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# Using "Technical Diving" Techniques for Short Dives in the 80-100 MSW Range

**R.W. Bill Hamilton, Ph.D., and Joel D. Silverstein**
Hamilton Research, Ltd.
80 Grove Street
Tarrytown, NY 10591-4138, USA
(914)631-9194, fax (914)631-6134
rwh@rwhamilton.com; jds@nitroxdiver.com

## Abstract

**Introduction:** Advanced recreational divers over the last 10 years have developed new techniques for open circuit scuba diving in the range to about 100 metres of sea water (msw). These techniques have potential application in military diving. This report describes the new practices, the equipment, procedures, and training required, and some results of several significant operations.

**Methods:** The techniques known popularly as "technical diving" involve the use of special breathing mixes, means of carrying the mixes, custom-designed decompression tables which include oxygen exposure management, means of performing proper decompression, adequate thermal protection, and appropriate redundancy. A typical dive to 80 msw for 20 min could use for the bottom mix a "trimix" of about 17% oxygen, 50% helium, and the balance nitrogen. This is carried in twin back-mounted tanks each of perhaps 3000 liter capacity, with two side tanks containing an oxygen-enriched air decompression gas and oxygen or a high-oxygen mix. The diver does a stage decompression, switching to the intermediate mixture at a depth appropriate for its oxygen content, say 33 or 30 msw for an enriched air mix of 36% oxygen, and then breathing oxygen at the stops at 6 and 3 msw. Decompression may be carried out in open water with the diver hanging on the vessel's anchor line or some other attachment, or the diver may get partially out of the water inside or some sort of air-filled decompression station. Because high oxygen partial pressures are used to optimize decompression, it is necessary to plan and monitor the oxygen exposure as a component of the dive. Although operating standards have yet to be put in place, technical diving practice has become fairly uniform worldwide, and training can be obtained from a number of organizations.

**Results:** Divers in pairs or small groups routinely dive on sunken vessels such as the *Andrea Doria*, but there have also been a number of well organized team efforts, including dives in the 80 to 100 msw range to wrecks such as the *Lusitania, Brittanic*, and *U.S.S. Monitor*. A number of significant dives have been done in water-filled caves in the same depth range. Considering the extent of the exposures decompression sickness is relatively rare, but there have been a number of accidents of an operational nature, due to such things as breathing the wrong gas mixture. In any case technical diving techniques using "trimix" are regarded as being considerably safer than making equivalent dives with air as the breathing gas, because this avoids the narcosis in the air dives.

**Conclusions:** Some U.S. Government agencies are showing serious interest in technical diving. NOAA is conducting technical diving operations on the U.S.S. Monitor, and the U.S. Navy has plans to provide technical diving training for some Navy divers. For diving organizations with the commitment to be able to operate in this depth range, technical diving methods are worth considering.

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## Technical diving

A new category of self-contained diving that greatly extended the range of recreational scuba diving began to be practiced in the late 1980s. At one time recreational diving was limited to air, but some advanced sport divers began to use special breathing gas mixes that permitted them to extend this range, at first to about 75 msw, and later even to 100 msw on a routine basis. The method they developed consisted of adding enough helium to air to relieve the narcosis, resulting in a "trimix" of oxygen, helium, and nitrogen The reason such mixes had not been used before was that there had been no available decompression tables for these kinds of mixtures. Other considerations were the management of oxygen toxicity, the ability to carry enough gas, and other exposure-related factors having to do with long decompression times

The development of technical diving was done primarily in the recreational and scientific communities, far removed from military diving, but the capabilities of the techniques could be of great relevance to some military operations. Making this point is the main objective of this paper.

The term "technical diving" has developed as a description of this category of special-mix diving. Strictly speaking as it has been developed this is still "recreational" diving—it is recreational in the sense that most practitioners do it for fun rather than employment, but is still a highly disciplined and professional undertaking that does not belong with traditional recreational diving. This is a method of self-contained or untethered diving (that is, no gas hose to the surface) that extends well beyond the traditional envelope of "recreational" diving; it relates to that as technical mountain climbing does to hiking.

