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Use of Surface-Supplied Gas for Scientific Diving

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Abstract

Many scientific diving entities face logistical challenges in their data collection, including high currents, low visibility, finite air supply, and high entanglement areas. This paper and presentation will discuss standard practices for the use of surface-supplied breathing gas for scientific applications to enhance both safety and efficiency of the scientific diver. The paper will examine the relevant regulatory requirements and applicable standards of the federal dive community (e.g., NOAA, EPA) relative to the application of scientific diving, as well as some pros/cons for the scientific diver of tether vs. surface-supply vs. free swimming. Lastly, the paper will make recommendations to advance the surface-supplied breathing gas mode within the scientific diving community.

Keywords: contaminated water protocols, epa diving, federal dive programs polluted diving, surface-supplied diving, surface-supplied gas

Introduction

Surface-supplied diving is unique compared to free swimming scientific divers' more routine use of self-contained underwater breathing apparatus (SCUBA) to accomplish their objectives. Using surface-supplied air, the diver is provided a virtually unlimited supply of breathing gas from tanks or a compressor on the surface through a three-part umbilical consisting of a breathing gas hose, a pneumofathometer (pneumo) hose and communication line (comm line)/strength member to the diver.



Figure 1. EPA conducting surface-supplied dive operations aboard the EPA vessel Biglane.

This paper presents the equipment and methodology used by EPA dive teams engaged in surface-supplied diving and discusses the potential advantages and disadvantages of this mode of diving. The methods presented are specific to the equipment used by the EPA dive teams but are generally applicable to any surface-supply equipment and will be useful in selecting equipment and developing methodology for any system. For the most up-to-date information, the EPA Dive Safety Manual and EPA Dive Standard Operating Procedures should be consulted (US Environmental Protection Agency, 2010).

Methods

Equipment



Figure 2. An EPA surface-supplied diver prepares to enter the water to collect sediment core samples at a Superfund site in New Jersey.

Depending on the planned dive profile, EPA typically uses air or enriched air (nitrox up to 40% oxygen), provided the equipment is approved by the manufacturer for that oxygen concentration and/or has been oxygen cleaned. Check the specifications or contact the manufacturer of the control box before using nitrox.

Gas may be supplied to the control box by pressurized tanks (working pressure can range from 3,000 pounds per square inch [psi] to 3,500 psi; check the manufacturer specifications for details), low pressure/high volume compressors, or a compressor/tank system. All breathing gases must be either generated on-site with a compressor, or purchased through a reputable dive shop or commercial gas supplier. Compressor-generated breathing gas is required to be analyzed to CGA grade E standards at least once every six months. Dive operations shall not be initiated unless there is a sufficient supply of breathing gas for all divers, including stand-by divers and emergency reserve.

All scuba tanks or other pressurized vessels used for breathing gases must be properly maintained, and undergo hydrostatic testing at a qualified facility at least every five years, and have an internal visual inspection by a qualified technician annually. The divemaster or designee shall check that each tank intended for dive operations has markings for current inspection and test dates. Prior to use, the yokes on all gas cylinders should be inspected for damage to the seat or O-rings. Gas pressure must not exceed the rated working pressure for any of the components of the entire diving gas supply system.

All breathing gas compressors must be properly maintained, with regularly logged maintenance records. Compressors must be capable of supplying breathing gas at a satisfactory volume (at least double the volume required) and pressure (at least 25% greater than the maximum pressure requirement anticipated) for all divers at the work site's deepest potential depth.

For voice communications, control boxes typically have an internal, rechargeable, 12-volt battery that must be charged prior to dive operations, and indicator lights that show the battery charge level. The box requires very little power, and a fully charged battery should last up to 20 hours. While plugging the control box into an electrical source is possible, some manufacturers caution to never connect the charger during a dive due to the potential electrical shock to the diver.

Surface-supply umbilicals provide breathing gas, communications, the diver's depth and a strength member between the tender and the diver. Diving umbilicals may either be the sinking or floating type. The sinking type is more likely to snag on bottom obstructions or disturb contaminated sediments. The floating type is positively buoyant and more likely to be affected by surface current or vessel traffic. The buoyancy of the umbilical can be modified in the field by adding floats or weights as required.

