SECTION 7. DIVING SYSTEMS OTHER THAN SELF-CONTAINED AIR

7.1. Introduction
For reasons of prolonged endurance, compactness, absence of bubbles and/or noise, it is sometimes necessary to use diving equipment other than scuba containing compressed air. Because of cost and complexity, these methods have not been widely used in the past. These alternate gas mixtures and supply systems are now increasingly being used by underwater scientists, particularly in saturation and habitat diving.

The use of non-scuba equipment usually requires specialized training not available to scientific divers except through commercial or Navy schools. In different countries there are various Navy manuals and codes of practice which cover the use of the equipment.

7.2. Scuba, mixed-gas, surface demand and other systems
This section summarizes very briefly the characteristics of the various non-scuba systems using different gas breathing mixtures. The technical requirements as regards training, safety precautions, etc. for each type of equipment are listed in later sections, as shown in brackets:

1. Surface demand, air (7.3). Very long endurance, relatively cheap, limited horizontal range, excellent communications, low breathing resistance.

2. Surface demand, mixed-gas (7.3). Very long endurance, limited horizontal range, excellent communications, low breathing resistance, reduced decompression times.

3. Underwater habitats (7.4). Endurance of days or weeks, excursion dives without decompression, advantages of saturation, very expensive, requires substantial permanent surface support teams.

4. Lock-out submersibles (7.5). Long horizontal range, depth range to about 100 m or more, advantages of umbilical diving with communications, option of different gas mixtures, very expensive, requiring support ship and technical back-up.

5. Oxygen closed-circuit (7.6). Small light sets, low acoustic noise, very low breathing resistance, long endurance, absolute depth limit of 8 m.

6. Oxy-helium bell diving (7.7). Depth range greater than 100 m, in-water duration of hours, voice communications, limited horizontal range, very expensive, requires extensive support ship or platform, and massive technical back-up.

7. Mixed-gas scuba (7.8). Prolonged endurance, reduced decompression, reduced maximum depth, good horizontal range, moderately expensive, specialist training of personnel needed.

Only a few scientific establishments have experimented with these systems outside the Navy and commercial sectors. Dr. Alan W. Hulbert, Center Director or David A. Dinsmore Operations Director, Undersea Research Center, (NOAA) NUR, University of North Carolina at Wilmington, 7205 Wrightsville Ave., Wilmington, South Carolina 28403, USA, would be good contacts for any group planning to develop diving based on these specialized breathing systems.
A problem with all mixed-gas systems is that cylinders may be filled, but not properly labelled or documented, and a subsequent user may not know what gas mixture is in the cylinder. Extreme discipline and control is needed in this respect. A diver could be seriously injured or killed by diving with the wrong mixture and making the wrong assumptions about maximum depth or bottom time. The safest rule to apply is that if any diving cylinder is found to be unlabelled, and the gas mixture and date of filling is not recorded, then the cylinder should be emptied.

When scientific diving is being conducted with self-contained equipment other than open-circuit scuba on compressed air, work-up dives should be conducted as recommended in Table 4.1. The time lapse from the last working dive should be calculated from the last dive carried out using the same type of equipment.

When a working scientist is using self-contained equipment other than open-circuit compressed air scuba, it may be convenient to have the standby diver or buddy-diver on compressed air scuba. However, there must always be at least one other trained diver on the surface who has experience with the specialized equipment that is in use.

7.3. Surface demand air and mixed-gas
Surface supply diving applies to diving operations where divers are supplied with breathing gases by an umbilical from the surface.

A surface supply demand regulator should be supplied by an air or gas bank on the surface which has adequate reserve for the work in hand including decompression, or from a compressor via a gas storage unit having adequate reserve to bring the diver to the surface with time for decompression in event of failure of the compressor. Compressors shall be operated by a competent attendant who, if circumstances permit, may also be the diver’s tender. The attendant is responsible for operating the breathing mixture supply system. The surface attendant on the gas hose should be a diver fully trained and experienced with the surface demand equipment. Each diver in the water shall be tended by a separate diver’s tender.

