In January 1990, I launched the first edition of aquaCORPS because I was hungry for information about a new kind of diving that was emerging from the closet, and no one was talking; there was little information. Indeed, deep diving, by which I mean diving beyond 40m/130 ft, and its companion decompression diving—the "D-Words"—were strictly verboten among the recreational diving establishment; few could even spell N-I-T-R-O-X, or trimix, let alone knew what they were.

In less than two years, the moniker "technical diving," which I coined to distinguish tech from recreational diving stuck, and tech diving along with the needed infrastructure to support it began to take off. Meanwhile aquaCORPS: The Journal for Technical Diving," continued to grow in size and readership. WIRED magazine described it as, "The Sea Geek's bible; part wish list, part chemistry book, part looking glass."

aqua CORPS

DIVE RITE EQUIPMENT FOR SERIOUS DIVERS

GLOBAL Underwater Explorers

Now on the 30th anniversary of its launch, I am excited and proud to bring you the first digital release of the original magazines beginning with aquaCORPS #4, MIX on mixed gas technology. **The text is completely searchable.** We recommend that you use Adobe Reader for best results.

I want to thank my illustrious, forward-thinking sponsors, all of which are pioneers in their own right, for making this possible. You will find their banners in the inside covers of this originally black & white digital edition.

In the coming year, I intend to release additional back issues of aquaCORPS, with the goal of digitizing the entire collection. Stay tuned at www.aquaCORPS.online.

aqua CORPS

fourth element

deeper blue

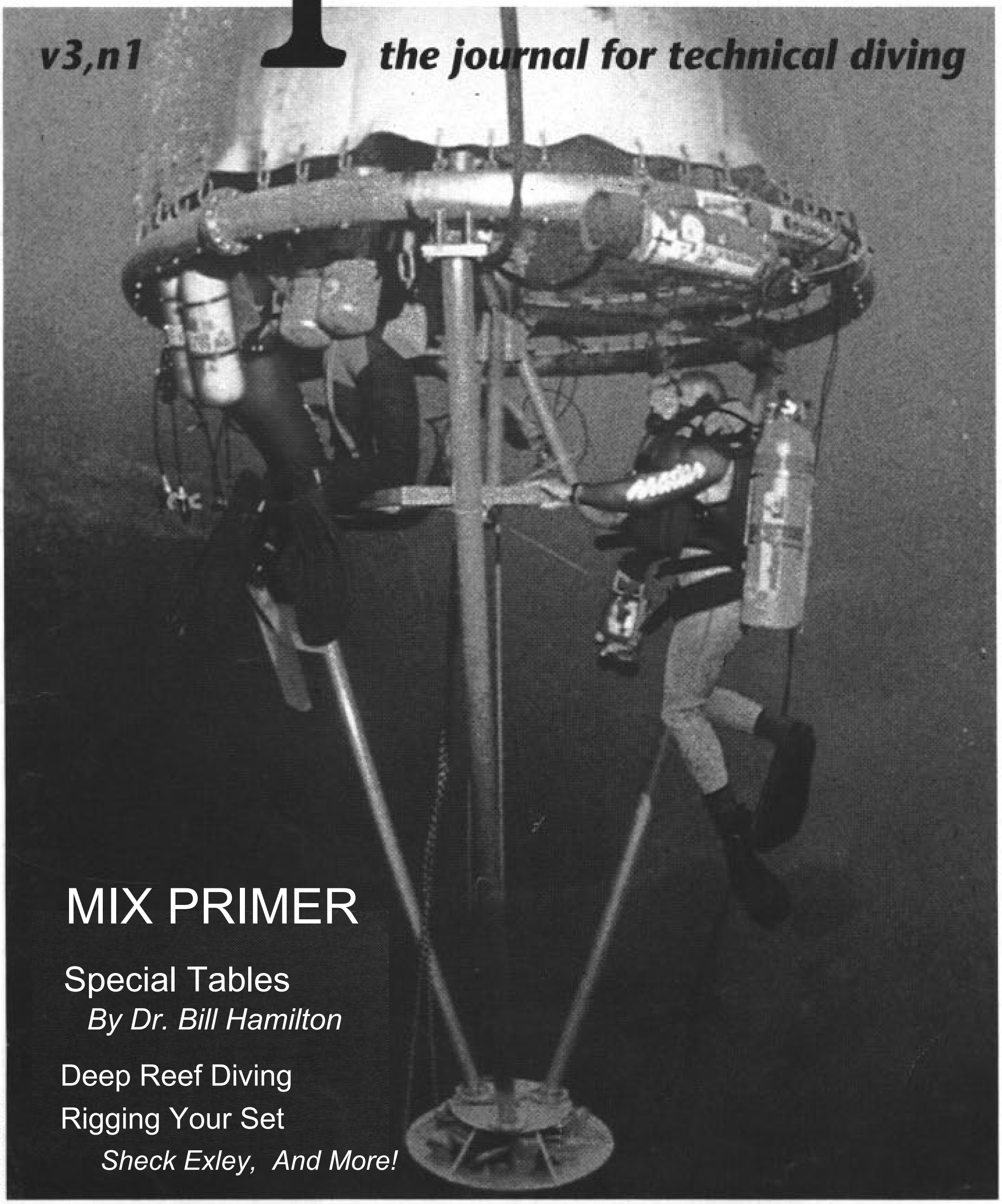

Image by Liz Rodgers
FOURTH ELEMENT
EST 1999
20 YEARS
NO SURFACE INTERVAL
fourthelement.com

aqua
C O R P S

aquaCorps

v3,n1

the journal for technical diving



CARL GANTER

MIX

"The best way to predict the future is to invent it. This is the century to be pro-active about the future."

Alan C. Kay, Stanford Computer Forum, 1987

MIX, Volume 3, Number 1 was published January, 1992.

Is The Market Ready For Mix?

"The best way to predict the future is to invent it. This is the century to be pro-active about the future."
Alan C. Kay,
Stanford Computer Forum 1987

There was a time not long ago, that "AIR" was rarely thought of as a gas in sport diving circles, much less a technology. Like the old adage regarding a fish's description of water, "AIR" was simply what we breathed and diving was no exception. Now it seems that the whole concept of "air technology"--a single gas to handle all exposures—may be outmoded before most of us knew enough to call it nitrox. What's going on?


PHILIPPE CASSGNOL

The self-contained diving market is in the midst of a technological revolution that is changing the way we think about diving. Similar to the PC in the world of computing, technologies and methods once limited to commercial and military use including; special mixed gases, more reliable decompression methods, diver propulsion vehicles, communications, closed circuit systems and more, are now being rescaled and applied to sport and special interest diving, driven by the need for increased safety and performance.

Until recently, this community was viewed largely as a single, homogeneous group known as "recreational divers." Now a more sophisticated view is emerging. To borrow several terms from the computer industry, the consumer diving market is in fact made up of many different *user groups*, each with it's own specific diving *environment and applications*, and a need for *appropriate tools*. That's what makes the technical revolution potentially so profound.

If the benefits of these technologies were limited to a few isolated *"high tech"* divers, their impact would be relatively minor. Instead the tools, methods and disciplines that are being pioneered today, are applicable to a wide range of diving, from recreation to professional, and hold great promise for improving diver safety. The result is a significant opportunity for growth, and with it the need for caution and responsibility.

Conceived in the early 1900's, and developed and used in industrial and military operations over the last fifty years, mix technology offers the capability of reliably supporting divers to depths beyond 2000 fsw. At the same time, if used improperly or irresponsibly, it can be deadly. And that is cause for great concern. Though mix has been a long proven standard among it's industrial and military counterparts, the sport diving industry has found challenge enough in teaching divers not to "run out of air" let alone to manage alternative breathing mixtures. Mix technology may be ready for the market; the real question is, *"Is the market ready for mix?"*

Like the personal computer of ten years ago, special mix is being successfully utilized today by only a small number of experienced divers representing the vanguard of the field. We still have a long way to go before this technology can be reliably employed by the masses. Safety is the primary concern. Training and education, information, and a consistent set of operating guidelines are sorely needed at both industry and consumer levels, and there is a good deal of supporting infrastructure that is simply not in place.

With foresight, work, and the willingness to tackle the many hard issues that remain, mix technology like the PC, will become accessible, reliable and easy to use, to the benefit of divers at all levels; if kept in the closet or ignored, it will surely become a source of harm.

Now is a time for the industry to pull together, and chart a path for the future as we transition from *"fixed mix"* to a multi-mix diving environment By being pro-active, we stand to usher in a new era of diving rivaling that initiated by open circuit scuba nearly 50 years ago, and in doing so, make it a safer and richer activity for generations of divers to come.

That's what this issue of aquaCorps is all about. —*M*^{2}

MIX

a/c letters

Thank you for your interest , letters, and support .Your comments and feedback are extremely important to us. M²

Intelligent Life Forms

I am not an active diver anymore for all sorts of reasons, but I did do some cave diving in my younger days and some strange things called PPLI in my early deep professional career back in the sixties (PPLI is a French acronym for "Light Deep Intervention Dives" involving scuba-based heliox dives to 300 fsw plus).

From what I have read of your journal, I admire and appreciate what you are doing. There has to be some intelligent nonprofessional divers who are serious about the sport and are willing and capable of doing it safely outside the "safe rules" intended for the masses. Your articles on the buddy system confirms that you are prepared to reexamine concepts which have been taken for granted for so long, and reassess them in the light of experience.

George Arnoux
Diving Safety Offier
Comex U.K. LTD

Continued Education

It's about time someone has come out with a publication that's not afraid to discuss the proper ways advanced diving can be done safely. Proper training is the only answer. I have seen a large number of divers in the Florida area continue to follow unsafe practices, probably because they are unaware of the dangers that they are placing themselves into by entering caves, caverns or deep diving with improper equipment and gas supplies. Continued education is the only safe way to dive at any level, basic or advanced.

Curt Bowen
Sarasota County Fire
Rescue Dept
Bradenton, Florida

Fellow Tekkie

Please accept my encouragement for the pioneering step you are taking to *"boldly go where no publisher has gone before"*. As you correctly point out, divers DO exceed the recreational limits and a journal such as yours can only help to make this facet of diving safer and by extension, more enjoyable.

Derek P. Montague
Parkes ACT, Australia

Bellwether

I'm a fairly cautious diver (There are old divers and bold divers, but no old bold divers!), so I read *DEEP* with a mounting sense of horror (scream marks heavily justified). Why? Just consider what you are doing.

You start off with a relatively dangerous piece of equipment designed by Murphy and built in his workshop; the demand valve. When it fails, and it will, the failure will occur the moment after you've exhaled. Maximum panic. To compensate for this eventuality, we give the chap another. In addition, because open-circuit systems are inefficient, we load him or her up with multiple bulky gas cylinders stuffed to bursting, most of which is merely there to make up the volume required to breath at 7-15 atmospheres. Finally, because the diver is going far from home out into a hostile environment where failure of any part of his or her equipment or psychology is potentially fatal within seconds, we encumber him with a stiff suit and a battery of devices and instruments until he resembles the larva of a caddis fly—not a bit like the seal he emulate or wishes to. Then away he or she goes deep into the soup along with one or more buddies so that there's an increased chance that if bad luck doesn't get him directly then one of his buddies will.

Contrast this with another approach. The diver slips away dressed in a much more flexible lightweight suit, because inspite of much longer bottom times, he or she is not exposed to the cold water for as long. He has virtually no gear on him, just a simple closed circuit set. The only extra gas the diver needs to carry is for emergency. No extra instruments, unless they are for his satisfaction or to do the job since he's diving only a few feet away from his base, and is in voice communication with an attendant. And not only is my diver nearly as free as the seal, but if he needs some powerful lift and shift he's got it at hand. Working from a bell is easy, safer, and cheaper in terms of dollars per diving minute. It can be installed anywhere from the surf line to the innermost recesses of the deepest cave or wreck and it has absolutely no *macho-appeal* whatever! Rule one and only, *"the diver shall not be allowed beyond the reach of immediate and effective assistance,"* It's something to consider.

Mark Terrell
Kini, Syros,
Greece

Many people believe that habitat and bell technology will eventually be adapted for technical diving much as it was for commercial diving–a matter of safety and economics. Micrbells? Decompression stations and closed circuit systems represent a first step. A little future pro-activity. —a/c

Fair Game

My concerns center on the philosophy that if a new technique of diving, e.g. enriched air diving, or a new technology, for example dive computers, are written about or used in the commercial dive industry, they become fair game for use by the recreational diver. There is an inherent danger in such a philosophy because the tools or methods will not be thoroughly understood or appreciated by the novice user. It can therefore be dangerously misused. The emphasis must be on "practicality and safety." That can only be achieved through education, training and practice.

I agree that there are probably many recreational divers with advanced training that can engage in diving activities that verge on professional, but we must not overlook the fact that most professional diving is done with a tremendous back-up infrastructure including support personnel and equipment that is not there for the recreational diver. There are also many hidden people behind these operations, including, the diving medical specialist, the diving paramedic, the gas mix specialist, the decompression specialist, research facility staff, and even the government regulators who have written many of the rules commercial divers must follow. The whole purpose of this infrastructure is the safety of the diver, and the need and desire to allow him or her to work underwater and return safely to the surface.

G.H. Koch, M.D.
Hyperbaric Dept.
Toronto Hospital
Toronto, Canada

Like it's commercial counterpart, technical diving has significant surface support requirements compared to recreational diving and there are many hidden support

Beyond The Flagroom

by Jim King

Location: Brooksville, Florida

Dive Team: Dustin Clesi, Larry Green, Jim King, Gordon Watkins and Rich Nicolini

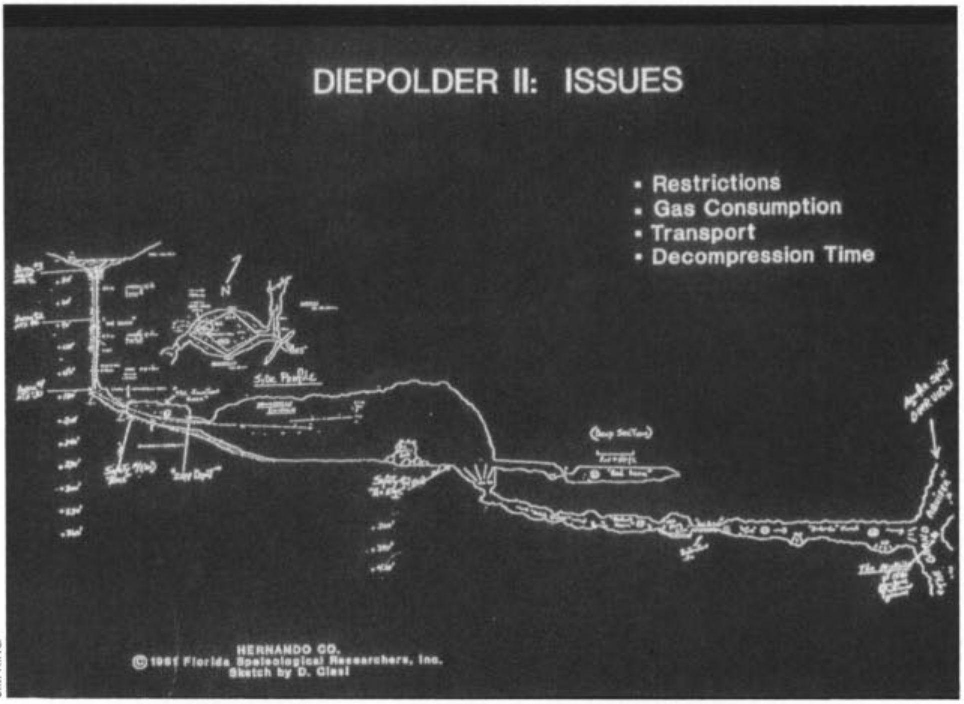
Surface Support: Jim Schlesinger

Diepolder #2 is an offset sink located on the Boy Scout Ranch in Brooksville, Florida. First discovered in the 1970's, it has seen limited exploration over the last few years. Our dives consisted of a series of deep special mix exploration dives to penetrate the unknown depths and extend the limits of the cave beyond the *Flagroom* (360 fsw), first discovered by Dale Sweet in 1980 using open-circuit scuba technology. A series of eight dives (four two-person teams) were completed over two consecutive weekends in March, 1991. The team layed approximately 700 feet of new line.

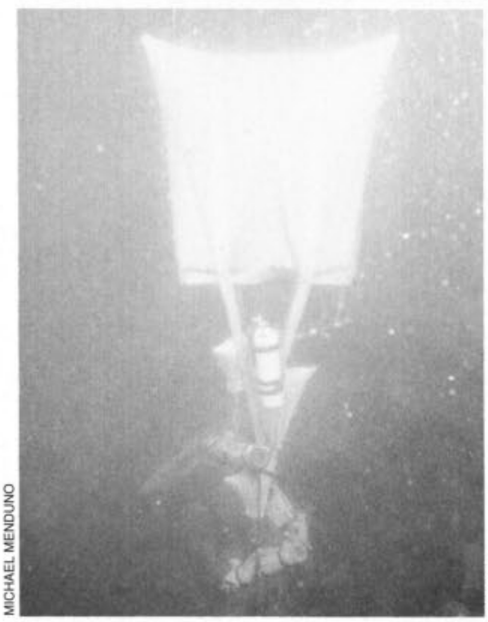
A combination of some of the latest tools available including a "habibag" decompression station, diver propulsion vehicles (DPV's), trimix and custom generated decompression schedules enabled us to conduct these dives safely. Using new methods developed by Dr. Bill Hamilton in conjunction with Deep Breathing Systems, and with support from the Defense and Civil Institute of Environmental Medicine (DCIEM), it was possible to evaluate *–doppler–* the dives as they were conducted in order to validate the decompression procedures.

Each team member understood stress would be associated with each dive due to the extreme depths involved, amount of exploration required and the total in-water time. Therefore, the continuing evaluation by DCIEM would be a critical factor in the overall mission plan.

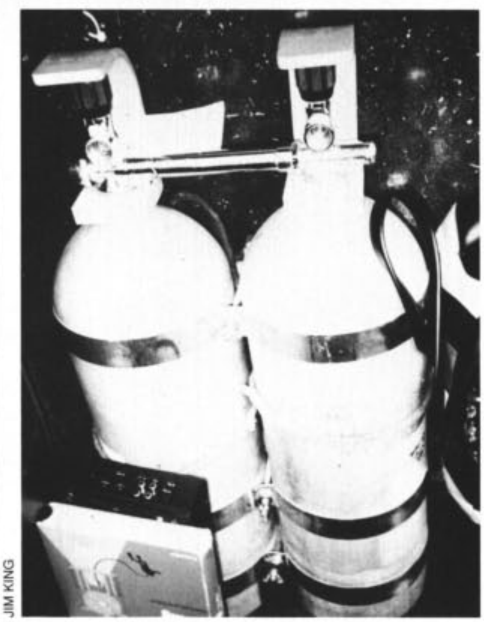
There were several major constraints associated with these dives. After descending to a depth of 40 feet, divers had to negotiate a vertical fissure known as *"the Crack"* that extended to 190 fsw, with an opening no more than 36 inches across. As a result, each diver was limited by the equipment and gas supplies that could be carried through the restriction; equipment and additional gas supplies had to be pre-staged in the cave.



JIM KING



MICHAEL MENDUNO



JIM KING

After reaching the Junction Room, divers switched to additional fresh gas cylinders, mounted their DPV's which had been pre-staged and motored as far as possible toward the main chamber at the

back of the cave, at a depth approaching 300 fsw. There they parked the DPV's, picked up fresh bottles and began exploration into the downstream pit area "on fin." Narrow restrictions and the depth limitations of the aquaZepp scooters restricted their use beyond the 300 fsw mark.

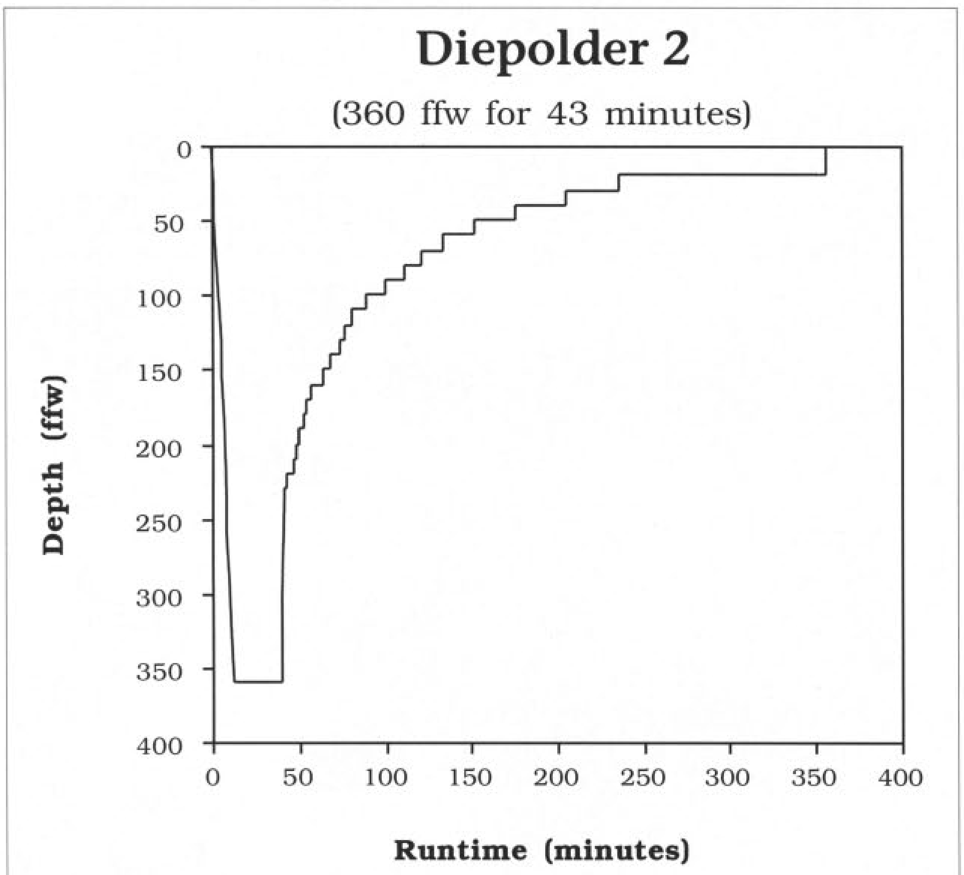
Because of the extreme depths involved and the duration of the dive, gas planning became a major operational consideration in the dives. Consequently, three gas depots were established in the cave prior to the exploration pushes to handle planned gas switches and provide bail-out capability in case of emergencies.

Profile: Maximum depth 365 ffw, with maximum bottom times of 43 minute. Total dive time 377 minutes (Six hours and 17 minutes).

Conditions: Visibility was 100 foot plus. Temperature: 78 -80 degrees Fahrenheit. No current.

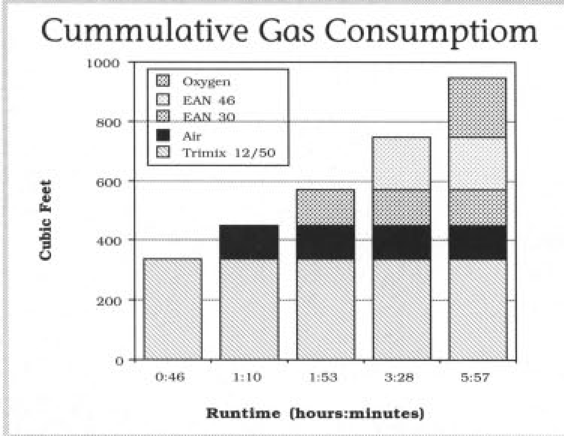
Set Configuration: Each diver carried double 104's and began his push in the downstream section using double aluminum 80 cf stage bottles. A third diver-carried stage

continued on page 33



How Much Gas?

Gas planning is a critical component for most special mix dives, particularly for exploration pushes where there's a



specific *"job"* or mission to be accomplished. In these cases, *passive* gas planning and management i.e. *"turning the dive at thirds"* is insufficient, and a more *"pro-active"* approach is needed.

Given a planned profile, decompression procedure and an empirically-derived surface equivalent consumption rate, expected gas consumption can be easily calculated for each planned mix to be used. This information can then be used to plan the number of cylinders that will be needed for the mission.Planned consumption can later be compared to actual results and refined for future dives.

How much gas is required for one of today's exploration runs? The figure above shows the gas consumed by a single exploration diver at Diepolder #2. Note that these figures represent actual consumption and do not include planned gas reserves, for example a "thirds," which are neccesary for diver safety.

Cover: The decompression habitat used at the Wakulla Springs Project, 1987. The variable-depth habitat was capable of housing six divers and could be manually raised by the dive team during ascent.

"Safety is the key consideration in diving; it entirely controls depth capability."

Imbert, Ciesielski & Fructus
Safe Deep Sea Diving Using Hydrogen

Mix Primer

by Michael Menduno and John T. Crea

We live in a compressed gas environment. The atmospheric air we breathe is a mixture of gases composed of about 78% nitrogen, 20.9% oxygen, 0.9% argon, and a balance of carbon dioxide and rare gases, at a total pressure of 14.7 psi at sea level, conveniently defined as one *atmosphere*, or *atm*. Of these, oxygen is the only gas required to sustain human life. The other gases breathed from the atmosphere, or in a diver's gas mix, serve as a carrier and *diluent* for oxygen in order to maintain it within physiological limits defined by partial pressures (PO2)[1].

Humans function optimally at an oxygen partial pressure of about 0.2 atmospheres (atm), and without too much CO2. Above and below this level, oxygen induces a variety of physiological effects depending on the dose (PO2) and exposure time.These can range from *hypoxia* (oxygen starvation) at partial pressures below about 0.14 atm, to whole *body toxicity* and *central nervous system (CNS) toxicity* at elevated partial pressures greater than 0.5 atm and above about 1.2 -1.4 atm respectively.

During the limited exposures encountered in diving, oxygen levels can be extended upward, and in fact it's beneficial to do so because it displaces inert gas which is a source of problems. For most surface-based dives scuba operations, elevating oxygen partial pressures to about 1.2-1.4 atm seems to be ideal and is unlikely to induce CNS toxicity, though PO2s are sometimes extended to as high as 1.6 atm and above for limited duration dives and during decompression, when the diver is at rest. Whole body toxicity resulting from very long exposures at PO2s above 0.5 atm is rarely an issue on most technical dives, but becomes critical during the lengthy exposures encountered in saturation diving. In this case, oxygen levels (PO2) are usually maintained near or below 0.5 atm.

Carbon dioxide (CO2) production, which serves to regulate respiration, also plays an important role in diving physiology. CO2 can be toxic at elevated pressures and is believed to "interact" with both oxygen and nitrogen increasing the diver's susceptibility to oxygen toxicity and narcosis.

Even though oxygen is the most vital gas physiologically, inert gas is important to any discussion about diving as it is the source of decompression and other physiological problems. With the important exception of helium and also neon, other inert gases such as nitrogen and sometimes hydrogen, used to dilute oxygen levels in diving mixtures, act as a narcotic at elevated partial pressures. Though this narcotic property is generally highly undesirable from a diving perspective, it can sometimes be used to advantage in dealing with another problem encountered by deep sea divers; the effects of rapid increases of hydrostatic pressure to about 600 - 800 fsw and beyond, referred to as High Pressure Nervous Syndrome (HPNS) and usually characterized by tremors.

Diving gases have thermal consequences as well and can also effect vocal communications. All of these effects must be taken into account when considering the use of diving gases. A summary of the diluent gases that are used in diving is shown in Table 1. (pg. 71) along with their physiological properties.

The Problem With Air

As a diving gas, air has several real limitations from a safety and performance perspective. For shallow water dives in the 30-130 fsw range, the high nitrogen levels found in air result in excessive decompressions (and short no-stop times); the oxygen levels being far below optimal.

Conversely, for deep dives beyond about 190- 220 fsw, the partial pressure of oxygen becomes excessive, increasing the likelihood of a CNS toxicity hit. However, the most immediate problem is usually narcosis. Nitrogen, the primary diluent gas in air, becomes increasingly narcotic beyond 100 fsw (a partial pressure of nitrogen of about 3 atm and greater), impairing the divers ability to perform and respond. Density is also an issue on deep dives; air is difficult to breathe at depth and can effect equipment performance. In the midrange, from about 130 to190 fsw, oxygen levels found in compressed air are close to optimal, and the narcosis is manageable with experience. In practice this is a workable range for air, though it is sometimes deeper for extended short duration dives.