Floating umbilicals, ranging in length from 150 to 300 ft, are typically used. The umbilicals are comprised of three separate spiral-wound hoses, although straight (not spiral wound) hoses may be utilized in order to use components separately. For contaminated water operations, a smooth polyurethane twisted umbilical is ideal because it can be more effectively decontaminated than straight umbilicals, which have tape holding them together (Barsky, 2007). The primary hose is the diver's breathing gas supply hose, which runs between the surface-supply control box and the diver's emergency manifold block.

The breathing gas supply hose should be rated to a working pressure of at least 300 psi. The hose typically measures 3/8 inch inside diameter, but some lightweight systems may utilize a 1/4 inch diameter breathing gas hose. To ensure a sufficient air supply, users should be aware that the diameter of the breathing gas supply hose may restrict the safe operation of the system at greater depths, umbilical lengths, or breathing rates. The manufacturer should be consulted to identify any possible limitations of the breathing gas system (Dive Lab, 2008).

The second component of the umbilical is the diver's hard-wired comm line, which allows open, two-way communication between the diver and surface support personnel. The comm line runs between the surface-supply box and the diver's mask-integrated communication system (microphone and earphones). The comm line is usually also equipped with a strength member capable of towing or lifting many times the diver's weight. The hard-wired umbilical may be eliminated if using a reliable wireless communication system, although a strength member is still required.

The third component of the umbilical is the pneumo hose, a gas a simple capillary tube connected to a gauge, which allows surface personnel to monitor the diver's depth. The 1/4 inch inner diameter pneumo runs from the surface-supply control box down to the diver, with its open end attached in the

area of the diver's chest. The control box operator can open the pneumo valve to blow gas through the pneumo hose, and when the valve is closed, the water pressure will back up the hose, allowing the pneumo gauge to read depth. In some instances, the diver can also use the pneumo as a tool to inflate a lift bag or to blow sediment out of a small work area. The pneumo hose may be eliminated in situations where the diver monitors and controls his/her own depth and dive profile with a depth gauge or dive computer.

The diver's harness-mounted manifold block has two ports for attachment of incoming gas supply, one port for the dry suit inflator hose, one port for attachment of the breathing regulator, and two low pressure ports for auxiliary equipment. The primary incoming port is for attachment of the umbilical breathing gas line. This port must have a functioning non-return valve to ensure that a loss of umbilical line pressure, combined with depth pressure, won't suck the gas out of the diver's lungs or the emergency gas supply tank. This ensures that in the event of umbilical air supply loss, the diver will receive air from the emergency gas supply (EGS), which must be worn by the diver for all surface-supplied diving operations. Prior to attachment of the umbilical hose to the manifold block, the non-return valve should be tested by blowing into the valve (air should flow freely through the valve), and then sucking on the valve (no air should come back through the valve). The second incoming port on the manifold block is for attachment of the EGS (a 'bail-out' bottle). For contaminated water operations, the one-way valve may be tested by spraying a soapy water solution from a spray bottle onto the valve with the surface-supply air hose removed. When pressurizing the EGS, no bubbles should emanate from the one-way valve. Then the breathing hose is connected and tested. This demonstrates the functioning of the one-way valve without ingestion of potentially contaminated material.



Figure 3. Pony bottle EGS. The smaller tank is an 'accumulation bottle' required for some light weight (e.g., 1/4" air supply hoses) surface-supply systems.

In the event of a loss of air from the surface, the manifold block has a knob that the diver turns to open the EGS. At the start of the dive, the knob must be in the closed position (fully turned clockwise). During the dive the diver should periodically confirm the knob is fully closed and the submerged pressure gauge (SPG) for the EGS is full. It should be noted that as little as a quarter turn may begin depleting the EGS. All divers must be aware of the operation and placement of the manifold block, so they can find it in an emergency. No other equipment may block the diver's access to the knob.