Figure 1. Technical trimix diver. Diver has manifolded "back" tanks and one sidemount of oxygen-enriched air, with regulators, a light and a dive computer. Photo by Joel Silverstein.

Technical divers use special breathing mixtures and custom decompression tables, but they do other things involving technology (Figure 1). They use special tactics to carry the amount of gas needed, either by means of larger tanks or by using higher pressures or both. Special attention is given to buoyancy control. Divers working in a current or exploring a cave often use battery-powered diver propulsion vehicles or "scooters" to increase mobility. Various techniques are used to protect divers during long decompressions. Because exposures may be long, special thermal protection is required.

**Figure 2. Technical trimix diver. Diver has manifolded "back" tanks and sidemount of oxygen-enriched air, with regulators, a light, and a dive computer.** **Photo by Joel Silverstein.**

To view technical diving from the proper perspective, keep in mind that it was developed to avoid having to use air for deep dives.

### Deep recreational dives

By way of background, recreational diving is well recognized as having strict limits, with depth generally limited to the range to 40 msw, and it is further limited to dives with air as the breathing gas and not involving decompression stops. Realistically, these are not the limits within which all recreational divers operate, but they are the limits to which divers are trained by the

recreational diving training agencies, particularly in the U.S.A. "Deep" is a relative term which involves the diver's own skill and preparedness as much it does the water depth. Even within these limits special "deep" training is needed to go even as deep as 130 fsw.
For some years now some scuba divers have exceeded the 40 msw (130 fsw) limit, using decompression stops when necessary, and under some conditions have even used oxygen for decompression. This tactic can make the otherwise unreliable USN Exceptional Exposure air decompression tables work quite well. These divers to go well beyond the depth at which nitrogen narcosis can become seriously debilitating. As depth increases much beyond 60 msw (200 fsw) the $PO_2$ in air also becomes a risk factor due to CNS toxicity.

As mentioned above, because of the narcotic risk, in the late 1980s deep cave divers began to add some helium to their bottom mixtures. This worked well for some depth ranges, and the practice soon expanded to the use of trimixes with all three components controlled. This also allowed the oxygen fraction to be reduced, allowing lower $PO_2$s at bottom depth and making longer bottom times feasible from an oxygen toxicity viewpoint. Another factor in selecting the exact composition of the breathing mix was ease of mixing, using air as the major component. For a certain depth range a mix can be made by adding helium to air. The use of special mixtures made special decompression tables necessary, and these were developed. This technology quickly spread to deep wreck divers, who learned to do this same pattern with diver-carried gas.

Because these divers were "recreational," they were not limited by having to comply with occupational safety codes. Their main motivation was to do extended range diving safely, and they were able to be quite creative in the process.

**Oxygen-enriched air or "nitrox"**

It is pertinent to mention another related development in scientific diving, and later recreational diving, starting a few years before technical diving. This is diving with oxygen-nitrogen breathing mixtures with more oxygen than air, referred to as oxygen-enriched air or "nitrox" or by compromise, "enriched air nitrox" (Hamilton , 1989; NOAA, 1991). The term "nitrox" paradoxically seems to focus on the nitrogen component of the mix, but the term refers to an oxygen-rich mixture. Diving with oxygen-enriched air provides advantages in decompression, either as longer time without the need for decompression stops, or faster decompression where stops are used. Although it is different from normal scientific and recreational diving practice, it does not in any way allow access to deeper depths, which is the focus of this paper, so is not discussed further here. Diving with "nitrox" or oxygen-enriched air as the only mix on a dive is not properly regarded as technical diving.

**Comments on the terminology**

Since there is possible confusion over the term "technical diving," it is pertinent to define it. By one definition the minimal requirement of a technical dive, the characteristic that sets it off from other kinds of scuba-based diving, is that on a technical dive the diver uses more than one breathing mixture. Just diving beyond the limits defined for recreational diving is not enough to qualify as technical diving, especially if air is the only breathing gas. However, deep air diving using other gas mixtures and oxygen for decompression, for example, would be regarded as technical diving. Also, a dive with rebreather apparatus might be regarded as a technical dive.