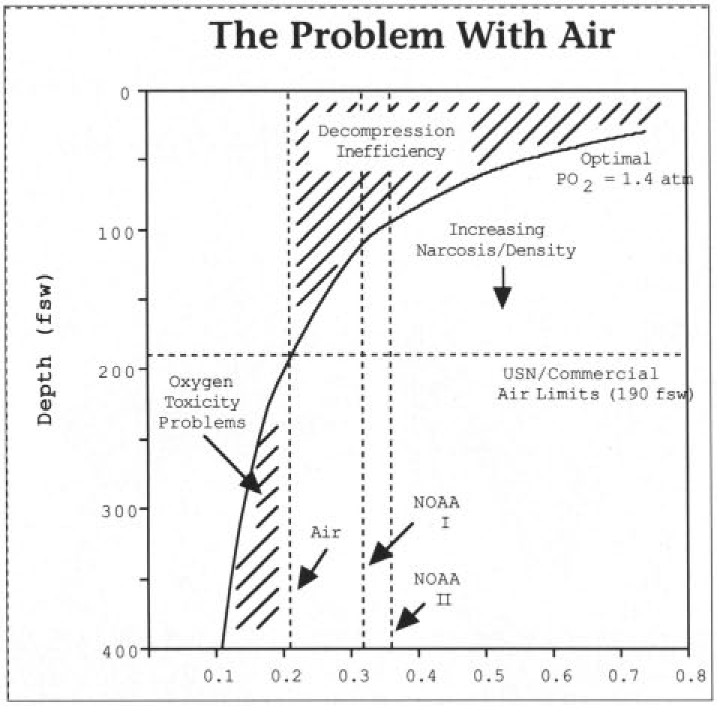
As a result of these limitations, air is generally considered to be inefficient as a diving gas for most applications, except from an availability and cost standpoint.

Special Mix Technology

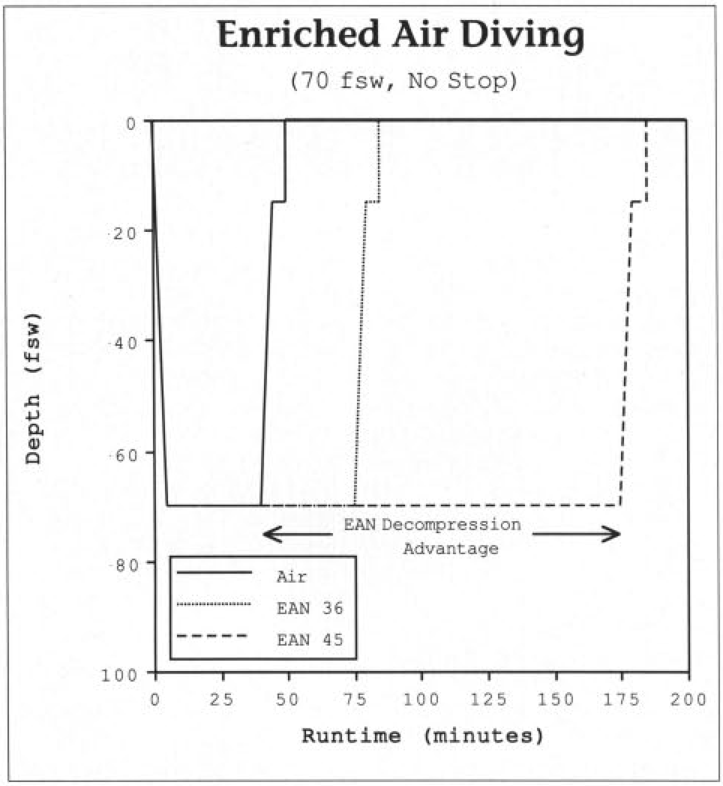
Conceived in the early 1900's and gradually applied to the problems of underwater breathing, the use of custom or special mix diving gases—*mix technology*—was developed to overcome the inherent problems and limitations associated with diving compressed air.

The fundamental idea behind mix technology is to improve safety and performance by optimizing a diver's breathing gas during various phases of the dive. This is best done by treating the dive in two distinct phases; the descent *and working* phase and *decompression.* Each has it's own set of issues and objectives.

The important issue during the working phase of the dive is to insure that the diver maintains a safe, sustainable level of oxygen based on the exposure, and that undesirable inert gas effects, such as nitrogen narcosis and unnecessary decompression, are minimized. On deep dives, levels based on the planned working depth, and selecting an appropriate inert gas to serve as a diluent, for example, substituting helium for all



The Problem With Air



Enriched Air Diving

(70 fsw, No Stop)

reducing breathing gas density is also important as it improves the ability to ventilate the lungs, facilitating CO2 removal thus allowing increased work capacity. These objectives are accomplished by setting reliable oxygen or a portion of the nitrogen found in air on deep dives to reduce or eliminate the effects of nitrogen narcosis, and to reduce gas density (see Table 1.).

During decompression, which generally represents the longest phase of many technical dives, the objective is to maximize oxygen levels subject to reliable limits; *oxygen management is the key to reliable decompression.* In addition, inert gas switches are also used to facilitate off-gassing and minimize additional gas loading during decompression. In open-circuit scuba 2, this is accomplished by switching mixes (usually by switching cylinders) during decompression according to a predetermined plan, normally included as a part of the decompression schedule. The types of gas used and number of switches depend on the specific exposure and operation.

In the case of a simple dive, for example a open water no-stop dive to 70 fsw, a single enriched air mix such as an EAN 36 (36% oxygen, balance nitrogen) might be used as the diving gas for both the working and decompression phases of the dive (in this case a controlled ascent and safety stop). Longer decompression dives might involve a single *bottom mix* such as air or enriched air supplemented with *oxygen* for decompression. For deep operations, multiple mixes are used, including a helium-based bottom mix and *intermediate* or *decompression mixes* (typically nitrox), before switching to pure oxygen at 20 fsw. This necessitates carrying and/or staging multiple cylinders, called stage bottles, in addition to the diver's set, containing the appropriate mixes. Staging is a matter of operations and depends on the specific environment and exposure.

Decompression Management Tools and DPVs

Though air tables and dive computers can sometimes be used directly for special mix diving, for example; breathing enriched air while following an air-based DC or table as a safety hedge, most mix dives require *special application tables*. However, in the case of enriched air, an *equivalent air depth* (EAD) can be calculated making it possible to use standard air tables (see *technically speaking*).

Because most shallow water (30 -100 fsw) sport applications tend to be multilevel, the prospect of being limited to using EAD tables when diving enriched air can represent some disadvantage.

However, a number of *EAN-compatible* dive computers (DCs) are currently in development and will be available soon.

In addition, because of the number of cylinders that must sometimes be carried by the diver using open circuit scuba, diver propulsion vehicles (DPVs) are becoming increasingly important for transport in long and deep diving applications and offer a tremendous advantage in range and reduce diver workload.

Anatomy Of A Special Mix Dive

Figures 1. and 2. span the range of today's special mix applications representing the simplest and one of the more involved type of mix diving.

Enriched Air

Figure 1. illustrates a series of no-stop dive profiles to 70 fsw utilizing two different enriched air mixes compared to a similar dive on air. These profiles were calculated using the DCIEM tables and an EAD calculation method. A five minute *safety stop* at 15 fsw is included on all profiles. The strategy here is to reduce nitrogen uptake which is the source of air decompression problems, by substituting oxygen which is consumed metabolically by the body. As shown, no-stop times can be greatly increased over air by using EAN 36 (36% oxygen, balance nitrogen), sometimes referred to as NOAA Nitrox II, yielding 75 minutes versus 40 minutes. However the maximum PO2 on the dive is only 1.1 atm at it's maximum depth of 70 fsw which is below optimal levels (PO2 = ambient pressure (3.12 atm) x the oxygen fraction, FO2, of.36 = 1.1 atm). By increasing the maximum PO2 to 1.4 atm, which represents a reliable and sustainable oxygen level for most sport dives, in this case by using an EAN 45, no-stop times can be increased to 175 minutes, a dramatic improvement.

The example also highlights two of the operational issues involved in enriched air diving; operating range and gas supply. All breathing mixes, including enriched air (and air as well!) have a maximum "reliable" operating depth, or MOD from an oxygen toxicity standpoint, which must be respected by the diver(see *technically speaking* for calculations). In the case of enriched air, these MODs can be quite shallow; for example 95 fsw for EAN 36, and 70 fsw for EAN 45 at a PO2 of 1.4 atm (see *technically speaking* for calculations).

Also, as seen above, in the case of shallow water dives, the diver is far less limited by no-stop (decompression) times. Consequently, gas management becomes all the more important. From a mix perspective, decompression dives using enriched air, with or without oxygen, are only slightly more complicated.

Trimix

Figure 2 (pg 32) profiles a typical trimix dive (an oxygen-helium-nitrogen mixture) to 250 fsw for 30 minutes showing the planned diving gases used during the working and decompression phases of the dive. The decompression procedures and calculations are based on the Haldane-Workman-Schreiner model using Matrix 11F6 (Hamilton Research DCAP computational program).The diving gases used are discussed below.

Travel mix is sometimes breathed during descent on specific operations to provide decompression advantages (minimize inert gas loading during descent) and/or to avoid problems of *hypoxia* (too little oxygen; less than about 0.14 atm) near or at the surface when using a bottom mix with a low oxygen fraction (FO2). Travel mix is not used in the profile shown below.

Bottom mix, in this case trimix, is breathed during the working and usually deepest portion of the dive. Both the oxygen and helium content (*fractions*) are predetermined based on the planned working depth and environmental specifics of the dive eg. physical overhead, open water etc. For the profile shown in Fig.2, a trimix 17/50 (17% oxygen, 50% He, balance N2) is used. The oxygen fraction is set at 17% to insure an oxygen partial pressure of 1.45 atm at 250 fsw, the deepest portion of the dive. The mix was set with 50% helium to create an *equivalent narcosis depth* (END) of 85 fsw (see *technically speaking* for calculations —*ed*). ENDs are commonly set at depths ranging from 75 feet to as high as 200 or more, depending on the dive and what needs to be accomplished.

For *very* deep dives, typically beyond about 800 fsw, High Pressure Nervous Syndrome, HPNS, associated with oxygen-helium (heliox) mixtures, becomes a critical limiting factor, though with the rapid ascent rates used in technical (self-contained) diving, this phenomenon may occurr at depths as shallow as 400 to 500 fsw. One way to reduce HPNS is

continued on page 32

Atm revisited

An *atm*, or *atmosphere*, is a unit for measuring pressure, that is used a great deal by technical divers. The total atmospheric pressure at sea level is defined as 1 atmosphere (atm), also called an "ata", an *atmosphere absolute*. At sea level, the fraction of oxygen in air is 0.21or 21%, so the partial pressure of oxygen, PO_2 (total pressure x gas fraction = gas partial pressure) is 0.21atm. 1 atm = 1.013 bars (another common unit of pressure). For physiological purposes atms and bars are more or less interchangeable. Another pressure unit with great utility is the kilopascal, a metric unit denoted kPa. A kPa is 1/100 of a bar—very close to 1/100 atm. In time most physiological pressures will be defined in kPa. Some other common pressure units are as follows

1 atm = 14.7 Psig (Pounds per sq. in. guage)
1 fsw = 1/33 atm (feet of seawater)
1 ffw = 1/34 atm (feet of fresh water)
1 msw = 1/10 bar (meters of seawater)
1 msw = 3.2568 fsw
1 kPa = 1/100 bar

The Case For Heliox: A Matter Of Narcosis And Economics

BY DR. BILL STONE

During the past year there has been substantial discussion in the high tech community concerning the use of mixed gas to deal with the problems associated with deep diving on compressed air, particularly that of narcosis. The fact is, compressed air is a mixed gas, specifically a nitrox mixture consisting of roughly 21% oxygen, so some intial nomenclature is in order.

Nitrox mixtures are composed of a binary combination of oxygen and nitrogen. When the oxygen content is greater than that found in air, the mix is referred to as "enriched air nitrox", or simply, enriched air (EAN). Mixtures with a lower oxygen content than found in air, used in saturation diving, are referred to simply as nitrox, though "nartrox" may be more appropriate since these mixtures lead to enhanced narcosis. At the opposite end of the narcotic spectrum are such binary gases as heliox (oxygen-helium), hydrox (oxygen-hydrogen) and neox (oxygen-neon). None of these mixes exhibit neurological side effects within the depth ranges likely to be visited by surface-based technical divers in the near future.

Between the two binary gas mix "extremes" of nitrox and heliox there is a sliding scale of mixtures which contain oxygen, helium and nitrogen. These latter blends are known as trimix, which as of late have become the darling of the high tech community. In view of this state of affairs, the question that many people are asking today is, "Why use heliox at all?" The answer is simple: the *complete elimination of narcosis.*

When conducting scientific or exploration work at substantial depth, there is a high premium on staying *frosty*, both because of the inherent risks associated with deep diving and the fact that divers are generally operating under a very tight time constraint in which to accomplish the maximum amount of productive work. Under these conditions any psychomotor impairment is undesireable. There is a further advantage in that heliox is less dense and therefore leads to reduced breathing resistance and the associated CO2 build-up.

Though the issue, *"to be, or not to be narced,"* is fairly straight forward, many between-the-lines questions still surround the use of heliox and trimix. Some of these gray areas include thermal considerations, decompression requirements, the issue of acceptable narcosis level, availabiltiy, access and cost.

Heat Loss

The issue of thermal considerations arises from the fact that helium has six times the ability to *conduct* heat than compressed air. Used in the wrong fashion, high-content helium mixes can push a diver into hypothermia in quick order, but not in the way that many people think. It's because of the misconceptions along these lines that some still hold the belief that trimix is *warmer* than heliox. Clearing up this confusion requires a brief discussion of the thermodynamics of heat transport. In the underwater environment, heat is drawn away from the diver by two primary means; *conductive* and *convective* heat transfer, though it has not been determined exactly how the actions of these two physical principles are divided.

Conductive, or radiant heat transfer, is a function of the conductivity of the medium surrounding an object and the object's surface area and is the primary source of diver heat loss for surface-oriented dives (in

LEO DICKINSON

EDWARD SCETTE

the 0 - 600 fsw range). For the diver, conductive heat loss occurs through the skin; body heat is ultimately radiated away through the thickness of the exposure suit and into the surrounding water. The rate of this heat loss depends on the conductive heat transfer capacity of the medium immediately in conduct with the skin. In the case of a wet suit, the surrounding medium is water; conductive loss is unaffected by the choice of breathing gas. However when wearing a dry suit, the immediate surrounding medium is the gas used to inflate the suit. This is where the high conductive capacity of helium mixes can cause a problem. When breathing a high-content helium mix, divers should use an auxiliary suit inflation gas to avoid rapid heat loss, preferably one with as low a heat conductive capacity as possible such as argon or carbon dioxide, though the latter can cause skin irritation when moisture is present. For that reason argon is probably a better choice.With a heat transfer capacity of about 50% that of compressed air, argon is an attractive inflation gas for cold water as well, whether or not mix is used.

The second form of heat transfer is convective and is typically a minor component of diver heat loss except at very great depth. This latter form of heat loss occurs as a result of normal respiration using open circuit scuba since each breath that is expelled into the surrounding water carries with it heat from the body. However the heat removed through the respiratory tract is more a function of the heat *capacity* (density) of the gas being breathed than its heat conductivity. A good case can be made that because of the greatly reduced density (and consequently thermal capacity) of helium, convective heat losses for helium mixtures are probably less that that for compressed air (and other nitrogen mixtures) at any given depth i.e. because air has a greater density, it will remove more heat when equilibrated.

In practice, heliox does *feel* cooler to breathe than air (a phenomena probably due to radiant heat loss at the surface of the lungs) and some divers report it makes them colder. However, as discussed above the reputed chilling effect of helium mixes is misunderstood, and trimix offers no superior thermal characteristics over heliox.

Decompression Requirements

Another misconception regarding heliox is that it leads to unreasonably long decompression schedules and that trimix can be used to significantly shorten decompressions. This belief is based upon the common knowledge that nitrogen is absorbed by body tissues at a slower rate than helium, and seems to be supported by a comparison of decompression times from the US Navy Heliox and Extreme Exposure Air decompression tables. There are several points to be addressed here.

First, it should be noted that both the USN Heliox and Extreme Exposure Air tables were generated under the assumption that dives are conducted on a single (bottom) mix which is used for both the working and decompression phases of the dive, though in the case of the heliox tables O_2 is used for the final phase of decompression. As a result, the comparison is a bit like matching up apples and oranges.

It has been known for some years that decompressions on deep dives can be dramatically improved by the selection of decompression mixtures with a high oxygen content. Indeed, it is now a common field practice in technical circles to use pure oxygen at the 20 and 10 fsw stops on most deep dives, and based on the development work that was carried out at Wakulla in 1987 and subsequent projects, many cave and wreck explorers have now begun to use enriched air mixtures at substantial depth.

Typically, for missions in the environs of 300 fsw, EAN 32 is utilized as a decompression gas beginning at 130 fsw, and in some cases EAN 30 for slightly deeper decompressions, although air (nitrox 21) has been used successfully as a safety hedge at stops as deep as 220 fsw. These mixtures were selected such that the PO2 levels did not exceed 1.4 - 1.6 atmospheres (atm) during decompression. *Note that a PO2 of 1.4 atm ris generally regarded as the maximum allowable for sustained surface-based diving*, though this restriction is relaxed somewhat during the decompression phase of the dive in which divers are completely at rest. This procedure of using EAN mixtures followed by oxygen has become a defacto community standard for special mix diving among cave, wreck and scientific user groups, and should be factored into any comparison between heliox and trimix.

Figure 1 compares the performance of three different bottom mixes from a decompression perspective. The decompression schedules were generated by the Hamilton Research DCAP computational program[1]. Each profile represents a 20 minute bottom time at a depth of 300 fsw for each of three mixes; nitrox -14, a.k.a. *nartrox* (14% O2, balance N2), trimix 14/34 (14% O2, 34% helium, balance N2), and heliox-14 (14% O2, balance He)[2]. In all cases, it is assumed EAN 32 is breathed during decompression, from 130 to 70 fsw, compressed air from 60 to 40 fsw, and oxygen from 30 fsw through surfacing.

Note that these profiles and decompression procedures were dive-tested at Wakulla Springs using heliox 14 with bottom times varying from 30 to 80 minutes. No bends incidents ocurred over 35 person-dives. The dives were conducted using a "microbell" during decompression which explains the somewhat unusual procedures. Air was used at the 60-40 fsw stops in the bell instead of a higher PO2 mix (ex. EAN 50) to give divers a "mask break," reduce their oxygen tolerance units (OTUs) and to purge the microbell atmosphere. The use of the bell also permitted oxygen to be breathed safely at 30 fsw versus the recomended 20 fsw limit for in-water decompression. The profiles for the other bottom mixes are calculated using identical procedures but have not been tested.

As can be seen in Figure 1, the use of nitrox-14 results in a total dive time (runtime) of 165 minutes, compared to 174 minutes for heliox, a 5% reduction (9 minutes) with trimix falling in between. Note that in this example the iso-narcotic depth of nitrox-14 (or *equivalent narcotic depth, END*, see *technically speaking*) would be 327 fsw making it highly undesirable bottom mix from an operational perspective. Figure 2 shows a similar comparison for bottom times of 80 minutes. In this case a very different scenario appears; heliox-14 yields a total dive time of 668 minutes (11 hours and 8 minutes) versus 818 minutes for nitrox-14, a reduction of 18% (a substantial 150 minutes) in favor of heliox. Trimix yielded a dive time of 698 minutes. What's going on here?

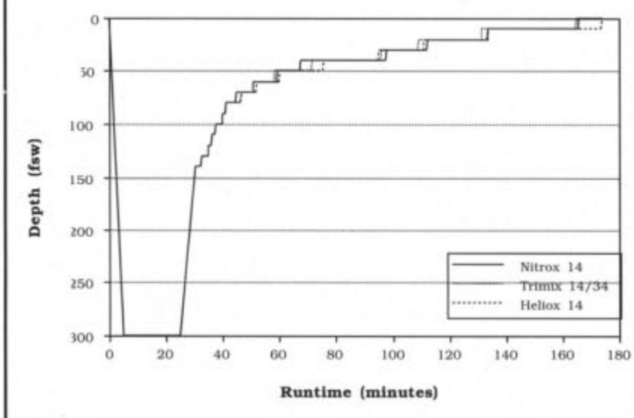


Fig. 1: Decompression profile for a 20 minute bottom time to 300 fsw using a) nitrox 14; b) trimix 14/34; and c) heliox 14

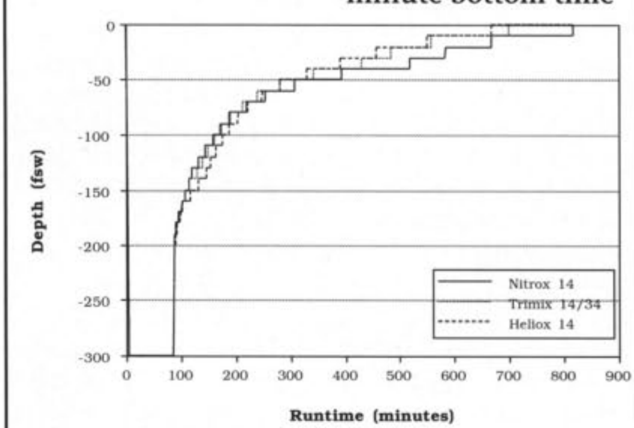


Fig. 2: Decompression profile for a 80 minute bottom time to 300 fsw using a) nitrox 14; b) trimix 14/34; and c) heliox 14

Note that for both the 20 and 80 minute dive profiles, bottom time represents only a small fraction of the total runtime (about 10% on average), the majority of the dive being taken up by decompression during which identical nitrox mixtures are used followed by O_2. The conclusion, as can be seen in Figure 3, showing the complete range of trimix mixes (from 0%He or nitrox to 100% helium, heliox), is that for a bottom time of 20 minutes in the 300 fsw range, there really is no significant difference in decompression between any of the possible bottom mixes[3].

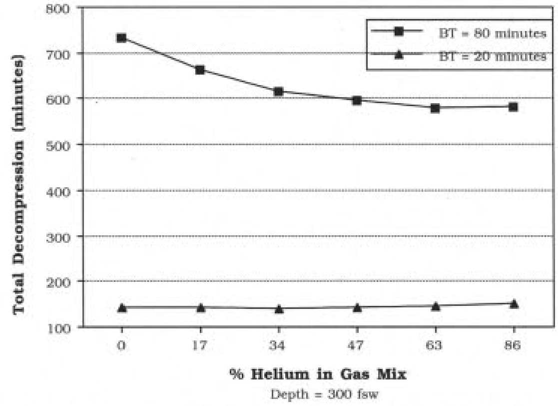


Fig. 3: Total decompression times for a spectrum of gases ranging from nitrox 14 (14% oxygen, balance nitrogen) through trimix to heliox 14 (14% oxygen, balance helium) for 20 minute and 80 minute bottom times at 300 fsw.

Figure 3 indicates however, that there is a definite trend in favor of heliox and or a high-percentage helium mix for longer (deeper) dives. This may be partly explained by the fact that while nitrogen dissolves in tissues at a slower rate than helium, it also outgases more slowly; helium, while reaching a higher percentage of saturation, offgases at a faster rate.

While the use of nitrox mixtures (EAN 32, air) for decompression actually accelerates helium offgassing through, there is no corresponding acceleration when nitrox-14 is used as a bottom mix. As bottom times are increased, the heliox (0% N_2) profile eventually cuts through the trimix profile leading to an overall reduced dive time (decompression time). It may be noted from Fig. 3 that the majority of the decrease in decompression time occurs by the time that the helium content reaches 50% of the bottom mix.

In summary, for short dives in the 300 fsw range, the choice of bottom mix appears to have little effect on total decompression time[3]. On long dives with a bottom time of about an hour or more, decompression can be substantially reduced by using a bottom mix with a helium content of 50% or more.

The Cost of Mix

Based on the discussion above, it would appear that trimix offers no special advantage over heliox from either a thermal or decompression perspective. So why shouldn't everyone use heliox on deep dives? The answer can be summarized in one word: *cost.*

Figure 4 shows the operating cost per hour of open-circuit scuba for various bottom mixes as a function of working depth. (Note that only helium costs are considered as the cost for decompression gas is assumed to be roughly the same in all scenarios. For example, an hour long swim at 300 fsw using heliox-14 as a bottom mix would cost approximately $163 for helium costs alone, or nearly three times the estimated $64/hour costs of trimix 14/34, which would produce the same narcosis level at 300 fsw as diving on compressed air at 165 fsw. If Air Products Corp. is planning to sponsor your next deep diving project the above discussion is irrelevant; use heliox. If not and the money for gas is coming out of your own pocket, then you can begin to wrestle with the essential trade-off of special mix diving; *how much narcosis can you afford to eliminate?*

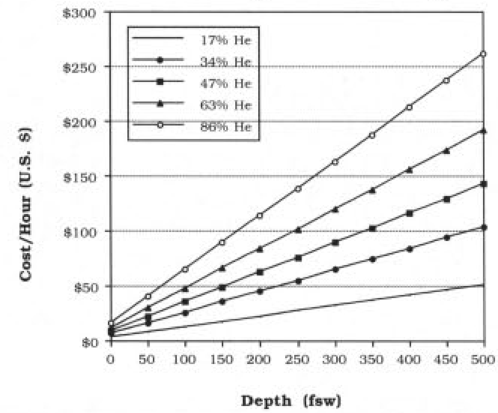


Fig. 4: Open-circuit scuba operating costs per hour as a function of the helium content of the mix, given commercial gas costs of approximately $75 per K-bottle or about $0.008/ liter.

Also note that the above costs assume the diver mixes and checks his/her own mix; blending costs are not included.

The Economics of Narcosis

Given a planned working depth and a desired narcosis level or *equivalent narcosis depth* (END), it is a relatively straightforward matter to calculate the required helium gas fraction in the breathing mix as a function of planned working depth and the narcosis level. Substituting this into the cost equation used in Figure 4, the operating cost per hour of open-circuit scuba can be calculated as a function depth and equivalent narcosis depth (END) *at the working depth of 300 fsw*, as shown in Figure 5. The graph summarizes the narcosis/cost trade-offs between heliox and various trimixes. The trade-off comes down to selecting a feasible operating cost and a tolerable narcosis level.

This discussion of operating cost assumes that the dive is to be conducted using open-circuit technology. If a fully closed-circuit breathing system (rebreather) is used, the numbers look very different. With closed-circuit, helium loss occurs only when the counterlung vents as a diver ascends. If the dive profile is monotonic, that is, there are no repetitive descents and ascents prior to surfacing, then

Fig. 5 Cost Of Mix vs. Equivalent Narcosis Depth / Open-Circuit Operations

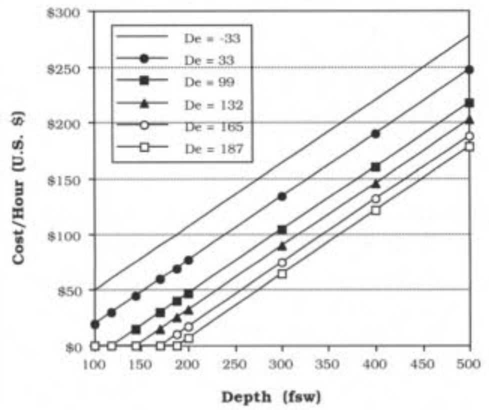
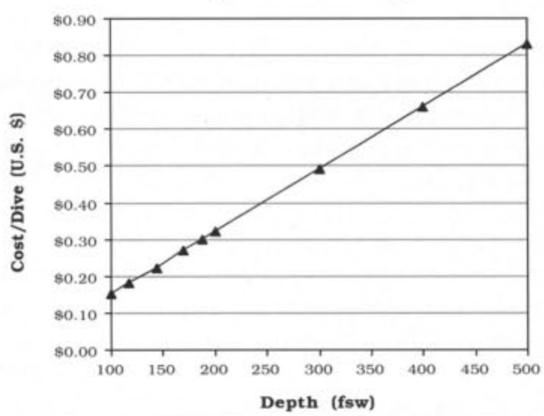


Fig. 5: Open-circuit scuba operating costs per hour as a function of *equivalent narcosis depth* (END), the depth at which the narcosis level would be the same if the dive were conducted on air. An effective narcosis level of "-33 " indicates that there is <u>no nitrogen</u> in the mix (i.e. heliox is being used); an equivalent narcosis depth of "0" is equivalent to breathing air at the surface (1 atm).

the total volume of diluent gas used (generally a single inert gas, ex. helium, with a small fraction of oxygen added in order to serve as a bail-out at depth) is that required to maintain counterlung volume at maximum depth. Given that most counterlungs have a capacity of approximately 7 liters, diluent gas used is roughly 7 liters times working pressure in atmospheres, and is independent of bottom time(for a discussion of closed-circuit systems see *Technologically Inspired* by Dr. RW Hamilton, aquaCorps Journal, Vol.2, pg. 10).