Dive planning must involve provision of sufficient air for the dive operation, including ascent and exigencies. The EGS bottle should be a scuba tank ranging in size from a 6-cubic-foot (cf) pony bottle to a 80 cf scuba tank. The size of the bail-out bottle is determined by the type of water, i.e., contaminated vs. non-contaminated, working depth, type of equipment, i.e., full face mask (FFM) vs. helmet, and the air consumption rate of the individual diver. The bail-out bottle is typically mounted with the valve in the down position, which allows the diver to turn the tank valve on, should the knob be inadvertently closed. The larger the bail-out bottle, the longer the diver has to surface in the event of a loss of surface-supplied gas. The deeper the diver is working and the more potential hazards present, the larger the bail-out bottle required. A SPG for the EGS must be accessible to the diver at all times. The first-stage regulator on the pony bottle must have an over-pressure relief valve so that a first stage malfunction will not cause a hose failure.

Sometimes it is necessary to fill the bail-out bottle in the field. In those instances, a filling whip (a length of high pressure air hose with tank yoke fittings on both ends) is used to connect the bail-out bottle to a full scuba tank. The empty bail-out bottle valve should be completely opened, and the full scuba tank valve should be opened very slowly, so the bail-out bottle does not heat up. Depending on the size of the bail-out bottle, it may be necessary to use several scuba tanks to get a satisfactory fill (greater than 2500 psi).

EPA divers typically wear a FFM when using surface-supplied gas, but diving helmets may also be used. Both the FFM and the helmet should be equipped with communication equipment (microphones and earphones). The decision to use either a helmet or full face mask depends on the resources and training available to the dive team, the dive objective, pollution/contamination level, or other environmental factors.

A harness should be worn by the diver for all surface-supplied dive operations. The harness is used as an attachment point for both the umbilical line and the diver's emergency breathing gas supply. The comm line must be clipped to the diver's harness prior to the start of the dive. This safety feature allows the diver to pull the umbilical along or for the diver to be towed back to the point of entry without straining any vital gas or communication links.

Operations

The control box should be secured in an area where it will not impede operations of the surface support crew. The box should be held open and secured to a fixed object (e.g., boat rail or a dock piling). The breathing gas source should be within easy reach of the operator. In inclement weather, the box should be set up in an area out of the rain (e.g., in the boat cabin or under a tarp). When the surface-supply control box is set up, the main power switch should be turned on and the battery power checked. The gas outlets should be uncapped and the breathing gas line and the pneumo line should be attached. Since the two lines are different diameters, they can only be attached to their respective outlets. The control box has gas outlets for two sets of umbilical lines, with each set uniquely colored (e.g., one set is marked in red and the other is marked in white). The control box operator must be sure to attach both lines from one umbilical to the same set of outlets. Each

umbilical line (breathing gas and pneumo) has a bronze Joint Industrial Conference (JIC) hose fitting which screws onto its gas outlet. These fittings should be lightly tightened with a wrench to prevent gas leaks, but not tight enough to put torque on the fittings. Both gas supplies have a gate lever that can be opened or closed to allow gas flow to the outlets.

The control box typically has independent inlets for tanks (two inlets) and for compressors (single inlet). When using tanks, the control box has a selector valve handle that is used to switch between two incoming tank inlets. Each tank inlet may be attached to a single or bank of tanks. Whether a single tank or bank of tanks is used, all the tank(s) on both incoming inlets must be open. When using a compressor, the compressor should be attached directly to the compressor inlet and at least one tank should be attached to the tank inlet as a backup to the compressor if it malfunctions during the dive.

After the gas tanks are attached to the system, the operator should blow out the breathing gas line to remove any dust or particles by briefly opening the outlet gate; then it can be attached to the diver's gas supply manifold block. The control box communications system can be operated either with a microphone and the built-in speaker so all surface personnel can hear the diver or the box operator can wear headphones to block out external noise (e.g., machinery, wind, extraneous conversation). When using headphones, the operator may turn off the speaker switch so that only the box operator can hear the diver. When in this mode, the operator must relay information to dive tender and other surface personnel. The set-up should be close enough to the dive operation and tenders to allow clear communication between the operator and dive tender. Prior to donning the helmet or FFM, the diver and control box operator must perform a communications check. The surface end of the comm line is wired with connectors for attachment to the control box, and the diver end of the comm line is wired to attach to the diver's communication line (microphone and earphones). The control box has adjustment knobs for surface-to-diver and for diver-to-surface volume. Proper two-way communications should be established prior to initiating dive operations.

