorbed. The second blower is for emergency use. Blower drive motors are helium-purged.
- **Instrumentation**—Instrumentation in the PTC is designed to ensure safe conditions for the divers at all times and to provide an optimum degree of comfort. PTC instrumentation monitors oxygen partial pressure (ppO₂) pressure in the PTC. Carbon-dioxide partial pressure (ppCO₂) is manually monitored. All controls and instruments concerned with personnel safety are provided with necessary redundancy.

ELECTRICAL SYSTEMS 12.7.1.7

- **Primary electrical system**—Primary electrical power for normal operation of the PTC is surface-supplied and transmitted to the PTC through the Strength-Power-Communication Cable (SPCC) at 450-volt, 3-phase, 60-Hertz. A harness directs the power wires to an oil-filled, pressure-compensated,

junction box mounted on the PTC support frame. In the junction box, wires are connected to the PTC transformer/rectifier unit and the submersible winch remote-controlled two-speed reversing controller. Power from the transformer supplies 230-volt, 3-phase, 60-Hertz power to carbon-dioxide scrubber motors, exterior lights, and power tools outlet; and 115-volt, 1-phase, 60-Hertz power to a television light. In addition, a bridge-type rectifier delivers 28-volt DC power for use within the PTC for instrumentation, communication, lighting, power control circuits, and diver suit heaters. When the submersible winch is not being used, the 450 VAC line used to power the winch motor may be applied to externally-mounted heating elements to heat the PTC. The heater control switch on the PTC Control Panel is used to turn the heater to the high heat (8.8 KW), low heat (4.2 KW) and off positions. A thermostat keeps the internal temperature below 100°F.

- **Secondary electrical system (emergency)**—A 25-ampere-hour, 28-volt nickel-cadmium battery provides secondary power for emergency operation to supply necessary services in the event of loss of primary electrical power from the surface. The battery is located in a pressure-resistant housing mounted on the PTC support frame. The battery is charged and maintained when the PTC is on the deck of the attending vessel. A remote-reading ampere-hour meter gives a continuous reading of state-of-charge of the battery. The battery supplies power for all services necessary to provide safety requirements in the PTC for a minimum of 25-ampere hours at working depth, during which time the scrubber may be operated up to 2.3 hours on a five minutes on, ten minutes off, duty cycle.

COMMUNICATIONS (AUDIO AND VISUAL) 12.7.1.8

The PTC communications system is part of the overall communication system for the Deep Diving System MK 1. The system is divided into three individual systems to ensure efficient operation under a variety of conditions.

- **Hard-wire intercom system**—The intercom system is an amplified voice system providing communications within the PTC, between the Main Control Console, the divers, the deck winch operator, Deck Officer, and Deck Decompression Chambers.

- **Underwater Mobile Sound Communication Set (UQC)**—The UQC is an emergency system providing voice communications between the PTC and the underwater telephone system of the attending vessel. A homing tone can be transmitted to aid in locating a disabled PTC. The UQC system is designed for use in event of failure or disconnection of the SPCC.
- **Closed-Circuit Television (CCTV)**—A video channel from the PTC to the MCC provides continuous observation of personnel inside the PTC. In addition, the underwater camera may be removed from the PTC at the work site and used as a portable unit to explore working areas or monitor work being performed. The camera is capable of deployment to 100 feet from the PTC.

Strength-Power-Communication Cable and Deck Winch 12.7.2

STRENGTH-POWER-COMMUNICATION CABLE (SPCC) 12.7.2.1 The SPCC is a 1,400-foot composite cable which acts as a strength member to raise



Figure 12-21 DDS MK 1—SPCC winch

and lower the PTC from the maximum working depth, and which conducts electrical power, wired communications, and coaxial transmission (CCTV signals) between the MCC and the PTC. The SPCC terminates in a mechanical breakout which is secured to a lifting eye on top of the PTC.

SPCC DECK WINCH 12.7.2.2 The deck winch, Figure No. 12-21, consists of a winding drum for receiving and stowing cable, level winding device for receiving cable on the drum, slip ring assembly capable of transmitting electrical signals and power from rotating ends of the cable to the PTC, and a drive to turn and control the winch. In addition, the winch is equipped with mechanical brakes, remote controls, and performance monitoring gages to ensure proper control of winch actions.

Deck Decompression Chambers and Entrance Lock 12.7.3

GENERAL 12.7.3.1 The deck decompression chambers, Figure Nos. 12-22 and 12-23, provide a pressurized environment to maintain off-duty living for teams in a saturated pressure state thus eliminating the need for decompression at the termination of each dive. Each chamber is equipped with the necessary living, sanitary, and rest facilities for two men. In addition, the decompression chambers are used as the primary means to affect decompression, individually at different pressures, or simultaneously at the same pressure. Normally, two deck decompression chambers are connected to the Entrance Lock (EL). The EL acts as the primary entrance to the deck decompression chambers, and as an equalizing pressure chamber for transferring diving teams between the decompression chambers and the PTC. The entrance lock also serves as a pressurizing chamber, enabling outside medical or technical personnel to enter either deck decompression chamber without affecting the pressurization level of the complex.

DECK DECOMPRESSION CHAMBER (DDC) 12.7.3.2

– **Chamber construction**—Each DDC pressure chamber consists of a welded cylindrical section, two ellipsoidal heads, two flanged end trunks, and two penetration plates for gas, electrical, and liquid



Figure 12-22 DDS MK 1—Deck Decompression Chamber



Figure 12-23 DDS MK 1—DDC interior

penetrations. Each chamber is equipped with five viewports for internal lighting, visual observation, and CCTV observation. A medical lock provides for the transfer of medical supplies, food, or other necessary articles between diving crews in the chambers and outside support personnel. Pressure-sealing hatches are mounted on the inner face of each trunk for affecting the internal chamber pressure seal. The outside end of the trunk provides a flange for bolting the chamber to the EL or to another DDC. If only one trunk is employed, the other may provide easy access to the chamber for removing an injured diver.

- Living accommodations—The living quarters in each DDC include two sleeping bunks, shower, wash basin, water closet, table, and compartments for stowage of personal articles.
- Gas systems—The DDC gas systems provide oxygen, helium-oxygen mixture, helium, and air for pressurization and life support of the divers. An inlet line pressurizes the chamber interior by supplying helium or air. An interrelated vent and decompression system provides equalization between chambers, protection against over-pressurization, and decompression. An oxygen breathing mask manifold and a helium-oxygen mixture breathing mask manifold accommodate four emergency masks each. Pressurizing or depressurizing of the DDC is normally done from the MCC. Life support equipment is externally mounted on each DDC and consists of: a scrubber to remove CO₂ and provide atmosphere circulation; a heat exchanger to control atmospheric humidity, heating, or cooling. A means of sampling the internal atmosphere is provided for environmental monitoring of CO₂ and oxygen partial pressure. An automatic oxygen addition system maintains oxygen partial pressure at preset levels. Manual override is provided in the MCC, and a manual control is provided on the chamber. A pressure relief system prevents over-pressurization of chambers.
- Liquid systems—The sanitary liquid system for each chamber consists of a hot and cold water supply for operation of the wash basin, shower, water closet, and fire hose. Wash basin and shower waste water empty into a common sump and are dis-

charged by chamber pressure to the ship's drain. An eductor provides for drainage at normal atmospheric pressure. Waste from the water closet is discharged directly into an interim waste-holding tank mounted on the chamber, then to the main waste-holding tank in the life support package, and then to the ship's waste system. An automatic fire suppression system in each DDC consists of an externally-mounted fire suppression water tank, two externally-mounted helium tanks which provide pressure to the water tank, internal fog nozzles, and internal flame sensors.

- **Communications**—Deck decompression chamber communications consists of an intercom system interconnected to the MCC. A CCTV system monitors the DDC interior. Music can be piped into either DDC from an AM/FM tuner located in the MCC.

ENTRANCE LOCK (EL) 12.7.3.3

- **Chamber structure**—The EL is a spherical pressure chamber with four flanged trunks and a penetration plate for gas, electrical, and liquid penetrations. Viewports are provided for internal lighting and CCTV observation. Pressure-sealing hatches are mounted internally on three interface trunks for affecting the internal chamber pressure seal. The upper hatch is counterbalanced. An external pressure-resisting closure on the fourth trunk provides for ingress and egress to the EL. The vertical trunk is equipped with a power closure to permit mating of the PTC to the EL.
- **Gas system**—The EL has the same basic gas systems as the two deck decompression chambers with the following exceptions: Humidity and temperature are not controlled in the EL, and an additional air system manifold is provided to operate the mating closure between the PTC and the EL.
- **Liquid system**—The EL is fitted with a waste water drain employing a drain eductor which permits drainage when the chamber interior is at normal atmospheric pressure. Waste is evacuated by gas pressure when the chambers are pressurized for diving operations.
- **Communications**—Communications for the EL are identical to the DDC.

Control Consoles 12.7.4

GENERAL 12.7.4.1 The prime function of the control consoles, Figure No's. 12-24, 12-25, and 12-26, is to provide operating controls and monitoring devices to ensure safe operation of the DDC, EL, and PTC. The consoles consist of the main control console and the power control console. Electrical power, metabolic gas, pressurization, vent and decompression, lighting, communications, and system monitoring are all controlled from the consoles. Each module contains interior lighting, and a window in the main control console permits observation of all pressure chamber exteriors.



Figure 12-24 DDS MK 1—Main Control Console

MAIN CONTROL CONSOLE (MCC) 12.7.4.2 The MCC gas section provides for control of the various gas supplies and operating pressures in the DDC and the EL. The operator controls pure oxygen (O_2), three helium-oxygen mixtures ($He-O_2$ mix), helium (He), compressed air, and from the return side of the gas section manually controls the decompression process. A separate section of the console provides for gas-charging of the PTC gas supply flasks with helium, oxygen, helium-oxygen or air. In addition, the operator monitors diver's oxygen partial pressure, PTC oxygen partial pressure and PTC depth and internal pressure.



Figure 12-25 DDS MK 1—MCC gas controls



Figure 12-26 DDS MK 1—MCC communications and monitoring systems

The MCC controls the communication system in the DDC and all communications, including that with the PTC, are directed to the console, or the console may permit conversation with other parts of the system. A tape recorder is installed in the MCC for monitoring intercom conversations. An AM/FM tuner provides entertainment to the off-duty diving teams in the DDC. Four television monitors mounted in the control console constantly monitor the four closed-circuit TV cameras installed on the DDC, EL, and PTC.

POWER CONTROL CONSOLE 12.7.4.3 The PCC contains all power-control components including circuit breakers, emergency batteries, battery charger, inverter, transformers, and an air-conditioner unit for the console complex. High voltage power (450-volt, 3-phase, 60-Hertz) is supplied to the elec-



Figure 12-27 DDS MK 1—Life Support Package

trical system from the attending ship. The high voltage power is directed to the SPCC deck winch, the life support system, MCC and PCC heating and air conditioning, DDC heating, and the PTC. Low voltage power is supplied by a step-down transformer to operate MCC and PCC lighting, PCC/PTC battery charger, four timers, oxygen and CO₂ analyzers, intercom system, TV system, and depth measuring system. Emergency batteries automatically supply power to critical electrical equipment in the event of failure of primary power. A 24-volt DC system of eight 34AH batteries, floating on the battery charger, supplies power to the deck complex, pressure transducers, oxygen valves, fire suppression system and annunciator.

Life Support Package (LSP) 12.7.5

GENERAL 12.7.5.1 The LSP, Figure No. 12-27, is a separate module containing components of the life support system and sanitary system.

LIFE SUPPORT SYSTEM 12.7.5.2 The LSP life support system consists of the following components—

- Low pressure pumps to recirculate hot water to heat exchangers mounted on the DDC.
- Immersion heaters to reheat water circulated by the low pressure pumps.

- Controls for DDC and EL scrubbers.
- High pressure pumps for DDC internal water supply.
- Water heater for DDC showers.
- Brine chillers for DDC air conditioning.

SANITARY SYSTEM 12.7.5.3 The LSP sanitary system consists of the following components—

- Sewage macerating pump.
- Sewage holding tank.
- Pumps to transfer sewage from the LSP to the ship's sewage system.

Operational Data 12.7.6

PERSONNEL TRANSFER CAPSULE

Manufacturer	FMC (Ordnance Eng. Div.)
Material	HY80 Steel
Construction	Welded
Dimensions—	
— Outside diameter at equator	79 in.
— Total height with support frame	144 in.
— Inside height (including trunk)	96 in.
— Trunk diameter	30 in.
— Trunk length	23 in.
Gas flasks—	
— Helium (He):	
Quantity	2
Volume (cubic feet water volume)	10 CFWV
Pressure	3,000 psig
— Helium-oxygen mix (He-O ₂):	
Quantity	1
Volume (cubic feet water volume)	10 CFWV
Pressure	3,000 psig
— Oxygen (O ₂):	
Quantity	1
Volume (cubic feet water volume)	4.0 CFWV
Pressure	3,000 psig

— Operating temperatures:	
In air	20° F to 120° F
In water	29° F to 90° F
— Emergency oxygen (O ₂):	
Quantity	1
Volume (cubic feet water volume)	.072 CFWV
Pressure	3,000 psig
Anchor—	
— Type	Lead
— Weight	1,000 to 2,080 lb.
Maximum operating pressure—	
— Internal	378 psig
— External (850 feet depth)	378 psig
Electrical power—	
— Surface supplied (trough SPCC)	440v, 3 ϕ , 60hz
— Emergency (on-board batteries)	24v, DC
CO ₂ scrubber—	
— Type	Baralyme
— Capacity	30-manhours 3.8 mmHg ppCO ₂
Hookah system (UBA)—	
— Quantity	2
— Type	MK 11
— Hose length	100 ft.
Emergency Mask Breathing system (MBS)—	
— Quantity	2
— Type	MK 11
— Helium-oxygen duration	2-manhours

DOWNHAUL WINCH

Manufacturer	Electro Kinetics Corp.
Type	2-speed, electric, reversible
Overall dimensions	30 in. x 22 in. x 34 in.
Maximum weight in air (w/cable installed)	1,463 lb.
Power requirements	440v, 3 ϕ , 60hz
Drum capacity	1,250 ft.
Cable (CRS 6X37 IWRC):	
— Diameter	3/8 in.

— Length	1,250 ft.
— Break strength	12,000 lb.
Indicators— — Tension	0 to 10,000 lb.
— Footage	0 to 1,200 ft.
Performance—	
— Maximum rated load	2,500 lb. @ fpm
— Minimum rated speed	2,500 lb. @ 12 to 15 fpm
— Water temperatures	20° F to 90° F
— Water pressures	1,700 ft
— Free spool capability	8 fpm w/drag force of 600 to 700 lb.
— Brake	Automatic

STRENGTH-POWER-COMMUNICATION-CABLE

Manufacturer	Simplex Corp.
Type Construction	Double layer plow shear steel
Dimensions—	
— Overall diameter	2 in.
— Overall length	1,400 ft.
Breaking strength	141,000 lb.
Fatigue strength	25,000 lb. @ 60,000 cycles

Electrical and communications conductors—

— No. 10, stranded-wire conductors	9
— Multistrand coaxial cables— type RG-59/U	3
— No. 18, shielded single conductors	12
— No. 18, shielded conductor pairs	12

SPCC DECK WINCH

Manufacturer	Western Gear
Type	Electro-hydraulic
Drive	Fixed displacement hydraulic motor
Control	Electro-mechanical, variable speed
Drum diameter	60 in.
Drum capacity (2.12-in. cable)	1,450 ft.

Motor—	
— Manufacturer	General Electric
— Type	30 hp, 3 ϕ , 440vac, 60hz

Dimensions (overall)—

— Length	154 in.
— Height	96 in.
— Width	110 in.
Total weight	25,000 lb.
Manual brakes—	
— Type	Flat band
Automatic brakes—	
— Type	Hydraulic, disc
Level wind	Chain-driven, two-sheave

Slip ring assembly—

— Coaxial for 3 RG 59/U coaxial cables	6
— Red brass for 440vac through copper graphite brushes	6
— Coin silver for 9 circuits of AWG #18 through silver graphite brushes	18
— Coin silver for 12 circuits of AWG #18 through silver graphite brushes	36

Indicators—

— Cable tension	0 to 30,000 lb.
— Cable speed (payout or reel-in)	0 to 60 fpm
— Total footage	resettable, 1,500 ft.
— PTC anchor cable tension	0 to 10,000 lb.
— PTC anchor cable footage	0 to 1,200 ft.

Performance—

— Rated load (raise or lower)	9,000 lb. @ 40 fpm
— Maximum rated load (raise)	30,000 lb. @ 10 fpm
— Maximum rated speed (raise or lower)	5,000 lb. @ 60 fpm

Environmental requirements—

— Operating	20° F to 120° F
— Stowage	—20° F to 120° F

DEEP DIVING SYSTEM MK 2 12.8

The Deep Diving System Mark 2 consists of a family of structures, operating systems, and associated equipment designed to support saturation diving operations on board the ASR-21 class of Navy submarine rescue ships and other specially configured ships. Major components of the diving system are: (1) two deck decompression chambers with their life support systems; (2) two personnel transfer capsules; (3) two main control consoles; (4) two SPC cable winches and their associated Strength, Power and Communications (SPC) cables; (5) ship support equipment; (6) two downhaul winches and downhaul cables; and (7) one helium recovery system. The components (port set, starboard set) that make up the diving system actually form two operational diving systems (port and starboard) with a common helium recovery system. The diving system is not self-supporting and depends on the support vessel for electrical power, potable water, chilled water, steam, handling, waste disposal, and compressed gases. All of the major units and their arrangements are shown in Figure No. 12-29.

Personnel Transfer Capsule 12.8.1

GENERAL 12.8.1.1 The Personnel Transfer Capsule (PTC), shown in Figure Nos. 12-28 and 12-30, is a submersible capsule capable of transferring four divers in full diving dress, with necessary work tools and associated operating equipment, from the deck of a ship to a maximum working depth of 850 feet while maintaining the required pressurized environment. The PTC consists of an elongated spherical hull with an ingress and egress trunk with hatches, support frame, gas system, electrical system, visual and audio communications system, submersible downhaul winch and anchor. The PTC is designed to operate with an internal pressure of 378 psi when fully charged. It is also capable of withstanding the full differential pressure externally and can therefore be used as a hydrostat (with removable external hatch installed) at maximum working depth with an internal pressure of one atmosphere. In this mode the PTC is used only for observation with divers and/or observers remaining inside the capsule. When operating in the pressurized mode, the PTC is pressurized to operat-



Figure 12-28 DDS MK 2—Personnel Transfer Capsule

ing depth aboard ship before commencing a mission. At depth, the diver may then leave the PTC through the trunk and internal hatch located at the bottom of the hull. Attaching "hookah" life support lines permits exploration at distances up to 150 feet from the capsule.

HULL 12.8.1.2 The PTC spherical hull is fabricated of welded HY80 steel and has an outside diameter of 84 inches. A 40-inch diameter cylindrical trunk, welded to the bottom of the sphere, provides for ingress and egress of personnel and equipment. Its lower flange is the mating flange between the PTC and transfer trunk of the Inner Lock of the DDC. The hull is reinforced locally to provide for eight viewports and a lifting eye. Also, a 12" wide straight cylindrical penetration plate located between the two hemispherical heads of the sphere accommodate the various electrical and gas penetrations. An upper and lower protective bumper ring circle the hull horizontally to protect the electrical and gas connections. Six exterior lights and two underwater television cameras (one portable) are secured to the external framework surrounding the pressure hull. The interior of the hull is equipped with control panels and mechanical controls for the operation of electrical and life support systems and PTC downhaul winch. A lifting eye installed on the interior overhead permits divers to use a block and tackle to haul objects into the PTC through the trunk. The internal deck of the PTC consists of a circular metal plate shelf surrounding the hatch. The folding removable PTC boarding ladder is stowed on

DEEP DIVING SYSTEM MK2 GENERAL CHARACTERISTICS

Designation: U. S. Navy Deep Diving System (DDS)
MK 2, MOD 0, MOD 1

Configuration: A DDS MK 2 diving complex consists of two complete systems. The complex consists of 2 DDC's, 2 PTC's, 2 MCC's, 2 LS's, 2 SPCC's and winches. Data cited below is for each system.

Operating Depth (Maximum)—
850 FSW

Divers Supported and Duration—
One each, four-man team for 14 days (max depth) plus decompression time

Personnel Capacity (PTC)—
4 Men

Personnel Required (Min)—
17 Men (including divers) plus PTC handling crew

Modes of Use and Normal

Submerged Endurance—

Observation (48-manhours)
Non-Saturation Diving
Saturation Diving (16-manhours @ max depth)

Construction—

Ship-Installed

Applicable Support Ships and Barges—

IX-501 (MK 2, MOD 0)
ASR-21 Class (MK 2, MOD 1)

PTC Utilities—Self-contained gas supply;
Self-pressurizing to 200 FSW (MOD 0), 500 FSW (MOD 1);
Power and communications via SPCC; onboard emergency gas and power supply;
Hot water heating (surface-supplied hose) of PTC interior.

PTC Downhaul Winch—

Active, electrically powered, submersible winch suspended by cables under PTC

Special Features—

Decompression of 34 rescued submariners in DDC



Figure 12-29 DDS MK 2 aboard the IX501.

Major Components and Overall Size—

Personnel Transfer Capsule—One Each

—Height—117 in.
—Width—85 in.
—Volume—240 cu. ft.
—Weight—26,000 lbs.

Deck Decompression Chamber (Overall)—One Each

—Length—314 in., diameter—80 in.
—Weight—39,500 lbs.
—Volume (inner lock)—750 cu. ft.
(outer lock)—250 cu. ft.

OTHER System Components Not Itemized

Operating Manuals:

Deep Dive System MK 2
NSRDL (Panama City) TM
—Diver Communication System—DDS MK 2 MOD 0
NSRDL (Panama City) TM
—PTC/Diver Water Heating System—DDS MK 2 MOD 0

Training Manuals—

NAVPERS
Deep Diving System MK 2 MOD 0
—Trainee's Guide
NAVPERS 94495
—Trainee Guide for Deep Diving System MK 2 MOD 1

Note—The DDS MK 2 MOD 0 and MOD 1 are essentially the same. The MOD 1 incorporates improved DDC hatches, viewpoints, PTC communications, PTC gas supply, and oxygen monitoring system.



Figure 12-30 DDS MK 2—PTC interior

the internal deck when not in use. In use, the ladder mounts on brackets and hangs down through the PTC trunk to aid the divers' entrance and exit. The folding removable PTC boarding ladder is stowed on the internal deck when not in use. In use, the ladder mounts on brackets and hangs down through the PTC trunk to aid the divers' entrance and exit.

HATCHES 12.8.1.3 The access trunk is fitted with a permanent internal hatch and a removable external hatch for hydrostatic dives.

- Internal hatch**—The internal hatch located at the top of the trunk, opens inward and seals with internal pressure. It is spring counterbalanced for easy operation.
- External hatch**—A separate external hatch assembly is provided that may be attached to the mating flange at the bottom of the access trunk. This pressure sealing hatch must be removed prior to any operations requiring mating of the PTC and DDC.

SUPPORT FRAME 12.8.1.4 The upper and lower bumper ring assemblies provide mounting points for ten 6-cubic-foot 3000-psi gas flasks (MOD 1, 5 each MOD 0) and associated piping and manifolds, battery container, transformer container, hookah hoses and hangers, suit heating cables, exterior lights, and TV cameras. Bumper cushions are fitted to the outboard surface of the framework's two main rings for protection purposes. The gas flasks, transformer container, and battery container are mounted vertically between the two bumper rings and are strapped in position. This framework terminates above the bottom face of

the transfer trunk to permit PTC attachment to the escape hatch of submarines. Consequently, the PTC cannot be placed directly on deck for servicing. A separate stowage stand is used to support the PTC when attaching and detaching the external hatch and downhaul winch.

SUBMERSIBLE WINCH AND ANCHOR 12.8.1.5

A removable downhaul winch and associated downhaul cable is suspended beneath the PTC by two downhaul winch support cable assemblies which include quick disconnect pelican hooks. A single electrical cable connects to the downhaul winch to provide power and control signals. This winch is primarily used to haul the PTC to the bottom against its own positive buoyancy at a slow or fast rate and for carrying an anchor or clump for bottom anchoring. A built-in hold mode maintains a downhaul cable pay out tension of approximately 750 pounds during hauling operations. A separate brake mode is used to lock the downhaul winch when the desired depth is reached or whenever it is desired to have the winch drum locked. The PTC anchor may be any suitable clump or explosive anchor having holding power from 2,000 pounds to 10,000 pounds, depending upon the operational situation (i.e. current, sea state, mission type, etc.). The maximum hauling capacity of the downhaul winch is 2,500 pounds. A downhaul cable cutter is provided to sever the anchor cable in case of an emergency, or the entire downhaul winch may be dropped by firing the two attaching explosively-separable eyebolts and the explosively-actuated electrical cable cutter.

GAS SYSTEM 12.8.1.6 The self-supporting PTC gas system consists of all the gas handling and monitoring components (flasks, piping, gages, valves, etc.) required to independently sustain 4 divers for a normal eight-hour mission (30 hours in an emergency). Helium, oxygen, and helium-oxygen mix are supplied by ten externally-mounted flasks (MOD 1, 5 each MOD 0) and one internally-mounted emergency oxygen flask. Internal pressure, gas-supply pressures, and PTC depth are continuously monitored. The system contains metabolic oxygen addition and a carbon-dioxide scrubber system which are used by the crew to control the breathing atmosphere.

—**Control equipment**—Color-coded and numbered valves at internal and external locations on the PTC provide for control of all gas system functions.

—**Oxygen system**—The PTC oxygen system consists of one 6.0 cubic-foot-volume externally mounted flask, one 0.35-cubic-foot-volume internally-mounted oxygen flask, and associated valves, piping, and fittings. The externally-mounted oxygen flask provides oxygen makeup inside the PTC for four divers for a maximum duration of 22 hours. The smaller internally-mounted flask is used to supply emergency makeup oxygen to the PTC interior for 10 hours per man, in the event of failure of the externally-mounted flask.

—**Helium system**—The PTC helium system consists of five 6.0-cubic-foot-volume externally-mounted flasks (MOD 1, 2 each MOD 0), and associated valves, piping, and fittings. The helium system is designed to self-pressurize the PTC and purge oxygen from all PTC electrical units to alleviate any fire hazard. The system contains sufficient helium to charge the MOD 1 PTC interior from one atmosphere to 282 psi (600 feet) without affecting mission capabilities.

—**Helium-oxygen mix system**—consists of five 6.0-cubic-foot-volume helium-oxygen mix flasks (MOD 1, 2 each MOD 0), an internal mask breathing system (BIBS) and associated valves, piping, and fittings. The mix system supplies breathing gas (helium-oxygen mixture) to the hookah units for use outside the PTC. In addition, breathing mix is supplied to the BIBS in the event of contamination of the internal atmosphere. In the MOD 1 there is sufficient gas for three hours per man, plus a 1.5 hour per man reserve, at 1,000 feet using the MK 11 UBA. Provision is also made for supplying diver breathing gas via umbilical from the surface.

—**Vent and environmental monitoring system**—consists of a combination of gases and valves to control and regulate internal pressure of the PTC. A relief valve, set at 416 psi, and a manual vent valve prevent over-pressurization of the PTC in the event of a line rupture causing full flask discharge into the PTC. A needle valve is employed to control depressurization. A sea-pressure gage, calibrated in feet of seawater, monitors PTC depth, and a caisson

gage indicates internal pressure. A transducer provides readout of depth and PTC internal pressure to the Main Control Console (MCC). Equalization and vent valves are also provided for the access trunk. A 0 to 100 psig differential gage, calibrated in feet of seawater, provides monitoring control during depressurization.

—**Carbon dioxide scrubber system**—The CO₂ removal system consists of two scrubber assemblies with each assembly having a replaceable canister filled with CO₂ removal material. The main unit of a scrubber assembly is the blower/transition chamber. The centrifugal flow fan is mounted on the discharge end of the chamber and is driven by a 31.5-volt AC induction motor. A canister assembly, fabricated from stainless steel, fits into the inlet end of the chamber. Canisters are filled with Baralyme (48-manhours duration) and are fitted with screens at both ends. An armablu felt filter at the canister discharge end prevents the transfer of dust from the absorbent material to the PTC atmosphere. The second scrubber assembly is reserved for emergency use.

—**Interior heating**—Interior heating of the PTC is accomplished with surface-supplied hot water. The hot water from a separate umbilical passes through heat exchangers in the discharge of the scrubber assemblies to warm the recirculating gas.

—**Instrumentation**—Instrumentation in the PTC is designed to insure safe conditions for the divers at all times and to provide an optimum degree of comfort. The partial pressure of oxygen is monitored and controlled automatically. An independent O₂ analyzer is also provided. Another analyzer monitors CO₂ level. Oxygen measurements are transmitted to the MCC through the SPCC in addition to internal, external and differential pressure readings.

ELECTRICAL SYSTEMS 12.8.1.7

—**Primary electrical system**—Primary electrical power for normal operation of the PTC is surface-supplied and transmitted to the PTC through the Strength-Power-Communication Cable (SPCC) at 450-volt, 3-phase, 60-Hertz. A harness directs the power wires to an oil-filled, pressure-compensated, circuit breaker container on the exterior of the PTC.

The circuit breaker container provides power to two external electrical components—the downhaul winch motor starter and the oil-compensated transformer control module. Within the module a 440V/120V 3 ϕ stepdown transformer provides power to the helium-purged 120V circuit breaker panel in the PTC. A separate transformer/rectifier unit supplies 28V DC to the helium-purged low voltage panel within the PTC. All non-critical electrical components including exterior lights, normal interior lights, electrowriter transceiver and helium speech amplifier are powered from the 120 volt panel. The 28V DC panel supplies all components which must operate in an emergency involving loss of primary power. These components include an internal emergency light, ppO₂ monitor and control, CO₂ scrubbers, depth transducer, downhaul winch controls and explosive device control panel. Electrically detonated explosive bolts and cutters are installed for severing the SPCC connection, downhaul wire and downhaul winch in emergency situations. With all PTC electrical systems energized, 34 kw of primary power is required.

- Secondary electrical system (emergency)**—A 28-volt nickel-cadmium battery pack provides secondary power for emergency operation of necessary services in the event of loss of primary power. The batteries are housed in an oil-compensated container on the exterior of the PTC. It provides power to a transfer panel which in turn supplies the 28 VDC panel. It can be charged when the PTC is on deck of the support ship. A self-powered, flashing signal beacon on the top of the PTC can be actuated from inside for locating purposes.

COMMUNICATIONS (AUDIO AND VISUAL) 12.8.1.8

The PTC communications system is part of the overall communication system for the Deep Diving System MK 2. The system is divided into five individual systems to ensure efficient operation under a variety of conditions.

- Hard-wire intercom system**—The intercom system is an amplified voice system employing a helium unscrambler which provides communications within the PTC, between the Main Control Console, the divers, the deck winch operator, Deck Officer, and Deck Decompression Chambers.

- Underwater Mobile Sound Communication Set (UQC)**—The UQC system is an emergency system providing voice communications between the PTC and the underwater telephone system of the attending ship. The UQC system is designed for use in event of failure or disconnection of the SPCC.

- Closed-Circuit Television (CCTV)**—consists of two video channels from the PTC to the MCC. Both cameras are normally mounted outside the PTC. One camera looks through a lower viewport into the PTC at the control panel circuit breakers and gages. The second camera is portable and used for transmitting pictures of the work site. To be deployed, it must be brought into the PTC and attached to an extension cable. Video signals from both cameras are transmitted via the SPCC.

- Sound-Powered Phones**—The PTC is equipped with an SP phone system for audio communications to the MCC in the event of loss of the normal audio system. The system consists of a control panel, handset and a headset. The control panel contains a phone call switch, an alarm switch and an incoming phone call light.

- Electrowriter**—The electrowriter provides a means of transmitting written or drawn information between the PTC and MCC. A transceiver at each location converts the image to an electrical signal which is transmitted over the SPCC.

Strength-Power-Communication Cable and Deck Winch 12.8.2

STRENGTH-POWER-COMMUNICATION CABLE (SPCC) 12.8.2.1 The SPCC is a 1,400-foot armored, torque balanced composite cable which acts as a strength member to raise and lower the PTC from the maximum working depth, and which conducts electrical power, wired communications, instrumentation signals and coaxial transmission (CCTV signals) between the MCC and the PTC. The SPCC terminates in a mechanical breakout which is secured to a lifting eye on top of the PTC.

SPCC DECK WINCH 12.8.2.2 The deck winch, Figure No. 12-31, consists of a winding drum for receiving and stowing cable, level winding device for receiving cable on the drum, slip ring assembly ca-



Figure 12-31 DDS MK 2—SPCC winch

pable of transmitting electrical signals and power from rotating ends of the cable to the PTC, and a drive to turn and control the winch. In addition, the winch is equipped with brakes, remote controls and performance monitoring gages to ensure proper control of winch actions.

Deck Decompression Chamber 12.8.3

GENERAL 12.8.3.1 The deck decompression chambers, Figure Nos. 12-32 and 12-33, provide a pressurized environment to maintain off-duty living for two teams in a saturated pressure state thus eliminating the need for decompression at the termination of each dive. Each chamber is equipped with the necessary living, sanitary, and rest facilities for four men. In addition, the decompression chambers are used as the primary means to affect decompression. The deck decompression chamber consists of an inner lock (IL), outer lock (OL), medical lock and transfer trunk. The transfer trunk and medical lock are built into the inner lock which is the primary living compartment of the DDC. The outer lock is employed for the pressurization and transfer of medical and other personnel into and out of the inner lock and also houses the sanitary facilities for the DDC. In normal operation the inner and outer locks are maintained at the same pressure to permit full use of facilities by DDC occupants.

CHAMBER CONSTRUCTION 12.8.3.2 Each DDC is a three-lock pressure chamber designed to withstand an internal pressure of 378 psig (850 feet of sea water). The main structure of the chamber is cylindrical and measures 7 ft. 6 in. in diameter and is 24 ft. 1¼ in. long. It consists of three cylinders welded together with a transition ring between two of the cylinders that forms part of the inner lock head. The ends of the chamber consist of elliptical dished heads welded to the main structure. The three main cylindrical sections, dished heads, and hatches are formed from HY-80 steel plate. The two dished heads at the chamber entrance end have reinforced center hatch-



Figure 12-32 DDS MK 2—Deck Decompression Chamber Inner Lock Interior



Figure 12-33 DDS MK 2—Deck Decompression Chamber Out Lock Interior

ways 3 ft. 6 in. in diameter. These hatchways are fitted with hatches, each consisting of a flange containing an ethylene propylene gasket and an elliptical dished head which forms the center section of the hatch. A 2-inch viewport is mounted in the center of the inner lock hatch to provide visual contact between the inner and outer lock personnel. The upper portion of the chamber is fitted with a transfer trunk and a transfer hatch 30 inches in diameter to permit personnel transfer between the DDC and the PTC. The transfer hatch swings down into the DDC inner lock and is fitted with a self-locking rotary actuator for power operation. To

aid in personnel transfer, a short section of ladder is attached to the inside of the transfer trunk which aligns with the main ladder. The main ladder is powered by a rotary actuator and swings down into a cut-out in the deck. The ladder is covered by a section of decking when it is not being used. Both hatch and ladder actuators are supplied with pressurized fresh water as a hydraulic fluid. The bottom of the chamber is fitted with a floor 4 ft. 10 in. wide throughout its length. Eight 6 in. viewports are installed for direct and CCTV viewing of the occupants.