The diver should be equipped with a reserve cylinder which can be turned on easily, or which automatically turns on, in the event of interruption of the surface supply. The reserve should preferably be adequate for surfacing including decompression. Where surface supplied equipment has not been designed to be used with a bail-out system, the diver shall wear an open-circuit scuba apparatus complete with an available regulator.
Each air line supplying air to a diver should be fitted with a pressure gauge downstream of the supply valve and installed so that the surface attendant can read it easily. The lower end of the hose should be attached to the diver's harness so that drag on the hose is not transmitted directly to the demand valve or mouthpiece. There must be a non-return valve at or near the demand regulator so that gas from the reserve cylinder does not vent in the case of failure of the hose, and low pressure in the hose cannot be transmitted to the diver.

A standby diver also with surface supply should be ready to enter the water. The standby system should also have voice communication and a longer umbilical than the working set. Two divers in the water can act as standby for each other.

In conditions of strong current a life-line should be used. It may be inadvisable to use surface demand equipment when working among mooring ropes or other lines to the surface or in kelp beds and in high currents.

Whenever possible an integrated communication system should be used, or a telephone wire should be run in conjunction with the hose or life-line; one of the main advantages of a tied diver is that clear, telephone communication with the surface is possible (Bevan, 1985; Walker, 1986, pp. 258).

7.4. Underwater habitats

Underwater habitats are artificial environments placed on the seabed or held at a fixed depth which are pressurized usually to near the ambient pressure of their depth. They contain living and working space and allow divers to remain underwater for extended periods of time. They allow diving excursions to be made longer than permitted by the standard air decompression tables that are designed for divers descending from, and returning to the water surface.

Photo 6: Although extremely expensive, underwater habitats are ideal for research that requires scientists to spend days or even weeks beneath the surface. Photo: G. Stanton

7.4.1. Introduction

Current underwater habitats are being designed to meet the requirements of a broad range of diving scientists. By incorporating saturation diving techniques with these work platforms, researchers have the capability of living and working for extended periods of time within the environment they are studying. This allows for the design of observation schemes and experiments which are otherwise not feasible when diving from the surface (Hydrolab Manual, 1984; Miller and Koblick, 1984).

7.4.2. Saturation diving

The term 'saturation' as used in diving refers to the body's tissues and their capacity for absorb-
ing inert gas at a given depth. When the tissues have absorbed all they can at a given depth, they are said to be saturated, and the amount of decompression necessary to rid the body of this inert gas will not increase with continued time at that saturation depth.

7.4.3. Safety considerations on saturation
The primary safety consideration for saturated divers is that the habitat rather than the surface is their refuge in the event of a diving emergency.

7.4.4. General procedures
While each habitat program has specific procedures unique to that system and program, divers in saturation must always:

1. Recognize that they are dependent upon the surface personnel for support.
2. Familiarize themselves with the saturation system, its operation and emergency procedures.
3. Be knowledgeable about fire safety.
4. Understand the diving equipment and its proper use.
5. Be familiar with the study area and any navigational aids available.
6. Understand procedures and limits for excursions from saturation depth.
7. Plan missions and excursions that are compatible with safety guidelines, equipment, depth, excursion limits and the abilities of the divers involved.
8. Assume responsibility for their own safety as well as their buddy’s.

7.4.5. Emergency procedures
Complete emergency procedures are developed for each habitat system and must be understood by surface personnel as well as saturated divers. Potential emergency situations may include the following:

1. Fire.
2. Loss of power.
3. Loss of communications.
4. Habitat flooding.
5. Habitat atmosphere becoming contaminated.
6. Accidental surfacing of a saturated diver.
7. Diver out of air.
8. Injured diver.
9. Lost diver.
10. Decompression sickness after excursion.
11. Loss of primary breathing gas source to habitat.

7.4.6. Health care
Throughout the history of habitat programs, the most common health problems have included ear infections, skin rashes, inflamed sores and diarrhoea. By following a strict regime of completely drying one’s ears after every dive, washing thoroughly daily with soap and water and periodically washing out wet suits, these maladies can be reduced or eliminated. In addition to the above, heat loss is of concern to the saturated diver. By wearing properly fitting thermal protection outside the habitat and warm dry clothing inside, heat loss can be minimized. Full medical precautions are most effectively described in proprietary commercial saturation diving manuals.
7.4.7. Hazardous materials
To reduce the possibility of fire, atmospheric contamination or health problems to the inhabitants, certain groups of materials must be excluded from the hyperbaric atmosphere of the habitat:

1. Flammables.
2. Volatile materials.
3. Volatile poisons.
4. Mood-altering drugs.
5. Medications whose effect may be altered by pressure.
6. Heavy metals or their salts.

