CHAPTER 15

Saturation Diving

15-1 INTRODUCTION

15-1.1 Purpose. The purpose of this chapter is to familiarize divers with U.S. Navy saturation diving systems and deep diving equipment.

15-1.2 Scope. Saturation diving is used for deep salvage or recovery using U.S. Navy deep diving systems or equipment. These systems and equipment are designed to support personnel at depths to 1000 fsw for extended periods of time.

SECTION ONE — DEEP DIVING SYSTEMS

15-2 APPLICATIONS

The Deep Diving System (DDS) is a versatile tool in diving and its application is extensive. Most of today's systems employ a multilock deck decompression chamber (DDC) and a personnel transfer capsule (PTC).

- **Non-Saturation Diving**. Non-saturation diving can be accomplished with the PTC pressurized to a planned depth. This mode of operation has limited real time application and therefore is seldom used in the U.S. Navy.

- **Saturation Diving**. Underwater projects that demand extensive bottom time (i.e., large construction projects, submarine rescue, and salvage) are best conducted with a DDS in the saturation mode.

- **Conventional Diving Support**. The DDC portion of a saturation system can be employed as a recompression chamber in support of conventional, surface-supplied diving operations.

15-3 BASIC COMPONENTS OF A SATURATION DIVE SYSTEM

The configuration and the specific equipment composing a deep diving system vary greatly based primarily on the type mission for which it is designed. Modern systems however, have similar major components that perform the same functions despite their actual complexity. Major components include a PTC, a PTC handling system, and a DDC.

15-3.1 Personnel Transfer Capsule. The PTC (Figure 15-1) is a spherical, submersible pressure vessel that can transfer divers in full diving dress, along with work tools and associated operating equipment, from the deck of the surface platform to their designated working depth.

15-3.1.1 **Gas Supplies.** During normal diving operations, the divers' breathing and PTC gas are supplied from the surface through a gas supply hose. In addition, all PTCs

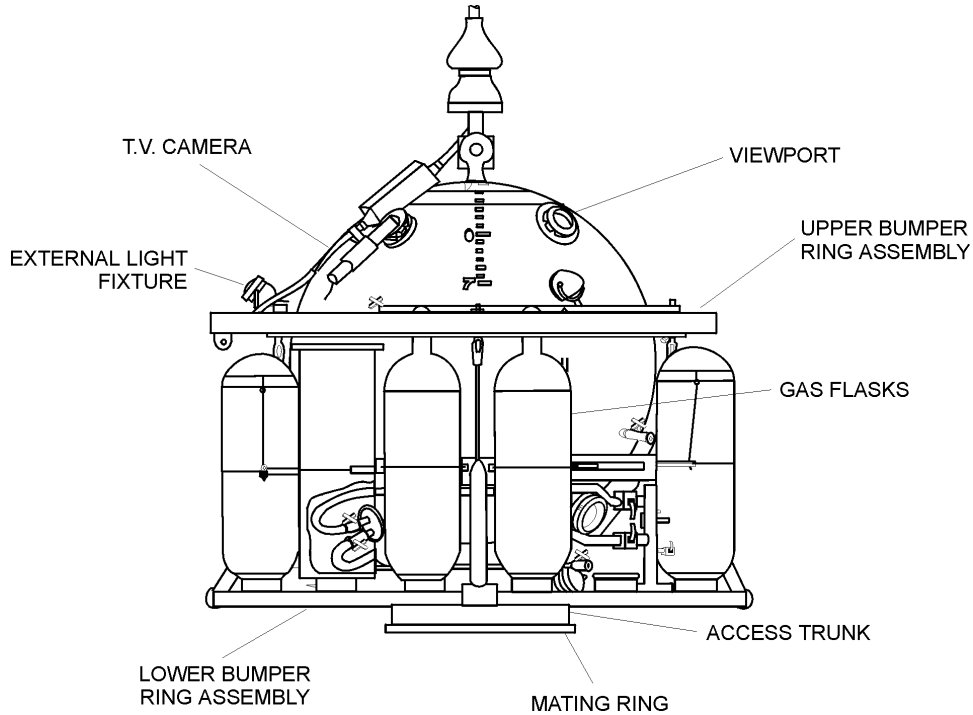

Figure 15-1. Typical Personnel Transfer Capsule Exterior.

carry emergency supplies of helium, helium-oxygen, and oxygen in externally mounted flasks. Internal PTC pressure, gas supply pressures, and water depth are continuously monitored from the PTC.

The typical helium system is designed to maintain PTC pressurization and purge oxygen from all PTC electrical units to alleviate any fire hazard.

The helium-oxygen mixed-gas system consists of an internal built-in breathing system (BIBS) with associated valves, piping, and fittings. The mixed-gas system supplies emergency breathing gas to the diver umbilicals when the topside supply is interrupted, and supplies the BIBS if the internal PTC atmosphere is contaminated.

15-3.1.2 **PTC Pressurization/Depressurization System.** The gas supply and exhaust system control and regulate internal PTC pressure. Relief valves and manual vent valves prevent overpressurization of the PTC in case a line rupture causes a full flask to discharge into the PTC. Needle valves are employed to control depressurization. Depth gauges, calibrated in feet of seawater, monitor internal and external PTC depth. Equalization and vent valves are also provided for the access trunk.

15-3.1.3 **PTC Life-Support System.** The life-support equipment for the PTC includes carbon dioxide scrubbers, a gas supply to provide metabolic oxygen, oxygen, and carbon dioxide analyzers.

15-3.1.4 **Electrical System.** The electrical system uses a multiple voltage distribution system that may be used for heating, internal and external lighting, instrumentation, and communications. Power for normal PTC operation is surface-supplied and is transmitted through power and communications cables. A battery supplies critical loads such as atmosphere monitoring, emergency CO_2 scrubber, and communications if the surface-supplied power is interrupted.

15-3.1.5 **Communications System.** A typical communications system is divided into four individual systems to ensure efficient operation under a variety of conditions.

- **Hardwire Intercom System**. The intercom system is an amplified voice system employing a helium speech unscrambler providing communications within the PTC and between the Main Control Console (MCC), divers, deck winch operator, Deck Officer, and the DDCs.

- **Underwater Mobile Sound Communications Set (UQC)**. The UQC system is a wireless emergency system providing voice communications between the PTC and underwater telephone system of the attending ship. The UQC system is used if the power and communications cables fail or are disconnected.

- **Closed-Circuit Television (CCTV)**. The CCTV consists of video channels from the PTC to the MCC. Cameras are usually mounted outside the PTC.

- **Sound-Powered Phones**. The PTC is equipped with a sound-powered phone system for communication with the MCC in case the normal system is lost.

15-3.1.6 **Strength, Power, and Communications Cables (SPCCs).** The strength, power, and communications cables typically provide electrical power, wired communications, instrumentation signals, a strength member, and coaxial transmission (CCTV signals) between the MCC and the PTC.

15-3.1.7 **PTC Main Umbilical.** The typical PTC main umbilical consists of a breathing-gas supply hose, a hot water hose, a pneumofathometer, and a strength member.

15-3.1.8 **Diver Hot Water System.** Hot water may be necessary when conducting saturation dives. The surface ship supplies hot water via the PTC main umbilical to the diver's suit and breathing gas heater. The PTC operator monitors the water temperature and ensures that the flow is adequate.

15-3.2 **Deck Decompression Chamber (DDC).** The DDC furnishes a dry environment for accomplishing decompression and, if necessary, recompression. The DDC is a multi-compartment, horizontal pressure vessel mounted on the surface-support platform. Each DDC is equipped with living, sanitary, and resting facilities for the dive team. A service lock provides for the passage of food, medical supplies, and other articles between the diving crew inside the chamber and topside support personnel.

15-3.2.1 **DDC Life-Support System (LSS).** The DDC Life Support-System maintains the chamber environment within acceptable limits for the comfort and safety of the divers. The typical system consists of temperature and humidity control, carbon dioxide removal, and equipment monitoring. Processing consists of filtering particulate matter, removing carbon dioxide and gaseous odors, and controlling heat and humidity.

15-3.2.2 **Sanitary System.** The sanitary system consists of hot and cold water supplies for operating the wash basin, shower, and head. Waste from the head discharges into a separate holding tank for proper disposal through the support platform's collection, holding, and transfer system.

15-3.2.3 **Fire Suppression System.** All DDCs have fire-fighting provisions ranging from portable fire extinguishers to installed, automatic systems. DDCs and recompression chambers have similar hyperbaric flammability hazards. Ignition sources and combustion materials should be minimized during critical fire zone times. (At the normal operating depth of PTCs, the oxygen concentration will not support combustion, so they have no built-in fire-fighting equipment.)

15-3.2.4 **Main Control Console (MCC).** The MCC is a central control and monitoring area. The MCC houses the controls for the gas supply and atmosphere analysis for the DDC, atmosphere monitoring for the PTC, pressure gauges for gas banks, clocks, communications systems controls, recorders, power supplies, and CCTV monitors and switches for the DDC and PTC.

15-3.2.5 **Gas Supply Mixing and Storage.** The DDC gas system provides oxygen, helium-oxygen mixtures, helium, and air for pressurization and diver life support. A BIBS is installed in every lock for emergency breathing in contaminated atmospheres, as well as for administering treatment gas during recompression treatment. Normal pressurizing or depressurizing of the DDC is done from the MCC. A means of sampling the internal atmosphere is provided for monitoring carbon dioxide and oxygen partial pressure. An oxygen-addition system maintains oxygen partial pressure at required levels. A pressure-relief system prevents overpressurization of the chamber.

A DDS should be outfitted with gas-mixing equipment, commonly referred to as a "Mixmaker," which provides additional flexibility when conducting deep saturation diving. The Mixmaker can provide mixed gas at precise percentages and quantities needed for any given dive. If necessary, the gas coming from the Mixmaker can be sent directly to the divers for consumption.

15-3.3 PTC Handling Systems. Of all the elements of DDS, none are more varied than PTC handling systems. Launch and retrieval of the PTC present significant hazards to the divers during heavy weather and are major factors in configuring and operating the handling system.

15-3.3.1 **Handling System Characteristics.** All handling systems have certain common characteristics. The system should:

- Be adequately designed and maintained to withstand the elements and dynamic loads imposed by heavy weather.
- Have the ability to control the PTC through the air-sea interface at sufficient speed to avoid excessive wave action.
- Keep the PTC clear of the superstructure of the surface-support platform to avoid impact damage.
- Have lifting capability of sufficient power to permit fast retrieval of the PTC, and controls and brakes that permit precision control for PTC mating and approach to the seafloor.
- Include a handling system to move the suspended PTC to and from the launch/retrieval position to the DDC.
- Have a method of restraining PTC movement during mating to the DDC.

15-3.4 **Saturation Mixed-Gas Diving Equipment.** The UBA MK 21 MOD 0 is an open circuit, demand-regulated diving helmet designed for saturation, mixed-gas diving at depths in excess of 300 fsw and as deep as 950 fsw (Figure 15-2). With the exception of the demand regulator, it is functionally identical to the UBA MK 21 MOD 1, which is used for air and mixed-gas diving. The regulator for the MK 21 MOD 0 helmet is the Ultraflow 500, which provides improved breathing resistance and gas flow over the MK 21 MOD 1.