INNER LOCK 12.8.3.3 The inner lock end of the chamber is fitted with a service/medical lock 17 inches in diameter and 23 inches long for the purpose of passing small articles, medical supplies and food into and out of the chamber. It is fitted with inner and outer doors and is supplied with pressurizing gases. The inner lock of the DDC is divided into two compartments by a nonstructural louvered partition. The compartment adjacent to the medical lock is used for sleeping and contains four submarine-type bunks and lockers for storing personal effects. All drawers and lockers are provided with vent holes to prevent gas entrapment. The remaining area of the inner lock forms the living compartment, and it is fitted with a table to permit eating and recreational or work activities for four persons at one time. The table may be folded partly out of the way when required.

OUTER LOCK 12.8.3.4 The outer lock of the DDC serves as an independent pressure facility which may be held at a different but lower pressure than the inner lock. Included in the outer lock are all the necessary sanitary facilities for a diving team including a flush-type water closet, a lavatory, a mirror, a shower, and small storage cabinets. The deck of the outer lock serves as the catch area for the shower and is fitted with a drain and trap.

GAS SYSTEMS 12.8.3.5 The DDC gas system provides oxygen, helium-oxygen mixtures, helium and air for pressurization and life support of divers. An oxygen/He-O₂ mixture breathing mask manifold, for each lock, accommodates 6 emergency masks (BIBS) each. Pressurizing or depressurizing of the DDC is normally done from the MCC. Externally-mounted gas

admission and exhaust control panels are provided for local use. Two life support systems consisting of a flow meter, CO₂ scrubber, blower motor, dehumidifier, demister, reheater, and filter are controlled by the life support console. A means of sampling the internal atmosphere is provided for monitoring of CO₂ and oxygen partial pressure. An automatic oxygen addition system maintains oxygen partial pressure at preset levels. Manual override is provided in the MCC, and a manual control is provided on the chamber. A pressure relief system prevents over-pressurization of the chamber.

LIQUID SYSTEMS 12.8.3.6 The sanitary liquid system for each chamber consists of hot and cold water supply for operation of the wash basin, shower, water closet, and fire hose. Wash basin and shower waste water empty into a common sump and are discharged by chamber pressure to a waste-holding tank. Waste from the water closet discharges directly into the holding tank. The holding tank discharges directly into the ship's waste system. A 40-gallon water tank, automatically filled and pressurized by ship's high pressure air, supplies the interior fire hoses for each lock.

COMMUNICATIONS AND INSTRUMENTATION

12.8.3.7 Two electrical panels, one in the inner lock and one in the outer lock, contain a caisson gage, intercom speaker and switch, sound-powered phone call light and pushbutton, emergency alarm pushbutton, helium speech unscrambler microphone, two handsets, entertainment speaker, sound-powered phone jacks, and two ppO₂ sensors. Three externally-mounted CCTV cameras monitor occupants in each chamber.

Main Control Console 12.8.4

Each of the two Main Control Consoles (MCC), Figure Nos. 12-34, functions as the central control and monitoring area for its half of the diving system. This includes: gas supply to the DDC; atmosphere analysis and control for the DDC inner and outer locks; atmosphere monitoring for the PTC; pressure gages for gas banks and gas lines, and for DDC inner and outer locks; digital clock; communications system controls; instrumentation readouts; power supplies and power

controls; and closed-circuit TV monitors and switches for the DDC and PTC. The two MCCs have a number of communication cross ties which include those for the intercom system, sound-powered phone system, closed-circuit TV, tape recorders, helium speech unscramblers, and electrowriters. The audio cross ties provide the following additional capabilities: (1) permits the use of both helium speech unscramblers simultaneously; (2) permits both tape recorders to be used together to provide an 8-channel recording capability; and (3) permits scrambled audio to be played back, processed, and then recorded as unscrambled audio. The following control actions are not performed at the MCC: shipboard handling and raising and lowering of the PTC's, PTC gas flask charging, PTC battery charging, operation of the life support systems, helium recovery system operations, PTC-DDC mating, DDC hatch and ladder actuation, and DDC service/medical lock operation.

Life Support System 12.8.5

There are two DDC Life Support Systems (LSS) in the DDS MK 2, one for each DDC. Each system consists of a life support console and associated piping and valves, filters, gages, blowers, temperature and humidity sensors, carbon dioxide absorbers, heat exchangers, mist eliminators, and flow meters.

The function of the LSS is to circulate and process the DDC atmosphere so that relatively impure gas is replaced with purified gas of the proper temperature and humidity. Processing consists of filtration to remove particular matter, absorption to remove CO₂ and odors, and separation to control moisture. The components and associated piping that make up the LSS are not mounted in a separate enclosure but are grouped together in the MCC area.

Each system is broken down into two loops with one loop serving the inner lock and the other loop serving the outer lock. The use of two life support loops for each DDC provides for operational flexibility and redundancy since the two loops can be cross-connected by opening or shutting the appropriate valves. Normal operation involves running one loop for the entire DDC, with the capability of using both loops during periods of peak demand or when using the locks separately. During normal operation, the one idle system may be serviced or repaired as needed.



Figure 12-34 DDS MK 2—PTC being mated to the DDC located below deck.



Figure 12-35 DDS MK 2—Main Control Console

Operational Data 12.8.6

PERSONNEL TRANSFER CAPSULE

Manufacturer	Hunters Point Naval Shipyard; Dixie Manuf. Co.
Material	HY80 Steel
Construction	Welded
Dimensions—	
—Outside diameter at equator	84 in.
—Overall Height (without External Hatch)	121 in.
—Overall Outside Diameter	126 in.
—Trunk diameter	40 in.
—Trunk length	18 in.

PERSONAL TRANSFER CAPSULE (CONT'D)

Operating temperatures—	
—In air	20°F to 120°F
—In water	29°F to 90°F
Gas flasks—	
—Helium (He)	
Quantity	5
Volume (cubic feet water volume)	6 CFWV
Pressure	3,000 psig
—Helium-oxygen mix (He-O ₂):	
Quantity	4 (MOD 1); 2 (MOD 0)
Volume (cubic feet water volume)	6 CFWV
Pressure	3,000 psig
—Oxygen	
Quantity	1
Volume (cubic feet water volume)	2.8 CFWV
Pressure	3,000 psig
—Emergency oxygen	
Quantity	1
Volume (cubic feet water volume)	0.35 CFWV
Pressure	3,000 psig
Anchor—	
—Type	Clump
—Weight	Maximum 2,500 lb.
Maximum operating pressure—	
—Internal	378 psig
—External (850 feet depth)	378 psig
Electrical power—	
—Surface supplied (through SPCC)	440v, 3 ϕ , 60hz
—Emergency (on-board batteries)	28v, DC
CO ₂ scrubbers—	
—Number	2
—Type	Baralyme
—Capacity (each)	48-manhours
Hookah system (UBA)—	
—Quantity	4

—Type	MK 11
—Hose length	150 ft.
Emergency Mask Breathing system (BIBS)—	
—Quantity	4
DOWNHAUL WINCH (Not currently employed)	
Manufacturer	Dortech, Inc.
Type	2-speed, electric, reversible
Overall dimensions	5½ ft. x 4½ ft. x 4 f
Maximum weight in air (w/cable installed)	2,300 lb.
Power requirements	440v, 3 ϕ , 60hz
Drum capacity	1,200 ft.
Cable (CRS 6 x 37 1WRC)	
—Diameter	¾ in.
—Length	1,200 ft.
—Break strength	12,000 lb.
Indicator—	
—Footage	0 to 1,200 ft.
Performance—	
—High Speed	1,000 lb. @ 37 to 51 fpm
—Low Speed	2,500 lb. @ 14 to 19 fpm
—Water temperatures	20°F to 90°F
—Water pressures	1,000 ft.
—Free spool capability	15 fpm w/drag force of 750 lb.

STRENGTH-POWER-COMMUNICATION CABLE

Manufacturer	Simplex Corp.
Type construction	Composite, double layer galvanized armor wise
Dimensions—	
—Overall diameter	2 in.
—Overall length	1,454 ft.
Min. Bending Radius (Armored)	30 in.
Breaking strength	141,000 lb.
Weight—	
—In air	4,435 lb./1,000 ft.
—In seawater	3,085 lb./1,000 ft.

Electrical and communications conductors—		Indicators—	
—No. 10, stranded-wire conductors	9	— SPCC Line Tension	
—Multistrand coaxial cables— type RG-59/U	3	— SPCC Line Speed	
—No. 18, shielded single conductors	12	— SPCC Footage Counter	
—No. 18, shielded conductor pairs	12	— Downhaul Winch Tension	
SPCC DECK WINCH		MAIN CONTROL CONSOLE	
Manufacturer	Western Gear	Type	Integrated, U-shaped
Type	Hydraulic with separate Power Unit	Dimensions (overall)—	
Drum diameter	60 in.	— Length	150 in.
Drum capacity (2.06 in SPCC)	1,523 ft.	— Depth	66 in.
Line speed	0 to 100 fpm	— Height	78 in.
Maximum rated load @ 10 fpm or less	30,000 lb.	Weight	15,000 lb.
Load at maximum line speed	3,000 lb.	Power requirements	120v AC, 3 ϕ , 60hz, 10kw; 120v AC, 1 ϕ , 60hz, 6kw
Winch assembly—		Ship's Service Gas	air, helium, oxygen, helium-oxygen
—Dimensions (overall)		Instruments—	Manufacturer—
Length	130 in.	— Speaker and Alarm Panel (Amplifier)	RCA, AM-2158 A/WIC
Height	88 in.	— Helium Speech Unscrambler	Integrated Electronics Corporation
Width	138 in.	— Electrowriter Dial Selector	Victor Comptometer Corp.
—Weight	25,000 lb.	— Tape Recorder	Ampex
Hydraulic power unit assembly—		— Intercommunications Panel (Amplifiers)	RCA, AM2118A/WIC, AM4760/WIC-2A
—Dimensions (overall)		— Video Monitors	RCA
Length	60 in.	— Video Switchers	RCA
Height	51 in.	— Digital Depth Indicators	Monsanto
Width	40 in.	— Digital Clock	Monsanto
—Weight	4,000 lb.	— Ground Detector (120 VAC)	Crouse-Hinds
Control console assembly—		— 28-Volt Power Supply	Sorensen
—Dimensions (overall)		— Electrowriter Transceiver	Victor Comptometer
Length	36 in.	— pO ₂ Remote Meter, Unit 2	Westinghouse
Height	62 in.	— pO ₂ Control, Unit 1	Westinghouse
Width	28 in.	— pO ₂ Control, Unit 3	Westinghouse
—Weight	500 lb.	— Temperature Indicator	Bristol
Power requirements	440v AC, 3 ϕ , 60hz, 42 Amp, 120v AC, 1 ϕ , 60hz, 20 Amp	— pCO ₂ Meter	Beckman
		— TV Camera Power Supply	Hydro Products

CHAPTER THIRTEEN

OXYGEN DIVING OPERATIONS

Although 100% oxygen is used as a breathing medium as an adjunct to decompression in several diving procedures, its use is limited to situations in which the diver is at rest. The use of 100% oxygen for breathing during working dives is generally limited to shallow water operations because of the significant hazard of oxygen toxicity.



Figure 13-1 Diver preparing for an operational dive wearing an "Emerson Rig"

A closed-circuit oxygen SCUBA is used for oxygen diving in the U. S. Navy. This unit, officially designated as the Recirculating Underwater Breathing Apparatus, Closed-Circuit, Oxygen and commonly called an "Emerson rig" or "oxygen rebreather," is employed by combat swimmers (UDT, EOD, SEAL) for missions in which its bubble-free characteristics are essential for undetected approaches to objectives (Figure 13-1). The use of the USN oxygen SCUBA is restricted to personnel specially trained and qualified in its use and the hazards associated with this mode of diving.

OXYGEN DEPTH-TIME LIMITS 13.1

Exposure to oxygen for 30 minutes at 60 feet is used as a routine oxygen tolerance test in selection of divers, and exposures of this depth and duration are

used in the treatment of decompression sickness. In decompression from helium-oxygen dives, oxygen is breathed at depths as great as 50 feet. **Such exposures are safe only if the diver is at rest.** This section concerns exposure limits for **working dives** in which oxygen is the breathing medium. These limits, established to provide safety from oxygen poisoning, anticipate exceptional operational requirements and emergencies as well as normal requirements.

The limits are divided into three categories defined as follows—

Normal Oxygen Limits—Based upon normal, uncomplicated daily requirements.

Exceptional Operations Limits—Sufficiently safe for exceptional operational requirements.

Emergency Limits—Experience with oxygen exposures beyond the normal and exceptional limits.

The potential results from oxygen poisoning at depth are so serious, and so many uncontrolled variables are present, that a relatively safe limit is necessary for normal operations. The effects that the amount of physical exertion and excess carbon dioxide have on controlling the onset of oxygen poisoning, along with other physiological factors, are explained in Chapter Nine. Review that entire section before diving with a high partial pressure of oxygen.

Normal Oxygen Limits 13.1.1. The normal limit is straightforward. When using oxygen as the breathing medium, **DO NOT DIVE DEEPER THAN 25 FEET** and stay within the time limits specified in Table 13-1.

Limits for Exceptional Operations 13.1.2 Provided that all other variables are optimum, tests indicate that short exposures at depths greater than 25 feet are safe. The diving officer may authorize use of the depth-time limits given in Table 13-1 for depths greater than 25 feet when he has weighed his operational objectives against the increased hazard and has taken all precautions possible.

Emergency Limit 13.1.3 Extraordinary situations, such as the requirement for an extremely important mission when oxygen is the only breathing medium that can be used, might dictate that an attempt be made to exceed the limits of Table 13-1. The following

TABLE 13-1 OXYGEN DEPTH-TIME LIMITS

(Depth and time limits of exposure for breathing pure oxygen during working dives)

1. Normal Operations—Depth		Time
(ft)		(min)
10		240
15		150
20		110
25		75
2. Exceptional Operations—Depth		Time
(ft)		(min)
30		45
35		25
40		10

commentary may help in evaluating the chances for success under these extraordinary conditions.

Figure 13-2 shows the results of experimental exposures to pure oxygen at different depths for various times. The proximity of possible warning symptoms and even convulsions to the Important Operation Limit Curve is apparent. Less apparent is the contrast between the perfect conditions that existed during these exposures and the conditions that would probably exist in the field. The experiments were conducted in a pressure tank; the work rates were moderate and uniform; the inspired gas was free of carbon dioxide; and two tenders were standing by each subject. It is likely that exposure to oxygen at these depths for the same times under operating conditions would produce a much larger proportion of unfavorable effects.

The necessity to exceed exceptional operations limits in order to accomplish a mission must be brought to the attention of the officer assigning the mission, who must accept the responsibility for the increased hazard to personnel.

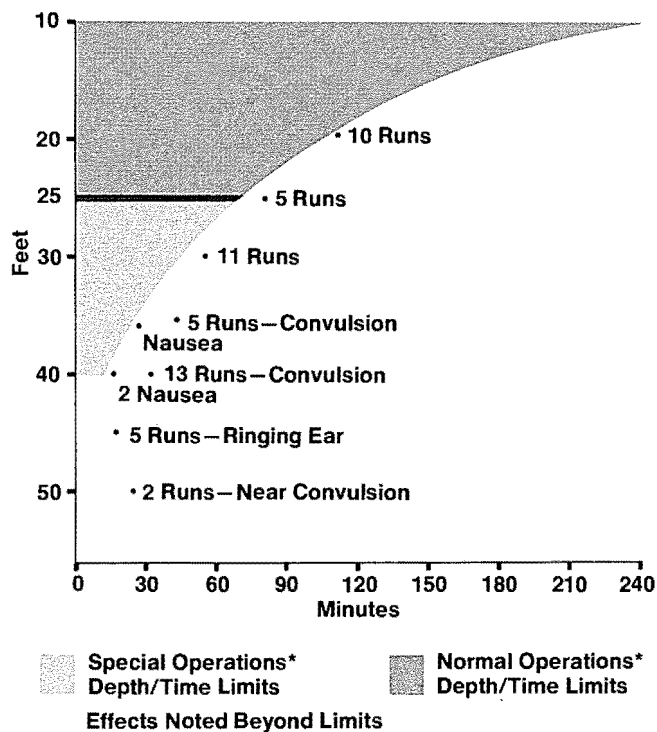
CLOSED-CIRCUIT OXYGEN SCUBA 13.2

The U. S. Navy oxygen SCUBA unit is a closed-circuit underwater breathing apparatus that consists of a mouthpiece-breathing valve assembly, breathing hoses, inhalation and exhalation breathing bags, a carbon dioxide absorption canister, an oxygen supply cylinder, and a manually adjustable gas-flow regulating assembly mounted on a nylon vest. Figures 13-3 and 13-4 show the oxygen breathing apparatus in position ready for use. The completely assembled apparatus weighs about 35 pounds out of water, and is approximately neutrally buoyant in use underwater.

Principles of Operation 13.2.1 The closed-circuit diving apparatus, employing carbon dioxide absorption, permits essentially complete utilization of the available gas supply at a rate independent of depth. Diving depth and duration are limited, however, by the physiological hazards from oxygen toxicity as previously discussed.

Compressed oxygen is delivered from the high-pressure oxygen cylinder into the breathing system at the inspiratory breathing bag by a manually adjustable

BREATHING 100% O₂ DEPTH/TIME LIMITS



*Considered safe for dives involving moderate work with minimal CO₂ inspired gas.

Figure 13-2 Experimental exposures breathing 100% O₂



Figure 13-3 "Emerson Rig"

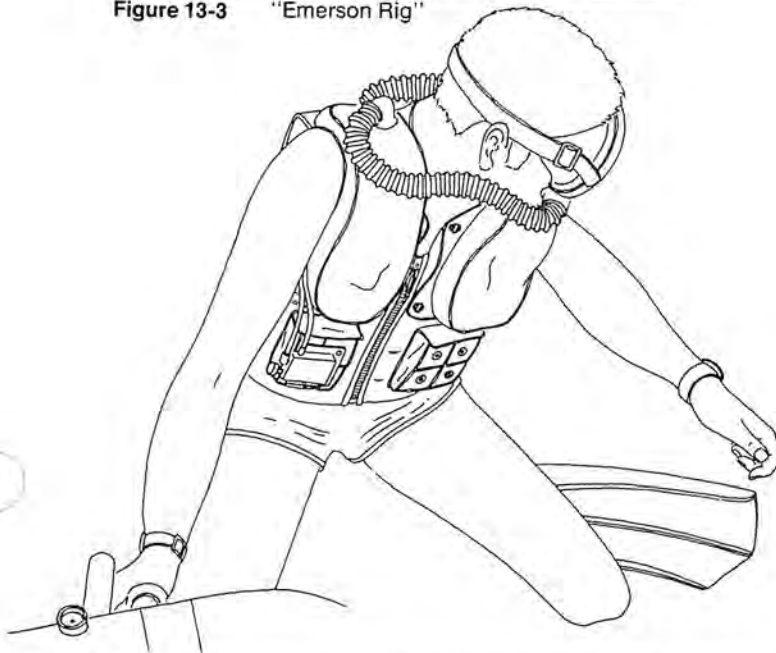


Figure 13-4 Diver fully outfitted with the Emerson O₂ SCUBA metering valve. Alternately, oxygen can be introduced by a manual bypass valve.

The flow of oxygen into the breathing circuit should be set to the rate at which the diver uses the oxygen. This flow is set by adjusting the metering valve of the waist valve assembly. Under average conditions the oxygen consumption and flow rate is set for 0.9 liters per minute. Oxygen consumption at other conditions is shown in Table 13-2.

Figure 13-5 shows a diagram of the rebreathing circuit. The diver holds the mouthpiece in place in his mouth and wears a facemask covering his eyes and nose, or he may wear an approved full facemask. Upon inhalation, the diver receives gas directly from the right-hand breathing bag through the right-hand inhalation hose and the inhalation checkvalve. On exhalation, exhaled gas (now containing carbon dioxide from the lungs) is prevented by the inhalation check-

TABLE 13-2—OXYGEN CONSUMPTION VS. WORK RATE

UNDERWATER ACTIVITY	OXYGEN CONSUMPTION (liters/min STPD)
Rest	0.5
Moderate Work	
—Swimming, 0.5 knot (slow)	0.9
Heavy Work	
—Swimming, 1.0 knot	2.0
Severe Work	
—Swimming, 1.2 knot +	3.0



Figure 13-5 Arrows indicate rebreathing circuit

valve from passing back into the right breathing bag. Instead, it passes from the mouthpiece assembly through the exhalation checkvalve, and through the left-hand exhalation hose to the left breathing bag. As it enters the left breathing bag, the exhaled gas displaces gas from the left-breathing bag, causing flow into the carbon dioxide absorption canister, where the carbon dioxide is removed. Gas within the canister, now freed of carbon dioxide gas, is displaced into the right breathing bag, where it remains until the next inhalation.

Main Components 13.2.2. The oxygen SCUBA consists of the following four primary component groups—

CYLINDER, VALVE, AND REGULATOR 13.2.2.1

One 2,000 psi standard cylinder of 12.7-cubic-foot capacity, a constant-reserve valve set at 500 ± 50 psig and a regulator preset to 80 psig, delivers oxygen to the system.

BACKPLATE, COVER, AND CANISTER ASSEMBLY 13.2.2.2

The backplate, 22½ inches long by 12 inches wide, has hinges (for the shoulder pin) at its upper edge. It provides cradles for the cylinder (on the right side) and the CO₂ absorbent canister (on the left side). The cylindrical fiberglass container has two quick-connect hose fittings, a low-pressure relief valve set at 3.0 ± 0.5 psig, and a removable cover and inside shell. The backplate cover has two ears at its lower edge and a latch at its upper edge. The cover protects the regulator and canister. It also streamlines the unit for minimum resistance, and aids in preventing entanglement.

VEST, BREATHING BAGS, AND MOUTHPICE ASSEMBLY 13.2.2.3

A vest with two detachable bags support the backplate assembly. The vest is nylon. The breathing bags have a three-layer construction with cotton on the exterior and interior surfaces and a gas-tight rubberized center. The mouthpiece assembly, which contains the check-valves, is attached to the breathing bags by two breathing hoses.

WAIST VALVE ASSEMBLY 13.2.2.4 This valve is mounted on the front, lower right of the vest and incorporates the metering valve and bypass valve.

Cylinder, Valve, and Regulator 13.2.3 One cylinder is provided to contain oxygen for use in diving. The cylinder is rated for filling to 2,000 psig and has a capacity of 359.6 liters when full (12.7 cu. ft.). Theoretically, the full cylinder contains sufficient oxygen for almost 6 hours' use during moderate work (oxygen consumption rate = 1 lpm). With an adequate safety factor and assuming that above average work rates will be periodically encountered, the practical duration of the apparatus is 120 minutes. The con-



Figure 13-6 Proper position of Emerson Rig on Diver

stant-reserve valve is set for one-fourth of the cylinder pressure (500 ± 50 psig). Pay special attention to the note in Section 13.8 regarding the operation of the constant-reserve valve.

In position, the cylinder is mounted vertically on the diver's back with the neck of the cylinder up, as shown in Figure 13-6. In respect to the diver, the cylinder valve handle extends through the cover near the right shoulder, and the constant-reserve valve rod extends through the lower center of the cover.

The regulator, shown in Figure 13-7, is attached to the higher-pressure cylinder by a standard yoke fitting. The outlet fitting provides a connection for the low-pressure, flexible gas-delivery hose to the re-breathing system. A relief valve is installed in the low-pressure side of the regulator.



Figure 13-7A Detail of cylinder valve, yoke and regulator assembly.

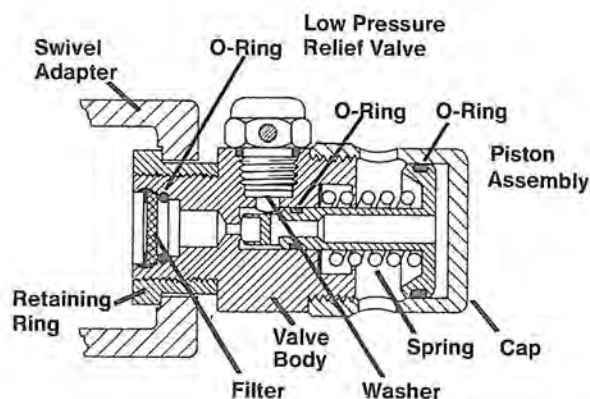


Figure 13-7B Regulator cross-section

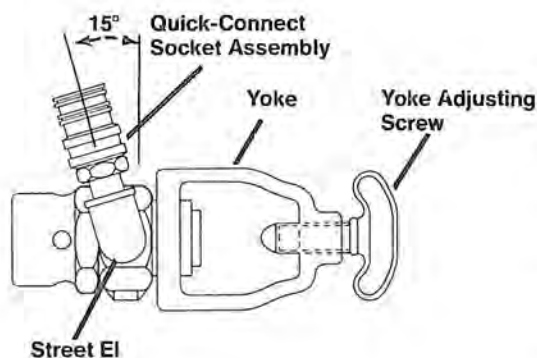


Figure 13-7C Standard yoke fitting

The regulator is a depth compensating, nonadjustable, piston-type. The body contains the filter, high and low-pressure porting, output connection, and relief valve. The bonnet, which has a threaded connection to the body, contains the piston and spring. The regulator is preset for an 80 ± 8 psig output. The relief valve is set to relieve at 300 ± 50 psig.

Dimensions of the cylinder with the valve and regulator: length, 19 inches; diameter, $4\frac{7}{64}$ inches; weight, 10 pounds.

Backplate, Cover, and Canister Assembly 13.2.4

The fiberglass backplate (Figure 13-8) provides a rigid mount for the oxygen supply system and CO₂ removal canister. These components are secured in position in their respective cradles by clamps.

The backplate is secured to the vest by a long removable shoulder pin which passes through two loops at



Figure 13-8 Backplate and cover

the top of the backplate and three corresponding loops on the vest. The fiberglass backplate cover has two ears at its lower edge which engage into slots in the lower portion of the backplate. The cover has a latch at its upper edge which engages with the backplate to lock it into place.

The three-piece (outside shell, inside shell, cover) fiberglass carbon dioxide absorption canister assembly is mounted vertically on the left side of the backplate. The canister is cylindrical, and has an outside shell incorporating two quick-connect breathing hose fittings at its upper end and a removable cover at its lower end. Within the outside shell is a fiberglass inside shell which holds approximately 6 pounds of absorbent. The absorbent will remove carbon dioxide for approximately 30 minutes in 40°F seawater and 5 hours in 70°F water at average work rates. At the cover, or lower end of the inside shell, is a removable screen which is attached to the canister cover by a spring. A similar screen is also used at the upper end of the inside shell. The inside shell is held in place $\frac{3}{16}$ inch from the outside shell by six raised bosses on

its outer surface, and it is connected directly to one of the canister outlets by an O-ring seal. Thus, the gas passes between the inside and outside shells to the lower or cover end, and returns through the absorbent in the inside shell and out to the breathing bag (see Figure 13-9). The canister cover, equipped with an O-ring seal and a secondary flat-ring seal, is held in place by two cover-clamp thumbscrews which are permanently attached to the cover. The inside shell is removable for periodic cleaning and inspection.

There is an overpressure relief valve set at 3.0 ± 0.5 psig mounted in the top of the canister.

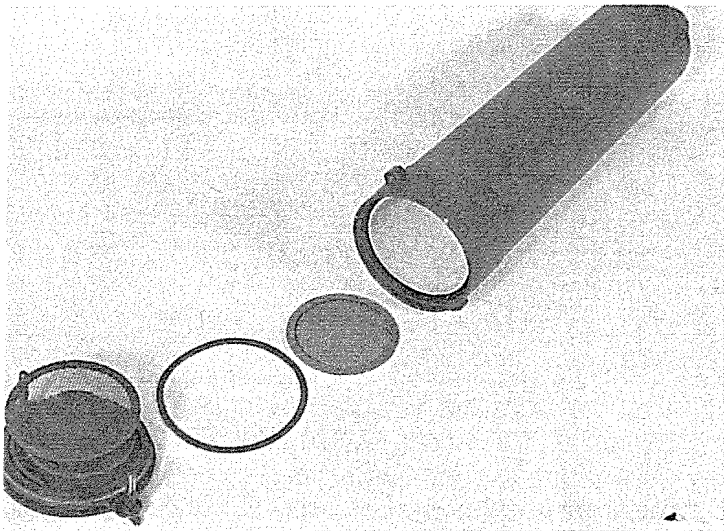


Figure 13-9 CO₂ absorption canister—disassembled

Vest, Breathing Bags, and Mouthpiece Assembly

13.2.5 The breathing apparatus components are supported on a vest. In use, the vest and backplate are secured in relation to the diver by the removable hinge pin in back of the shoulders and by three pairs of side straps.

In front, the vest is divided vertically in the midline and is provided with a nylon zipper closure for ease of donning and removal. A circular opening is provided for the head and neck. The breathing bags are removable from the vest and are located to the right and left of the midline closure. Below each breathing bag is a small weight pouch closed with flaps at the top and bottom by commonsense fasteners. Two-

pound rectangular weights are inserted in these pouches to achieve desired trim in the water. Figure 13-10 shows the breathing bag and vest assembly.

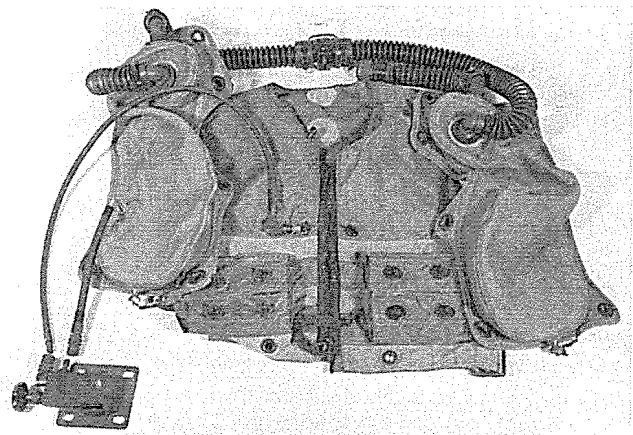


Figure 13-10 Breathing Bag—Vest assembly

Buckles at the lower side corners of the vest provide means for securing and adjusting the free ends of the side straps coming from the backplate.

The right and left breathing bags (Figure 13-5) are held in place on the vest by commonsense fasteners. Each bag extends from behind the neck, over the shoulder, and down over the upper portion of the chest. When inflated, the volume of each breathing bag is approximately 4 liters. Removable elbows are mounted on the front of each bag at about neck level for attaching the breathing hoses to and from the mouthpiece. A second pair of removable elbows extend from the back edge of the bags. These provide a means for conducting exhaled gas from the left breathing bag to the carbon dioxide absorption canister, and from the canister to the right breathing bag. An inlet for oxygen is permanently mounted on the right breathing bag. At the bottom of each breathing bag is a drain fitting with a chain plug-and-cap assembly. After use, the drains should be opened for condensate removal and for ventilation. This will preserve the breathing bags when the unit is stored.

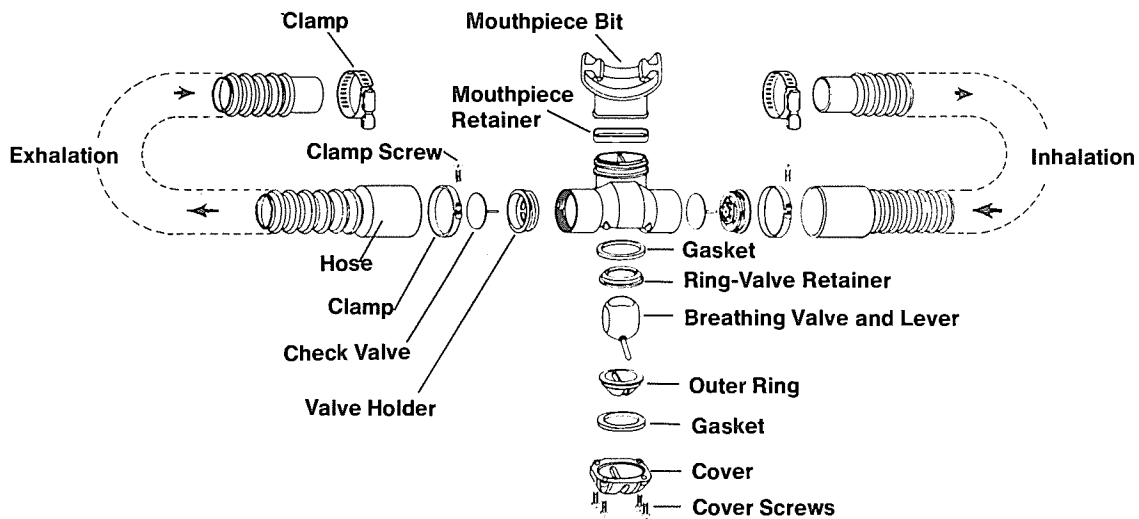


Figure 13-11 Exploded view of the mouthpiece assembly

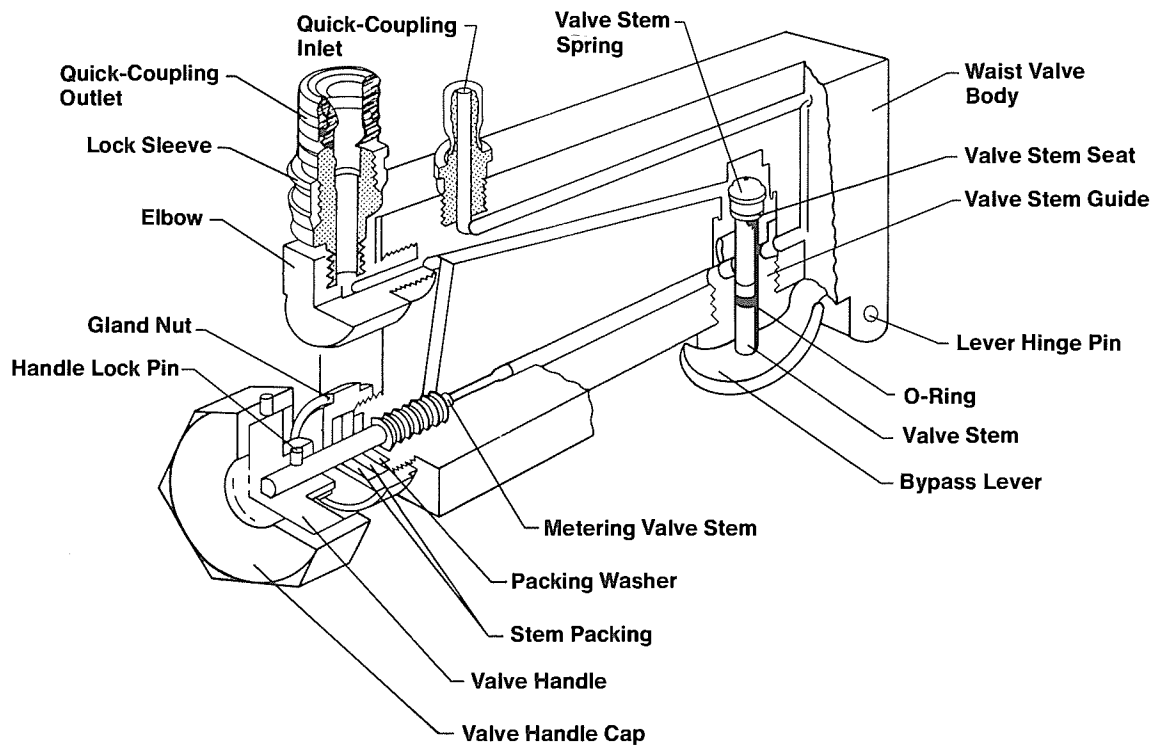


Figure 13-12 Waist valve assembly cut away



Figure 13-13 Detail of mouthpiece

Figures 13-11 and 13-13 show the mouthpiece breathing valve. The rubber mouthpiece bit is attached to the outer shell of a molded nylon mouthpiece body. The valve has a lever that protrudes through the cover and can be rotated to an ON position, which permits the wearer to breathe, or to an OFF position, which seals the circuit from the outside air or water.