Fig. 6 Cost Of Mix (Heliox) Open-Circuit Operations



Factoring in the cost of helium, Figure 6 shows closed-circuit operating costs as a function of depth. Note that the equivalent narcosis depth, END, is "-33" at all depth ranges i.e. there is no nitrogen in the mix. The conclusions that can be drawn is obvious; mix costs are inconsequential for closed-circuit operations, which offer roughly 100 times the efficiency of open-circuit systems. The observation regarding rebreather costs is worth discussion.

Currently there are two groups in the U.S.; Cis-Lunar Development Laboratories, and Carmellan Ltd., preparing to market a closed-circuit system in the near future with prices in the neighborhood of $10-15,000. Are these costs out of reach?

Assume that you expect to be diving in the 300 fsw range, not an unreasonable depth considering that many of the more advanced wreck and cave explorers are routinely working this depth range today. A simple method of estimating the equipment costs involved in open-circuit scuba is to calculate the gas required for a one hour dive at 300 fsw, expressed in terms the number of scuba tanks required, times an average capital cost per tank of $400 (which includes regulator, pressure gauge and supporting hardware).

assuming 80 cf cylinders are used for the purpose of analysis, each containing approximately 2200 liters of gas, the open-circuit hardware cost (OCHC) per one hour dive is

Hydrogen Abstract

Safe Deep Sea Diving Using Hydrogen reviews safety considerations in hydrogen diving with reference to the experimentation of hydrogen-helium-oxygen mixtures ("hydreliox") at depths to 1,750 ft. in the open sea. Hydrogen improves divers' safety and performance at great depths. Demonstrated benefits include neurological (alleviation of the High Pressure Nervous Syndrome) and respiratory (increased breathing comfort) improvements. The combination of both these benefits from hydrogen-helium-oxygen mixtures is without equal in any other known diving mixture. Other benefits in using hydrogen are speculated, such as its potential involvement in body metabolism (the concept of *biochemical decompression*) that may contribute to the prevention of decompression sickness and to protection from the cold.

Hydrogen mixtures can be safely handled on board diving support vessels under extremely strict operational conditions. Flammability and explosiveness, characteristics of hydrogen, are discussed with reference to hydrocarbon gases or vapors that are commonly manipulated in the offshore industry. Specific, state-of-the-art equipment for overcoming H_2 risks in open sea saturation diving are comprehensively described. Hydrogen diving may be considered a safe, reliable technique for underwater operations at great depth.

Reprinted from *Marine Technology Society Journal, Vol. 23 No. 4, December , 1989*

Imbert G., Ciesielski T. Fructus X. 1989 December, Safe Deep Sea Diving Using Hydrogen. Marine Tech Soc J 23(4) 26-33

thus:

$$OCHC(\$) = \frac{(VO2 \times RMT/VO2 \times 60\ min/hr)}{2200\ liters/tank} \times (Dw + 33)/33) \times \$400/\ tank$$

where:

Dw = working depth in fsw

VO_2=1.0 metabolic oxygen consumption in liters/ minute per atm.

RMT/VO2 = 26 the mean respiratory rate in liters of mix/ minute per atm, divided by the metabolic oxygen consumption.

Note that RMT/VO2 is generally taken to be the constant 26, i.e. total gas consumption per minute per atm. is approximately 26 times the metabolic oxygen consumption based on empirical tests.

Assuming heliox 14 is used on the dive, and that the capital costs of a closed-circuit system is \$10,000, a rebreather will pay for itself in gas cost savings alone within:

$$\text{Breakeven} = \frac{(\$10{,}000 - \$4293)}{(\$163 - \$0.49)}$$

= 35 one hour dives to 300 fsw

Note that the cost and bulk of open-circuit hardware needed for such a dive is not inconsequential. Experience at Wakulla Springs in 1987 showed that the volume of tankage required could only be effectively moved with a diver propulsion vehicle (DPV).

A more general form of breakeven analysis is given in Figure 7, which shows the number of one hour dives

Fig. 7 Cost Vs Open Circit Open-Circuit / Dives To Breakeven

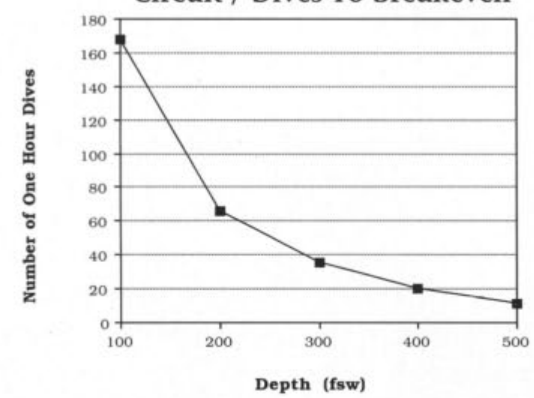


Fig. 7: Number of dives to breakeven point, as calculated solely on the basis of helium usage cost between a closed-circuit (C^2) system (assumed to cost \$10,000 per unit) versus presently available open-circuit technology.

needed to breakeven as a function of planned working depth. This graph indicates that serious sport divers who expect to be diving regularly at depths as shallow as 200 fsw would do well to consider the C^2 technology option when it becomes generally available. Other substantial benefits of rebreathers, such as range-enhancement (a *virtually* unlimited gas supply), compactness (the elimination of open-circuit bulk), near optimal decompression and silence add further to its appeal.

In summary, the heliox versus trimix debate presently rests with the cost trade-offs inherent in the inefficiences of open-circuit scuba at depth. Eventually, as C^2 technology becomes widely available, the debate will come to an end and heliox will become the bottom mix of choice for deep diving.

Dr. Bill Stone is the chairman and founder of Cis-Lunar Develop-ment Laboratories which specializes in the design of advanced life support systems for undersea and space exploration. A cave diver and member of the Explorers Club, Dr Stone has organized and led over 26 speleological expeditions over the last twenty years and can be contacted at: Cis-Lunar Labs, 7739 Laytonia Dr., Derwood, MD 20855. Fax: 301-975-2128 x 6075. For a set of formulas used in this article contact Cis-Lunar.

Footnotes:

1. The DCAP program utilizes the Tonawanda II algorithm with ascent-limited matrix designated 11F6, based on the Haldane-Workman-Schreiner model. Use of a different model might yield different results (see footnote 3. below). The exact behavior of different inert gases in the body is not well established. The principles used here have been validated in several hundred diverse exposures, but the basic gas transport physiology is still somewhat uncertain.

2. Note that the oxygen fraction for the three bottom mixes is set at 14%. This yields the optimal PO2 of 1.4 atm at the working depth of 300 fsw (10 atm) i.e. PO2 = 10 atm x .14 = 1.4 atm.

3.Note that these results(i.e. the specfic crossover points) are dependent on the depth range considered and also the specific decompression regime used, though the conclusion that the use of heliox yields shorter decompressions for *long* dives (dives greater than 80-100 minutes) is generally accepted.

For example, at 300 fsw using a decompression regime of EAN 32 from 120 fsw, EAN 50 from 70 fsw, and pure oxygen from 20 fsw, the deompression associated with heliox is significantly longer for a 20 minute bottom time and does not show a decompression improvement over "nartrox" until after about 100 -125 minutes of bottom time, based on Submariner Research Ltd's modified Buhlmann algorithm. Note that specific crossover points can vary somewhat with the computational algorithm used to generate the schedule but is not the major factor.—*Ed*

Deep Reef Set

By Richard Pyle

"Learnin' to fly, but I ain't got wings.
Coming down is the hardest thing."

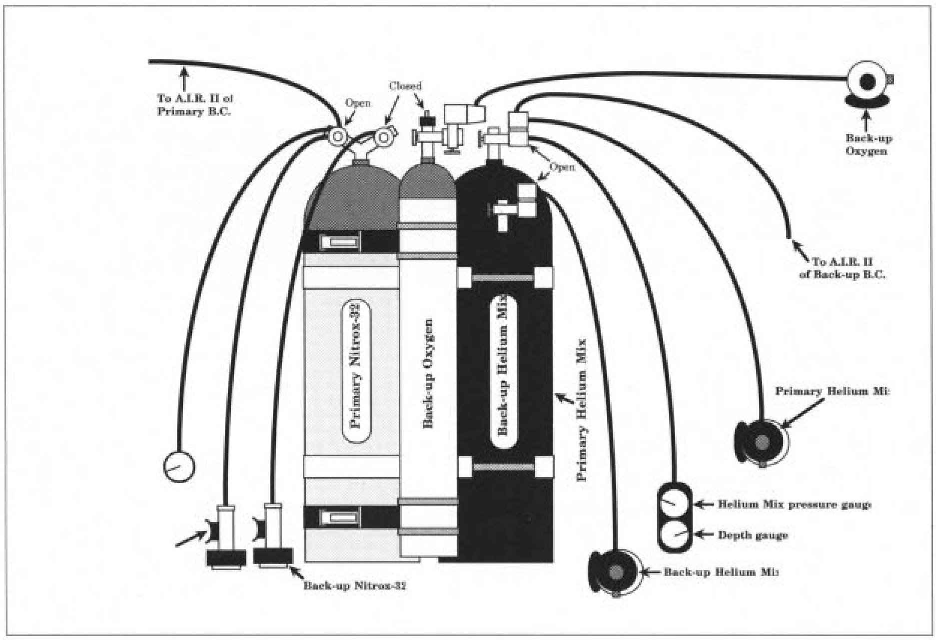
Tom Petty, *Learning To Fly*

Though the deep cave and wreck divers have received considerable attention in the community, there is another class of divers who have also been taking technical diving out to the edge and beyond; the deep coral reef explorers. Though not formally organized, the deep reef community has regularly been making forays into reef habitats sometimes in excess 300 fsw.

The coral reef environment is very different from the typical cave and, to some extent, wreck environments. Consequently, the ideal equipment and diving practices for reef diving differ from those found in deep cave or wreck diving. This article is intended to outline my own thoughts and philosophies regarding deep coral reef diving, especially with respect to a mixed gas set design.

The mixed gas set I use for deep reef diving differs from the configurations commonly used for deep mixed gas cave and wreck diving with regard to both total volume of gas and equipment redundancy. For my primary gas sources, I use two independent aluminum 100's mounted on a Hawaiian-style backpack (shoulder hooks instead of shoulder straps). The right cylinder is filled with helium mix (the exact mixture depends on the particular dive I intend to do), and is equipped with a standard K-valve and a ScubaPro Mk-X/G250 regulator. The left cylinder is filled with EAN 32 (an enriched air mixture with 32% O2, balance nitrogen) and is equipped with a "Y"-valve and two Poseidon regulators. Nestled between the two cylinders is a standard 22 cu. ft. medical oxygen cylinder with a scuba adapter and an oxygen-cleaned regulator, along with a 30 cu. ft. pony bailout bottle of bottom mix. My primary B.C. is a Sea Quest backmounted wing fitted with a Scuba Pro A.I.R. II connected to my EAN cylinder. I also wear a back-up horse-collar B.C. with an AIR II running off my primary helium cylinder.

An important characteristic of this rig is the fact that all gases needed to conduct the entire dive, including decompression, are carried by the diver. Deep reef dives are generally conducted from anchored boats. On a vertical drop-off or steep slope (typical deep reef habitats), it is usually necessary that the anchor be set near the top of the drop, often in fairly shallow water. Strong currents are also typical of coral reef habitats, and boat anchors have been known to break loose. Even if the anchor holds, sudden unpredictable currents may render it impossible for a diver to return to the boat immediately (if at all). For these reasons, the deep reef diver cannot rely on stage bottles



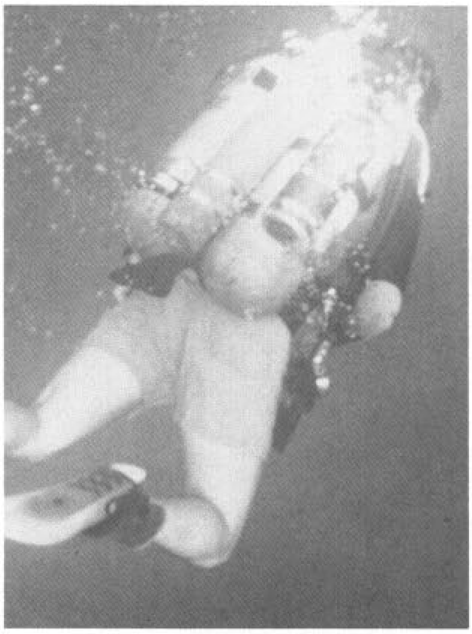
attached to the boat or anchor line.

Unfortunately, the drop-offs and steep slopes associated with the deep reef environment are notoriously difficult terrains for leaving stage bottles. Negatively buoyant objects have a tendency to slide down a drop-off or slope towards the abyss, and typically will not stay exactly where they are placed. Furthermore, staging bottles on the reef during the descent requires that the diver ascend along the same path. This is frequently impractical, and in the event of unexpected current shifts, often impossible. For that reason, it is essential that a diver be entirely self-contained. This in turn creates it's own problems.

For biologists, like myself, whose primary purpose is to collect specimens, maneuverability is crucial. Although cave and wreck divers generally carry double steel 104's or 120's often filled with close to 250 - 300 cubic feet of gas, I typically carry a mere 130 cubic feet of bottom mix of it on my back. Though in some circumstances, carrying large capacity side mount bottles could be a viable alternative, attempts at collecting many kinds of fishes while burdened with two side-mount cylinders (or four back-mounted ones) would likely be futile, particularly in the presence of strong currents. Furthermore, the deep diving scientist is often hampered by other equipment such as fish-collecting gear and bulky underwater cameras. If the rig and equipment provides too much drag in a current, diver exertion can easily exceed acceptable levels. For these reasons I have chosen to sacrifice long bottom times in exchange for being relatively streamlined and entirely self-contained.

Another aspect of my set which needs discussion is the extent and design of redundant equipment. As a general rule, technical divers are far more equipment-dependent than their recreational counterparts, and must take steps to ensure that equipment malfunctions can be dealt with *under pressure.* Redundancy should be designed into the set so as to minimize the probability of a "system failure", an equipment malfunction which threatens the life of a diver. By incorporating extra redundancy into a system, some pieces of critical equipment can malfunction while still allowing the diver access to enough breathing gas to allow a safe trip home.

Redundancy in an open-circuit,

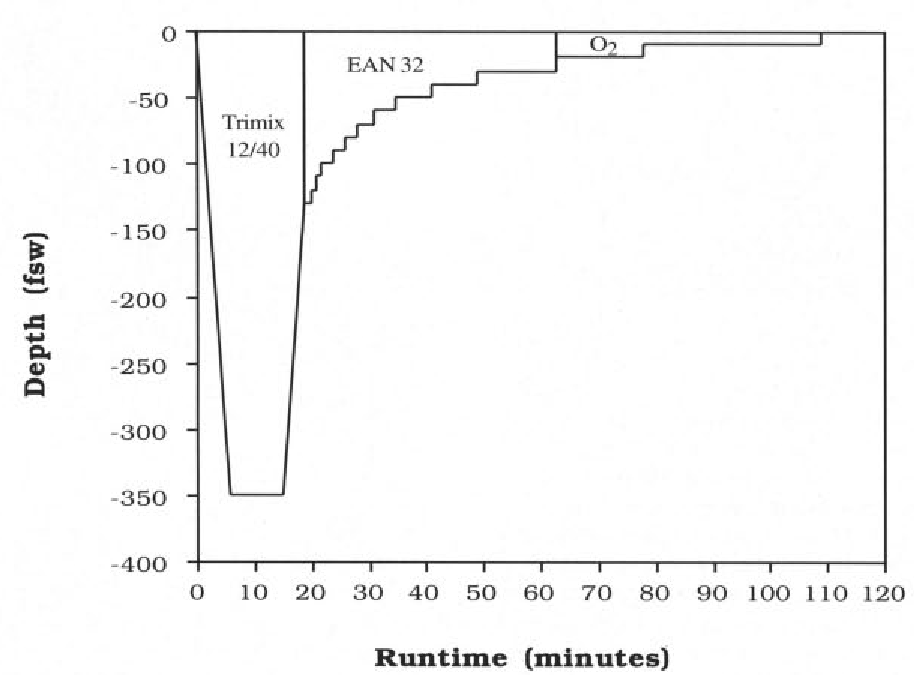


mixed gas operation is confounded by the fact that several different breathing mixtures are required. Since each mixture is crucial to some portion of the dive, each gas system requires its' own set of redundant equipment. Thus, on a deep trimix or heliox dive utilizing enriched air and oxygen as decompression gases, effectively three times as much equipment is necessary to achieve the same redundancy as an equivalent dive on air. Since deep coral reef explorers often need to be both self contained and relatively streamlined, providing enough equipment redundancy to safely conduct a deep reef dive is a rather formidable task. It is also important to consider the nature of the most likely failures when deciding upon a configuration. In general, breathing system failures fall into one of three categories: *no gas delivery, too much gas delivery, and gas mismanagement.*

A *no gas delivery* failure, characterized by a regulator which suddenly fails to deliver breathing gas to a diver independent of cylinder content, is perhaps the most serious. The good news is that this kind of failure is extremely rare (although not nonexistent) in modern, well-maintained two stage regulators.

Too much gas is a much more common form of equipment failure. Typical examples are a free-flowing second stage, a blown hose, blown o-rings, blown burst disks, or any other tank or regulator malfunction which causes an increased rate of gas loss.Although some *gas mismanagement* errors are the result of equipment failures such a s a faulty pressure gauge, problems which fall under this third category are usually associated with human error (for example, not providing enough

Fig. 8 Deep Reef Profile (350 fsw for 15 minutes)

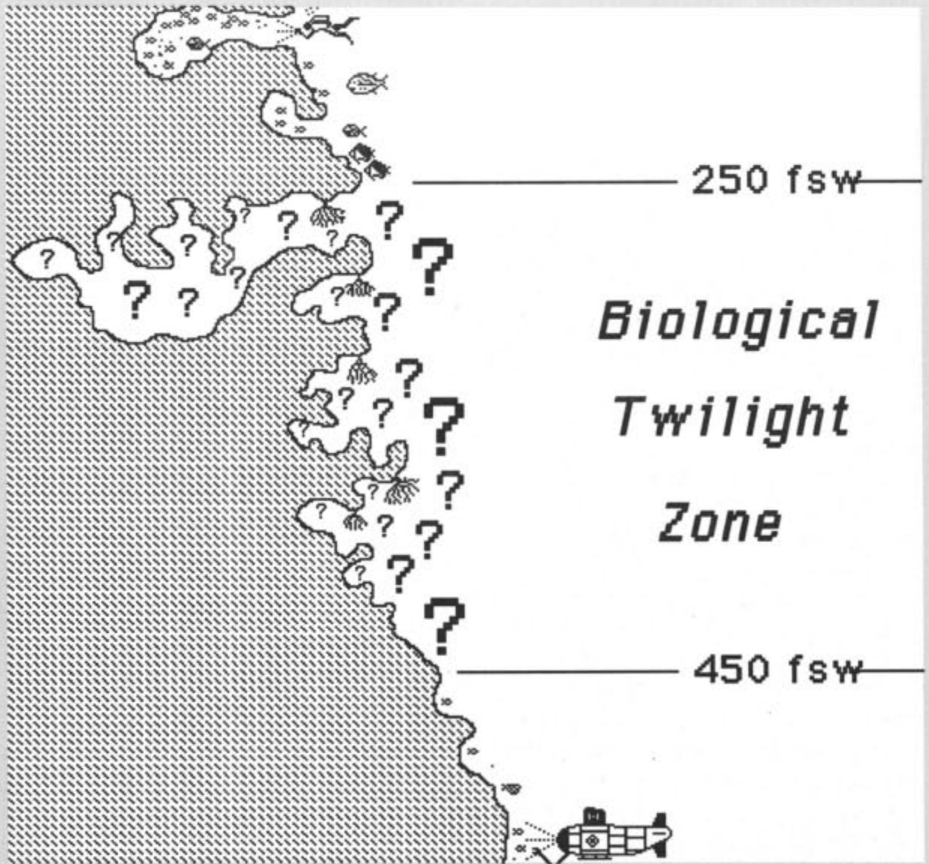


decompression gas to follow the planned schedule). Another form of gas mismanagement in mixed gas diving operations is breathing a gas mixture outside its depth range of allowable oxygen partial pressure. An example of this type of failure recently happened here in Hawaii when a diver accidentally switched from bottom mix to an EAN 32 at a depth of 300 fsw. Big mistake. The diver luckily survived the ordeal, suffering only a moderate amount of nausea. As mentioned above, deep trimix diving usually involves at least three different gasses in three different systems. Of these, redundancy in the helium-mix system is perhaps the most critical. At the depth range where such a mixture is usually utilized (i.e., below 130 feet), it is the **only** gas carried by the diver which may be safely breathed; *the enriched air and oxygen systems cannot be relied on as back-up in an emergency situation at depth.*

In order to design effective helium mix redundancy for the deep reef diver, it is important to distinguish *real* from *virtual* overhead environments. Essentially, an overhead environment is one in which something prevents the diver from returning immediately to the surface. For obvious reasons, caves,

RICHARD PYLE

Genus: "Centropyge sp.," known as the " pepermint swimmey," was first collected by Boyles and Pyle at 360 fsw on a hazardous deep air excursion, before their use of special mix. The team couldn't believe their good fortune. Particularly when a buyer agreed to pay the unbelieveable sum $600 for each fish which more than covered the cost of the trip. Later they found out these same fish sold for 1.4 million yen each at retail in Japan, or US $14,000. How much was that Cis-Lunar rebreather?



The Twilight Zone

Coral reef communities are among the richest and most diverse ecosystems on earth. They flourish where bright tropical sunlight penetrates relatively clear ocean water, and provides the basic energy to fuel photosynthesis processes in the primary producers (algae), at the bottom of the food chain. For that reason, the coral reef community is limited to the upper reaches of the sea and cannot exist in the dark abyssal depths below about 400-500 fsw.

Since the advent of conventional scuba gear, professional marine biologists have been busy exploring coral reef habitats, collecting and documenting the incredibly wide diversity of organisms which inhabit them. However, because virtually all of these scuba explorations have been conducted while using air as a breathing gas, thorough biological investigations have been generally limited to depths of less than 250 fsw. To study the marine life at greater depths, marine biologists have had to rely on such devices as traps, trawls, and deep sea submersibles. Unfortunately, traps and trawls are not very selective catching methods, and are generally ineffective at collecting the many smaller, more cryptic organisms typical of coral reef environments. Submersibles (both manned and remote) are cumbersome and extremely expensive to operate. Most are designed to penetrate depths of thousands of feet or more, and the rare researcher fortunate enough to obtain funds to utilize them generally concentrate their efforts at depths below 400 fsw.

As a result, there remains a zone of coral reef habitat at depths between about 250 and 500 feet throughout the tropical seas, which has escaped extensive exploration and documentation. This zone, the biological *"twilight zone"*, undoubtedly harbors vast numbers of undiscovered species of marine life, and represents a new frontier for the qualified researcher suitably equipped with the mix technology.

PAULINE FIENE

Pyle on mix

Here are a few of the things I've learned after making the switch to mix. Though this list is certainly not comprehensive, I've chosen to underscore those areas of mix safety which overconfident experienced deep air divers (like myself) may tend to overlook or consider unimportant. Although many of these points also pertain to deep air diving, they are especially important to special mix operations.

1. Plan your dive and don't get over your head.

2. Redundancy is important. Redundancy is important. Redundancy is important.

3. Regulators aren't the only thing you need to back up.

4. Don't pinch pennies.

5. Invest in an oxygen analyzer.

6. Be careful when working with high pressure oxygen.

7. Invest in proper decompression schedules.

8. Know your equipment inside and out.

9. Make sure you can get to your stage bottles.

10. Don't forget how deep you are.

ice, and wreck penetration, are examples of *physical* overhead environments; there is a physical obstruction (rock, ice, metal) between the diver and the surface. Decompression dives are also thought of as overhead environments: the obstruction between the diver and the surface being the decompression obligation, a *virtual* overhead.

Under normal conditions, when a dive goes as planned, physical and virtual overheads are essentially the same from a diver's perspective. But in the event of an emergency, the differences can be profound. For example, a diver lost in a silt-out inside a shallow cave, who runs out of air at a depth of 10 fsw will almost certainly die; but a diver with a twenty-foot decompression ceiling who runs out of air can dash up to the boat, grab another tank, and drop right back down to below twenty feet in a minute or two. While certainly not recommended as standard decompression procedure, a diver in this situation will, in all probability, fare just fine. Another fundamental difference between physical and virtual overheads become important when considering helium mix redundancy in a deep diving rig. When conducting a deep mixed gas dive in a physical overhead environment, the helium mix redundancy system must be designed so that a diver has access to large volumes of breathing gas (usually a set of crossed-over doubles with two regulators and an isolation valve). This is because a diver under these conditions often must travel extensive distances horizontally, to circumvent the physical overhead obstruction, before reaching depth where the decompression gas (i.e., EAN) may be safely breathed. For short dives in the 250-350 fsw range, virtual overheads (decompression ceilings) are generally shallower than 130 fsw where EAN 32 may be safely breathed. For that reason, a diver who needs only to worry about a virtual overhead requires an entirely different redundancy design to facilitate a safe bailout than a diver who must swim great distances through cave tunnels or sunken ships.

In utilizing a single cylinder of bottom mix for my deep reef rig, a logical system of regulator redundancy would be to attach two regulators to the cylinder via a "Y"-valve. This would effectively provide the same amount of redundancy as the crossed-over doubles system. However, I did not opt for this approach because I believe the costs outweigh the benefits. Extra equipment usually carries a cost (and I don't mean dollars) in addition to the benefit it provides. In addition to added weight and water resistance, making it harder to swim, such a rig also presents problems of hoses becoming hopelessly tangled. Furthermore, coral reef habitats are characterized by hard, sharp limestone rock intricacies where regulator hoses may easily become snagged, tangled, and possibly ruptured.

Since most coral reef exploration dives do not usually involve deep penetration into physical overheads, I believe a more effective form of helium mix redundancy is a separate 30 cu. ft. pony bailout bottle, with its own regulator, maintained in the "open" pressurized state. This pony bottle has sufficient gas capacity to allow a controlled ascent to 130 feet, where a diver can safely switch to breathing enriched air. Moreover, a *too much gas* malfunction in either system will not affect the other. *(Note: A 30 cf pony bottle would be totally ineffective as a bailout **to the surface** on a deep mix dive.—ed)*

The use of a "Y" valve is, however, an effective means of redundancy in the enriched air breathing system. In this case, the valve to the secondary enriched air regulator is maintained in the "closed" state, so that a *too much gas* failure in this regulator will not cause a rapid loss of the enriched air supply. The reason this can be done safely is that the helium mix system serves as an emergency back-up in the event of an "immediate danger" failure in the primary enriched air regulator. If need be, the diver can breathe the helium mix while taking the time to close the valve to the faulty enriched air regulator and open the valve to the secondary one. The A.I.R. II on the primary B.C. provides additional second stage redundancy for this system.

The primary source for decompression oxygen is some form of rig (either a stage bottle or a surface-supplied system) secured to the decompression line at the boat. The 22 cu. ft. pony bottle incorporated into this rig serves only as the redundant system. Its valve is kept closed, and is opened only in the event that the diver is unable to return to the boat at the end of the dive (or if the primary oxygen rig malfunctions). If an "immediate danger" situation arises during the oxygen decompression portion of the dive, the enriched air (and in some cases, helium mix) serves temporary back-up.

Some mixed gas rig designs include redundant pressure gauges to minimize gas mismanagement problems, but I do not incorporate them into my system: I use only two gauges; one on my primary helium mix supply, and one on my enriched air system. I am vividly aware of the real possibility of a malfunctioning gauge *(I spent more than a year- learning how to walk as a result of a diving accident - largely because a faulty pressure gauge convinced me that my empty tank still had 750 psi remaining.)*, but I believe that additional pressure gauges present more potential costs than benefits. Too many gauges can be confusing and dangerously misleading if they are not very carefully organized.