The UBA MK 22 MOD 0 is an open circuit, demand-regulated, band-mask version of the UBA MK 21 MOD 0 (Figure 15-3). It is used for the standby diver for saturation, mixed-gas diving at depths in excess of 300 fsw and as deep as 950 fsw. It is provided with a hood and head harness instead of the helmet shell to present a smaller profile for storage.

15-4 U.S. NAVY SATURATION FACILITIES

15-4.1 **Navy Experimental Diving Unit (NEDU), Panama City, FL.** NEDU's mission is to test and evaluate diving, hyperbaric, and other life-support systems and procedures, and to conduct research and development in biomedical and environmental physiology. NEDU then provides technical recommendations to Commander, Naval Sea Systems Command to support operational requirements of our the U.S. Armed Forces.

NEDU houses the Ocean Simulation Facility (OSF), one of the world's largest man-rated hyperbaric facilities. The OSF consists of five chambers with a wet pot and transfer trunk. The wet pot holds 55,000 gallons of water. The OSF can simulate depths to 2,250 fsw and can accommodate a wide range of experiments in its dry and wet chambers (see Figure 15-4, Figure 15-5, and Figure 15-6).

Figure 15-2. MK 21 MOD 0 with Hot Water Suit, Hot Water Shroud, and Come-Home Bottle.

Figure 15-3. MK 22 MOD 0 with Hot Water Suit, Hot Water Shroud, and Come-Home Bottle.

15-4.2 Naval Submarine Medical Research Laboratory (NSMRL), New London, CT. The mission of the Naval Submarine Medical Research Laboratory is to conduct medical research and development in the fields of hyperbaric physiology, operational psychology and physiology, human factors engineering, and other allied sciences as they apply to biomedical programs in operational environments (Figure 15-7).

SECTION TWO — DIVER LIFE-SUPPORT SYSTEMS

15-5 INTRODUCTION

Saturation diver life-support systems must provide adequate respiratory and thermal protection to allow work in the water at extreme depths and temperatures. Because of the increased stresses placed upon the diver by deep saturation dives, this equipment must be carefully designed and tested in its operating environment. The diver life-support system consists of two components: an underwater breathing apparatus (UBA) and a thermal protection system. The actual in-water time a diver can work effectively depends on the adequacy of his life-support apparatus and his physical conditioning. Important considerations in the duration of effective in-water time are the rate of gas consumption for the system and the degree of thermal protection. Present U.S. Navy saturation diving UBAs are designed to operate effectively underwater for at least 4 hours. Although a given diving apparatus may be able to provide longer diver life support, experience has

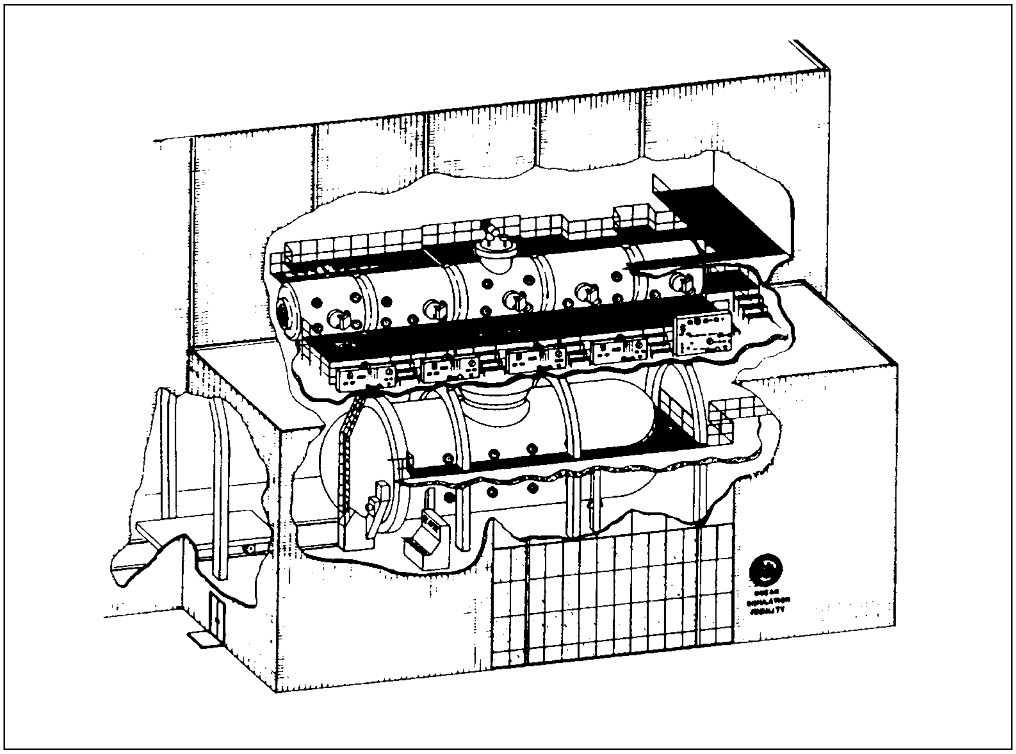

Figure 15-4. NEDU's Ocean Simulation Facility (OSF).

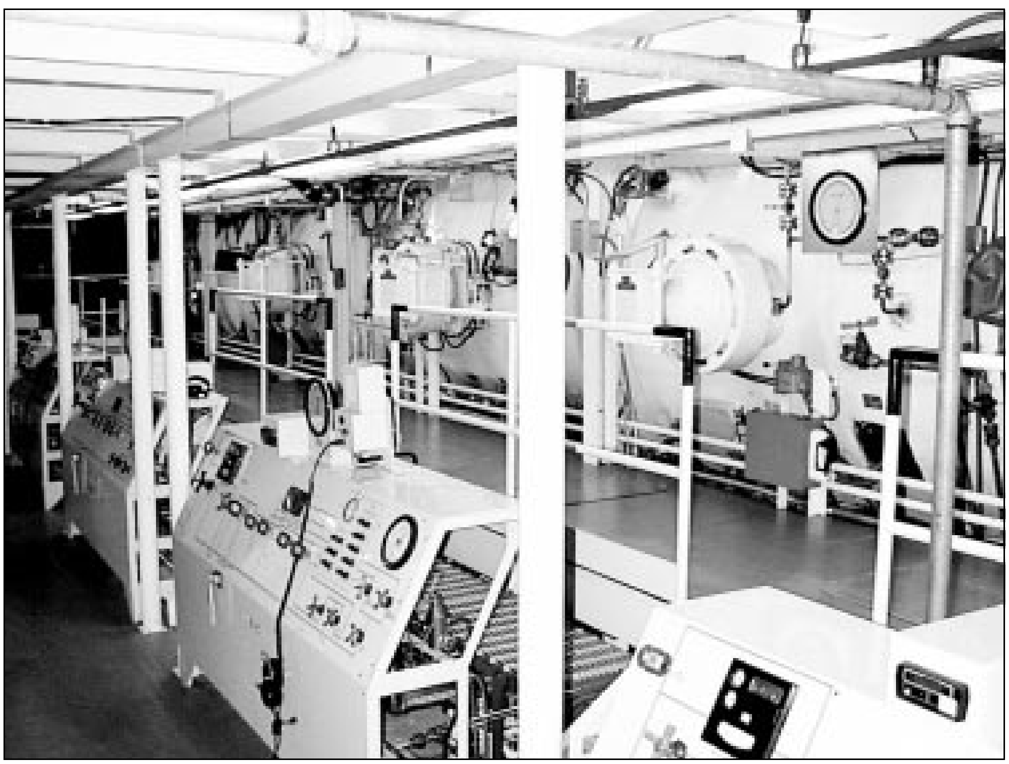

Figure 15-5. NEDU's Ocean Simulation Facility Saturation Diving Chamber Complex.

Figure 15-6. NEDU's Ocean Simulation Facility Control Room.

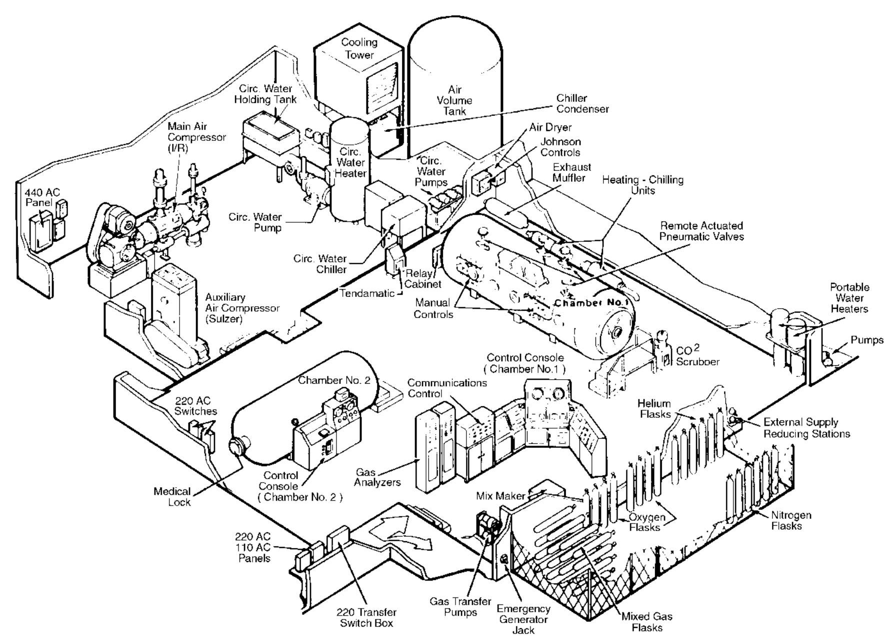

Figure 15-7. Naval Submarine Medical Research Library (NSMRL).

shown that cumulative dive time at deep depths will progressively reduce diver effectiveness after a 4-hour in-water exposure.

15-6 THERMAL PROTECTION SYSTEM

All saturation diver life-support systems include diver thermal protection consisting of a hot water suit and a breathing gas heater. The thermal protection is designed to minimize the diver's heat loss caused by helium's high thermal conductivity. Helium conducts heat away from the body rapidly and causes a significant heat loss via the diver's breathing gas. The diver's metabolic rate may not be great enough to compensate for the heat loss when breathing cold gas, resulting in a drop in body temperature and increasing the chance of hypothermia.

15-6.1 **Diver Heating.** Because of the high thermal conductivity of helium and depths attained, most conventional diving suits (i.e., wet suits/dry suits) provide inadequate insulation in a helium environment. As a result, thermal protection garments for helium-oxygen saturation diving must employ active heating. The most successful thermal protection currently used is the non-return valve (NRV) hot water suit using circulating hot water as the heat source. The typical NRV hot water suit is constructed from closed-cell, pre-crushed neoprene with an outer layer of tough canvas-type nylon. The interior is lined with a softer nylon with perforated hot water hoses along the limbs, chest, and backbone. Divers are required to wear Polartec Diveskins or Neoprene liners under their NRV suits. The liners or Diveskins offer almost no protection from cold water. The liners or Diveskins keep the divers from getting burned by hot water discharge from the NRV suit and minimize chafing of skin.