An exhalation checkvalve and a molded nylon valve holder are located in the opening at the left end of the mouthpiece body. An inhalation checkvalve and valve holder are located at the right end of the mouthpiece body.

The mouthpiece breathing valve assembly is connected by appropriate fittings to the two breathing hoses. Each hose is 19 inches long with a $\frac{7}{8}$ -inch internal diameter.

Waist Valve 13.2.6 The low-pressure outlet of the regulator is connected by a flexible low pressure hose to the waist valve shown in Figures 13-12 and 13-14. Upon entering the valve, the oxygen has two flow paths available; one to the metering valve, and the other to the by-pass valve. Normally, oxygen entering the waist valve passes through the metering valve and out of the waist valve to the right-hand breathing bag. The metering valve handle has markings for flows of 0.5, 0.9, 2, and 3 liters per minute and has a maximum flow ranging from 3.5 to 4 liters per minute. When the by-pass valve lever is depressed, oxygen bypasses the metering valve and provides maximum flow directly to the right-hand breathing bag. The waist valve is secured to the supporting vest by four commonsense fasteners on the right-hand weight pocket.



Figure 13-14 Detail of waist valve

HANDLING AND ASSEMBLY 13.3

Although the underwater rebreathing apparatus is not fragile and is constructed to resist wear and damage in normal use, it should in all phases of assembly, use, handling, and storage be treated as equipment made for the support of life under adverse conditions. Therefore, this equipment must be treated with care.

Assembly of Components 13.3.1 The oxygen SCUBA should be carefully assembled using the following procedures—

CHECK COMPONENTS 13.3.1.1 The following components are required to assemble the apparatus—

- (1) Vest and backplate
- (2) Breathing bags
- (3) Mouthpiece assembly
- (4) Canister
- (5) Cylinder with constant-reserve valve
- (6) Regulator
- (7) Waist valve
- (8) Backplate and straps
- (9) Cover

VEST AND BREATHING BAG ASSEMBLY 13.3.1.2

Tighten the four elbow connections on the breathing bags (two on each). Secure the drain plug caps. Attach the breathing bags to the vest with the commonsense fasteners.

CYLINDER, REGULATOR, AND WAIST VALVE ASSEMBLY 13.3.1.3

Attach the regulator to the cylinder valve and tighten the yoke securely. Attach the waist valve inlet hose to the regulator by inserting the male quick-connect fitting (elbow) firmly into its receptacle on the regulator and securing the lock ring.

FINAL ASSEMBLY 13.3.1.4

The following procedures must be executed in the indicated sequence—

1. Place the canister assembly in the left cradle on the backplate. The two outlets are now at the upper end of the backplate. Rotate the canister so that the outlets are toward the backplate and about equidistant from it (rather than rotated away from it). Thread the retaining clamp through the cradle and fasten it securely around the canister. The thumbscrew of the retaining clamp should be positioned between the canister and the cylinder so that it does not interfere with the cover.
2. Place the cylinder assembly in the right-hand cradle. The reserve pull rod should fall between the canister and the cylinder, and the cylinder valve should extend to the right. Now attach the retaining clamp, again positioning its thumbscrew in the central space.
3. Attach the vest assembly to the backplate assembly by aligning the three vest hinge loops with the two corresponding loops on the backplate and inserting and closing the shoulder pin.
4. Attach the mouthpiece assembly to the breathing bags using the clamps provided. Be sure to attach the inhalation hose to the right bag and the exhalation hose to the left bag. In the diving (DIVE) position, the lever on the mouthpiece is pointing downward.
5. Connect the canister to the breathing bags by inserting the male hose connections into the proper receptacles on the canister; the left bag hose to the left-hand inlet, and the right bag hose to the right-hand outlet. Do not twist or kink the hoses.
6. Attach the backplate cover to the backplate by placing the two ears of the cover in the receiving slots at the lower edge of the backplate. Before securing the retaining latch at the top, be sure the reserve arm is in the START DIVE position, and that the reserve rod extends through the slot provided for it in the bottom of the cover. Close the cover and secure the retaining latch.
7. After the weights are inserted (as required), attach the waist valve to the right-hand weight pocket using the commonsense fasteners. The metering valve should be at the lower edge. Connect the breathing bag supply hose and waist valve inlet hose to the waist valve by placing the quick-connect fittings down over their counterparts on the waist valve. When the fitting is snapped in place, rotate the locking ring clockwise to prevent the fitting from inadvertently becoming disengaged.

PREDIVE EQUIPMENT PREPARATION 13.4

To prepare the oxygen SCUBA for use, the oxygen cylinder must be charged, the CO₂ absorption canister filled, the inhalation and exhalation valves checked, and the entire apparatus leak tested.

Charging the Oxygen Cylinder 13.4.1 The oxygen cylinder must be filled with medically pure oxygen (FSN 9G683-290-4290) to a pressure of 2,000 psig. Observe the following safety rules for charging—

WARNING

1. Avoid all contact of oil or grease with high pressure fittings. Such material exposed to oxygen under high pressure may explode.
 2. The oxygen cylinder should be treated with care.
 3. Charge cylinders with the proper grade oxygen only.
 4. Do not charge above 2,000 psig.
- A. Remove the regulator from the cylinder valve and place the reserve arm in the RESERVE position.
 - B. Purge the high-pressure filling line of gas and particles by briefly opening the high-pressure oxygen source.
 - C. Connect the high-pressure oxygen source to the valve on the cylinder and fully open the cylinder valve.

D. Slowly open the valve of the high-pressure oxygen source, and fill the oxygen cylinder to the desired pressure, taking at least 5 minutes per 1,000 psig. The cylinder will become warm during filling. Allow the cylinder to cool, and finish charging if maximum pressure is desired.

NOTE

To insure maximum pressure, the cylinder should be cooled by immersing it in a bucket of water during charging.

E. Close the cylinder valve and the valve of the high-pressure oxygen source. Then bleed the charging line, and detach the filled cylinder.

F. Test the cylinder valve for complete closure.

G. Reattach the regulator to the cylinder valve.

Loading the Carbon Dioxide Absorption Canister

13.4.2 The carbon dioxide absorption canister must be filled with fresh Baralyme (barium and calcium hydroxide, a commercially available product) prior to every dive. It is carried in the Navy Stock System under FSN 6505-053-2461 (granular 7 lb).

To load the carbon dioxide absorption canister—

A. Remove the canister from the backplate and detach the two quick-connect fittings of the hoses from the canister.

B. Detach the canister cover by loosening the cover-retaining thumbscrews simultaneously. Lift the cover off gently with the screen attached.

C. Wipe the canister free of absorbent dust if it is not already clean.

D. Fresh absorbent must be poured onto a screen of appropriate mesh size to allow broken particles of absorbent to be discarded. The screened absorbent must be then blown free of dust using oil-free air, nitrogen or oxygen.

E. Insert the canister charging funnel in the open end of the inside shell. Fill the inside shell with the screened absorbent. To insure proper packing of absorbent granules, gently tap the side of the canister with the hand as it is filled. The canister should be

filled to the bottom lip of the funnel or to within about ¼ inch from the top of the inside shell.

F. Hold the screen and cover assembly in place over the open end of the inside shell and blow sharply through the outlet quick-disconnect fitting several times to clean the canister of any remaining dust.

G. Replace the canister cover in its indexed position, making sure that the O-ring and its seat are clean (a small amount of Dow Corning No. 4 silicone lubricant is recommended for the O-ring), and that the cover flat-ring seal seats properly on the canister rim. Secure the retaining thumbscrews firmly.

H. Reattach the canister to the backplate in the correct position.

Checking The Inhalation and Exhalation Valves

13.4.3 To check the inhalation and exhalation valves, place the mouthpiece in the mouth with the lever in the DIVE (downward) position. Squeeze closed the inhalation (right-hand) hose and try to inhale through the mouthpiece. Next squeeze closed the exhalation (left-hand) hose and attempt to exhale through the mouthpiece. If it is possible to inhale with the inhalation hose closed or exhale with the exhalation hose closed, the check valves are improperly positioned or faulty. Do not use the apparatus until this condition has been corrected.

Checking the Apparatus for Oxygen Leakage

13.4.4 The entire apparatus, including the high-pressure and low-pressure oxygen delivery systems and the rebreathing system, should be tested for defective connections as follows—

A. Close the mouthpiece shutoff valve.

B. Open the cylinder valve and metering valve, then fill the breathing bags to a firm condition by depressing the bypass valve. Close the cylinder valve to stop gas flow through the waist valve. No excess gas pressure now exists in either the high- or low-pressure gas systems.

C. Immerse the entire apparatus in water and carefully search for sources of leakage in the rebreathing system.

D. Carefully search for leaking gas at the delivery connections, using soap suds, Leak-Tek, or a similar commercial product.

E. When finished, relieve the pressure in the breathing system by opening the mouthpiece valve.

PREDIVE EQUIPMENT CHECKLIST 13.5

The following minimum equipment is required to conduct oxygen SCUBA diving—

Closed-Circuit SCUBA	Swim Fins
UDT-Type Life Jacket	Knife
Depth Gage	Wristwatch
Facemask	

The following optional equipment may be required depending upon diving conditions and mission requirements—

Protective Clothing	Floats
Wrist Compass	Slate and Stylus
Signal Flares	Noseclip

PREDIVE APPARATUS INSPECTION 13.6

When the canister and cylinder are full and the unit has been checked for leaks, a final routine pre-dive inspection must be made before donning the apparatus—

1. Check all fittings and screws for tightness. Pay careful attention to the five quick-connect fittings.

WARNING

Check all five quick-connect fittings for complete closure. Be sure that the lock rings are tight, then tug on hoses to insure that they are securely locked.

2. Check the breathing bags for torn edges or worn spots that might rupture during use.

3. Insure that the breathing bag drain caps are tightly in place.

4. Make sure that the shoulder pin passes through all three loops on the vest, as well as both hinge loops on the backplate, and that it is closed.

5. Check the breathing hoses by stretching and inspecting for pinholes and possible deterioration of the neoprene (this is indicated by numerous small cracks on the exterior surface).

6. Check the mouthpiece valve assembly, as discussed in Section 13.4.3.

7. Close the metering valve and slowly open the cylinder valve handwheel all the way. Insure that the reserve arm is in the START DIVE (Up) position. The apparatus is now ready to don.

DONNING EQUIPMENT 13.7

Use the apparatus only after proper charging of the cylinder and canister, a thorough check for gas leakage, and a complete pre-dive inspection—

1. Place the apparatus over the shoulders with the front vest zipper open. Close the front zipper, and adjust the side harness straps securely.

2. Close the mouthpiece shutoff valve and inflate the breathing bags by depressing the bypass lever. Check the closed mouthpiece valve for tightness of seal by forcibly attempting to blow air through it.

3. Don the UDT-type life jacket. Although the breathing bags of the oxygen SCUBA will provide a certain amount of buoyancy under normal conditions, an inflatable lifejacket is an essential piece of safety equipment. Partial flooding of the CO₂-removal canister or the onset of oxygen toxicity may cause a stricken diver to lose his mouthpiece (without closing the mouthpiece valve) and flood the apparatus. The lifejacket provides immediate buoyancy assistance through actuation by the diver or his swim buddy.

4. Review the mission and dive profile with the Diving Supervisor.

5. Don swim fins, facemask, and noseclip, if required. (Many divers experienced with air SCUBA have a tendency to exhale a portion of each breath through the nose into the facemask to keep it clear. This action must be avoided when diving with oxygen SCUBA, since it would allow oxygen to escape from the circuitry. A noseclip is often helpful in eliminating the habit.) Insert the mouthpiece in the mouth, and open it to connect with the rebreathing system.

6. Purge the system as follows—

WARNING

It is necessary to purge the rebreathing system; a procedure that must be done with extreme care. If excess air is not removed from the breathing bags and from the lungs before oxygen breathing starts, a considerable amount of nitrogen will remain in the respiratory system. This may be sufficient to provide a breathable volume of nitrogen after all the oxygen has been used. Because the body requirements for oxygen will not be satisfied, unconsciousness or death may occur from lack of oxygen (hypoxia).

A. Empty the breathing system. Do this by closing the metering valve, opening the mouthpiece valve, inhaling, closing the mouthpiece valve, and then exhaling to the atmosphere. Repeat this operation until the bags are sucked empty and are completely collapsed.

B. With the bags collapsed, the mouthpiece valve in the closed position, and the cylinder valve open, add oxygen to the rebreathing system using the bypass valve until it is approximately three-quarters full.

C. Now exhale to the atmosphere, insert the mouthpiece, and open the mouthpiece valve. Purge the lungs by inhaling from the mouthpiece, closing the mouthpiece valve, removing it, and then exhaling to the atmosphere. Add oxygen as required by operating the bypass valve. Breathe down the bags three times, being careful not to allow any atmosphere to enter the breathing apparatus or lungs. If this occurs, steps (A) through (C) must be repeated.

D. If the mouthpiece (or faceplate) is removed before entering the water, the breathing bags and diver's lungs must be purged again.

E. Adjust the oxygen level in the bags, using the bypass valve, and set the metering valve to the appropriate setting. To start a dive, 0.9 liter is usually adequate.



A After dressing (trunks or wet suit) the diver puts on the life vest buckling it at his waist, letting it hang in front of him.



B The tender then assists the diver into the vest, positioning the SCUBA on the diver's back.



C The vest is zipped.

Figure 13-15 Predive dressing procedures.



D — The tender cinches the vest adjustment straps securing the SCUBA to the diver.



F — The mouthpiece is brought over the diver's head into its proper position.



E — The life vest is brought up over the diver's head—positioned and adjusted.



G — With the addition of face mask, swim fins and other equipment, the diver will be ready for the pre-dive checkout of his equipment.

SURFACE CHECKOUT 13.8

When the apparatus is properly donned and functioning, obtain approval from the Diving Supervisor to enter the water.

1. Check the metering valve setting.
2. Enter the water and make, or have a swim buddy make, a final check for leaks. Do the same for the swim buddy.
3. Check the bypass valve.
4. Check the time and take surface bearings.

UNDERWATER PROCEDURES 13.9

Descend to the directed depth using the bypass valve as necessary to maintain an adequate supply of oxygen in the breathing bags. During descent, the decrease in the bag volume due to compression by the increasing water pressure may result in negative buoyancy and increasingly rapid descent. The preset flow should be supplemented on descent by intermittent use of the bypass valve to adequately maintain the volume of the bags for breathing and for control of the rate of descent. The diver must not descend more rapidly than the breathing volume can be restored. To do so will result in squeeze of the bags and lungs, as well as of structures within the faceplate.

NOTE

The cylinder constant reserve valve is set for 500 ± 50 psig, but it starts restricting the gas flow at approximately 800 psig. The flow rate between 800 and 500 psig is adequate to maintain a constant bag level, but is not enough to give full flow through the bypass valve. If it is necessary to use the bypass valve and the flow appears to be inadequate, it is an indication that the cylinder pressure is somewhere between 800 and 500 psig. For full flow, the constant reserve valve rod must be pulled to place the valve in its reserve position.

Do not exceed the diving limits for pure oxygen as established in Section 13.1 or the planned dive profile. While underwater the diver must be constantly alert for the symptoms of oxygen toxicity as discussed

in Section 9.3.2 (V-E-N-T-I-D: Vision-Ears-Nausea-Twitching-Irritability-Dizziness). Surface immediately if any symptoms are felt.

If the apparatus is accidentally flooded or if water leakage occurs, carbon dioxide poisoning will result. If the presence of seawater is suspected in the absorbent canister, surface immediately using the additional buoyancy of the lifejacket if required.

The oxygen rebreather is not equipped with an exhaust valve. During ascent observe the following warning—

WARNING

Because the apparatus has no exhaust valve, excess gas must be expelled through the mouth (or nose) during ascent to prevent lung damage and embolism.

POSTDIVE PROCEDURES 13.10

Careful preventive maintenance of the diving equipment extends its useful life and enhances diver safety. Wash, dry, and carefully stow all accessory equipment. Maintain the oxygen rebreather as indicated below.

Routine Cleaning 13.10.1

A. Salt removal—As soon as practicable after each day's use in salt water, thoroughly rinse the outside of the apparatus with fresh water. This is best done by hosing or by dipping the entire assembled apparatus into a large can of fresh water, first making sure that the mouthpiece shutoff valve and bag drains are closed and all gas delivery fittings are connected. This procedure will wash salt off the fittings.

B. Alkali removal—If the breathing system has been flooded during use to the extent of wetting the carbon dioxide absorbent, wash the inside of the entire respiratory system (breathing bags, canister, breathing hoses, and mouthpiece assembly) to remove alkali. Do not wash the gas delivery system if it is clean. Instead, disconnect the two hoses from the waist valve so moisture will not reach it. If possible, dry all components before reuse.

If flooding causes entrance of water and alkali into the gas delivery system, corrosion and crystallization may in time obstruct the passages in the waist valve.

The waist valve should be separated from the regulator and breathing bag, and flushed thoroughly with fresh water. The waist valve and connecting hoses should be dried before reassembly. The regulator can usually be cleared of dampness by discharging oxygen through it for one or two minutes at low pressure.

C. Canister cleaning—After every dive dump the used absorbent and wipe the inside of the canister clean of absorbent dust. Prior to dumping the Baralyme, however, check it for dampness. Excessively damp absorbent is probably a sign that one or more of the valves or fittings in the circuit is leaking. Should this be evident, determine the location of the leak and make the necessary repairs. A common cause of leakage in the canister is a faulty relief valve.

Periodically, the inside shell should be removed from the outside shell for thorough cleaning and inspection. To remove the inside shell remove the cover, detach the outlet quick-connect fitting and O-ring from the canister, and slide the shell out. After it has been cleaned, reinsert the inside shell into its outside shell, making sure it is properly aligned, and press firmly into place. There are two corresponding markings on the outside shell and the canister cover for easy alignment.

Remove the low-pressure relief valve from the top of the canister and inspect the sintered filter in its base; remove and clean if required.

Lubrication 13.10.2 No lubrication of metal parts of the apparatus should be necessary. If corrosion occurs on threaded areas of the fittings, clean them with a fine brass wire brush.

Before reassembly, take care to blow corrosion dust off with oil-free compressed air or nitrogen.

On the O-rings which seal the fiberglass components it is advisable to use a small amount of silicone lubricant (such as Dow Corning No. 4 compound). Use of the lubricant significantly reduces the possibility of water leakage into the canister.

General Inspection 13.9.3 A general inspection should be carried out routinely in the following manner—

- A.** Check all fittings and screws for tightness.
- B.** Check the breathing bags and vest assembly for torn edges and punctures.
- C.** Check the breathing tubes by stretching and inspecting for pinholes and possible deterioration of the neoprene (as revealed by a multiplicity of small cracks on the exterior-surface).
- D.** Check the breathing bags and mouthpiece hoses for water, and drain if necessary.
- E.** Close the cylinder valve handwheel.

TROUBLESHOOTING 13.11

Improper function of the apparatus will rarely be caused by mechanical failure of a part or wear of components, because the equipment contains few moving parts. The most common cause of malfunction will be leakage of oxygen out of the apparatus or water into it, caused by improperly maintained connections. Malfunction can be practically eliminated by careful routine inspection of the apparatus.

Loss of Gas Apparatus 13.11.1

A. Check high-pressure system—Locate the source of the leak by submergence, or painting with soap solution or Leak-Tek. Repair individual leaks as follows—

- 1. Reserve-valve safety disk**—Empty the cylinder and replace the disk.
- 2. Cylinder valve**—Empty the cylinder, remove the valve handwheel, and tighten the gland nut. If necessary, remove the gland nut and replace the O-ring.
- 3. Reserve arm**—Empty the cylinder, remove the reserve valve arm, and tighten the gland nut. If necessary, remove the gland nut and replace the O-ring.
- 4. Threads between cylinder and cylinder valve**—Remove the valve, clean the threads on both valve and cylinder, and replace. Use a small amount of oxygen service, thread-sealing compound of a type approved by the Naval Ship Engineering Center. Never use oil, grease, or paint where it can come in contact with high-pressure oxygen.

5. Connection between cylinder valve and regulator yoke—This is the most common source of high-pressure leaks and usually requires only tightening of the yoke wingnut to stop the leak. If the O-ring is damaged, replace it.

B. Check low-pressure system—First check the high-pressure system, as in 13.11.1A. Locate the source of the low-pressure leak by submerging or painting system with soap solution.

1. Regulator body low-pressure fitting—Remove, clean the threads, and replace using a thread-sealing compound of a type approved by the Naval Ship Engineering Center.

2. Regulator relief valve—Replace sealing O-ring.

3. Regulator inlet hose—Replace leaking hose or damaged pressure fitting.

4. Waist valve—Remove and clean or replace leaky fittings. Replace defective quick-connect fittings. Replace the packing in the metering valve. Replace damaged O-rings.

C. Check rebreathing system—Close the mouthpiece shutoff valve, and inflate the breathing bags. Locate the source of the leak by submerging.

1. Canister cover—Correct for overfilling of canister by removing some of the absorbent. Reseat or clean the canister cover O-ring and seal if displaced or dirty. Replace canister cover if damaged. The most likely cause of leakage is a dirty canister cover O-ring.

2. Breathing hoses and connections—Tighten loose connections and replace worn hoses.

3. Mouthpiece shutoff valve—Replace gaskets or valve clamps, as needed.

Entrance of Water Into Apparatus 13.11.2

Neither the high-pressure nor the low-pressure gas delivery systems, even if leaking gas, should allow water to enter the apparatus during use. Water leakage into the apparatus is therefore most probably due to a defect in the rebreathing system. To detect the source of water leakage, proceed as in checking for and correcting gas leakage from the breathing system.

Regulator Failure 13.11.3 If the regulator malfunctions, completely disassemble it by removing the relief valve, yoke, bonnet piston, spring, snapping, and filter. Clean all parts, except the relief valve, with a cleaning solvent approved by Naval Ship Systems Command for cleaning oxygen equipment. Blow through all passages and the filter, using approved oxygen. Inspect all parts for wear and replace as required. Allow all parts to dry and reassemble, installing new O-rings if required. Apply a small amount of oxygen lubricant approved by NAVSHIPS Inst 9320.15 to the O-rings.

Reassemble the regulator to the cylinder and check the regulated output (80 ± 8 psig).

If the relief valve fails to actuate or reseal within a range of 300 ± 50 psig, remove from the regulator, disassemble, clean with an oxygen cleaning agent approved by Naval Ship Systems Command, and reassemble.

SHIPMENT AND STORAGE 13.12

In routine shipment, the detachable components of the apparatus should be removed, wrapped in dustless, shock-absorbent packing materials, and carefully supported with a rigid packing container. The carbon dioxide absorption canister and the gas cylinder should be emptied prior to packing for storage or shipment.

The apparatus should not be stored near fire nor at temperatures above 110° F, nor should it be exposed to prolonged periods to the direct rays of the summer or tropical sun. Heating of the high-pressure cylinder can cause an increase in cylinder pressure, with rupture of the safety disk and violent discharge of oxygen.

Between periods of use, care should be taken to avoid damage to the apparatus from continuous distortion of its flexible components, or from pressure of heavy parts upon its fabric and rubber components.

Contamination of the apparatus with oils, greases, paints, etc., should be carefully avoided. Provision should be made for drying components after use to deter rot and corrosion. ■

MIXED-GAS DECOMPRESSION

Mixed-gas diving permits operations to be performed at greater depth than air diving. A quantity of inert gas (usually helium) is taken up by the body during every dive. As in air diving, the amount of inert gas absorbed depends upon the depth of the dive and the exposure (bottom) time. If the quantity of helium dissolved in the body tissues exceeds a certain critical amount, the ascent must be delayed to allow the gradual elimination of excess helium. Decompression sickness results from failure to delay the ascent and allow adequate time for elimination of excess inert gas.

Many decompression procedures for mixed-gas diving are similar to those for air diving. Prior to the commencement of mixed-gas operations, the Air Decompression Chapter (Seven) of Volume I should be reviewed.

DEFINITION OF TERMS 14.1

Those terms which are frequently used in discussions of the mixed-gas decompression tables are defined as follows—

Residual Helium—Helium gas still dissolved in the diver's body following completion of a dive.

Residual Helium Time—The additional bottom time which must be added to a repetitive dive to account for the residual helium gas from the previous dive and the loss of helium gas during the surface interval (interval at saturation pressure for saturation-excursion dives). Residual helium time is expressed as minutes of bottom time at the depth of the repetitive dive.

Partial Pressure—The fraction of the total absolute pressure of a gas mixture exerted by a single component of the mix, usually measured in atmospheres (absolute), millimeters of mercury (mmHg), or feet of seawater.

Excursion Depth—The maximum depth, below saturation depth, attained in an excursion, expressed in feet of seawater.

Excursion Time—The elapsed time from leaving the saturation pressure in descent until leaving the excursion depth in ascent, expressed in minutes.

TABLE SELECTION 14.2

Mixed-gas decompression tables are divided into three categories by diving mode—SCUBA, Surface-Supplied and Saturation. Overall choice of the type of table to be used is dependent upon the diving technique employed; in turn, the choice of technique is governed by the mission (bottom time required, depth), environmental conditions, and the availability of equipment and trained personnel as discussed in Chapter Nine.

Briefly stated, the three categories of tables are used as follows—

SCUBA—

1. Combat swimmer missions at depths (to 200 feet) below the limits for air SCUBA.
2. Combat swimmer missions of an underwater duration beyond the capacity of air SCUBA.
3. Certain ordnance disposal operations requiring minimum acoustic noise.
4. Support of research, development, and test activities in which diver mobility and minimum surface support are required.

Surface-Supplied—

1. Short bottom time, deep (to 300 feet) missions beyond the limits of air diving, e.g., search, salvage, submarine rescue.
2. Short bottom time, shallower (deeper than 100 feet) missions in the air diving range but requiring maximum mental acuity and freedom from nitrogen narcosis.

Saturation—

1. Very deep missions (beyond 300 feet), usually involving extended bottom time e.g., deep submarine rescue and salvage, weapons recovery, seabed implantments, scientific activities.
2. Shallower missions (generally below 100 feet) requiring extensive bottom time and seabed activities, e.g., underwater construction, large salvage projects, scientific observations.

The three categories of mixed-gas decompression tables in this chapter are organized into separate, index-tabbed sections. Each section includes instruc-

tions for the tables and examples of their application, the tables themselves and operating procedures for handling emergencies involving omitted decompression.

Tables included in each section are as follows—

A. Mixed-Gas SCUBA Decompression—Section 14.4—

HELIUM-OXYGEN SCUBA DECOMPRESSION TABLE

HELIUM-OXYGEN SCUBA DECOMPRESSION TABLE USING OXYGEN

HELIUM-OXYGEN SCUBA NO-DECOMPRESSION LIMITS TABLE

HELIUM-OXYGEN SCUBA RESIDUAL HELIUM TIMETABLE FOR REPETITIVE DIVES

NITROGEN-OXYGEN SCUBA TABLE

B. Helium-Oxygen Surface-Supplied Decompression—Section 14.5—

OXYGEN PARTIAL PRESSURE LIMITS TABLE
HELIUM-OXYGEN PARTIAL PRESSURE TABLE

HELIUM-OXYGEN SURFACE-SUPPLIED DECOMPRESSION TABLES

EMERGENCY HELIUM-OXYGEN DECOMPRESSION TABLE

EMERGENCY AIR DECOMPRESSION TABLE

C. Saturation Diving Procedures—Section 14.6—

EXCURSION TIMETABLE FOR SATURATION DEPTH BETWEEN 150 AND 300 FEET OF SEAWATER

EXCURSION TIMETABLE FOR SATURATION DEPTH BETWEEN 300 AND 850 FEET OF SEAWATER

CHAMBER INTERVAL CREDIT TABLE FOR SATURATION EXPOSURE AT A DEPTH BETWEEN 150 AND 850 FEET OF SEAWATER
INITIAL ASCENT TABLE FOR DECOMPRESSION FROM SATURATION-EXCURSION OPERATIONS

SATURATION DECOMPRESSION ASCENT SCHEDULE
DAILY ROUTINE SCHEDULE

GENERAL INSTRUCTIONS 14.3

As in air diving operations, all instructions for mixed-gas decompression must be rigidly followed to maximize diver safety. Alteration of established mixed-gas decompression procedures and tables shall be made only under the direction of a qualified diving medical officer in emergency situations.

Oxygen Concentration 14.3.1 As a consequence of greater depth, longer exposure times and the capability to vary the amount of oxygen in the diver's breathing gas, the problem of oxygen toxicity is more pronounced in mixed-gas diving than in air diving. Operationally the diver and surface crew must be constantly alert for developing symptoms of oxygen toxicity as discussed in Section 9.3.2.

Particular care must be taken in the mixing of gases to insure the proper oxygen composition for the breathing apparatus to be used and the depth and duration of the planned dive. The oxygen partial pressure limits found in Section 14.5.1 of this chapter establish the allowable exposure criteria for normal and exceptional operating conditions. It is essential that dives be conducted within the specified limits. It should be noted, however, that these values are for divers at work and are routinely exceeded during certain decompression procedures when the divers are at rest.

Selection of Schedules 14.3.2 Selection of the appropriate non-saturation decompression schedule should take into account not only the depth and bottom time of the dive but also the condition of the diver. If the bottom activity has been extremely arduous or the diver has been particularly cold during the dive, use the next longer bottom time schedule for that depth. If the actual dive depth is within a few feet of the selected schedule depth and surface conditions interfere with accurate depth control during decompression, use the next deeper schedule for decompression.

Exceptional Exposures 14.3.3 Normal and exceptional exposure schedules are combined in the "SCUBA" and "Surface-Supplied" sections of this chapter. Exceptional exposure schedules are printed in RED. Exceptional exposure schedules should

never be used except in cases of extreme operational necessity or in the case of a fouled diver who has exceeded his normal bottom time. Because of the limited assurance of successful decompression using these schedules, their use for operational dives shall be directed only by the Commanding Officer of the diving facility involved.

Repetitive Dives 14.3.4 Non-saturation, repetitive mixed-gas diving may only be conducted using SCUBA. Procedures for determining the decompression schedule to be used for a repetitive SCUBA dive are similar to those for air diving and will be found in Section 14.4.5. Repetitive dives using surface-supplied mixed gas are not permitted; a minimum 12-hour surface interval is required between surface-supplied dives. In saturation diving an excursion dive from saturation pressure occurring less than 24 hours from a previous excursion is considered to be a repetitive dive. Procedures for determining repetitive group designations, changes in group designation based upon saturation pressure interval credit, and bottom time to be added to the repetitive excursion are discussed in Section 14.6.7. The terms and procedures used for repetitive excursion dives in saturation diving are analogous to those employed for repetitive air and mixed-gas SCUBA diving.

Decompression Sickness 14.3.5 Decompression sickness occurring in non-saturation mixed-gas diving (both SCUBA and Surface-Supplied) is treated in the same manner as in air diving. Required procedures will be found in Chapter Eight, Volume I of the Diving Manual. Use of the oxygen treatment tables is the preferred method. Decompression sickness which occurs as a result of a saturation exposure is not treated using the conventional recompression procedures. Special treatment procedures have been developed for saturation diving and are included at the end of the section on Saturation Decompression (14.6.7).

He-O₂ Diving Chart 14.3.6 The He-O₂ diving chart, shown in Figure No. 14.1 should be used for assistance in conducting a helium-oxygen dive. The chart provides spaces for information required to determine the dive schedule and for the recording of in-

formation required for the dive record (OPNAV 9940/1). Place the stop times as determined from the He-O₂ Surface-Supplied Decompression Table in the column marked "Decompression Time At Stop." Place the stop times as determined from the Emergency Air Table in the "Emergency Air" column.

All information should be filled out on the chart (next page) to insure a complete record and the availability of an emergency table without further reference to the Diving Manual during the dive.

DIVING CHART – He-O₂ **NAVSHIPS 9940/11 (8-69) S/N 0105-643-3200**

DATE

NAME		RATE		TABLE USED		SCHEDULE USED		MAXIMUM O ₂		EFFECT. ATMOS.		CUT OFF DEPTH	
LEFT SURFACE		REACHED BOTTOM		LEFT BOTTOM		TIME TO FIRST STOP		BOTTOM TIME		PRESSURE IN PSI			
DEPTH IN FEET		O ₂ %		TOTAL DECOMP. TIME		TOTAL TIME OF DIVE		COMP. OF TABLE		TENDER (SIGN NAME)			
DESCENT ASCENT		EMERG. AIR		Depth of Stops; Ft.		Decompression Time At Stop		Emerg. HE-O ₂		Pressure in PSI		Time	
				200						89		R / L	
				190						85		R / L	
				180						80		R / L	
				170						75		R / L	
				160						72		R / L	
				150						67		R / L	
				140						62		R / L	
				130						58		R / L	
				120						54		R / L	
				110						49		R / L	
				100						44.5		R / L	
				90						40		R / L	
				80						36		R / L	
				70						32		R / L	
				60						27		R / L	
				50				26		22		R / L	
				40		WATER CHAMBER		30		18		R L	
				30				35		13		R L	
				20				42		9		R L	
				10				55		4.5		R L	
REACHED SURFACE		DIVER'S CONDITION AND REMARKS											

Figure 14-1

MIXED-GAS SCUBA DECOMPRESSION TABLES 14.4

The tables presented in this section provide decompression procedures for initial and repetitive dives made using constant mass-flow semiclosed-circuit SCUBA (MK 6) with various mixtures of helium-oxygen and nitrogen-oxygen. Additionally, emergency procedures for aborted decompression are provided.

The mixed-gas decompression tables are based upon the partial pressure of inert gas in the inhalation breathing bag of the SCUBA (not the partial pressure of the inert gas in the supply). This partial pressure requirement will be met as long as the mixed-gas flow rates are set as designated in Table 10-1 (page 10-16).

Helium-Oxygen SCUBA Decompression Table

14.4.1 At the present time, two gas mixtures are permitted for use in He-O₂ SCUBA diving. The standard mixture is 68 percent helium, 32 percent oxygen, and all decompression schedules relate to this mixture which can be used to a maximum depth of 200 feet for 30 minutes. The schedules in this table will also provide safe decompression from dives using a mixture of 60 percent helium-40 percent oxygen, provided the dives are limited to a maximum depth and bottom time of 80 feet for 100 minutes. Because of the higher oxygen percentage of this mixture, its use requires lower flow rates than the 32 percent oxygen mixture. Since the semiclosed-circuit SCUBA has a fixed supply of mixed gas, a lower supply flow rate permits longer dives. The intended use of the 40 percent oxygen mixture, therefore, is for long duration dives to 50 feet or less.

The decompression table for He-O₂ SCUBA is very similar to the Standard Air Decompression Table and is self-explanatory. This table permits repetitive diving, and consequently, repetitive group designators are included for each schedule. In using this table, the rate of descent should not exceed 75 feet per minute. The rate of ascent from the bottom and between stops should be 60 feet per minute.

EXAMPLE—

PROBLEM—A diver using a MK 6 SCUBA is to make a dive to 178 feet for 28 minutes. What is his decompression obligation?

SOLUTION—Select the next deeper and next longer decompression schedule. This would be the 180/30 schedule.