In fact, British terminology, especially with respect to military diving, has regarded diving with rebreathers as "technical diving" for over half a century.

This paper focuses on diving in the 80 to 100 msw range. For this there is a reasonably uniform practice, and this requires using the appropriate breathing gas mixtures. Bottom mix is usually a "trimix" of oxygen, helium, and nitrogen, and intermediate mixes are usually oxygen-enriched air. Oxygen level is controlled to maintain efficient decompression yet avoid toxicity. Thus a "technical" dive as we are using the term is essentially a "technical trimix dive."

The term "trimix" is also used elsewhere in another sense. It may refer to the addition of a small amount of nitrogen to the breathing mixture to reduce the effect of the High Pressure Nervous Syndrome in a very deep saturation dive.

## Previous technical trimix diving operations

In the 1970s Italian coral gatherers with the help of diving physiologists began performing dives remarkable similar to the technical diving practice described here (Zannini and Magno, 1987). Their practice included routine dives in the 70 to 100 msw range. Their breathing mix was 10% oxygen, 40% helium, and 50% nitrogen. Decompression procedures were based on a Haldane-Workman-Schreiner algorithm very similar to the one used for the procedures covered below, and the dive profiles appear to be similar in shape and duration, except that coral gatherers performed surface decompression in a deck chamber. Decompression from a 30 min dive to 80 msw required 140 min of decompression time, and about half that was on oxygen. In a series of 860 trimix dives no decompression sickness was reported.

The British Navy began a trimix program in the late 1970s, using a mix of 20% oxygen, 40% helium, and 40% nitrogen with a target depth of 15 min at 75 msw (Shields et al, 1978). Laboratory trials were used to develop parameters for a computational model (Shields et al, 1978), and trials at sea were conducted later (Shields et al, 1982). Efforts to work out a satisfactory decompression plan were essentially stymied because of excess oxygen toxicity, and the project was eventually discontinued.

## Decompression from trimix dives

As mentioned, the key to implementing technical trimix diving was the ability to perform an efficient and reliable decompression that did not pose a substantial risk of oxygen toxicity. This was worked out with field trials (Hamilton and Turner, 1988) based on an algorithm that had been empirically developed and laboratory validated for extreme exposure air dives (Hamilton et al, 1988). Since that time the computational methods have been refined, and methods for handling oxygen exposure have been worked out.

Selection of the optimal breathing mixtures is a key part of planning a trimix decompression. For the bottom mix one wants enough helium to eliminate significant narcosis. However, the more helium in a trimix the longer the decompression; while this effect is moderate, it is felt to be important. Also, the divers who worked out these techniques regarded the cost of helium as significant, so they normally used only enough to get what they regarded as an adequate reduction in narcosis. There is some uncertainty involved in calculating the "equivalent narcotic depth" of a trimix. There is a common belief that the oxygen can be ignored as it is in making some decompression calculations, but the properties of oxygen say it should be even more narcotic than nitrogen. Unfortunately there is no way to know exactly how much oxygen is present in the cells of the nervous system that regulate narcosis. This topic is in need of further study. Limited data suggest that with regard to narcosis the oxygen should not be ignored (Bennett, 1970; Linnarsson et al, 1990).

A technical dive normally includes descent, time on the bottom, and ascent to the first decompression stop breathing a bottom mix with helium to avoid or reduce narcosis, and having the appropriate oxygen level. The ascent or decompression calls for one or more intermediate breathing mixtures, and usually ends with oxygen breathing at the shallow stops. The intermediate mixes are generally oxygen-enriched air ("nitrox"). This does two things. It allows a higher oxygen to be used, and it reduces the helium component. The diver after a bottom time on trimix will usually have a significant load of helium.