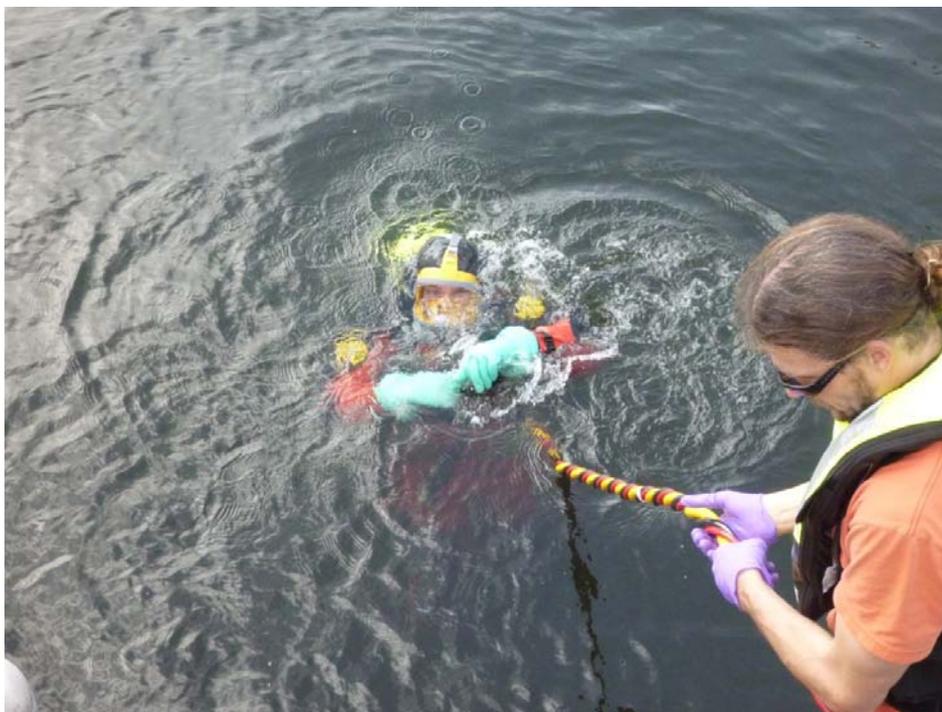


Figure 4. An EPA surface-supplied diver is held at the surface as the tender maintains line tension with two hands.

In the event of a loss of voice communication, the dive unit should practice backup line pull signals to ensure the dive can be safely and efficiently aborted. To insure proper interpretation of line pulls, it is vital that there is no slack in the umbilical. Line pulls should be discussed during the dive briefing and included in the Dive Plan. Standard line pull signals are available in the US Navy Diving Manual, 2008.

Example Emergency Line-Pull Signals

Primary Diver to Tender:

- 2-2-2 *I am in a difficulty but I am OK, I need assistance, send the backup diver.*
- 3-3-3 *I am entangled and OK, I am stopping to handle it myself but ready the backup diver.*
- 4-4-4 *I am not OK, I need immediate assistance.*

The area in which the diver dresses and uses for access to the water should be kept clear of all debris and items that could present slip, trip or fall hazards. The tender should always be available to physically assist the fully dressed diver. The tender should assist the diver in donning all equipment and ensure all belts, clips and harnesses are securely fastened. The dive tender and/or the box operator should ensure that all air systems and communications are functioning properly. The tender should complete all pre-dive checks as specified in a Surface-supplied Air Checklist.



Figure 5. Diver entering the water to conduct a bottom search in zero visibility conditions.

The tender should assist the diver entering the water and always maintain a grip on the umbilical. When the diver jumps into the water, it is the tender's responsibility to ensure that there are no obstacles in the diver's landing area. The tender should also give the diver enough slack in the umbilical to get into the water just below the surface. Immediately after the diver has entered the water, the tender should pull the diver back to the surface. Once back at the surface, the diver should ensure that he or she is properly weighted and do another communication check. The tender and the diver should assess the diver for leaks (bubbling, particularly around the mask). Once the diver is

ready to submerge, the tender should give the diver enough slack to descend. Since the tender is usually in the best position to witness the diver submerging, the tender should call out to the box operator and/or divemaster when the diver has submerged so the submergence time can be recorded.