In my opinion, a better redundant system for gas management, is to simply become intimately familiar with your own breathing rates, and employ a great deal of common sense and conservatism. Know how long a given volume of gas at a given depth, and under a given workload will last you. If the gauge says you have more, then don't trust it!

Besides safeguarding against equipment failures, I designed my system to reduce the probability of human error as well. In order to minimize the risk of accidentally breathing the wrong mix at the wrong depth, I code my regulators as to what type of gas they deliver. One note of caution: the secondary EAN and oxygen regulators should be pressurized by opening the tank valves prior to the dive to maintain them in a pressurized (but "closed") state. This will help prevent water from flowing back up into the regulator on the deeper portions of the dive.

My system is certainly not without its weaknesses. A failure could occur in the helium mix rig if a gas mismanagement problem arises in the primary cylinder with a simultaneous regulator malfunction in the pony bottle regulator. A system failure could occur in my EAN system in the event of a blown burst disk. To minimize this as a potential problem, the burst disk could be replaced by a plug (*Note, though done in the field, plugging a burst disk is not recommended by tank manufacturers—ed.*), and an additional EAN cylinder kept on the anchor line or decompression line, strictly as a reserve. Also, all three systems are at the mercy of two simultaneous regulator failures, but the same is true for almost any set.

> ### *A Pony And A Prayer*
> *Taking a cue from the underground, crossover manifolds and stage bottles are gradually upstaging the pony as the bailout system of choice among deep wreck divers. For good reason. As summed up by cave diver Mike Hanna, general manager of Ginnie Springs Dive Center, "A single pony will give you enough time at 250 to say the Lord's Prayer."Amen.*

A final area of concern to the coral reef diver is buoyancy considerations. Unlike most freshwater cave diving and a great deal of wreck diving, where cool water temperatures require the use of drysuits for long exposures, reef divers are often quite comfortable wearing only wetsuits. While wetsuits have the advantage of allowing increased mobility, they also reduce the over-all buoyancy of a diver when compared with a drysuit. Consequently, the deep reef diver's set should be made as close to neutrally buoyant as possible (this is also important if a diver needs to remove the set to open or close a tank valve). This explains the choice of aluminum 100's for primary gas sources: each tank is +3.5 pounds buoyant when empty, causing the complete rig to be only slightly negatively buoyant at the end of a dive. Large capacity steel cylinders are much too heavy underwater if the diver wears only a wetsuit. To further safeguard against potential buoyancy problems, we carry a back-up B.C. as a standard part of our deep reef diving equipment.

Although not perfect, I believe this rig to be ideal for use in short-duration, mixed gas coral reef exploration dives. While the bottom times allowed by only 100 cu. ft. of bottom gas may seem scant (usually not exceeding 15 minutes), it is enough to make some formidable exploration forays into the "*twilight zone*." With a rig of smaller capacity (steel 75's instead of aluminum 100's) and far less redundancy, Chip Boyle and I managed to collect a number of ichthyological treasures in Raratonga. I designed my present system in response to the weaknesses and shortcomings of the previous rig, and believe that it serves my needs well. I am continuously learning new things and having new experiences, however, so my philosophies and rig configuration will probably change over time—presumably for the better.

Let me emphasize that the diving rig and practices just described pertain **only** to short-duration exposures in the absence of "physical" overhead obstructions! Do **not** use this rig for deep cave or penetration wreck diving!

I sincerely encourage anyone with comments or criticism in reference to the points I've addressed to contact me. I would especially love to correspond and exchange ideas with fellow *deep reefers* (no narcotic connotations intended). Safe mixing.

An ichthyologist and fish collector with over 40 published papers, Richard Pyle has been conducting deep reef dives for over a decade, racking up several hundred dives in excess of 200 fsw spread out over a nearly dozen major projects. Currently working with Bishop Museum, Honolulu, Hawaii, Pyle plans to attend the Ph.D program at University of Hawaii next fall. He can be contacted at: Bishop Museum, PO Box 19000A, Honolulu, Hawaii 96817. Fax: 808-841-8968. Mark it, "Deep

Set Theory:
a look at rigging options

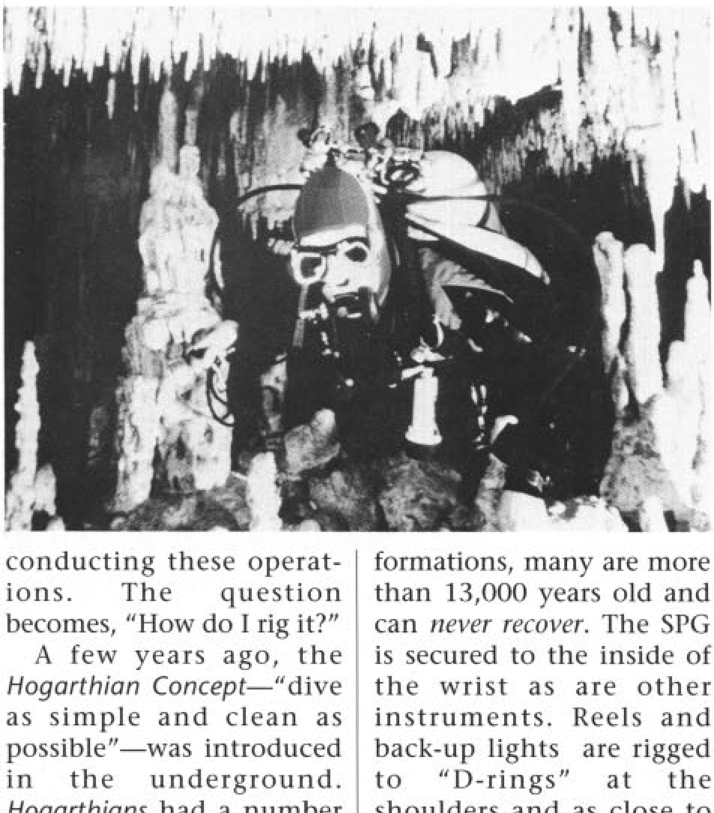
Though double tanks and stage bottles are generally a requirement for most technical diving operations, diving sets vary significantly depending on the specific application and diving environment. Here's a look at some of the more common methods of set rigging as practiced today in the "doubles community "

Diving In Little Places

Modern equipment is designed to make diving in an overhead environment as safe as possible. Redundancy is the key to conducting these operations. The question becomes, "How do I rig it?"

A few years ago, the *Hogarthian Concept*—"dive as simple and clean as possible"—was introduced in the underground. *Hogarthians* had a number of specific ideas which created a furor in the cave community, but got people thinking. Though some of the ideas were rejected, the concept is valid and has been implemented in various ways by members of the community.

Equipment is never rigged externally on the sides of tanks, and nothing, in particularly the long hose, lies above the manifold crossover bar. All split rings are removed so as not to create a line trap, and so is anything that can foul or break delicate cave formations, many are more than 13,000 years old and can *never recover*. The SPG is secured to the inside of the wrist as are other instruments. Reels and back-up lights are rigged to "D-rings" at the shoulders and as close to the back plate as possible on the waist straps using short tethers. Pouches mounted on the waist band are used for carrying smaller items such as a line cutter, slates and tables, and line markers. The back-up second stage regulator is secured by a piece of surgical tubing that is worn around the neck.



E.J. LALO FIORELLI

Rigging completed, there is no substitute for technique. In order to protect the cave, diving in small fragile places requires the finesse and brainwork of a technical climber. Like their free hanging counterparts, divers relay on a series of *"moves"* rather than brute force. And the edge is never more than a breath and a prayer away. *E.J. "Lalo" Fiorelli, 250 Rocky RD., Soquel, CA 95073. Fax: 408-464-1854.*

Squeezing By

Originally developed for the tight low visibility sump diving that is common in Europe, sidemounts allowed spelunkers to more easily transport single cylinders through a dry cave to the dive site. In North Florida, the use of sidemount techniques has allowed exploration into small silty areas that were once thought impassable and has opened up entire new cave systems that were simply inaccessible with back mounted doubles. Side-mounts reduce the strain of carrying heavy doubles up steep inclines, lowering cylinders down into a hole, and making those long walks through the woods to the dive site. Cave systems known to be silty can now be penetrated without heavy silting.

WAKULA SPRINGS PROJECT

Sidemount configuration means wearing the cylinders on the hips instead of the back.The cylinders are fastened in the middle with a snap to a harness at the waist. The necks are clipped off at the armpit using bunjii material (a bicycle inner tube is preferred) so that the cylinders are forced to lay parallel to the divers' body . Adjustments are usually needed at first to insure a snug comfortable fit.

When diving with sidemounts, gas supplies must be balanced for adequate reserves throughout the dive. The regulator and SPG hoses no longer lay across the back and instead are clipped across the chest area. The management of these is critical for proper monitoring of gas supplies and switching regulators during the dive. Back-up and emergency equipment must be streamlined and tucked away to achieve the desired profile—*no thicker than the the two cylinders that lay along the divers' hips.*

Clearly sidemount diving is not for everyone because of the potential hazards that exist; low visibility, line traps and squeezes that seem to get smaller and smaller are only a few of the obstacles to be overcome. A diver must be totally comfortable in all these conditions before considering sidemount as an alternative. Suitably equipped,divers who are, can usually find a way to squeeze by. *Lamar Hires, Dive Rite Mfg.Inc., Rt.14, Box 136,Lake City, FL 32055. Fax: 904-755-0613*

China Cult

Previously isolated from the underground and fellow wreckers to the south, the east coast wreck diving community evolved it's own style of set rigging suitable to the cold dark waters of the north and the available technology. Still seen on the boats that work the *Doria, Texas Tower,* the *Virginia* and the *San Diego,* a typical east coast wreck diving set consists of a pair of double 80's or 95's secured to a large capacity BCD jacket with a manifold system, or commonly two independent regulators which are rotated through-out the dive. A 40 cubic foot pony mounted between the doubles serves as a bail-out, along with an aluminum-spindled upreel. For the

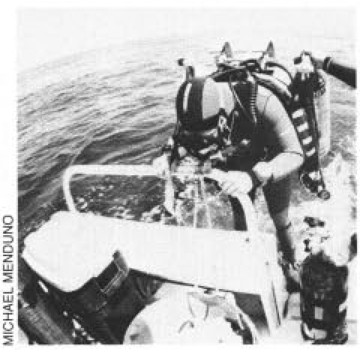

MICHAEL MENDUNO

most part, stage bottles, typically air, are something divers leave tied off to the anchor line at 10 feet, and oxygen for decompression is still used sparingly, if at all.

Now with the advent of larger tanks, harness and manifold systems, improved decom-pression methods and mix technology all that is changing. Today, a well-outfitted *high tech* wreck diver carries a pair of cold-filled Genesis 120's with DIN crossover manifold and valve protectors, shoulder-mounted stage bottles, or *"wing tanks"*, containing decompression gas (EAN and or oxygen) *—do you really want to bet your tissues on that cylinder clipped off to the anchor line?* —harness, bag and back plate system, argon inflation system and of course an upreel. The result? Wreck divers are staying down longer, getting more of that *first class* china, and most importantly are doing it safer . After all, when you come right down to it, the most valuable artifact that you'll ever bring home is yourself. *Billy Deans, Key West Diver, MM4.5, US1, Stock Island, Key West, FL.33040. Fax: 305-294-7612*

Quads

For *long deep* exposures, particularly those associated with expedition-level pushes, carrying sufficient gas volumes *to do the job* becomes a major operaional consideration. Fortunately, most of these dives are conducted in cavernous passageways or open water where restricted space is not the issue. According quads (*"tank packs"*) are often used in conjunction with diver-carried stage bottles in


MICHAEL MENDUNO

order to carry sufficient bottom gas, and that required for decompression, where self-sufficiency is the key. DPVs are generally a requirement to overcome hydrodynamic drag.

A typical quad set-up consists of doubles, often 104's with crossover manifold containing bottom mix , mounted to a pair of side tanks containing decompression gas; an enriched air nitrox and a bottle of oxygen, each with an independent regulator. In addition, divers typically carry a 80 cf bail-out bottle of bottom mix, and a second cylinder of *deep* nitrox mix (sometimes air) for decom-pression—*six cylinders in all*—making the diver relatively self-sufficient. High performance regu-lators, such as the Poisedon, are the standard, as well as double buoyancy compensator bags. Gas and quad equipment management are critical, and takes practice to get down.

How much gas? An explorer with a good quad set and stage bottles can carry just over 600 cubic feet of gas. An awful lot until you consider that gas consumption in the 300-500 fsw range being broached by leading explorers, will drain an 80 cf cylinder in a little over *five minutes*, and the gas requirements for decompression—often in excess of four to six hours—are stiff. Of course, once *closed circuit (C_2) technology* hits the street, quads and six plus tank dives will become a relic of the past. With a *virtually* unlimited gas supply in a 50 lbs. pack, gas won't be the issue. But then that's technology for you. *—Staff*

Futures Market

If Dr. Bill Stone has his way we may all be taking another breath. Rated to 300 msw (that's *meters* of seawater!), Cis-Lunar's MK-2R *fully-redundant* closed circuit "rebreather" will change the way we think about diving, blazing a trail for others to follow. Offering a 12-18 hour heliox gas supply, near optimal decompression, and a fail-safe systems architecture that would send any self-respecting tekkie into orbit—*literally,* the MK-2R, now in beta test, is scheduled to make it's debut sometime in 1992.

The tougher issue is whether Cis-Lunar's initial production run of six units will saturate the market? Considering that IBM first estimated the *world-wide market* for computers to be only *four systems*, Stone and his colleagues may not have to worry for long. All they have to do is hang in there. But then that's exactly what Stone has in mind. Microbells anyone?*M²*

WAKULLA SPRINGS PROJECT

"In 1948, the first "aqualungs" were shipped to the U.S. for sport diving distribution. Rene Buzzoz sold twelve units during that first year. When questioned by the French manufacturer as to how many units could be sold the following year Buzzoz replied, " I think we have saturated the market." Buzzoz's little sporting goods store is well known today as U.S. Divers."

Rick Freshee,SportDiver Magazine, 1977

Safer Than Air?

by John T Crea

Over the last few years we have heard that enriched air is the wave of the future for the sport diving community; that it gives longer bottom times, shorter decompressions and is *safer* than diving air. Is enriched air safer? Well, that depends.

In theory, if we decrease the amount of nitrogen presented to the lungs during a dive (by breathing enriched air), we also decrease the uptake of nitrogen at a given ambient pressure. This results in decreased nitrogen loading in any given compartment which leads to longer allowable exposures or shorter decompressions.

Based on this premise, the concept of *equivalent air depth* (EAD) (see *technically speaking*) can be utilized to simplify the logistics of diving enriched air i.e. air tables can be used. So the issue of safety really boils down to whether or not the tables that are being used are *reliable* for the dive in question. Since most enriched air tables are actually air tables that have been "converted" using EAD, the answer depends on the underlying tables themselves.

For short no-stop dives, there is substantial evidence based on the experience of NOAA and the AAUS that enriched air dives utilizing the US Navy Standard Air Tables (the basis of the NOAA nitrox tables) are very reliable. In fact, the USN tables have an enviable record when it comes to no-stop diving. However, when we begin to enter the realm of *"D-Word,"* particularly on long dives, the story is not quite the same.

Today, it's not uncommon for exploration divers and others to make an air dive to a maximum depth of 100 - 130 fsw with bottom times in excess of 100 minutes. These dives appear to be tailored for enriched air which offers significant decompression time savings over air. And it's safer, isn't it?

Consider a dive to 120 fsw for 120 minutes. The US Navy Standard Tables calls for stops of 10 minutes at 40 ft., 19 minutes at 30 ft., 47 minutes at 20 ft., and 98 minutes at 10 ft., total ascent time: 176 minutes. Using NOAA Nitrox I (EAN 32) the decompression becomes; 12 minutes at 30 ft., 41 minutes at 20ft., followed by 78 minutes at the 10 foot stop, total ascent time 133 minutes, a savings of 43 minutes!

Can this dive be conducted more safely using enriched air? Yes, *but is either dive really safe?*

In 1984, Capt. Ed Thalmann conducted a series of experiments to examine the reliability of the USN Standard Air Tables on dives with long bottom times. Over 835 person-dives were conducted. The results were eye opening (Undersea Biomedical Research, 1985; 12 (Suppl): 54-55):

Air decompression dives conducted over the 50 - 190 fsw range showed that ***tripling*** *total decompression times for long shallow dives (eg. 60ft./180 min.; 80ft./120 min.), and near* ***doubling*** *times for medium deep dives (eg. 150ft./40 min.; 190ft./30 min.) were necessary for safe decompression. Many air schedules could not be safely dived even when decompression times were more than* ***tripled*** *(eg. 150ft./60 min; 190ft./40*

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Getting

In keeping with our goal of serving as a forum for the technical diving community, we've decided to expand the editorial section of the journal. The thoughts and opinions expressed below are those of the authors, and not necessarily shared by the aquaCorps editorial staff. If you have an opinion or something you'd like to share with our readership please contact Michael Menduno at our editorial office.

by Brian Skerry

When *aquaCorps* first appeared in print, my sentiments were, *"Not bad. A journal for experienced divers is long overdue."* As I read the subsequent issues, my appreciation for the wealth of information provided grew even more. Early in 1991, I was asked to join the editorial staff for the next issue in the series titled, *MIX*. I accepted the task looking forward to contributing and hoping to learn something in the process. With *MIX* now complete, I feel it necessary to say a few words to our readers.

It's a bit of a tautology to say MIX is a technical journal. It is a *very* technical journal. I found myself reading and re-reading certain passages just to let them sink in before attempting to edit them for our readers. In many cases, the words could not be made more exciting nor easier to read and are presented exactly as written. I believe this is the way it should be when discussing these important topics.

aquaCorps is aimed primarily at the experienced diver and individuals seeking to learn and gain a broader understanding of diving. Our contributing writers are some

& REVIEW

Technical

of the best and brightest in the business from whom we can learn. Many of the advanced tools and methods discussed in these pages are currently being used by a only a small percentage of the diving population but there is something to be learned from their pioneering efforts. What is considered cutting edge today is likely to become common place in years to come. History is filled with examples of pioneers and adventurers whose ideas and methods, though once considered radical, are now used to great advantage by many. The same is true of diving. The tools and methods discussed in *aquaCorps* today hold great promise for improving the safety and performance of divers at all levels, from the beginner to the professional, in the years to come.

Few people take a basic scuba course with the intention of becoming exploration divers using exotic gas mixes, however, we live in an age where such progression is possible. It is human nature to want to improve, to go beyond what was done before. In diving this must be done with great caution and an emphasis on safety which can only come about through information and education. And that is the basis of *aquaCorps*.

Not every issue of the journal will be as technical as *MIX*, but I believe the importance of the information presented here is worth the effort required on the part of interested readers. Our next issue, *BENT*, which focuses on decompression sickness, other diving injuries, will be less technical, though equally *"information-rich."* For myself, I wouldn't want it any other way.

No Glove. No Love.

Deep Diving In The Age of Sexually Transmitted Disease

by Mike Emmerman

Deep diving (DD) and sexually transmitted diseases (STDs)? What does one have to do with the other? Is there an added risk with depth? Of course not! But if there's a way, well, I suppose someone will figure it out.

The subject matter of this article actually came out of a personal experience at a recent dive show. There I was minding my own business when an extremely attractive woman modeling a body glove surf suit came into view. My first thoughts, unsuitable for print, were rapidly followed by a series of concerns over sexually transmitted diseases, *STDs*. I found myself debating whether education and protection are enough to insure two people can enjoy physical pleasure without the worry of potential disease or even death. Some things may just not be worth the cost.

Shortly after I stopped debating this paradox a diver confronted me with a question about the risks of deep diving. I thought for a minute and told him that *" the risks inherent in deep diving are very similar to those inherent in catching a sexually transmitted disease."* He looked at me a bit dumbfounded, mumbled something about a blond, and walked away hurriedly without waiting for clarification. For his sake and mine, let me explain.

STDs: If precautions are not taken, there is the potential for both short and long term health difficulties and even the possibility of death.

DD: If precautions are not taken, there is a potential for short and long term injuries, including neurological impairment, and the possibility of death.

STDs: The general public has been warned and educated about the the potential dangers.

DD: The diving public has been warned *but not adequately educated* about the dangers.

STDs: The individual makes the decision about taking the required precautions. Safety equipment and training is relatively cheap.

DD: The individual diver must make the decision and the required equipment and training is *relatively expensive.*

STDs: Substantial money has been spent on research to help define the problems and the risks.

DD: *Very little money* has been spent on research.

STDs: Many people ignore the warnings of danger with such phrases as *"it can't happen to me"*, and many who are thought to have infections deny the existence of the problem.

DD: Many divers ignore the warnings, *"who me?"* , and some who exhibit neurological impairment as a result of deep diving exposures deny the problem.

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SAFER THAN AIR?/continued from 24

*min.). Similar results were found with repetitive dives. DCS-free dives could not obtained on many repetitive dive sets such as 100 ft./60 min. or 150ft./40 min, both with 60 minute surface intervals, even when total decompression times were **doubled** (emphasis added —Ed).*

The conclusion? Enriched air diving using EAD is only as safe as the tables on which they it is based and neither the US Navy tables, or the NOAA nitrox tables which are derived from them, are not as reliable as one would like them to be on long dives. Some of the work by Weathersby estimates the DCS risk for an 80ft./120 minute using the USN air tables to be 10 - 16%. What are the risks of a 100 foot EAD dive for 120 minutes, let alone a 120 foot dive for 120 minutes?

Is diving enriched air nitrox safer than diving air? The answer is yes, but a qualified yes. The more pertinent question to ask is *"Can this dive be conducted safely with the tools and methods available?"* It is obvious that on long decompression dives utilizing the USN tables the answer is NO, whether you are diving the Standard Air or EAD-corrected nitrox tables.

Divers venturing into the realm of longer and/or deeper dives should be using the most reliable tables available. For that reason, many divers are switching to more conservative tables such as the Canadian DCIEM table or special application tables, and are utilizing in-water oxygen for decompression. It's something to consider, particularly when your safety is at stake. Hang in there.

John T. Crea is an anesthesiologist, cave diver and president of Submariner Research Ltd., a diving physiology consulting firm that specializes in custom decompression table generation, special mix diving, and high tech set-up and equipment. He can be contacted at: PO Box 1906, Bainbridge, GA. 31717.

STDs: Quite a few people continue to explore random sexual encounters and appear to be healthy.

DD: Many divers continue to explore the deep and also appear to be healthy.

All of have not stopped seeking physical pleasure with a consenting partner just because of the potential risk of STDs. And lots of divers still make deep dives knowing that these dives carry greater risks than shallow exposures. The "Fix" for STDs is relatively easy; get educated about high risk profiles, acquire the necessary protective devices, and use the education and protection when needed. The "Fix" for deep diving is a little more complicated.

Many diving professionals are now calling deep diving "technical", however deep diving in itself, is not the same as technical diving. Technical diving denotes a need for education, training and practice, and involves discipline. To date however, there is a limited infrastructure in place to provide this education, training and practice. Several training courses are currently in discussion within various parts of the community, and some already exist for divers who want them and who are willing to invest the time and money required. But until these courses are generally available, the "*improperly prepared*" diver is at substantial risk.

The lack of training is obvious. What is not so obvious is the lack of research related to deep diving. Unlike the STD problem, the research dollars needed to clarify the risks inherent in deep diving—both physical and physiological—are simply not available. Some of these risks have been quantified; for example, oxygen toxicity tolerances, CO_2 build-up and certain aspects of narcosis. And while it is true that deep diving has been practiced for years in certain segments of the diving industry, for example among commercial divers, strict scientific protocols have not been employed to verify the results and experiences of these groups. Do commercial divers experience more problems with DCS? Do they have a higher incidence of bone necrosis? We just can't answer these questions without in-depth studies of commercial and non-commercial divers. It will take many years before we can accumulate the data that is necessary to define the real risks associated with deep diving.

So next time an extremely attractive potentially sexually active partner comes walking into your view, remember that you probably have enough education, training and equipment to reduce your potential risk. However, if you are planning a deep dive, you may not. If you choose to participate in exceptional diving experiences, then you owe it to yourself to become an educated diver. Seek out those individuals within your community who already have the training and experience needed to reduce your potential risks. And remember, all of us who choose to step outside accepted norms, either sexually or with tanks on our backs, have ~~agreed to accept the risks.~~

Mike Emmerman is the research director at Lifeguard Systems Inc., a rapid deployment rescue training organization. He is also the research coordinator of the Diving and Water Rescue Committee of the National Association For Search and Rescue (NASAR). Mostly Mike loves to dive (The editorial staff refrains from drawing any conclusions regarding Mr. Emmerman's other proclivities. Readers, your on your own.-ed.) *He can be contacted at 522 Fifth Ave, Suite 900, New York, New York 10036-7673.*

" I have spent half my life trying to get away from journalism, but I am still mired in it —a low trade and habit worse than heroin, a strange seedy world of misfits, drunkards and failures."

Hunter S. Thompson

Tables

Ever since the invention of a reliable means to supply compressed gas to divers, diving operations have been limited by the availability of appropriate decompression tables and methods. Now, with increased interest in alternative breathing mixes, advanced decompression methods, and exposures outside the range of standard air tables, special application tables are becoming an important tool in the high tech diver's arsenal and are growing in use.


DAN BURTON

Conceptually, special tables are no different than their public domain counterparts. Each represents a decompression procedure designed to bring a diver back to the surface without incident after carrying out a planned exposure. Where public domain tables span an entire range of dives, for example 0-190 fsw with bottom times ranging from 5 to several hundred minutes depending on the depth, and typically involve a single gas mix, usually air, special tables are typically calculated for a specific operation involving a narrow range of exposures, multiple gas mixes, decompression procedures and custom J-factors ("Jesus" factors added for conservatism).

Another important difference.Though most public tables have been tested on a significant number of dives, this is not always the case with special tables for which limited diving data may exist, a reason to proceed with caution. Anyone with a computer and computational algorithm can generate a table. The real issue is what the numbers mean. As Dr. Bill Hamilton points out in the accompanying article, special tables are only as good as the experience and judgement behind them. For that reason decompression engineering is still as much of an art as it is a science.

"No matter what computational algorithm is used to produce a decompression table, it's basis is still empirical. What works, works."

Currently special tables are being used by a small minority of technical divers and there are only few suppliers.For good reason. Planning and conducting dives involving special tables requires a degree of skill, sophistication and understanding that does not yet exist in the community as a whole.Training, experience, and a supporting infrastructure are needed, and the potential for injury is no small matter. For that reason, many professionals in the field remain leery of producing tables for just anyone, particularly in light of the current legal climate in the industry.

As special mix diving becomes more accessible, the need for special tables will continue to grow, and with it, the number of reliable suppliers. Until that time it's wise to proceed with caution, and work with qualified, experienced individuals who know what they're doing. As Dr. Hamilton explains, there is a lot more involved than simply cutting a table. —Michael Menduno

Understanding Special Tables: Some things you should know.

by Dr. R.W. Bill Hamilton

Many of you have asked about the preparation of *special application tables*. This is a somewhat sensitive subject that raises many issues , and I think it worthwhile to discuss. One issue is whether professional diving physiologists and decompression consultants should support the extreme exposure diving that some people want to do. Another is whether a *calculated* table is reliable enough to keep the user out of trouble.

When I first began working with the technical diving community, I was approached by several divers who told me what they were planning to do, and it appeared they would make up the tables themselves if I could not provide them. Thus blackmailed, and having the humility at least to realize that some of the more experienced *high tech* divers could easily construct a table as well as I could, I went ahead with it. With some trepidation, I might add. Fortunately, it has worked out well, and because of the excellent feedback and sufficient repetition I now am relatively comfortable with the process. Note, I do not view this business as "selling tables", rather it is a professional service provided to clients that includes the generation of tables. As you will see this involves much more.

Generating a special or custom table typically begins by finding out something about the client. The individual must be totally comfortable with gas and pressure physics and physiology, oxygen safety with regards to both the gas and understanding its physiological effects, gas logistics and decompression methods, as well as the technical and operational aspects of diving they're doing

The important thing to understand is that a reliable decompression table is not based on a formula alone. With today's state of knowledge, no matter what computational algorithm is used to produce decompression table, it's basis is still empirical; tables are based on field experience (*data! —ed*) *"what works, works"*. Although we have sophisticated computational methods—and they are getting better—there is a fair degree of judgement involved in incorporating the experience of yesterday's dive into tomorrow's table. For that reason, table development is still something of an art that extends beyond the ability to solve exponential gas loading equations.