After the intermediate or “deco” mix the diver usually switches to 100% oxygen for the last two stops, normally at 6 and 3 msw. As long as the diver is breathing oxygen the last stop can be taken at the depth of the next deeper stop. That is, the 3 msw stop can be taken at 6 msw. This is often helpful if the sea is rough. This has been found to make no difference as far as the decompression is concerned, but taking the stop at the deeper depth does increase the oxygen exposure, and this has to be taken into account.

## Decompression tables

As mentioned above, a key factor in making trimix diving accessible to a variety of recreational and scientific divers was the development of methods of decompressing. These began with custom tables calculated specifically for the dives to be done, including such details as following the profile of a cave, and adjusting the gases to those that would be optimal for the profile to be followed or that would be relatively easy to get. Other approaches have been developed including dive computers designed for trimix diving, and computer programs that allow divers or diving engineers or operations managers to generate their own custom tables. As sample of one of the early tables, from a set that is still in wide use, is shown in Figure 2. Because of the importance of oxygen exposure and the fact that mixtures are not always precisely mixed, this table calculates the oxygen as a range, with the decompression figured on the lower end, and the toxicity on the higher end of the oxygen range.

SAMPLE TRIMIX DIVE — DEPTH 75 MSW
RWH/DJK 91Aug07 — BOTTOM TIME 30 MIN
DA59T0.H00 MM11F6.DCP — BOTTOM MIX 17TX50
BOTTOM PO2 1.45 BAR
Times are in minutes

| DEPTH MSW | STOP TIME | DECOM TIME | MIXTURE | PO2.RANGE BAR BAR | COMMENTS |
|---|---|---|---|---|---|
| 00 | 00 | 00 | AIR | 0.21_0.21 | DESCEND AT A COMFORTABLE RATE |
| | 00 | 00 | 17TX50 | 0.16_0.17 | BREATHE 17TX50 FROM SURFACE |
| 75 | 30 | 00 | 17TX50 | 1.36_1.45 | ASCEND TO FIRST STOP AT _20 MSW/MIN |
| 36 | 02 | 04 | 17TX50 | 0.74_0.78 | FIRST STOP: ASCENT RATE NOW _10 MSW/MIN |
| 33 | 02 | 06 | 36EANX | 1.51_1.55 | SWITCH TO EANx INTERMEDIATE MIX 36EANX |
| 30 | 01 | 08 | 36EANX | 1.40_1.44 | |
| 27 | 01 | 09 | 36EANX | 1.30_1.33 | |
| 24 | 03 | 12 | 36EANX | 1.19_1.22 | |
| 21 | 04 | 16 | 36EANX | 1.09_1.12 | |
| 18 | 05 | 22 | 36EANX | 0.98_1.01 | |
| 15 | 07 | 29 | 36EANX | 0.88_0.90 | |
| 12 | 16 | 45 | 36EANX | 0.77_0.79 | |
| 09 | 10 | 56 | OXYGEN | 1.71_1.90 | BREATHE O2, 9 MSW TO SURFACE, RESTING. |
| | | | | | O2 CYCLES: 20 MIN ON, 5 MIN OFF |
| 06 | 20 | 76 | OXYGEN | 1.44_1.60 | |
| 03 | 31 | 107 | OXYGEN | 1.17_1.30 | |
| 00 | 00 | 108 | AIR | 0.21_0.21 | REACH SURFACE |
| | | | | | TOTAL TIME = 02:18 HR:MN |
| | | | | | DECOM TIME = 01:48 HR:MN |

OTU = 188 VC DROP =_1.1%

Figure 2. Sample trimix table. This format shows the stop depths and times, with the mix names and the range of oxygen used, plus operational comments on how to run the dive. This table uses oxygen at 9 msw, breathed in cycles; this is considered too deep for oxygen under most circumstances.