The effectiveness of the hot water suit in keeping the divers warm is dependent upon maintaining an adequate flow of water at the proper temperature. A 4-gallon per minute (gpm) (3 gpm to the suit and 1 gpm to the breathing gas heater) hot water flow rate with the suit inlet temperature adjusted to diver's comfort generally provides adequate protection. During normal operation, hot water is distributed through the NRV hot water suit and is then discharged to the sea through the NRV. If there is a diver heating system failure, the diver shuts the NRV and opens the bypass valve, trapping sufficient hot water in the suit to allow him to return to the PTC. To prevent burn injury to the diver, the water temperature at the suit inlet should not exceed 110°F. Hot water thermal protection systems should be designed to provide individual control of water temperature and rate of flow supplied to each diver. All divers normally use umbilicals of similar length.

15-6.2 **Inspired Gas Heating.** The thermal protection system includes a breathing-gas heater to warm the gas to a temperature sufficient to minimize respiratory heat loss. A typical breathing-gas heater is a hot water heat exchanger that can raise the breathing-gas temperature by 30–50°F. Breathing cold helium-oxygen at deep saturation diving depths can cause incapacitating nasal and trachea-bronchial secretions, breathing difficulties, chest pain, headache, and severe shivering. These symptoms may begin within minutes of starting the dive excursion.

Breathing apparently comfortable but low-temperature helium-oxygen at deep depths can rapidly lower body temperature through respiratory heat loss, even though the skin is kept warm by the hot water suit. The diver usually remains unaware of respiratory heat loss, has no symptoms, and will not begin to shiver until his core temperature has fallen. Metabolic heat production may not compensate for continuing respiratory heat loss. Table 15-1 contains guidelines for the minimum allowable temperatures for helium-oxygen breathing gas. These limits are based on a 4-hour excursion with a maximum core body temperature drop of 1.8°F (1.0°C) in a diver wearing a properly fitted and functioning NRV or hot water suit.

Table 15-1. *Guidelines for Minimum Inspired HeO_2 Temperatures for Saturation Depths Between 350 and 1,500 fsw.**

	Minimum Inspired Gas Temperature	
Depth (fsw)	**°C**	**°F**
350	-3.1	26.4
400	1.2	34.2
500	7.5	45.5
600	11.7	53.1
700	14.9	58.8
800	17.3	63.1
900	19.2	66.6
1000	20.7	69.3
1100	22.0	71.6
1200	23.0	73.4
1300	23.9	75.0
1400	24.7	76.5
1500	25.4	77.72

* Ref: C. A. Piantadosi, "Respiratory Heat Loss Limits in Helium Oxygen Saturation Diving," Navy Experimental Diving Unit Report NR 10-80 Revised 1982 (ADA 094132).

15-7 SATURATION DIVING UNDERWATER BREATHING APPARATUS

The rate of gas consumption and the composition of the gas supply depend in part upon the design of the UBA. Three types of underwater breathing apparatus have been used successfully to support saturation diving operations: demand open-circuit, semiclosed-circuit, and closed-circuit.

UBA systems should be designed to support saturation diving excursions of at least 4 hours duration in temperatures as low as 29°F. Specific information on

U.S. Navy certified diving equipment can be found in the applicable system-specific technical manuals.

15-8 UBA GAS USAGE

Gas usage can be the controlling factor in the planning for a mission and determining appropriate excursions. However, gas usage is UBA- and platform-specific.

15-8.1 Specific Dives.

Specific Dives. For a specific dive, storage of gas to support the mission may be the controlling parameter. The following formulas may be used to calculate gas usage by divers:

$$\text{ata} = \frac{D + 33}{33}$$

scfm (for one diver at depth) = ata × acfm

total scfm = scfm × number of divers

scf required = scfm × minutes

D = depth of diver

ata = atmosphere absolute

acfm = actual cubic feet per minute required by specific UBA being used (refer to the tech manual)

number of divers = total number of divers making excursion

minutes = duration of excursion

scf required = standard cubic feet of gas required to support the divers

Example. Two divers and one standby diver using the MK 21 MOD 0 and MK 22 MOD 0 UBAs at 300 fsw are deployed for a 15-minute excursion. Determine the gas usage.

1. Convert the depth to atmospheres:

$$\frac{300 \text{ fsw} + 33 \text{ fsw}}{33 \text{ fsw}} = 10.09 \text{ ata}$$

2. Calculate gas usage for 1 diver:

10.09 ata
x 1.4 acfm for MK21 MOD 0
14.13 scfm for 1 diver at 300 fsw

3. Calculate gas usage for 3 divers:

14.13 scfm for 1 diver at 300 fsw
x 3 divers (2) and standby (1)
42.39 scfm for 3 divers at 300 fsw

4. Calculate the total gas usage requirement:

42.39 scfm
x 15 minutes excursion time
635.85 scf (round up to 636 scf)

A gas usage requirement of 636 Standard Cubic Feet of helium-oxygen can be expected for this two-diver excursion.

NOTE Usage for three divers is computed even though the standby would not normally be using gas for the entire 15 minutes.

15-8.2 **Emergency Gas Supply Duration.** The gas computation in paragraph 15-8.1 is used to determine excursion limits based on diver's gas storage. The diver's emergency gas supply (EGS) duration should also be calculated using the following formulas:

mmp = (D × .445) + psi (obp)

psi available for use = psi (cylinder) - mmp

$$\text{scf gas available} = \frac{\text{psi (Available)} + 14.7}{14.7} \times \text{fv}$$

scfm = acfm × ata

$$\text{duration in minutes} = \frac{\text{scf}}{\text{scfm}}$$

D = depth of diver

psi (obp) = over-bottom pressure required for specific UBA

mmp = minimum manifold pressure

fv = floodable volume of cylinder

acfm = actual cubic feet per minute at excursion depth required by specific UBA being used

scfm = standard cubic feet per minute required to deliver acfm

Example. Using an 80-cubic-foot aluminum cylinder (floodable volume = .399 cu. ft.) filled to 3,000 psig, calculate the diver's EGS duration at 300 fsw.

1. Calculate the psi available for use:

$$\begin{array}{l} \ 185.0 \text{ overbottom psi, MK 21 MOD 0} \\ \underline{+\ 133.5 \text{ psi (300 fsw converted to psi)}} \\ \ 318.5 \text{ psi (round up to 319 psi)} \end{array}$$

2. Calculate the psig available for use:

3,000 - 319 psig = 2,681 psig available for use

3. Calculate the scf of gas available:

$$\frac{2681 + 14.7}{14.7} \times 0.399 = 73.2 \text{ scf of gas available}$$

4. Calculate the standard cubic feet per minute required:

1.4 acfm × 10.09 ata = 14.13 scfm

5. Calculate the duration of the gas supply:

$$\frac{73.2 \text{ scf}}{14.13 \text{ scfm}} = 5.18 \text{ minutes}$$

The duration of the emergency gas supply is very short, especially at greater depths.

15-8.3 Gas Composition. The percentage of oxygen in the mix depends on diver depth and can be calculated as follows:

1. % decimal equivalent = $\frac{ppO_2 \text{ desired}}{\text{ata}}$

2. % decimal equivalent × 100 = % of O_2 required to maintain desired ppO_2

Example. Calculate the minimum and maximum percentage of O_2 required to sustain a .44 to 1.25 ppO_2 range at 300 fsw.

1. Calculate the minimum percentage of O_2 required to sustain the lower value of the range:

$$\frac{0.44 \text{ ata}}{10.09 \text{ ata}} = 0.0436 \times 100 = 4.36\%$$

4.36% O_2 in He provides the minimum ppO_2.

2. Calculate the maximum percentage of O_2 required to sustain the lower value of the range:

$$\frac{1.25 \text{ ata}}{10.09 \text{ ata}} = 0.1239 \times 100 = 12.39\%$$

12.39% O_2 in He provides the maximum ppO_2.

SECTION THREE — SATURATION DIVING OPERATIONS

15-9 INTRODUCTION

Saturation diving is the mode of choice for diving operations requiring long bottom times or diving operations deeper than surface-supplied tables permit. Saturation diving allows divers to remain at working depths without concern for decompression. The Unlimited Duration Excursion Tables (Table 15-7 and Table 15-8) allow a large vertical range of working depths without time limits.

15-10 OPERATIONAL CONSIDERATIONS

Saturation diving requires complex saturation diving systems designed to precisely control depth, atmosphere composition, and temperature. Commanding Officers, Diving Officers, and Master Divers must consider personnel and training requirements, the physiological stress imposed by depth and dive duration, logistics, and gas supply requirements. Refer to Table 15-2 for the personnel requirements for saturation diving.

15-10.1 **Dive Team Selection.** All candidates for a saturation dive shall be physically qualified to make the dive as determined by a Saturation Diving Medical Officer. With the exceptions of authorized research, testing of equipment, or training purposes, all divers shall be qualified and experienced with the UBA being used and in the particular dive system to which they are assigned. Depending on mission requirements, divers may need to have special skills that are required for the operation.

15-10.2 **Mission Training.** When the schedule permits, training in preparation for a specific saturation diving mission shall be conducted. This training provides an opportunity to ensure that all personnel are in optimal physical condition and facilitates the development of special skills required for the operation. Training also provides an opportunity for individuals to function as a team and to identify an

Table 15-2. *Personnel Requirements for Saturation Diving.*

Deep Diving System DDS MK 2 MOD 1 Dive Team	
Watch Station	**NOBC/NEC (Note 1)**
Diving Officer	9315, 5346
Diving Medical Officer (Note 2)	0107
Master Diver	5346
Diving Supervisor	5311, 5346
Atmosphere Monitor	5346, 5311, 8493, 8494
MCC Gas-Control Operator	5311, 5342, 5346, 8493, 8493, 8494
Life-Support Operator	5311, 5342, 5346, 8493, 8494
MCC Communications and Log Operator	5311, 5342, 8493, 5343, 5346, 8494
Surface-Support Divers	5311, 5342, 8493, 5343, 5346, 8494
Gas King	5346, 5311, 8493, 5342, 8494
PTC Operators	9315, 5346, 5311, 8493, 8494
PTC Divers	9315, 5346, 5311, 8493, 8494
Main Deck Supervisors	5346, 5311, 5342

Notes:

1. The NECs listed are the minimum level qualifications allowed. The surface-support divers must be qualified in the diving method being used. NOBC 9135 and NEC 5346 can stand any watch for which qualified except Diving Medical Officer. NEC 5311 can qualify to stand Dive Watch Supervisor. Manning is shown for use of one DDC only. Additional handling crew for the PTC is required from ship's personnel, but the PTC handling crew is not shown on the chart.

2. A Diving Medical Officer is required on site for all saturation diving operations. ("On site" is defined as accessible within 30 minutes of the dive site by available transportation.)

individual with leadership skills necessary to fill the role of dive team leader. Alternate divers should be identified and trained with the team in the event of illness or injury to a primary diver.

15-11 SELECTION OF STORAGE DEPTH

The selection of the storage depth for the deck decompression chamber (DDC) is based on the approximate planned diver working depth. This can be achieved by comparing the storage depth and planned diver working depth with the descent and ascent limits of the Unlimited Duration Excursion Tables (Table 15-7 and Table 15-8). When the diver's working depth range is small, the DDC should be compressed to approximately the middle of the range. This minimizes the amount of gas used in pressurizing or depressurizing the personnel transfer capsule (PTC).

When the expected diver work range is large or multiple objectives at different depths are to be accomplished, several different storage depths will be required. The unlimited excursion procedures may be used at several progressively shallower storage depths to accomplish the objective.

15-12 RECORDS

This section covers the records required to be maintained during the conduct of a saturation dive.