When a diver is in the water, the box operator must maintain regular, open communication. Once the diver has descended to the work site, the operator should monitor the diver's depth using the pneumo. Using the correct pneumo gauge for the diver's umbilical, the operator should open the pneumo valve below the gauge by turning it in a counter clockwise direction until the depth gauge reads a depth that is known to be deeper than the diver, or until the diver reports bubbles coming from the open end of the pneumo hose. The operator should then close the valve, monitor the depth gauge and record the diver's depth (measured in feet of sea water [fsw]) when the gauge needle stabilizes. The operator should monitor the diver's depth frequently, especially when the diver is moving around. The divemaster or designee records this information on the tending form during the dive. The divemaster may choose to use a computer or depth gauge to monitor depth in lieu of using a pneumo hose, as long as the control box operator appropriately compensates for intermediate pressures throughout the dive, as discussed below.

The control box operator should ensure that the diver is getting sufficient breathing gas pressure at depth. The umbilical pressure gauge on the control box should read between 115 psi and 225 psi depending upon the specifications of the mask or dive helmet being utilized, bottom depth, and particular control box instructions. Lower umbilical pressure results in more effort on the diver's part to breathe. The EPA typically maintains umbilical pressure at 150 psi for light to moderate workloads. If the diver is performing manual labor (e.g., pounding sediment cores or moving heavy objects) and is breathing hard, it may be necessary to increase the umbilical pressure by turning the umbilical pressure knob until the diver reports that gas flow is comfortable.

The control box operator must maintain careful watch over the pressure gauge on the line that is supplying gas to the diver when using breathing supplied from tank(s). When the gauge reads approximately 500 psi, the operator should flip the selector handle to the other incoming gas line. The selector handle must be turned all the way to its stop for breathing gas to flow properly. As soon as possible, the operator, or designee, should replace the spent gas cylinder with a full cylinder. When using scuba tanks, the spent tank valve should be closed, and the pressure should be bled out of the hose between the tank and the control box using the bleed valve on the yoke. Upon removing the spent tank and replacing it with a full tank, the bleed valve should be closed and the tank valve should slowly be fully opened. The operator should ensure that the pressure gauge on the control box indicates a full tank. This procedure should be followed each time a spent tank is replaced. It is the responsibility of the control box operator to ensure that a sufficient gas supply is readily available for all diving.

Prior to switching the gas source, the operator should notify the diver to suspend the current activity, locate the EGS manifold block and be ready to switch to emergency gas. Once the diver has responded to the operator and has put a hand on the manifold block, the operator can switch the gas source. In the event that a gas line or a seal (O-ring or fitting) should fail upon changing pressure, the diver will be prepared to immediately switch to EGS. If a seal should fail and gas pressure to the system is lost, the operator must switch back to the previous tank and inform the diver to be ready to switch to the EGS. The box operator should replace the failed tank with a new tank as quickly as possible and switch to the replacement tank. Once the situation has been resolved, it is the divemaster's decision to either continue or terminate the mission.

It is the responsibility of the divemaster, the diver and the tender to ensure that the valve of the bail-out bottle is opened after it is connected to the manifold block and that the manifold block knob is

closed. The bail-out bottle pressure should be checked and recorded prior to every working dive. The EGS should be mounted upside down, and the divemaster should verify that the diver can reach the tank valve to re-open it, should it become closed.

At the termination of each dive, the operator should notify the surface support crew that the diver is ready to ascend. If conditions permit the diver to control the ascent, the tender should slowly pull in the slack from the umbilical as it becomes available. The umbilical should be coiled in alternating over-under loops to facilitate the next deployment. If conditions do not permit the diver to control the ascent (e.g., low visibility or mid-water current), the tender should gently pull in all slack umbilical and the operator should have the diver swim on the bottom in the direction of the umbilical. Once the diver is close to or below the boat/platform, the diver should become negatively buoyant and the tender will use the umbilical to lift the diver to the surface. The tender must maintain an ascent rate of no more than 30 feet per minute, and the operator must continually communicate with the diver to ensure that the ascent rate is not causing discomfort (e.g., reverse squeeze). The box operator can monitor the diver's rate of ascent simply by watching the pneumo gauge. The operator should warn the diver if any surface hazards are present. Once the diver surfaces, the tender should call out to the divemaster or box operator, who should record surface time on the dive log. Once at the dive platform, the tender should assist the diver exiting the water. When diving in contaminated water, proper decontamination methods should be utilized prior to undressing the diver.