		Elapsed Decompression Time Min:Sec
Procedure		
1.	Ascend from 178 feet to 40 feet at 60 feet per minute	2:18
2.	Remain at 40 feet for 5 minutes	7:18
3.	Ascend to 30 feet	7:28
4.	Remain at 30 feet for 10 minutes	17:28
5.	Ascend to 20 feet	17:38
6.	Remain at 20 feet for 15 minutes	32:38
7.	Ascend to 10 feet	32:48
8.	Remain at 10 feet for 20 minutes	52:48
9.	Ascend to surface	52:58

HELIUM-OXYGEN SCUBA DECOMPRESSION TABLE

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent time (min:sec)	Repetitive group
			50	40	30	20	10		
40	260						0	0:40	L
50	180						0	0:50	L
	200	0:40					20	20:50	L
60	130						0	1:00	L
	150	0:50					20	21:00	L
	170	0:50					35	36:00	L
70	85						0	1:10	J
	100	1:00					15	16:10	K
	115	1:00					25	26:10	L
	130	1:00					40	41:10	L
* 80	60						0	1:20	I
	70	1:00				5	10	16:20	J
	80	1:00				10	15	26:20	K
	90	1:00				10	25	36:20	K
	100	1:00				10	35	46:20	K
90	45						0	1:30	H
	60	1:10				5	10	16:30	J
	70	1:10				5	20	26:30	K
	85	1:10				10	30	41:30	L
100	35						0	1:40	G
	50	1:20				5	15	21:40	J
	60	1:20				10	20	31:40	K
	70	1:10			5	15	25	46:40	K
110	30						0	1:50	G
	40	1:30				5	10	16:50	H
	50	1:30				10	20	31:50	J
	65	1:20			5	15	25	46:50	L
120	25						0	2:00	G
	35	1:40				5	10	17:00	I
	45	1:30			5	10	15	32:00	K
	55	1:30			10	15	20	47:00	L
130	20						0	2:10	F
	30	1:50				5	10	17:10	I
	40	1:40			5	10	15	32:10	J
	50	1:30		5	5	15	20	47:10	L
140	15						0	2:20	E
	25	2:00				5	10	17:20	G
	35	1:50			5	10	20	37:20	J
	45	1:40		5	5	15	25	52:20	K
150	15						0	2:30	E
	20	2:10				5	10	17:30	G
	30	2:00			5	10	15	32:30	J
	40	1:50		5	10	15	20	52:30	K

*Depth limit for use of 40 percent oxygen supply mixture.

HELIUM-OXYGEN SCUBA DECOMPRESSION TABLE

	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent time (min:sec)	Repetitive group
			50	40	30	20	10		
160	10						0	2:40	E
	20	2:10			5	5	10	22:40	G
	35	2:00	5	10	10	20		47:40	K
170	10						0	2:50	E
	20	2:20			5	5	10	22:50	H
	35	2:10	5	10	15	20		52:50	K
180	5						0	3:00	C
	10	2:40				5	10	18:00	E
	20	2:20		5	5	10	10	33:00	H
	30	2:20	5	10	15	20		53:00	K
190	10	2:50				5	10	18:10	E
	20	2:30		5	5	10	20	43:10	H
	30	2:20	5	5	10	15	25	63:10	K
200	10	3:00				5	15	23:20	F
	20	2:40		5	5	10	20	43:20	I
	30	2:30	5	5	10	15	35	73:20	K

Helium-Oxygen SCUBA Decompression Table Using Oxygen 14.4.2 The same mixtures, flow rates, depth limitations and descent and ascent rates apply to the Helium-Oxygen SCUBA Table Using Oxygen as apply to the previous table. By administering pure oxygen to the diver during decompression, there is a significant saving in decompression time as compared with using helium-oxygen throughout the dive.

The semiclosed-circuit apparatus presently in use in the U. S. Navy is not normally provided with a capability for oxygen decompression. However, by the addition of a separate oxygen cylinder and injection system it can be adapted for this kind of decompression. If this type of adaptation is used, the shift to oxygen is made at the first oxygen stop (20 or 30 feet) in these schedules. At the first oxygen stop, the oxygen apparatus is activated and the helium-oxygen mixture injection is secured. The breathing bags are then purged thoroughly three times. The table allows 2 minutes to complete this procedure. The decompression

time at the first oxygen stop does not start until after the required 2 minutes allowed for oxygen purging have elapsed.

Oxygen decompression can also be accomplished even if the apparatus has not been adapted for this purpose. This can be done by supplying the diver with a surface-supplied source of oxygen which is delivered to a demand regulator at the required decompression depth. It should be noted that this procedure should only be used when the exact location of the diver is known. A pneumofathometer, attached alongside the oxygen supply hose, is the recommended method of measuring the diver's exact depth.

EXAMPLE—

PROBLEM—A diver using a MK 6 SCUBA is to make a dive to 178 feet for 28 minutes. His apparatus is equipped for oxygen breathing. What is his decompression obligation?

SOLUTION—Select the 180/30 schedule.

HELIUM-OXYGEN SCUBA DECOMPRESSION TABLE USING OXYGEN

Depth (ft)	Time (min)	Decompression stops (min)				Repetitive group
		He-O ₂		Oxygen		
		50 feet	40 feet	30 feet	20 feet	
60	170				20	L
70	115				15	L
	130				25	L
*80	80				15	K
	90				20	K
	100				25	K
90	70				15	K
	85				25	L
100	50				15	J
	60				20	K
	70			5	20	K
110	50				15	J
	65			5	20	L
120	45			5	15	K
	55			10	20	L
130	40			5	15	J
	50		5	5	20	L
140	35			5	15	J
	45		5	5	20	K
150	30			5	15	J
	40		5	10	20	K
160	20			5	10	G
	35		5	10	20	K
170	20			5	10	H
	35		5	10	20	K
180	20		5	5	10	H
	30		5	10	20	K
190	20		5	5	15	H
	30	5	5	10	20	K
200	20		5	5	20	I
	30	5	5	10	25	K

ALLOW 2 MINUTES TO COMPLETE BAG PURGE TO OXYGEN

*Depth limit for use of 40 percent oxygen supply mixture.

Procedure	Elapsed Decompression Time Min:Sec
1. Ascend from 178 feet to 40 feet at 60 feet per minute	2:18
2. Remain at 40 feet for 5 minutes	7:18
3. Ascend to 30 feet	7:28
4. Purge the breathing bags with oxygen 3 times	9:28
5. Breathe O ₂ at 30 feet for 10 minutes	19:28
6. Ascend to 20 feet	19:38
7. Breathe O ₂ at 20 feet for 20 minutes	39:38
8. Ascend to the surface	39:58

Helium-Oxygen SCUBA No-Decompression Limits Table 14.4.3 The He-O₂ SCUBA No-Decompression Limits Table is for use with 68% helium-32% oxygen to depths down to 180 feet of seawater, and with 60% helium-40% oxygen to depths down to 80

feet of seawater. The limits given in the column entitled "No-Decompression Limits" provide the maximum bottom time, corresponding to the diver's depth, which permits surfacing directly at 60 feet per minute.

All depths are given in feet of seawater and exposure times are given in minutes.

The remainder of the table is used in the same manner as the Air No-Decompression Limits Table to determine the diver's repetitive group designation following a no-decompression dive. Exposure limits for depths less than 40 feet are listed up to 12 hours although this exposure time is significantly beyond the field requirements for the table.

EXAMPLE—

PROBLEM—A diver is to make a dive to 100 feet for 20 minutes using a MK 6 SCUBA. What is his repetitive group designation at the end of the dive?

SOLUTION—A dive to 100 feet for 20 minutes is a no-decompression dive. Enter the He-O₂ SCUBA No-Decompression Limits Table at the 100 foot row and move horizontally to the 20 minute column. The repetitive group, found at the top of this column, is "D."

HELIUM-OXYGEN SCUBA NO-DECOMPRESSION LIMITS TABLE

Depth (ft)	No-decom- pression limits (min)	Repetitive groups (He-O ₂ dives)											
		A	B	C	D	E	F	G	H	I	J	K	L
10		70	190	720									
20		25	60	95	145	215	335	720					
30		15	35	60	80	110	145	185	245	335	525	720	
40	260	10	25	40	55	70	90	110	140	165	200	245	260
50	180	10	20	30	40	55	70	85	100	120	140	160	180
60	130	5	15	25	35	45	55	65	75	90	105	120	130
70	85	5	10	20	30	35	45	55	65	75	85		
80	60	5	10	15	25	30	40	45	55	60			
90	45	5	10	15	20	25	35	40	45				
100	35	5	10	15	20	25	30	35					
110	30	5	9	12	15	20	25	30					
120	25	5	8	10	15	20	22	25					
130	20		5	10	15	17	20						
140	15		5	10	12	15							
150	15		5	10	12	15							
160	10		5	6	8	10							
170	10		5	6	8	10							
180	5			5									

Helium-Oxygen SCUBA Residual Helium Timetable For Repetitive Dives 14.4.4

A helium-oxygen repetitive dive is a He-O₂ SCUBA dive made after a 30 minute surface interval and before 12 hours have elapsed. A second dive made prior to the 30 minute minimum surface interval is considered a continuation of the first dive. In this event, the bottom times of the first and second dives are added together to determine the appropriate decompression schedule of the second dive. If the surface interval is more than 12 hours, normal He-O₂ decompression procedures are used.

Procedures for computing the residual helium time are the same as those for computing the residual nitrogen time, except that a different timetable is used. Enter the Residual Helium Timetable along the diagonal line at the letter which corresponds with the diver's repetitive group designation from his previous dive. Read horizontally to the interval in which the diver's surface interval lies. The time spent on the surface must be between or equal to the limits of the selected interval.

Next, read vertically downwards to the new repetitive group designation. This designation corresponds to the present quantity of residual helium in the diver's tissues. Continue downward in this same column to the row which represents the depth of the repetitive dive. The time given at the intersection is the residual helium time, in minutes, to be added to the actual repetitive dive bottom time.

In some instances, when the repetitive dive is to the same or greater depth than the previous dive, the residual helium time may be longer than the actual bottom time of the previous dive. In this event, add the actual bottom time of the previous dive to the actual bottom time of the repetitive dive to obtain the equivalent single dive time.

EXAMPLE—

PROBLEM—A previous dive was conducted to 143 feet for 23 minutes. The repetitive group designation following this dive was "J." The diver's surface interval has been 2 hours 20 minutes. He is to make a repetitive dive to 86 feet. What is his residual helium time?

SOLUTION—Enter the Residual Helium Timetable along the diagonal line at J. Read horizontally to the 2:01 interval, in which the diver's 2 hours 20 minute surface interval lies. Read vertically downward to find his new repetitive group designation; E.

Continue downward to the intersection of this column with the "90 FEET" row, which is the next greater depth than the repetitive dive depth. The residual helium time, located at this intersection is 29 minutes.

Nitrogen-Oxygen SCUBA Tables 14.4.5 Semi-closed-circuit, constant mass-flow SCUBA may also be used with nitrogen-oxygen, rather than helium-oxygen, mixtures. The Nitrogen-Oxygen SCUBA Table provides decompression procedures for this situation.

The fundamental principle of decompression from nitrogen-oxygen dives is that an **equivalent air depth** is established for the actual depth of the dive. The equivalent air depth is that depth at which the partial pressure of nitrogen in air (79% N₂) is equal to the average nitrogen partial pressure in the breathing bags of the semiclosed-circuit SCUBA. Using this equivalent air depth and the actual bottom time of the dive, the decompression schedule to be employed is selected from the Standard Air Decompression Table (Section 7.5.1, Volume 1). No credit is allowed for the fact that high-oxygen mixtures are breathed during decompression on the stops established for air decompression.

The Surface Decompression Table Using Oxygen (Section 7.5.4) or the Surface Decompression Table Using Air (Section 7.5.5) may be used routinely for decompression from nitrogen-oxygen dives. After the corresponding equivalent air depth is determined, either table may be used in the standard manner.

The Nitrogen-Oxygen SCUBA Table provides equivalent air depths for nonswimming and swimming dives, and for nitrogen-oxygen mixtures of 60, 40 and 32.5 percent oxygen. The maximum allowable bottom time for these dives is controlled by the exposure limits of the Oxygen Partial Pressure Limits Tables discussed in Section 14.5.1. In determining these limits, the oxygen partial pressure in the supply mixture should be used.

New Group At End of Surface Interval	L	0:30	0:31	0:41	0:51	1:21	1:41	2:01	2:31	3:11	4:01	5:11	7:11	12:00	A	0:30	12:00								
	L	0:30	0:40	0:50	1:20	1:40	2:00	2:30	3:10	4:00	5:10	7:10	12:00	B	0:30	2:01	12:00								
	K	0:30	0:40	1:00	1:20	1:50	2:20	3:00	3:50	5:00	7:00	12:00	C	0:30	1:21	3:11	12:00								
	J	0:30	0:40	1:00	1:30	2:00	2:40	3:30	4:40	6:40	12:00	D	0:30	0:51	2:01	4:01	12:00								
	I	0:30	0:50	1:20	1:50	2:20	3:10	4:20	6:20	12:00	E	0:30	0:41	1:31	2:41	4:41	12:00								
	H	0:30	0:51	1:30	2:00	2:50	4:00	6:00	12:00	F	0:30	0:36	1:11	2:01	3:11	5:11	12:00								
	G	0:30	0:31	1:00	1:40	2:30	3:40	5:40	12:00	I	0:30	0:31	1:01	1:41	2:31	3:41	5:41	12:00							
F	0:30	0:41	1:10	1:51	2:21	3:11	4:21	6:21	12:00	H	0:30	0:31	1:01	1:31	2:01	2:51	4:01	6:01	12:00						
E	0:30	0:40	1:00	1:30	2:00	2:40	3:30	4:40	6:40	12:00	J	0:30	0:41	1:01	1:31	2:01	2:41	3:31	4:41	6:41	12:00				
D	0:30	0:41	1:01	1:21	1:51	2:21	3:01	3:51	5:01	7:01	12:00	K	0:30	0:41	1:01	1:21	1:51	2:21	3:01	3:51	5:01	7:01	12:00		
C	0:30	0:41	1:01	1:21	1:41	2:01	2:31	3:11	4:01	5:11	7:11	12:00	L	0:30	0:40	0:50	1:20	1:40	2:00	2:30	3:10	4:00	5:10	7:10	12:00
B	0:30	0:40	1:00	1:30	2:00	2:40	3:30	4:40	6:40	12:00	A	0:30	0:36	1:10	2:00	3:10	5:10	12:00							
A	0:30	0:40	1:00	1:20	1:50	2:20	3:00	3:50	5:00	7:00	12:00	B	0:30	0:51	2:00	4:00	12:00								
Repetitive Group At The Beginning Of The Surface Interval	L	0:30	0:31	0:41	0:51	1:21	1:41	2:01	2:31	3:11	4:01	5:11	7:11	12:00	C	0:30	1:21	3:11	12:00						
Surface Intervals (Hours:Minutes)	L	0:30	0:40	0:50	1:20	1:40	2:00	2:30	3:10	4:00	5:10	7:10	12:00	D	0:30	0:51	2:01	4:01	12:00						
	L	0:30	0:41	1:01	1:31	2:01	2:41	3:31	4:41	6:41	12:00	E	0:30	0:41	1:31	2:41	4:41	12:00							
	K	0:30	0:41	1:01	1:21	1:51	2:21	3:01	3:51	5:01	7:01	12:00	F	0:30	0:36	1:11	2:01	3:11	5:11	12:00					
	J	0:30	0:50	1:20																					

MIXED GAS DECOMPRESSION

Nitrogen-oxygen dives which expose the diver to exceptionally high concentrations of oxygen, as defined in the table of Oxygen Partial Pressure Limits For Exceptional Exposure, are printed in RED. Because of the increased potential of developing oxygen poisoning under these conditions, the exceptional exposure schedules should be used only in emergency situations as authorized by the Commanding Officer of the diving facility involved.

Nonswimming dive flow settings are required in ordnance disposal for brief exposures with minimal exertion in order that the exhaust can be reduced to avoid excessive sound production in the water. The decreased flow setting does not provide sufficient oxygen in the breathing mixture for dives with greater than minimal exertion.

EXAMPLE —

PROBLEM—A diver is to make a swimming dive to 86 feet using a mixture of 60% nitrogen-40% oxygen. What is the equivalent air depth of this dive, and what is the diver's maximum allowable bottom time?

SOLUTION—Enter the Nitrogen-Oxygen SCUBA Table for a 40% oxygen mixture in the column designated "Swimming dive flow setting 12 lpm." Follow that column down to the depth which is equal to or next greater than the depth of the dive; in this case it would be 97 feet. Move one column to the right to find the equivalent air depth; 80 feet. Move one column further to the right to find the maximum allowable bottom time; 30 minutes. If the diver uses his maximum bottom time, he will decompress according to the 80/30 schedule of the Standard Air Table which is a no-decompression dive.

NITROGEN-OXYGEN REPETITIVE DIVE PROCEDURE 14.4.5.1 The Nitrogen-Oxygen SCUBA Table provides an equivalent air depth from which a decompression schedule in the Standard Air Table may be selected. This schedule, or possibly the No-Decompression Air Table, will designate a repetitive group for the surfaced diver.

If a repetitive dive is to be conducted, an equivalent air depth must be determined. Use the Nitrogen-Oxygen SCUBA Table to find the equivalent air depth corresponding to the depth of the repetitive dive. Using

the diver's repetitive group designation at the beginning of the surface interval, his surface interval and the equivalent air depth, his residual nitrogen time is computed directly from the Residual Nitrogen Time-table (Section 7.5.3).

EXAMPLE —

PROBLEM—A diver completed a 60% nitrogen-40% oxygen dive according to the 80/30 schedule of the Standard Air Table 3 hours 28 minutes ago. He is about to begin a repetitive swimming dive to 66 feet on the same mixture. What is his residual nitrogen time?

SOLUTION—The diver's repetitive group designation at the beginning of his surface interval, found using the 80/30 schedule in the No-Decompression Air Table, was G. The equivalent air depth of the repetitive dive, using the Nitrogen-Oxygen SCUBA Table is 60 feet.

Enter the Residual Nitrogen Timetable at G and move horizontally to the $\begin{smallmatrix} 2:59 \\ 4:25 \end{smallmatrix}$ interval. Read downward to the intersection of the 60 foot repetitive dive depth row. The residual nitrogen time is 17 minutes.

Omitted Decompression in Emergencies—Mixed-Gas SCUBA 14.4.6

Certain emergencies may interrupt or prevent specified decompression. Blowup, exhausted gas supply, bodily injury, and the like are among such emergencies. If there are symptoms of decompression sickness or gas embolism, immediate treatment by recompression (Chapter Eight, Volume 1) is essential. Even without evidence of any ill effects, omitted decompression must be made up in some manner to avert later difficulty.

USE OF SURFACE DECOMPRESSION TABLES

14.4.6.1 It may appear that surface decompression schedules offer an immediate solution to the problem of interrupted decompression because they provide for a surface interval. Such schedules should only be used, however, if the emergency surface interval occurs at such a time that water stops are not required or have already been completed in accordance with whichever surface decompression table is considered most appropriate.

NITROGEN-OXYGEN SCUBA TABLE

Oxygen Supply	Non-swimming dive flow setting	Actual depth up to - (feet)	Swimming dive flow setting	Actual depth up to - (feet)	Equivalent air depth (feet)	Maximum Allowable Bottom Time (Minutes)	
						Normal Exposure	Exceptional Exposure
60%	4 lpm	51	8 lpm	55	30	30	—
		51		65	30	→	60
		64		77	40	→	30
		77		—	50	→	30
40%	8 lpm	36	12 lpm	39	30	No Limit	—
		47		51	40	240	No Limit
		58		62	50	100	No Limit
		69		74	60	60	240
		80		85	70	45	160
		91		97	80	30	100
		102		108	90	→	80
		113		120	100	→	50
		124		131	110	→	30
32.5%	12 lpm	33	21 lpm	35	30	No Limit	—
		44		46	40	No Limit	—
		54		57	50	No Limit	—
		65		68	60	240	No Limit
		75		79	70	120	No Limit
		86		89	80	80	No Limit
		96		100	90	60	240
		107		111	100	50	180
		117		122	110	40	110
				129	120	30	
		128		133	120	→	90
		138		144	130	→	70
		149		155	140	→	50
		160		165	150	→	35
		170		170	160	→	30

SURFACE DECOMPRESSION TABLES NOT APPLICABLE 14.4.6.2 When the conditions in the paragraph above are not fulfilled, the diver's decompression has been compromised. Special care should be taken to detect signs of decompression sickness regardless of what action is initiated. The diver must be returned to pressure as soon as possible. The use of a recompression chamber, if available, is always preferable to in-water decompression.

A. WHEN A RECOMPRESSION CHAMBER IS AVAILABLE

Even if the diver shows no ill effects from his omitted decompression, he needs immediate recompression. Take him to depth as appropriate for Treatment Table 1A or 5. If he shows no ill effects, decompress him in accordance with the Treatment Table. Consider any decompression sickness developing during or after this procedure as a recurrence.

B. WHEN NO CHAMBER IS AVAILABLE

Recompress the diver in the water. Using the Helium-Oxygen SCUBA Decompression Table with helium-oxygen SCUBA and the Standard Air Decompression Table with nitrogen-oxygen SCUBA—

1. Repeat any stops deeper than 40 feet.
2. At 40 feet, remain for one-fourth of the 10-foot stop time.
3. At 20 feet, remain for one-half of the 10-foot stop time.
4. At 10 feet, remain for 1½ times the scheduled 10-foot stop time.

Stops in the above procedure shall not be shorter than those in the table being used. Keep the diver at rest, provide a standby diver, and maintain good communications and depth control.

HELIUM-OXYGEN SURFACE-SUPPLIED DECOMPRESSION TABLES 14.5

The Helium-Oxygen Surface-Supplied Decompression Tables, also referred to as the "partial pressure decompression tables," are used for deep diving with recirculating hard hat gear and surface-supplied flow-through or demand-type breathing equipment. These tables permit the use of He-O₂ mixtures with a wide range of oxygen concentrations.

Oxygen Limits 14.5.1 The normal minimum oxygen concentration in the supply gas should be 16%. This is the lowest level which will permit breathing on the surface without the development of hypoxia. The maximum allowable oxygen concentration is governed by the hazard of oxygen toxicity and is dependent upon the depth and bottom time for a given dive. The oxygen partial pressure and exposure time that will be experienced at depth with a given gas mixture must not exceed the limits of the following tables—

OXYGEN PARTIAL PRESSURE LIMITS TABLE NORMAL EXPOSURES

Exposure Time (min.)	Maximum Oxygen Partial Pressure (atmospheres)
30	1.6
40	1.5
50	1.4
60	1.3
80	1.2
120	1.1
240	1.0

EXCEPTIONAL EXPOSURES

Exposure Time (min.)	Maximum Oxygen Partial Pressure (atmospheres)
30	2.0
40	1.9
60	1.8
80	1.7
100	1.6
120	1.5
180	1.4
240	1.3

The following three equations are useful in computing oxygen concentrations under various conditions—

equation 14.1

$$\text{Maximum depth for a particular oxygen mixture} = \frac{\text{limiting oxygen partial pressure in atmos.} \times 33}{\text{oxygen percentage decimal fraction}} - 33$$

equation 14.2

$$\text{Maximum oxygen percentage for a particular depth} = \frac{\text{limiting oxygen partial pressure in atmos.} \times 33}{\text{depth} + 33} \times 100$$

equation 14.3

$$\text{Effective oxygen partial pressure in atmospheres} = (\text{depth} + 33) \times \frac{\text{oxygen percent decimal fraction}}{33}$$

Inert Gas Partial Pressure 14.5.2 Using the partial pressure of the inert gas instead of the actual depth of dive is the main difference between the surface-supplied air and helium-oxygen decompression methods. Since decompression from any given depth and bottom time exposure is governed by the uptake of inert gas by the body, the partial pressure of the inert component in the breathing mixture establishes the decompression profile. Based upon this principle, a series of tables were developed for surface-supplied helium-oxygen diving. Each table provides decompression schedules for a given partial pressure of inert gas (expressed in feet of seawater) in the breathing mixture at depth.

Selection of the correct He-O₂ decompression table may be accomplished by either of two methods—use of the He-O₂ Partial Pressure Table or by direct computation. Direct computation is the most accurate and the most commonly used procedure. Since the partial pressure of the inert component is equal to the absolute depth minus the partial pressure of oxygen, any reduction in oxygen percentage increases the inert gas partial pressure. When the recirculating mixed-gas helmet is used, a 2% reduction in oxygen content in the breathing mixture occurs due to metabolic consumption, and a suitable correction factor must be used in the equation. This correction factor is an inte-

HELIUM-OXYGEN PARTIAL PRESSURES TABLE

Depth (feet)	Oxygen percent												
	15	16	17	19	21	23	25	30	35	40	45	50	55
40	64	63	63	61	60	58	57	[*]	[*]	[*]	[*]	[*]	[*]
50	73	72	71	69	68	66	64	60	56	[*]	[*]	[*]	[*]
60	81	80	80	78	76	74	72	67	63	58	54	[*]	[*]
70	90	89	88	86	84	82	80	75	70	64	59	54	[*]
80	99	98	97	94	92	90	88	82	76	71	65	59	54
90	108	106	105	103	100	98	95	89	83	77	71	64	
100	116	115	114	111	108	106	103	96	90	83	76		
110	125	123	122	119	116	113	111	103	96	89	82		
120	134	132	131	127	124	121	118	111	103	95			
130	142	141	139	136	133	129	126	118	110	102			
140	151	149	148	144	141	137	134	125	116				
150	160	158	156	152	149	145	141	132	123				
160	168	166	165	161	157	155	149	139					
170	177	175	173	169	165	161	157	147					
180	186	184	182	177	173	169	165	154					
190	195	192	190	186	181	177	172						
200	203	201	199	194	189	185	180						
210	212	209	207	202	197	192	188						
220	221	218	216	210	205	200	195						
230	229	227	224	219	214	203	203						
240	238	235	233	227	222	216							
250	247	244	241	235	230	224							
260	255	252	250	244	238								
270	264	261	258	252	246								
280	273	270	267	260	254								
290	282	278	275	269									
300	290	287	284	277									
310	299	295	292	285									
320	308	304	301										
330	316	313	309										
340	325	321	318										
350	334	330	326										
360	342	338											
370	351	347											
380	360	356											

Numbers in red indicate exposures which exceed the limit for a 30 minute exposure at 1.6 atmospheres PO₂.

*No-decompression

gral part of the He-O₂ Partial Pressures Table. If non-recirculating breathing apparatus, e.g., MK 1 Mask, is used, no correction factor is employed. The procedures are as follows:

USE OF HE-O₂ PARTIAL PRESSURES TABLE 14.5.2.1

- A. Enter the He-O₂ Partial Pressures Table along the left margin using the exact or next greater depth.
- B. Select the oxygen percent column with the exact or next lesser oxygen percentage in the mix.
- C. At the intersection read the exact or next greater partial pressure table to be used.

COMPUTATION OF CORRECT TABLE 14.5.2.2

Formula— $PP = (D + 33) \times [1.00 - (O_2 - 0.02)]$

Where— PP = partial pressure in feet of all other gases except oxygen (table designation = partial pressure)

D = depth of dive in feet of seawater

O₂ = decimal equivalent of oxygen percentage

0.02 = an assured loss of 2% O₂ in helmet

EXAMPLE—

PROBLEM—Determine the proper decompression schedule to dive with a mixed-gas deep-sea rig to 290 ft. with an 84% He-16% O₂ mixture for 12 minutes—

SOLUTION—

- 1a. Using Table

D = 290

PP = 278

Use PP = 280

or

- 1b. Computation

$PP = (290 + 33) \times [1.00 - (0.16 - 0.02)]$

$PP = 323 \times (1.00 - 0.14)$

$PP = 323 \times 0.86$

$PP = 277.8$

Use PP = 280

2. Conduct the dive using the He-O₂ Decompression Table with a Partial Pressure of 280, and the 20 minute schedule.

Decompression Procedure 14.5.3 Both in-water and surface decompression may be performed using the same Helium-Oxygen Surface-Supplied Decompression Tables by varying the operating procedure. Oxygen breathing (with the diver at rest) is used in both procedures.

OPERATING PROCEDURES FOR IN-WATER DECOMPRESSION 14.5.3.1

- A. Select the appropriate partial pressure table as previously discussed.

- B. The rate of ascent from the bottom to the first stop is found as follows—

Rate of Ascent $= \frac{\text{Bottom Depth} - \text{Depth of First Stop}}{\text{Time to First Stop}}$

- C. Remain at the first stop for the number of minutes indicated.

- D. The rate of ascent between stops should be 60 ft./min. Include the time of ascent in the subsequent stop.

- E. The use of these tables in in-water decompression requires a switch to oxygen at the 50 foot (if included in the schedule) or 40 foot decompression stops. Upon arrival at the 50 foot stop, ventilate the diver with 25 actual cubic feet of oxygen then have him circulate for the remaining time. Three (3) minutes are allowed for ascent from the previous stop and ventilation. These 3 minutes are included in the 50 foot or 40 foot stop time.*

- F. Surface the diver at a rate of 40 feet per minute from the 40 foot stop during the last minute of decompression time.

EXAMPLE—

PROBLEM—Using the previous example of a dive to 290 feet for 12 minutes with an 84% helium-16% oxygen mixture, develop the dive profile.

SOLUTION—A dive profile is a valuable tool for planning every phase of a dive. Information readily avail-

*If the travel time to the 50 foot stop plus the time to ventilate with 25 actual cubic feet of oxygen exceeds 3 minutes, the difference must be added to the remaining 50 foot stop time.

able includes —

- rate of descent
- rate of ascent to first stop
- rate of ascent between stops
- stop times (including time of ascent)
- depth of dive
- stop depth
- bottom time
- total ascent time
- total dive time
- surface interval (when applicable)
- oxygen stops
- He-O₂ stops

The dive profile for in-water decompression of the example dive is shown below.

OPERATING PROCEDURE FOR SURFACE DECOMPRESSION 14.5.3.2 It is routine procedure to employ the surface decompression technique with oxygen breathing in helium-oxygen surface-supplied diving as an alternate to complete in-water decompression. This technique improves the comfort and safety of the diver by reducing his time underwater

and provides simplified handling of oxygen toxicity problems. A recompression chamber equipped for oxygen breathing is required. Selection of the correct schedule using the Helium-Oxygen Surface-Supplied Decompression Table and initial in-water decompression are the same as the instructions for in-water decompression. The following changes are made in the final stages of decompression —

- A. For Schedules in Which the First Stop is 40-Feet—**
1. Upon reaching the 40 foot stop, ventilate with 25 actual cubic feet of oxygen.
 2. Circulate on O₂ for 10 minutes at 40 feet.
 3. Surface in 1 minute.*
 4. Repressurize to 40 feet in the recompression chamber, breathing O₂ from the surface.*
 5. Breathe O₂ by mask for the full time of the 40 foot stop.
 6. During the last 5 minutes of decompression time, surface at a uniform rate while continuing to breathe oxygen.

*Maximum allowable combined time for these steps is 5 minutes.

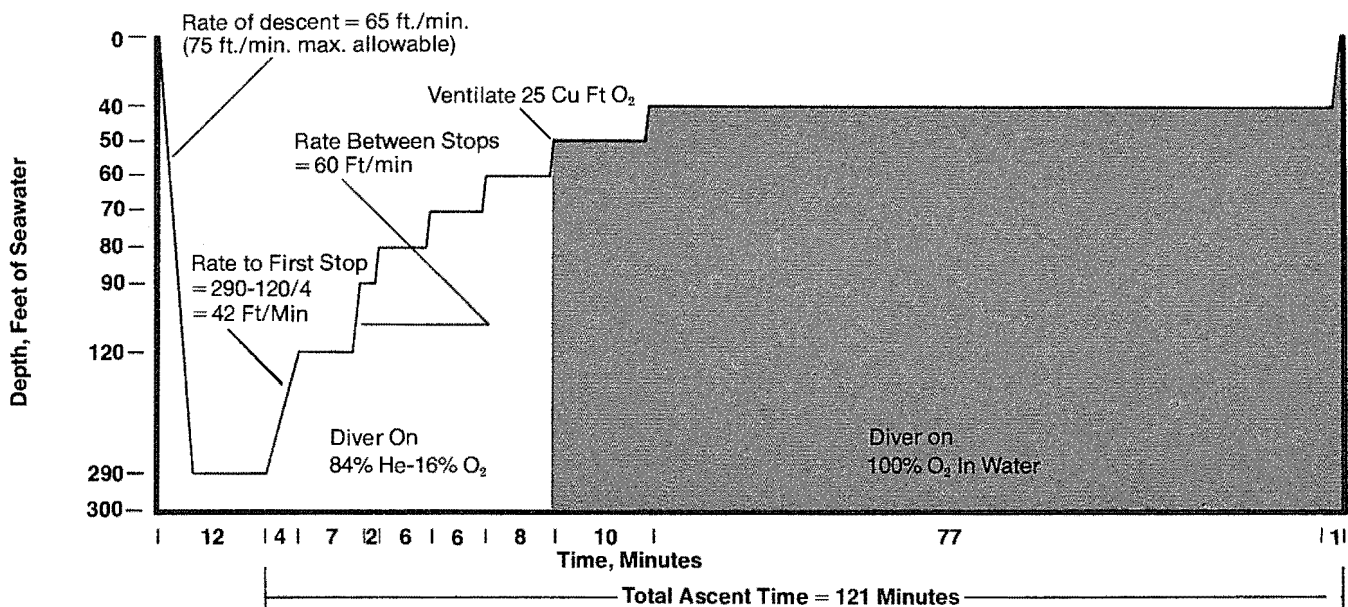


Figure 14-2 Dive profile for dive to 290 feet, 12 minutes, 84% He-16% O₂, in-water decompression

B. For Schedules in Which the First Stop is Deeper than 40 Feet—

1. Upon reaching the 50 foot stop, ventilate with 25 actual cubic feet of oxygen.
2. Circulate on O₂ for the time of the 50 foot stop.
3. Ascend to the 40 foot stop and remain on oxygen for a length of time equal to that of the 50 foot stop.
4. Surface in 1 minute.*
5. Repressurize to 40 feet in the recompression chamber, breathing O₂ from the surface.*
6. Breathe O₂ by mask for the full time of the 40 foot stop.
7. During the last 5 minutes of decompression time, surface at a uniform rate while continuing to breathe oxygen.

EXAMPLE—Using the previous example of a dive to 290 ft. with an 84% He-16% O₂ mix for 12 minutes, the 280/20 Table is used. When surface decompression using oxygen is employed, the dive profile is as follows:

*Maximum allowable combined time for these steps is 5 minutes.

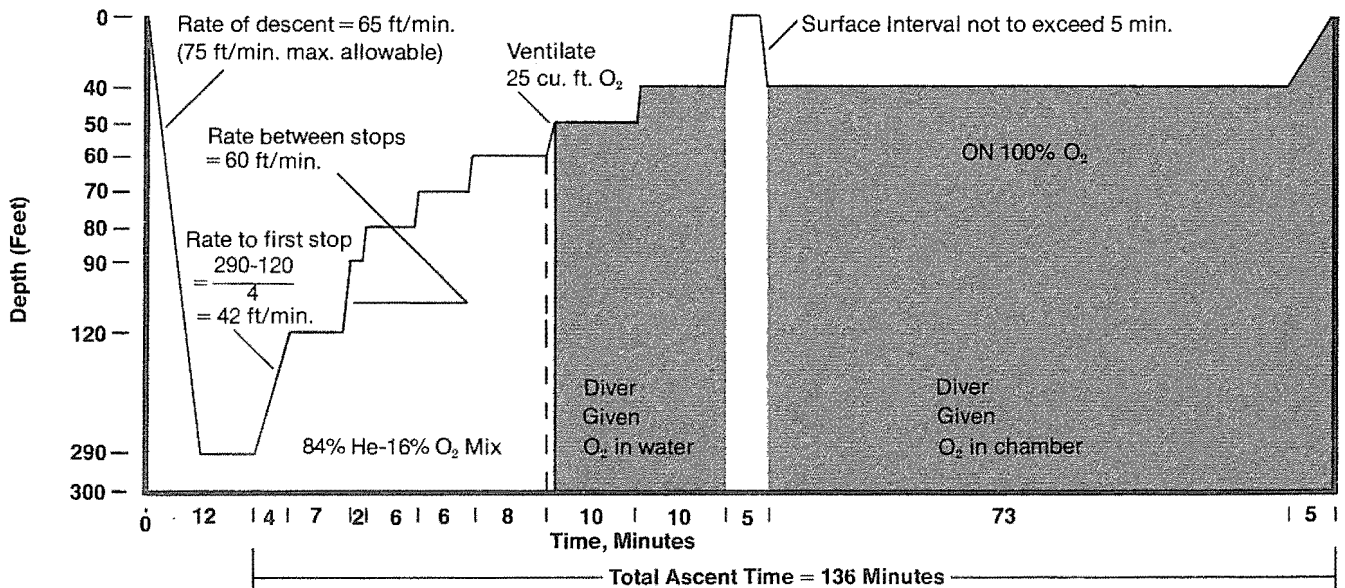


Figure 14-3 Dive profile for dive to 290 feet, 12 minutes, 84% He-16% O₂, surface decompression

NOTE

Repetitive diving is not allowed with less than a 12-hour surface interval. Exceptional Exposures (schedules printed in red) should only be used in cases of extreme operational necessity or in the case of a fouled diver who has exceeded the normal maximum bottom time. Use of these schedules for operational dives shall be directed only by the Commanding Officer of the diving activity involved, and he shall assume the responsibility for any mishap which might occur because of their use. The only exception to the above limitations is that these schedules may be used with discretion at the Naval School, Diving and Salvage, during certain phases of diver training.