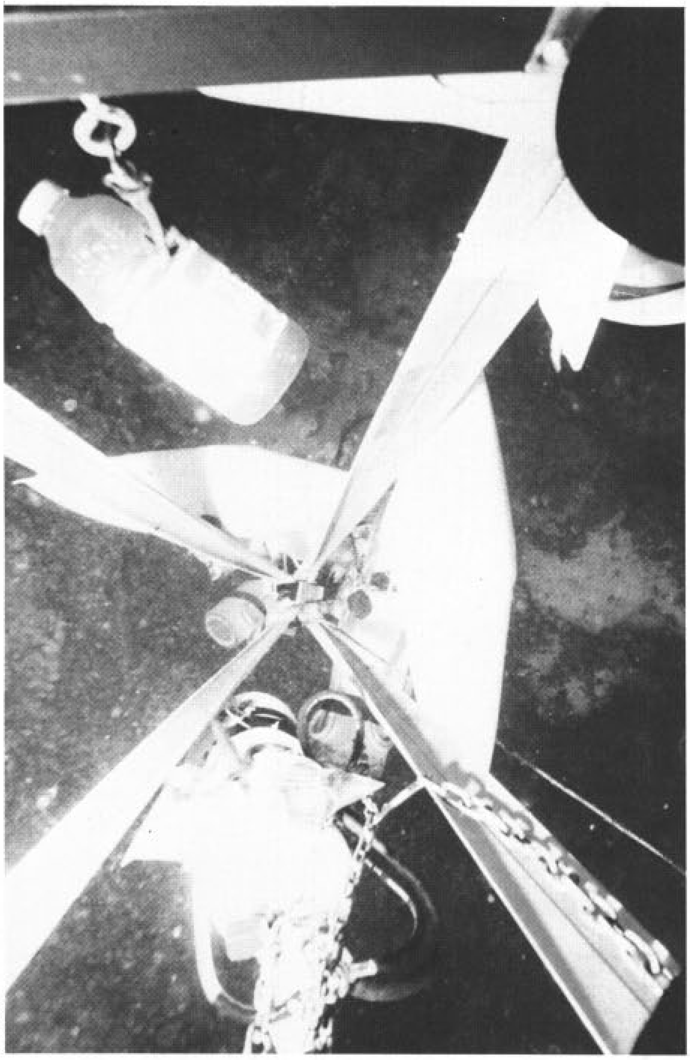
One reason for this is the statistical nature of the process; it takes many, many dives to know anything at all about incidence rates inherent in a set of tables. For example, if an individual does five dives with no problems, this only means that at a *95% confidence level*, the tables have a bends incidence of *less than 50%*. It takes literally *hundreds of clean dives* to be sure the incidence is less than 1%. Even a couple dozen clean dives should not be greeted with too much confidence. This is especially true if many of these are not conducted for the full time and depth.

To help mitigate this situation, the relatively new technique of applying maximum likelihood analysis to decompression is making it possible to estimate the risk involved with a given table, based on a set of previous dives. In addition, guidelines have been developed for the development and validation of new and revised tables, and the ongoing management of existing ones, see Validation *of Decompression Tables,* Report 74(VAL) 1-1-88, the Undersea and Hyperbaric Medical Society, Bethesda, MD. Under these guidelines, tables based on documented experience can be introduced at the "operational evaluation" stage, if done with sufficient care.

The basic table computational methods used by most decompression consultants are still primarily Haldanian which uses compartments (commonly but inappropriately called "tissues"), exponential gas loading equations, and ascent constraints called M-values. Promising variations include bubble growth or bubble generation factors as well, but these too are usually fed by gas loadings. The Haldane method has it's defects, but is workable as long as one takes its weaknesses into account and stays sufficiently close to past experience i.e. *what worked in the past*. Personally, I prefer the "Haldane-Workman-Schreiner" method, which is a considerable advancement over Haldane.

Once a formula is decided upon, it is necessary to consider other factors involved in decompression management such as the range and variation of gas mixtures and particularly oxygen management; *oxygen is the key to reliable decompression.* The table should take into account the oxygen tolerance limits of the diver, both central nervous system (CNS) and "whole body". The rates of travel, gas mix changes, etc. should be included in the table as instructions where they are needed, as well as the accumulated decompression time, or " *decom time*", as well as the "*stop time*" at each stop (for a discussion of decompression time management, see *Decompression Strategies*, M. Menduno, *technical Diver 2.2* , Summer 1990).

For technical dives, gas switches are usually determined by the specific dive plan. These are of course worked out in conjunction with the dive team. Once a basic operational approach is established for a dive, it is usually a relatively simple matter to make adjustments for the many factors involved such as extensions of depth and time, J-factors etc. However to consider all of these, check the process thoroughly, and be sure the user has the right instructions is not a trivial matter. For that reason, I feel it's important to label tables and the corresponding computations with a unique traceable *basecase* name, and I encourage others to do the same rather than just calling a table, the "*DCAP 250/30*" or the" *Wakulla tables* . "That way the origin of any table or computation can be traced and reviewed, an otherwise time consuming task that can result in confusion.


JIM KING

Looking down from inside the "Habibag" decompression station (microbell) designed and used by Deep Breathing Systems.

Another important thing that I feel is necessary is to provide the user with *instructions* on how to use the tables. Although you obviously cannot tell the user everything he or she needs to know in order to perform a sophisticated dive operation requiring special tables, it is important that they include at least a description of each item on the table and how to use them. Finally, although it's not something that can always be enforced, I feel it is important that clients agree to provide feedback as to the results of using a set of tables. The data we get from such feedback is valuable and allows us to continue to improve the methodology.

Generating special tables for a range where the parameters are familiar and there is sufficient available experience typically represents about a days work and can run anywhere from $200-500 and up depending on the supplier. More exotic tables, requiring the acquisition and analysis of specific data, takes a good deal more time and thus can cost a great deal more (often a couple of orders of magnitude more for the development of a full set of commercial or professional tables). Note the time it takes may bear very little relation to the value of the table, but it does have an impact on the cost.

No table or decompression method is completely "safe". In fact I do not even use that word in conjunction with decompression. It's wrong on several counts. First, no significant dive is free of the risk of decompression sickness. Second,DCS is not an *accident*; it happens and will continue to happen as a predictable part of diving. The dive team should plan for it, and in doing so can reduce the consequences to as near zero as possible.When DCS does occur, it can and should be treated promptly and adequately, and if this is done the chance of residual injury is quite small.

The real accidents that take divers lives are due to operational problems like running out of gas, getting lost or entanglement, not pushing a dive computer or running over a table. In my opinion this is where some current technical diving practices seem to be operationally inadequate.

Technical dives are *operations*. As such they should have a leader and or safety manager, planning, cooperation, and the predetermined ability to cope when

KWD USS Wilkes Barre Table
RWH/ BD 91May31
D159TO.HO3

Depth: 250 FSW
Bottom Time: 45 MIN
Bottom Mix: TX 17/50
Bottom PO_2: 1.46 ATM

DEPTH FSW	STOP TIME	DECOM TIME	MIXTURE	COMMENTS
00	00	00	AIR	Descend To Bottom Comfortable
00	00		TX 17/50	Rate Breath Trimix 17% O_2, 50% He,
250	45	00	TX 17/50	Balance N2, From Surface.Ascend
140	02	04	TX 17/50	To First Stop At 60 FSW/ MIN,
130	01	05	Tx 17/50	Rate 30 FSW/ MIN After First Stop.
120	02	08	Tx 17/50	
110	03	11	EANx36	Breathe EAN 36% At 110 FSW
100	03	14	EANx36	
90	04	19	EANx36	

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxx **STOPS INTENTIONALLY OMITTED**
xxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

DEPTH FSW	STOP TIME	DECOM TIME	MIXTURE	COMMENTS
30	33	114	EANx36	
20	27	141	Oxygen	Breathe100% O_2, 20 FSW
10	49	190	Oxygen	To Surface
00	00	191		Reach Surface

TOTAL Time = 236 MIN
DECOM Time = 191 MIN
OTU's = 299

This is an example of a special table calculated for a 45 minute exposure at a maximum working depth of 250 fsw, using a trimix 17/50 (17% O_2, 50% He, balance N_2) bottom mix and an intermediate mix of enriched air (EANx36: 36% O_2, Balance N_2) and oxygen for decompression. The table was generated using the Hamilton Research Ltd. DCAP computational program with the Tonawanda II algorithm and the ascent-limiting matrix designated 11F6, without added "conservatism factors." Rates and gas switches are given in the Comments section, but a more detailed set of instructions should accompany a table of this complexity. Note the individual stop times and cumulative decompression times are included. The diver starts the clock upon leaving the bottom and leaves each stop at the time in the "DECOM TIME" column, and thus doesn't have to worry about individual stop times. This is an easier way to manage a decompression than timing stops, it involves fewer chances for error, and this method enables a dive to be "reconstructed" at any time.For a dive with a planned bottom time, RUNNING TIME, which starts on leaving the surface is preferred by some technical divers.See Decompression Strategies, technical Diver 2.2, for a discussion. Note, the cumulative oxygen dosage, measured in oxygen tolerance units (OTUs) is also displayed. For a discussion see Reference #2 above.

any step falls short. This means building in redundancy throughout; in equipment, extra gas for contingencies, extra oxygen on board, and ensuring that other team members, especially the boat captain, know what's going on and what to do if things don't go as planned. Having understanding and agreements *before the fact*, can go a long way to allay the consequences of a glitch in the operation.

Technical diving can also be risky. The divers assume this risk, fully and personally, but this does not justify taking unnecessary risks. Tricks like diving on air to 290 feet are selfish and irresponsible. The diver who does not get away with this may be the only one to die, but will not be the only one to suffer. Accidents reflect on all divers, and can set progress back in a variety of ways. If you want to keep pushing the envelope, fine, but do it intelligently with care and responsibility.

The decision to use special tables depends on the specific operational plan for the dive, whether special breathing mixtures or accelerated decompression methods are to be used, and whether or not a general purpose table is applicable. Whatever your decision, make sure that the tables you're planning to use were generated by a reputable supplier and are in fact, appropriate for the dives you're planning to do. It goes without saying that you should have the necessary experience, training, and equipment required for the operation in question. *No matter how reliable, no table can make up for lack of judgement or the inability of the diver to carry it out.*

Dr. R.W. Bill Hamilton is a diving physiologist and principal of Hamilton Research Ltd. with over 20 years of decompression management experience in the hyperbaric and aerospace industries. He can be contacted at 80 Grove St., Tarrytown, NY 10591 Fax: 914-631-6134.

"DCS is not an accident ; it happens and will continue to happen as a predictable part of diving. The dive team should plan for it, and in doing so can reduce the consequences to as near zero as possible."

Recommended Reading:

1. Hamilton R.W. 1989 Dec., Tolerating Exposure To High Oxygen Levels: Repex and Other Methods. Marine Tech Soc J 23(4): 19-25

2. Hamilton R.W. 1990. Processing Decompression Tables. In: Knudsen G, Lindrup AG. Vitenskapelig FUDT seminar innen dykkemdisin/ fysiologi. Bergen: Norwegian Underwater Technology Center.

3. Hamilton RW, Kenyon DJ 1990. DCAP Plus: New Concepts In Decompression Table Research. In: MTS: Science and Technology For A New Ocean's Decade. Volume 3. Washington: Marine Technology Society.

4. Schreiner HR, Hamilton RW, Validation of Decompression Tables, Report 74 (VAL) 1-1-88, the Undersea and Hyperbaric Medical Society, Bethesda, MD.

Mix Primer

continued from page 9

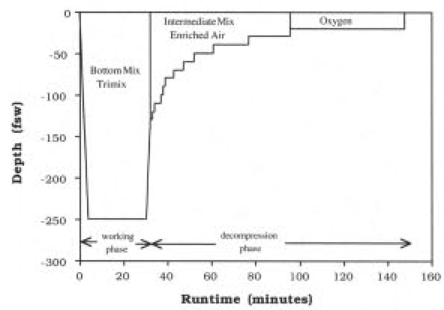
to greatly slow descent rates with depth (from hours to days), providing the diver with time for pressure adaption. However this method is impractical for most deep dives. A method that is frequently used today involves counterbalancing the excitatory effects of pressure with gas narcosis. In this approach, nitrogen and sometimes hydrogen which cause narcosis at depth, are added in suitable concentrations to the basic heliox mix used in deep diving, to make rapid descents (compression rates) possible.

Intermediate** or **decompression mixes, usually one or more increasingly enriched nitrox mixtures, and sometimes air, are breathed during the decompression phase of the dive, prior to switching to oxygen at 20 fsw. The strategy here is to boost oxygen levels back up to an optimal PO2 of normally about 1.4 - 1.6 atm during the decompression[3], and to get off of the helium-based bottom mix as soon as operationally feasible by substituting nitrogen—a *slower* diffusing gas—for helium, to facilitate helium off-gassing and slow additional gas loading· For the profile shown in Figure 2., a single enriched air mix, EAN 36, is breathed from 110 to 30 fsw before switching to oxygen at 20 fsw. For deeper and longer exposures requiring deeper stops, a series of mixes might be used, for example; air (from 220 to 150 fsw) to EAN 30 (from 150 to 80 fsw) to EAN 50 (from 70 fsw) to oxygen at 20 fsw.

Oxygen is normally breathed beginning at 20 fsw (PO2 = 1.6 atm) to complete the decompression prior to surfacing, though it is sometimes used as deep as 30 fsw under special circumstances (*Technical divers are advised to limit the use of in-water oxygen to 20 fsw —ed*). Often both the 20 and 10 fsw stops are *pulled at twenty* to avoid wave surge in the case of open ocean diving, and to maximize the inert gas off-loading gradient. Generally in-water oxygen is recommended whenever a decompression exceeds about 20-30 minutes and acts to *open* what is called an "oxygen window". Five minute *"air breaks"* are usually also taken every 25 minutes or so while breathing oxygen to decrease the divers sensitivity to elevated oxygen pressures and avoid CNS toxicity problems. Note that these breaks generally do not count towards the diver's decompression obligation unless calculated into the tables.

Oxygen is sometimes breathed on the surface as well, about two to three hours after long deep (beyond 250-300 fsw) trimix dives. Doppler bubble scores for this type of dive seem to increase for several hours after surfacing indicating potential decompression stress. Surface oxygen can also be used to shorten surface intervals and reduce time-to fly limitations, and has long been recognized as a requirement in treating dive injuries.

Fig. 1 Anatomy of a Trimix Dive
(250 fsw for 30 minutes)



Mix Operations

It's important to understand that the improved safety and performance offered by mix technology comes at the price of increased planning, logistics and expense. Even though making a simple enriched air dive is as easy as air, and involves minimum additional training, requirements on a *big* dive including; planning and set-up, water skills, gas and gear management and insuring adequate back-ups, can be significant and demand an experienced team, particularly for long and deep dives. Safety comes first.

> *"The fundamental idea behind mix technology is to improve safety and performance by optimizing the diver's breathing gas during various phases of the dive"*

Conducting a deep mix dive safely requires *caution*, special training, knowledge, understanding, the proper equipment, and *practice*—lots of it; the ability to manage multiple mixes, tanks and regulators requires it. With practice these aspects of the dive become "second nature" and the individual is able to focus on his or her specific mission and objectives.

Expense is also an issue; *special mix diving costs more.* However, the primary expense is usually in equipment investment, eg. tanks, regulators, exposure suits etc, which would be partly needed in any case. Gas is generally a relatively small part of operational costs compared to *hardware*, though it can be significant in open circuit technical diving operations (see *The Case For Heliox*). However this extra cost can usually be more than justified by the safety and performance it adds. Presently, enriched air fills in the U.S. are running about $8-14 per hundred cubic feet, while a trimix dive can cost $100 and up. If you think about it, it's a small price to pay for increased safety and the ability to do much more[4].

As special mix technology becomes more available, we can expect to see improved and simplified methods, more consistent informational materials, standardized training courses, and more accessible supplies. Until that time it's wise to approach this technology with care, and work with experienced individuals and facilities who understand what they are doing, and have invested the time and money to do it right, and as safely as possible. When you come right down to it, that's what it's all about.

Michael Menduno is the publisher of the aquaCorps Journal.

John T. Crea is president of Submariner Research Ltd., a diving physiology consulting firm that specializes in custom decompression table generation, special mix diving, and high tech set-up and equipment. He can be contacted at: PO Box 1906, Bainbridge, GA. 31717. Fax: 912-246-9349.

Footnotes

1. Note that from a physiological perspective, it is the partial pressure of oxygen that's important, not it's fraction (percentage) in the breathing mix. Human oxygen limits are defined by partial pressures.

2.In closed circuit systems, both the oxygen and diluent are mixed dynamically "on the fly" to maintain a constant partial pressure of oxygen called the set point. The inert gas used as a diluent, for example usually helium, can be switched during decompression through a special valve manifold on some systems or by using stage bottles.

3. The 1.4 - 1.6 atm seems to be reliable for decompression on

Inert Gas Summary

	Nitrogen (N2)	Helium (He)	Neon (Ne)	Hydrogen (H2)
Narcosis	Narcotic beyond about 100 fsw	Non-narcotic	Non-narcotic	Narcotic at great depth
Decompression	Good on short dives; slow to eliminate on long dives	More easily eliminated than N2; longer deco on short dives	Fairly easy to eliminate on long dives; fast on short dives	Worse than helium but better than Ne or N2, biochemical deco plausible
Breatheability	Hard to breathe at depth	Easy to breathe	Relatively easy to breathe	Easier than helium
Thermal Conductivity	Low to average*	High	Average	Very high
Voice Distortion	Normal	Large distortion	Nearly normal	Large distortion
Cost & Availability	Lowest cost Readily available	Moderate cost Fairly available	Very high cost Limited availability	Low cost/costly to handle Readily available *

*Compared to argon or CO2

surface-based scuba dives. Oxygen limits are generally reduced as the length of the dive increases. For example during long saturation dives the partial pressure of oxygen is usually set at around 0.4-0.6 atm during decompression.

4. Calculated on a $/diving hour basis, the added cost is insignificant in many cases.

Beyond The Flagroom

was used to negotiate the Crack, and carry divers to the pit area.

Bottom Mix: Trimix 12/50 (12% O2, 50% He, balance N2), with a maximum PO2 of 1.4 atm, was used on descent and for the working portion of the dive. Each explorer used approximately 500 cu.ft. of bottom mix on each push.

Decompression Mix: Air, enriched air 30 and 46, oxygen. Total decompression gas consumption: 500 cu.ft per diver. Note that the enriched air mixes were supplied to divers via a high pressure surface-supplied system in order to solve the problem of carrying multiple decompression cylinders in "the Crack."

Procedures: Bottom mix was breathed on descent and during the working portion of the dive. First decompression stops were at about 240 fsw. Air was breathed as a "safety hedge" from 200 to 140 fsw (Note: air use was not calculated in the tables-Ed.). Divers then switched to EAN 30 at 140 fsw (PO2 = 1.6 atm), EAN 46 at 80 fsw (PO2 = 1.6 atm), and switched to pure oxygen at 30 fsw (PO2 = 1.9 atm). (*Note: It is strongly recommended that in-water O2 be limited to 20 fsw or less unless special training and operational precautions are utilized —ed).* The remaining oxygen decompression was pulled at 20 fsw, inside the "habibag" decompression station. Total decompression time: 334 minutes. OTU's: 555.

Tools: Runtime schedules were generated using the DCAP computational algorithm licensed by Deep Breathing Systems from Hamilton Research Ltd.

Repetitive Schedules: One dive per day. Individuals who were exploration divers on day #1, became support divers on day #2 etc.

Special Considerations: Divers used argon for their dry suit inflation systems based on lengthy in-water times. The Habibag decompression station was positioned at 20 fsw to allow divers to pull both their 20 and 10 foot stops.

Surface Support:

Support consisted of two safety divers; one in-water diver and one topside. The topside support person was responsible for monitoring gas supplies provided to the divers by high pressure umbilical hoses.

Jim King is the president of Deep Breathing Systems, which focuses on exploration, surveying, mapping and technology development He can be contacted at DBS, PO Box 4220, Sevierville, TN 37864. Fax: 615-428-3446.

inTribute

Parker Turner: An Exemplary Cave Diver

R.W. Bill Hamilton

On 1991 November 17, veteran cave diver Parker Turner, 39, was killed in a freak flow reversal in a water-filled cave known as Indian Springs, located near Tallahasee in northeast Florida. While Parker and his teammate Bill Gavin were exploring deep into the cave a change in hydrostatic pressure caused the exit to be blocked. There is more to the story, but the important part is that it opened up a bit in time for Gavin to get to his next gas tank and out, but it was too late for Parker. The geological forces at work that caused the phenomenon are under investigation.

My purpose is to say a word about Parker. I am not the person to classify his record of accomplishment as a cave diver, but I can talk about him as a person. Parker came to be a very close personal friend of mine. He got me into this cave diving business about five years ago as a decompression consultant, and he taught me the little I know about it. He constantly challenged me with planning for difficult missions, and occasionally fed my ego by calling me up with a question on diving physiology that I could answer. I welcomed his insightful stories, and learned a great deal from the questions and problems he posed.

Parker never finished college, but he was one of the most polished professionals I have known. He was an absolutely fabulous instructor. A born pedagogue, he had the right demeanor and attitude to teach how things should be done, as well as superb knowledge about what to do or not do. He taught well, and his students knew that. When a stranger calls me with a request, nothing he can say about his skill level does as much good as to tell me he was trained by Parker Turner.

Parker was extremely safety conscious. He was engaged in a dangerous sport, but he did it as well as it can be done —in fact it took something like an earthquake to do him in. When he and his companions went on one of their challenging penetrations I worried a lot about them, but I always felt confident that Parker was going to do it right. Parker was generous. He organized his resources in such a way that he could donate his time to the Academic Diving Program at Florida State University, supplemented by some teaching and funded projects. That is dedication.

Parker was a good family man. His passing leaves a big gap in his little family, but he loved them so much one did not actually have to watch him work to know how careful he was; he would never take an unnecessary risk because of them. Parker had a somewhat wry sense of humor. I knew that if someone in his world of diving did something silly I would get a most entertaining report about it. He was uncomfortable saying bad things about others, but he also had a rather low threshold of tolerance for incompetence or the lack of attention to safety by others; this led to some interesting discussions. He was terribly concerned when someone else did something stupid because he thought it cast the whole cave diving community in a bad light, all of which makes the irony of his death a lot harder to take. We are going to miss him a lot.

A Parker A. Turner Memorial Fund has been established and will provide support for graduate students doing work in underwater speleology. Contributions and information requests should be addressed to:, Parker A. Turner Memorial Scholarship, c/o Annette Weglinski, Florida State University, College of Arts and Sciences B-155, Tallahasee, Florida 32306 aquaCorps

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The Legal Risks of Technical Diving:

How To Protect Yourself

By Bill Turbeville

Scuba diving has come of age. From double hose regulators and "J" valves to decompression computers and Aqua-Zepps, the qualitative nature of diving is advancing as rapidly as the quantitative expansion of the sport. Technical advances combined with our evolving understanding of hyperbaric physiology are enabling sport divers to push the underwater envelope deeper and longer than once thought possible.

But pushing this envelope not only leads to the greater challenges and rewards, but also to greater risks. And these risks are not limited to the obvious personal safety concerns. The litigious nature of our society does not end at the waters edge; nor do all sharks live in the sea. Scores of lawsuits are filed every year against dive industry professionals and, increas-ingly, dive buddies and dive club members.

The litigious nature of our society does not end at the waters edge; nor do all sharks live in the sea. Scores of lawsuits are filed every year against dive industry professionals and, increasingly, dive buddies and dive club members.

This article briefly outlines some strategies to minimize the legal risks associated with diving in general and technical diving in particular.

An Ounce of Prevention

Obviously, the best way to avoid a lawsuit is to make sure that an accident never happens. For the diving professional involved in technical diving, this means being highly aware of who you are training or bringing on board. In the same way that a beginning or poorly trained mountain climber has no business challenging Everest or K2, the typical recreational diver has no business diving the Andrea Doria or Diepolder #2. Check their certification levels, review their log books - make a phone call to a known reference if given. Make certain the self-professed experienced diver is just that. Lots of divers can talk the talk, but can they walk the walk? Do they have the proper gear? More importantly, can they use it with the casual familiarity necessary to avoid panic in an emergency? What kind of physical shape are they in? A hung-over, overweight, middle-aged man with a cigarette dangling from his lips is a poor risk no matter how experienced. Someone who seems unusually nervous or tentative should be left on shore. Stress may be the leading cause of diving fatalities, according to recent reports from the University of Rhode Island, because it can lead progressively to panic. Failure to prevent an obviously nervous diver from diving is not an uncommon allegation in recent lawsuits.

For the diving participant, this means knowing just who you have chosen to guide you on that rewarding but potentially hazardous adventure. Unless you are diving with one of the established names in technical diving field, such as a Billy Deans or a Tom Mount, you need to do your homework before ever getting wet. How long has this person been in the business? How long have they been pursuing advanced fields of diving? Do they make these dives themselves? How well are their facilities equipped? How well do they brief their charges before allowing the dive? Do they seem more interested in your money than you?Don't be shy to ask very specific questions. It won't matter one bit to you how rich your heirs may get from that operator's negligence. And if you yourself are not really ready for the challenges of technical diving, remember Groucho Marx's adage that he wouldn't be associated with any club that wouldn't have him as a member. So don't be offended if your money is declined. Ask for recommendations on the training you need,get the experience, and come back later.

For charter operators the same is true of all crew members. Are they competent for the demands of high-tech diving? Full CPR and first aid training is a must. Competence in the emergency administration of oxygen should be mandatory. Virtually every scuba lawsuit involving a failed resuscitation has some allegation of improper CPR/oxygen use. Make certain that there is plenty of oxygen with 100% delivery capability at the dive site with a full demand type regulator. Positive pressure oxygen systems are fine if someone at the site has the EMT or better training necessary to use such a potentially hazardous system safely, but this is not always the case. Have a rescue and resuscitation plan ready. If the worst happens, don't just react to events as they arise, anticipate what might happen and be ready to respond. Know where the emergency equipment is and how to use it. Know where the nearest chamber is located. Know how to contact the Coast Guard or other emergency agency for quick evacuation.

These preventative measures should be obvious to anyone interested in saving a life as well as avoiding a lawsuit. They should be part of any technical diver's basic training. But no matter how professional an attempted rescue or resuscitation may be, a lawyer may find some "expert" to say it could have been better.

Preparing For The Worst

Because there is no way to completely avoid a lawsuit, the best that can be done is to place yourself in a position to quickly dispose of it, or, if unsuccessful there, in keeping your damages to a minimum. The secret to that is to minimize your liability by:

1. Shifting the risk to the voluntary participant;

2. Limiting exposure; and

3. Insurance

Let's take a quick look at some of the techniques to accomplish each of these.

Shifting The Risk

There is a common misconception that you "cannot sign away your rights". Nonsense. Courts across the country have, to a decidedly increasing degree, found that properly drafted releases of liability stop lawsuits in their tracks. Nothing is more important to avoiding liability from a diving accident than a legally sufficient release. Even if you were not negligent, it could take literally hundreds of thousands of dollars to prove it should the case proceed to trial. The right kind of release could spring you early on from a lawsuit through a summary of judgement motion. In that type of motion, you tell the judge that even accepting as true all facts as alleged by the plaintiff (or decedent) expressly and voluntarily assumed the risk and released you from liability. It may not prevent a suit from being filed, but it could save you a fortune in costs and attorneys fees.

What is a legally sufficient release? In a nutshell it is one that:

1. Clearly and specifically releases you from your negligent actions;

2. Clearly, simply, and in a language the average person could understand, explains the risks involved to the person signing it;

3. Was signed voluntarily with a full understanding of just what rights were being given to you;

4. Does not use small print or "boiler plate" to obscure any material portions;

5. Was not signed as a group waiver, but was directed individually to each person who signs;

6. Was given to the person who signed it well ahead of the dive a "cooling off" period is needed so that those who would back off have an opportunity to do so. Do not expect a release given to someone on the boat to work; and

7. Does expressly absolve all persons or entities involved from liability.

Make sure that not only the shop owner, but the captain and crew, the boat, the corporation—everyone involved in any way in the dive—is listed on the release.

If these guidelines are followed, recent decisions in California and Florida suggest that the lawsuit may never make it to the jury. And even if it does, a signed release can be very persuasive to those fellow citizens on the jury.The question of release forms is more complicated than this thumbnail sketch, and will be the topic of a future aquaCorps article. You should speak with an attorney, preferably one versed in diving law, before putting one together.