When switching divers, the same harness rig is worn but the next diver's personal FFM should be used. To switch FFMs, the box operator should close the gate on the umbilical gas outlet, and the tender should push the purge button on the first diver's FFM to bleed the pressure out of the breathing gas hose. The FFM should then be removed and the next diver's mask put on the system. Dive computers must not be shared.

Equipment Maintenance

At the end of each day, the main power switch on the control box should be turned off, and the battery power should be checked. If the battery is low, the box should be charged overnight prior to the next dive operation. The microphone should be disconnected and stowed in the battery compartment, and the comm line connectors should be gently pulled. The gas supply tank valves should be closed and the bleed valves on the tank yokes should be opened to depressurize the supply hoses. The scuba tanks should be taken off the system, and any tanks that have not been exhausted should be capped for future use. Tanks that have been exhausted should not be capped, and should be kept separate from the full tanks. The FFM purge button should be pushed to bleed the gas out of the umbilical. The gas supply gate should then be closed. Using a wrench, the umbilical lines (both breathing gas and pneumo) should be disconnected from the box and the breathing gas hose should be capped immediately. The gas outlets should then be capped, finger-tight, with their brass caps. The control box should then be closed and latched.

The harness should be disconnected by unclipping the umbilical and using a wrench to disconnect the breathing gas supply hose. The pony bottle valve should be closed, and the valve on the manifold block should be briefly opened to bleed the hose pressure so that the regulator first stage can be removed from the bottle and capped. After decontamination, the umbilical should be coiled neatly and stowed. Once all gear has dried, the umbilical, harness, pony bottle and regulator should be stowed and all of the latches should be tightened. If shipping the case by air, the pony bottle must either be removed or emptied. After the project is completed, all equipment should be allowed to air dry prior to being stored.

The control box should be serviced by a qualified technician on an annual basis or as recommended by the manufacturer. The breathing gas hose must be pressure tested to 1.5 times its working pressure and cleaned internally by a qualified facility on an annual basis. The breathing gas hose must be kept clean, inside and out. For cleaning, a 20–30 minute detergent and water flush should be followed by a 10-minute rinse, then drying using diver's air or nitrogen. It is important to ensure that both ends of the hose are properly capped when the hose is not in use to prevent dust and particulate contaminants from getting into the breathing system. (DiveLab, 2008).

Personnel

Each member of the surface-supplied dive team will have the experience or training necessary to perform the assigned tasks in a safe and efficient manner. This experience and training will include the use of tools and equipment needed for the specified tasks and techniques required for surface-supplied diving. Each member of the dive team will also have training in the emergency procedures required in the event of a diving accident. Each dive team member will only be assigned tasks in accordance with that person's training and experience.

A simple surface-supplied diving operation (a single diver and shallow, short duration dives) requires a minimum of four people; a diver, a stand-by diver, a tender, and control box operator/divemaster. However, dive projects requiring multiple dives, depths greater than 30 ft and multiple divers may need a larger minimum crew. If two divers are in the water simultaneously, a minimum of six people are required: two divers, two tenders, a stand-by diver, and a control box operator/divemaster. These minimum numbers assume that all personnel, with the exception of tenders, are qualified divers who could switch duties from surface support to in-water operations. Crew size will ensure that each diver shall be continuously tended while in the water. The responsibilities of the dive team are described in the EPA Diving Safety Manual, but those responsibilities specific to surface-supplied diving follow.

The divemaster carries the overall responsibility for the safety and performance of the dive operation. On small operations, the divemaster may also assume the responsibilities of another surface support person or even perform in-water duties if there is a qualified divemaster available to assume the divemaster's surface responsibilities.