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)																TOTAL ASCENT TIME (MIN.)
			180	170	160	150	140	130	120	110	100	90	80	70	60	50	40		
60	10	4															0	4	
	20	4															0	4	
	30	4															0	4	
	40	4															0	4	
	60	4															0	4	
	80	4															6	8	
	100	2															7	9	
	120	2															9	11	
70	240	2															13	15	
	10																6	9	
	20																7	10	
	30																9	12	
	40																10	13	
	60																15	18	
	80																17	20	
	100	3															22	25	
80	120																25	28	
	140																27	30	
	160																29	32	
	180																31	34	
	200																31	34	
	220																33	36	
	240																33	36	
	10																6	9	
90	20																10	13	
	30																13	16	
	40																17	20	
	60																24	27	
	80																32	35	
	100	3															40	43	
	120																42	45	
	140																45	48	
	160																47	50	
	180																48	51	
	200																48	51	
	220																48	51	
	240																50	53	
	10																8	11	
	20																15	18	
	30																18	21	
	40																23	26	
	60																35	38	
	80																45	48	
	100	3															50	53	
	120																55	58	
	140																58	61	
	160																60	63	
	180																60	63	
	200																62	65	
	220																62	65	
	240																63	66	

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)																TOTAL ASCENT TIME (MIN.)
			180	170	160	150	140	130	120	110	100	90	80	70	60	50	40		
100	10	3																10	13
	20																	17	20
	30																	24	27
	40																	31	34
	60																	47	50
	80																	56	59
	100																	63	66
	120																	67	70
	140																	70	73
	160																	72	75
	180																	73	76
	200																	73	76
	220																	73	76
	240																	75	78
110	10	3																12	15
	20																	21	24
	30																	31	34
	40																	39	42
	60																	56	59
	80																	67	70
	100																	75	78
	120																	78	81
	140																	81	84
	160																	83	86
	180																	84	87
	200																	84	87
	220																	85	88
	240																	86	89
120	10	3																14	17
	20																	25	28
	30																	36	39
	40																	47	50
	60																	66	69
	80																	77	80
	100																	84	87
	120																	87	90
	140																	90	93
	160																	92	95
	180																	93	96
	200																	93	96
	220																	95	98
	240																	97	100

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)																TOTAL ASCENT TIME (MIN.)
			180	170	160	150	140	130	120	110	100	90	80	70	60	50	40		
130	10	3															0	16	19
	20																0	29	32
	30																0	42	45
	40																0	53	56
	60																0	73	76
	80																0	86	89
	100																0	92	95
	120																0	96	99
	140																0	99	102
	160															10	92	105	
	180															10	93	106	
	200															10	94	107	
220														10	95	108			
240														10	96	109			
140	10	3															0	19	22
	20																0	34	37
	30																0	49	52
	40																0	62	65
	60																0	82	85
	80																0	94	97
	100																0	99	102
	120														10	97	110		
	140														10	98	111		
	160														10	99	112		
	180														12	99	114		
	200														13	99	115		
220													14	99	116				
240													15	99	117				
150	10	3															0	10	11
	20																0	10	28
	30																0	10	45
	40																7	10	59
	60																7	10	78
	80																7	10	90
	100																7	10	96
	120																7	11	98
	140																7	13	99
	160																8	15	99
	180																9	15	99
	200																10	16	99
220															11	16	99		
240															12	16	99		

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)		
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40	
160	10	3													0	0	10	12	25
	20														0	7	10	33	53
	30														0	7	10	50	70
	40														0	7	10	65	85
	60														0	7	10	84	104
	80														0	7	10	96	116
	100														0	7	13	99	122
	120														0	9	16	99	127
	140														0	15	16	99	133
	160														0	18	16	99	136
	180														0	20	16	99	138
	200														0	22	16	99	140
	220														0	23	16	99	141
	240														7	19	16	99	144
170	10	3													0	7	10	15	35
	20														0	7	10	36	56
	30														0	7	10	55	75
	40														0	7	10	70	90
	60														7	6	10	83	109
	80														7	9	10	98	127
	100														7	13	14	98	135
	120														7	17	16	99	142
	140														8	21	16	99	147
	160														11	22	16	99	151
	180														11	23	16	99	152
	200														12	23	16	99	153
	220														14	23	16	99	155
	240														16	23	16	99	157
180	10	3													0	7	0	10	37
	20														0	7	0	10	61
	30														0	7	1	10	83
	40														0	7	4	10	101
	60														0	7	10	10	122
	80														0	9	14	13	137
	100														7	5	18	15	147
	120														7	9	21	16	155
	140														7	11	22	16	158
	160														7	15	23	16	163
	180														7	17	23	16	165
	200														7	19	23	16	167
	220														7	21	23	16	169
	240														7	23	23	16	171

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)			
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40		
190	10	4												0	7	0	10	20	41	
	20													0	7	0	10	44	65	
	30													0	7	4	10	67	92	
	40													7	0	8	10	81	110	
	60													7	5	11	10	96	133	
	80													7	9	15	15	99	149	
	100													7	13	19	16	99	158	
	120													7	17	23	16	99	166	
	140													9	19	23	16	99	170	
	160													11	20	23	16	99	173	
	180													13	21	23	16	99	176	
	200													14	22	23	16	99	178	
220												15	23	23	16	99	180			
240												17	23	23	16	99	182			
200	10	4												0	0	7	0	10	22	43
	20													0	7	0	2	10	50	73
	30													0	7	0	7	10	69	97
	40													0	7	4	9	10	84	118
	60													0	7	9	13	12	93	138
	80													7	3	13	18	15	99	159
	100													7	6	16	21	16	99	169
	120													7	8	20	23	16	99	177
	140													7	11	21	23	16	99	181
	160													7	15	23	23	16	99	187
	180													7	17	23	23	16	99	189
	200													7	18	23	23	16	99	190
220												7	20	23	23	16	99	192		
240												8	20	23	23	16	99	193		
210	10	4												0	7	0	0	10	25	46
	20													0	7	0	4	10	53	78
	30													7	0	3	7	10	74	105
	40													7	0	7	10	10	86	124
	60													7	4	10	14	13	98	150
	80													7	8	14	18	16	99	166
	100													7	12	17	23	16	99	178
	120													8	15	21	23	16	99	186
	140													10	17	21	23	16	99	190
	160													12	17	22	23	16	99	193
	180													14	18	22	23	16	99	196
	200													16	18	23	23	16	99	199
220												17	19	23	23	16	99	201		
240												18	20	23	23	16	99	203		

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)	
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40
220	10	4									0	0	7	0	0	10	28	49
	20										0	7	0	1	6	10	57	85
	30										0	7	0	6	7	10	79	113
	40										0	7	3	9	10	10	90	133
	60										7	0	9	11	17	13	98	159
	80										7	3	11	15	20	13	99	172
	100										7	6	14	19	23	16	99	188
	120										7	8	18	23	23	16	99	198
	140										7	11	18	23	23	16	99	201
	160										7	14	19	23	23	16	99	205
	180										7	15	20	23	23	16	99	207
	200										7	16	20	23	23	16	99	209
220									8	17	20	23	23	16	99	210		
240									9	19	20	23	23	16	99	213		
230	10	4									0	0	7	0	2	10	30	53
	20										0	7	0	3	7	10	61	92
	30										0	7	2	6	9	10	81	119
	40										7	0	6	9	11	10	93	140
	60										7	4	9	12	18	14	99	167
	80								0	7	8	12	17	21	16	99	184	
	100								0	7	12	15	20	23	16	99	196	
	120								0	8	14	19	23	23	16	99	206	
	140								0	10	16	20	23	23	16	99	211	
	160								7	6	18	20	23	23	16	99	216	
	180								7	7	19	20	23	23	16	99	218	
	200								7	9	19	20	23	23	16	99	220	
220							7	11	19	20	23	23	16	99	222			
240							7	13	19	20	23	23	16	99	224			
240	10	4								0	0	7	0	0	3	10	33	57
	20									0	7	0	1	4	7	10	65	98
	30									0	7	0	5	7	10	10	85	128
	40									7	0	3	7	9	13	11	95	149
	60									7	0	8	10	14	18	15	99	175
	80								7	3	10	14	18	23	16	99	194	
	100								7	6	12	17	23	23	16	99	207	
	120								7	7	16	19	23	23	16	99	214	
	140								7	11	16	20	23	23	16	99	219	
	160								7	13	19	20	23	23	16	99	224	
	180								8	15	19	20	23	23	16	99	227	
	200								8	17	19	20	23	23	16	99	229	
220							9	17	19	20	23	23	16	99	230			
240							11	17	19	20	23	23	16	99	232			

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)			
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40		
250	10	4									0	7	0	0	2	4	10	35	62	
	20										0	7	0	2	5	7	10	68	103	
	30										7	0	2	6	7	10	10	87	133	
	40										7	0	5	8	9	14	12	96	155	
	60								0	7	4	8	11	14	19	16	99	182		
	80								0	7	7	11	16	18	23	16	99	201		
	100								0	7	10	14	19	23	23	16	99	215		
	120								7	3	12	17	19	23	23	16	99	223		
	140								7	4	15	18	19	23	23	16	99	228		
	160								7	7	16	19	19	23	23	16	99	233		
	180								7	9	17	19	20	23	23	16	99	237		
	200								7	11	17	19	20	23	23	16	99	239		
	220								7	12	17	19	20	23	23	16	99	240		
	240								7	13	17	19	20	23	23	16	99	241		
260	10	4									0	7	0	0	2	4	10	37	64	
	20										7	0	0	3	7	7	10	70	108	
	30										7	0	4	6	8	10	10	89	138	
	40										7	2	5	9	9	14	13	96	159	
	60								7	0	7	9	12	16	21	16	99	191		
	80								7	3	9	13	15	21	23	16	99	210		
	100								7	6	11	14	19	23	23	16	99	222		
	120								7	8	13	19	20	23	23	16	99	232		
	140								7	11	15	19	20	23	23	16	99	237		
	160								8	13	17	19	20	23	23	16	99	242		
	180								9	14	17	19	20	23	23	16	99	244		
	200								10	16	17	19	20	23	23	16	99	247		
	220								11	16	17	19	20	23	23	16	99	248		
	240								13	16	17	19	20	23	23	16	99	250		
270	10	4									0	7	0	0	4	4	10	40	69	
	20										0	7	0	2	4	6	7	10	74	114
	30										7	0	2	5	6	9	10	92	145	
	40										7	0	3	8	9	10	15	14	96	166
	60								0	7	3	7	10	14	16	21	16	99	197	
	80								0	7	6	10	13	17	23	23	16	99	218	
	100								7	2	9	13	16	20	23	23	16	99	232	
	120								7	4	11	14	19	20	23	23	16	99	240	
	140								7	5	14	15	19	20	23	23	16	99	245	
	160								7	7	15	17	19	20	23	23	16	99	250	
	180								7	9	16	17	19	20	23	23	16	99	253	
	200								7	11	16	17	19	20	23	23	16	99	255	
	220								7	13	16	17	19	20	23	23	16	99	257	
	240								7	15	16	17	19	20	23	23	16	99	259	

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)		
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40	
280	10	4								0	7	0	0	2	3	4	10	42	72
	20									7	0	0	2	6	6	8	10	78	121
	30									7	0	3	6	6	9	13	10	93	151
	40							7	0	2	5	8	8	12	16	13	98	173	
	60							7	0	6	8	10	14	19	23	16	99	206	
	80							7	3	8	11	14	17	23	23	16	99	225	
	100							7	5	11	13	16	20	23	23	16	99	237	
	120							7	8	12	16	19	20	23	23	16	99	247	
	140							7	10	16	17	19	20	23	23	16	99	254	
	160							8	13	16	17	19	20	23	23	16	99	258	
	180							9	14	16	17	19	20	23	23	16	99	260	
	200							10	15	16	17	19	20	23	23	16	99	262	
	220							12	15	16	17	19	20	23	23	16	99	264	
	240							14	15	16	17	19	20	23	23	16	99	266	
290	10	4							0	0	7	0	0	3	3	4	10	46	77
	20								0	7	0	0	4	6	7	7	10	81	126
	30								7	0	1	5	5	9	9	12	10	96	158
	40						0	7	0	4	6	8	9	12	17	15	98	180	
	60						0	7	4	6	8	12	15	18	23	16	99	212	
	80						7	0	7	9	11	15	17	23	23	16	99	231	
	100						7	2	9	11	15	17	20	23	23	16	99	246	
	120						7	4	11	13	16	19	20	23	23	16	99	255	
	140						7	5	13	16	17	19	20	23	23	16	99	262	
	160						7	8	14	16	17	19	20	23	23	16	99	266	
	180						7	10	15	16	17	19	20	23	23	16	99	269	
	200						7	12	15	16	17	19	20	23	23	16	99	271	
	220						7	13	15	16	17	19	20	23	23	16	99	272	
	240						7	14	15	16	17	19	20	23	23	16	99	273	
300	10	5				0	0	0	7	0	0	0	4	3	4	10	49	82	
	20					0	0	7	0	0	2	6	6	9	10	83	134		
	30					0	0	7	0	2	5	5	9	14	12	94	162		
	40					0	0	7	0	5	7	8	11	13	17	15	98	186	
	60					0	7	0	6	7	9	12	15	20	23	16	99	219	
	80					0	7	2	8	10	12	16	19	23	23	16	99	240	
	100					0	7	5	10	12	15	19	20	23	23	16	99	254	
	120					0	7	8	11	16	17	19	20	23	23	16	99	264	
	140					0	8	9	14	16	17	19	20	23	23	16	99	269	
	160					0	8	13	15	16	17	19	20	23	23	16	99	274	
	180					7	3	13	15	16	17	19	20	23	23	16	99	276	
	200					7	5	14	15	16	17	19	20	23	23	16	99	279	
	220					7	6	14	15	16	17	19	20	23	23	16	99	280	
	240					7	9	14	15	16	17	19	20	23	23	16	99	283	

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)		
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40	
310	10	5				0	0	0	7	0	0	2	3	3	5	10	52	87	
	20					0	0	7	0	0	4	5	6	6	11	10	84	138	
	30					0	7	0	0	5	5	7	8	9	14	12	96	168	
	40					0	7	0	3	5	8	8	11	13	18	15	99	192	
	60					0	7	3	6	7	10	12	18	22	23	16	99	228	
	80					7	0	6	9	11	12	16	19	23	23	16	99	246	
	100					7	1	9	10	14	17	19	20	23	23	16	99	263	
	120					7	4	11	12	14	17	19	20	23	23	16	99	270	
	140					7	5	12	15	16	17	19	20	23	23	16	99	277	
	160					7	8	14	15	16	17	19	20	23	23	16	99	282	
	180					7	10	14	15	16	17	19	20	23	23	16	99	284	
	200					7	12	14	15	16	17	19	20	23	23	16	99	286	
	220					8	13	14	15	16	17	19	20	23	23	16	99	288	
	240					9	13	14	15	16	17	19	20	23	23	16	99	289	
320	10	5				0	0	0	7	0	0	3	3	3	7	10	54	92	
	20					0	0	7	0	0	2	4	5	6	7	10	85	141	
	30					0	0	7	0	2	4	5	7	8	11	15	13	98	175
	40					0	7	0	1	4	6	7	8	12	15	19	16	99	199
	60					0	7	0	5	6	9	11	13	17	20	23	16	99	231
	80					0	7	3	7	9	11	13	17	20	23	23	16	99	253
	100					0	7	5	9	11	13	17	19	20	23	23	16	99	267
	120					0	7	7	12	13	16	17	19	20	23	23	16	99	277
	140					7	2	9	12	15	16	17	19	20	23	23	16	99	283
	160					7	3	11	14	15	16	17	19	20	23	23	16	99	288
	180					7	5	11	14	15	16	17	19	20	23	23	16	99	290
	200					7	6	13	14	15	16	17	19	20	23	23	16	99	293
	220					7	7	13	14	15	16	17	19	20	23	23	16	99	294
	240					7	9	13	14	15	16	17	19	20	23	23	16	99	296
330	10	5				0	0	0	7	0	0	4	3	3	7	10	56	95	
	20					0	0	7	0	0	3	5	5	6	8	10	88	147	
	30					0	7	0	0	4	4	6	7	9	11	17	13	98	181
	40					0	7	0	4	4	6	7	9	12	16	20	16	99	205
	60					7	0	2	6	8	9	11	14	17	23	23	16	99	240
	80					7	0	6	8	8	13	14	19	20	23	23	16	99	261
	100					7	2	7	10	13	16	17	19	20	23	23	16	99	277
	120					7	4	9	12	13	16	17	19	20	23	23	16	99	283
	140					7	6	11	13	15	16	17	19	20	23	23	16	99	290
	160					7	8	13	14	15	16	17	19	20	23	23	16	99	295
	180					7	10	13	14	15	16	17	19	20	23	23	16	99	297
	200					7	12	13	14	15	16	17	19	20	23	23	16	99	299
	220					9	12	13	14	15	16	17	19	20	23	23	16	99	301
	240					10	12	13	14	15	16	17	19	20	23	23	16	99	302

HELIUM-OXYGEN SURFACE SUPPLIED DECOMPRESSION TABLE

PARTIAL PRESSURE	BOTTOM TIME (MIN.)	TIME TO FIRST STOP (MIN.)	Decompression Stops (Feet)														TOTAL ASCENT TIME (MIN.)			
			180	170	160	150	140	130	120	110	100	90	80	70	60	50		40		
340	10	5			0	0	0	7	0	0	0	2	3	3	4	7	10	59	100	
	20			0	0	7	0	0	2	3	4	6	5	10	10	10	90	152		
	30			0	0	7	0	1	4	5	6	8	8	13	17	14	98	186		
	40			0	7	0	1	4	5	7	7	10	12	17	22	16	99	212		
	60			0	7	0	5	6	8	9	11	15	20	23	23	16	99	247		
	80			0	7	2	7	8	10	13	15	19	20	23	23	16	99	267		
	100			0	7	5	9	9	13	16	17	19	20	23	23	16	99	281		
	120			7	1	7	10	13	15	16	17	19	20	23	23	16	99	291		
	140			7	2	9	12	14	15	16	17	19	20	23	23	16	99	297		
	160			7	4	10	13	14	15	16	17	19	20	23	23	16	99	301		
	180			7	5	12	13	14	15	16	17	19	20	23	23	16	99	304		
	200			7	6	12	13	14	15	16	17	19	20	23	23	16	99	305		
220		7	8	12	13	14	15	16	17	19	20	23	23	16	99	307				
240		7	10	12	13	14	15	16	17	19	20	23	23	16	99	309				
350	10	5			0	0	0	7	0	0	0	3	3	3	4	7	10	61	103	
	20			0	0	7	0	0	2	4	5	7	8	9	10	10	90	157		
	30			0	7	0	0	3	5	5	6	8	9	13	18	14	98	191		
	40			0	7	0	2	4	6	7	8	10	13	16	22	16	99	215		
	60			7	0	3	5	6	9	10	13	16	18	21	23	16	99	251		
	80			7	0	7	7	8	11	13	15	19	20	23	23	16	99	273		
	100			7	2	8	8	12	13	16	17	19	20	23	23	16	99	288		
	120			7	4	9	11	13	15	16	17	19	20	23	23	16	99	297		
	140			7	6	11	13	14	15	16	17	19	20	23	23	16	99	304		
	160			7	9	11	13	14	15	16	17	19	20	23	23	16	99	307		
	180			8	9	12	13	14	15	16	17	19	20	23	23	16	99	309		
	200			8	11	12	13	14	15	16	17	19	20	23	23	16	99	311		
220		10	11	12	13	14	15	16	17	19	20	23	23	16	99	313				
240		11	11	12	13	14	15	16	17	19	20	23	23	16	99	314				
360	10	5			0	0	0	7	0	0	0	2	2	3	3	5	7	10	64	108
	20			0	0	7	0	0	4	4	5	5	7	9	13	10	94	163		
	30			0	0	7	0	1	4	4	5	7	8	11	13	18	14	99	196	
	40			0	7	0	1	3	5	6	7	8	11	14	17	23	16	99	222	
	60			0	7	0	5	5	8	8	11	12	16	19	23	23	16	99	257	
	80			0	7	2	7	7	10	11	13	17	19	20	23	23	16	99	279	
	100			7	0	6	8	9	11	15	16	17	19	20	23	23	16	99	294	
	120			7	1	7	9	12	14	15	16	17	19	20	23	23	16	99	303	
	140			7	3	9	11	13	14	15	16	17	19	20	23	23	16	99	310	
	160			7	4	10	12	13	14	15	16	17	19	20	23	23	16	99	313	
	180			7	5	11	12	13	14	15	16	17	19	20	23	23	16	99	315	
	200			7	7	11	12	13	14	15	16	17	19	20	23	23	16	99	317	
220		7	9	11	12	13	14	15	16	17	19	20	23	23	16	99	319			
240		7	11	11	12	13	14	15	16	17	19	20	23	23	16	99	321			

Emergency Decompression Procedures 14.5.4

Two Emergency Decompression Tables are provided in this section. These tables give alternate decompression schedules for situations in which the planned decompression mix cannot be used.

A list of emergency procedures to be used under various operating situations is also included at the end of this section. These guidelines include provision for omitted decompression, loss of He-O₂ and O₂ supplies, and development of oxygen toxicity while in the water and during surface decompression.

EMERGENCY HELIUM-OXYGEN TABLE 14.5.4.1

The Emergency He-O₂ Table should be used only when oxygen cannot be given during decompression. This may result from a failure of the oxygen supply or oxygen toxicity symptoms threatening the diver. If it is known in advance that oxygen cannot be used during decompression, use the regular schedules up to the first oxygen stop and then shift to the Emergency He-O₂ Table.

The helium-oxygen mixture used must contain a minimum of 16 percent oxygen.

EXAMPLE—

PROBLEM—A diver is undergoing decompression on the 190/30 schedule of the He-O₂ Surface-Supplied Table. The oxygen supply has fouled at the 40 foot stop. What is the diver's remaining decompression obligation?

SOLUTION—The diver, according to the 190/30 schedule has already spent 7 minutes at 70 feet, 4 minutes at 60 feet and 10 minutes at 50 feet. Having lost oxygen, he must now complete the decompression breathing a He-O₂ mixture according to the Emergency He-O₂ Table.

Procedure	Elapsed Decompression Time (Minutes)
(Prior to loss of oxygen)	
1. Remain at the 40 foot stop a total of 30 minutes	25
	55

2. Ascend to 30 feet and remain there for 35 minutes	90
3. Ascend to 20 feet and remain there for 42 minutes	132
4. Ascend to 10 feet and remain there for 55 minutes	187
5. Surface	

EMERGENCY HELIUM-OXYGEN DECOMPRESSION TABLE

Decompression Stop Depth (feet)	Decompression Stop Time (min)
50	26
40	30
30	35
20	42
10	55

EMERGENCY AIR TABLE 14.5.4.2 This table is used in an emergency when neither oxygen nor helium-oxygen can be used during decompression.

When using this table, the rate of ascent to the first decompression stop should be the same as that listed in the Helium-Oxygen Surface-Supplied Table, but it must never exceed 60 feet per minute. The rate of ascent on subsequent stops is not critical as long as full decompression is received at each stop.

Schedules are provided for loss of the helium-oxygen or oxygen supply anywhere between the surface and 400 feet. Select the schedule that is equal to or the next deeper depth than the depth at which the supply was lost.

EXAMPLE—

PROBLEM—The helium-oxygen supply to a diver at 220 feet has been lost. His normal decompression would have been conducted using the 220 partial pressure table. What is his new decompression obligation?

SOLUTION—Switch the diver to air immediately and bring him to the first decompression stop. According to the 250 foot schedule of the Emergency Air Table, which is the next deeper schedule, this stop would be 110 feet.

Procedure	Elapsed Decompression Time (Minutes)
1. Ascend from 220 feet to 110 feet at $\frac{220 - 110}{4} = 27.5$ feet per minute	4
2. Remain at 110 feet for 13 minutes	17
3. Ascend to 100 feet and remain for 18 minutes	35
4. Ascend to 90 feet and remain for 19 minutes	54
5. Ascend to 80 feet and remain for 22 minutes	76
6. Ascend to 70 feet and remain for 24 minutes	100
7. Ascend to 60 feet and remain for 26 minutes	126
8. Ascend to 50 feet and remain for 30 minutes	156
9. Ascend to 40 feet and remain for 35 minutes	191
10. Ascend to 30 feet and remain for 42 minutes	233
11. Ascend to 20 feet and remain for 52 minutes	285
12. Ascend to 10 feet and remain for 68 minutes	353
13. Surface	

EMERGENCY AIR DECOMPRESSION TABLE

Stops (feet)	Depth up to (feet)—						
	100	150	200	250	300	350	400
190							3
180							11
170							12
160						9	12
150						13	13
140					4	13	14
130					14	15	15
120					16	16	16
110				13	16	17	17
100				18	18	18	18
90			7	19	19	20	20
80			22	22	22	22	22
70			24	24	24	24	24
60		22	26	26	26	27	27
50		30	30	30	30	30	30
40	14	35	35	35	35	35	35
30	42	42	42	42	42	42	42
20	52	52	52	52	52	52	52
10	68	68	68	68	68	68	68

RULES FOR He-O₂ SUPPLY & O₂ TOXICITY PROBLEMS DURING ASCENT 14.5.4.3

A. LOSS OF He-O₂ SUPPLY

Deeper Than 50 Feet

- Shift to air, decompress in accordance with the Emergency Air Table. No surface decompression is to be used.

B. LOSS OF O₂ SUPPLY

Loss at 50-Foot Stop

- Shift to air (or He-O₂). Complete the stops in accordance with the Emergency Air Table (or Emergency He-O₂ Table). Surface decompression can be used after the 30 foot stop. The time spent on O₂ counts towards decompression.

Loss at 40-Foot Stop

- If the loss occurs before the diver is within 5 minutes of repeating his 50 foot stop time (Emergency Surface Decompression Limit), shift to air or He-O₂. Complete the stops in accordance with the Emergency Air Table or the Emergency He-O₂ Table. Surface decompression can be used after the 30 foot stop. The time spent on O₂ counts towards decompression.

2. If the loss occurs when the diver is within 5 minutes of repeating his 50 foot stop time, surface decompress the diver. Double the missed time of the required water stop for surface decompression and add this to the normal 40 foot chamber stop.
3. If the loss occurs after the diver has repeated his 50 foot stop time, surface decompress him in the normal manner.

C. O₂ TOXICITY SYMPTOMS

Symptoms at 50-Foot Stop

1. Ascend to the 40 foot stop. Shift to He-O₂ (preferably) or air. Surface decompression can be used after the 30 foot stop. Disregard the missed time at 50 feet.

Symptoms at 40-Foot Stop

1. Not Within Normal Surface Decompression or Emergency Surface Decompression Limits: Ascend to the 30 foot stop. Shift to He-O₂ (preferably) or air. Surface decompress after the 30 foot stop. Disregard the missed time at 40 feet.
2. Within Emergency Surface Decompression Limits: Surface decompress the diver. Double the missed time of the required water stop for surface decompression and add it to the chamber stop.
3. Within Normal Surface Decompression Limits: Surface decompress the diver normally.
4. Symptoms During Chamber Stop: Remove the mask. Complete decompression in accordance with the Emergency Air Table. Time spent on O₂ counts towards total decompression time.

D. CONVULSION AT 40- or 50-FOOT STOPS

1. If symptoms proceed to convulsion in spite of the above measures, bring the diver to the surface at a moderate rate, immediately recompress him to 165 feet and decompress on Treatment Table 3, 4, or 6A depending on the diver's condition at the end of 30 minutes at 165 feet.

NOTE

The danger of causing gas embolism by bringing the diver up during a convulsion caused by oxygen decompression is outweighed by the dangers of failing to do so. Since the possibility that gas embolism has occurred cannot be ruled out in these

cases, the diver requires treatment for such.

OMITTED DECOMPRESSION IN EMERGENCIES

14.5.4.4 Certain emergencies may interrupt or prevent specified decompression. Blowup, exhausted gas supply, bodily injury and the like are among such emergencies. If there are symptoms of decompression sickness or gas embolism, immediate treatment by recompression is essential. Even without evidence of any ill effects, omitted decompression must be made up in some manner to avert later difficulty.

A. Use of Surface Decompression Tables

It may appear that surface decompression procedures offer an immediate solution to the problem of interrupted decompression because they provide for a surface interval. Such procedures, however, can only be used if the diver is at the 40-foot or 50-foot stop in accordance with instructions given in Section 14.5.4.3

B. Surface Decompression Procedures are Not Applicable

When the conditions in the paragraph above are not fulfilled, the diver's decompression has been compromised. Even if the diver shows no ill effects from his omitted decompression, he needs immediate recompression. Take him to depth as appropriate for Treatment Table 1A or 5. If he still shows no ill effects after being held at treatment depth for the required period of time, decompress him in accordance with the Treatment Table. Consider any decompression sickness developing during or after this procedure as a recurrence.

SATURATION DIVING PROCEDURES 14.6

The primary advantage of saturation diving is that once the body tissues are saturated with gas, the diver can remain at depth for extended periods without increasing his decompression time. The schedules and procedures presented in this section are the latest available; however, it can be expected that they will be revised and updated as additional information on saturation diving becomes available.

The conduct of a USN saturation dive is characterized by the following sequential factors—

- A.** Initial compression to 14 feet
- B.** Life support system checkout
- C.** Compression to saturation depth
- D.** Establishment of chamber atmosphere control.
- E.** Breathing apparatus oxygen partial pressure selection
- F.** Determination of minimum safe inspired gas temperature limits.
- G.** Excursion diving
- H.** Standard saturation decompression
- I.** Decompression sickness treatment

Initial Compression to 14 Feet 14.6.1 The chamber is compressed to 14 feet gage with either air or an 80% helium-20% oxygen mixture to establish a chamber atmosphere with a 0.3 atmosphere oxygen partial pressure.

Life Support System Checkout 14.6.2 Oxygen sensors are calibrated and monitors adjusted to maintain an oxygen partial pressure of 0.30 to 0.35 atmospheres. Life support systems are checked to ensure proper functioning before continuing compression.

Compression to Saturation Depth 14.6.3 Pressurize with helium to the saturation depth. Saturation divers may be compressed at different rates varying from 60 feet per minute to 40 feet per hour consistent with operational needs to a depth of 300 feet. However, 40 feet per hour compression is recommended to achieve saturation depths between 300 and 1,000 feet. Normally, this is accomplished by pressurizing 40 feet during the first 20 minutes of each hour and then stopping 40 minutes. Compressions to saturation depths deeper than 1,000 feet require gradual diminution of the 40 feet per hour rate.

Establishment of Chamber Atmosphere Control

14.6.4 The hyperbaric atmosphere in the saturation chamber is controlled to maintain the gaseous components as follows—

Oxygen partial pressure—0.30 to 0.35 atmospheres (228 to 266 millimeters of mercury)

Carbon dioxide partial pressure—less than 0.0050 atmospheres (4 millimeters of mercury)

Nitrogen partial pressure—1.12 atmospheres (855 millimeters of mercury) or less

Helium—balance of total pressure

Temperature—regulated to the comfort of the diver(s).

The comfortable temperature range for divers occupying a chamber filled with helium-oxygen narrows as the depth increases and requires careful regulation at the deeper depths.

Relative Humidity—50% to 70% as required for comfort of the diver(s).

Breathing Apparatus Oxygen Partial Pressure Selection 14.6.5

The gas mixture supplied to the diver by the underwater breathing apparatus during an excursion dive should be helium-oxygen with the following oxygen partial pressure—

Semiclosed-Circuit—The oxygen percentage and flow rate is selected to maintain an oxygen partial pressure in the inspired gas generally between 0.8 and 1.0 atmosphere. (608 to 760 mmHg).

Fluctuations of the inspired gas in semiclosed-circuit apparatus in the range between 0.5 atm and 1.5 atm (380 to 1140 mmHg) are acceptable.

Closed-Circuit—Adjust the apparatus for an oxygen partial pressure in a range from 0.4 to 1.2 atm (304 to 912 mmHg).

Demand Open-Circuit—Select an oxygen percentage to provide an oxygen partial pressure in the range of 0.4 to 1.2 atm (304 to 912 mmHg).

Determination of Minimum Safe Inspired Gas Temperature Limits 14.6.6

As discussed in Chapter Nine, the temperature/depth line shown in Figure No. 14-4 is the limit for the minimum safe inspired gas temperatures for use in operational dive planning.

This limit specifies the **MINIMUM** temperature for breathing gas being delivered to a diver at each

FSW	°C	°F	FSW	°C	°F
600	-1.0	30.1	850	9.4	48.9
650	1.7	35.0	900	10.8	51.5
700	4.0	39.2	950	12.1	53.8
750	6.0	42.9	1000	13.3	55.9
800	7.8	46.1			

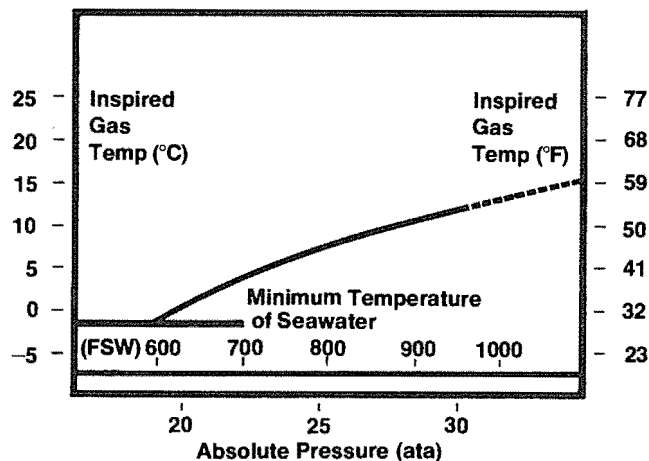


Figure 14-4 Minimum safe inspired gas temperature limits

depth and assumes that all other measures are being taken to keep the diver warm. The level of respiratory heat loss at these depths and temperatures is thought to be tolerable with some degree of safety, however, it must be pointed out that temperatures only 2 and 3 degrees Celsius colder are considered **HAZARDOUS**. Even at the minimum temperature, it has been shown that exposures have been discomforting to the point of distraction and task performance degradation. Consequently, these limits must truly be considered **MINIMUM** temperatures from a safety standpoint regardless of the bottom time, work rate, or other factors.

When using a system which does not heat the breathing gas, the gas should be assumed to be water temperature, and the minimum safe inspired gas temperature curve sets a limit on diving depth in a given temperature water.