## Oxygen in decompression

It has been know for some time now that oxygen is beneficial to decompression (Behnke, 1942; 1955; 1967; Lambertsen, 1967). One of the characteristics of technical diving is that it takes full advantage of oxygen. This requires that oxygen be used in the decompression calculations, and further that methods for tolerating these oxygen levels be an integral part of every operation. The latter point can be stated another way, that procedures for avoiding oxygen toxicity always be used.

The use of oxygen is integral to the basic technical trimix dive pattern; it is implemented by adjusting the level of oxygen in the breathing mixes at the various stages throughout the dive. Oxygen in the bottom gas is kept at as high a level as it can be, consistent with its toxicity. Wise technical divers do not push the oxygen limits in the bottom mix because the diver is usually exercising (see next section), and during that part of the dive is necessarily at the farthest distance from the surface. After the diver leaves the bottom and ascends through the first few short stops the mix is usually switched to an intermediate or “deco” mix. This mixture is selected to be at nearly the highest tolerable level during the first stop it is breathed, but its oxygen partial pressure is reduced at subsequent stops. Sometimes if the dive is deep and/or long a second intermediate mix is used so that the oxygen can once again be increased to the optimum level. As mentioned, the final stops near the surface are taken on pure or almost pure oxygen.

These changes of breathing mix are needed for the open-circuit scuba mode of diving, but with a fully-closed, oxygen-controlled rebreather the oxygen level—the partial pressure—can be set at an optimal but tolerable level such as about 1.4 atm and kept there throughout the dive. This is more efficient than switching mixes.

Another less important benefit of switching gases during decompression is to change the inert gas. Most computational models for computing decompression tables show an increased elimination of one inert gas from the body when the diver is breathing a mix which is rich in a different inert gas. Thus an oxygen-nitrogen intermediate mix is favorable when the diver's body is loaded with helium.

## Oxygen tolerance

Since optimizing decompression procedures is very much a matter of optimal use of oxygen, dives are usually planned so that the diver uses the maximum level of oxygen consistent with avoiding toxicity. By way of review, two specific forms of oxygen toxicity are of concern to divers. The most important of these is toxicity to the central nervous system that can result in an epileptic-like convulsion. CNS toxicity can follow short exposures, minutes, to a relatively high oxygen level. A slower moving toxicity affects many other parts of the body, including peripheral nerves, but is manifest primarily in the lungs. This has been called "pulmonary" toxicity because the development of toxicity effects can be monitored by measurements on the lungs, changes in vital capacity. A more general term is "whole body" toxicity, to recognize the general effects as well. This toxicity results from longer exposures, many hours or days, to levels of oxygen above normal but less than those required to cause CNS effects.

#### Avoiding CNS toxicity

The main tactic to avoid CNS toxicity is by means of **limits**. The traditional way this is implemented is to limit exposure to a dose believed to be tolerable and without problems. A "dose" is an exposure level for a given time. This is usually implemented as a limit on exposure duration at a given oxygen partial pressure. Tolerance limits are usually determined empirically, either by means of explicit experiments (e.g., Butler and Thalmann, 1984, 1986; Butler, 1985, 1986) or by an accumulation of experience.

The dive operation has to consider factors that affect oxygen tolerance as well as the exposure doses. For example, exercise and breathing a dense gas tend to make a diver more susceptible to CNS toxicity. Extremes of temperature also reduce tolerance, as does immersion. There are significant individual factors, both between different individuals and in the same individual at different times.

For some years the limits used by the U.S. Navy were the only ones available. These served a purpose and defined the concept, but they were not physiologically realistic in terms of present day understanding. A set of limits drawing on more recent data has been prepared by NOAA, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. These widely used procedures are published in the 1991 edition of the NOAA Diving Manual and are essentially unchanged in the 2000 edition.