Divers are primarily responsible for performing dive duties as instructed, and maintaining open communication with surface personnel. The diver is also responsible for ensuring all dive equipment is present and in working order. The surface-supply control box operator and the divemaster should be aware of the diver's status at all times. It is the diver's responsibility to ensure that he/she understands the objectives of the dive and is aware of all safety equipment and procedures that may be required. For supplied diving operations, at least one qualified member of the team will be designated as a stand-by diver. The stand-by diver will be ready to enter the water promptly in case of an emergency.

The dive tender must assist the diver while preparing for, conducting, and recovering from in-water operations. The dive tender will maintain control of the surface-supply air umbilical, ensuring that the diver has enough umbilical to work freely, but not so much umbilical to pose an entanglement hazard. The dive tender will also be responsible for visually tracking the diver's location while in the water. The dive tender and all surface personnel are responsible for advising other vessels of the dive operation and warning off any vessels that may pose a hazard to the diver. Although the tender does not need to be a certified diver, the tender must be trained to perform the required duties and have an understanding of the diving equipment.



Figure 6. Box operator monitoring the diver's air supply and depth during scientific dive operations.

A qualified and trained person will be dedicated to running the surface-supply control box. This person's sole responsibilities are maintaining sufficient breathing gas delivery and communications with the diver. The dive control box operator, in conjunction with the divemaster, must be aware of the diver's profile (maximum allowable depth and bottom time) and actual bottom time and depth to ensure that all diving is performed in a safe manner and the diver does not exceed the no-decompression limits (NDL) or the dive-specific profile limits. The control box operator is directly responsible for the safety of the diver. In certain circumstances, at the discretion of the divemaster, the surface-supply control box operator may also maintain the dive logs.

The boat operator is responsible for all boat operations in support of the dive mission. The boat operator must have experience or training in operating the vessel during dive operations and performing emergency procedures that may be required. During the dive, if the boat is secured in position (anchored or docked), this person may also perform the duties of one of the surface support personnel.

Discussion

Free swimming scuba is often the mode used by scientific divers and has been used safely and successfully on numerous projects. While free swimming scuba will continue to be a viable mode of diving on many projects, the use of either tethered scuba or surface-supplied is often a safer and more efficient method.



Figure 7. An EPA diver dons a dive helmet for polluted water dive operations.

There are many advantages to tethered scuba, such as being able to hold a diver on station in current, communicate with the diver using clear hard line comms, pass instruments to the diver, and easily navigate a diver to a location with directions relative to the umbilical.

There are even more advantages to the surface-supplied diving mode. Not only does surface-supplied air provide the diver with extended bottom times compared to scuba, but it also provides a safer and more efficient mode of diving to conduct scientific diving operations. When using surface-supplied air, the diver is no longer limited to bottom times based on the volume of air that can be carried by the diver, but rather by decompression limits, which, at shallow depths (less than 50 ft), are significantly longer. This provides the diver more time to safely complete tasks without having to return to the surface to change tanks. The single greatest hazard to a diver is running out of air, or running low on air inadvertently or due to entanglement. When using surface-supplied air this hazard is greatly reduced. The risk of inadvertent loss of air supply is completely eliminated and if a diver is entangled, the surface support team will be in communication with the diver and able to supply air until the diver frees himself or the standby diver is sent in to render assistance. Even if the planned dive times or no decompression limits are exceeded, there is still sufficient air supply to extend safety stops or run in water decompression so the diver can safely return to the surface with no increased risk of decompression sickness.



Figure 8. Surface-supply hoses should be managed in the vessel's "hot zone" for polluted water operations.

Due to the virtually unlimited air supply, surface-supplied diving offers the scientific, polluted water diver the ability to conduct extensive decontamination without exposing the diver. For example, at some dive sites, an antimicrobial solution may be required to have "contact time" on the diver before he or she may remove the mask or helmet. The surface-supplied gas allows the diver this extended time to egress his or her personal protective gear safely.

A scientific diver, using surface-supplied air, is supported by several dive team members topside who will monitor the diver's air supply, bottom time, depths and direction of travel, freeing the diver to concentrate solely on accomplishing the dive objectives. The diver does not have to constantly monitor air supply, rush to finish, or leave tasks uncompleted, due to dwindling air supply. This is also beneficial in areas with extremely low visibility where it is difficult (if not impossible) to read diver worn gauges and/or compass. The surface-supply team can also direct a diver to targets verbally, using the umbilical, and/or tracking the diver's bubbles.



