# DIVER EDUCATION SERIES

## A Portable Diving System for Search & Rescue, Scientific, and Commercial Divers

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CONTENTS



### INTRODUCTION



Modern diving operations must be conducted safely and efficiently on a cost-effective basis. Increased costs, reductions in funding, personnel shortages, limited availability of large vessels, and more complex underwater projects have challenged scientific, search and rescue, and commercial divers to re-evaluate the selection of diving equipment and their mode of diving [3, 4]. A versatile compact and portable diving system that enables a diver to transport and select from components to support scuba, tethered scuba, and surface-supplied diving is described in this publication.

The advantages of surface-supplied diving for selected environmental conditions and underwater tasks are well documented. Modern communications units, combined communications and safety lines, and full-face masks have significantly improved the safety of tethered scuba diving. The modern scientific and search and rescue diver need no longer be limited to open-circuit scuba as the principal mode of diving. On the other hand, shallow water commercial divers may find that improved tethered scuba and lightweight surface-supplied diving systems and techniques offer greater operational versatility than previously considered possible.

The compact and portable diving system described here was developed to meet the needs of scientific, search and rescue, and commercial divers working from small vessels, docks, breakwaters, and similar structures. The philosophy behind this system includes:

- Portability
- Personnel efficiency
- Component availability
- Scuba, tethered scuba, or surface-supplied diving option
- Simplicity
- Efficient and effective training procedures

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- Economic feasibility
- Improved communications/data recording
- Diving operation versatility
- Safety

While all of the components of such a system already exist, some may not be readily recognizable and available to scientific and search and rescue divers who have developed a more conventional scuba diving philosophy toward underwater work. Many scientific and search and rescue diving equipment suppliers and instructors are often recreational diving industry oriented. Some of the components for this system are generally only available from commercial diving equipment suppliers.

Divers and organizations who are unfamiliar with commercial diving equipment must use reasonable judgment in selecting and using some of the equipment discussed in this publication. For example, many commercial diving companies construct their own air control consoles and umbilical assemblies. However, the author suggests that scientific divers and search and rescue teams acquire off-the-shelf equipment from a reputable firm unless technical personnel with specific expertise in assembling equipment are available.

Conventional scuba diving remains the principal mode of diving for underwater scientific research and search and rescue. The desirable attributes of scuba diving include portability, underwater mobility, simplicity, and training availability. Although the scuba mode of diving has been the cornerstone of scientific and search and rescue diving for three decades, there are some significant deficiencies that must be considered. The duration of a scuba dive is limited by the amount of air that the diver can carry in backmounted cylinders. High-capacity scuba is heavy and cumbersome, especially for smaller divers and when diving from small vessels.

Accurate and detailed data recording is a major consideration in many scientific projects and in crime or accident scene investigation. Although most divers successfully use the slate and pencil method and a few have used tape recorders housed for underwater application, more efficient methods are available.

Scuba diving safety standards require that at least two divers be deployed for any underwater task. In reality, many underwater research and search and rescue tasks can be effectively accomplished by a single diver. Finally, a scuba diving team swimming blindly in poor visibility waters may be far less safe than a single, tethered diver.

To extend capabilities and improve safety for scientists and search and rescue specialists, *a diving system should allow for selection of scuba, tethered scuba, or surface-supplied diving modes*. Naturally, tethered scuba and surface-supplied diving modes have specific limitations. However, the advantages far outweigh the limitations for selected diving situations. An experienced scuba diver can be easily and effectively trained in the use of tethered scuba and surface-supplied diving systems. Scientific and search and rescue divers need no longer be limited to open-circuit scuba diving.

The standards of equipment, operational procedures, and personnel training suggested in this paper may vary from those of traditional recreational, scientific, search and rescue, commercial, or military diving. However, years of review and field experience in a variety of diving operations have shown that these standards are acceptable within the limitations consistent with scientific and search and rescue diving operations. The highest standards of safety are retained.