7.4.8. Excursion diving
A saturated diver must adhere strictly to vertical excursion limits outlined for a particular habitat diving program. There is a danger of developing decompression sickness both in the water by an ascent shallower than the habitat or on returning to the habitat after a descent deeper than the habitat.

7.4.9. Decompression after saturation (Also see Section 11)
Decompression procedures after a saturation dive vary with different systems. Factors determining the decompression procedures include:

1. Depth of saturation.
2. Gas mixture used.
3. Depth and duration of last excursion prior to decompression.
4. Time elapsed since last excursion.

Depending on the habitat system used, divers may be decompressed inside the habitat, either on the bottom or at the surface; brought to the surface in a pressure vessel, mated to a surface chamber and decompressed; or swim from the habitat to the surface and immediately enter a surface chamber and be recompressed to saturation depth and begin decompressing.

7.5. Lock-out submersible
A lock-out submersible is a vehicle that allows divers to be kept at variable pressures on the surface and on descent and ascent while allowing them to dive directly from it following 'lock-out' after reaching depth.

Some scientific uses for lock-out diving are for exacting, manipulative experiments, sampling micro-habitats not accessible to a manipulator and collecting fragile and delicate organisms. The lock-out submersible may be used for long excursions from undersea habitats, while maintaining the diver at constant pressure; also it may be used by the habitat diver for travel to and from greater depths, allowing for safe, dry decompression before returning to the habitat (Youngbluth, 1983; 1984).

7.5.1. Design principles and applications
The lock-out submersible has, in addition to the 1-atmosphere chamber, a separate chamber capable of pressurization which permits a diver to exit the submersible at depth (Busby 1976, 1981; Haux, 1982). Divers may be transported to the study site at surface pressure or at storage depth from saturation. The dive chamber is then pressurized to a slightly greater pressure than that of the ambient depth, thus allowing the dive hatch to be opened.
The benefits of lock-out diving include greater safety and comfort for the diver and immediate decompression following return to the submersible. Also the submersible pilot is usually able to control the gas supplies and decompression, thus avoiding misjudgements by the diver owing to the effects of narcosis. Some lock-out submersibles are capable of mating with a surface, double-lock, decompression chamber which allows food and medical supplies to be passed to the divers.

7.5.2. Operational procedures
Divers must complete training prior to lock-out for familiarization with dive gear to be used and with operating procedures for compression and decompression of the submersible’s dive chamber. A shallow water lock-out dive should be made prior to deep or mixed-gas dives. Current velocity, direction and bottom obstacles must be assessed before diving. Precautions must be taken to prevent pinching of the gas supply hose in case the submersible shifts from current or surge during the dive.

**Equipment:** The following gear must be used:

1. Umbilical consisting of a non-kinking primary gas supply hose, and a communications wire linking diver, tender and pilot.
2. If scuba is necessary, then a neutrally or positively buoyant safety line must be tended by the dive tender.
3. Bail-out emergency bottle with either air or mixed-gas, depending on the composition of the primary supply gas.
4. Heavy-duty nylon web harness with lifting 'D' ring.
5. Firm attachment for umbilical to diver’s harness.
6. Lifting device capable of recovery of unconscious diver into dive chamber shall be rigged and ready.
7. Weight belts must not have quick release buckles.
8. Flotation vests must never be worn, especially those vests with CO2 emergency cartridges.

**Pressurization:** Air or nitrox is recommended for dives less than 50 m and helium-oxygen gas mixture for dives deeper than 50 m. The dive tender should control pressurization rate to allow immediate attention in the case of equalization difficulties.

**Decompression:** In planning total bottom time for a dive, adequate time must be allowed to return to the submersible, to retrieve the umbilical and to secure the dive hatch. The pilot or tender should control decompression. Oral-nasal masks must be available with oxygen supply.