Limiting Exposure

Limiting exposure means, for all practical purposes, incorporation. If you plan to sponsor or teach technical diving, even if you are not charging for your services, you should be doing it through the auspices of a corporation. The fact that you supply the gear, provide access to the dive site, or even come up with the idea of the dive could subject you to liability should something go wrong. Make certain the corporation is not a "shell," all the formalities must be followed in both setting up and running the company. If you have a boat or a lot of expensive dive gear you want to protect, have the corporation rent it from you, but make sure the money actually changes hands. Do not allow sloppy attention to procedure to allow a sharp plaintiff's lawyer to "pierce the corporate veil" and get at your assets in case of an adverse judgement.

There is a common misconception that you "cannot sign away your rights". Nonsense. Courts across the country have, to a decidedly increasing degree, found that properly drafted releases of liability stop lawsuits in their tracks

Insurance

Insurance is the logical way to manage risk; that is specifically what it's designed to do and in fact has been done since the middle ages. The problem is that most insurance companies that would even consider insuring scuba activities, stop their coverage at 130 feet—the depth of a first or second decompression stop on many high tech dives! Many homeowner's policies have a water sports exclusion that disallows coverage for any divingrelated activity, though virtually none will cover any sort of commercial activity. This is a difficult question without an easy answer. The best you can do for now is ask an experienced agent to look around for you. If you can find insurance at all it will not be cheap.

Professionals will have to look for commercial coverage. For the non-professional, a good homeowners policy may give you some coverage, but never assume that it does. Carefully check your policy for exclusions. Ask your agent if you have any questions at all. Try to get a commitment in writing, but do not expect compliance with such a request. Most agents are loath to given written assurance of coverage on such a questionable issue. Try writing the company directly instead. That will also avoid any question of the agent's capability of binding the company.

If The Worst Occurs

So what should you do if, after following all this good advice, your dive customer or partner makes his last dive a one-way trip to Davey Jones' locker? A lot. First, never discuss any wrongdoing at the scene of the accident. *Do not say* "if only I had done this or that", even if that is exactly what you are thinking. First of all, you really don't know if you are to blame. Everyone feels some sense of guilt when an accident happens in a dive group. Second, the law treats such a statement as a legal admission, not subject to the normal hearsay exceptions. What you say can, and probably will, be used against you. So keep your mouth shut to all but official investigators and your insurance company, if any.

Second, have your attorney get sworn statements from every person involved in the dive. If it was a boat dive, that means the captain, divemaster, and every single other person on board. Sworn statements are taken only after your attorney talks to each person separately, and finds out what questions to ask before going on the record. That is the best way of getting favorable testimony on record before relatives of the "dearly beloved" come looking for your "deep pockets." Also, make sure it is your lawyer taking the statements, and not you or a friend. If taken in anticipation of litigation by your attorney, they may not be easily "discovered" by the opposite side, due to the attorney-client and work product rules.

Third, avoid speaking to the press to the extent you possibly can. If you feel you must make some comment, limit it to a general regret over the fact that the accident happened. Your case, if a lawsuit is filed, should not be tried in the media.

Fourth, get copies of all accident reports, medical examiner findings (if a fatality), and any other documentation prepared by any official or unofficial, (i.e., newspapers) investigators. Locate and safeguard the release form you fortuitously had the victim sign.

Finally, notify your insurer as soon as possible. Some policies carry a waiver if the carrier is not notified within a certain amount of time of an accident. So look it up before an accident and know when notice must be given.

If A Lawsuit Is Filed Against You

The release voluntarily signed well before the dive, is your line of defense. It won't save you the expense of hiring a lawyer, but it can make his or her job much simpler, and cheaper. Move for summary judgement as quickly as possible. Try to short circuit the litigation by showing the court's satisfaction that the injured or dead diver knew what he or she was facing and expressly and voluntarily assumed all risks involved in the sport.

If summary judgement is denied on the basis of the release, save it for the jury. But move again for summary judgement on the issue of damages if the diver was from a commercial dive boat. Depending on where the accident occurred, either the Death on the High Seas Act (for a fatality more than 3 miles from state territory) or common law admiralty law (for most commercial boat diving trips) may apply. The use of these federal law doctrines can limit the total amount of damages recovered by the plaintiff - significantly so in the case of the Death of the High Seas Act.

There are obviously many other litigation strategies available in the defense of a diving lawsuit. Far too many to be discussed in this brief overview. Just make certain that if it becomes necessary to consult with or (heaven forbid!) actually hire a lawyer, that your lawyer understands the issues involved in diving litigation. A death on the U-853 is not the same thing as a slip and fall in your local supermarket.

If the technical diving community is to thrive, it must have a pro-active approach to legal liability, not a reactive posture of simply defending each lawsuit on its individual merits.

Fear of litigation ha kept many useful products and techniques out of this country for years. With a little preparation and luck we can avoid that fate here. If the technical diving community is to thrive, it must have a pro-active approach to legal liability, not a reactive posture of simply defending each lawsuit on its individual merits. Through the types of techniques touched in this article, liability concerns will not stand in the way of pushing underwater envelope back further.

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Oil Free Business

by Michael Parker

One of the issues imbedded in the controversy over diving with oxygen enriched air is a matter of pumping gas. Air considered acceptable for breathing may contain too much oil vapor for it to be acceptable for mixing with oxygen to make enriched air. Likewise, compressors which can pump compressed air acceptable for breathing are not necessarily safe for use with enriched air mixtures. Filtration can clean gas sufficiently well, but only if the correct filters are used and they are properly sized, installed and maintained. Experience shows that this is rarely done correctly on an ongoing basis. One way to ensure that air or enriched air is clean is to use a compressor that does not allow the gas stream to come in contact with oil. RIX Industries Inc., manufactures such compressors. Some thoughts on their use are contained in the following article from Mr. Parker, RIX's vice president for marketing. RWH

The explosion blew a large whole in the ceiling. Had anyone been in the apartment upstairs they could have been seriously injured by the shrapnel. The old, warn-out, ex-military compressor had exploded almost blowing the head off the dive shop owner. After a few days his hearing came back and the flesh wounds began to heal. Such is the condition of high pressure compressors in all too many dive shops around the world.

This incident took place in Berkeley, California a few years ago. It was not a RIX compressor. It was an old used oil-lubricated, air-cooled compressor that was never intended for breathing air use. The owner was not trying to pump nitrox, he was pumping air. Had an enriched air mixture been introduced to this compressor the results would have been even worse.I hate to speculate on the outcome had air from this machine been mixed with pure oxygen.

RIX industries is a compressor manufacturer with many years of experience in engineering, designing and manufacturing compressors for many different kinds of breathing gasses including air, enriched air (nitrox) and pure oxygen. We define these gasses as follows; ambient air: 19-21% oxygen, enriched air (nitrox): 22 - 50% oxygen, and oxygen: 51 -100% oxygen. We build high pressure compressors for each of these gasses; each of these compressors are different.

First, they are all *oil-less* or *oil-free*. In our opinion any compressor that allows lubricating oil to come in contact with the air (or gas) stream is not suitable for compressing breathing air (or mixed breathing gas). Oil-lubricated compressors heavily contaminate the air stream with lube oil and gaseous contaminants caused by the decomposition of lube oil. These contaminants must be removed before the air can be used for breathing.

A new compressor with a properly designed separation and filter system can do a fairly good job of removing lube oil contaminants. As compressors age they pass more oil, run hotter and contaminate the air more, causing a higher reliance on the filter system to clean-up the bad air. In all cases, some of the lube oil contamination passes through the filter system. Build-up occurs in the piping, storage cylinders and tanks causing a film of oil. Should pure oxygen come into contact with this oil, the results could be fire, an explosion, or generation of toxic gaseous contamination of the breathing gas.

It's been pointed out that some of the manufacturers who say it's okay to use lubricated compressors for breathing air will not allow the air from their compressors to be used to mix with pure oxygen to make nitrox; there is too much lube oil contamination in the air to safely mix with oxygen. The implication seems to be that it's okay to breathe this contaminated air, but not okay to mix it's with oxygen.

Air, as a gas, is relatively stable, even at high temperatures and high pressures. The higher the oxygen content of any gas, the more unstable it becomes when under increased pressure and temperature. Pure oxygen is highly unstable in comparison to air.

Compressors used for oxygen service are very different from air compressors. Simply being "oil-free" isn't enough. There are a great many differences between an "oil-free" air compressor and an "oil-free" nitrox or oxygen compressor.

Oil-lube compressors should not be used for enriched oxygen mixtures.

Because of the unstable nature of oxygen, many other considerations must also be taken into account in the design of an enriched air or oxygen compressor that do not necessarily have to be considered in air compressors. Piston speed, compression ratio, gas passage design, operating temperature, component materials, component design, manufacturing procedures and oxygen cleaning must all be considered. Pure oxygen will burn anything, including stainless steel. All components in an oxygen compressor must be contaminant free. Proper valves, fittings, "O" rings, gaskets, lubricants, etc. must be suitable for oxygen service.

When compressing oxygen enriched air (nitrox) mixtures, the compressor must be suitable for limited oxygen service. There is no guarantee that the compressor will not be exposed to pure oxygen during the mixing process. Therefore, the compressor must be capable of processing limited amounts of high concentrations of oxygen for short periods of time. This dictates that enriched air mixture compressors be dedicated for enriched air mixtures only, and be oxygen compatible and oxygen clean.

Nitrox compressors should be certified by their manufacturers as suitable for compressing the gas mixture that they will be used for. Oil-free air compressors are not certified for enriched air use unless they are specifically manufactured for that purpose and certified by their manufacturer for enriched air use. This is done on a compressor by compressor basis and is not applicable in general to a "type" of compressor or a "model" of compressor.

Very few, if any, dive shops today are using nitrox certified compressors for compressing oxygen enriched gases. In doing so, they are taking risks they do not know about and do not understand. Regrettably, most of them learn the hard way only after an accident. It's a hard way to learn.

Mike Parker is the Vice President of marketing at RIX industries. He can be contacted at: RIX Industries, 6460 Hollis St., Oakland, CA 94608. Fax: 415-428-9102

Technical Diving: Does PADI Have It's Head In The Sand

by Drew Richardson

For a number of years, PADI has designed educational programs to train people to safely enjoy scuba diving. Improvements in the design and function of diving equipment and teaching methodologies, combined with effective marketing efforts, have helped scuba evolve from a sport only a few elite and aquatically physically fit people could participate in, into a recreation that welcomes people of all ages, shapes and sizes. Things were not always this way.

Many years ago, divers measured their abilities in terms of maximum depth, decompression obligation, and size of game taken.

Brawn was the sorter of "menfish," and diving was not for everybody.In some circles these types of measurements are still in place today, although for the most part, the years have tarnished the appeal of these status symbols. Today, you are more likely to see exotic travel, aquatic awareness and underwater photography dominating the conversation of recreational divers. Typically, the recreational scuba diver is one who enjoys a relaxing *no-stop* dip in the shallow depth ranges. As a result of this shift, the public image of the dive explorer is being redefined. The elitism of deep, decompression, mixed gas diving has become a minority compared to the social diver who enjoys scuba diving along with other recreational lifestyle activities.

During this industry metamorphosis, a community of non-recreational or "technical" divers has quietly existed. Technical divers have practiced their art effectively on the sidelines and outside of the definition of recreational scuba diving. Many excellent developments and improvements have emerged from within its community. As an example, the cave diving community took the initiative to provide the education and training necessary for individuals interested in this activity. By definition, cave diving is not recreational diving, and so a training niche was created for individuals with specialized expertise in the methodology of safe underwater cave exploration. With an increasing safety record, this community is to be applauded for these efforts.

In the interests of diving safety, PADI supports education of this nature. We feel that it is better to provide training and educational standards than allow divers to learn through discovery methods.

In the interests of diving safety, PADI supports education of this nature. We feel that it is better to provide training and educational standards than allow divers to learn through discovery methods.

Other communities of technical diving have been less clearly defined. Pockets of specialized expertise in diving practices well beyond the realm of recreational diving as we know it have existed safely for years.

Within the past year or two, however, a great deal of consumer press has been given to air depth records, decompression, and diving with mixed gases including enriched air. PADI found itself in the position to publicly emphasize its scope and mission to provide training to the general public for safe air diving within the no stage decompression arena. As a result, in 1989, we issued policy statements concerning deep and decompression diving, which we view as being beyond the scope of recreational diving, and on the use of enriched air nitrox.

It should not be perceived that PADI is against individuals who engage in this type of activity. PADI acknowledges the risks of technical diving can be managed safely with proper training and equipment. However, PADI does not feel that technical diving has mass appeal and it is certainly not for everyone. Technical divers are now recognized as a distinct community and are supported by a publication. PADI is supportive of this distinction between recreational diving and technical diving.

PADI is interested in marketing recreational diving broadly and safely. Our sophisticated educational program is backed by a competent quality assurance program. PADI feels the proper controls over the conduct of training recreational scuba diving on air are in place. We are not convinced however that the controls for certain technical diving activities are in place. All technical diving areas have increased risks when compared to recreational diving. For example, enriched air nitrox diving relies on an accurate percentage mix of oxygen to nitrogen. However a problem exists in that the mechanisms of control for it's widespread use in the recreational field are not in place at this time. The same can be said of deep diving and the use of other special diving gases.

Concerned industry officials exercise caution to discourage the widespread marketing of technical diving as a trend or measure of diving ability to the recreational diving consumer. To avoid inviting trouble, technical diving should not be competitively positioned as the mark of a *real* diver.

There appears to be an emerging segment of people interested in technical diving. One has to ask, are these people who have become bored with plain old recreational scuba diving? Scuba divers don't need PADI's permission to engage in diving beyond the scope of recreational definitions, and PADI will not stand in the way of this type of diving. PADI respects the individual's right of self-determination. However, the individual diver must be aware of the risks associated with technical diving and accept these risks as an individual.

It serves little to criticize deep air divers or conversely ridicule the recreational diver who dives shallower than 130 fsw/40 msw. Continuing educational philosophy applies equally to both the recreational and the technical diving communities.

PADI, along with other recreational diver associations, have been criticized publicly and accused of "burying our heads in the sand" over the so called "real issues" of the day. PADI has been challenged to reexamine depth limits, diver training and community responsibility. I suggest that PADI has been doing just that the last several years with tangible results. PADI is in the business of diver safety.We have reexamined our scope and approach to diver education targeting the majority public interested in the adventure of recreational scuba diving. PADI will also continue to encourage individuals involved in the promotion of technical scuba diving field to follow the model the cave diving community initiated in providing a pathway for interested individuals to train. This involves educating the diver to the risks they are taking, not marketing trend appeal with regards to gas mixtures or depth limits. It would be a step backwards to motivate people to engage in technical diving for reasons of ego, competition or as a measure of diving ability.

PADI will remain objective and open to developments in equipment and technology in our educational offering to the general public. Our role in the future will remain as the market leader of safe recreational scuba educational programs.

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Drew Richardson is the Vice President of Training and Education at PADI. He can be contacted at; PADI, 1251 East Dyer Rd. #100, Santa Ana, CA 92705. Fax: 714-540-2609.

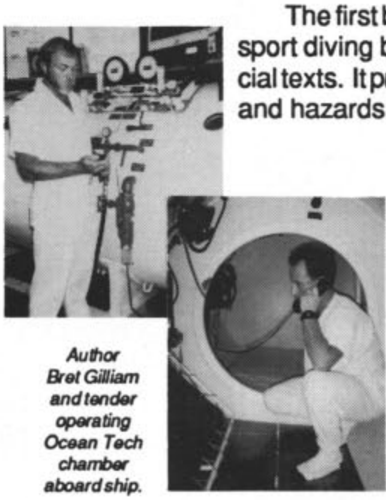
PADI's Position on Enriched Air Nitrox Diving

PADI Headquarters does not sanction gas mixtures other than air for recreational scuba diving at this time. It is viewed as a highly specialized diving activity, requiring specific training and special tables.

Enriched air nitrox and gas mixtures (other than air) have a variety of safe applications within many contexts (for example, scientific diving, commercial diving and recompression therapy). Because these specialized applications have not yet been widely adapted to the needs of recreational diving, PADI does not feel that their use has broad applications at this time for recreational diving. Many safety concerns exist with regard to enriched air nitrox use. We realize that with proper supervision, gas mixture, training, dive planning, tables and other necessary factors, enriched air can be used safely.Used improperly, it can be very dangerous and life-threatening.

PADI feels that the parties who offer enriched air training bear responsibility for expertise and control of safety and conditions. PADI certification and course sanctions apply to air diving and air tables only. PADI does not sanction enriched air nitrox nor accept liability for enriched air nitrox certification courses.

Deep Diving: An Advanced Guide to Physiology, Procedures and Systems



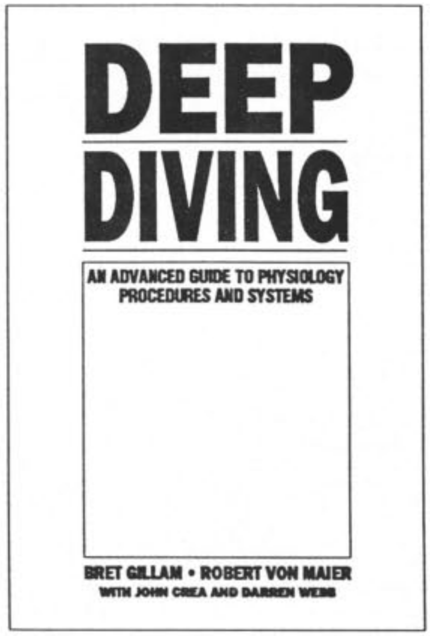
Author Bret Gilliam and tender operating Ocean Tech chamber aboard ship.

The first book to span the depth between traditional sport diving books and the complex medical/commercial texts. It provides a balanced view of the fascinations and hazards of deep diving through extensive factual development of its technical chapters. It also features first hand accounts and perspectives by top deep diving experts such as Dr. Bill Hamilton, Bret Gilliam, Tom Mount, Sheck Exley, John Crea, Gary Gentile, Dick Rutkowski, Jim Lockwood, and many others. A detailed history of deep diving and the individuals who pioneered this challenging and hazardous area of diving opens the book.

Chapters include: History, Physiological and Mental Preparation, Stress, Inert Gas Narcosis, Oxygen Toxicity, Staged Decompression, Equipment and Self-sufficiency, Dive Computers, Scientific Applications, Nitrox, Mixed Gas, Dive Tables, and Decompression Sickness Theory and Treatment including recompression chambers, field accident management, helicopter evacuation, oxygen systems and in-water treatment protocols.

A special reference section includes a recommended list of training centers, and sources for specialized equipment outfitting and custom tables. An extensive section includes recommended books, articles and journals for readers who wish to pursue a particular topic in more detail.

The 256 page book includes over 75 photos and is illustrated with detailed graphics and tables.



THEN: Zale Parry, women's depth record-holder 209 fsw on air in 1954.

NOW: Modern deep diver preparing for 250 fsw dive on "Wilkes Barre" in 1991.

THE FUTURE: The Cis-Lunar MK-2R fully redundant re-breather.

"This text is the only responsible source currently addressing the overall concept of depth. Many of the dives profiled in this book are completely on the frontier of human diving performance and are discussed in detail for the first time. The wealth of information compressed into these pages bridges the gap from kindergarten to graduate school for most divers. This is a book who's time has come."

Tom Mount

"I can think of no one who is more knowledgeable on the subject of deep air diving than Bret Gilliam. I strongly recommend this book to all persons interested in any aspect of deep diving."

Sheck Exley

"I still can't believe that Gilliam wasn't narked on his record 452 ft. air dive, but then that's what makes technical diving so exciting; there's always more to learn. That's the best reason I know to read Gilliam and Crea's new book on deep diving. There's a lot of important information that's simply not written down anywhere else, presented by people who have been there. A definite addition to your reading mix."

Michael Menduno

Send check or money order for $20.00 (includes signed copy by author, first class postage & packing) to:

OCEAN TECH
3098 Mere Point Rd.
Brunswick, ME 04011
Phone: 207-442-0998 FAX: 207-442-9042

Dustin Clesi and Rick Nicolini of Team DiePolder '91 and their support equipment.

The following guide includes training agencies, facilities, instructors, table suppliers and books.

TRAINING AGENCIES

American Nitrox Divers Inc.
74 Woodcleft Ave
Freeport, NY 11520
516-546-2030

International Association of Nitrox Divers Inc.
490 Carribean Dr.
Key Largo, FL 33037
305-451-2551

NASDS
8099 Indiana Ave
Riverside, CA 92504
714-687-8792

FACILITIES

Ad Venture Sports
303 Potero St. #15
Santa Cruz, CA 95060
408-458-3648

All American Sport Shop
27 North Broad St.
Norwich, NY 113815
607-334-5277

All American Sport Shop
Utica, NY
315-733-9282

Aquifer Dive Center
4564 Atlantic Blvd
Jacksonville, FL 32207
904-398-1274

Bellingham Dive and Travel
2720 West Maplewood
Bellingham, WA 98225
800-338-6341

Brownies Third Lung
940 North West 1sst St.
Ft. Lauderdale, FL 33311

Carroll Scuba
2027 Suffolk Road
Finksburg, MD 21048
301-833-3638

Enchanted Diver
259-19 Hillside Ave
Floral Park, NY 11004
718-470-6858

The Gas Station Inc.
831 Charles St.
Gloucester, NJ
609-456-4316

Ginnie Springs Dive Center
7300 NE Ginnie Springs Rd.
High Springs, FL 32643
904-454-2202

Island Scuba Centers, Inc.
74 Woodcleft Avenue
Freeport, NY 11520-6132
516-546-2030

Key West Diver
MM 4.5 US #1, Stock Island
Ley West, FL 33040
800-873-4837

National Academy of Police Diving
12074 South West 117th Terrace
Miami, FL 33186

National Diving Center
4932 Wisconsinn Avenue N.W.
Washington, DC 20016
202-363-6123

Ocean Oddessy
2345 South Rodeo Gulcch
Santa Cruz, CA 95062
408-475-3483

Pisces School Of Dive
781 Fairport Road
Coral Gables, FL 33146
305-445-7837

Underwater Unlimited
4633 Le Jeune Road
Coral Gables, FL 33146
305-445-7837

University Of California-Davis
Davis, CA 95616
916-754-1419

University of California-Santa Cruz
Santa Cruz, CA
408-459-4286

Scuba Adventures
965 South Mt. Vernon Avenue
Colton, CA 92324
714-825-2502

The Scuba Shop
348 Miracle Strip Pkwy #19
Fort Walton Beach, FL 32548
813-243-32548

Seahunt Dive & Travel
3395 East Bay Rd.
Largo, FL. 34641
813-539-0227

Steamboat Dive Inn
PO Box 1000
Branford, FL. 32008
904-935-1471

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Australia 2066

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EAN Tables:

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Fax: 914-631-6134

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912-246-9349

Underwater Applications Corp.
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Nashua, NH 03063
508-433-6586

NOAA Nitrox Tables:
See Training Agencies

Books:

The Application of Enriched Air Mixtures
by Edward Betts & Doug Petty

ANDI
74 Woodclift Avenue
Freeport, NY 11520
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Fax: 516-546-6010

Harbor Branch Workshop On Enriched Air Nitrox Diving 1989
Hamilton, Crosson, Hulbert & al

NOAA
6010 Executive Blvd. Room 805
Rockville, MD 20852
Order from NTS:
ph: 703-487-4600

Nitrox Manual
by Dick Rutkowski

IAND
490 Carribean Dr.
Key Largo, FL 33037

TRAINING POLICY STATEMENT

Though a consistent set of national guidelines for enriched air use are now being developed, there are currently no training standards for other special mixes such as trimix, heliox and many technical diving applications. As a result, the level and quality of available instruction varies significantly, as does the qualifications and experience of the individual instructors.

aquaCorps policy is to accept advertising from companies and individuals who we believe are reputable, however we are not in a position to evaluate individual facilities, instructors, programs, or our other suppliers, nor do we accept liability for them.

We strongly recommend you investigate a facility and or instructors thoroughly before signing up for a course. Talk to them, ask for credentials, relevant experience (number of relevant dives, number of courses taught, their training etc.), and get references from others who have been through their program. Remember, "Your Safety Comes First."

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"A verbalizing race has words for every old concept...and creates new words or new definitions for old words whenever a new concept comes along. Always! A nervous system that is able to verbalize cannot avoid verbalizing; it's automatic."

Robert A. Heinlein
Stranger In A Strange Land

Understanding the language and concepts behind mix technology is key to it's safe utilization. Here are several ideas and definitions for your consideration that are used throughout this issue of aquaCorps.

user groups, environments and applications: Historically, the sport diving industry was viewed as a single, homogeneous group known as *recreational divers*. Now a more sophisticated view is emerging. To borrow several terms from the computer industry, the scuba market is in fact made up of many different *user groups* each with their own *diving environment, applications* and need for appropriate tools and methods. Mix technology is one of these tools.

mix:

special mix: Special mix applies to diving gases other than air, including trimixes of oxygen, helium, and nitrogen, mixtures of oxygen with other inert gases (helium, neon, nitrogen) and to enriched air mixes. The mixtures delivered by closed circuit rebreathers are special mixes as well. Commercial divers universally refer to oxygen-helium mixtures—*heliox*—as "mixed gas," so the term is not quite right for technical diving. Currently in the technical and scientific communities, special mix is primarily oriented to *self-contained* diving.

enriched air: An oxygen-nitrogen ("nitrox") mixture with an oxygen content (fraction) greater than that found in air (21%) typically ranging from 30-50%, also referred to as *nitrox, enriched air nitrox* (EANx) and *oxygen-enriched air*. We at aquaCorps prefer the term *enriched air* , designated by EAN, to "nitrox" because it is more accurate (air and normoxic mixtures with an O_2 content of less than 21% are also properly called nitrox), and more user-friendly. In this convention, *EAN 36* specifies an enriched air mixture with 36% O_2, balance N_2. Enriched air is used as both a bottom gas for shallow water diving in the 30-150 fsw range, though the real benefits are pretty well limited to about 50 100 fsw, and for use during decompression.

trimix "x/y": An oxygen-helium-nitrogen mixture generally used for dives in excess of about 190 fsw, in which the oxygen fraction (FO_2), typically less than that found in air, is set to provide a safe oxygen partial pressure at the planned working depth, and helium is substituted for a portion of the nitrogen to reduce narcosis and decrease gas density.

Naming Conventions: Though in U.S. commercial diving circles, the inert gas fraction is generally specified first , we prefer the European convention of specifying the oxygen fraction first followed by that of helium as ***oxygen safety-and awareness is a key issue in most technical diving. operations.*** In this convention, *trimix x/y* is a mix containing x% O_2, y% helium, the balance being nitrogen. Typical mixes include trimix 17/17 (17% O_2, 17% He, balance N_2) known as *poorman's mix* because it can be simply blended using air as an add gas to helium and is relatively inexpensive, trimix x/25 and trimix x/50, the oxygen fraction being determined by the planned depth. Note that the helium fraction is generally set to yield an *equivalent narcosis depth* (END) of 150 fsw or less.

heliox: The standard oxygen-helium breathing mixture used in deep commercial and military diving, in which helium is substituted for all of the nitrogen found in air to eliminate narcosis and reduce breathing gas density. For deep dives in excess of 600-800 fsw, *compression rates* (rate of descent) are reduced, and narcotic gases such as nitrogen and sometimes hydrogen are often added back into the basic heliox mix to ameliorate High Pressure Nervous Syndrome (HPNS).

Following the European convention, *heliox x*, for example, heliox 12, specifies a mix with 12% O2, balance He. Though not commonly used in technical diving because of the expense, heliox will become a standard breathing mix for use in closed circuit systems which offer a hundredfold improvement over open circuit in terms of gas utilization efficiency.

travel mix: A gas mix, typically carried in stage bottles, used on descent prior to beginning the working portion of a dive.