15-12.1 Command Diving Log. An official diving log shall be maintained at all times throughout the dive. It shall contain a chronological record of the dive procedure in addition to any significant events. A narrative of significant events is to be recorded by the Diving Officer (or Diving Supervisor) and Saturation Diving Medical Officer (as necessary). This log shall be retained for 3 years.

15-12.2 Master Protocol. Each diving operation shall have a master protocol submitted by the Master Diver, reviewed by the Saturation Diving Medical Officer and Diving Officer, and approved by the Commanding Officer. This master protocol shall contain all the information needed to ensure that the dive follows a program consistent with the requirements for saturation diving as defined in this manual and shall include the necessary information to carry out these procedures on the specific operational platform.

A copy of the protocol shall be maintained as the master copy at the MCC. No alterations except those made by the Diving Officer and approved by the Commanding Officer are permitted. Any changes to this protocol shall be signed and dated.

15-12.2.1 **Modifications.** Because saturation dives generally follow a predictable pattern, only a few elements of protocol need to be modified from mission to mission. Consequently, once a complete and carefully written protocol is available, only minor modifications will be needed to support future missions.

15-12.2.2 **Elements.** The dive protocol shall include, but is not limited to, the following:

- A detailed gas-usage plan, including projected gas supply requirements (paragraph 15-15). The required mixtures for supplying emergency, treatment, and excursion gas shall be specified for the depth ranges expected with specific depths to shift mixes indicated.

- A compression schedule, including planned rate of travel with rest stops, if applicable.

- Manning requirements, including a watchbill.

- Predive and postdive procedures.

15-12.3 Chamber Atmosphere Data Sheet. Hourly readings of chamber pressure, temperature, humidity, oxygen, and carbon dioxide concentrations shall be recorded. In addition, time of operation of the carbon dioxide scrubbers and time of carbon dioxide absorbent replenishment shall be recorded.

15-12.4 **Service Lock.** The following information shall be recorded: date, depth, clock time upon leaving the surface or leaving the bottom, and items locked in or out of the chamber. This information is useful in controlling the spread of contaminants and in minimizing the combustibles in the chamber while in the fire zone.

15-12.5 **Machinery Log/Gas Status Report.** A record of the status of all gas banks, including their pressure and mixture, and of the status of all DDS gas delivery equipment, shall be maintained. This log shall be reviewed by each oncoming Diving Supervisor prior to assuming the watch and daily by the Diving Officer and Master Diver.

15-12.6 **Operational Procedures (OPs).** Currently approved operational procedure sheets are to be properly completed and signed by the operator and then reviewed and signed by the Diving Supervisor and Dive Watch Officer and logged in the Command Smooth Log.

15-12.7 **Emergency Procedures (EPs).** A set of approved emergency procedures with each individual watch station's responsibilities shall be separately bound and available at the main control console throughout a saturation dive. The convenience of having emergency procedures on station does not relieve any diver or any saturation diving watch team member from being sufficiently knowledgeable, thoroughly trained, and fully qualified to react efficiently and instantaneously to any emergency. Constant training in these emergency procedures is necessary to maintain watchstanding proficiency.

15-12.8 **Individual Dive Record.** Use the Dive Reporting System (DRS) to record and report dives, as outlined in paragraph 5-9.

15-13 LOGISTICS

In planning an extended diving operation, care must be taken to ensure that sufficient supplies and power to support a diving mission are available. When operating at remote sites, the Commanding Officer and Diving Officer must carefully evaluate the availability of shore-based support. Loss of steam and/or electrical power at sea is an emergency situation. The loss of either of these vital services to the saturation dive system with a dive team committed to lengthy decompression constitutes a major emergency that must be acted upon quickly. Accordingly, transit times and contingency plans must be made prior to commencing saturation diving operations at remote sites in case support services for the dive complex are threatened or lost.

15-14 DDC AND PTC ATMOSPHERE CONTROL

The hyperbaric atmosphere within the DDC and PTC is controlled to maintain the gaseous components as follows:

Oxygen Partial Pressure	.44 – .48 ata
Carbon Dioxide Partial Pressure	Less than 0.005 $ppCO_2$ (.5% SEV) (3.8 millimeters of mercury)
Helium and Nitrogen	Balance of total pressure

Oxygen levels and time limits are presented in Table 15-3.

Table 15-3. *Chamber Oxygen Exposure Time Limits.*

	Oxygen Level (ata)	Time
Storage	.44 – .48	Unlimited
Excursion	.40 – .60	4 hours (6 hours)***
Excursion associated with decompression	.42 – .48*	Unlimited
Emergency	.60**	24 hours

Notes:
* This level may be exceeded prior to starting the upward excursion for decompression.
** If oxygen levels exceed this limit, switch to emergency gas.
*** Diver performance exponentially decreases between 4 and 6 hours of an in-water excursion.

These levels, particularly that of oxygen, are essential for safe decompression and the use of the Unlimited Duration Excursion Tables. Increases in the oxygen partial pressure above 0.6 ata for extended periods (greater than 24 hours) risk pulmonary oxygen toxicity and should only be used in emergency situations. A ppO_2 below 0.42 ata may result in inadequate decompression, and a ppO_2 below 0.16 ata will result in hypoxia. Once carbon dioxide concentration reaches 0.5 percent surface equivalent (3.8 millimeters of mercury) for 1 hour, the scrubber canister should be changed, because carbon dioxide levels tend to rise rapidly thereafter. An inspired carbon dioxide level of 2 percent surface equivalent (15.2 millimeters of mercury) can be tolerated for periods of up to 4 hours at depth. Nitrogen concentration tends to decrease with time at depth, due to purging by helium during service lock operation.

NOTE **Discharging UBA gas into the PTC during diving operations may make it difficult to control the oxygen level.**

15-15 GAS SUPPLY REQUIREMENTS

The following gases shall be available for use in a UBA, for emergency supply, and for the treatment of decompression sickness.

15-15.1 UBA Gas. An adequate quantity of gas within an oxygen partial pressure range of 0.44–1.25 ata shall be available for use.

15-15.2 Emergency Gas. Emergency gas is used as a backup breathing supply in the event of DDC or PTC atmosphere contamination. An emergency gas with an oxygen partial pressure of 0.16 to 1.25 ata shall be immediately available to the built-in breathing system (BIBS). The volume of emergency breathing gas shall be sufficient to supply the divers for the time needed to correct the DDC atmosphere.

Upward excursions of the PTC or DDC or decompression shall not be started during emergency gas breathing unless the oxygen partial pressure of the diver's inspired gas is 0.42 ata or above.

Example. An emergency gas schedule for a dive beyond 850 fsw is:

Bank Mix	Allowable Depth Range (fsw)	Shift Depth (fsw)
#1 84/16 HeO_2	0–224	200
#2 96/4 HeO_2	99–998	99

15-15.3 Treatment Gases. . Treatment gases having an oxygen partial pressure range of 1.5 to 2.8 shall be available in the event of decompression sickness. The premixed gases shown in Table 15-4 may be used over the depth range of 0 – 1,600 fsw. A source of treatment gas shall be available as soon as treatment depth is reached. The source shall be able to supply a sufficient volume of breathing gas to treat each chamber occupant.

Table 15-4. *Treatment Gases.*

Depth (fsw)	Mix
0–60	100% O_2
60–100	40/60% HeO_2
100–200	64/36% HeO_2
200–350	79/21% HeO_2
350–600	87/13% HeO_2
600–1000	92/08% HeO_2
1000–1600	95/05% HeO_2

15-16 ENVIRONMENTAL CONTROL

Helium-oxygen gas mixtures conduct heat away from the diver very rapidly. As a result, temperatures higher than those required in an air environment are necessary to keep a diver comfortable. As depth increases, the temperature necessary to achieve comfort may increase to the 85–93°F range.

As a general guideline to achieve optimum comfort for all divers, the temperature should be kept low enough for the warmest diver to be comfortable. Cooler divers can add clothing as needed. All divers should be questioned frequently about their comfort.

The relative humidity should be maintained between 30 and 80 percent with 50 to 70 percent being the most desirable range for diver comfort, carbon dioxide scrubber performance, and fire protection.

15-17 FIRE ZONE CONSIDERATIONS

Every effort shall be made to eliminate any fire hazard within a chamber. When oxygen percentages are elevated as during the later stages of decompression, a fire will burn rapidly once started, perhaps uncontrollably. As a result, special precautions are necessary to protect the diver's safety when in the fire zone. The fire zone is where the oxygen concentration in the chamber is 6 percent or greater. Using standard saturation diving procedures (oxygen partial pressure between 0.44 and 0.48 ata), fire is possible at depths less than 231 fsw. Thus, during a saturation dive the divers will be in the fire zone during initial compression to depth and during the final stages of decompression.

Example. The chamber atmosphere is 0.48 ata ppO_2. The minimum oxygen percentage for combustion is 6 percent. Compute the fire zone depth.

The fire zone depth is computed as follows:

$$\begin{aligned}\text{Fire zone depth (fsw)} &= \frac{ppO_2 \times 33}{O_2\%/100} - 33 \\ &= \frac{0.48 \times 33}{0.06} - 33 \\ &= 231 \text{ fsw}\end{aligned}$$

Although the design of the DDS minimizes fire potential, personnel must remain vigilant at all times to prevent fires. Appropriate precautions for fire prevention include:

- Fire-suppression systems, if available, must be operational at all times when in the fire zone.
- Chamber clothing, bed linen, and towels shall be made of 100% cotton. Diver swim trunks made of a 65% polyester–35% cotton material is acceptable.
- Mattresses and pillows shall be made of fire-retardant material when in the fire zone.
- Limit combustible personal effects to essential items.
- Limit reading material, notebooks, etc., in the fire zone.

- All potential combustibles shall be locked in only with the permission of the Diving Supervisor.
- Whenever possible, stow all combustibles, including trash, in fire-retardant containers, and lock out trash as soon as possible.
- Being thoroughly familiar with all emergency procedures (EPs) regarding fire inside and outside the Deep Diving System.

15-18 HYGIENE

Once a saturation dive begins, any illness that develops is likely to affect the entire team, reducing their efficiency and perhaps requiring the dive to be aborted. To minimize this possibility, the Saturation Diving Medical Officer should conduct a brief review of the diver’s physical condition within 24 hours of compression. If an infectious process or illness is suspected, it shall be carefully evaluated by the Saturation Diving Medical Officer for possible replacement of the diver with a previously designated alternate diver. Strict attention to personal hygiene, chamber cleanliness, and food-handling procedures should be maintained once the dive begins to minimize the development and spread of infection.

15-18.1 **Personal Hygiene.** Personal hygiene and cleanliness is the most important factor in preventing infections, especially skin and ear infections. All divers should wash at least daily, and as soon as possible after wet excursions. Fresh linens and clothing should be locked into the complex every day. To prevent foot injury, clean, dry footwear should be worn at all times except while showering, sleeping, or in diving dress. Feet must be thoroughly dry, especially between the toes, to minimize local infections. A personal toiletry bag shall be maintained by each chamber occupant. These bags shall be inspected by the Diving Supervisor or Master Diver prior to commencing the dive to prevent potential contaminants or fire hazards from being carried into the chamber.

15-18.2 **Prevention of External Ear Infections.** Severe ear infections can develop unless preventative measures are taken. An effective preventative regime includes irrigating each ear with 2 percent acetic acid in aluminum acetate solution (i.e., DOMEBORO) for 5 minutes at least twice daily. Irrigation shall be observed by the Diving Supervisor, timed by the clock, and logged.