Since many potential users of the system described here will be unfamiliar with some of the equipment and diving techniques discussed in this publication, they are encouraged to consult selected publications [5, 6] and seek special training. Commercial divers and other employed divers who must comply with state or federal occupational safety and health regulations [7, 8] must assure themselves that the equipment and procedures comply with applicable regulations. Scientific divers should consult the standards of the American Academy of Underwater Sciences and seek approval from their institutional diving control board before using the equipment and procedures discussed in this publication.

## Design/Selection Criteria

Literature review, familiarity with commercial diving systems, research, and experience gained during numerous scientific and search and rescue diving operations dictated that the system design and component selection criteria include, but not necessarily be limited to, the following:

- Capability to support self-contained or surface-supplied diving operations to depths of 130 ft. and tethered scuba diving to a depth of 60 ft.;
- Minimum dive team of three persons;
- Components assembled into a minimum number of modular or packaged units;
- Maximum weight of 100 lbs. for each individual packaged unit;
- Components sized and packaged to facilitate transport by land vehicle (station wagon, pickup truck, or Land Rover type), small vessel (16 ft. or larger inflatable or solid structure boat), helicopter, or fixed wing aircraft. Space measurement should not exceed 24 cu. ft., including a supply of 600 standard cu. ft. of air;
- Limited maintenance requirements;
- Surface-supplied diving components should be scuba diving compatible (discussed separately);
- Reasonable cost;
- Silent vessel operation;
- Air compressors optional;
- Training requirements not to exceed 16 hours;
- Most periodic equipment inspections and repairs to be completed by manufacturer-trained technicians rather than the individual divers (similar to scuba diving periodic inspection/repair procedures); and
- Diving generally to be under favorable environmental conditions and the divers' work level to be light to moderate.

The surface-supplied components of the compact and portable diving system described in this paper must not be confused with the "float-mounted, low-capacity gasoline engine air compressor units" advertised in recreational diving publications. This is not a recreational diving "hookah" system.

## Compatibility With Scuba

Since nearly all diving scientists and search and rescue divers are trained and equipped for scuba diving, the surface-supplied diving components of this system must incorporate both scuba philosophy and component compatibility. The following factors were taken into account in developing this system:

- Trainees/users would be previously certified and experienced scuba divers;
- The air supply system, the emergency scuba, and the mask or helmet must be of a nature to facilitate rapid learning in use, operation, design, and maintenance. Selection of equipment with similar design features to that used in scuba diving would be a significant aid in achieving this goal;
- As many items of equipment as possible should be available in existing scuba diving lockers and from recreational diving equipment suppliers; and
- The diving team in the field could readily switch the mode of operation.

## Primary Components

The primary components include:

- Two demand breathing full-face masks (or helmet for special applications);
- Surface-supplied diver's umbilical assembly;
- Air control-depth monitoring-communications module;

- Air supply module;
- Communications/safety line and compact communicator for tethered scuba diving;
- Emergency scuba for surface-supplied and tethered scuba diving;
- Complete scuba diving outfit for each diver;
- Thermal protection system for each diver;
- Accessory equipment; and
- Diving supervisor's kit.

**Mask**

From a safety and communications standpoint, it is necessary to use a full-face diver's mask rather than a conventional mouthpiece-style scuba regulator for tethered scuba and surface-supplied diving. First, proper communications is very difficult with a mouthpiece-style regulator. Second, in the event that the diver is injured or loses consciousness, the mouthpiece-style regulator could easily be dislodged and lost. With a full-face mask, even if the diver is unconscious, he/she can continue to receive air.

Based on personal preference, a diver or diving group may select one of several conventional surface-supplied demand breathing masks (i.e., Heliox-18, KMB-10, DM-5 or equivalent) which have been standard equipment in scientific, commercial and military diving for more than a decade, or a lightweight demand breathing mask (i.e., AGA, Widolf, DSI EXO-26, or equivalent).