Travel mix can be used to provide decompression advantages in conjunction with special tables, and/or to avoid problems of *hypoxia* (too little oxygen) near the surface when using a bottom mix with a low oxygen fraction (FO_2).

bottom mix: The gas mix (air, enriched air, trimix or heliox) used during the working and/or deepest portion of a dive.

intermediate mix, *a.k.a.* ***decompression mix:*** The gas mixes used during the decompression phase of a dive. Today, most special mix diving operations follow a planned *decompression procedure* of switching to one or more enriched air mixtures during decompression followed by pure O_2 at the 20 and 10 fsw stops in order to eliminate any helium as soon as possible, and maximize allowable oxygen partial pressures. Enriched air, oxygen, or a combination of both are used for decompression during extended air diving.

pre-mix: A specified gas mixture that has been premixed and analyzed by a commercial gas supplier. Note that boosting premix into scuba cylinders is a relatively simple, reliable and economic alternative for technical diving operators getting started in mixed gas, requiring only an oxygen-cleaned booster and supporting equipment.

home brew: A good ole' boy expression and sometimes emotion-laden euphemism associated with mixing gas at home in the garage or on site. Ironically today, most of the individuals involved in garage mixing know what they're doing and are probably far more knowledgeable and qualified than many of the critics who bandy about the term. Nevertheless, as reliable sources of gas become available, homebrew will go the way of the "build-it-at-home" computer. Remember them?

oxygen use:

oxygen toxicity: Oxygen is toxic to the human body at elevated partial pressures above 0.5 atm. The severity of oxygen's toxic effect depends on the dose measured in *partial pressure*, and the *duration* of the exposure. Of primary concern to technical divers is *central nervous system (CNS) toxicity which can occur at partial pressures of about 1.3-1.4 atm and above* and result in convulsions that resemble grand mal epileptic seizures. A second form of toxicity is *whole-body toxicity* resulting from *very long* exposures to oxygen partial pressures above 0.5 atm, and is characterized by chest pain, temporary lung impairment and other effects. Whole body toxicity becomes an issue during saturation diving and long multi-day diving operations and is generally not a problem for technical divers.

oxygen tolerance units (OTUs): A "unit" used to quantify the exposure to oxygen for the purposes of monitoring tolerance to whole-body toxicity. An OTU is the same size as the University of Pennsylvania's "UPTD," (unit pulmonary toxicity dose, or when cumulative, CPTD). The new term OTU takes a positive approach by saying" tolerance" rather than "toxicity", eliminating the term "pulmonary" since much more of the body is affected, and avoids the slight confusion between UPTD and CPTD. It also helps call attention to a specific set of tolerance limits that CPTD never had, called the *Repex method*. One OTU is about equal to an exposure of 1 minute to 1 atmosphere of oxygen, but is slightly more when above 1 atm. and less when below, the threshold being .5 atm. OTUs can be calculated as:

$$\mathbf{OTU = t \times ((PO_2 - .5) / .5)^{.83}}$$

where t is the duration of the exposure in minutes. Many special application tables include a calculation of OTUs and the corresponding predicted drop in vital capacity. For additional information on OTUs and the Repex method, see: Hamilton R.W. 1989 Dec., *Tolerating Exposure To High Oxygen Levels: Repex and Other Methods*. Marine Tech Soc J 23(4): 19-25.

physics & physiology:

gas laws: The *ideal gas laws,* in particular, Dalton's law which states," *the total pressure exerted by a gas mixture is equal to the sum of the partial pressures of the component gases in the mixture,*" has great utility for technical divers and is used frequently in calculating the essential operational characteristics of a special mix. A common form of this equation can be expressed as:

$$\mathbf{Pg = P \times Fg}$$

where *Pg* is the partial pressure of a gas g , and is equal to the total pressure, *P*, of the gas mixture times the proportion or fraction, *Fg* of the gas in the mixture. Uses of this formula include; *1) Calculating the partial pressure of a gas,* for example PO_2 or PN_2, given the working depth in pressure, and the fraction in the mix.
2) Calculating the proper fraction of gas, Fg to be used in a in a mix, given the working depth, and required partial pressure, and
3) Calculating the Maximum Operating Depth (MOD) of a mix, from an oxygen toxicity perspective,given the oxygen fraction, as discussed below.

maximum operating depth (MOD): The *maximum operating depth*, or

MOD of a mix is the maximum depth that the mix can be used at and still maintain a safe working oxygen partial pressure. For surface-oriented mix dives the PO2 is normally set at about 1.4 atm, *which can be sustained for the duration of most scuba-based runs.* Note that oxygen limits are sometimes extended as high as 1.6 atm or more for limited duration runs and for decompression.The MOD in feet of seawater (fsw) for a specific mix can be calculated by using a variation of Dalton's law, $PO_2 = P \times FO_2$, where P is absolute pressure in atmospheres. Rearranging terms, the formula becomes:

$$MOD = \left(\frac{\text{max } PO2}{FO_2} - 1\right) \times 33$$

Example, the MOD of air is found by setting the PO_2 to 1.4 atm, FO_2 to .21, and solving for depth; 1.4 = ((D/33)+1) x .21, or D = 186 fsw. At a PO2 of 1.6 atm, the MOD for air is 218 fsw. Hence, rounding up, *190-220 fsw represents the reliable limits of air*, depending on the duration, from a CNS toxicity perspective.

equivalent air depth (EAD): Given a planned working depth, the *equivalent air depth*, or *EAD* of an enriched air mix, is the depth at which the nitrogen partial pressure would be the same if the dive were conducted on air. The EAD principal states that only this nitrogen partial pressure need to be considered when calculating a decompression. The benefit of EAD is that it allows standard air tables to be used when diving enriched air. An EAD (fsw) can be calculated as:

$$EAD = \frac{(1 - FO_2)}{.79} \times (D/33 + 1) \times 33 - 33$$

Example: The EAD of an EAN 36 mix at a working depth of 90 fsw is .81 x 3.7 atm x 33 -33 = 65 fsw.

equivalent narcotic depth (END): Given a planned working depth, the *equivalent narcotic depth* (END) of a specific mix, is the depth at which the partial pressure of nitrogen i.e.*the narcosis level* or *goon-factor*, would be similar if the dive were being conducted on air. Typically, the END of a trimix is typically set at 100-150 fsw depending on the operation. END (fsw) can be simply calculated as:

$$END = \frac{(FN_2)}{.79} \times (D/33 + 1) \times 33 - 33$$

Example: The END of a trimix 14/50 at a working depth of 300 fsw is
.45 x 10 atm x 33 -33 = 115 fsw

gooned: What you get from breathing air beyond about 200 fsw, and other things. Ask those *deep reefers.*

mixing, analysis & pumping:

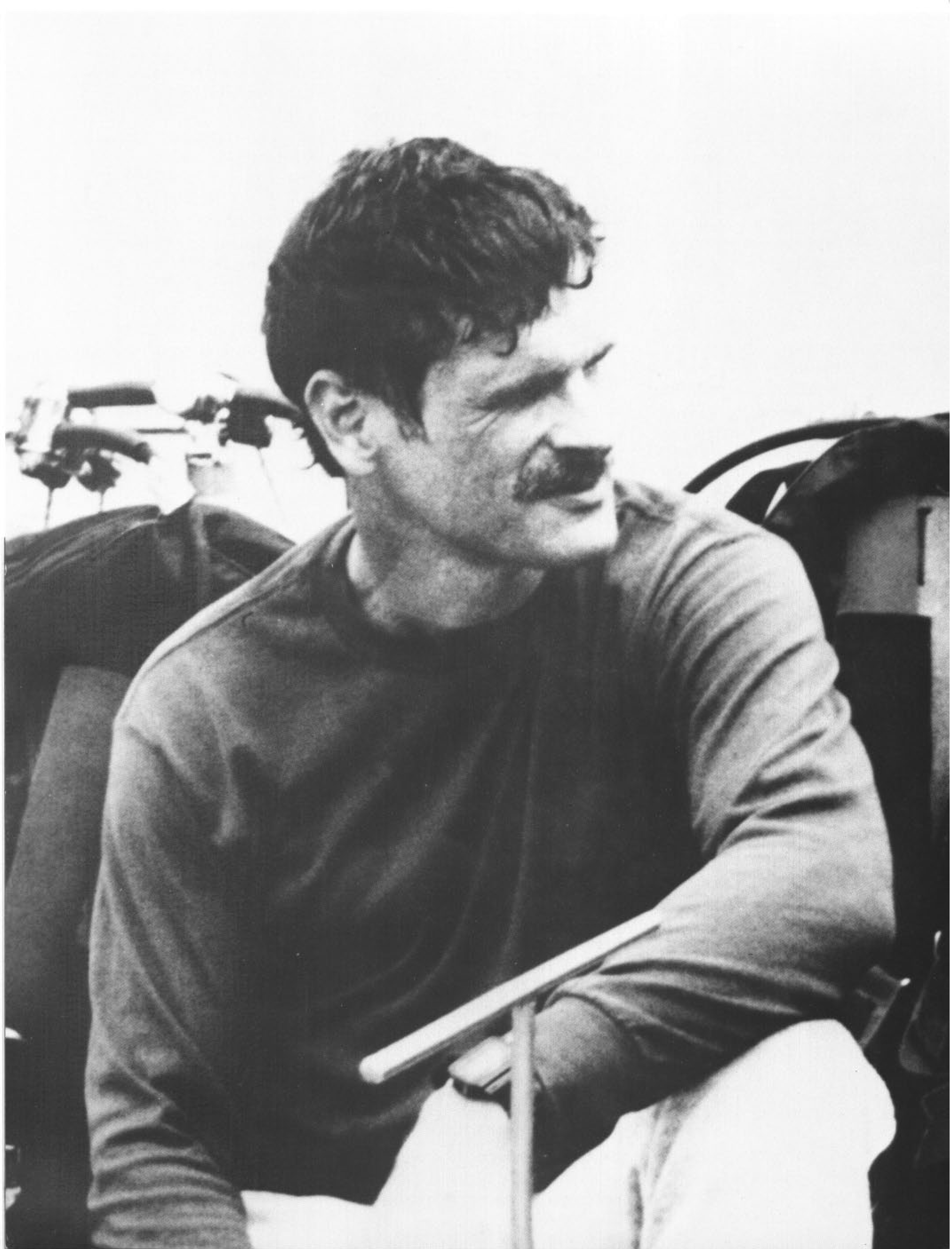
gas analysis: Special gas mixtures must be analyzed prior to diving them. Oxygen is by far the most critical component in any gas mix and must be accurately analyzed for all operations using one of several methods available. Nitrogen and helium are more difficult (and expensive) to analyze and field practices vary with regard to analysis.
As a general rule, only oxygen analysis is essential for enriched air and heliox mixes, though it's essential to verify that the helium is *really* helium. The accepted industrial procedure for trimix is to analyze for both oxygen *and* helium, though this is rarely done in technical diving operations and some disagreement exists as to whether or not it is necessary, good recording and careful mixing being sufficient.

oil-free compressor: A compressor which uses self-lubricating materials in contact with process air to reduce mechanical wear and prevent hydrocarbon contamination. The oil-free compression stages are connected to a conventional oil bath crankshaft via distance pieces equipped with seals prevent any oil leakage out of the crankcase and into the compression stages. A post compression filtration system is included to separate water vapor, remove particles and absorb contaminants such as carbon monoxide.Oil-free compressors are typically used for pumping oxygen enriched mixes where potential hydrocarbon contamination is an issue.

operations:

operations: Technical dives are *operations, a project or venture involving; planning, preparation and set-up, the use of proper equipment and methods,competent execution, and the capability to respond to contingencies effectively and immediately, where* ***diver safety is always the first priority.*** This is particularly true when utilizing special mix.The level of operation, or work involved, can vary from following a simple pre-determined profile and decompression schedule, for example on an enriched air dive (*EAN-compatible* DCs will come), to executing a deep multi-team mixed gas push, involving specific individual assignments, staged gas mixtures,use of special equipment such as DPVs and microbells, and advanced decompression methods. Note that *all dives are in fact operations.* In the case of recreational diving, the requirements are minimal, though recreational divers could no doubt benefit from more *operational minded* thinking.

COMING IN technicalDiver 3.1, the "D-Word" Dictionary by Richard Van, Ph.D.



EXLEY ON MIX

An interview by Michael Menduno

I glanced over at Sheck. He was again lost in thought, staring blankly into the night. It had been fascinating listening to him discuss the facts and figures of the dive, but what I really wanted to hear about were the things that go on inside his head when he's buried under hundreds of feet of water, inside a rock crevice, on the very edge of life, and still going on."How are you going to decide when you have gone deep enough? "I asked. "Fear." Sheck answered immediately as if he had been patiently waiting for such a question."

Ned Deloach, *The Deepest Dive*

To say that Sheck Exley is not your average 42 year old high school algebra teacher is a bit more than understatement. By vocation, he is in fact a teacher at Suwannee Highschool in Live Oak, Florida. By avocation he is an explorer, pioneer, and educator has become a diving legend.

Certified in scuba at the age of sixteen, Exley became the first person to log a thousand cave dives accomplishing this feat in less than seven years. Over the nearly two and a half decades that have followed, Exley has explored and surveyed most of the world's known deep water cave systems, pioneered many of the methods and techniques of deep air and special mix scuba, and in the process has repeatedly redefined the limits of self-contained diving; his 13 1/2 hour dive to 870 fsw at El Nacimento de Rio being one example.

Exley's exploits and dedication have earned him the reputation of being one of the finest divers in the world, and have helped shaped the development modern cave diving, regarded by many as a model for specialized training. A teacher and soft spoken educator, Exley helped to establish the National Speological Society's Cave Diving Division (NSS-CDS) in 1973, has published over 100 articles and six books on the subject of his passion, lectures extensively, and currently offers a mixed gas training program for experienced divers throughout the community.

Perhaps pioneers like Exley will always remain an enigma. An explorer and athlete of the highest magnitude—combining physical ability with the psychological stamina necessary to venture where few will ever go—to others perhaps, he is seen as a thrill seeker or daredevil. Recently aquaCorps caught up with Exley hoping to try to explain and reconcile the many stories that have grown up around the man, to understand his motivation, to get inside his head. The results were more than we had anticipated. Exley on mix? Perhaps ithe best way to explain is simply to start at the beginning. —M. Menduno & B Skerry

a/c: When did you start diving Sheck?

SE: I got started in 1965 but I didn't really start keeping a log until February, 1966 when I went on my checkout dive with Ken Brock. He taught me how to dive. That first dive we went down and I stuck my head under a coral ledge, what you might call a coral cave, maybe 16 feet deep (chuckles). Wasn't much of anything, and I really didn't enjoy it. But then Ken took me to Crystal River and I really got turned on. I didn't have a light or anything so I kinda wandered off into the cavern there, my eyes adjusted and I swam a little bit further, peering off into the darkness. I guess I've been peering off into that darkness ever since.

a/c: You've made some incredible divesin your career; your *Salute the Flag* dive at Diepolder II to 360 fsw *on air*, Wakulla, El Nacimiento de Rio Mante to 870 fsw, your 10,939 foot penetration at Cathedral, why do you do what you do?

SE: I'm not sure. My motivation has changed a lot over the years. I grew up diving, and as a teenager I wanted to be important and to be thought of as important. I went through a stage where I wanted to see how deep I could go. Then I went through a stage to see how *far* I could go. I still enjoy that.
There are places that no one else has been to since the dawn of time. We can't see what's there. We can see what's on the dark side of the moon or what's on Mars, but you can't see what's in the back of a cave unless you go there. There's a special feeling when you know no one else has been there before. And it's an extra special feeling when you know no one has ever been that far. I enjoy that feeling.

ac: Your Nacimiento Mante dive must have been like that?

SE: It was frightening. I'd use the term "physiological roulette "to describe my four Mante dives. The first to 520 fsw in 1987 was probably the most frightening. It was really stepping out into no-man's land as far as the western hemisphere was concerned. Jochen Hassenmayer of course had been deeper at Fontaine de Vaucluse.

a/c: Was Mante your first big mix dive?

SE: I had done practice dives of course; 130 fsw at Cathedral and 260 fsw at Holton Springs. Dale Sweet's 360 fsw trimix dive at Diepolder back in 1981 was the only dive in the western hemisphere that was close to it. In the eastern hemisphere, there was Jochen's dives. He had been to 660 fsw which gave me a lot of confidence.

a/c: You knew it was doable.

SE: I knew it was doable. I had dived with Jochen. He's an extremely impressive diver, as good as any I have dived with. The fact that I had actually met the man and dived with him made me feel a bit more confident. Decompression tables were a problem of course. There was nothing available. I had never heard of Bill Hamilton at the time. Fortunately I was able to get a hold of some commercial tables that Jim Melton got for me as a model.

a/c: You used commercial tables?

SE: No, I had to extrapolate them; the tables stopped at 400 feet. I had to take the model and extrapolate beyond that. I did the same thing on the 660 fsw dive two months later.

a/c: You know a lot of people would say, *"Sheck's nuts."* Why would he construct his own decompression tables; isn't that just fool-hardy and crazy?

SE: Isn't that basically what everyone does?

a/c: Ha! Good point.

SE: I may not be the world's greatest mathematician, but mathematics is my profession and I have a degree in computers; both of them lend themselves quite well to figuring out a decompression schedule. I'm sure Bill Hamilton wouldn't do it quite the way I did. But then I did have a vested interest in doing a good job.

a/c: You were the one on the line.

SE: I wouldn't begin to say that I could construct better decompression tables than Bill Hamilton, Angel Soto or Randy Bohrer, all of whom later worked with me. I don't have the information to make that statement. But it was all I had to work with at the time.

a/c: There's a myth out there—a subtle one, but it's still their—that decompression tables represent some kind of truth, as opposed to what they are; *peoples guesses as to what will work based on experience.*

SE: That's exactly right. I tell people early on in my mixed gas course that it's important to realize that any decompression table is just a mathematical model based on a poorly understood physiological phenomena. The degree that the model is valid for a given exposure is the degree to which you do or you don't get bent. A lot of the early models were very simple, like a kid with building blocks — not much to them. Of course they've become more sophisticated now, but their success still depends on whether or not they work.

a/c: Have you ever been bent?

SE: Never.Well, sometimes when I'm wearing a dry suit and woolen underwear, I've surfaced with what may have been skin bends, but I don't know. I've never had anything other than skin bends. It's a combination of a lot of luck, probably some unique physiology when I was younger, and a lot of conservatism as I get older. Fear.


RANDY BOHER

a/c: The decompression times you pulled on your Mante dives are so amazing, ten hours plus for your 780 foot jump and more on your last one to 870 fsw.

SE: (Pulls out his log) My 520 foot dive required 7 hours and 30 minutes of decompression for a 15 bottom time. Two months later, the 660 foot dive for 24 minutes took 11 hours and 13 minutes. The following year I made my dive to 780 fsw using Bill's tables which were only 10 hours and 43 minutes for a 24 minute bottom time. Besides the fact I was more confident in the safety factor in his tables, he got me out of the water quicker. My most recent dive to 870 fsw for 23 minutes had a decompression of 13 hours and 30 minutes.

"I've never had anything other than maybe skin bends. It's a combination of a lot of luck, probably some unique physiology when I was younger, and a lot of conservatism as I get older. Fear."

a/c: How do you prepare for a decompression like that? It must have physically and mentally grueling?

SE: From the standpoint of getting my tissues prepared, Bill Hamilton suggested that I make a deep dive, but not too extensive, the day before just to get my tissues limbered up. That worked out real well with my plans because my profile called for me to stage three bottles of decompression gas at 330 feet. We didn't want to do any mix dives before the big one because of the possibility of getting bent which would mess up the whole expedition, so I did the dive on air and got my tissues ready.

As far as being psychologically ready for the tedium of the thing, I was just coming off a record penetration at Chip's Hole near Tallahasee, Florida, for 10, 444 feet, which was the longest dive I ever made; 14 hours in 69 degree water with a wetsuit.

a/c: You survived!

SE: What made it worse was that I was in a current the whole time. *I got cold.* Fortunately the chemical heaters I was using kept me alive. After that, decompression at Mante, in 78 degree water seemed pretty easy as far as time went. As you know, with helium mixes I was making about fifty odd stops all of them relatively short. The time passed very quickly and I had plenty to keep me busy including wondering if all the little twitchs were going to be bends, CNS toxicity, or just my old bones getting tired.

a/c: You did it in a wetsuit?

SE: No, a drysuit.

a/c: Diapers or a catheter?

SE: No, I just cut it loose. Those are the only dives I use that drysuit for. And I enjoy having the back-up buoyancy compensation the dry suit provides. I sure wouldn't want to be down at 900 fsw without buoyancy.

a/c: Are you scared or anxious before your big dives ?

SE: Up until the time I get in the water, I'm scared. I'm sure I get as scared as any diver there was. In fact, I got so scared the night before my Mante dive—I'm not sure what caused it—I actually became physically ill. I don't know whether it was a short little bug or what. The way I control it is through meditation. I meditate for ten minutes back in the cave before I start down; that clears my head of all that stuff.

a/c: When you were in the water did you think about all the things that could go wrong or do you just deal with things as they happen?

SE: I spent roughly nine months in preparation for my last dive at Mante, in addition to my previous dives there. You play " what if " and try to think of *every* possible thing that could go wrong, and figure out all the little variations. You make plans and redundant plans to handle those things, and *rehearse, rehearse, rehearse*. And then when you make the dive, it's all business. Your mind is totally occupied with everything that has to happen. A lot of it has to happen very quickly. It's mental conditioning. I wouldn't be alive today if it wasn't for that.

a/c: I heard your watch went dead during one of your deep decompression stops?

SE: It was the 520 foot dive and it didn't stop; I lost my watch on the dive and I wound up counting all my deeper stops from 260 fsw in my head. Fortunately, I've known CPR since I was 16, so *that second, "one-one-thousand, two-one-thousand, three-one-thousand..."* is ingrained in my memory; but when your talking about a thirty minute stop, you're counting on your fingers. Eventually my safety diver, Mary Ellen Eckoff, who's probably one of the best cave divers in the world, and by far the best female, came to check on me at my 80 foot stop and brought me a watch.

a/c: Let me ask you the obvious question; *why weren't you wearing a back-up?*

SE: It was dumb on my part. After that, I carried three watches on each dive, and I had another one waiting for me at 520 feet with an additional depth guage. Back-up, back-up, back-up.

a/c: What about the cave itself?

SE: It's real involved. What helps is having gone there before. I don't think anyone's going to down and add to my line anytime soon, although it's only a matter of time before someone goes goes out there and does it. It would be very difficult however for someone who's never been there before to jump in the water at Mante and go to the bottom. You really have to build up to it. And then there's a lot of intricacies. For example, the cave is not really designed for decompression. You have a strong current blasting upwards and very jagged sharp ledges,but not as many as you'd like. That's where you have to hang your decompression tanks. The passages are very narrow; some of them too narrow to go through. If you drop anything it's gone and you have to plan your gas carefully.

I try to design everything around the thirds rule. I overestimate my breathing rate at all levels and provided a third cushion based on the deepest possible dive profile/diving time combination I thought I'd get. I also design my mixtures to stay within the oxygen toxicity envelope, both CNS and " whole body", raising the oxygen and nitrogen levels as I go up. Generally I try to run my nitrogen levels as high as tolerable, and switch over at 280 fsw from air to deep mix on the way down, and from deep mix to air on the way up. I used two deep mixes this last time, 13 mixes in all. And I do a lot of other things as well. I worry about diet before the dive and during the dive.

a/c: How about your support team?

SE: I had lots of help. Jochen shared some information. Dale Sweet shared everything he knew and supported me with equipment. Paul De Loach, my regular diving partner, maybe the best cave diver we have, helped me; Mary Ellen Eckoff, Tom Morris, Paul Smith, Paul Heinerth, Mexico's top two divers, Sergio Zambrano,

"Now days, the only rational recommendation is to build yourself up to where you can do your air dives to 200 feet; than after 200 do your helium diving."

and Angel Soto, who headed up my support teams, Randy Bohrer, and of course Bill Hamilton, the list just goes on and on.

a/c: You know there's an old joke running around. People ask me all the time, *"What kind of regulators did Sheck use on his Mante dives?."* Answer: *Every one he could get his hands on.* Obviously rigging 30 some cylinders took a fair bit of equipment, not to mention gas. Did you have any sponsors?

SE: Early in my career, I guess it was around December, 1970, I was involved as a safety diver in a record deep air dive attempt down in the Bahamas. There was a lot of those going on at the time; sponsorships, calling in the news media, getting official Bahamian folks to come and witness the thing, all that kind of stuff. It put a lot of pressure on the divers. As a result of the pressure, two divers never came up. That's when I made my *famous* air dive to 465 fsw which almost cost me my life. I couldn't reach them and nobody else could either. They knew going into the dive that their profile was not ideal. There were safety factors that they had counted on that were compromised at the last minute under the pressure from the sponsorship, the media and this whole expedition scenario. They compromised their safety procedures and died as a result.

I never want to be in that situation. That's why I keep my involvement small. I don't want a lot of big sponsors. I don't want a lot of divers around. Those that are involved are close friends and I tell them up front, *"We might just be going to Mexico for a long drive, turn around and come back. If I'm sick, or just don't feel right, or if a light goes out at the wrong time, whatever, the dive's over."*

a/c: I understand you were nervous about getting involved with mix in the beginning.

SE: My best friend back in the early 70's was probably Lewis Holtzendorf. Gosh, he was one of the best we had back in the early and mid-70s. Lewis made a mixed gas dive at Wakulla with Court Smith. They were diving heliox, and using the US Navy helium/oxygen tables which called for the use of pure O2 at 50 feet. We know now, that was asinine, but back then they thought the profile was safe, and discussed it with one of the Navy people at the Experimental Dive Unit (EDU). As it turned out, Lewis convulsed and died. His partner almost did too. That was 1975.

There were other incidents. Hal Watts had tried to do a body recovery in an open sink in Orlando on heliox and got severely bent in the process. After that, Frank Fogarty, Terry Moore and Rodger Miller made a 325 foot run in a Missouri sink, in 1978, on trimix and got severely hypothermic. We were all looking and

RANDY BOHER

thinking, *my god, what's going on.* You have to understand, the world depth record for cave diving was only 340 fsw back in 1977 and it stayed that way until Sweet made his successful trimix dive at Diepolder in 1980. It was Jochen's dives that got me thinking that mixed gas might be done safely.

a/c: Sheck, you've done a lot of deep air diving over the course of your career; you've mentioned quite a few *deep* air dives over the last half hour. What are the practical limits of air?

SE: You have to understand, I've built up a lot of experience and tolerance to nitrogen over the last 25 years, and what works for me might not work for everyone. In the early days air was all we had and we didn't have the knowledge we had today. If I were starting again, I'd probably do things a lot different.

Today, I think you have to look at each individual environment and application and judge it on that basis. There are quite a few people who are teaching deep air technique these days, I know Hal Watts,Tom Mount and I do and there's others. With those techniques, basically anyone can be taught to dive to 200 fsw. Beyond that it becomes an individual thing.

Now days, the only rational recommendation is to build yourself up to where you can do your air dives to 200 feet; than after 200 do your helium diving. There's no longer any point to build ourselves up to 300 foot dives on air, because most people can't possibly handle it to that extent; it's just one of those individual things. Trying to build up beyond 200 feet, you're taking chances. Maybe you can handle it, maybe you can't.

a/c: Physiological roulette?

SE: Exactly. I was one of the lucky ones, or perhaps,unlucky ones.

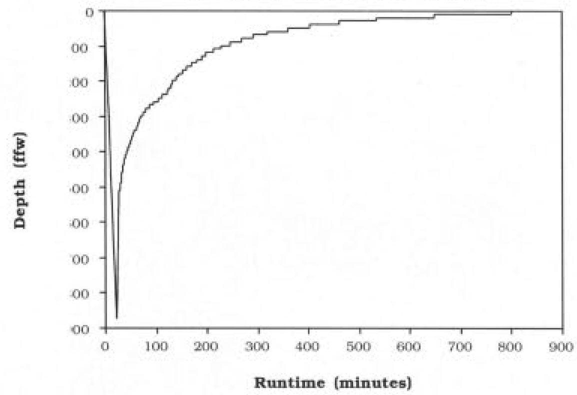
a/c: Is air technology dead?

SE: I don't think so. I think there will always be a use for air. Hal Watts really got the deeper air stuff started from the viewpoint of trying to acclimate to higher partial pressures of nitrogen, but as we continue to learn more, like some of the amazing stuff Bret Gilliam's doing, it will make it easier for the rest of us to dive to 200 feet, maybe more. Let's face it: we have a lot of experience with air and we're more comfortable with the decompression. I'm not aware of any helium tables that are as reliable as some of the air tables that are available. The decompression is more reasonable and you can decompress closer to the surface. If you can do a dive on air, or an appropriate enriched air mix, and do it safely, you ought to do it.

a/c: What about people going deeper?

SE: It's obvious that there's an enormous amount of interest has been generated, particularly now with the advent of mix gas diving. Back in the 60's and 70's we used to try as instructors to tell everyone there's not much to see beyond 130 feet. Of course it depends on what you're interested in seeing. We've all known from the beginning of cave diving in Florida, that the most beautiful and interesting caves are all deeper than 130 fsw. It's sad. You know we tell people, "Don't go below 130", and then we turn right around and do it ourselves. All cave diving instructors dive deeper than 130 feet.