After a week or so, even with the ear prophylaxis regimen, the ear canals may become occluded with debris. Once this happens, an ear infection may develop rapidly. In order to prevent this occurrence, all divers should be trained to detect and treat blockage. Before beginning a dive, all divers should be trained by qualified medical personnel to use an otoscope to view the ear drum. Also, they should be trained to use an ear syringe. At least weekly during a dive, divers should examine each other’s ear canals. If the ear drum cannot be viewed because of a blockage, then the canal should be gently irrigated with the ear syringe until the canal is unplugged.

15-18.3 **Chamber Cleanliness.** Strict attention shall be paid to chamber cleanliness at all times, particularly in the area of the toilet, wash basin, shower, and service locks. Only approved compounds shall be used to clean the chamber, components, and clothing used in the pressurized environment. During wet excursions, close attention shall be paid to routine postdive cleaning of the diver-worn equipment to prevent rashes and skin infections.

Upon completing a saturation dive, the chamber should be well ventilated, emptied, and liberally washed down with non-ionic detergent (MIL-D-16791) and water and then closed. Additionally, all chamber bedding, linens, and clothing shall be washed.

15-18.4 **Food Preparation and Handling.** All food provided to the divers during a saturation diving evolution shall meet the standards prescribed in NAVMED P-5010. All food locked in shall be inspected by the Dive Watch Supervisor or Dive Watch Officer. The Saturation Diving Medical Officer should inspect food preparation areas daily.

15-19 ATMOSPHERE QUALITY CONTROL

Preventing chamber atmosphere contamination by toxic gases is extremely important to the health of the divers. Once introduced into the chambers, gaseous contaminants are difficult to remove and may result in prolonged diver exposure.

15-19.1 **Gaseous Contaminants.** Gaseous contaminants can be introduced into the chamber through a contaminated gas supply, through chamber piping and/or gas flasks containing residual lubricants or solvents, or by the divers or maintenance personnel.

The hazard of atmospheric contamination can be reduced by ensuring that only gases that meet the appropriate federal specifications are used and that appropriate gas transfer procedures are used. All gas flasks and chamber piping used with helium, oxygen, or mixed gases shall be cleaned using approved cleaning procedures to remove substances that may become chamber contaminants. Once cleaned, care shall be taken to prevent introduction of contaminants back into these systems during maintenance by marking and bagging openings into the piping system. Finally, inadvertent chamber contamination can be prevented by limiting the items that may be taken inside. Only approved paints, lubricants, solvents, glues, equipment, and other materials known not to off-gas potential toxic contaminants are allowed in the chamber. Strict control of all substances entering the chamber is an essential element in preventing chamber contamination.

15-19.2 **Initial Unmanned Screening Procedures.** To ensure that chamber systems are free of gaseous contaminants, the chamber atmosphere shall be screened for the presence of the common contaminants found in hyperbaric systems when contamination of the chamber and/or gas supply is suspected, or after any major chamber repair or overhaul has been completed. Only NAVFAC- or NAVSEA-approved procedures may be used to collect screening samples.

Table 15-5 lists a few selected contaminants that may be present in hyperbaric complexes, with their 90-day continuous exposure limits (or 7-day limits where a 90-day limit is not available). In the absence of specific guidelines for hyperbaric exposures, these limits shall be used as safe limits for saturation diving systems.

Table 15-5. *Limits for Selected Gaseous Contaminants in Saturation Diving Systems.*

Contaminant	Limit
Acetone	200 ppm (Note 1) (Note 3: Same limit)
Benzene	1 ppm (Note 3)
Chloroform	1 ppm (Note 1)
Ethanol	100 ppm (Note 3)
Freon 113	100 ppm (Note 1)
Freon 11	100 ppm (Note 1)
Freon 12	100 ppm (Note 1) (Note 3: Same limit)
Freon 114	100 ppm (Note 1)
Isopropyl Alcohol	1 ppm (Note 1)
Methanol	10 ppm (Note 3)
Methyl Chloroform	30 ppm (Note 2) (Note 3: 90-day limit = 2.5 ppm, 24-hour limit = 10 ppm)
Methyl Ethyl Ketone	20 ppm (Note 2)
Methyl Isobutyl Ketone	20 ppm (Note 2)
Methylene Chloride	25 ppm (Note 2)
Toulene	20 ppm (Note 1) (Note 3: Same limit)
Trimethyl Benzenes	3 ppm (Note 2)
Xylenes	50 ppm (Note 1) (Note 3: Same limit)

Notes:

1. 90-day continuous exposure limit. *National Research Council Committee on Toxicology Emergency and Continuous Exposure Limits for Selected Airborne Contaminants*, Vols. 1-8, Washington, D.C., National Academy Press, 1984–1988.

2. 7-day maximum allowable concentration in manned spacecraft. National Aeronautics and Space Administration, Office of Space Transportation Systems. *Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion*, NHB 8060, 1B, Washington, D.C., U.S. Government Printing Office, 1981.

3. 90-day limit. *U.S. Naval Sea Systems Command Nuclear Powered Submarine Atmosphere Control Manual*, NAVSEA S9510-AB-ATM-010 (U), Vol. 1, Revision 2, 30 July 1992.

When any one of these contaminants is reported in chamber samples, the calculated Surface Equivalent Value (SEV) shall be compared to the limit on this list. If the calculated SEV exceeds this limit, the chamber shall be cleaned and retested. Assistance with any contamination identification and resolution can be obtained by contacting NEDU or the system certification authority for guidance.

15-20 COMPRESSION PHASE

The initial phase of the dive is the compression of the dive team to the selected storage depth. This phase includes establishing the chamber oxygen partial pressure at a value between 0.44 and 0.48 ata, instrument and systems checkouts, and the actual compression of the divers to storage depth.

15-20.1 **Establishing Chamber Oxygen Partial Pressure.** Prior to compression to storage depth, the chamber oxygen partial pressure shall be raised from 0.21 ata to 0.44–0.48 ata. There are two methods of raising the oxygen partial pressure to the desired level.

- **Air Method**. Compress the chamber with air at a moderate rate to 36 fsw. This will raise the chamber ppO_2 to 0.44 ata. If desired, further elevation of the chamber ppO_2 to 0.48 ata can be undertaken by using the oxygen makeup system.
- **Helium-Oxygen Method**. Compress the chamber at a moderate rate with a helium-oxygen mixture containing less than 21 percent oxygen. The depth of the required compression can be calculated using the following formula:

$$\text{Compression Depth (fsw)} = 33 \times \frac{(ppO_2 - 0.21)}{O_2\%} \times 100$$

Example. If a 20 percent mixture of helium-oxygen is used and the desired ppO_2 is 0.44 ata, calculate the compression depth.

$$\text{Compression depth} = 33 \times \frac{(0.44 - 0.21)}{20} \times 100$$

$$= 37.95 \text{ fsw}$$

15-20.2 **Compression to Storage Depth.** Rapid compression to saturation storage depth may provoke symptoms of High-Pressure Nervous Syndrome (HPNS) and may intensify compression joint pains. To avoid these complications, the slowest rate of compression consistent with operational requirements should be used. Table 15-6 shows the range of allowable compression rates.

Table 15-6. *Saturation Diving Compression Rates.*

Depth Range	Compression Rate
0–60 fsw	0.5 – 30 fsw/min
60–250 fsw	0.5 – 10 fsw/min
250–750 fsw	0.5 – 3 fsw/min
750–1000 fsw	0.5 – 2 fsw/min

If operational necessity dictates, compression to storage depth of 400 fsw or shallower can be made at the maximum rates indicated in Table 15-6 with little risk of HPNS. Direct compression at maximum rates to deeper storage depths, however, may produce symptoms of HPNS in some divers. These divers may be unable to perform effectively for a period of 24 to 48 hours. Experience has shown that the appearance of such symptoms can be minimized by slowing compression rates or introducing holds during compression.

The depth and time duration of holds, if used, may be adjusted to suit operational requirements and diver comfort.

15-20.3 Precautions During Compression. During compression the chamber atmosphere shall be monitored carefully. The chamber atmosphere may not mix well during rapid compression, resulting in areas of low oxygen concentration.

15-20.4 Abort Procedures During Compression. The following abort procedure is authorized if a casualty occurs during compression. Consult with a Saturation Diving Medical Officer prior to committing to this procedure. This procedure is normally used for shallow aborts where the maximum depth and bottom time do not exceed the limits of the table.

Using the Surface Supplied HeO_2 Tables, the following procedure applies:

- **Depth**. Use the actual chamber depth.
- **Bottom Time**. If the initial compression uses air, time spent shallower than 40 fsw, up to a maximum of 60 minutes, is not counted as bottom time. If the initial compression uses helium, time starts when leaving the surface.
- **BIBS Gas**. Maintain BIBS between 1.5 – 2.8 ppO_2.
- **Stops**. Follow the scheduled stops of the Surface Supplied HeO_2 Tables.
- **O_2 Breaks**. For every 25 minutes of breathing BIBS gas, take a 5-minute break breathing a gas between 0.16 to 1.25 ata ppO_2. The 5-minute break counts as a stop time. The lower oxygen percentage shall not be less than 0.16 ata ppO_2.

Upon completing abort decompression, all divers shall be closely monitored and observed for a minimum of 24 hours. For deeper emergency aborts beyond the limits of the Surface-supplied HeO_2 Tables, refer to paragraph 15-23.7.2.

15-21 STORAGE DEPTH

The Unlimited Duration Excursion Tables (Table 15-7 and Table 15-8) allow multiple diver excursions to be conducted during the course of a saturation dive. When using these excursion procedures, the diving supervisor need only be concerned with the depth of the divers. To use these tables when planning the dive, select a chamber storage depth in a range that allows diver excursions shal-

Table 15-7. Unlimited Duration Downward Excursion Limits.