Many tethered scuba and shallow water surface-supplied divers prefer to use a lighter weight, lower internal volume demand breathing full-face mask rather than the heavier, more complex commercial/military masks. The lightweight masks are constructed with either soft rubber full-face assembly or a solid support frame with a rubber face seal. They are fitted with a high impact polycarbonate plastic wide-view faceplate. A large, flexible nose pocket facilitates pressure equalization in the ears. The mask is secured to the diver's face using a head harness (or spider) assembly.

A demand regulator is fitted to the front of the mask. Lightweight masks do not generally include the special side block assembly for attachment of a secondary air supply as described below. Communications components are fitted inside the mask with an earphone positioned in a pocket in the face seal or on a head strap. The lightweight masks are generally less expensive than the conventional commercial surface-supplied divers' masks and scuba divers find them to be more comfortable.

The popular commercial and military divers' masks are built around a molded fiberglass or plastic frame. This frame supports a rubber face seal/hood, post for attaching a head harness, a face plate lens made of high impact acrylic plastic, a side block air control assembly, a demand regulator, an interior oral/nasal mask, a movable nose pad (to aid in ear/sinus pressure equalization), and speaker/earphone components. The demand breathing system is basically the same as that used in an adjustable scuba regulator second stage. The side block assembly is designed to accept an emergency or secondary air supply hose. A separate padded head protector may be used if desired.

Although the diver will generally use the demand breathing mode, a valve on the side block assembly (Heliox-18, KMB-10, etc.) allows for activation of free-flow air for clearing condensation from the face plate or for increased respiratory requirements associated with heavy work. In addition, another valve on the side block assembly enables the diver to activate air supply from an auxiliary first stage regulator or separate compact scuba in the event that the primary supply malfunctions.

A demand breathing helmet (i.e., Superlite-17 or equivalent) has many of the same features and components as the commercial divers' mask described above. In addition, the helmet covers the diver's entire head. A watertight seal is formed at the neck by means of a rubber sleeve called a neck dam. The diver's head, ears, and face remain dry when diving. This is advantageous for cold or polluted water and quality of communications. The interior of the helmet is lined with a foam head cushion which comfortably surrounds the diver's head and upper neck. This firmly attaches the helmet to the diver's head.

Movement of the head results in an identical movement of the helmet. The helmet is designed to be slightly heavy underwater; however, the weight of the helmet can be adjusted to individual diver preference. The helmet is secured to the diver's head with a yoke system which slips around the diver's neck and firmly locks into place. The helmet may also be attached directly to the diver's dry suit to prevent any contact with the water. Although slightly more cumbersome and expensive, the helmet offers improved communications quality and greater protection from polluted water.

The demand breathing system for both the helmet and mask, similar to that used in an adjustable scuba regulator second stage, allows the diver to achieve optimum breathing characteristics regardless of depth, supply pressure, and body position. Instead of gripping a mouthpiece (as with scuba), the diver's face is surrounded by a comfortable rubber mask which also includes the speaker component for quality voice communications.

*Since most scuba diving instructors are not familiar with full-face mask or diving helmet design, function, and maintenance, and since standard scuba diving training manuals do not discuss these masks, tethered scuba and surface-supplied diving instructors, divers, and trainees should be provided with a copy of the manufacturer's operation and maintenance manual for the particular mask used in training or operational diving.*

**Umbilical Assembly**

The umbilical assembly consists of an air supply hose, pneumofathometer hose, combination communications cable/strength member, and diver attachment component. The *air supply hose* is a heavy duty 1/4 in. or 3/8 in. inside diameter (I.D.) synthetic rubber, braid-reinforced hose with pressure and construction characteristics similar to a hydraulic hose (SAE 100 R-3 or equivalent). Although actual working pressure in the field seldom exceeds 200 lbs./in.2, this hose is rated for a working pressure of 1125 lbs./in.2 and burst pressure of 4500 lbs./in.2 (for 3/8 in. hose). This type of hose greatly exceeds the working pressure requirements and its tensile strength and minimal shrinkage (when pressurized) characteristics make it more desirable compared to a lower pressure hose.