El Nacimiento de Rio Mante (874 ffw for 23 minutes)



I think it's more realistic to try to establish some guidelines for people who want to venture deeper, rather than say, "Don't!", and be seen as hypocrites. Otherwise people will begin to think, "Well, if that rule isn't worth paying attention to, maybe they all aren't."

a/c: Deep diving is getting more expensive Do you think that will limit people?

SE: Diving is a much more expensive pursuit now then it's ever been. And when the rebreathers start coming out—Bill Stone's probably real close to having a fully redundant closed circuit system now —it's gonna be even more expensive. Quite frankly, the people who want to do these dives are going to find the money to do them. I remember when scooters first came out. Shoot, I didn't have any money. But I realized if I wanted to continue to do the type of diving I wanted to do, I had to step up, borrow the money and buy one. I did. Bill Stone once made the observation that he wasn't aware of any explorers that died rich.

a/c: What does it take to be a cave explorer?

SE: You have to love it. You have to love the diving. Loving recognition is not enough. That wears off. That's why you see such a high instructor dropout rate. The ones that got in it because it's another merit badge and everyone around thought it was a big deal—it wears off. You see it over and over again in diving. When I got started in diving back in the sixties, I wanted to be special. I grew out of that and got to where I just loved diving, and that's what kept me going. If I hadn't I would have quit a long time ago.

a/c: Love. Perhaps that really is the key to it all. What's your advice for people who want to expand their diving capabilities?

SE: Don't forget the basics. Make sure you have plenty of gas, make sure you know the way back, and make *damn* sure if you're going into nitrogen land or helium land, you know what you're doing.

a/c: How about you? Who do you look to for inspiration?

SE: There's a book by Roland Huntford called *Last Place On Earth* which contrasts the exploration styles of Robert Falcon Scott and Roald Amundson in their drive to reach the South Pole. Scott was the guy with all the money, recognition, power and supplies, which he arrogantly threw at the problem. Amundson was poor and didn't have much, but he carefully thought out everything, every little step of the way with infinite preparation. He listened to everyone for advise, even the Eskimos who Scott thought were ignorant savages who couldn't possibly have any ideas. The end result was that Amundson got to the South Pole first and Scott wound up killing himself and a lot of other people. I think Amundson provides a tremendous role model for explorers and divers.

a/c: What are your diving plans Sheck?
SE: I have a cave real close to me here on my property. In fact, it's under my feet as we talk. The last time I went diving there I was over two miles underground and the

continued on page 70

The Story Of CO_2 Build-up

by The Reverend Edward Lanphier

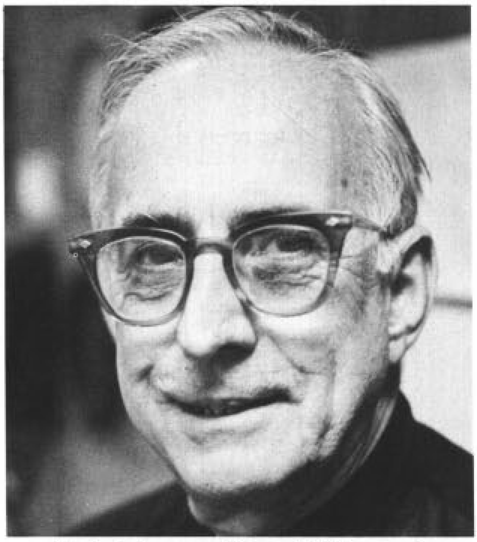
"I started out writing a "scientific" sort of thing, but it kept putting me to sleep. So I decided to try taking experiences of my own as a skeleton on which to hang facts, using more colloquial language. I like the result very much better; and I hope that will be acceptable to you."

How did I ever get myself into this? That question crossed my mind; but I knew the answer, and it felt good. *"This"* was trying to determine oxygen tolerance limits for US Navy oxygen and mixed gas diving. The year was 1953, and I was under pressure equivalent to 50 feet of sea water in the "wet pot" of a research chamber at the old US Navy Experimental Diving Unit (EDU) in Washington, D.C. I was Assistant Medical Officer and Physiologist there. In those days, the only assurance the enlisted divers had that an experiment was reasonable was the willingness of officers like me to go through it ourselves, which we always did.

Right then, I was swimming vigorously on the "trapeze swim ergometer" that Engineering Officer Jolly Dwyer and I had dreamed up for just such purposes. I was very glad that I'd spent weeks working out in the pool with my giant duckfeet to get in shape for runs like this. We had to be working hard to make the tests meaningful; exertion was one of the main factors known to make oxygen toxicity come on sooner. My legs were handling the load pretty well, the full-face mask was supplying plenty of pure oxygen, and the 15 minutes of the test must have been nearly over. A week or so before, I'd made the same run,15 minutes at 50 feet, with no problems, but the work load had been lighter then.

I wasn't expecting any trouble, but very suddenly one of the muscles in my right leg contracted sharply—involuntarily and uncontrollably. It didn't last for long, but it upset my swimming completely. Could this be a warning of an impending oxygen convulsion? It probably was. If so, I was lucky. Some of the subjects, like Dwyer, had gone into grand-Malabar epileptic-type seizures with no warning at all.

I started to get off the "trapeze," and my alert in-water tender grabbed me. Good thing! Now I was having great all-over jerks and spasms and



couldn't help myself at all. The tender maneuvered me to a ledge where he could keep my head out of water, and he took off the mask so I could breathe chamber air instead of oxygen.

The outside tenders kept us at the 50 foot pressure to make sure they didn't cause gas embolism by decompressing me with airways in spasm. Gradually, I straightened out. Otherwise, I'd probably have gone on into a full seizure with unconsciousness and board-like rigidity followed by violent thrashing. No wonder scuba divers usually drowned when this happened to them in open water.

Anyhow, I'd been lucky. They told me later that I'd stopped at 14 minutes, 45 seconds , just 15 seconds short of my goal. That was OK. If I'd been the whole 15, we would never have known how close I'd been to real trouble. As it turned out, that was the riskiest dive in the entire series; and we set the final limits well on the safe side of that.

The divers were instructed to quit if they developed any of the recognized warning symptoms like muscular twitching, nausea, dizziness, or abnormalities of vision or hearing. But a symptom like that was often not definite enough to add to the data. Convulsions were the unquestionable thing, and they were bound to happen occasionally. Neither brain waves nor anything of that sort would provide adequate end points.

We knew from earlier studies, especially those conducted by the Royal Navy, that developing reasonable O_2 limits wasn't going to be easy. For reasons largely unknown, oxygen tolerance varies greatly between individuals and even in the same person from one time to the next. The best we could do was to draw a line at times that missed, by a reasonable margin, the instances of apparent toxicity of different depths.

For simplicity, we'd started out with pure oxygen; and most people thought we could just translate the limits to mixed gas on the basis of inspired oxygen partial pressure (PO_2), much as the nitrogen pressure was used to figure mixed gas decompression according to the "equivalent air depth" principle. Fortunately, we decided to test the tentative PO_2 limits with dives on mixed gas at greater depths. What happened then gave us a real shock. Convulsions occurred with nitrogen-oxygen mixtures at pressures and times that should have been safe. The results were quite different from those with 100% O_2, and at first there was no obvious reason.

Diving medical people had known for some time that when carbon dioxide accompanied inhaled oxygen, the onset of toxicity was speeded up. A few years before our study, Dr. C.J. Lambertsen and his research team at the University of Pennsylvania showed why. CO_2 not only derails a mechanism that normally helps protect the brain from high PO_2 but actually increases brain blood flow and the "dose" of oxygen reaching brain tissue.CO_2 buildup was a frequent problem in closed circuit scuba, where failure of the CO_2 absorbtion system could easily occur. Excessive dead space in the breathing circuit is another cause. We could find nothing about our setup that would have added CO_2; but at about this time, studies elsewhere suggested that some divers held onto excessive amounts of the CO_2 produced in their own bodies. Wouldn't *"retained"* CO_2 have the same effect in the brain as CO_2 that is inhaled?

Body metabolism involves consumption of oxygen and production of CO_2. Muscular effort greatly increases both processes. Oxygen is supplied and CO_2 is removed by diffusion between blood and gas in the lungs. Normally, ventilation of the lungs and lung blood flow increase along the CO_2 production in such close proportion that the partial pressure of CO_2 (PCO_2) in arterial blood leaving the lungs is almost steady over a wide range of exertion.

We had to go through a major research effort to be sure of what was going on, but it became clear that some of our divers did not increase their breathing sufficiently when they worked, developing a high $PC0_2$ as a result. This tendency was aggravated, apparently by higher gas density and increased work of breathing, when mixtures were tested at greater depths. It's been suggested that 0_2 toxicity may increase during exertion only if body PCO_2 levels increase; but this idea has never been tested.

The divers who didn't breathe enough came to be called *CO_2 retainers.* We were never sure how they got that way, nor were we able to find a sure-fire way of identifying them in advance. Most of our retainers were hardhat divers, and being exposed to high CO_2 levels in the helmet may have blunted their breathing response to CO_2. But our champion retainer hadn't done much actual diving.

Submarine escape training tank instructors at New London did a lot of deep breath-hold diving, and low response to CO_2 wasn't surprising in them. In frogmen, retaining CO_2 appeared related to years of habitual "skip-breathing" attempting to save air during SCUBA dives.

Most retainers showed unusually small increases in breathing when they inhaled various percentages of CO_2, but this characteristic wasn't dependable enough for a good test. The retainers didn't form a distinct and easily identifiable group; they covered the range from "almost-normal" to "far-out." In more recent years, we tried to study CO_2 retention at the University of Wisconsin. We focused on scuba divers who claimed to use less air than anybody, or who had CO_2-type headaches during or after dives. We found that the only conclusive test was measurement of the PCO_2 in blood or expired gas during exertion in water. We found only one young man who had responses entirely like those of our retainers at EDU; and in him, there was no obvious cause.

Actually, we didn't find Sam. He found us. He was an avid scuba diver, but he'd had some very scary experiences at depth, enough so that he was willing to consult my laboratory and be studied. He'd nearly passed out at depth on several occasions and once had a massive headache with nausea and vomiting for hours after aborting such a dive.

CO_2 Retention and "Narcosis"

Sam's case reminded us that speeding the onset of oxygen poisoning isn't the only serious consequence of CO_2 retention. One of our EDU retainers had passed out during a simple air dive to 150 feet in the wet pot. A student at a Navy diving school had been sent to us for study when he lost consciousness on a shallow open-water training dive, and we found that he retained CO_2 to a marked degree. Almost all authorities assumed that CO_2 excess would be signaled by increases in breathing that couldn't be missed, but we had learned that this isn't always true.

I'm the exact opposite of a CO_2 retainer; but I discovered that I wasn't immune to serious CO_2 effects. A student and I were testing a new bicycle ergometer at 7.8 atm (224 ft.) in the dry chamber in my lab in Buffalo. Nitrogen narcosis is very evident on air at that pressure, but we were doing ok until we started breathing on the measuring circuit. That, it turned out, gave us only about half the air we needed at the work rate set on the bike. Herb tried the bike first. He stopped pedaling after about three minutes, out cold with his eyes rolled back.

As soon as I could get Herb out of the way, I took the bike. I knew I wasn't getting nearly enough air, but I was too narc'd to think straight and was determined to finish the 5-minute test no matter what. I pedaled myself right into oblivion, and coming around slowly afterwards with a horrible feeling of suffocation was the worst experience of my entire life. Both of us surely would have drowned if such a thing had happened when we were alone underwater.

CO_2 can knock you out all by itself, but the combination with nitrogen narcosis is especially potent. It turned out what we weren't the first to discover that, and others since have described similar effects. On the day we started studies on Sam, the latest issue of *Undersea Biomedical Research* arrived. It carried a fine description of studies on two British divers who had passed out at depth, apparently because of CO_2 retention.

In 1980, we invited world authorities on CO_2 and related matters to Madison for a conference on loss of consciousness in divers. There was no question that CO_2 could sometimes be a major problem, but not much new information surfaced. Since then, there have been scattered reports of fatalities or near-misses that sound like CO_2 narcosis with or without nitrogen effects. Very recently, reports from the US Navy and from Dr. Lundgren's laboratory in Buffalo have stressed the precarious mental condition that can develop in hard-working dives with CO_2 buildup.

Conclusions.

It is hard to say whether excess CO_2 is more hazardous with high PO_2 or in situations involving narcosis. Under sufficiently stressful diving conditions, such as very heavy exertion, unusualork of breathing, or failure of CO_2 absorption, CO_2 build-up can threaten any diver. CO2 retainers who do not realize that they have this problem are certainly at the greatest risk of all, and we know no easy means of identifying them. My own opinion is that any diver who habitually uses less air than otherwise comparable divers, or who often has headaches associated with diving, or who has experienced unusually severe narcosis should dive with particular caution. A CO2-response test in a pulmonary function laboratory, and an exercise stress test with measurement of expired volume and alveolar or blood CO2, may be indicative especially if the results are abnormal. Normal findings do not necessarily rule out the retention tendency.

Good advice for all divers is to not "push the limits," particularly those who may be CO2 retentive. The general "rules" for oxygen or mixed gas safety may be just fine for almost everybody else. Likewise, "safe" depth limits, "moderate" levels of exertion, and usual warnings of O2 toxicity or CO2 poisoning definitely do not apply to everybody equally; individual susceptibility is always a major factor . Though the US Navy has liberalized the oxygen limits that we worked out in the 1950's; the 1987 Diving Manual, Volume 2, contains this inconspicuous but important proviso on page 16-4:

"Although the limits described in this section have been thoroughly tested and are safe for the vast majority of individuals, occasional episodes of central nervous system oxygen toxicity may occur. This is the basis for the practice of requiring buddy lines on closed-circuit oxygen diving operations."

Dr. Lanphier has been involved in dive-related research since 1951. He is now a Senior Scientist in Preventative Medicine at the University of Wisconsin,Madison, and Assistant Director for Biomedical Research at U.W. Biotron. His current research concerns decompression and is supported by the University of Wisconsin Sea Grant Institute. Dr. Lanphier can be contacted at U.W. Biotron, 2115 Observatory Dr., Madison, Wisconsin 53706

CO2 Risk Management Summary

by Bret Gilliam

Carbon dioxide (CO2) makes up approximately 0.03% of the atmosphere, for a partial pressure at sea level of about 0.0003 atm or .03 kPA. At low concentrations, it is colorless, odorless, tasteless, and nontoxic, but in greater percentages or at high elevated partial pressures, it has an acid taste and can be toxic to humans.

Carbon dioxide is a waste product of the body's metabolic energy production process and is eliminated during the exhalation phase of respiration. Almost a liter of carbon dioxide (CO2) is produced for every liter of oxygen consumed the human body . The exact amount depends on the individual and varies according to diet, and can change dramatically when a diver is subjected to to increased workloads and exercise. CO2 also serves as the primary stimulus to breathing. That's why excessive hyperventilation prior to extended or deep breathhold diving is dangerous and insidious.

Hyperventilation reduces normal levels of CO2 and thus lowers the *urge to breathe* enabling the breathhold diver to momentarily extend his or her bottom time. If the oxygen partial pressure is reduced too far the result can be hypoxia, or "shallow water blackout". Essentially, the body's normal warning system is temporarily disabled and is slow in alerting the diver to his or her hypoxia crisis. Several champion free divers have fallen victim to this phenomenon and it is strongly advised that breathhold divers refrain from excessive hyperventilation techniques.

Another problem for scuba divers is CO2 retention. This can arise from poorly performing equipment and inadequate ventilation of the lungs for example, as a result of "skip breathing." Symptoms of carbon dioxide build up include headache, weakness, labored breathing, a feeling of air hunger,nausea, dizziness and confusion and eventually loss of consciousness at very high levels. Observable signs are typified by rapid breathing, clumsiness or foolish, incoherent actions and the slowing of response.

Some individuals are more sensitive to CO2 build up then others, and are often categorized as "CO2 retainers." Many diving physicians are sufficiently concerned about this abnormality in divers that they will recommend exclusion if a predisposition to CO2 retention is detected.

It is extremely important for divers to consider the effects of CO2 in planning their diving activities. Aside from the potential problem of CO2 toxicity itself, *elevated partial pressures of CO2 contribute to the onset and severity of both nitrogen narcosis and CNS oxygen toxicity.*

There are several ways in which divers can manage these risks. First, matching the performance of a regulator to the diver's operational needs is vital. Breathing resistance and exhalation should both be considered. Note that increased gas density with depth can potentially overload a regulator. Make sure your regulator is capable of delivering the performance required. Ask for the test results. Proper breathing techniques are also essential. Never "skip breathe." If your worried about conserving gas you should probably be carrying more. Slow deep ventilation cycles are recommended. And remember, not to get out of breath. Finally when utilizing closed environments such as a decompression station make sure venting is adequate.

Bret Gilliam is a diving consultant, instructor, and recompression chamber supervisor with over 12,000 dives. He is also is the lead author of the new book titled, "Deep Diving, An Advanced Guide To Physiology, Procedures and Systems." *He can be contacted at: Ocean Tech, 3098 Mere Point Rd., Brunswick, ME 04011 Fax: 207-442-9042.*

EXLEY ON MIX

condinued from page 66

thing was still 50 feet wide and 20 feet high and going strong. No tellin' how far it goes. I haven't seen that anywhere else. All these other Florida caves start branching out, getting smaller; this one just keeps on going and going and going. I'd like to see what's back there, but I'm not sure I'll be able to do it with the technology we have right now. A lot of our technology may be obsolete here in a short while.

a/c: I guess you're gonna have to borrow some more money and plunk it down on one of Stone's rebreathers.

SE: And then there's hydrogen. From what I've been learned there seems to be some real potential for hydreliox though no one has looked at it's use for deep bounce dives. With the kind of compression rates I was dealing with at Mante, you need the heavy nitrogen to avoid HPNS, but I'd rather have the hydrogen.

a/c: What about Mante; are you planning to dive any deeper?

SE: I've had opportunities to go deeper, but it looks real unlikely with my advancing age that I'll go back down there. I'd like to see more people go as deep as I've been in Mante before I go too much further. Since Jochen got the bends so bad he had to quit diving, there is no one else who's been beyond 500 fsw.
You know it's funny, on my last two Mante dives, my first decompression stops were at 520 feet. Only one other person had ever been that deep and here I was making a decompression stop. How crazy can I be? I'd like to see Jim King and some of the others start diving to 500 feet, then I'd feel better about going a little deeper.

a/c: Five hundred feet. A thousand feet. Pretty heady stuff. What do you think the ultimate limit is?

SE: There is no limit. We'll always find a way to go deeper and deeper. That's been the pattern all along.Ten years from now, twenty years from now, people will be doing things we've never dreamed of. And I see no reason for it to change.

Sheck Exley can be contacted at Rt 8, Box 373, Live Oak, FL 32060, where he teachs cave and mixed gas courses. His books, include, Basic Cave Diving: A Blueprint For Survival

personnel associated with a given dive operation. Specific requirements depend of course on the operational parameters of the dive. Interestingly enough, technical diving may require greater training and knowledge at a diver level than the commercial industry, since the diver has to plan and manage his or her own gas supply, mix, decompression etc. Something to think about. —a/c

For The Masses Or The Classes

aquaCorps has been a new frame of reference where divers like myself can honestly start talking about issues totally ignored by the typical sport diver and their certification agencies. Having said that however, I must express a concern that has surfaced, no pun intended.
I know it is necessary to define the limits of scuba by demonstrating what the ultimate fringe is up to. It makes for exciting reading and interesting conversations. However I hope that after demonstrating these limits over the next few issues, aquaCorps will not become a journal exclusively for those technical divers who are professionally funded to levels unattainable by the majority of other technical divers.
Frank Novak
Mentor, Ohio

We can all learn from the big projects and the experiences of the individuals who are working the envelope; that's where the development work is going on. The important thing to realize is that the methods and much of the technology they're utilizing is now becoming available to all of us. Our focus will be to help you understand the latest thinking and developments, relate the experiences of leading divers and practitoners, and help you apply it to your own diving environment and application. And have some fun to boot .That's our rock'n'roll strategy. Please let us know how how we're doing. —a/c

Keeping Our Subscribers In Mind

Like *PFM* , my long awaited issue arrived in the mail. It was a pleasure to read it, but I have a question with regards to your newly revised subscription offer at the the back of the journal. My interpetation of this information is that this latest issue of the journal will be my second and I will only be receiving two more for my $39. Originally, I understood that I would receive six issues with my subscription. I hope that your intial subscribers who paid $39 under the premise that they would receive six issues will be kept in mind as future issues approach. Looking forward to the best of the best.
Robert Seitz
Metro Dade Police
Underwater Recovery Unit

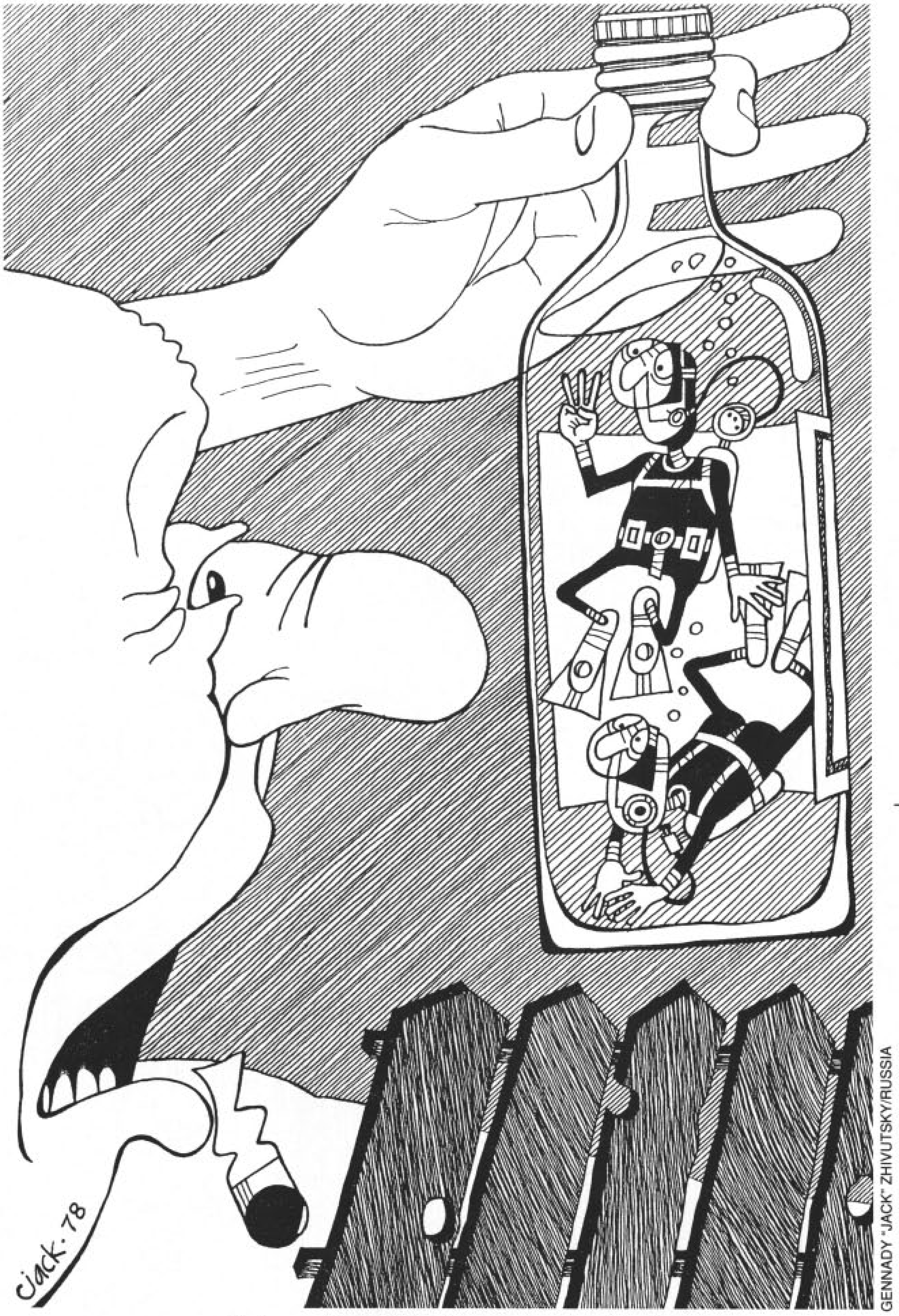
We've been working hard over the last year to find the formula with regards to format, content, advertising etc., that will allow us to provide quality information to our subscribers on a consistent basis, and at the same time will represent value for your money. ***Our current subscriber plan gives you seven issues in total*** *(four newsletters, two journals and one guide)* ***versus the original six.*** *We appreciate your patience and willingness to work with us on this issue, particularly those brave souls who signed up at the beginning. We are definitely keeping you in mind. —a/c*

If All Else Fails Call 1-800 -

Having perused a copy of *DEEP*, courtesy of my Poseidon / Zeagle rep, I entered my subscription to your journal and have yet to receive anything. Every day I've trekked to my mailbox ardently hoping for my copy of what appears to be a well-written, highly interesting, topical and thought provoking journal all to no avail. Each day yields greater disappointment, *" Have they forgotten me? Have I been left by the wayside in this increasingly complex technological society? Is it just that they don't like the way I spell my name?"* It's come to the point I'm holding a suicide prevention hotline number in one hand, and "flicking my Bic" near my oxygen filled aluminum 80 with the other. The time is ticking down.Please send me a copy of your publication post haste.
Sign me forlorn In Escondido,
Perry Armor
Escondido, CA

Dear Forlorn,
Enclosed is your copy of the journal. My apologies for the wait. Because of our small staffing level, we often wait to accumulate orders and process them in batchs. Sometimes this causes delays, a situation we're working to gradually improve. If you think we might have missed your order, please call our toll free number and leave a detailed message and your address (it's often difficult and expensive to return calls) or drop us a line. How high do you have that "oxygen-cleaned" 80 pumped to anyway? —a/c

Letters to should be addressed to: aquaCorps, 590 Se 12th St, Suite 301, Dania Beach, FL 33004



It's ok. We're on mix!

Lifetime members

Our sincere thanks go out to those brave souls who signed up for a lifetime of information. Your support has been invaluable and has gone a long way in making aquaCorps possible and keeping us alive,well and publishing.

Glen Armentor
James Brown
Norman R. Cooter
Samy Elashmawy
John Griffith
Pam Dillingham-Hucht
Jim King
Stephen Ligtelyn
Robin Lockwood
Mike Madden
Hardwin Mead
Brian Skerry
Peter Storm

" For me the world is wierd because it is stupendous, awesome, mysterious, unfathomable; my interest has been to convince you that you must assume responsibility for being here, in this marvelous world, in this marvelous desert, in this marvelous time. I wanted to convince you that you must make every act count, since you are going to be here only for a short while; in fact, too short for witnessing all the marvels of it."

Carlos Castenada,
Journey To Ixtlan

Special Mix Summary

• Special mix can be used to improve diving *safety* and *performance* and is applicable to a wide range of diving applications and environments, from recreational diving to exploration.

• The most common form of special mix is *enriched air* which offers significant decompression benefits over air and will likely become the diving gas of choice for most shallow water diving applications . Helium-based mixes such as *trimix* and *heliox*, are also growing in use for deep dives because of the enormous safety advantage and extended capabilities they add. In addition, the practice of using of in-water oxygen for decompression is emerging as a *community standard* for dives requiring more than about 20 -30 minutes of decompression.

• Though the use of enriched air is relatively simple and requires minimum training, in general the safety and performance benefits of special mix come at the expense of increased planning, logistics and expense. *Knowledge and understanding, the proper equipment and training are required to safely and effectively use these tools.*

• Currently there are a growing number of facilities and instructors that offer special mix training, and the availability of alternative gas mixes is becoming more widespread. We reccomend that interested individuals seek out knowledgable and experienced instructors and operators in order to get the neccessary training. And remember, ***safety should always be the first priority.***

surfacing Next

technicalDiver 3.1

Beyond Machismo ~ How Much Oxygen Is Too Much?

Thermal Strategies ~ Setting Up An Enriched Air Fill Station

Postcards From The Edge ~ Tekkie reading list

aquaCorps Journal: Bent 3.2

DCS: What Do We Really Know? ~ The Theory Behind Treatment Tables

"I Got Bent." Four Leading Technical Divers Share Their Experience—Before, During and After.

Microbell Primer, Doppler technology, Portable Chambers,

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