Excursion Diving 14.6.7 In saturation diving the occasion often exists when a diver must make an excursion dive to a depth greater than the saturation depth. The diver may dive for short periods of time to deeper depth and return to his saturation pressure without difficulty using the saturation-excursion tables in this section. These tables are designed to limit the

quantity of inert gas (helium) absorbed during the excursion to an amount which can be safely released in his body by the return to the lesser saturation pressure of the chamber. This is the same situation as in diving from the surface except, instead of saturation with nitrogen at a fixed pressure of 1 atmosphere, the saturation pressure can be varied. It is not possible at this time to permit the saturated diver to ascend to depths shallower than his saturation depth, except in the process of final decompression from his saturation exposure. The tables are limited to those depth and bottom time combinations which still permit the excursion diver to ascend back to his saturation pressure without a requirement for decompression stops at any intermediate depth.

EXCURSION LIMITATIONS 14.6.7.1

A. Depth—Two Excursion Timetables are provided for excursion diving. One table covers the saturation depth range of 150 to 300 feet; the other is employed for the depth range of 300 to 850 feet. These Timetables provide the excursion depth and duration limits as well as repetitive group designations for excursion dives within their respective saturation depth ranges. Use of these tables in excursion dives from saturation exposures at any depth shallower than 150 feet exposes the diver to a risk of decompression sickness and shall not be permitted.

The saturation pressure of the capsule will normally be kept constant while the excursion diver is in the water. The pressure of the PTC (and DDC) may be increased, though, and the excursion diver safely brought back to a saturation depth greater than the one from which he left. Under no circumstances, however, will the excursion diver be brought back to a saturation pressure less than the pressure from which he departed.

B. Duration—All excursions below saturation depth must be limited to the time duration specified in the No-Decompression Limit column of the appropriate Excursion Timetable. No procedures are currently approved for decompression during a return from an excursion dive to saturation pressure. If a diver accidentally exceeds these time limits, the chamber pressure must be increased to his excursion depth.

C. Rate of Descent and Ascent—The excursion diver shall descend and ascend at a rate no greater than 60 feet per minute. Descent time is included in excursion time and variations in the rate of descent require no adjustment in procedure.

1. If the ascent rate exceeds 60 feet per minute—the diver should pause at a pressure 10 feet greater than his saturation depth for the time that should have been taken in an ascent at 60 feet per minute.

2. If the ascent rate is slower than 60 feet per minute—

- a. If the additional time used in ascent does not take the diver beyond the No-Decompression Limit for his excursion, then it is only necessary to consider the additional delay as part of the excursion time for repetitive excursions.
- b. If the additional time used in ascent takes the diver beyond the No-Decompression Limit for his excursion (as in situations such as diver entrapment), pressurize the PTC to the depth at which the delay occurs. Thereupon, he may safely return to the capsule.

D. Repetitive Excursion Dives—A method and a Chamber Interval Credit Table is provided by which repetitive excursion dives to any depth included in the Excursion Timetables can be conducted. An excursion performed within 24 hours after return to the saturation pressure from a previous excursion is a repetitive excursion. The period between excursions is the chamber interval. Approximately 24 hours are required for the body to effectively release its excess of helium. The repetitive excursion procedures are designed to protect the diver from the effects of this excess residual helium.

E. Ascent Excursions and Blowup—Under no circumstances should the diver be permitted to ascend to a depth less than the saturation depth. Decompression sickness may result from such ascent excursions.

Normally, the saturation depth for any particular operation is selected to utilize excursion dives and will be dependent upon several variables such as work site depth, allowable excursion time required at the work

site, diver umbilical length, tool requirements, etc. It is important to remember that in any diving operation the possibility always exists of diver “blowup” or loss of buoyancy control. This situation would cause the diver to rise to the limit of his umbilical. Therefore, when operational conditions permit, the PTC should be lowered as close to the work site as possible, allowing the diver to use a minimum length umbilical.

Figure No. 14-5 illustrates in Cases 1 and 2 how the PTC can be positioned at a depth below the saturation depth so that the length of umbilical used will prevent the diver, in case of blowup, from exceeding the saturation depth. For example, if an 80-foot excursion is to be made, the PTC can be lowered the entire 80 feet below the saturation depth to the excursion depth (Case 1) allowing the diver to make longer horizontal swims or the PTC can be positioned no less than 40 feet below the saturation depth, and the diver's umbilical can be tended to allow no more than 40 feet of free length (Case 2). In both Cases 1 and 2 it is necessary to temporarily increase the internal pressure in the PTC to compensate for the greater depth. Upon completion of the excursion dive, the PTC must be raised and depressurized back to the saturation pressure within the time duration of the No-Decompression Limit for the excursion dive.

Case 3 illustrates the worst case wherein the PTC must be located at the saturation depth due to bottom obstructions or other causes. The diver who makes an 80-foot excursion from the PTC in this case must be exceptionally cautious about blowup as he could rise as much as 80 feet above the saturation depth. In no case should the allowable excursion time (no-decompression limits) be exceeded whether the excursion is made by the diver from the PTC positioned at the saturation depth or at a depth below the saturation depth.

DEFINITIONS FOR EXCURSION TIMETABLES AND CHAMBER INTERVAL CREDIT TABLE 14.6.7.2

A. Units—Excursion depths are expressed in feet of seawater. Excursion times are expressed in minutes. The excursion depth is the maximum depth attained in the excursion. The excursion time is the elapsed time from leaving the saturation pressure in descent until leaving the bottom in ascent.

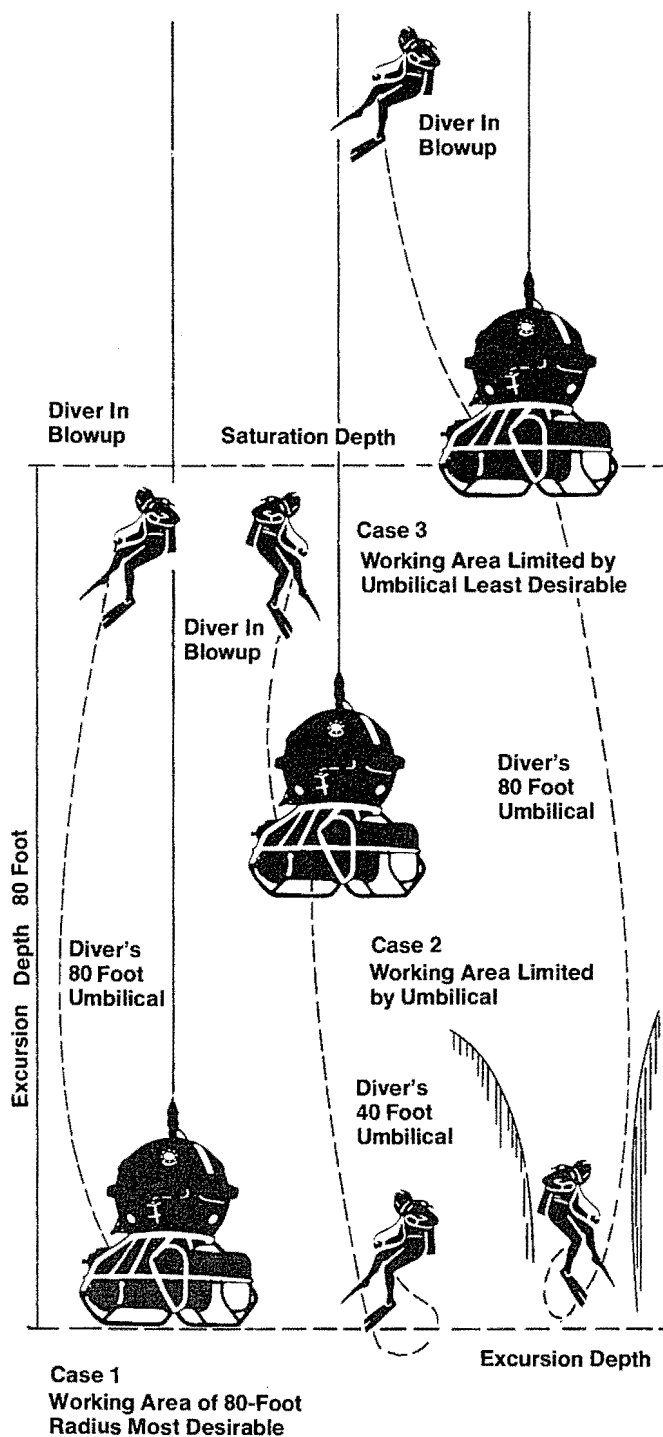


Figure 14-5 Diver blowup relative to PTC depth and saturation depth

B. No-Decompression Limits Column gives the number of minutes of excursion time permitted at any excursion depth for a no-decompression excursion.

C. Repetitive Group Designation Column gives the repetitive group designation for any excursion which may have preceded a repetitive excursion. This column is also used to determine the number of minutes of Residual Helium Time which must be subtracted from the no-decompression limits of a repetitive excursion based upon the new repetitive group designation from the Chamber Interval Credit Table.

D. Chamber Interval Credit Table gives credit for the release of residual helium from the diver's body during the interval at the saturation pressure of the chamber between excursions.

INSTRUCTIONS FOR THE USE OF EXCURSION TIMETABLES AND CHAMBER INTERVAL CREDIT TABLE 14.6.7.3

A. Single Excursion Dive Procedure

1. Select the appropriate Timetable encompassing the saturation pressure of the chamber (150 to 300 ft. or 300 to 850 ft).
2. Read the exact, or next greater, depth to which the excursion dive is to be made in the Depth of Excursion column.
3. Read in the No-Decompression Limits column the maximum allowable excursion time which is permitted without requiring decompression stops.

EXAMPLE—

PROBLEM—A 40 foot excursion dive is to be conducted from a saturated depth of 220 feet. What is the allowable excursion time for which no decompression is required?

SOLUTION—

- A. Use the 150 to 300 Foot Table.
- B. Enter the Depth of Excursion column at "plus 50 feet" (next greater than 40 feet).
- C. Read 270 minutes in the No Decompression Limits column.

The maximum excursion time for a 40 foot excursion dive is 270 minutes.

4. Read in the Repetitive Group Designation column the repetitive letter group which corresponds

to the actual, or next greater than actual, excursion time.

EXAMPLE—

PROBLEM—In the above dive, the diver actually spends 70 minutes during the 40 foot excursion dive. What is his Repetitive Group Designation?

SOLUTION—

- A. Enter the Depth of Excursion column at "plus 50 feet."
- B. Read horizontally to the 100 minute column (next greater than 70 minutes).
- C. Read vertically to the Repetitive Group Designation = C.

B. Repetitive Excursion Dive Procedure

NOTE

Dives following chamber intervals of more than 24 hours are not considered to be repetitive excursion dives.

1. Use the Chamber Interval Credit Table to determine the new repetitive group designation when the interval at chamber pressure is less than 24 hours. The Table should be used only when the gage depth of the saturation exposure is between 150 feet and 850 feet of seawater. Chamber interval time in the Table is in hours and minutes: 5:30 means 5 hours and 30 minutes. Enter the Table on the diagonal line at the repetitive group designation from the previous

excursion (from the appropriate Timetable). Read horizontally to select the interval between which the actual chamber exposure time lies. Read vertically to locate the repetitive group designation for the end of the chamber interval.

EXAMPLE—

PROBLEM—After the above dive, the diver spends 6 hours in the chamber. What is his new Repetitive Group Designation?

SOLUTION—

- A. Enter the Chamber Interval Credit Table on the diagonal slope at the letter C (Group Designation from previous dive.)
- B. Read horizontally to the ^{2:30}_{6:29} interval between which the 6-hour interval lies.
- C. Read vertically to the new Repetitive Group Designation = B.

The diver has lost sufficient inert gas to place him in Repetitive Group B.

2. To determine the Residual Helium Time for a repetitive excursion dive, enter the Repetitive Group Designation column of the appropriate Excursion Timetable corresponding to the letter group from the Chamber Interval Credit Table. Enter the Depth of Excursion column corresponding to the exact or next greater depth of the repetitive dive. Read the Residual Helium Time at the intersection of these columns.

EXCURSION TIMETABLE FOR SATURATION DEPTH BETWEEN 150 AND 300 FEET OF SEAWATER

Depth of Excursion From Saturation Exposure	No Decompression Limits (minutes)	Repetitive Group Designation					
		A	B	C	D	E	F
Plus 25 feet	—	60	150	300	600	—	—
50	270	30	60	100	150	210	270
75	150	20	40	65	90	120	150
100	100	15	30	45	60	80	100
125	75	10	20	30	45	60	75
150	60	10	20	30	40	50	60

EXCURSION TIMETABLE FOR SATURATION DEPTH BETWEEN 300 and 850 FEET OF SEAWATER

Depth of Excursion From Saturation Exposure	No Decompression Limits (minutes)	Repetitive Group Designation					
		A	B	C	D	E	F
Plus 25 feet	—	60	150	300	600	—	—
50	270	30	60	100	150	210	270
75	150	20	40	65	90	120	150
100	60	10	20	30	40	50	60

CHAMBER INTERVAL CREDIT TABLE FOR SATURATION EXPOSURE AT A DEPTH BETWEEN 150 AND 850 FEET OF SEAWATER

Repetitive Group at the End of the Chamber Interval (Before Repetitive Excursion)						
	F	E	D	C	B	A
F	0:00	1:00	2:30	4:00	6:30	12:00
	0:59	2:29	3:59	6:29	11:59	24:00
E		0:00	1:30	3:00	5:30	10:00
		1:29	2:59	5:29	9:59	24:00
D			0:00	2:00	4:00	8:00
			1:59	3:59	7:59	24:00
C				0:00	2:30	6:30
				2:29	6:29	24:00
B					0:00	4:00
					3:59	24:00
A						0:00
						24:00

Repetitive Group at the
Beginning of the Chamber Interval
(From Previous Excursion)

EXAMPLE—

PROBLEM—Following the above dive, a repetitive excursion dive to 60 feet below the saturation depth is planned for the same diver. How much Residual Helium Time does the diver have? What is the maximum duration of the repetitive excursion dive?

SOLUTION—

- Enter the Repetitive Group Designation column of the 150 to 300 Foot Excursion Timetable under the letter B (group designation from Chamber Interval Credit Table after 6 hours in chamber).
- Enter the Depth of Excursion column at the "plus 75 feet" depth (next greater than 60 feet).
- Read at the intersection of these two columns Residual Helium Time = 40 minutes.
- Read the No Decompression Limits column corresponding to the "plus 75 feet" depth = 150 minutes.
- Subtract 150 — 40 (Residual Helium Time) = 110 minutes.

The diver may spend up to 110 minutes during the 60 foot excursion dive.

Standard Saturation Decompression 14.6.8

Standard saturation decompression procedures are as follows:

1. Chamber atmosphere control
Oxygen partial pressure—0.30 to 0.35 atm (228-266 mmHg)
Carbon dioxide partial pressure—less than 0.0050 atm (4 mmHg)
2. Divers will normally remain at the saturation depth for 24 hours subsequent to the last excursion for the purpose of re-equilibration of tissues.
3. Initial Ascent
An initial 30 foot ascent from saturation depth may be performed at a rate of 10 feet per hour if a 24 hour re-equilibration period has passed since the last excursion dive.

If ascent is initiated prior to complete re-equilibration, the ascent distance will be governed by the tissue gas loading of the diver with the greatest amount of residual helium remaining from his last excursion. To determine the ascent distance, find the repetitive group designation of the diver who has the most residual helium and refer to the Initial Ascent Table below. Ascend at 10 feet per hour for the initial distance indicated.

INITIAL ASCENT TABLE FOR DECOMPRESSION FROM SATURATION-EXCURSION OPERATIONS

Repetitive Group Designation	Feet of Initial Ascent
—	30
A	25
B	20
C	15
D	10
E	5
F	0

4. Decompression Rates
Decompress at the rates given in the following table for the depth range indicated—

SATURATION DECOMPRESSION ASCENT SCHEDULE

1000-200 feet—6 feet per hour
200-100 feet—5 feet per hour
100- 50 feet—4 feet per hour
50- 0 feet—3 feet per hour

5. Daily Routine
Decompression is conducted only 16 hours of each 24 hours according to the following table—

DAILY ROUTINE SCHEDULE

2400-0600	STOP
0600-1400	TRAVEL
1400-1600	STOP
1600-2400	TRAVEL

Decompression Sickness Treatment 14.6.9 Decompression sickness in saturation diving is not an infrequent occurrence. In all cases in the U. S. Navy, however, it has been characterized by musculoskeletal pain alone rather than the more serious symptoms involving the cardiopulmonary system, the central nervous system, and the organs of special sense. The onset is usually gradual and generally occurs while the diver is still under pressure. Pre-existing compression arthralgias and heavy exercise on the bottom or during compression may be contributing factors.

Treatment should not be delayed. The few hours required for proper treatment are inconsequential in comparison to the total decompression time required in saturation diving.

In treatment use the following guidelines—

1. Recompress in increments of 10 feet at 5 feet per minute until improvement is indicated by the diver.

NOTE

An initial recompression to depth of complete relief is not necessary unless the recompression is 30 feet or less. A recompression depth increase of more than 30 fsw is usually not necessary and may result in increasing pain.

2. During recompression and at treatment depth, a treatment mixture may be given by mask to provide an oxygen partial pressure of 1.5 to 2.5 atmospheres. Pure oxygen may be used at treatment depths of 60 feet or less.
3. Interrupt the mask treatment every 20 minutes with 5 minutes of breathing the chamber atmosphere.
4. Remain at the treatment depth a minimum of 2 hours.
5. Resume the Standard Saturation Decompression Schedule from the treatment depth. ■

DIVING GASES—PURITY STANDARDS AND CYLINDER DATA; MIXING PROCEDURES; ANALYZING PROCEDURES

Purity Standards and Cylinder Data II-A.1

Oxygen—Federal Specification BB-0-925

Type I (gaseous) oxygen is available in three grades—

- Grade A—Aviator's breathing
- Grade B—Industrial and medical
- Grade C—Technical

Only grades A and B may be used as diver's breathing gas. Grade C is not suitable for breathing and, whenever possible, it should not be aboard diving ships and activities.

Grades A and B, differing only in moisture content, must both contain not less than 99.5 percent oxygen and pass the tests specified by the U. S. Pharmacopeia (XIV Revision). Aviator's breathing (grade A) oxygen must be extremely dry to avoid the possibility of moisture freezing in valves or lines with consequent stoppage of flow at low temperatures at high altitude. The amount of moisture in grade B oxygen (not more than 5 ml of free water per cylinder is specified) rarely presents a problem in diving, so this grade is generally satisfactory.

Nitrogen—Federal Specification BB-N-411a (1955) Military Specification MIL-N-6011 (1950)

Type I (gaseous), class I (oil-free) nitrogen is suitable for use in diver's breathing mixtures. Non-oil-free nitrogen must never be used for breathing. Approved nitrogen is available in three grades—

- Grade A—99.95 percent pure, maximum moisture content 0.02 mg. per liter.
- Grade B—99.5 percent pure, maximum moisture content 0.02 mg. per liter.
- Grade C—99.5 percent pure, not more than 5 ml of free water per cylinder.

Moisture content of compressed gases is rarely critical in diving, and 99.5 percent purity is satisfactory, provided that the remainder consists of oxygen with no more than a trace of carbon dioxide and with no other contaminants. Class 1, grade C nitrogen should generally be satisfactory for use in preparing breathing mixtures. However, the specifications evidently do not take into consideration the use of nitrogen for breathing, and tests for various possible trace contaminants are not specified as they are for oxygen.

In obtaining nitrogen for use in making up breathing mixtures, the supplier should be informed of the intended use and consulted concerning the possibility of harmful substances in the grades available. Care exercised in preparing and filling cylinders will sometimes vary with the grade and thus may also influence the choice. Where there is doubt concerning the presence of contaminants, some of the tests described for oxygen in the Pharmacopeia may be applied by a qualified laboratory.

Helium—No Federal Specification

Helium is produced by the Federal Government. Four grades—A, B, C, and D—are listed, but only grades A and D are currently being produced. Grade A helium is approximately 99.999 percent pure and is free of oil and moisture. Grade D is of similar purity except that it is oil-pumped and therefore unsuitable for the preparation of breathing mixtures. (Grades B and C, if again produced according to existing specifications, would both presumably be suitable for use in diving.)

Compressed Air—No Federal Specification

The following are considered as maximum standards for compressed air to be used as a diver's breathing gas—

- Oxygen concentration—20 to 22 percent by volume.
- Carbon dioxide—not more than 0.05 percent (500 ppm).
- Carbon monoxide—not more than 0.002 percent (20 ppm).
- Oil vapor—not more than 5 mg/m³.
- Gross moisture, dust, or other foreign matter—must be free of these contaminants.

Most air supplied aboard ships or at field activities is pumped by oil-lubricated compressors and may contain harmful contaminants. Wear and inadequate maintenance cause excessive amounts of oil vapor to contaminate the air. Contamination may also originate at the compressor intake if the carbon monoxide-laden exhaust from the compressor's gasoline engine is not properly vented to the atmosphere.

Filtering systems are the only means of dealing with contaminants when the output of an unsatisfactory

**TABLE II A-1 CYLINDER DATA
STANDARD FEDERAL CYLINDERS**

Gas	Capacity (cu. ft.)	Full Cylinder Pressure at 70°F (psig)	Height excl. cap (in.)	Outside Diameter (in.)	Federal Stock Number 8120
Air	200	1,800	51	9 ± ¼	151-9745
Air	250	2,265	51 ± ¼	9 ± ¼	577-4108
Helium	217	2,265	51 ± 1	9 ± ¼	244-6981
Hydrogen	176	1,800	51 ± ½	9 ± ¼	151-9754
Nitrogen	184	1,800	51 ± ½	9 ± ¼	151-9759
Oxygen	200	1,800	51	9 ± ¼	151-9758

STANDARD INDUSTRIAL CYLINDERS

Gas	Capacity (cu. ft.)	Full Cylinder Pressure at 70°F (psig)	Height incl. cap (in.)	Outside Diameter (in.)	Water Volume (cu. in.)
Air	229	2,200	56	9	2,640
Air	305	2,640	60	9¼	3,000
Helium	286	2,640	60	9¼	3,000
Nitrogen	224	2,200	56	9	2,640
Oxygen	244	2,200	56	9	2,640
Oxygen	330	2,640	60	9¼	3,000
Oxygen	150	2,200	51	7¾	1,630

compressor must be used. Studies are being conducted with the aim of producing optimal detailed specifications for filter systems. Materials such as activated alumina or other appropriate substances that remove carbon monoxide and carbon dioxide must be used, often in combination, depending upon the contaminants concerned. The system must also prevent carryover of dust or particles from the absorbents employed. Care must be exercised to be sure that the materials are renewed or regenerated at appropriate intervals. Even with a good filter system, it is unsafe to mix oxygen with air from an oil-lubricated compressor.

Where the source is not satisfactory beyond all doubt, air samples must be submitted at intervals to a suitable laboratory for analysis. There is no simple, re-

liable method for analyzing air for oil vapor in the field, but checks for carbon monoxide can be obtained with the instruments described in Section II-A.3. Sufficiently accurate analysis for small concentrations of carbon dioxide requires the use of an infrared-type analyzer, but gross contamination can be detected with a simpler apparatus described in Section II-A.3.

Despite the lack of formal standards, most manufacturers of compressed gases can supply water-pumped air of satisfactory purity and will do so if air for breathing is specified. (Specifying the intended use is important since some concerns also supply a lower grade of compressed air for commercial purposes. This may be oil-pumped, contain various contaminants, or be sold in cylinders inadequately cleaned and evacuated.)

Mixing Procedures II-A.2.

Two or more pure gases, or gas mixtures, may be combined by a variety of techniques to form a final mixture of predetermined composition. The techniques for mixing gases, in the order of their frequency of use in the U. S. Navy, are—

Mixing by partial pressure—based on the fact that the proportion by volume of each gas in a mixture is in direct relation to its partial pressure.

Continuous-flow mixing—in which a pre-calibrated mixing system proportions the amounts of each gas in a mixture by controlling the flow of each gas as it is delivered to a common mixing chamber.

Mixing by volume—whereby known volumes of each gas are delivered to a constant-pressure gas holder at near-atmospheric pressure, and the final mixture is subsequently compressed into high-pressure cylinders.

Mixing by weight—most often employed where small, portable cylinders are used, proportions the gases in the final mixture by the weight that each gas adds to the initial weight of the container.

Aboard ships, where space is limited and motion might affect the accuracy of precision scales, gases are normally mixed by partial pressure or by continuous-flow mixing systems. The latter two techniques, respectively, require large, gas-tight holding tanks and extremely accurate scales, and, consequently, are most suitable for use in shore-based facilities.

Mixing By Partial Pressure

The method of mixing gases in proportion to their partial pressures in the final mixture is commonly used at most Navy facilities. The basic principle behind this method is Dalton's Law of Partial Pressures (Chapter Two, Volume 1), which states that the total pressure of a mixture is equal to the sum of the partial pressures of all the gases in the mixture.

Two methods are available to calculate the partial pressure of a gas in a mixture; the ideal- (or perfect) gas method and the real-gas method. The ideal-gas method assumes that pressure is directly proportional to the temperature and density of a gas. The real-gas method additionally accounts for the fact that certain gases will compress more or less than other gases.

Compressibility is a physical property of every gas. Helium does not compress as much as oxygen. If two cylinders with the same internal volume are filled to the same pressure, one with oxygen and the other with helium, the oxygen cylinder will hold more cubic feet of gas than the helium cylinder. As pressure is increased, and/or as temperature is decreased, the difference in the amount of gas in each cylinder will increase. The same phenomena results when two gases are mixed together in one cylinder. If an empty cylinder is filled to 1000 psia with oxygen and then topped off to 2000 psia with helium, the resulting mixture will contain more oxygen than helium.

An awareness of the differences in the compressibility of various gases is usually sufficient to avoid the problems which are often encountered when mixing gases. When using the ideal-gas procedures which follow, a knowledgeable diver will add less oxygen than is called for, analyze the resulting mixture and compensate as necessary. As an alternate, the U. S. Navy Diving Gas Manual (NAVSHIPS 0994-003-7010, June 1971) may be consulted for procedures to accurately calculate the partial pressures of each gas in the final mixture. These procedures take into account the compressibility of the gases being mixed. Regardless of the basis of the calculations used to determine the final partial pressures of the constituent gases, the mixture must always be analyzed for oxygen content prior to use.

A. Single Cylinder Mixing Procedure—Ideal-Gas Method—When small quantities of a gas mixture are needed, it may be prepared using one cylinder at a time. The equipment needed consists of a partially filled cylinder of inert gas, a high pressure oxygen cylinder, a two-cylinder mixing manifold (Figure II-A-1) and an oxygen analyzer.

1. Measure the pressure in the inert-gas cylinder, P_i .
2. Calculate the pressure in the inert-gas cylinder after mixing, using the following equation—

$$P_F = \frac{P_i}{A}$$

Where,

P_F = final cylinder pressure, psig*.

A = decimal percent of inert gas in the final mixture

* P_F cannot exceed the working pressure of the inert-gas cylinder.

3. Measure the pressure in the oxygen cylinder, P_o .
4. Determine if there is sufficient pressure in the oxygen cylinder to accomplish mixing without the need of an oxygen transfer pump—

$$P_o \geq P_F - P_i + 50$$

Where,

P_o = pressure in the oxygen cylinder, psig

50 = required minimum overpressure, psi

\geq means greater than or equal

5. Connect the inert-gas and oxygen cylinder together using the two-cylinder mixing manifold as shown in Figure II-A-1.
6. Open the inert-gas cylinder valve.
7. Crack open the oxygen cylinder valve and bleed oxygen into the inert-gas cylinder at a maximum rate of 70 psi per minute until the desired P_F is reached.
8. Close the oxygen cylinder valve. The heat of compression will have caused the inert-gas cylinder to increase in temperature and give a false indication of the pressure in the cylinder. The calculation requires that P_F be taken at the same temperature as P_i . However, because of the compressibility effects previously discussed, more oxygen will normally have been bled into the inert-gas cylinder than expected. Therefore; allow the cylinder to stand for at least 6 hours to permit the gases to mix homogenously, or, if equipment is available, roll the cylinder for at least one hour. Analyze the gas mixture to determine its oxygen percentage. It should be near or slightly below the desired percentage.
9. Add oxygen as judged necessary, roll the cylinder and re-analyze the mixture. Repeat this procedure as required until the desired mixture is attained.

B. Multiple-Cylinder Mixing Procedure—Ideal-Gas Method—If large amounts of mixed gas are required, two or more cylinders may be prepared using the multiple-cylinder mixing procedure. The equipment needed to conduct this operation consists of a number of inert-gas cylinders equal to the number of mixed-gas cylinders required, an equal number of high pressure oxygen cylinders, a manifold arrangement as illustrated in Figure II-A-2 and an oxygen analyzer.

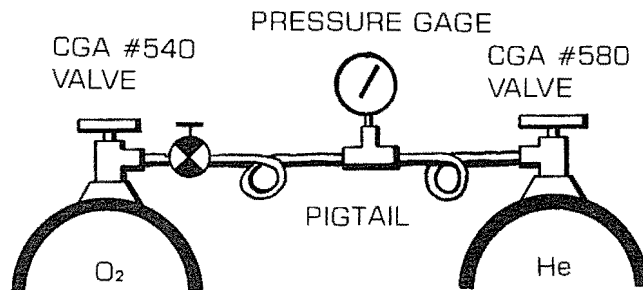


Figure II-A-1 Two-cylinder mixing manifold

1. Connect up a multiple-cylinder mixing manifold as shown in Figure II-A-2.
2. Open all the cylinder valves.
3. Crack valve A to equalize the pressure in all the oxygen cylinders.
4. Crack valve B to "split" the inert gas.
5. Read the equalized pressure in the inert-gas cylinders (P_i); Gages 3 and 4).
6. Calculate the pressure in the inert-gas cylinders after mixing (P_F).

$$P_F = \frac{P_i}{\text{Decimal percent helium in final mixture}}$$

7. Read the equalized pressure in the oxygen cylinders (P_o).
8. Determine if there is sufficient pressure in the oxygen cylinders to accomplish mixing.

$$2P_F - P_i + 50 \leq P_o$$
9. Crack valve C (and valve D if two operators are available) and bleed oxygen into the inert-gas cylinders at a rate not to exceed 70 psi per minute, until the desired P_F is reached.
10. Close valves C (and D) and allow the mixed-gas cylinders to stand for at least 6 hours to permit homogenous mixing. As mentioned in the single-cylinder mixing procedures, the temperature effect will approximately compensate for the compressibility effects.
11. Analyze the oxygen percentage of the mixture.
12. Add oxygen as judged necessary, allow adequate mixing and re-analyze the mixture. Repeat this procedure until the desired mixture is attained.

Continuous—Flow Mixing

Continuous-flow gas mixing systems perform a series of functions which ensure extremely accurate mixtures. Constituent gases are regulated to the same pressure and temperature before they are metered through precision micro-metering valves. The valve settings are pre-calibrated and displayed on curves, provided with every system, which relate final mixture percentages with valve settings. After mixing, the mixture is analyzed on-line to provide a continuous history of the oxygen percentage. Many systems have feedback controls which automatically adjust the valve settings when the oxygen percentage of the mixture varies from pre-set tolerance limits. The final mixture may be supplied directly to a diver or chamber or, alternately, compressed into storage tanks for later use.

Mixing By Volume

Mixing by volume requires accurate gas meters to measure the volume of each gas added to the mixture. When preparing mixtures using this technique, the gases being mixed must be at the same tem-

perature unless the gas meters are temperature compensated.

The volumes of each of the constituent gases are calculated, based on their desired percentages in the final mixture. For example, if 1000 standard cubic feet of a 90% helium-10% oxygen mixture is needed, 900 standard cubic feet of helium will be added to 100 standard cubic feet of oxygen. Normally, an inflatable bag, large enough to contain the required volume of gas at near atmospheric pressure, is used as the mixing chamber. The pure gases, which are initially contained in high pressure cylinders, are regulated to atmospheric pressure, metered and piped into the mixing chamber. Finally, the mixture is compressed and stored in high pressure flasks or cylinders.

Extremely accurate mixtures are possible using the volume technique of mixing, providing that the temperatures of the constituent gases are essentially the same. Additionally, care must be taken to ensure that the mixing chamber is either completely empty or filled with a known mixture of uncontaminated gas prior to mixing.

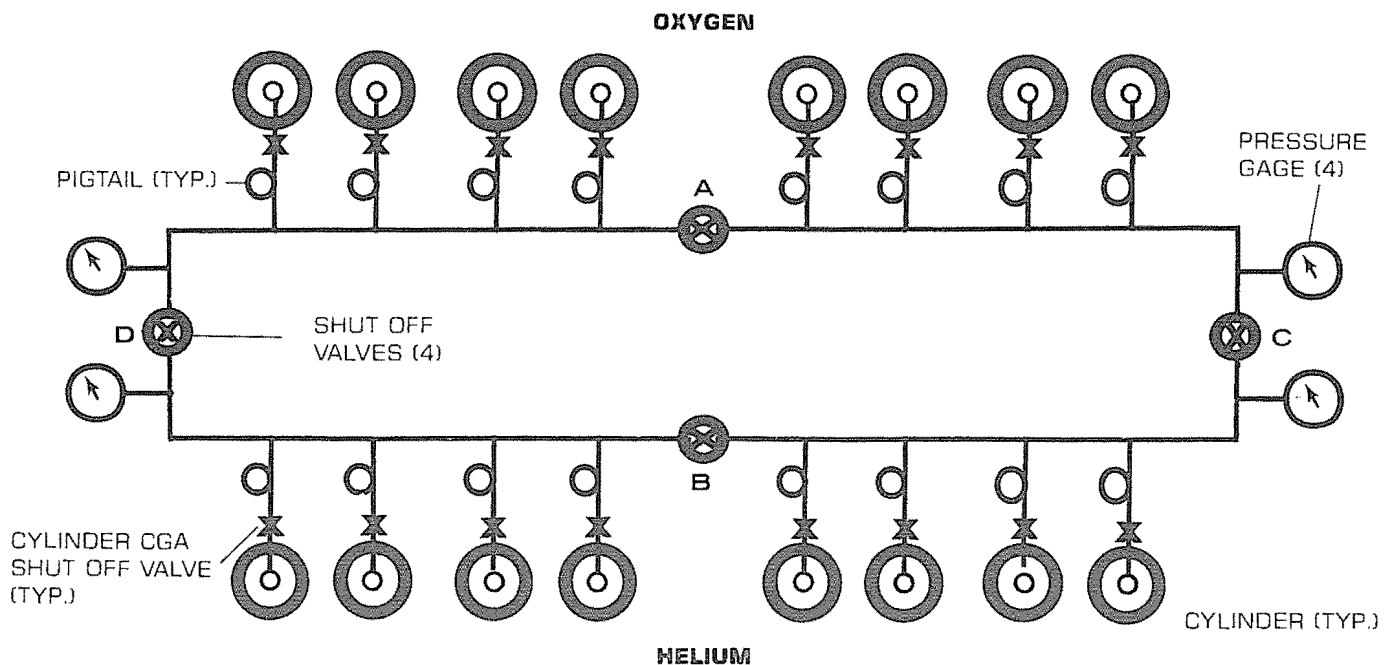


Figure II-A-2 Multiple-cylinder mixing manifold

Mixing By Weight

If mixing by weight, the empty weight of the container must be known, as well as the weight of any gases inside the container before mixing. The weight of each gas to be added to the container must then be calculated using the procedures described in the U. S. Navy Diving Gas Manual. Although the accuracy of the mixture when using this technique is not affected by variations in gas temperature, it is directly dependent on the accuracy of the scale being used to weigh the gases. This accuracy should be known and the operator must be aware of its affect on the accuracy of the composition of the final mixture. As a safeguard, the final mixture must be analyzed for composition using a suitably accurate method of analysis.