A 3/8 in. or 1/2 in. I. D. hose is commonly used for military and commercial diving umbilical assemblies where optimum high volume air flow characteristics must be achieved in umbilical units 300 to 600 ft. long. However, a 1/4 in. I.D. air hose has recently been introduced to achieve a lighter, more compact umbilical assembly. This has resulted in a weight reduction of about 15 lbs. for a 150 ft. umbilical assembly. The air flow characteristics remain satisfactory for shallow water, moderate exertion diving requirements and 100- to 200-ft. long assemblies.

The *pneumofathometer hose* is a small diameter (1/4 in. I.D. or less) synthetic rubber hose with a working pressure of about 200 lbs./in.2. Some divers are experimenting with high pressure (300 lbs./in.2), small diameter, and extremely lightweight laboratory-type tubing in order to further reduce the size and weight of the total assembly. The pneumofathometer hose is attached to a pressure gauge on the control console and is open at the diver's end. Air is valved into the hose at the console. When all the water has been evacuated from the hose, the resulting pressure reading is the gauge pressure at the diver's depth.

The *communication cable / strength member* commonly used is a thermoplastic coated, 4-conductor cable with a steel braid internal shielding. This cable is commonly termed spiral 4 communication wire in the commercial diving industry. It has a tensile strength of about 1500 lbs. and is relatively inexpensive. Normally, only two of the four conductors are used at a time. The spares remain available in the event that one of the wires breaks or shorts in use. This increases the overall useful lifetime of the cable. The diver's end of the cable may be fitted with special underwater connectors compatible with the connector available on masks and helmets or simply fastened directly to post-type connectors. In this case, the wire ends are generally prepared with solder for added strength and ease of connection. The surface end of the cable is fitted with a connector that is compatible with the console communicator.

A *combination safety/communications line* constructed of 7 mm nylon static kermantle rope with a tensile strength of 5800 lbs. is now available. The communications wires are woven into the rope. This rope has the strength and handling characteristics of ordinary safety rope. Tying knots in the rope apparently has no adverse effects on the communications wires. Quick-connect electrical connectors are fitted to each end and special adapters are available. This type of safety/communications line is highly desirable for tethered scuba diving.

Military and commercial diving groups often include a separate braided nylon line strength member in umbilical assemblies. Unless the scientific diver is working under the rigorous conditions encountered in military and commercial diving, this added component is not considered necessary by most divers. It adds weight and bulk to the assembly. The combined tensile strength of the communication cable and air hose is considered more than sufficient for less rigorous diving operations.

The diver's end of the umbilical assembly is fitted with a large stainless steel D-ring or equivalent to facilitate attachment to the diver's safety harness. In this case, the harness is fitted with a snap shackle or caribiner (diver preference). This system allows any stress on the umbilical assembly to be transferred to the diver's harness instead of the mask or helmet. The D-ring is bound to the assembly with strong cord or a clamp which allows most of the stress to be transferred to the strength member. A similar device is secured to the surface end of the assembly so that it may be secured at the diving station. This prevents damage to the console or danger to the tender and pulling all of the assembly overboard in the event of underwater stress.

All components are assembled under appropriate tension so that the strength member will take most of the stress when the hoses are pressurized and the diver is being tended from the surface. Improper assembly can result in looping of the air hose under pressure or unnecessary stress being applied to the air hose during diving. The components are bound together with heavy-duty, pressure-sensitive polyethylene cloth-laminated (duct tape) or vinyl tape at one-foot intervals. The lower 50 ft. of the assembly is marked at 10 ft. intervals with brightly-colored tape beginning at the D-ring. Above the lower 50 feet the assembly is marked every 50 feet. In the event of pneumofathometer failure, the tender can estimate the diver's depth by these markings.

