DeepTech JOURNAL

ADVANCED DIVING TECHNIQUES

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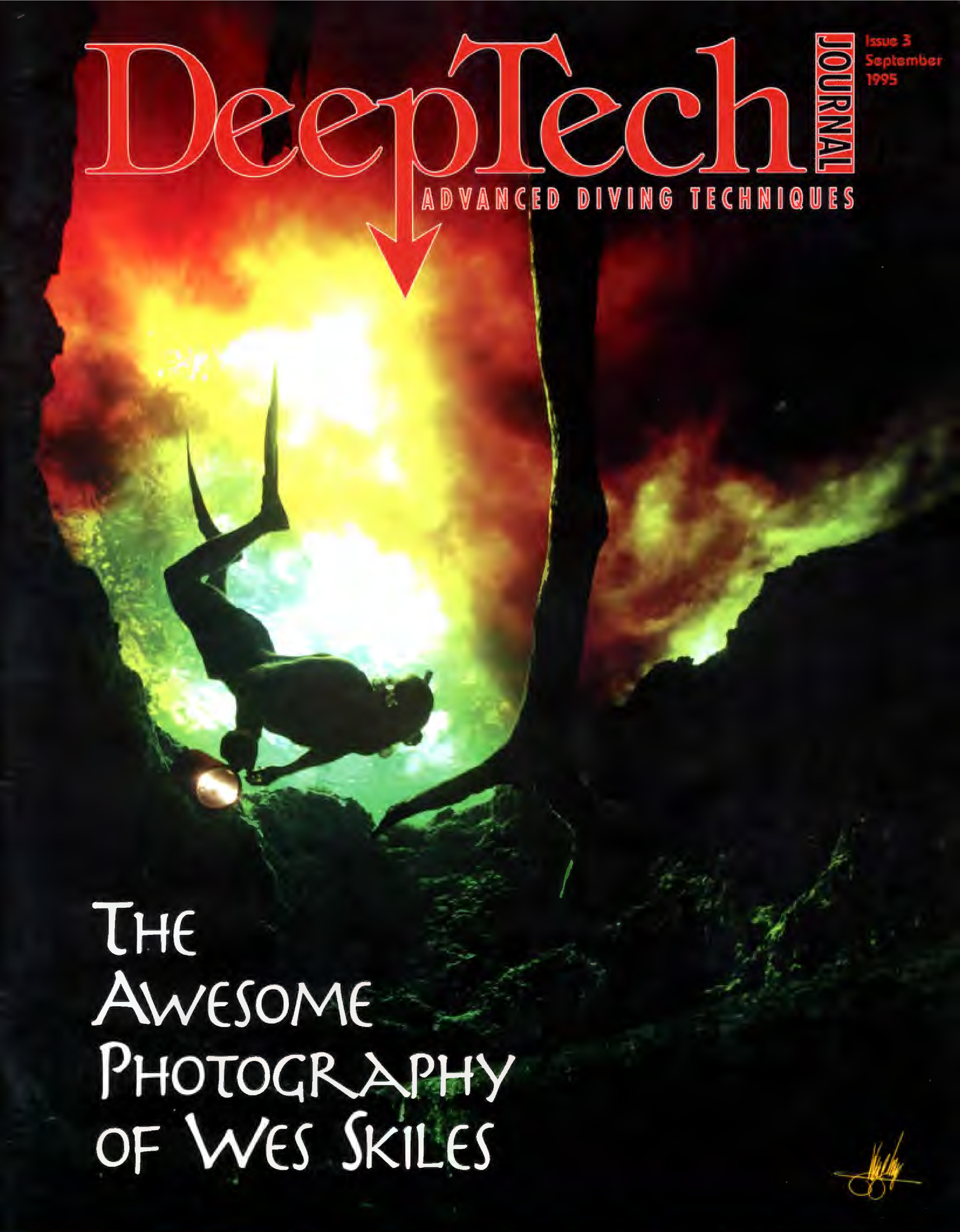
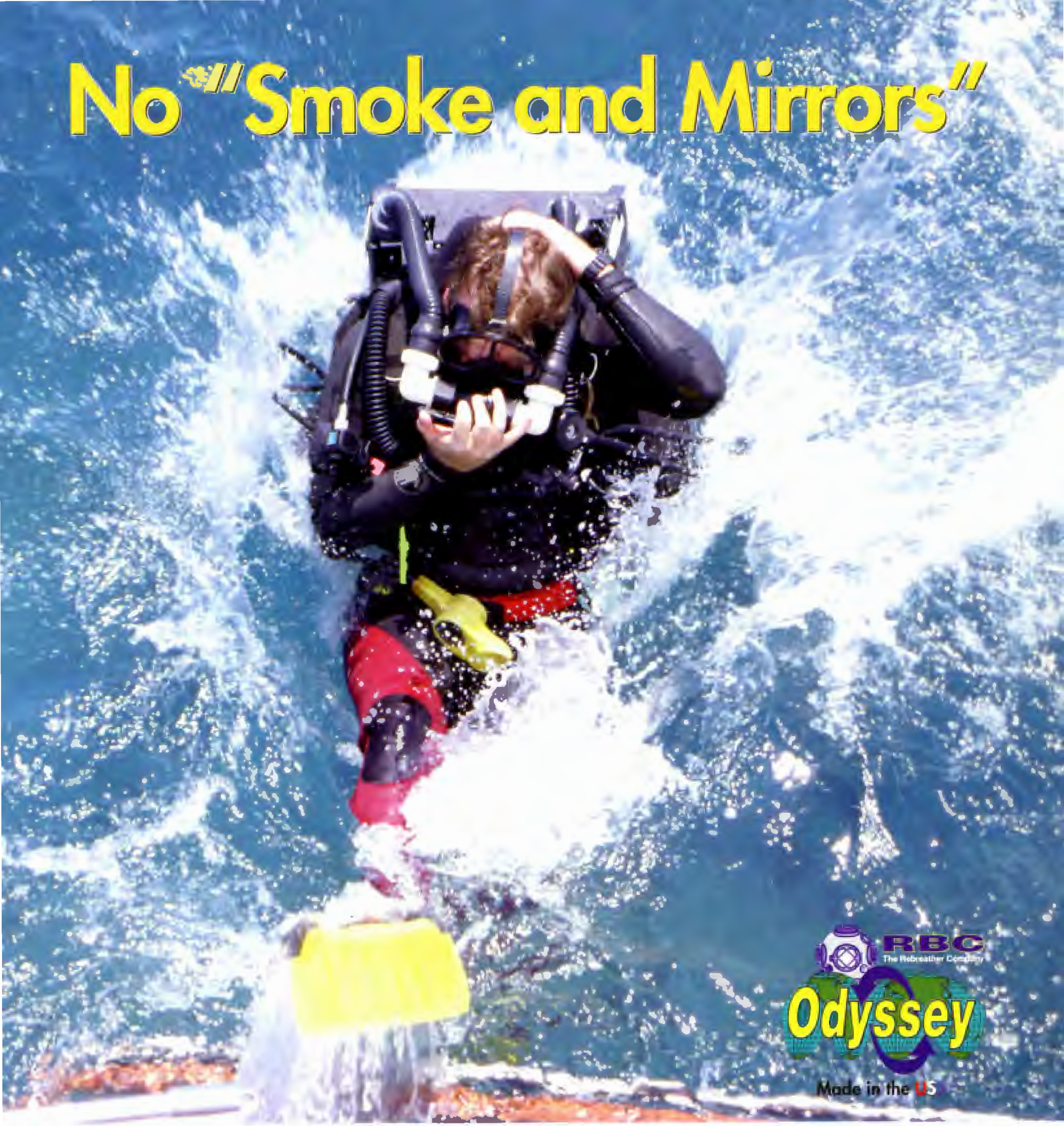