#### Whole body or pulmonary toxicity

Another classical symptom of oxygen poisoning in addition to those of the CNS is "pulmonary," the result of oxygen's effect on the lung. This takes hours or longer to develop from exposure levels that are usually be lower than those that cause CNS symptoms; it is seen as chest pain or discomfort, coughing, and a decrease in vital capacity. Because this can be measured with careful technique, this tends to focus this form of oxygen toxicity on the lung, but there are a collection of symptoms in addition to the lung problems that include paresthesia, headache, dizziness, nausea, effects on the eyes, and a dramatic reduction of aerobic capacity. These symptoms have been found to be, in time, fully reversible. The type of long, low-level exposure used in technical trimix diving is not likely to result in these symptoms unless the diver has to be treated for decompression sickness.

## Equipment for technical diving

As suggested by its name, technical diving involves some "high tech" equipment, but much of the equipment involved in technical diving is the same as for ordinary diving, but perhaps of higher quality (regulators, thermal protection) or greater range (depth gauges, tanks, etc.), etc. Some equipment items are specialized for the specific mission and are not specific to technical diving, such as survey equipment or lights for cave diving, or a diver propulsion vehicle ("scooter") where long swims are to be done. Technical divers do not have the option that is more or less available to sport scuba divers to ascend to the surface when in trouble, so most technical divers have some degree of redundancy for each item or function.

In the early days of technical diving in order to carry enough gas for long dives divers often overpressurized their tanks. Now larger tanks that take higher pressures are readily available. The manifolds and valves to connect such tanks need not be fabricated by the user, but can now be purchased ready made. They are configured to conserve the remaining gas if a single regulator or valve fails. High quality regulators are attached to each tank. For the deeper dives there may be a problem with the depth range in which a mix can be used, such that the intermediate "deco" mix has too much oxygen to be used at bottom depth for more than a short time, and perhaps the bottom mix has too low an oxygen level to be used at the surface; provisions have to be made to ensure that the gases are breathed in the right sequence. In fact, proper identification of all mixes can be as important as having the right mix, because breathing a mix at the wrong depth can easily be a fatal mistake. One diving group puts the maximum operating depth, "MOD," on each tank in big letters. Various safeguards prevent the wrong regulator from being used. A small "pony bottle" of extra gas suitable for the deeper part of a dive provides a means of escape to a safe area. Gas analysis equipment for checking mixes is essential for field operations.

Both conventional wet suits or dry suits are used, with the choice influenced by the conditions of the dive. Dry suits are made even more efficient by filling them with argon, which has a lower thermal conductivity than air and especially lower than helium.

Buoyancy control is especially important in technical diving, because unintended ascent can be dangerous, and because the gear may be quite heavy. A dual-bladder buoyancy compensator would be used with a wet suit, but a dry suit may act as additional buoyancy. It is felt that dehydration makes a diver more susceptible to decompression sickness, so divers are advised to stay well hydrated; because of this for very long dives some method of handling urine is needed. The long stops of long decompressions are often carried out in underwater decompression stations that may be made of an inverted tank or well-anchored air-filled lift bags. Divers with a high oxygen exposure sometimes use full-face masks instead of mouthpieces to improve chances of survival in the event of a convulsion.

Another aspect of buoyancy control has to do with decompression. Divers in the open sea carry an inflatable float or lift bag with the necessary lines to manage their own decompression. Where there is a current the divers may decompress while hanging from a float, and the boat follows the floats to pick up the divers when they surface. An essential part of the rig of open sea technical divers is rescue and location equipment, to help the dive boat find a diver and in the event that that does not happen, to help rescuers locate a lost diver.

## Training and organization

As one might expect from the description, technical diving demands intense dedication and discipline, and special training (Irvine, 1995). Although training is available, one thing lacking in the technical community is a set of peer-developed operating standards. Diving with this degree of commitment and risk requires teamwork, and those organizations or groups that have developed their own standards have been effective and safe, whereas there have been accidents among the independent and unsupported diving teams or individuals.

## Some operations conducted with technical diving

To further emphasize that technical diving belongs in the real world of diving we her e review some operations that have been conducted with open-circuit scuba technical diving techniques. We are not necessarily endorsing these operations, but rather are just describing them to provide an idea of what has been done.