### Air Control-Depth Monitoring-Communications Module

The surface diving station for the surface-supplied diver must be equipped with the necessary components to control the diver's air flow, monitor depth, and communicate with the diver. These components may be positioned separately, or combined into a single console-type unit (i.e., Diving Systems International's Dive Control System 1 or Amron International's Amcommand 1). These consoles provide the following:

- Provisions for air hose supply, pneumofathometer hose supply, communications cable attachment and air control for one or two divers;
- Provisions for air supply from two high-pressure sources and one low-pressure source;
- Provisions for rapid change from one air source to another in the event of air supply depletion or malfunction;
- Provision for reducing high-pressure air (3000 lbs./in.2) to umbilical supply pressure (115 to 225 lbs./in.2);
- Complete protection of components during storage and transport;
- One-person operation and monitoring of all functions;
- Visual readout of air pressure at all times.

All gauges, valves, and communication components are systematically panel-mounted in a console-type assembly. Color coding and/or labels on the panel clearly define air source and diver supply flow paths/connections. High-pressure air supply gauges allow the operator to monitor the status of remaining air at all times, and a low-pressure gauge allows for constant monitoring of umbilical supply pressure. The umbilical supply pressure can be conveniently controlled using the regulator adjustment knob located on the panel. On the two-diver model, color coded pneumofathometers and purge valves are located on the upper portion of the console.

The high-pressure air source hoses connected to the console are fitted with scuba-type yokes that are compatible with conventional scuba cylinder valve assemblies. A low-pressure air supply hose fitting is available.

A standard push-to-talk diver communicator is located on the upper right side of the console. The communicator is equipped with an internal rechargeable battery system and provisions for attachment of an external power source in the event that the primary battery fails. The cable connection fittings are located adjacent to the hose connection fittings. Various switches allow for surface-to-diver and diver-to-diver communications. A speaker is located in the upper portion of the console; however, provisions are included for a headset earphone-microphone unit. A battery level indicator and tape recorder plug-in are also included. Several electronic stop watches may be attached to the console using Velcro fasteners.

The console is designed for convenient monitoring and operation by one person. The diver's umbilical is connected to labeled fittings on the console and separate air sources are clearly designated. Both (or all three) air sources are opened and the operator selects the preferred air source by turning on the appropriate valve on the console. If one air source is depleted or malfunctions, the operator can immediately switch to the second air source. At the same time, the depleted or malfunctioning air source is isolated for replacement or repair. This air supply redundancy is an important safety factor. In the event of regulator failure, overpressure air will vent while the diver is returned to the surface or the control is switched to a low pressure source. In addition, the diver is wearing an emergency scuba.

Other control systems are also available; however, the air control and depth monitoring components are generally housed as a single unit and the communications system is separate. Furthermore, most systems are designed only for low-pressure air input and the pressure must be reduced to umbilical pressure at the air source using a separate regulator. Although these systems are satisfactory, the handling and placement of additional components can be a disadvantage on some diving operations.

**Air Supply System**

Military and commercial surface-supplied diving operations traditionally include large diesel-powered, low-pressure air compressors. A single air compressor may weigh 2000 to 3000 lbs. and occupy up to 20 sq. ft. of deck space. Weight, size, and cost considerations often preclude the use of acceptable low-pressure compressors for most scientific and search and rescue diving operations. The size and weight far exceed the limits imposed by small vessels and transport vehicles. Furthermore, the noise of any compressor, large or small, is unacceptable in small vessel operations where voice communication for scientific data recording is vital. Although small low-pressure compressors are available, their delivery capacity, weight, and/or noise still make them unacceptable for most diving operations.

Standard single- and twin-cylinder scuba units were selected for this diving system. Twin 72, 80, or 100 cu. ft. cylinder units are compact, portable, readily filled at any scuba shop, and may also be used for conventional scuba diving. Twin-cylinder units weigh approximately 76, 81, and 99 lbs. respectively (filled). Large 200 to 300 cu. ft. storage cylinders may also be used. However, they are heavier; less convenient to handle, transport, fill, and store; and, cannot be used in the scuba mode. Four sets of twin-80's are far more compatible than two 300 cu. ft. storage cylinders. The scuba cylinders may be stacked in a rack assembly and serve as a table for the console, secured adjacent to the console, or placed under boat seats.