7.6. Oxygen closed-circuit
Oxygen diving must only be carried out after personnel have received a full course of instruction from a Navy establishment or other establishment experienced with this mainly military equipment. Diving must be conducted in strict accordance with whatever rules apply to the particular equipment and usually full consultation must be made with the manufacturer to arrange for suitable training.

Normal rules concerning diving pairs and standby divers apply; it may be an advantage to have the standby diver equipped with scuba rather than oxygen equipment. No oxygen diving should take place unless at least one experienced diver fully trained in oxygen equipment remains on the surface during diving.

Gas must be medically pure oxygen and special care must be taken to ensure that all pipes,
seals and taps are free of oil and grease.

Flow-rates must be checked at the start of the project, and weekly thereafter. Working diving on oxygen should not be carried out deeper than 8 m.

Divers who normally work with compressed air should, when preparing for work involving oxygen diving, carry out work-up dives according to a recognized schedule.

7.7. Oxy-helium and bell diving
Variable amounts of oxygen and helium are supplied to the diver as a breathing mixture in order to reduce narcosis, avoid oxygen poisoning, reduce gas density and shorten the time of inert gas flushing during decompression. Much of this diving is done from bells.

7.7.1. General principles
To increase capability of safely diving to depths greater than the limit for air diving operations (8.2.21) and avoid nitrogen narcosis, oxygen-helium diving techniques must be used.

Two basic categories of diving can be identified:

1. Intervention diving for short exposure to a maximum depth of about 100 m.

Intervention diving can be carried out by experienced scientific teams without an extensive logistical and equipment support. Surface supplied diving techniques are recommended, while free diving using closed, semi-closed or open-circuits, and particularly scuba diving with bottles-filled with oxy-helium mixtures, is discouraged and is considered excessively dangerous. Decompression sickness caused by helium gas is more likely than air to attack the nervous system and cause permanent disability. With an umbilical hose and safety-line the diver is always tethered and safety is improved by a virtually unlimited gas supply, along with a secure voice communication system. Umbilical facilities may be changed to oxygen or nitrox supply for decompression on ascent.

2. Saturation diving for greater depths and/or extended bottom time missions.

Saturation diving requires a pressurized bell and a complete diving system; civil research establishments rarely can manage these high cost and bulky equipment sets and so, usually, saturation bell diving is carried out in conjunction with commercial companies or with the Navy (Trent and Orzech, 1984; Keith and Frey, 1979; Colanonti, 1983).

7.7.2. Guidance for operations
Oxy-helium diving is technically and physiologically more complex than normal scuba diving, and any diver approaching oxy-helium must first be fully qualified and trained in air diving operations. If semi-closed equipment is to be used, special training is required.

1. Fullest discussion with the Naval, commercial, or government authorities must be held before considering this method of work; personnel and equipment must be selected carefully.
2. All personnel shall attend a suitable course on the equipment to be used, including training in a decompression chamber on the mixtures to be used and pool and sea practice dives.
3. Decompression must include stages breathing oxygen, nitrox or air.
4. Only approved decompression tables must be used for the dives (Appendix 3).
5. Diving must never be carried out without an on-site compression chamber with a transfer-under-pressure facilities. It must be operated by a fully-trained operator.
6. Divers should be equipped with a full-face mask or helmet. An emergency cylinder and
suitable thermal protection should be worn.
7. A tender on the surface should handle the umbilical and may maintain the communications, while a fully equipped standby diver must be prepared to enter the water immediately for emergency assistance. These attendants should always be divers trained on oxy-helium equipment.
8. A suitably qualified person shall control and time all the procedures and maintain a complete diving log. He/she should be responsible for the possible use of the decompression chamber.
9. An open bell or stage for recovery of divers during in-water decompression stops is also recommended as well as a heating system, i.e. warm water circulation, to compensate for loss of body heat owing to the longer than usual times spent in the water and the thermal transfer properties of helium in the breathing mixture.

7.7.3. Legislative requirements
Oxy-helium diving is controlled by detailed offshore industrial legislation in most countries where it is practiced. Scientists wishing to use these techniques may have to comply with government regulations and conform to commercial practice.