Storage Depth (fsw)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (fsw)
0	29	29
10	33	43
20	37	57
30	40	70
40	43	83
50	46	96
60	48	108
70	51	121
80	53	133
90	56	146
100	58	158
110	60	170
120	62	182
130	64	194
140	66	206
150	68	218
160	70	230
170	72	242
180	73	253
190	75	265
200	77	277
210	78	288
220	80	300
230	82	312
240	83	323
250	85	335
260	86	346
270	88	358
280	89	369
290	90	380
300	92	392
310	93	403
320	95	415
330	96	426
340	97	437
350	98	448
360	100	460
370	101	471
380	102	482
390	103	493
400	105	505

Storage Depth (fsw)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (fsw)
410	106	516
420	107	527
430	108	538
440	109	549
450	111	561
460	112	572
470	113	583
480	114	594
490	115	605
500	116	616
510	117	627
520	118	638
530	119	649
540	120	660
550	122	672
560	123	683
570	124	694
580	125	705
590	126	716
600	127	727
610	128	738
620	129	749
630	130	760
640	131	771
650	132	782
660	133	793
670	133	803
680	134	814
690	135	825
700	136	836
710	137	847
720	138	858
730	139	869
740	140	880
750	141	891
760	142	902
770	143	913
780	144	924
790	144	934
800	145	945
810	146	956
820	147	967
830	148	978
840	149	989
850	150	1000

Table 15-8. *Unlimited Duration Upward Excursion Limits.*

Storage Depth (fsw)	Shallowest Excursion Distance (ft)	Shallowest Excursion Depth (fsw)
29	29	0
30	29	1
40	32	8
50	35	15
60	37	23
70	40	30
80	42	38
90	44	46
100	47	53
110	49	61
120	51	69
130	53	77
140	55	85
150	56	94
160	58	102
170	60	110
180	62	118
190	63	127
200	65	135
210	67	143
220	68	152
230	70	160
240	71	169
250	73	177
260	74	186
270	76	194
280	77	203
290	79	211
300	80	220
310	81	229
320	83	237
330	84	246
340	85	255
350	87	263
360	88	272
370	89	281
380	90	290
390	92	298
400	93	307
410	94	316
420	95	325
430	96	334
440	97	343
450	99	351
460	100	360
470	101	369
480	102	378
490	103	387
500	104	396

Storage Depth (fsw)	Shallowest Excursion Distance (ft)	Shallowest Excursion Depth (fsw)
510	105	405
520	106	414
530	107	423
540	108	432
550	110	440
560	111	449
570	112	458
580	113	467
590	114	476
600	115	485
610	116	494
620	117	503
630	118	512
640	119	521
650	119	531
660	120	540
670	121	549
680	122	558
690	123	567
700	124	576
710	125	585
720	126	594
730	127	603
740	128	612
750	129	621
760	130	630
770	131	639
780	131	649
790	132	658
800	133	667
810	134	676
820	135	685
830	136	694
840	137	703
850	137	713
860	138	722
870	139	731
880	140	740
890	141	749
900	142	758
910	142	768
920	143	777
730	144	786
940	145	795
950	146	804
960	146	814
970	147	823
980	148	832
990	149	841
1000	150	850

lower or deeper than the storage depth. The actual depth of the work site or PTC may be significantly different from the storage depth.

When using Table 15-8, enter the table at the deepest depth attained at any time within the last 48 hours. While the DDC may be at 400 fsw, if one diver had reached a depth of 460 fsw during an in-water excursion, the maximum upward excursion depth for the divers is 360 fsw instead of 307 fsw. After completing work at one depth and then compressing DDC to a deeper storage depth, unlimited downward or upward excursions are permitted immediately upon reaching the new storage depth. When decompressing the DDC from a deeper depth using standard saturation decompression procedures, unlimited downward excursions, as defined in Table 15-7, may begin immediately upon reaching the new chamber storage depth. A minimum of 48 hours shall elapse at the new storage depth before any upward excursions may be made.

Example. After decompression from 1,000 fsw to 400 fsw, the maximum downward excursion is 105 fsw. After 48 hours have elapsed at 400 fsw, a full upward excursion of 93 fsw to 307 fsw is permitted.

If less than 48 hours is spent at the new storage depth, the maximum upward excursion is based on the deepest depth attained in the preceding 48 hours.

Example. Decompression from a 1,000 fsw dive has been conducted to the 400 fsw depth. Twenty-four hours have been spent at 400 fsw. The dive log shows that the deepest depth attained in the preceding 48 hours is 496 fsw. The maximum upward excursion from Table 15-8, based on a 496 fsw depth, is to 396 fsw (500 – 104) allowing a maximum of a 4 fsw upward excursion. After 36 hours have elapsed at 400 fsw, the dive log shows that the deepest depth attained in the preceding 48 hours was 448 fsw. From Table 15-8, the shallowest excursion depth is now 351 fsw.

The ascent rate should not exceed 60 fsw/min during an excursion. When it is detected that a diver is ascending faster than 60 fsw/min, the diver shall immediately stop and wait until enough time has elapsed to return to the 60 fsw/min schedule. The diver may then resume ascent at a rate not to exceed 60 fsw/min from that depth.

If storage depth falls between the depths listed in Table 15-7, use the next shallower depth (e.g., if the storage depth is 295 fsw, enter Table 15-7 at 290 fsw). If storage depth falls between the depths listed in Table 15-8, use the next deeper depth (e.g., if the storage depth is 295 fsw, enter Table 15-8 at 300 fsw).

15-21.1 Excursion Table Examples.

Example 1. The chamber was compressed to 400 fsw from the surface. The initial depth in Table 15-7 is 400 fsw. The maximum downward excursion for an unlimited period not requiring decompression is 105 fsw, allowing a maximum diver depth of 505 fsw. If the diver descends to 450 fsw, the maximum depth achieved from the 400 fsw storage depth will be 450 fsw. Table 15-8 at 450 fsw allows a 99 fsw upward excursion to a depth of 351 fsw. Thus, these divers may move freely between the depths of 351 and 450 fsw while at a storage depth of 400 fsw.

Example 2. At a storage depth of 600 fsw, during which dives were made to 650 fsw, the maximum upward excursion that may by made to begin saturation decompression is:

- If less than 48 hours have elapsed since the 650 fsw excursion, Table 15-8 allows a maximum upward excursion of 119 fsw from a deepest depth of 650 fsw to a depth of 531 fsw.

- If more than 48 hours have elapsed since the excursion, the maximum upward excursion allowed is 115 fsw from 600 fsw to 485 fsw.

Example 3. At the new shallower storage depth of 350 fsw, divers conduct an excursion to 400 fsw. Using the deepest depth of 400 fsw achieved during storage at 350 fsw, a maximum upward ascent from Table 15-8 of 93 fsw to a depth of 307 fsw is allowed, provided the chamber and the divers have been at the storage depth of 350 fsw for at least 48 hours. Otherwise, no upward excursion is permitted.

15-21.2 PTC Diving Procedures. Actual PTC diving operations are dictated by the Unit's operating instructions. In conducting these operations, experience indicates that a maximum in-water time of 4 hours is optimal for diver efficiency. Longer dive times result in a loss of diver effectiveness because of fatigue and exposure, while shorter dives will significantly increase the time at depth for the completion of operations. Standard practice is to rotate in-water divers with the PTC operators, allowing two 4-hour dives to be conducted during a single PTC excursion to the work site. Proper positioning of the PTC near the objective is important in ensuring that the diver does not exceed the maximum permitted excursion limits (Figure 15-8).

15-21.2.1 **PTC Deployment Procedures.** A brief overview of PTC deployment procedures follows:

1. For initial pressurization, the PTC, with internal hatch open, is usually mated to the DDC. Divers enter the DDC and secure the hatches.

2. The DDC and PTC are pressurized to bottom depth. The divers transfer to the PTC and secure the DDC and PTC hatches after them.

3. The trunk space is vented to the atmosphere and then the PTC is deployed and lowered to working depth. The hatch is opened when seawater and internal PTC pressures are equal. The divers don diving equipment and deploy from the PTC.

4. Divers return to the PTC and secure the hatch. The PTC is raised and mated to the DDC, and the divers transfer to the DDC. Until they are decompressed in the DDC, the divers rotate between periods of living in the DDC and working

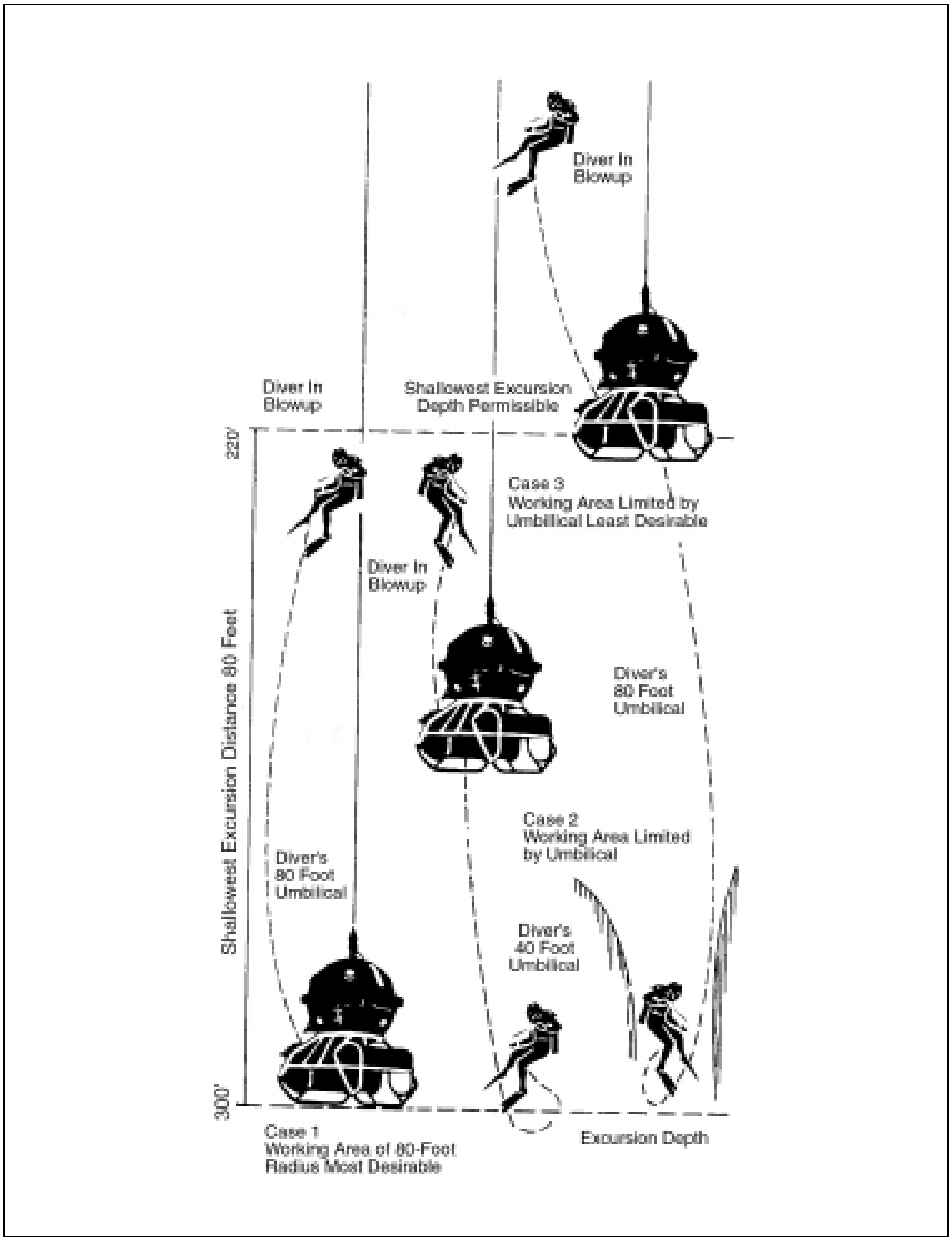

Figure 15-8. PTC Placement Relative to Excursion Limits.

on the bottom. Deep underwater projects requiring moderate bottom 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 storage depth within the ascent and descent limits of the Unlimited Duration Excursion Tables (Table 15-7 and Table 15-8), maximizing diving efficiency for deep, long dives. Once tissue saturation is reached, decompression requirements no longer increase.

15-22 DEEP DIVING SYSTEM (DDS) EMERGENCY PROCEDURES

Major DDS emergencies include loss of atmosphere control, loss of depth control and fire in the DDC. Emergencies will be covered by locally prepared and NAVSEA- or NAVFAC-approved emergency procedures. The following are guidelines for establishing these procedures.

15-22.1 Loss of Chamber Atmosphere Control.