Gas Analysis II-A.3.

The precise determination of the type and concentration of the constituents of breathing gas is of vital importance in many diving operations. As has been shown in Chapters Three and Nine of this manual, adverse physiological reactions can occur whenever exposure time and concentrations of various components in the breathing atmosphere vary from prescribed limits.

Concern for the quality of the breathing gas is important in both air and mixed-gas diving. In air diving, because basic gas composition is fixed, primary consideration is directed toward determination of gaseous impurities that may be present in the air supply (carbon monoxide, hydrocarbons) and the effects of inadequate ventilation (carbon dioxide). The use of analytical equipment in air diving, however, is not routine practice; it is generally employed only when improper functioning of the air supply is suspected or in the evaluation of new equipment.

The use of gas analysis in mixed-gas diving is essential. Because of the potential hazards presented by anoxia, CNS and pulmonary oxygen toxicity, it is mandatory that the oxygen content of the gas supply be determined before a dive. Oxygen analysis is the commonest, but not the only type of analytical measurement that is performed in mixed-gas diving. In deep diving systems, the performance of scrubbing equipment must be monitored by carbon dioxide analysis of the atmosphere. Long-term maintenance

of personnel under hyperbaric conditions often necessitates the use of a range of analytical procedures. Analyses are required to determine the presence and concentration of minor quantities of potentially toxic impurities resulting from the off-gassing of materials, metabolic processes, and other sources.

When selecting an instrument for analysis of one or more constituents of a gaseous atmosphere, two characteristics are of particular importance—accuracy and response time. Accuracy within the range of expected concentration must be adequate to determine the true value of the constituent being studied. This characteristic is of particular importance when a sample must be taken at elevated pressure and expanded to permit analysis. Response time of the instrument to changes in concentration is important in the measurement of constituents which may rapidly change and result in quick development of toxic conditions. Other factors in selection of instruments such as sensitivity, repeatability, rangeability, portability, etc., are normally of secondary importance.

The constituents of a gas may be analyzed both qualitatively (type determination) and quantitatively (type and amount) using many different techniques. Although each technique will not be discussed, the major types are listed below as a reference for the reader who desires to study them in detail—

- Mass Spectrometry**
- Colorimetric Detection**
- Ultraviolet Spectrophotometry**
- Infrared Spectrophotometry**
- Gas Chromatography**
- Electrolysis**
- Paramagnetism**

The remainder of this section lists many of the commercially available instruments, both those which are specific for a given constituent and those which are multi-component analyzers. The listing includes instruments for measuring the concentrations of oxygen, carbon dioxide, carbon monoxide, water vapor, hydrocarbons and various trace contaminants in a gas sample. For operational details concerning each instrument, the reader is referred to the respective manufacturer's technical manual.

TABLE II A-2—GAS ANALYSIS EQUIPMENT

OXYGEN Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Bacharach Model K525	Electrolytic Cell	0-5%; 0-25%	$\pm 0.1\%$ O ₂	
Fyrite Model CPD	Orsat (volume) rec absorption	0-7.6%; 0-21%; 0-60%	$\pm 1\%$	30 sec.
Beckman Minos Undersea O ₂ Monitor	Polarographic	0-250; 0-1000mmHg	$\pm 3\%$ full scale 65 to 95°F	< 10 sec.
Minos Atmos. O ₂ Monitor	Polarographic	0-1000mmHg 0-13 ata	$\pm 5\%$ f. s. (0-500 mmHg); $\pm 10\%$	15 sec. to a step function change in sample avg. pressure.
Model 715	Polarographic	0-5%; 0-25%	$\pm 1\%$ f. s. at a given temp; $\pm 6\%$ f. s. at temp varying from 32-110°F	20 sec.
Model F3	Paramagnetic	0-1% min 0-100% max 0-5ppm avail.	$\pm 1\%$ f. s.	40 sec. normal 10 sec. optional
Model D2	Paramagnetic	0-25%; 0-100%	$\pm 2\%$ f. s.	10 sec.
Model C2	Paramagnetic	0-75% 75-100%	$\pm 1\%$ f. s.	
Bio-Marine OA232	Galvanic Cell	0-40%; 0-2 atm.	$\pm 2\%$ f. s.	< 20 sec.
Burrell Industro Model B	Orsat	0-21%	$\pm \frac{1}{2}\%$ O ₂	
General Electric PO ₂ Controller	Electro- chemical cell	0.1-1.5 atm.	$\pm 1\%$ of reading	12 sec.

TABLE II A-2—GAS ANALYSIS EQUIPMENT (cont'd)

OXYGEN

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Leeds & Northrop 7803-6	Thermomagnetic	0-5%; 0-25%	1.0% f. s.	35 sec.
MSA 802	Paramagnetic	0-1% 0-10%		80 sec.
Servomex QA-150	Paramagnetic	0-25% 0-100%	± 1% of span	7 sec. for 75 ml/min sample
QA-101 MK2	Paramagnetic	0-100% linear dial reading 0-1%	± 0.1% O ₂	10 sec. for 75 ml/min sample
QA-137	Paramagnetic	0-2.5; 0-5; 0-10; 0-25; 0-100%	± 0.05% O ₂ or ± 1% f. s., whichever greater	7 sec.
Teledyne 326 M	Galvanic Cell	0-5%; 0-25%	± 2% f. s.	< 30 sec. @ 0.2 SCFH
326	Galvanic Cell	0-1%; 0-5% 0-10%	± 1% f. s.	< 30 sec. @ 0.2 SCFH
306	Galvanic Cell	0-10 ppm; 0-10,000 ppm	± 2% of primary range	< 2 min.
316	Micro-fuel cell	0-10; 0-100; 0-1000; 0-10,000ppm	± 2% f. s. @ constant temp	30 sec.—0-10 ppm; 5-10 sec. all other scales
Westinghouse 209	Electro- chemical cell	0.8-150ppm 80-15,000ppm 0.8-100%		< 1 sec. on meter

CARBON DIOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Bacharach CND	Orsat	0-7.6% 0-20%	± 1%	

TABLE II A-2—GAS ANALYSIS EQUIPMENT (cont'd)

CARBON DIOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Beckman ACDM	Electro- chemical	0.1 to 30 mmHg	$\pm 4\%$ f. s. @ 60- 90°F; $\pm 8\%$ f. s. @ 40-110°F; $\pm 10\%$ f. s. @ 35-130°F	63% mL 1 min.
Intertech Corp.	Infrared	0-0.005% volume		
Metro Physics	Infrared	20mmHg; 40mmHg	$\pm 2\%$ f. s.	1.5 sec.
MSA and Unico	Colorimetric	0.01-10%	10%	3 min.
Unico 760	Photoelectric	0-0.1% 0-1.4%	$\pm 5\%$ f. s.	3 sec.

CARBON MONOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Bacharach Monoxor 19-0240	Colorimetric	5-2000ppm- 5-5000ppm		2 min.
Horiba AIA-2 •	NDIR	0-250 ppm; 0-1%; 0-3%	$\pm 1\%$ f. s.	0.5 sec.
Intertech Corp. CG-Co T 5611-131	NDIR	0-10%	$\pm 2\%$ f. s.	2 sec. for 100%
MSA	Colorimetric	10-3000ppm		3 min.
Sylvania 100	NDIR	0-5ppm	$\pm 3\%$ f. s.	1-6 sec.
Thermonetics Corp. Code IV	Thermopile detector cell	0-500ppm; 0-1000ppm; 0-5000ppm	$\pm 1\%$ f. s.	25 sec.

TABLE II A-2—GAS ANALYSIS EQUIPMENT (cont'd)

CARBON MONOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Unico 901 400 pump/#100 tubes	Photo-optical Colorimetric	Alarm 20-1000ppm 10-3000ppm		1 hr. for 50ppm 3 min.

WATER VAPOR

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Anacon 20		0-100%	± 3% between 20 and 90 RH	50% in 5 sec.
Atkins Technical 3 Z02B	Wet & dry thermistor beads	7°F to 192°F	0.5%	10 sec. to 3 min. for wet bulb temperature
Beckman	Electrolytic cell	0-50; 0-100; 0-1000ppm	± 5% f. s.	1 min.
Hankison 901 Dewmeter	P/T relationship of pure refrigerants	30 in. Hg Vac to 300 psi	± 1°F	
Honeywell W611A	Electrolytic cell	20-45% 35-60% 50-75%		
Hygrodynamics 15-3001	Change in electrical resistance		± 1.5 RH from 40 to 120°F	65% in 3 sec.
15-3030E	Change in electrical resistance	41-61%	± 1.5 RH from 40 to 120°F	65% in 3 sec.
Kahl Scientific Gemware Electro-V	Motorized psychrometer	10-110°F	± 1°F	20 sec.

TABLE II A-2—GAS ANALYSIS EQUIPMENT (cont'd)

WATER VAPOR

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Meeco Instruments W NEP-PL	Electrolytic cell	to 1000ppm or 50 lb/msct		
Panametrics 1000	Electrolytic cell	0-1; 0-1000ppm	± 5% f. s.	63% in 30 sec.
Yellow Springs 90	Psychrometer	0-40°C dry bulb; 0-5°C wet bulb	2% RH	< 2 min.
VAP-Air 44	Dewmeter	-20 to 80°F dew point	± 2°F	1°F/sec. dew point change

GASEOUS HYDROCARBONS

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Beckman 400	Flame ionization			0.5 sec.
109A	Flame ionization	10ppm methane		3-15 sec.
Delphi C	Flame ionization	0-1ppm 0-1%	± 1% f. s.	
Horiba AIA-2	NDIR, n-hexane equivalent	0-200; 0-1000; 0-1000ppm	± 1% f. s.	0.5 sec.
	Flame ionization	0-100 0-50,000 ppm carbon	± 1% f. s.	1 sec.
Sylvania 100	NDIR	0-1500ppm	± 3% f. s.	1-6 sec.
Teledyne Analytical 402	Flame ionization	0-10; 0-100; 0-1000ppm	± 1% f. s.	1 sec. for 10 to 1000ppm change

NITROGEN OXIDES

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Beckman NOx Analyzer		0-1000; 0-5000ppm	$\pm 5\%$ f. s.	
Dynasciences NX-100	Electrochemical	0-10; 0-50ppm	$\pm 2\%$ f. s.	60 sec.
Mast Development 725-11	Colorimetric	0-10; 0-120ppm		85% in 30 sec.
MSA 83099	Colorimetric	0.1-50ppm		
OL1/Horiba VVA-1		0-200ppm	$\pm 1\%$ f. s.	
Precision Scientific 63100	Colorimetric & photoelectric	0-0.5; 0-2.0ppm	$\pm 1\%$ f. s.	63% in 4 min.
Technicon II A	West-Gaeke method	0-1ppm		10.5 min.
Unico 117	Colorimetric	1-1000ppm		

SULFUR DIOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Dynasciences SS-310	Electrochemical cell	0-2; 0-10ppm/vol.	$\pm 2\%$ f. s.	60 sec.
Ericson Inst. 52	Electrochemical cell	0-1; 0-5ppm	$\pm 5\%$ f. s.	2-3 min.
Instrumentation Assoc. U35	Electrolytic conductivity	0.4; 2.0ppm		1.5 min.
Leeds & Northrop 7860	Electrolytic conductivity	0-0.5; 0-20ppm	$\pm 3\%$ f. s.	3 min.

SULFUR DIOXIDE

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
MSA 92623	Colorimetric	1-400ppm		
Process Analyzer Tetrig II	Titration cell	0-0.4; 0-1; 0-10ppm		70% in 1 min.
Technicon Corp. II A	West-Gaeke method	0-0.2; 0-0.5; 0-1ppm		11.5 min.
Unico 103D	Colorimetric	1-80ppm		

HALOGENS

Manufacturer and Model Number	Detection Principle	Scale Ranges	Accuracy	Response Time (90%)
Bacharach Leakator	Light glows until halogen enters probe			Instant
Billion-Aire	Ionization	Depends on gas measured	$\pm 2\%$ f. s.	10 sec.
General Electric H-2 & H-5P	Light flashes when halogen enters probe			1 sec.
MSA Universal Tester	Colorimetric	0-100ppm	$\pm 10\%$	
Panametrics Panatek 2000	Gas chromatography & electron capture	Traces		1 sec.

CLEANING OXYGEN SYSTEMS

Many diving ships and activities have, or may consider installing, a system by which oxygen is piped from a central bank to the recompression chamber, the diving station, or a charging board. Smaller systems such as manifolds are in common use. The necessity for avoiding all possible contact between high-pressure oxygen and oily materials has been stressed repeatedly in this manual because of the risk of explosion and fire. Any kind of system used with oxygen must be cleaned thoroughly upon installation, kept clean, and recleaned whenever there is known or possible contamination (such as allowing compressed air from an oil-lubricated compressor to enter a system).

An example of an oxygen system being contaminated as the result of improper cleaning procedure was once provided by a manufacturer who "cleaned" the oxygen and high-pressure fittings of a SCUBA unit with a highly flammable solvent and left a considerable residue of this material in the system. Only the vigilance of an alert diver kept the unit from being charged with oxygen—an operation that would almost certainly have caused an explosion resulting in several deaths and much damage. NAVSHIPS' approved method, MIL STD 1330 (Ships), for cleaning shipboard oxygen-distribution systems, if followed carefully, will safely remove all foreign matter.

The term "cleaned for oxygen service" means that all dirt, filings, grease, oil, and other foreign materials have been removed from all parts of the equipment and piping to be used in oxygen service. Equipment received from a manufacturer, such as cylinders and valves, that has been cleaned for oxygen service and that has all connections sealed when delivered need not be recleaned. If the systems are received with unsealed connections, they should be cleaned according to the method described herein.

Mixed-gas piping systems shall be cleaned in the same manner and maintained to the same standards as oxygen systems.

Materials Required

A Degreasing solution—
Trisodium phosphate

Na_3PO_4 , anhydrous, technical grade, Fed. Spec. O-S-642, type I, FSN C 6810-664-7487.

or

$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$, dodecahydrate, technical grade, Fed. Spec. O-S-642, type II, FSN G 8610-240-2116.

Nonionic detergent—FSN 7930-282-9699, MIL-D-16791E, type I.

- B Fresh water, oil-free, filtered.
- C Flushing solvent—Freon PCA less than 1 ppm total organic content.
- D Gaseous nitrogen (water-pumped).
- E Steam or other source of heat for the cleaning solution and rinse water.
- F Rubber gloves, safety goggles, rubber boots and aprons, or other protective clothing to be worn while cleaning.
- G Portable cleaning machine consisting of 55-gallon tanks connected to a Gould Co. ½-horsepower bronze centrifugal pump (or equivalent) with a capacity of 15 gpm at 20 psi.

The cleaning solvent should be prepared by dissolving 65 pounds of technical-grade anhydrous trisodium phosphate to each 100 gallons of water with 1 pint of nonionic detergent. The mixture should be heated to $190^\circ\text{F} \pm 20^\circ\text{F}$ with a steam coil or other source in 55-gallon drums.

Cleaning Procedure

The cleaning procedure is as follows—

- A All parts, including fittings, piping, and valves must be completely disassembled and washed before final assembly.
- B The cleaning solution should be prepared as described in the preceding paragraph.
- C Small parts should be placed in the cleaning bath and soaked for at least 10 minutes. Agitate the solution, or scrub with a brush, until all visible traces of dirt or grease disappear.
- D Prior to cleaning, piping subassemblies containing valves shall have the valve internals removed. During valve reassembly, after cleaning the piping, valve internals are cleaned with Freon PCA and then blown dry using oil-free nitrogen.
- E Circulate the cleaning solvent through the pip-

ing system with the circulating pump for 15 minutes.

- F Rinse thoroughly with running, oil-free water. Drain off excess water.
- G Fill system with Freon PCA flushing solvent. Allow the system to soak for 1 hour at ambient temperature and pressure. Pressurize system with oil-free nitrogen and blow down solvent to used solvent drum at each exit point.
 - 1 If the discharge shows evidence of foreign matter or discoloration, repeat the fill and blowdown.
 - 2 Obtain a 2-liter sample from each exit point in a clear glass container for analysis.
- H Obtain laboratory analyses of the samples. If the analysis indicates 5 ppm or less total organic content, the piping is to be considered clean. If more than 5 ppm total organics are present, flushing is repeated until 5 ppm, or less, total organics in the solvent are obtained.
- I Purge piping using oil-free nitrogen to remove all the solvent.

The indicating, recording, and controlling equipment, or other small or delicate equipment should be cleaned with O₂ system cleaner MIL SPEC. MIL-C-8638, Stock No. RN 6850-597-7166-G500.

Special Precautions

Trisodium phosphate solutions and O₂ system cleaner are harmful to the eyes and skin. If contact occurs, the area should be flushed with copious quantities of water.

Only materials approved for oxygen use should be used for pipe dope, gaskets, etc. when reassembling oxygen systems.

When systems have been cleaned, extreme care must be taken to prevent oil or any other combustible material from entering.

SAFE HANDLING OF GASES

The following is a general list of safety procedures to be used in the handling and storage of gases and their containers. Additional precautions are the subject of Chapter 9920 of the NAVSHIPS Technical Manual (NAVSHIPS 0901-920-0003).

Handling of Cylinders

The following are general safety rules for working with compressed-gas cylinders—

1. Never drop cylinders, or permit them to strike each other violently.
2. Never use a lifting magnet or sling when handling cylinders.
3. Securely close valves and replace valve-cover caps before moving, storing, or returning cylinders.
4. Insure that all cylinders used are MIL. SPEC. or approved under the Department of Transportation regulations.
5. Do not fill any cylinder with a gas other than that for which the cylinder was designated, with the exception of nitrogen-oxygen and helium-oxygen mixtures which shall be made up in the inert-gas cylinders (not in O₂ cylinders). Cylinders containing mixed gas will be tagged conspicuously.
6. Never use cylinders for rollers, supports, or any purpose other than to carry gas.
7. Do not tamper with the safety devices or valves on cylinders.
8. Never hammer or strike the valve wheel in attempting to open or close valves. Use only wrenches or tools provided and approved for this purpose.
9. Insure that the threads on regulators or other auxiliary equipment are the same as those on cylinder valve outlets. Never force connections that do not fit.
10. Do not subject compressed-gas cylinders, either in storage or service, to a temperature in excess of 130°F.
11. Protect cylinders from objects that will produce a cut or other abrasion on the surface of the metal.
12. Do not use any cylinder which is improperly marked.
13. Keep compartments where compressed gases are stored (or in use) well ventilated. Prohibit smoking in such compartments.
14. If valve outlets become clogged with ice, use warm, not boiling, water to thaw them. The use of boiling water will melt the fusible plugs (if present) and vent the cylinder.
15. Never use cylinders that show evidence of damage—for example, cylinders that are severely dented or gouged, bulged from internal pressure, or corroded.

Oxygen and Compressed Air

The following are safety rules for working with high concentrations of oxygen—

1. Never permit oil, grease, or other readily combustible substances to come in contact with oxygen cylinders, valves, regulators, gages, and fittings.
2. Never lubricate oxygen or compressed-air valves, regulators, gages, or fittings with oil or other flammable substances.
3. Be sure that all oxygen distribution systems have been cleaned for oxygen service in accordance with the Ship Systems Command approved method (see Appendix II-B) to remove all dirt, filings, grease, oil, and other foreign materials. Repeat the cleaning process whenever contamination of the system (as by oily compressed air, for example) is known to have occurred or is suspected.
4. Never use oxygen from a cylinder without reducing the pressure through a suitable regulator.
5. Use only approved regulators, hose, and other appliances.
6. Never use compressed gases for cooling the body or for blowing dust from clothing. The danger of combustion is great.
7. Do not smoke where oxygen is stored or in use.

Nitrogen-Oxygen Mixtures

Never mix oil-contaminated air with oxygen to obtain a specific nitrogen-oxygen mixture. Handle nitrogen-oxygen and helium-oxygen mixtures according to the same rules applied to oxygen.

U. S. NAVY APPROVED MIXED-GAS DIVING EQUIPMENT

DEEP-SEA DIVING OUTFIT, SPECIAL HELIUM-OXYGEN

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's	
		Name	Designation
CO ₂ absorbents			
Baralyme, granular	FSN 9L-6505-053-2461	NA*	NA
Helmet, MK 5	FSN H-4220-293-7382	NA	NA
modified, complete with the following—			
1. Breastplate			
2. Canister			
3. Injector			
a. Nozzle, discharge	FSN H-4220-508-1584	NA	NA
b. Nozzle, fitting	FSN H-4220-696-1699	NA	NA
c. Nozzle, high pressure	FSN H-4220-322-1440	NA	NA
4. Retainer assembly	FSN H-4220-300-9644	NA	NA
a. Retainer, elbow	FSN H-4220-508-1586	NA	NA
b. Screen, bushing	FSN H-4220-508-1585	NA	NA
c. Screen, injector	FSN H-4220-322-5493	NA	NA
5. Diver's air hose, standard length, 3 ft. 9 in.	FSN H-4220-230-6532	NA	NA
6. Control valve	FSN H-4220-265-6953	NA	NA
7. Control valve, adapter	FSN H-4220-300-3018	NA	NA
8. Hoke valve, needle	FSN H-4220-221-1603	NA	NA
9. Recirculator, supply hose			
Oxygen analyzer, Beckman, Model D-2		NA	NA
Oxygen analyzer, Beckman, Model C	FSN H-6630-308-604	NA	NA

Note

Equipment allowance for EOD Mobile Teams shall be in accordance with EOD Equipment Management Data List (NAVORD OD-44627 of 7/1/70).

*Not Applicable

SCUBA, SEMICLOSED-CIRCUIT

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's	
		Name	Designation
MK 6, Underwater Breathing Apparatus, mixed gas	FSN 2S-4220-088-2968 Low magnetic effect as specified in MIL-M-19595A; Manual #393-0653 as per APL.	Allowance Parts List (APL), provided through Naval Supply System from Scott Aviation Corporation	APL, identification no. 990010009 as appropriate to diving activities
	Low magnetic effects as specified in MIL-M-19595A	Allowance Parts List (APL), provided through Naval Supply System from Scott Aviation Corporation	APL, identification no. 990010012 as appropriate to diving activities

SCUBA, CLOSED-CIRCUIT, OXYGEN

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's	
		Name	Designation
Breathing Apparatus, Underwater, Navy, Diver's (Emerson)	Manual number 0993-001-4000; FSN-TID-S-4220-12-88016-01	Allowance Parts List (APL), available from Westinghouse Electric Corporation through the Naval Supply System	APL, identification no. 99010013; Service approved through OPEVAL (OPNAVINST 010470.13 of 22 July 1961)

DEEP DIVE SYSTEMS

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's	
		Name	Designation
Salvage Diving System (SDS 450)	Operational to maximum depth of 450 feet	NAVSHIPS special material.	NA*
Deep Dive System, MK 1	Operational to maximum depth of 850 feet with excursions from the PTC not to exceed 150 feet.	NAVSHIPS special material.	NA

*Not Applicable

OTHER DIVING EQUIPMENT

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's	
		Name	Designation
Inhalator, divers HeO ₂ decompression	FSN G-4220-240-7150	NA*	NA
Recompression chambers, double lock, steel, 100 psi	FSN S-4220-368-3345	NA	NA
Recompression chambers, single lock, steel, 100 psi	FSN S-4220-368-3346	NA	NA
Recompression chambers, double lock, aluminum 100 psi	FSN S-4220-540-2785	NA	NA
SCUBA, Aquanaut equipment, MK11, Mod 0	Special material, available only as directed by SUPDIVE	NA	NA
Diver's Mask USN MK 1	Special material, available only as directed by SUPDIVE	NA	NA
UNISUIT	Special material, available only as directed by SUPDIVE	NA	NA

*Not Applicable

MK 6 MOD 0 Mixed-Gas SCUBA

Pre-Dive Equipment Preparation Checklist II-E.1

The MK 6 MOD 0 Mixed-Gas SCUBA uses standard air SCUBA accessories such as wetsuit, swim fins, knife, mask, etc. Preparation for MK 6 mixed-gas diving is essentially the same as that for air SCUBA diving with the exception that considerably more attention need be paid to the breathing supply and to proper preparation of the equipment system itself.

1. Lay out the MK 6 apparatus on a clean surface.
2. Make sure that all equipment needed for the dive (or that may possibly be used during the dive) is on the station.

Minimum Equipment

- Swim trunks or wet suit
- MK 3 life preserver
- Belt and knife
- Fins
- Face Mask
- MK 6 SCUBA and standby gear
- Charging Assembly

— Depth gage

— Wristwatch

Optional Equipment

- Wrist compass
- Signal Flare
- Slate
- Lifeline
- Floats
- Protective Clothing

3. Check the gas supply to ensure that the mixture is correct as required by the depth and duration of the specific dive. Ensure that an adequate supply of proper breathing mixture is on hand to completely service the divers (and standby divers) throughout all phases of the operation. Be sure that an emergency supply is available.

4. Check the descending line.
5. Check the recompression chamber.
6. Take accurate depth soundings.
7. Brief the diving team.

8. Fill MK 6 cylinders—

A Remove the canister assembly from the backplate by removing the cylinder spreader bar from the cylinder lugs. Disconnect the cylinder block at the gas inlet block by unthreading the canister hose. Unthread the hoses connecting the canister to the breathing bag and vest assembly, and slide the canister up and out of the lip of the backplate.

B Remove the regulator assembly and the control block assembly from the backplate by discon-

necting the pull rod, removing the spring, and loosening the regulator yoke assembly.

C Recharge the cylinders with the proper gas mixture selected for the dive. Do not exceed 3,000 psi.

D In filling the cylinders, avoid all contact with oil and grease. Follow all procedures set forth in Appendix II-C for the handling of oxygen cylinders.

E Open the manifold shutoff valve first to bleed off any gas that may remain in the cylinder.

F Connect the charging line assembly to the manifold valve assembly.



Figure II-E-1 Cylinder recharging

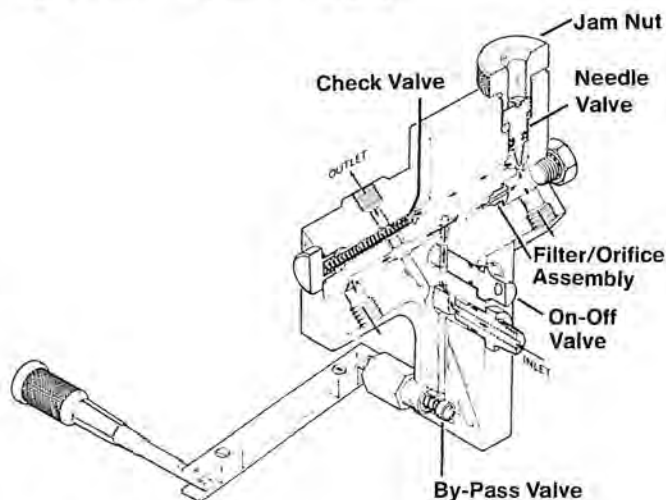


Figure II-E-2 Control block assembly

G Slowly open the valve of the high-pressure gas supply source and fill the cylinders to the desired pressure.

Do not exceed a filling rate of 500 psi per minute to avoid rapid heating during charging.

H Close the manifold shut-off valve and the high-pressure gas supply source valve. Bleed the charging line assembly at the high-pressure source. Disconnect the charging line assembly from the manifold valve.

I When charging is complete, tag the cylinders to indicate the exact composition of the gas mixture used to fill the cylinder and the pressure to which cylinder has been filled.

If the mixture used is a change from the gas previously filled in the cylinder, empty the cylinders and flush thoroughly using a 100 psi charge of the new gas mixture before filling to the required capacity.

9. Install the appropriate filter and orifice assembly by removing the access cap from the control block. Check to make sure that the proper assembly is being used. Replace the access cap.

10. Fill the MK 6 canister assembly:

A Turn the canister assembly upside down.

B Unthread the screws retaining the canister cover assembly. Remove the cover.

C Inspect the screen assembly for any contamination or damage. Place the screen assembly in the inner canister.

D Place the canister filling collar inside the canister to prevent Baralyme pellets from entering between the inner and outer canister shells.

E Fill the inner canister with fresh granular Baralyme pellets. Tap the canister regularly to insure that channels do not form between the pellets.

F When filled, remove the filling collar, replace the cover assembly and retaining screws.

11. Turn the canister rightside up.

12. Reconnect the regulator assembly and the control block assembly to the backplate by connecting the pull rod and tightening the yoke assembly.

13. Secure the filled canister to the backplate—

A Position the canister assembly on the backplate so

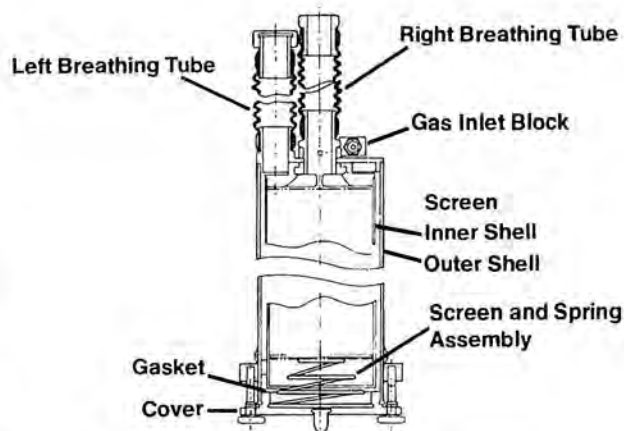


Figure II-E-3 Cross section of the MK 6 canister.



Figure II-E-4 Regulator adjustment

that the canister is hooked under the lip provided on the backplate.

- B Replace the cylinder spreader bar.
 - C Mate the control block to the canister hose at the gas inlet block.
 - D Reconnect the hoses to the breathing bag and vest assembly.
14. Adjust the regulator and control block assemblies for the proper pressure setting and flow:
- A Make all adjustments following accepted procedures to ensure proper differential pressure readings.
 - B Verify that the manifold shutoff valve and the control block on/off valve are in the OFF position.
 - C Actuate the bypass valve by pulling the ring several times.
 - D Back off the regulator spring button in a counter-clockwise direction using the special wrench provided. Back off fully.

**DO NOT BACK OFF THE SPRING BUTTON
WITH PRESSURE ON THE REGULATOR**

- E Check that all differential pressure gage fittings on the control block are plugged.
- F Disconnect the control block to the canister hose at the gas inlet block junction, and connect a pressure gage and test hose to the end of the control block. Be sure that the pressure gage has been calibrated.
- G Place the control block on/off valve in the ON position.
- H Slowly open the manifold shutoff valve.
- I Adjust the regulator for the required pressure depending on the filter and orifice assembly used in the control block.
- J Wait two minutes and check adjustment. This is a critical function, and no slippage of the adjustment can be tolerated.
- K Turn the control block on/off valve to the OFF position. Bleed off trapped gas by disconnecting the pressure gage.
- L Actuate the bypass valve by pulling the ring several times.

- M Connect the pressure gage to the end of the test hose and place the on/off valve in the ON position.
- N Check the pressure gage. The reading should be identical to that observed before actuation of the bypass valve. If correct, place the on/off valve in the OFF position and remove the gage.

15. Adjust the MK 6 for the proper liter flow—

- A Check that the control block on/off valve is in the OFF position.
- B Verify that the manifold shutoff valve is OPEN.
- C Loosen the needle valve jam nut, turn the valve gently clockwise until closed (a standard $\frac{3}{16}$ inch screwdriver is used).



Figure II-E-5 Control block adjustment

- D Connect the end of the test hose to the proper inlet on the flowmeter.
- E Control block on/off valve is placed in the ON position.
- F Back off the needle valve and jam nut simultaneously until the proper flow registers on the meter. This function is critical. Wait two minutes, recheck the flowmeter reading. It must be steady without any fluctuation.
- G If the flowmeter reads satisfactorily, hold the needle valve in place with the screwdriver and tighten the jam nut.
- H Place the control block on/off valve in the OFF position.
- I Remove the plugs from the control block.
- J Connect the differential pressure gage to the control block fittings.
- K Place the control block on/off valve in the ON position.
- L Check the indication of the differential pressure gage. The needle must be in the safety area.
- M Disconnect the test hose from the flowmeter.
- N Actuate the bypass valve by pulling the ring several times.
- O Connect the test hose to the flowmeter and recheck the indicator on both the flowmeter and the differential pressure gage.

The reading on the flowmeter **must** be identical to that observed before actuation of the bypass valve. The differential pressure gage indicator needle **must** be in the safety area. If this is not the case, do not use the gear until the situation is corrected.

- P Place the control block on/off valve in the OFF position.
 - Q Disconnect the test hose.
 - R Re-connect the control block to the canister hose at the gas inlet block.
16. Adjust the differential pressure gage for correct indication—
- A Be sure that the regulator assembly setting and flow requirements outlined above have been met.
 - B Disconnect the control block at the gas inlet block.

- C Connect the pressure gage and test hose.
- D Place the control block on/off valve in the ON position.
- E Open the manifold shutoff valve.
- F Using the test gage, check that the proper pressure exists for the filter and orifice assembly being used.
- G Loosen the screws retaining the adjustment plate.
- H Using a standard screwdriver, turn the adjustment screw until the indicator needle is centered in the safety area (the luminescent zone on the indicator dial).
- I Tighten the retainer screws. Place the on/off valve in the OFF position.
- J Disconnect the test gage and hose.
- K Reconnect the control block assembly.

17. Check the breathing apparatus for leakage either by submerging in water or by soap test. Submergence is preferred.

18. Check the mouthpiece T-tube assembly.

- A Place the mouthpiece and shutoff valve in the DIVING position.
- B Place the mouthpiece in the mouth, squeeze the inhalation (right) hose closed, and attempt to inhale. If it is possible to inhale with the hose closed off, then the check valve is either missing or defective. This must be corrected before using the gear.
- C Squeeze the exhalation (left) hose closed and attempt to exhale. If it is possible to exhale with the hose closed, then the check valve is either missing or defective. This too, must be corrected before any use of the apparatus.
- D Place the mouthpiece shutoff valve in the SURFACE position.

19. The MK 6 SCUBA is now ready for use.

20. Don the accessory equipment and the MK 6 SCUBA—

- A Put on the vest with all equipment attached and intact. Zip up and adjust the straps until comfortable.
- B Place the mouthpiece in the mouth. Put the mouthpiece valve in the DIVING position and adjust the system exhaust valve.