In summary, high-pressure scuba cylinders were selected instead of a low-pressure air compressor based on the following:

- Scuba cylinders are readily available at most research institutions and search and rescue departments;

- The same cylinders may be used for scuba or tethered scuba diving, thus avoiding the necessity of carrying extra components (storage cylinders or compressors);
- The size and weight of a twin cylinder unit falls within the system component specifications for handling and transport;
- The cylinders may be filled at any dive shop. This has proven far more convenient than carrying a compressor for most diving operations;
- All compressor noise is avoided during diving operations; and
- The scuba cylinders are more convenient for use on small boats and for transport in small vehicles.

In the event that diving operations are conducted in remote locations where dive shop scuba filling is unavailable, portable high-pressure compressors may be used to fill the cylinders. The cylinders may be filled at the dock, or between dives if operating from a large vessel. This still allows for low noise level diving operations. Two or more compact portable compressors will meet the filling and weight/size requirements for this system. Furthermore, if one compressor malfunctions, diving operations can still continue using the other(s), and parts are interchangeable.

**Thermal Protection Garments**

The selection of thermal protection garments is based on geographic area, dive duration, environmental conditions, and individual diver preference [1, 2]. Although excellent active diver thermal protection suits using a hot water supply system are available, the size and support requirements may not be compatible with many diving operations.

Recent improvements in lightweight variable-volume dry suits and undergarments have significantly increased the thermal comfort potential for all divers. The majority of scientific and search and rescue divers operating in temperate to polar climates now use this type of thermal protection. These suits may be used for any of the modes of diving discussed in this publication.

Air for suit inflation may be supplied from conventional scuba, the emergency scuba cylinder or a separate small cylinder (for surface-supplied diving), or a special manifold fitted to the surface-supplied umbilical assembly or mask. Special developments in techniques and protection garments for polluted water diving have been the subject of considerable research by the Diving Office of the National Oceanic and Atmospheric Administration. For specific information on polluted water diving, contact that office and review a doctoral thesis by Williscroft [9].

**Emergency Self-Contained Air Supply and Safety Harness**

If the air supply from the surface is interrupted for any reason, the diver may activate the scuba emergency air supply by turning a valve located on the side of the helmet or mask or manifold assembly located on the harness. Generally, small air cylinders ranging from 15 to 50 standard cu. ft. capacity are used for surface-supplied divers. A standard single-hose regulator first stage is connected to the side block or manifold assembly. *This regulator must be fitted with an over-pressure relief valve.*

Some divers also prefer to connect their buoyancy compensator or suit inflator hose to the emergency regulator. Although some question this practice, it has proven satisfactory for a decade in tests and actual field use. The regulator may also be fitted with a pressure gauge to facilitate convenient air monitoring throughout the diving operation. A high-pressure filling hose equipped with scuba yokes at both ends allows for the smaller emergency cylinders to be conveniently recharged from one of the primary supply twin-cylinder units.

Most lightweight full-face masks are not fitted with a side block manifold to accept an emergency air supply fitting. In this case, the diver may connect the emergency scuba to a manifold assembly secured to the diver's harness.

In the past some divers used an emergency scuba with a conventional mouthpiece style regulator and carried a compact scuba diver's mask in a special pocket attached to the safety harness or regulator hose. In the event of an air supply loss, the diver removed the full face mask, switched to the scuba regulator, donned the mask, and surfaced.

*Although this technique was successfully used in the early years of lightweight helmet commercial diving, it is not a favored option by most divers today. I include it here as a historical notation and encourage divers to consider other options.* Naturally, if this technique is to be employed, it must be taught and practiced in the training program. Some surface-supplied divers fear that the scuba regulator may develop an undetected free-flow during the dive and deplete the emergency air supply. A small ball-valve may be fitted at the second-stage end of the low pressure hose. The scuba cylinder valve remains open during the dive and the ball-valve is turned to activate the supply to the diver. If this special modification is used, the first stage of the regulator must be fitted with an over-pressure relief valve.