15-22.1 Loss of Chamber Atmosphere Control. Loss of chamber atmosphere control includes loss of oxygen control, high carbon dioxide level, chamber atmosphere contamination and loss of temperature control.

15-22.1.1 **Loss of Oxygen Control.** Divers can be safely exposed to chamber oxygen partial pressures between 0.16 and 1.25 ata; however, efforts should be implemented immediately to correct the problem and reestablish normal oxygen levels. For an oxygen partial pressure from 0.16 to 0.48 ata, the normal oxygen addition system can be used to increase the oxygen level slowly over time. For an oxygen partial pressure above 0.48, it may be necessary to secure the oxygen addition system and allow the divers to breathe down the chamber oxygen to a normal level. Table 15-3 lists the chamber oxygen exposure time limits. If these limits are exceeded, the divers should be placed on BIBS and the chamber ventilated to reduce the oxygen level.

15-22.1.2 **Loss of Carbon Dioxide Control.** When the DDC's life-support system loses its ability to absorb carbon dioxide, the level of carbon dioxide within the chamber will rise at a rate depending on the chamber size and the combined carbon dioxide production rate of the divers. An increasing carbon dioxide level may be the result of exhaustion of the carbon dioxide absorbent or inadequate gas flow through the carbon dioxide absorbent canister. If, after the carbon dioxide absorbent canister is changed, chamber carbon dioxide level still cannot be brought under 0.005 ata (3.8 mmhg), the flow through the canister may be inadequate. Divers shall don BIBS when the chamber carbon dioxide level exceeds 0.06 ata (45.6 mmhg).

15-22.1.3 **Atmosphere Contamination.** If an abnormal odor is detected or if several divers report symptoms of eye or lung irritation, coughing, headache, or impaired performance, contamination of the chamber atmosphere should be suspected. The divers shall be placed on BIBS and emergency procedures executed. The divers should be isolated in the part of the complex thought to be least contaminated. Test the chamber atmosphere using chemical detector tubes or by collecting a gas sample for analysis on the surface, as described in paragraph 15-19.2. If atmosphere contamination is found, the divers should be moved to the chamber or PTC with the least level of contamination and this chamber isolated from the rest of the complex.

15-22.1.4 **Interpretation of the Analysis.** The allowable contaminant limits within a diving system are based upon the Threshold Limit Values (TLV) for Chemical Substances and Physical Agents guidelines published by the American Conference of Governmental Industrial Hygienists (ACGIH). TLVs are the time-weighted average concentration for an 8-hour work day and a 40-hour work week, to which nearly all workers can be repeatedly exposed day after day without adverse effect. These guidelines are published yearly and should be used to determine acceptability. Because the partial pressure of a gas generally causes its physiological effects, the published limits must be corrected for the expected maximum operating depth (ata) of the diving system.

The solution to an atmosphere contamination problem centers around identifying the source of contamination and correcting it. Gas samples from suspected sources must be checked for contaminants. Special attention should be given to recently changed and cleaned piping sections, gas hoses, and diver umbilicals, any of which may contain residual cleaning solvents. Surfaced chambers should be thoroughly ventilated with air or a breathable helium-oxygen mixture (to prevent hypoxia in maintenance personnel), inspected, and thoroughly scrubbed down to remove residual contaminants. These chambers can then be compressed to depth using a gas bank that is free of contaminants, the divers can be transferred to this chamber, and the surface cleaning process can be repeated on the remaining chamber(s). After cleaning and compression to depth, the chamber should be checked periodically for recurrence of the contamination.

15-22.1.5 **Loss of Temperature Control.** Loss of temperature control of more than 2–3°F above or below the comfort level may lead to severe thermal stress in the divers. Studies have shown that heat loss by perspiring is less effective in a hyperbaric atmosphere. Heating a chamber to warm up cold divers may result in the divers rapidly becoming overheated. Heat stroke may then become a possibility. The potential for uncontrolled chamber heating occurs when chambers and PTCs are exposed to direct sunlight.

When the chamber temperature falls, the divers begin intense shivering and hypothermia develops unless rapid and aggressive measures are taken to correct the problem. Divers may be provided with insulated clothing, blankets, and sleeping bags. The best of these insulators are of limited effectiveness within the helium-oxygen environment and will provide marginal protection until the problem can be corrected. Special thermal protection systems have been designed for the use within DDCs. These systems include thermal protection garments, insulating deck pads or hammocks, and combination carbon dioxide absorbent and respiratory-heat regenerator systems.

15-22.2 **Loss of Depth Control.** Loss of depth control is defined as a pressure loss or gain that cannot be controlled within the normal capabilities of the system. When loss of depth control is encountered, all deployed divers shall be recovered immediately and all divers placed on BIBS. Attempt to control depth by exhausting excess gas or adding helium to minimize depth loss until the cause can be found and corrected. If the depth change is in excess of that allowed by the Unlimited Duration Excursion Tables, the divers should be returned to the original storage depth immediately and the Diving Medical Officer notified.

15-22.3 **Fire in the DDC.** Because fire within a DDC may progress rapidly, the divers and watchstanders must immediately activate the fire suppression system and secure the oxygen system as soon as a fire is suspected. When the fire suppression system is activated, all divers shall immediately go on BIBS. Watchstanders should monitor depth carefully because an extensive fire will cause an increase in depth. If the fire suppression system fails to extinguish the fire, rapid compression of the chamber with helium may extinguish the fire, in that helium lowers the oxygen concentration and promotes heat transfer. After the fire is extinguished, chamber atmosphere contaminant emergency procedures shall be followed.

15-22.4 **PTC Emergencies.** PTC emergencies, like DDC emergencies, require specific, timely, and uniform responses in order to prevent injury or casualty to divers, watchstanders, and equipment.

15-23 SATURATION DECOMPRESSION

Saturation decompression may be initiated by an upward excursion as long as the excursion remains within the limits permitted by the Unlimited Duration Excursion Tables. The alternative is to begin travel at the appropriate decompression rate without the upward excursion. Decompression travel rates are found on Table 15-9.

Table 15-9. *Saturation Decompression Rates.*

Depth	Rate
1,600 – 200 fsw	6 feet per hour
200 – 100 fsw	5 feet per hour
100 – 50 fsw	4 feet per hour
50 – 0 fsw	3 feet per hour

15-23.1 **Upward Excursion Depth.** The minimum depth to which the upward excursion may be made is found by entering Table 15-8 with the deepest depth attained by any diver in the preceding 48 hours. The total upward excursion actually chosen is determined by the Diving Officer and Master Diver, and approved by the Commanding Officer, taking into consideration environmental factors, the diver’s workload, and the diver’s physical condition.

15-23.2 **Travel Rate.** The travel rate for the upward excursion is 2 fsw/min. Beginning decompression with an upward excursion will save considerable time and may be used whenever practical.

15-23.3 **Post-Excursion Hold.** Due to the increased risk of decompression sickness following an upward excursion for dives with a storage depth of 200 fsw or less, a 2-hour post-excursion hold should be utilized. The 2-hour hold begins upon arrival at upward excursion depth.

15-23.4 **Rest Stops.** During decompression, traveling stops for a total of 8 hours out of every 24 hours. The 8 hours should be divided into at least two periods known as

“Rest Stops.” At what hours these rest stops occur are determined by the daily routine and operations schedule. The 2-hour post-excursion hold may be considered as one of the rest stops.

15-23.5 Saturation Decompression Rates. Table 15-9 shows saturation decompression rates. In practice, saturation decompression is executed by decompressing the DDC in 1-foot or 2-foot increments when indicated in the dive protocol. For example, using a travel rate of 6 feet per hour will decompress the chamber 1 foot every 10 minutes. The last decompression stop before surfacing may be taken at 4 fsw to ensure early surfacing does not occur and that gas flow to atmosphere monitoring instruments remains adequate. This last stop would be 80 minutes, followed by direct ascent to the surface at 1 fsw/min.

Traveling is conducted for 16 hours in each 24-hour period. A 16-hour daily travel/rest outline example consistent with a normal day/night cycle is:

Daily Routine Schedule

2400–0600	Rest Stop
0600–1400	Travel
1400–1600	Rest Stop
1600–2400	Travel

This schedule minimizes travel when the divers are normally sleeping. Such a daily routine is not, however, mandatory. Other 16-hour periods of travel per 24-hour routines are acceptable, although they shall include at least two stop periods dispersed throughout the 24-hour period and travel may continue while the divers sleep. An example of an alternate schedule is:

Alternate Sample Schedule

2300–0500	Travel
0500–0700	Rest Stop
0700–0900	Travel
0900–1500	Rest Stop
1500–2300	Travel

The timing of the stop is dependent upon operational requirements. The travel rate between stops should not exceed 1 fsw per minute.

15-23.6 Atmosphere Control at Shallow Depths. As previously stated, the partial pressure of oxygen in the chamber shall be maintained between 0.44 and 0.48 ata, with two exceptions. The first is just before making the initial Upward Excursion and the second during the terminal portion of saturation decompression. Approximately 1 hour before beginning an Upward Excursion, the chamber ppO_2 may be increased up to a maximum of 0.6 ata to ensure that the ppO_2 after excursion does not fall excessively. The ppO_2 should be raised just enough so the post-excursion ppO_2 does not exceed 0.48 ata. However, when excursions begin from depths of

200 fsw or shallower, a pre-excursion ppO_2 of 0.6 ata will result in a post-excursion ppO_2 of less than 0.44 ata. In these cases, the pre-excursion ppO_2 should not exceed 0.6 ata, but the post-excursion ppO_2 should be increased as rapidly as possible.

The second exception is at shallow chamber depth. As chamber depth decreases, the fractional concentration of oxygen necessary to maintain a given partial pressure increases. If the chamber ppO_2 were maintained at 0.44–0.48 ata all the way to the surface, the chamber oxygen percentage would rise to 44–48 percent. Accordingly, for the terminal portion of saturation decompression, the allowable oxygen percentage is between 19 and 23 percent. The maximum oxygen percentage for the terminal portion of the decompression shall not exceed 23 percent, based upon fire-risk considerations.

15-23.7 Saturation Dive Mission Abort. If it is necessary to terminate a saturation dive after exceeding the abort limits (see paragraph 15-20.4), standard saturation decompression procedures shall be followed.

15-23.7.1 **Emergency Cases.** In exceptional cases it could be necessary to execute a mission abort and not be able to adhere to standard saturation decompression procedures. The emergency abort procedures should only be conducted for grave, unforeseen casualties that require deviation from the standard decompression procedures such as:

- An unrepairable failure of key primary and related backup equipment in the dive system that would prevent following standard decompression procedures.
- Unrepairable damage to the diving support vessel or diving support facility.
- A life-threatening medical emergency where the risk of not getting the patient to a more specialized medical care facility outweighs the increased risk of pulmonary oxygen toxicity and increased risk of decompression sickness imposed upon the patient by not following standard saturation decompression procedures.

An Emergency Abort Procedure was developed and has received limited testing. It enables the divers to surface earlier than would be allowed normally. However, the time saved may be insignificant to the total decompression time still required, especially if the divers have been under pressure for 12 hours or more. In addition, executing the Emergency Abort Procedure increases the diver’s risk for decompression sickness and complications from pulmonary oxygen toxicity.