The first operation in this mode of diving was a series of dives conducted in the aquifers on north Florida, an early operation by the Woodville Karst Plain Project. These divers conducted 27 man-dives at 60 to 75 msw for times up to 90 min (Hamilton and Turner, 1988). Later operations by the same project in Wakulla Springs involved swims of up to 90 min at a depth of 87 msw (Irvine and Hamilton, 1995).

Shortly after these techniques became available divers began more actively to dive the wreck of the *Andrea Doria*, which lies on her side at about 70 msw depth 160 km off Nantucket in the north Atlantic. Most dives by recreational divers on the *Andrea Doria* as they are normally conducted are not really "operations," in the sense that they are not organized with a leader and an operational plan, but rather are individual divers or pairs of divers who dive from charter boats whose purpose is to deliver the divers to the site but not to supervise or manage them. Despite the lack of operational control, hundreds of successful dives are done each season to the *Doria*. There have been a number of fatalities among trimix divers; most of these have been "operational" accidents that would not be likely to happen on a closely supervised team operation, but many of them are not explained. It is not uncommon for as many as 100 repetitive trimix dives to be done on this wreck over a 3 day period, with little or no decompression incidents occurring. A typical "season" can see as many as 750 dives on the *Doria*.

During the summer of 1994 some 120 technical trimix dives were made on the wreck of the *Lusitania*, which is located at about 100 msw just off the west coast of Ireland. Significant about this well-organized operation—*Starfish Enterprise*— was that from a team of 12 divers there were always two who were not diving but were serving as standby diver or topside supervisor. The team had a pentagon-shaped rig to hang on during decompression, and the divers were monitored; detailed records were kept on both divers and equipment (Gentile, 1995). The operation was continued in 1995. This time the organization paid off in the successful rescue of a diver who had an oxygen convulsion while decompressing at 6 msw; no special circumstances were found that might explain the convulsion.

Two expeditions have been conducted on the *Brittanic*, sister ship to the *Lusitania*. She lies at 120 msw in the Mediterranean offshore Greece. Because the vessel is covered by the rules for antiquities, no salvage was done, only photography.

Several of the more high-profile technical diving operations have been on the *USS Monitor*, a historically important Civil War vessel at about 60 msw off Cape Hatteras, NC, by NOAA, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. Certain things about these operations made them significant. First, they were done by NOAA and contract divers using decompression tables prepared especially for NOAA, and they represent official government recognition of technical diving practice. Some dives were conducted off a U.S. Navy vessel, another "first" in the development and growth of technical diving.

Most of the early dives on the USS Monitor were conducted by civilian volunteers who employed the use of technical diving to accomplish specific goals. These dives were conducted with a NOAA archeological manager on board, but with the team managing their own diving operations. One specific operation in 1997 utilized only 8 persons, yet they were able to conduct 12 hours of on-the-bottom time achieving over 600 measurements, 6 hours of digital imagery, and over 900 frames of still images, which could not have been done nearly as well or possibly at all by divers breathing air.

## Application to military operations

Technical diving techniques make the depth range to 100 msw readily available to properly trained and equipped divers using open circuit scuba equipment, for bottom times of up to 30 min and with inwater decompression times of 1 to 3 hr. Greater depths and times are possible, but will of course cost extra decompression time and require sufficient gas. Advanced military development might include a variety of gas staging techniques, gear configurations, propulsion and communication hardware, computers, and mission-related equipment. There is room for improvement in decompression and gas manipulation techniques.

It makes good sense for military operations using divers to include technical diving capability.

## References

Behnke AR. 1942 Jul. Effects of high pressures: Prevention and treatment of compressed air illness. In: The Medical Clinics of North America, p. 1213-1237.

Behnke AR. 1955. Oxygen decompression. In: Goff LG, ed. (First) Underwater Physiology Symposium. NAS_NRC Publication 377. Washington: National Academy of Sciences_National Research Council.

Behnke AR. 1967. Special problems in the etiology and treatment of decompression sickness. In: Lambertsen CJ, ed. Underwater Physiology III, proceedings of the third symposium. Baltimore: Williams and Wilkins.