21. Signal readiness to the Diving Supervisor.

TROUBLESHOOTING CHART II-E.2

SYMPTOM	PROBABLE CAUSE	POSSIBLE REMEDY
Mouthpiece T-tube assembly		
High inhalation resistance	Contaminated or faulty check valve	Clean or replace inhalation check valve
High inhalation and exhalation resistance	Mouthpiece and shutoff valve not in DIVING position	Place valve in DIVING position
High exhalation resistance	Contaminated or faulty exhalation check valve	Clean or replace exhalation check valve
Leakage at hose connections	Improper connections	Tighten connections
Exhaust valve assembly		
Leakage	Contamination	Disassemble and clean valve
	Loose clamp assembly	Tighten clamp assembly
	Broken or weak spring	Replace spring
	Deteriorated or cut diaphragm assembly	Replace diaphragm assembly
Regulator assembly		
No output	Manifold shutoff valve closed	Open valve
Restricted flow	Contaminated inlet filter	Clean or replace filter
Unable to adjust properly	Damaged first-stage components or bellows assembly	Inspect and replace filter
Leakage through diaphragm cap	Deteriorated or cut diaphragm assembly or top diaphragm gasket	Replace bellows assembly
No depth compensation	Punctured or broken bellows assembly	
Leakage at inlet	Faulty inlet seal	Tighten yoke assembly or replace preformed packing
Cylinder and manifold valve assembly		
Leakage at neck of cylinders	Faulty preformed packing	Replace preformed packing
Leakage at manifold connections	Loose fittings	Tighten fittings
	Damaged fittings	Replace manifold valve assembly or defective elbow assembly
Leakage at manifold shutoff valve	Damaged or scored valve seat	Replace retainer assembly
	Faulty gasket	Replace gasket
	Loose or damaged diaphragm cap	Tighten or replace diaphragm cap

TROUBLESHOOTING CHART II-E.2 (cont'd)

SYMPTOM	PROBABLE CAUSE	POSSIBLE REMEDY
Control block assembly		
Unable to obtain proper system flow	Needle valve not properly adjusted	Adjust needle valve
	Incorrect or damaged filter and orifice assembly	Change or replace filter and orifice assembly
Leakage at bypass valve	Faulty preformed packing gasket	Replace defective parts as necessary
	Worn or scored valve seat	Replace valve stem assembly
Leakage at access caps	Faulty preformed packings	Replace preformed packings
Leakage at fittings	Loose or damaged couplings	Tighten or replace as necessary
Canister assembly		
Leakage at bottom end of canister	Loose cover assembly or faulty sealing gasket	Tighten cover and/or replace sealing gasket
Leakage at upper end of canister	Faulty sealing gasket	Replace sealing gasket
	Loose or damaged hose clamp assemblies	Replace hose clamp assemblies as required
	Gas inlet block loose	Tighten gas inlet block
Breathing bag and vest assembly		
Leakage at breathing bags	Loose elbow(s)	Tighten elbow(s)
	Loose band assembly	Tighten band assembly
	Water drain plugs not secure	Tighten plugs
	Damaged breathing bag(s)	Replace breathing bag(s)

MK 10, MOD 4 Mixed-Gas UBA

Pre-Dive Equipment Preparation Checklist II-F.1

1. Check that all equipment and accessories that may possibly be used in all phases of the diving operation are present on station.

- | | | |
|-----------------------------|---------------------------|--|
| 2. Minimum Equipment | —Weight Belt | |
| —MK 10 MOD 4 UBA | —Depth Gage | |
| —Face Mask | —Wrist Watch | |
| —Fins | Optional Equipment | |
| —Knife | —Wrist Compass | |
| —Thermal Protection System | —Slate/stylus | |
| | —Tools | |

3. Verify that the ship's (support facility) oxygen supply is tagged as either Type A or Type B oxygen. Check all supply cylinder valves and fittings.

4. Check that the support facility's diluent gas supply is charged with the correct mixture designated for the depth and profile of the dive. Verify that a sufficient quantity is available for all phases of the operation.

5. Perform predive checkout of PTC.

6. Take accurate depth soundings.

7. Brief the diving team.

8. Determine the exact status of each MK 10 unit from the log of the previous dive and maintenance records. Any discrepancies or gaps in the records must be corrected before proceeding further in the pre-dive checklist.

9. Inspect the unit to be sure all components are present and secured in place. This is a primary superficial system check.

10. Check the unit for cleanliness, signs of damage or wear, tightness of joints and/or connections.

11. Verify that the nickel cadmium batteries are fully charged and record the voltage indicated on the chest display meter. Note: All readings from sensors and displays should be recorded in a consistent manner to provide base line operating and calibration data.

12. Check that the oxygen partial pressure sensors are within ± 5 percent of the actual ppO_2 at the sensor face. Calibrate the sensors if necessary. (Note: for detailed steps in calibrating sensors, refer to the approved service manual for the MK 10 MOD 0 UBA (NAVSHIPS 0994-004-7010).

13. Check that the alarm system is operational. Checkout of this system is accomplished while checking the outputs of Sensors 1 and 2. The amber light must be lit anytime the ppO_2 at both sensor faces is within 25% of the reference voltage. The alarm system should be tested in both the HIGH and LOW ranges, switching from one to the other alternately.

14. Verify that the solenoid valve is operational. This is accomplished by listening for an audible sound when the valve is open. Whenever the outputs of Sensors 1 and 2 are less than the oxygen SET point, the valve must open once every two seconds. If the output of either sensor is equal to or greater than the oxygen SET point, the solenoid valve must remain closed.

15. Remove and charge both the oxygen and diluent cylinders to a pressure (up to 3,000 psi) sufficient to perform the planned dive. Record the type of gas filled and pressures. Return the cylinders to the MK 10 assembly.

16. Check that the oxygen and diluent gas supply bypass valves are operational. This can be done by opening the particular gas cylinder valves and then depressing the bypass valve handles. If the bypass valves are operating properly, the breathing bags will inflate. The mouthpiece should be closed during this check.

17. Install a new disposable CO_2 absorbent cartridge in the scrubber housing. Check the duration of the absorbent at the expected seawater temperature. A slight resistance to the installation should be experienced due to the seal at the forward end of the cartridge engaging the inlet tube in the canister. If no resistance is noted, remove and inspect the complete assembly. A neoprene gasket between the cartridge end plate and the container provides a water-tight seal. This gasket is provided with each disposable cartridge and should not be re-used.

18. Secure the new cartridge with the four latches attached to the housing.

19. Check the operation of the diluent add (make-up) valve. This check should be performed while breathing the unit by switching the selector knob to the OFF position and exhausting all breaths to the atmosphere. When the breathing bags are completely deflated, the

diluent add valve must function to permit further breathing. There should be no resistance.

20. Check the operation of the vent valve by closing the mouthpiece and depressing the diluent bypass valve. When the breathing bags completely inflate, excess gas must escape through the vent valve.

21. After completing the above two valve checks, the entire system should be checked for leaks. This is best accomplished by placing the mouthpiece in the CLOSED position and submerging the unit in water. The plastic cover should be removed prior to submergence. Increase the pressure in the breathing circuit by depressing the diluent bypass valve until the breathing bags start to expand. The vent valve button must be depressed and held to maintain the internal pressure. Visual examination should make note of any bubbles escaping from around joints, fittings or seal areas.

If this check is satisfactory, the unit should be surfaced, and the plastic cover replaced to protect the apparatus during diving operations.

22. The MK 10 UBA is now ready for use.

23. Don the accessory gear.

24. Don the MK 10 UBA.

25. Check that the gas cylinder valves are open.

26. Switch the controls to AUTOMATIC in the LOW range. The diver should breathe the unit and check that the desired level of O₂ is automatically maintained and that the lights on the wrist and chest displays are working properly.

Repeat the check in the HIGH range.

27. Turn the selector knob on the chest display to the selected ppO₂ control range. Set HIGH or LOW and attach the display to the D-ring on the right shoulder harness.

28. OPEN the mouthpiece valve to avoid damage to components in the breathing circuit when the PTC is pressurized.

Post-Dive Procedures II-F.2

1. Depressurize all lines.

2. Clean and wash down all hardware. Keep mouthpiece closed during rinsing.

3. Close the oxygen and diluent cylinder valves. If the cylinders are not going to be used for some time, the cylinder pressure should be 300 ± 50 psig. Under no condition should cylinder pressure be allowed to fall below 50 psig.

4. Remove and discard the disposable scrubber cartridge. Wipe the inside of the scrubber housing with a lint-free cloth or blow dry with an air line.

5. Remove all flexible components such as mouthpiece/hose assembly, breathing bags. Clean and hang up to dry. Use zephiran chloride solution for cleaning.

6. Check and record the sensor readings, battery voltages, and values of the HIGH and LOW O₂ SET POINTS.

7. Verify operation of the alarm system and solenoid valve as per the Pre-Dive Checklist.

8. Attach the battery charger or the battery module set on charge.

9. Visually inspect all components for damage. Record all deficiencies in appropriate logs and maintenance records.

10. When charging is complete, re-install all components and assemble the MK 10 UBA. Do not replace the disposable cartridge.

11. Store apparatus in a rigid container in a cool, dry location.

Note:

The MK 10 apparatus is a sophisticated complex equipment system. Maintenance and overhaul of the system should only be accomplished by trained personnel with continuing referral to approved service manuals. The service manual for all maintenance on the MK 10 MOD 4 Mixed-Gas UBA is designated NAVSHIPS 0994-004-7010.

MK 11 MOD 0 Mixed-Gas UBA

Pre-Dive Equipment Preparation Checklist II-G.1

INTRODUCTION TO THE CHECKLIST

The MK 11 MOD 0 Mixed-Gas UBA is a highly sophisticated and complex life-support system. It is pre-supposed that users of this system are well trained and experienced divers. In all cases, a firm understanding of the system, its maintenance, and operational use is necessary for the conduct of safe diving. All users of the MK 11 should carefully read the approved service manual for the equipment; this manual is designated as **NAVSHIPS 0994-005-2010**.

Prior to preparing the equipment for operational use, a careful inspection of all components should be conducted. This inspection should include not only all operational components, but those necessary subsystems used for calibration, checkout, and charging. These include:

- Field Test Kit
- Maintenance Kit
- Charging Assembly
- Bib-Whip
- Gasometer
- Maintenance and Calibration Whip
- Special Tools

The initial inspection should include all Preventive Maintenance required in the appropriate checklists indicated FOR EACH DIVE.

Preventive Maintenance Tables for the three major components of the MK 11 system are presented in Tables G-1 through G-3 at the end of this Appendix.

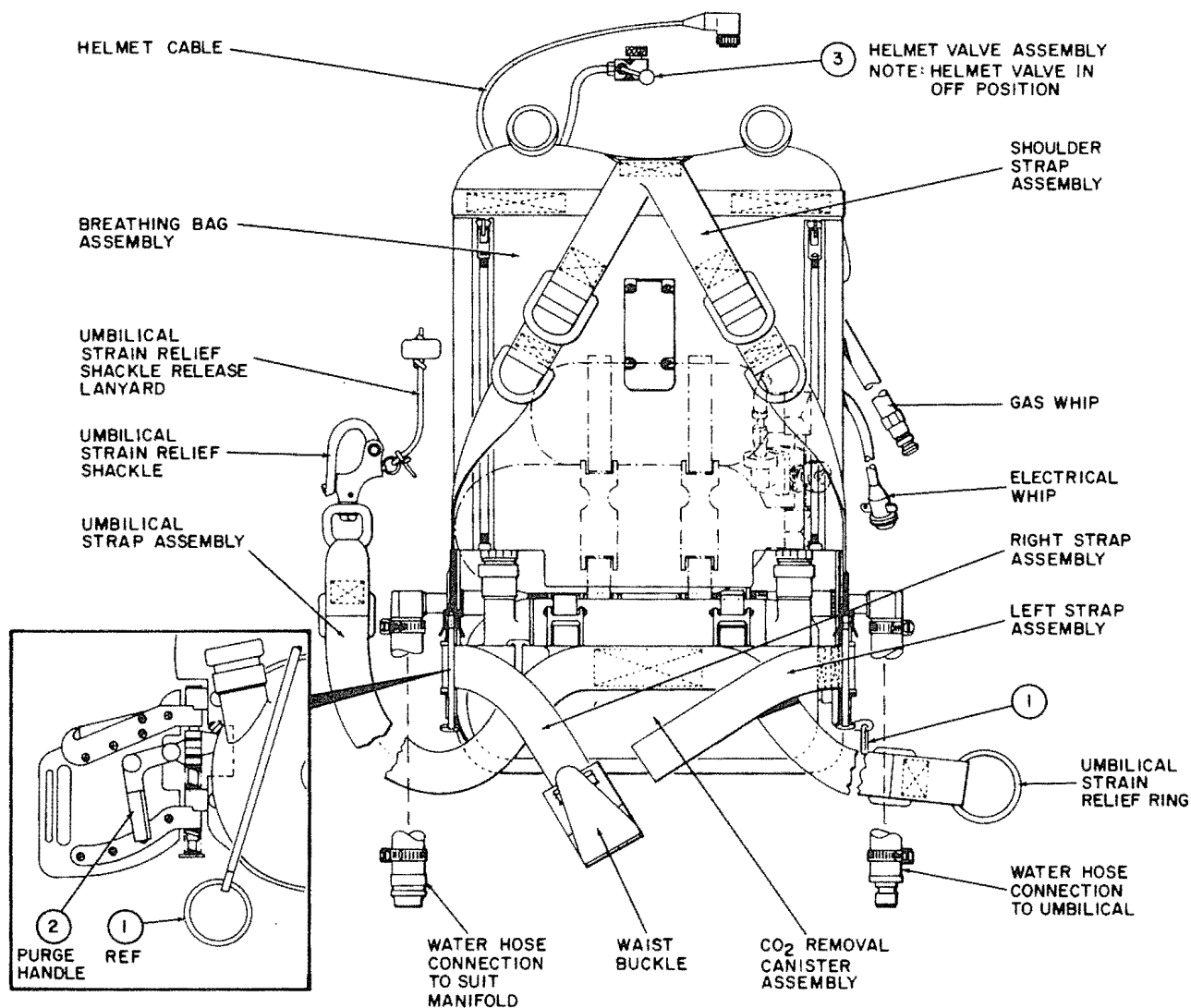
1. Charge the Emergency Gas Supply—Remove the manifold assembly from the backpack and charge as follows (See Figure No. 11-G-1)—

WARNING

At the time of charging, breathing gas cylinders should be labeled with masking tape (or appropriate substitute), noted to show mix, date, and signatures of two qualified people who conducted and checked the filling process. During set up, the predive checklist should be noted to show cylinder(s) serial number, mix date, and names from label. Label tapes

should not be removed from the gas cylinders until they are refilled. If a transfer pump is required, use a BUSHIPS approved pump such as TID S4320-T4-92387 or TID S4320-T2-8690-01.

- A Unzip the breathing bag assembly, unscrew the CO₂ removal canister inlet and outlet connector knobs from the breathing bag fittings, and fold the breathing bag assembly out of the way.
- B Unlatch the two holddown buckles from the front rib holddowns and fold the straps back off the manifold assembly cylinders.
- C Ensure the manifold assembly on-off valve is closed, loosen the Phillips-head screw on the retainer assembly, and remove the retainer assembly from the manifold assembly on-off valve stem.
- D Remove the manifold assembly-to-absolute pressure regulator block (APRB) line from the disconnect adapter. The manifold assembly can now be lifted free of the backpack.
- E Clear the charging assembly of contaminants by a short blast of breathing gas from the high-pressure breathing gas source.
- F Ensure the manifold assembly valve is closed.
- G Connect the charging assembly knurled knob to the manifold assembly disconnect adapter. Ensure the charging assembly bleed valve is closed.
- H Open the manifold assembly on-off valve.
- I Slowly open the breathing gas supply on-off valve and fill the manifold assembly cylinders to 3000±50 psig. Do not fill manifold assembly cylinders at more than 500 psig per minute. To ensure maximum pressure, the manifold assembly cylinders should be cooled by immersing them in a bucket of cold water during charging.
- J Close the manifold assembly on-off valve.
- K Close the breathing gas supply valve, open the charging assembly bleed valve to bleed the line, and detach the charging assembly from the manifold assembly disconnect adapter.
- L Check the manifold assembly with a commercial leak detector.
- M Reverse steps (C), (D), and (E) above to replace the manifold assembly in the backpack. Make sure



INDEX NO.	NAME	TYPE	POSITIONS	FUNCTIONS (EACH POSITION)
1	ON-OFF RING	PUSH/PULL RING	DOWN UP	KEEPS MANIFOLD ASSEMBLY ON-OFF VALVE CLOSED OPENS MANIFOLD ASSEMBLY ON-OFF VALVE TO SUPPLY EMERGENCY BREATHING GAS TO THE ABSOLUTE PRESSURE REGULATOR BLOCK
2	PURGE HANDLE	LEVER	IN OUT	PURGE VALVE IS CLOSED OPENS PURGE VALVE TO ADD BREATHING GAS TO SEMICLOSED-CIRCUIT SYSTEM TO INCREASE PO ₂ LEVEL
3	HELMET VALVE ON-OFF KNOB	BALL HANDLE	DOWN-OFF UP-ON	CLOSES DEMAND LINE OPENS DEMAND LINE FOR OPEN-CIRCUIT OPERATION OR ORAL-NASAL MASK PURGING

Figure II-G-1 MK 11 MOD 0 UBA controls

stand up and lift the garment to position the buttocks. Bend forward slightly to help position the suit. Insert one arm partially into the sleeve then start the other arm into its sleeve. Stretch both arms and work them until the sleeves are properly positioned. Close and lock the front, sleeve, and leg zippers.

- B Sit down and grasp the rubber tube extending from one suit leg between the big toe and adjacent toe of the foot and position the boot on the foot. Wiggle the toes to position the rubber tube in the boot. Ensure the tube does not remain between the toes or discomfort can result during a long dive. Pull the hood over the head and fasten the velcro flap.
- C Don the backpack.
 - 1. Plug the gas and electrical umbilical whips into the umbilical. Ensure the umbilical water and gas hoses and electrical cable are connected to the PTC. Ensure the locking O-ring is engaged in its slot, preventing unscrewing of the electrical connector. Do not lift or in any way manipulate the backpack by the hoses or whips.
 - 2. Put shoulders through the harness assembly and fasten the quick release buckles. Also fasten the waist buckle. Rethread the right strap through the triple-slot buckle interface for adjustment.
 - 3. Tighten the shoulder straps until the cardioid valve pad can be felt pressing against the diver's back. This is done by pulling on the loose strap ends of the shoulder harness. After adjusting the straps, tack the loose strap ends down on the velcro so the straps are against the diver's body.
- D Snap the umbilical strain relief shackle hook around both the umbilical ring and the umbilical strain relief harness ring.
- E Place helmet on head and fasten shock cords, after checking that the inside of the lens is coated with a thin film of Joy soap. Adjust the head harness of the helmet for proper fit if not previously adjusted. A comfortable fit in air results in a fit that is too loose when underwater.
- F Connect the helmet cable to the helmet. Ensure the threaded locking rings on the connector cover the

color band on the receptacle. Be sure the coupling ring is screwed down until the red band on bulkhead half is covered. Connector is sealed by a piston O-ring, over-tightening the coupling ring does not provide a tighter seal. DO NOT USE A WRENCH.

- G Turn on the diver support facility communications system for a verbal check. Adjust the volume level for both the microphone and the headset.
- H Cover the exhaust tube with one hand to seal it completely; exhale to check for sealing integrity, including the inhalation check valve. Remove the hand and seal off the intake port on the second-stage regulator and intake hose connection in the same manner. Inhale slowly to check the exhalation check valve. Also, check the purge and nose clearing assemblies.
- I Ensure the umbilical gas hose is connected to the backpack gas whip. Listen for gas flow by placing the inhalation (right) hose close to the ear. A slight hiss should be heard to verify flow. If this is not heard, remove the backpack and repeat the flow-rate check.
- J Connect the helmet to the two breathing hoses. Ensure the O-rings are in place. Tightly connect and screw down the breathing hose connections.
- K Ensure BOTH filaments of the helmet warning light are glowing. If one is burned out, replace the indicator.
- L Push up on the ring at the lower left of the backpack to turn the manifold on-off valve on. The helmet light should go out immediately. If the light remains on, remove the backpack and repeat the switchover check.
- M Actuate the purge valve to ensure that it is functioning correctly.
- N Strap on knife, compass, and depth indicator, either flippers or weighted shoes as required, and attach slate and stylus. When securing the weighted shoes, ensure the back of the diver's leg is against the back of the shoe. If the leg is bent forward, the closure cannot be made tightly enough to keep the shoe on the diver's foot.
- O Screw the helmet valve onto the second-stage

regulator in the helmet. Ensure the teeth on the helmet and helmet valve are engaged before tightening the knob. Open the on-off valve and press the demand button to ensure it is functioning correctly. Close the on-off valve.

P Set up the dual diver monitor alarms as follows—

1. Make sure that the power supply is connected.
2. Place the POWER switch in the ON position; the red pilot lamp should light.
3. Allow 45 to 60 seconds to warm up.
4. Test the alarm circuits as follows—
 - a. Place the ALARM SELECT and POWER SELECT switches in position A. The DIVER A meter should indicate the ppO₂ level to which the attached sensor is exposed.
 - b. Move the left DIVER A alarm pointer until it contacts the ppO₂ indicating needle. The alarm should sound. If it does not, check all connections.
 - c. When the alarm sounds, move the pointer fully counterclockwise.
 - d. Move the right DIVER A alarm pointer until it contacts the indicating needle. The alarm should sound. When the alarm sounds, return the pointer to the fully clockwise position.
 - e. Move the ALARM SELECT and POWER SELECT switches to position B. The DIVER B meter should indicate the ppO₂ level to which the attached sensor is exposed.
1. Adjust the alarm points to the desired settings by hand or with a screwdriver.
2. Place the ALARM SELECT switch in position A, A-B, or B, depending upon the desired alarm use.
3. Place the POWER SELECT switch in position A, A-B, or B, depending upon which aquanaut or aquanauts are connected to the diver monitor.
4. Place the POWER switch in the OFF position.

Q Put on gloves.

R Ensure water is flowing from the umbilical water hose and connect the umbilical water hose to the water whip. Close the hot water suit bypass valve and connect the water hose from the CO₂ removal canister to the hot water suit manifold coupling.

Use care to avoid squirting hot water from the bypass on other personnel. Test operation of all valves and of water flow.

S When comfortable and all equipment is functioning correctly, breathe on the apparatus for at least 2 minutes, then enter water.

THE MK 11 UBA IS NOW READY FOR USE

16. MK 11 MOD 0 Mixed-Gas UBA In-Water Pre-Dive Check—

- A Once in water, have buddy diver check for leaks. Make sure that the cardioid valve is functioning correctly by noting lack of inhalation or exhalation resistance.
- B Check the connections and seals on the various aquanaut diving equipment components while still in the immediate area of the PTC.
- C Check the microphone and earphone communication.
- D Purge any water leaking into the faceplate by pressing in on the waterpurge button on the bottom of the faceplate when the diver is in an upright position.
- E If fogging occurs on the viewing port, allow some of the purge water to enter the eye cavity by placing the head lower than the breathing bags and opening the waterpurge valve. A small amount of water can be left in the lower portion of the faceplate outside the oral-nasal mask to rinse fog from the view-port during the dive.
- F Ensure that helmet lamp is still off.
- G If any appreciable leaks are detected, return to the PTC for correction.
- H Check ppO₂ sensor and diver monitor operation.
- I Adjust the hot water suit bypass valve, front flow control valve, and rear flow control valve to achieve maximum comfort. As the level of activity changes, the valve settings may have to be changed to maintain comfort.

Note

The operator of the diver support facility hot water supply must increase the hot water umbilical inlet water temperature after the umbilical is exposed to ambient seawater. Figure 11-16, presented in Chapter

MK 11 MOD 0 UBA PREVENTIVE MAINTENANCE CHECKLIST (Continued)

ACTION REQUIRED	FREQUENCY	COMMENTS
CO₂ REMOVAL CANISTER ASSEMBLY		
Clean canister thoroughly inside and out with a mild solution of PhisoHex, rinse with fresh water, and dry thoroughly.	Each dive day	Dry with a blower or hair dryer.
Ensure sealing edge of canister housing is clean and undamaged.	Before each dive	
Ensure water jacket inlet, outlet, and passages are not blocked.	Before each dive	
Check canister housing and top for cracked, gouged, or broken areas in the fiberglass and resin where fiberglass cloth is exposed.	Before each dive	
Check the connector knob-threads for damage and chase the threads if necessary. If threads are badly damaged, return the canister top to the factory to have the knob replaced.	Before each dive	
MANIFOLD ASSEMBLY		
Pressurize and leak-check the assembly.	Before each dive	
Inspect disconnect adapter threads for damage and chase threads if necessary.	Before each dive	
TUBING AND FITTINGS		
Connect apparatus to breathing gas supply and check all connections, tubing, and fittings for leaks.	Before each dive	
Check high-pressure circuit. If flooded, rinse all components with fresh water and dry thoroughly with inert gas.	After each dive	
SWITCH ASSEMBLY		
Check condition of electrical cable and replace if damaged or deteriorated.	Before each dive	
Check metal parts for corrosion.	Before each dive	

MK 11 MOD 0 UBA PREVENTIVE MAINTENANCE CHECKLIST (Continued)

ACTION REQUIRED	FREQUENCY	COMMENTS
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HELMET CABLE AND ELECTRICAL WHIP

Inspect cables and preamplifier for breaks in sheath or other wear or damage.	Before each dive	
Inspect connectors for wear, damage, or bent pins.	Before each dive	
Clean and lubricate connectors.	After 6 dives or two weeks	Use Halocarbon 25-5S grease.

ppO₂ SENSOR-AMPLIFIER ASSEMBLY

Clean assembly with a clean damp cloth. Check sensor face for accumulation of debris.	After each dive	DO NOT IMMERSE IN WATER.
Check condition of cable and connector.	Before and after each dive	
Clean and lubricate connector.	Before and after each dive	Lubricate with Halocarbon 25-5S

MOUNTS (CARDIOID VALVE, SWITCH ASSEMBLY, RIB ASSEMBLIES)

Check plastic mounts for damage and replace if necessary.	Before each dive	
Ensure the mounts are securely fastened to the backpack shell.	Before each dive	

PURGE VALVE ASSEMBLY

Inspect all metal parts for corrosion and wear and replace as necessary.	Before each dive	
Ensure the purge lever-to-purge valve linkage is clean and operates freely and smoothly.	Before each dive	No lubrication of linkage is necessary.

LEFT HAND AND RIGHT HAND ARM ASSEMBLIES

Ensure the purge lever and linkage on the right hand arm assembly is clean and operates freely and smoothly.	Before each dive	
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HARNESS

Check for fraying and stitching deterioration. Restitch, if necessary with nylon thread or replace assembly if damage is serious.	Before each dive	
Check the function and condition of all buckles and slides.	Before each dive	

SURFACE-SUPPLIED MIXED-GAS DIVING OPERATIONS—PRE-DIVE CHECKLIST

Diving Equipment Preparation

1. Assemble and lay out all equipment that may be used in the dive—including primary gear, standby gear, accessories tools and spares.
2. Carefully inspect all equipment for signs of wear, distortion, cracks or tears, rot, corrosion, and dirt. Clean and repair as necessary, or discard and replace.
3. For the **heavyweight mixed-gas helmet group**, specifically check the following items—
 - A Examine the faceplate rubber gasket for wear.
 - B Examine the glass in the faceplate and ports for cracks or inadequate seal.
 - C Check the interior of the helmet to ensure that all portions are dry and free of verdigris and dirt. Check the terminals of the diver's communication system.
 - D Check the threads on the goosenecks for damage, verdigris or wear.
 - E Ensure that the safety lock (dumbbell) moves freely, and that the safety latch on the breastplate has a brass cotter pin.
 - F Check that the breastplate studs are free of distortion or thread damage.
 - G Check serial numbers on the breastplate straps to verify that they are the correct set for the breastplate.
 - H Verify the presence of four copper washers and twelve wing nuts (four of which should be flanged and one of which is of a special design to accommodate the control valve/Hoke valve assembly).
 - I Check the operation (by smoke test) of the non-return valve.
 - J Check the packing on the control valve; verify the presence of the cotter key.
 - K Check the freedom of movement of the exhaust valve handwheel and chin button.
 - L Check the secondary exhaust valve. The rubber diaphragms should be supple, clean, and free from cracking.
 - M Check all Koroseal or neoprene washers; clean with fresh water. In cold weather operations pre-warm washers in warm fresh water before use.
 - N Check and clean aspirator screen; replace if defective or corroded.
- O Check all connections on the hose leading from the Hoke needle valve (at the control valve unit) to the venturi.
4. For the **lightweight mixed-gas outfit**, check the following items—
 - A Check the lightweight diving suit for rips or excessive wear.
 - B Check the weight belt for correct number of weights, as well as for wear in leather or grommets.
 - C Check the MK 1 Mask for general appearance or discrepancies. Check straps.
 - D Check the faceplate and seal.
 - E Check that the face seal and oral-nasal mask are properly attached to the main mask body.
 - F Check that all metal components are properly secured to the fiberglass body.
 - G Check for any loose mounting bolts, or any visible dents or damage.
 - H Check that the nose clearing device slides in and out easily.
 - I Check the head spider for wear.
 - J Gage the emergency gas supply cylinder.
 - K Check all other accessory equipment according to the SCUBA equipment checklist in Chapter Five of Volume I.
5. Check the following **general equipment**—
 - A Check that all needed accessory equipment, tools, lights, special systems, spares, etc., are on scene and in order. In testing lights, all tests should be conducted with the lights submerged in water and extinguished before removal to prevent overheating and failure.
 - B Erect the diving (decompression) stage or attach the diving ladder. Make up and place the decompression line. In the case of the stage, be careful to ensure that the shackle connecting the stage line is securely fastened, **with the shackle pin siezed with wire to prevent opening.**
 - C Place the gas hose bulwark roller in place at the rail.

Mixed-Gas Supply Preparation

1. Check the primary and standby system to verify that a mixed-gas breathing supply is available with a

capacity in terms of purity, volume, and supply pressure to completely service all divers and accessory equipment throughout all phases of the planned operation. Supply pressure must be capable of supporting continual 100 psi overbottom pressure at the operating depth.

2. Check that the standby air supply system (which may be used as a back-up for emergencies and for the recompression chamber) is fully adequate. A checklist concerning air supply systems can be found in Chapter Six, Volume I.

3. The Mixed-Gas Supply System check should include—

- A Assemble proper amounts of He-O₂ and O₂ cylinders. Check and handle cylinders in accordance with Cylinder Handling Rules found in the Appendix II-C.
- B Gage and check all cylinders for contents—both as to type of gas and proper percentages.
- C Conduct an oxygen analysis of the contents of all mixed-gas cylinders (See Appendix II-A).
- D Verify that extra, filled O₂ cylinders are located in the rack area in case of emergency requirements. (Observe all safety rules regarding storage and use of oxygen.)
- E Install all He-O₂ and O₂ in supply banks. Connect up manifolding, piping, and gaging systems.
- F Be sure that all connections and fittings are free of any trace of oil or grease.
- G Check that all filters, cleaners, and oil separators are installed as required and clean.
- H Bleed off all condensed moisture from lines, filters and the bottom of volume tanks (accumulators). All manifold drain plugs should also be checked.
- I Check that all petcocks are placed in the closed position.
- J Check all pressure-relief valves, regulators and unloaders. Be sure that all unloaders are in the compressed position.
- K Hook up all connections between the supply bank, volume tanks, and supply hoses leading to helmets or open bell.
- L Check the line of supply both through the volume

tanks, and through the bypass system for direct supply.

M Rig a water line to the diving station for use in washing out canisters (Deep-Sea Outfit).

N Rig an air line to the diving station for use in blowing out canisters (Deep-Sea Outfit).

O Verify that all supply hoses running to and from supply points have proper leads. Do not pass hoses near high-heat areas such as steam lines. Ensure that they are free from kinks and bends, and are not exposed on deck in such a way that they could be rolled over, damaged, or severed by machinery or other activities.

Verify hoses on all systems.

- Primary Mixed Gas
- Secondary Mixed Gas
- Standby Air
- Water (Deep-Sea Outfit)

P Check "Do Not Touch—Diver's Breathing Supply" tags on all lines and controls as needed.

Air Supply Activation

1. Open Bank Valves and check the pressures at the gages.

2. Activate system, working from banks, to volume tanks, to control rack, to diving station. Check all bypasses, regulators, dome loaders, and gages.

3. Check that the control rack can deliver both the primary and secondary supplies of mixed-gas, standby air, and pure O₂. This supply must be available to—

- Divers
- Diving Station
- Recompression Chamber
- Accessory Operation Lines

4. Check all fittings, hoses, piping, valves, etc., by soap testing, with pressure on.

5. Test the recompression chamber by blow-down.

6. Test the chamber O₂ system.

Hose Inspection

1. Verify that no hose length exceeds three years in age from the date of manufacture (age is marked on each length 4" from end).

2. If possible, make sure that the hose (or any length) has not been used in a burst test program. No length involved in such a program may be part of an operational gas supply hose.
3. Check that the newest (or best) hose length is the section nearest to the surface, since that is the region where the hose will be subject to the greatest pressure differential.
4. Check that hoses are free of moisture, packing material and chalk.
5. Soap test all hose connections after they have been hooked up to the activated gas supply.
6. Check that all tie-offs and the canvas chaffing over the first length of the hose are in proper condition.

Equipment Test With Activated Gas Supply

1. Hook up all hoses to helmets, masks, and chambers.
2. Verify both flow and composition of mixed-gas to all helmets, masks and chambers. If a standby, lightweight mask is being used for emergency surface assistance to a diver, verify that air is being supplied to this mask.
3. Check all non-return control, Hoke, and exhaust valves. Check both primary and secondary exhausts.
4. On hard-hat He-O₂ rig, close the control valve and Hoke valve and check for gas leaks. Soap test.
5. On hard-hat He-O₂ rig, open control valve, close Hoke valve, and check for leaks. Soap test.
6. Open control valve and Hoke valve and test helmet connections for leaks.
7. Set exhaust valve. Fully close and then back off 2½ turns.

Recompression Chamber Check-Out

1. Check that the chamber is completely free of all combustible materials including paint cans, refuse, matches, lighters, etc.
2. Check that the primary and back-up gas supply is hooked up to the chamber and all pressure gages. Verify the supply of He-O₂, pure O₂, and air.
3. Check that the chamber is free of all odors or other contaminants.

4. Verify the presence of a fire bucket in the chamber.
5. If blankets are to be placed in the chamber, the **must** be of the prescribed non-flammable type procured through the Navy supply system.
6. Verify that the medical kit is completely outfitted and in the chamber.
7. Verify that a suitable number of O₂ breathing masks are present in the chamber. There should be enough for two divers, a tender, and medical personnel.
8. Verify that the chamber electrical system is fitted with armoured cable and special lighting fixtures and bulbs. All switches should be on the outside of the chamber.
9. Check all doors and seals.

Final Preparations

1. Verify that all necessary records, logs, and time-sheets are on the diving station.
2. Check that the appropriate and most up-to-date decompression tables are on hand, together with personnel trained in their use. Be sure that the decompression program has been pre-planned, and the diving team briefed.
3. Verify that all gas supply systems have a volume tank or accumulator installed in the supply system between the supply source and the diver's hose connection or bell. Verify that the standby air system conforms to the checklist in Chapter Six, Volume I.
4. If possible, an extra mask and hose should be rigged to the air supply source. Note: Many Navy diving operations always have a lightweight mask rigged as a standby even when conducting mixed-gas deep sea operations. This is done in case a man must enter the water and assist a diver on or near the surface.
5. Check the source and supply of CO₂ absorbent. Break out the appropriate amount of absorbent for the dive (Deep-Sea Outfit).
6. Set up special canister filling racks (Deep-Sea Outfit).
7. Place the dressing bench in position, making sure that the diver does not have a long way to travel to reach the diving ladder or stage (Deep-Sea Outfit).

8. Rig a small block and tackle (jigger) on the decompression stage. The diver should be dressed to the breastplate on the dressing bench, and then moved to the stage for placement of the helmet (Deep-Sea Outfit).

9. Make a final check of all descending, stage, and decompression marker lines (Deep-Sea Outfit).

Immediately Prior To Start of Diving

1. Verify that a Diving Medical Officer and a Recompression Chamber are present on the diving station.

2. Check the moor; verify the position of the vessel, and that it is in a secure two or four-point moor.

3. Take accurate depth soundings, using two methods (pneumofathometer and ships' fathometer, preferred).

4. Determine that all valves, switches and controls that can influence the diving operation are properly tagged to prevent inadvertent activation or shut-down.

5. In particular, verify that all components of the diver's gas supply are properly marked and that no unauthorized or untrained personnel are in a position to cause problems.

6. Verify that proper signals, indicating that diving operations are being conducted, are properly displayed.

7. Make certain that all personnel who can in any way influence the conduct of the operation, have been informed that diving operations are about to commence.

8. Do not start diving until final permission has been given by the OOD acting for the commanding officer.

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