The surface-supplied diver's emergency scuba backpack also serves as the diver's safety harness. This harness is equipped with D-rings for attachment of the diver's umbilical assembly and is designed to withstand a minimum of 1000 lbs. pull in any direction. Consequently, no strain is placed on the diver's mask or helmet when a pull is taken on the umbilical assembly.

**Standby Diver Equipment**

The need for deploying a standby diver for underwater rescue of a surface-supplied or tethered scuba diver is remote in most scientific diving operations. However, the possibility of diver entanglement or incapacitation underwater is of real concern to search and rescue and commercial divers. The availability of a standby diver must always be considered when diving under conditions where underwater entanglement or entrapment is possible. Even though the need for a standby diver may appear to be minimal, common sense safety practices and regulations dictate that a standby diver must be prepared to immediately administer aid, if needed. The standby diver should be equipped and positioned so that he/she may deploy within one minute of notification.

A standby diver may be equipped with scuba that is fitted with a demand breathing mask and a combined safety line and communications cable (tethered scuba). For surface-supplied diving operations some dive teams prefer to include a second complete umbilical assembly and mask. Both standby diver systems have been successfully tested in the field. However, in more than 10 years of scientific surface-supplied diving, the author has deployed a standby diver just once, and even this situation could have been satisfactorily resolved without use of the standby diver. Since a surface-supplied diving team can go into the field also equipped for tethered scuba diving, tethered scuba appears to be a very satisfactory standby diver mode.

**Spare Parts/Tool Kit**

A small kit containing necessary wrenches, emergency battery, microphone, o-rings, tape, communication cable connectors, and so on, is assembled in accord with team preference. The content will vary slightly with location and specific equipment. More complete spare parts/tool kits are carried for diving operations in remote locations to facilitate field repairs. Some teams will routinely carry a compact secondary communicator for tethered scuba diving. The unit can also be used as a backup communicator for surface-supplied diving.

**Diver's Personal Kit**

Each diver will be responsible for providing a complete scuba diving field kit except for scuba cylinders. This kit shall include a regulator (with alternative breathing unit and pressure gauge), instruments (timer, depth gauge, decompression microprocessor, etc.), weight belt and weights, buoyancy compensator, appropriate thermal protection suit, knife, and accessory scuba diving equipment. A backpack must be selected that is compatible with the attachment system on the twin scuba cylinder units and usable with a single scuba cylinder (if included).

**Dive Supervisor's Kit**

The diving supervisor (or team leader) will assure that appropriate first aid supplies, dive timers, decompression tables, manuals, record-keeping materials, surface communications unit, and other items required by health, safety, and operational standards are available in the field.

**Component Weight and Size**

The following is a summary of the approximate weight and size specifications for various system components. Naturally, exact values will depend upon model and packing. Approximate sizes and weights, including transport containers, are:

| Component | Weight/lbs | Size/in. |
|---|---|---|
| Air Control-Depth Monitoring-Communication Module | 20 to 47 | 26x17x9 |
| Mask or Helmet | 5 to 27 | 12x10x9 |
| Umbilical Assembly | 37 | 30x14x10 |
| Emergency Scuba, Tools, and Accessories | 20 to 30 | 20x14x8 |
| Air Supply (per unit, 2 minimum) | 76 to 99 | 30x16x7 |
| Compressors (per unit, 2 minimum) | 70 to 90 | 22x15x10 |
| Individual Diver Kit | 30 to 70 | 28x15x1 |
| Supervisor's Kit | 20 to 40 | Variable |

For example, a complete diving system (including 640 standard cu. ft. of air) for use in an 18-ft. outboard motor boat and transportable in a station wagon weighs about 600 lbs. This would allow for more than 3 hours of underwater work at a depth of 60 feet using proper rotation of a 3-person team in the surface-supplied diving mode (without recharging air cylinders).

## Tethered Scuba Diving

The equipment and procedures for present day tethered scuba diving referred to in this publication and the tethered scuba diving manual [5] are significantly different from those used in past years. Commonly, tethered scuba diving has implied attaching a rope to a solo diver using a conventional mouthpiece-style scuba regulator. There was no full-face mask security, no emergency air supply alternatives, no communications (except line-pull signals), and, generally, no specific training. Tethered scuba diving equipment, procedures, and application is discussed in another publication in this series (see reference 5).