Berghage TE, Donelson C IV, Gomez JA. 1978. Decompression advantages of trimix. Undersea Biomed Res 5(3):233-242.

Butler FK Jr. 1985 May. Closed_circuit oxygen diving. NEDU Report 7_85. Panama City, FL: Navy Experimental Diving Unit.

Butler FK Jr. 1986. Central nervous system oxygen toxicity in closed_circuit scuba divers III. Rept 5_86. Panama City, FL: U.S. Navy Experimental Diving Unit.

Butler FK Jr, Thalmann ED. 1984. CNS oxygen toxicity in closed_circuit scuba divers. In: Bachrach AJ, Matzen MM, eds. Underwater Physiology VIII. Bethesda, MD: Undersea Medical Society. Pp. 15_30.

Butler FK Jr, Thalmann ED. 1986 Jun. Central nervous system oxygen toxicity in closed circuit scuba divers II. Undersea Biomed Res 13(2):193_223.

Bennett PB. 1970. The narcotic effects of hyperbaric oxygen. In: Wada J, Iwa T, eds. Proceedings Fourth Int'l Congress on Hyperbaric Medicine. Baltimore: Williams and Wilkins.

Gentile G. 1995 Jan. Lusitania revisited. aquaCorps 9:26-35.

Hamilton RW, Crosson DJ, Hulbert AW, eds. 1989 Sep. Harbor Branch Workshop on enriched air nitrox diving. Report 89_1. Rockville, MD: NOAA National Undersea Research Program.

Hamilton RW, Muren A, Röckert H, Örnhagen H. 1988. Proposed new Swedish air decompression tables. In: Shields TG, ed. XVth annual meeting of the EUBS: European Undersea Biomedical Society. Aberdeen: National Hyperbaric Center.

Hamilton RW, Turner P. 1988. Decompression techniques based on special gas mixes for deep cave exploration. Undersea Biomed Res 15(Suppl):70.

Irvine G. 1995 Sep. Do it right, or don't do it! DeepTech J 3:48.

Irvine G, Hamilton RW. 1995 Jun. Recent developments in self_contained "technical" diving, with suggested safety techniques. J Undersea and Hyperbaric Med 22(Supplement):25_26.

Lambertsen CJ. 1967. Basic requirements for improving diving depth and decompression tolerance. In: Lambertsen CJ, ed. Proceedings of the third symposium on underwater physiology. Baltimore: Williams and Wilkins Co. pp. 223-240

Linnarsson D, Ostlund A, Sporrong A, Lind F, Hamilton RW. 1990. Does oxygen contribute to the narcotic action of hyperbaric air? In: Sterk W, Geeraedts L, eds. Proceedings XVIth Meeting of the European Undersea Biomedical Society. Amsterdam: Foundation for Hyperbaric Medicine.

NOAA Diving Manual: Diving for Science and Technology. 1991 Oct. Third edition. Silver Spring, MD: NOAA Office of Undersea Research, U.S. Department of Commerce.

Shields TG. 1982. Re-trial at sea of 70 and 80 metre 15 minute trimix decompression schedules. Report R82-409. Alverstoke, UK: AMTE(E).

Shields, TG. 1982. Sea Trial of 70 and 80 metre 15 minute trimix decompression schedules. Report 82-407. Alverstoke, UK: AMTE(E).

Shields TG, Greene KM, Hennessy TR, Hempleman HV. 1978 Mar. Trimix diving to 75 metres. Undersea Biomed Res 5(1, Suppl):24.

Zannini D, Magno L. 1987. Procedures for trimix scuba dives between 70 and 100m: A study on the coral gatherers of the Mediterranean Sea. In: Bove AA, Bachrach AJ, Greenbaum LJ Jr., eds. Underwater and hyperbaric physiology IX. Bethesda, MD: Undersea and Hyperbaric Medical Society, 1987, Pp 215_18.