Figure 9. An EPA surface-supplied scientific diver conducts sediment sampling.

For some scientific dive tasks, it is not always more efficient or safe to use a buddy team of free swimming scuba divers compared to a single diver on surface-supplied air. Often a task may be more efficiently performed by a single diver and the second diver's only purpose is to be the buddy for the primary diver. In this case, a second non-essential diver increases costs and hazards. This is also the case when diving in water with limited or no visibility, the primary diver is trying to accomplish the required task while remaining aware and in contact with his buddy throughout the dive.

The most exhausting, potentially hazardous and inefficient parts of a dive operation involve the diver's entry and exit from the water and changing/handling/carrying heavy tanks. With a scuba diver, these activities occur more frequently, as the diver must return to the surface to exchange tanks. They can be greatly reduced by using surface-supplied air. In this manner, surface-supplied diving not only makes the operation more efficient, but also reduces unnecessary bounce dives, which minimizes the potential for bubble formation.

The comm line allows the surface support team to be in constant two-way communication with the diver throughout the dive. Not only does this provide an increased level of safety, but it also allows the scientific diver to verbally record and/or dictate his observations to the topside support team for more efficient and effective documentation. Compared to wireless communication options, wired communications are more reliable and easier to understand.



Figure 10. A fully encapsulated EPA diver prepares to install a groundwater sampling probe into the sediments.

Diving in currents exceeding one knot is generally not safe or feasible using scuba divers. In certain situations the use of surface-supplied air allows scientific divers to conduct work in high current conditions that would not be possible using scuba. The use of a single diver using surface-supplied air eliminates the risk of buddy team separation and having the diver swept away from the support vessel by the current. The surface tender can physically hold the diver in place, allowing him to perform tasks with his hands that would not be possible with scuba. Wearing an emergency gas supply (EGS) instead of a full tank plus EGS, the diver can maneuver more easily and maintain a lower profile in high currents. Generally, the diver will have to work down current from the support vessel within an approximate 70 degree arc, due to the force exerted by upstream current and excessive drag on the umbilical when trying to work cross-current.

The potential drawbacks of surface-supplied diving are the amount of equipment and personnel required and having fewer divers in the water at one time to complete tasks. Surface-supplied diving requires additional training (initial and routine) and is more equipment intensive (control box, umbilical hose, harness, EGS, manifold block) than scuba diving. Surface-supplied diving also requires a larger crew (box operator, standby diver, tender) to support a single diver. EPA and NOAA currently require a minimum of four team members to conduct surface-supply dive operations, while the Association of Diving Contractors International (ADCI) requires a minimum of three team members (no designated standby diver is required by ADCI for some dive profiles).

Surface-supplied equipment and personnel may require a larger vessel or staging area than other diving methods. Surface-supplied diving at deeper depths may not be effective if the diver's bottom time is limited by the no-decompression tables rather than air supply. At deeper depths, the diver's range may become too limited due to the length of the umbilical. A diver in 20 ft of water will have a range from the support vessel of about 120 ft on a 150-ft umbilical, while a diver in 120 ft of water would be limited to a range of about 20 ft.

Surface-supplied diving has numerous safety and efficiency advantages over traditional free swimming scuba. Although free swimming scuba will continue to be a valuable tool for scientific diving operations, the use of surface-supplied diving should be evaluated and considered as a safer and more efficient mode of diving, often under demanding conditions. Scientific dive teams currently using free swimming scuba should consider the numerous advantages of this mode of diving. If there is an apparent need, the team should pursue the training and equipment required to utilize this valuable method of diving to safely fulfill their scientific diving objectives.

Special Note: The standard practices presented in this article presume and require prior training and experience with surface-supplied diving and are not a substitute for actual hands-on training. Each component of a diver's equipment shall be maintained in a safe operating condition, and shall be inspected, tested, serviced and logged as required. Divers should be dive certified and medically qualified to perform their diving duties. The US EPA requires preparation and review of a Dive Safety Plan prior to conducting dive operations, with additional information required for polluted water dives. A Job Safety Analysis (JSA) will insure that all appropriate safety equipment is available at the dive site, as specified in the Dive Safety Plan.

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