7.8. Oxy-nitrogen/ self-contained mixed-gas and modified air
Conventional scuba equipment can be altered in performance by using oxygen-enhanced breathing mixtures, either 40% or 60% oxygen. Any equipment that is used to store or handle pure oxygen must be specially designed for the purpose, and the risk of combustion is such that lubricants and rubber or plastic components must not be employed unless designed for use with oxygen. Under no circumstances should ordinary open-circuit equipment be used with pure oxygen.

The use of an oxygen-rich breathing mixture provides greater endurance at a given depth before the diver will require decompression stops during ascent. The tables for calculating the 'equivalent air depth' can be found in Navy diving manuals. Since the partial pressure of nitrogen is reduced, the equivalent air depth is shallower than the real depth of the dive, and decompression is also reduced. On the other hand, the higher partial pressure of oxygen means that oxygen poisoning will occur at depths shallower than the maximum depths on pure air; this depth limit must also be calculated before the dive and never exceeded.

Although it seems simple to use an oxygen-rich mixture in open-circuit scuba, because the equipment is so simple, extreme discipline is needed to make sure that divers stay within the safe range of depth and make the correct calculations for ascents. The technique has been used successfully in some university and institute diving groups, but it is recommended strongly that divers planning to use such a system attend a full training course in oxy-nitrogen mixed-gas diving.

Oxy-nitrogen mixed-gas can also be used in semi-closed circuit or completely closed-circuit systems. The older types of sets, usually designed for military use, have a reducing valve that feeds pre-mixed gas at a constant rate into a flexible counter-lung. The diver breathes the gas from the counter-lung and exhales through a carbon-dioxide absorbent, with the scrubbed gas going back into the counter-lung. In this way the diver breathes each unit of gas several times and removes more oxygen from the gas than on an open-circuit system. Professional training is mandatory, either at a commercial or military diving center. The equipment requires careful maintenance, and extreme discipline is needed in filling sets, changing carbon-dioxide absorb-
An oxy-nitrogen mixed-gas breathing system gives prolonged endurance for a given weight and volume of equipment and has a reduced bubble outflow compared with open-circuit scuba. It is also quieter.

Since 1965 there have been a series of totally closed-circuit mixed-gas breathing systems. The principle is to use a sensor to measure the partial pressure of oxygen in the breathing circuit, with an electrical output that adjusts the flow of oxygen and inert gas from separate cylinders, so as to keep the breathing mixture within safe limits. The objective is to obtain a very quiet set, with no bubble noise, and very long duration in relation to weight and volume. Some models have been developed for military use, but a number have been marketed for commercial or scientific use (Hanlon et al., 1983). Reliability of the gas control system is obviously critical, and in order to obtain this reliability, sets have become complex, expensive and require very professional maintenance. The performance of military sets of this type is not available, but it is fair to say that no set, which is commercially available, has yet received wide use. Since this type of equipment is still uncommon, very careful training would be required, usually in conjunction with the manufacturer, or a training establishment recommended by the manufacturer.

7.9. Multiple mixture diving, tri-mix
Multiple mixture diving is currently regarded as being outside of the range of breathing mixture supply systems available to scientific divers for use in the course of their work.

7.10. Snorkel diving as part of a scuba program
All the time spent underwater by staff engaged in snorkel diving during the course of scuba operations should be taken into account for nitrogen deficit-table purposes. Even though the diver is not breathing compressed air, gas exchange with the diver’s tissue is taking place while diving with a snorkel. It is known for decompression sickness to afflict deep diving snorkelers who spend considerable time at depth, and mixing snorkel and scuba demands consideration of all time spent under pressure. Snorkel diving that does not exceed 2 ATM following scuba may usefully extend the scientific work programme but the time of exiting the water after the last snorkel must be considered as the end of the overall diving schedule.

Snorkel divers must be visually observed at all times. Snorkelers should be strong swimmers and should show proficiency at the working depth prior to work diving. It should not be necessary to change weight belts for a diver to transition from scuba to snorkel. The wearing of an inflatable life-jacket or ABLJ during snorkel diving should be mandatory, even if easily dumped weights are worn.