The following conditions and limitations are recommended for modern tethered scuba diving operations:

- Depth is generally limited to 60 ft. (except in standby diver deployment emergency);
- Communications/strength member tether must be secured to the diver's scuba or safety harness;
- A full-face mask must be used;
- An emergency or secondary air supply and/or regulator system must be used; and
- The diver must surface when cylinder pressure is reduced to no less than 500 lbs./in.2 (300 lbs./in.2 for twin cylinder scuba).

Although tethered scuba diving is not considered as acceptable as surface-supplied diving by some researchers and commercial divers, it has proven satisfactory and safe for selected diving operations and standby diver application. It has been especially useful for very limited to zero visibility shallow water research where the dive team does not have a surface-supplied system available. Under such conditions the presence of a second diver is of little or no safety benefit and may even constitute additional risk.

Tethered scuba diving has also been effectively used for extremely cold weather diving from small, open boats where the deployment of two divers would have greatly complicated logistics and increased the surface exposure time. This mode has been successfully used for under-ice diving.

The equipment for tethered scuba diving must include:

- Demand breathing mask with communications;
- Twin 72, 80, or 100 scuba unit with dual regulator manifold or a 15 to 40 cu. ft. emergency scuba (commonly called a pony bottle in scuba diving);

- Two first stage regulator assemblies with overpressure relief valves (standard mouthpiece second stage if used with pony);
- Submersible pressure gauge on primary regulator;
- Communications/strength member tether; and
- Surface communications unit.

## Training

The criteria for the system described in this publication specify that certified *and* experienced scuba divers should be able to complete surface-supplied and tethered scuba diving training within 16 hours. This would qualify the divers to proceed to properly supervised tethered scuba and surface-supplied diving to a depth of 30 ft. Progressive acquisition of supervised experience would enable the diver to extend his/her capability to 130 ft. in a fashion similar to that used for scuba diving progression by universities, research groups, and the American Academy of Underwater Sciences. Courses would be specifically designed to meet the diving requirements/equipment availability of individual research groups. The author has conducted numerous experimental training courses for scientific surface-supplied diving since 1974 and has more recently introduced a tethered scuba diving program. The training program includes, but is not necessarily limited to, the following:

- Historical development of scientific surface-supplied and tethered scuba diving with emphasis on diving operations best undertaken using these modes of diving;
- Systems design and application philosophy;
- Surface-supplied and tethered scuba diving team members, responsibilities, and personal equipment requirements;
- Description, selection, use, and maintenance of mask/helmet; air control-depth monitoring-communications module; emergency scuba; umbilical assembly; and accessory equipment;
- Routine dive planning and procedures;
- Training experiences in all personnel assignments including supervisor, diver, console operator, tender, and standby diver. Console operators and/or supervisors also serve as timekeeper and recordkeeper;
- Emergency procedures for mask/helmet flooding; communications system malfunction; air supply failure; fouling; blow up; and other diver/surface crew distress factors; and
- Confined water and open water training activities.

Since there is presently no nationally recognized certification for completion of surface-supplied and tethered scuba diver training, only a letter of participation or entry in the diver logbook is generally issued by instructors or institutions. Instructors of tethered scuba and surface-supplied diving are generally certified scuba diving instructors with significant scientific, military, or commercial surface-supplied diving training and experience.

## Conclusion

A compact and portable air diving system has been assembled and field tested by University of Michigan scientific divers. Tethered scuba and surface-supplied diving is routinely used on University projects. The system meets the criteria specified in this paper. Field testing and operational diving have proven the system to be safe, efficient, and highly satisfactory for selected diving operations. Training/operations manuals for tethered scuba diving and lightweight, shallow water surface-supplied diving have been prepared [5, 6] and training workshops conducted within the time criteria of 16 hours.

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