Before executing a mission abort procedure that does not follow standard decompression procedures or the abort procedures contained in paragraph 15-20.4, the Commanding Officer must carefully weigh the risk of the action, relying on the advice and recommendations of the Master Diver, Diving Officer, and Saturation Diving Medical Officer. Specifically, it must be determined if the time saved will benefit the diver’s life despite the increased risks, and whether the Emergency Abort Procedure can be supported logistically.

NOTE **USN dive system design incorporates separate primary, secondary, and treatment gas supplies and redundancy of key equipment. It is neither the intent of this section nor a requirement that saturation dive systems be configured with additional gas stores specifically dedicated to execution of an emergency abort procedure. Augmentation gas supplies if required will be gained by returning to port or receiving additional supplies on site.**

Except in situations where the nature or time sensitivity of the emergency does not allow, technical and medical assistance should be sought from the Navy Experimental Diving Unit prior to deviating from standard saturation decompression procedures.

15-23.7.2 **Emergency Abort Procedure.** Emergency Abort Procedures should only be conducted for grave casualties that are time critical. Decompression times and chamber oxygen partial pressures for emergency aborts from helium-oxygen saturation are shown in Table 15-10.

Table 15-10. *Emergency Abort Decompression Times and Oxygen Partial Pressures.*

Post Excursion Depth (fsw)	ppO_2 (ata)	One-Foot Stop Time (min) 1000–200 fsw	200–0 fsw
0–203	0.8	11	18
204–272	0.7	11	19
273–1000	0.6	12	21

Emergency Abort decompression is begun by making the maximum Upward Excursion allowed by Table 15-8. Rate of travel should not exceed 2 fsw/min. The upward excursion includes a 2-hour hold at the upward excursion limit. Travel time is included as part of the 2-hour hold. Following the Upward Excursion, the chamber oxygen partial pressure is raised to the value shown in Table 15-10. Decompression is begun in 1-foot increments using the times indicated in Table 15-10. Rate of travel between stops is not to exceed 1 fsw/min. Travel time is included in the next stop time. The partial pressure of oxygen is controlled at the value indicated until the chamber oxygen concentration reaches 23 percent. The oxygen concentration is then controlled between 19 and 23 percent for the remainder of the decompression. Stop travel at 4 fsw until total decompression time has elapsed and then travel to the surface at 1 fsw/min.

For example, the maximum depth of the diver in the last 48 hours was 400 fsw, and the Commanding Officer approves using the Emergency Abort Procedure. From the Upward Excursion Table, the complex travels to 307 fsw at a rate not to exceed 2 fsw/min. It takes 46.5 minutes to travel. This time is part of a 2-hour hold requirement as part of the upward excursion for emergency aborts.

Because the post-excursion depth is between 273–1,000 fsw, the chamber oxygen partial pressure is raised to 0.6 ata. Once the atmosphere is established and the remainder of the 2-hour hold completed, begin decompression in 1-foot increments with stop times of 12 minutes from 307 to 200 fsw. The travel rate between stops should not exceed 1 fsw/min. Travel time is included in the stop time. It will take 21.4 hours to arrive at 200 fsw.

At 200 fsw the 1-foot stop time changes to 21 minutes. It will take 70 hours to reach the surface. The total decompression time is 93.4 hours (3 days, 21 hours, 21 minutes, 36 seconds). By contrast, standard saturation decompression would take approximately 4 days and 3 hours to complete.

During and following the dive, the divers should be monitored closely for signs of decompression sickness and for signs of pulmonary oxygen toxicity. The latter includes burning chest pain and coughing. The divers should be kept under close observation for at least 24 hours following the dive.

If the emergency ceases to exist during the decompression, hold for a minimum of 2 hours, revert to standard decompression rates, and allow the oxygen partial pressure to fall to normal control values as divers consume the oxygen. Venting to reduce the oxygen level is not necessary.

15-23.8 Decompression Sickness (DCS). Decompression sickness may occur during a saturation dive as a result of an Upward Excursion or as a result of standard saturation decompression. The decompression sickness may manifest itself as musculoskeletal pain (Type I) or as involvement of the central nervous system and organs of special sense (Type II). Due to the subtleness of decompression sickness pain, all divers should be questioned about symptoms when it is determined that one diver is suffering from decompression sickness. For treatment, refer to Figure 15-9.

15-23.8.1 **Type I Decompression Sickness.** Type I Decompression Sickness may result from an Upward Excursion or as the result of standard saturation decompression. It is usually manifested as the gradual onset of musculoskeletal pain most often involving the knee. Divers report that it begins as knee stiffness that is relieved by motion but which increases to pain over a period of several hours. Care must be taken to distinguish knee pain arising from compression arthralgia or injury incurred during the dive from pain due to decompression sickness. This can usually be done by obtaining a clear history of the onset of symptoms and their progression. Pain or soreness present prior to decompression and unchanged after ascent is unlikely to be decompression sickness. Type I Decompression Sickness that occurs during an Upward Excursion or within 60 minutes immediately after an Upward Excursion shall be treated in the same manner as Type II Decompression Sickness, as it may herald the onset of more severe symptoms. Type I Decompression Sickness occurring more than 60 minutes after an Upward Excursion or during saturation decompression should be treated by recompressing in increments of 5 fsw at 5 fsw/min until distinct improvement of symptoms is indicated. Recompression of more than 30 fsw is usually unnecessary. Once treatment

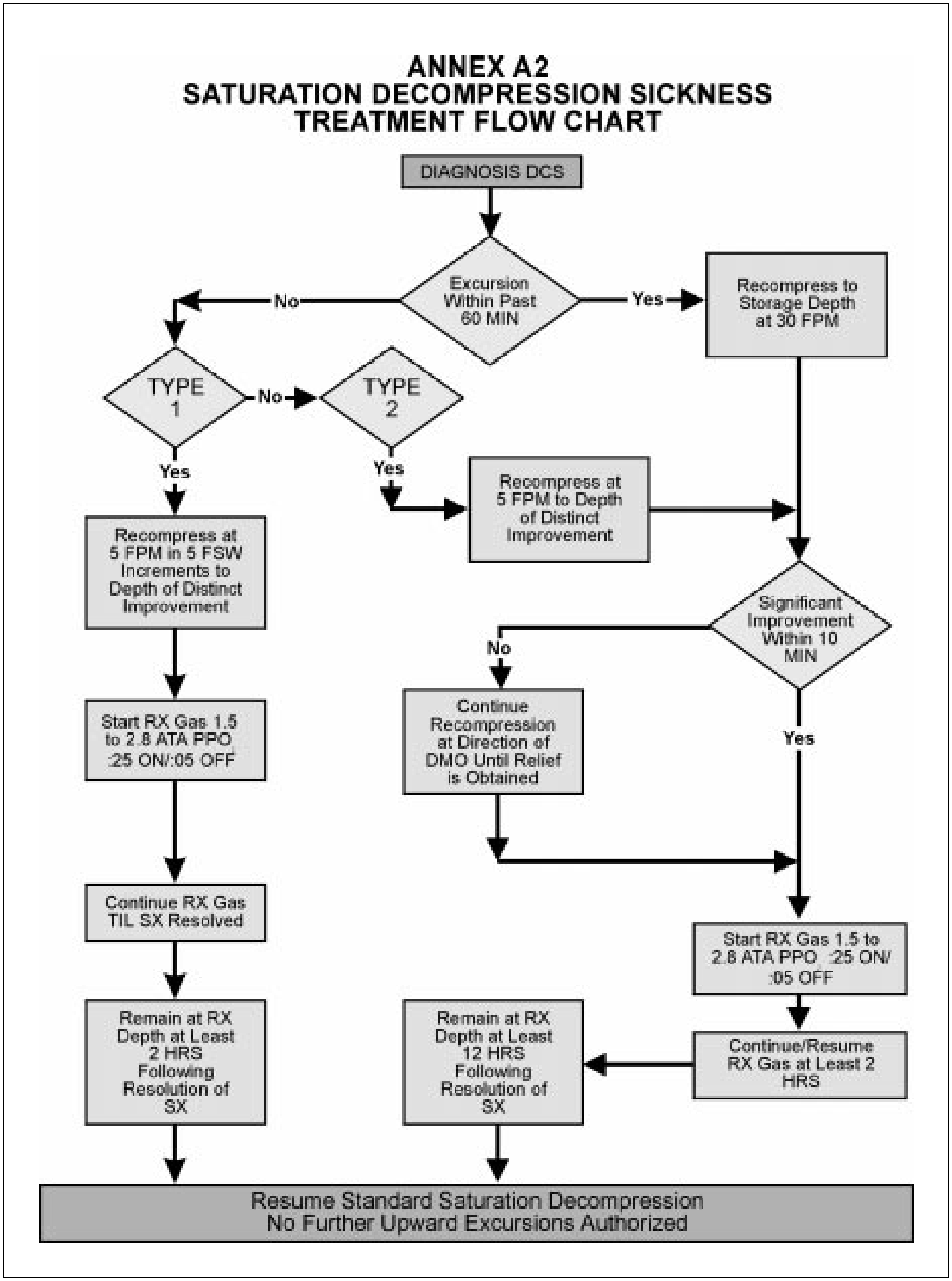

Figure 15-9. Saturation Decompression Sickness Treatment Flow Chart.

depth is reached, the stricken diver is given a treatment gas, by BIBS mask, with an oxygen partial pressure between 1.5 and 2.8 ata. Interrupt treatment gas breathing every 25 minutes with 5 minutes of breathing chamber atmosphere. Divers should remain at treatment depth for at least 2 hours on treatment gas following resolution of symptoms. Decompression can then be resumed using standard saturation decompression rates. Further Upward Excursions are not permitted.

15-23.8.2 **Type II Decompressions Sickness.** Type II Decompression Sickness in saturation diving most often occurs as a result of an Upward Excursion. The onset of symptoms is usually rapid, occurring during the Upward Excursion or within the first hour following an excursion ascent. Inner ear decompression sickness manifests itself as nausea and vomiting, vertigo, loss of equilibrium, ringing in the ears and hearing loss. Central nervous system (CNS) decompression sickness may present itself as weakness, muscular paralysis, or loss of mental alertness and memory. Type II Decompression Sickness resulting from an Upward Excursion is a medical emergency and shall be treated by immediate recompression at 30 fsw/min to the depth from which the Upward Excursion originated. When Type II Decompression Sickness symptoms do not occur in association with an Upward Excursion, compression at 5 fsw/min to the depth where distinct improvement is noted should take place. Upon reaching treatment depth, symptoms usually begin to abate rapidly. If symptoms are not significantly improved within 5 to 10 minutes at the initial treatment depth, deeper recompression at the recommendation of a Saturation Diving Medical Officer should be started until significant relief is obtained. After reaching the final treatment depth, treatment gas having an oxygen partial pressure of 1.5 to 2.8 ata shall be administered to the stricken diver for 25-minute periods interspersed with 5 minutes of breathing chamber atmosphere. Treatment gas shall be administered for at least 2 hours and the divers shall remain at the final treatment depth for at least 12 hours following resolution of symptoms. Decompression can then be resumed using standard saturation decompression using rates shown in Table 15-9. Further Upward Excursions are not permitted.

15-24 POSTDIVE PROCEDURES

After surfacing from the dive, the divers are still at risk from decompression sickness. Divers shall remain in the immediate vicinity of a chamber for 2 hours and within 30 minutes travel of a chamber for 48 hours after the dive. Divers shall not fly for 72 hours after the dive surfaces.

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