The Awesome Photography of Wes Skiles

Homebrew • First Dive on the Fitzgerald • RGBM • Risk and the Law



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TECHNICAL DIVING
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DeepTech Journal
Advanced Diving Techniques

Publishers Win Remley, Curt Bowen

Photography Robin Gruters

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WARNING:

Diving is a potentially dangerous activity. Neither DeepTech Journal, nor it's contributors accept liability for diving related injuries incurred by our readers. The materials contained within this journal are for informational purposes only and are not intended as a substitute for dive training.

Cover photo by Wes Skiles.

FEATURES

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DEPARTMENTS

DeepTech's "In My Opinion" column is written each issue by a guest writer. The opinions of these authors do not necessarily reflect those of the staff of DeepTech Journal.

PUBLISHERS PAGE

This being our third issue we thought we would stop and take stock of where DeepTech Journal might be headed. Each month we get a good many comments, both verbal and written, that say we're doing a good job and that we should keep up the good work. We also receive comments that say we're not addressing the needs of technical divers and that we should head in a direction other than the one we are apparently heading in. These comments are, for the most part, constructive in nature, except for the one written by Johnny Richards in black crayon on top of the article about Jim Bowden in our last issue. We printed it in our letters column (page 4) so you can all see how well lawyers write. After all we did promise to not sugar-coat-it as some magazines do. We print the good with the bad. When boiled down to their essence the constructive criticisms seem to be saying one of two things, either we are too technical, or we are not technical enough.

Those that think we are too technical say that we should write about stuff that everyone can understand. This group will definitely not like Dr. Weinke's article on the reduced gradient bubble model (page 29). These people tend to be new to technical diving, or they're advanced recreational divers looking to get into techdiving. This is an important group and we want very much to meet their need for a technical journal that they can understand. After all, even Sheck Exley and Jim Bowden were new to techdiving at one point. New techdivers help to give momentum to the sport of techdiving. The more techdivers there are, the more manufacturers will focus on developing tools for exploration, like deep scooters, lights, instruments, better manifolds, etc. Training agencies like IANTD and TDI will continue to flourish, teaching safe diving to extended range divers. This is a group that should be included in the future direction of DeepTech Journal.

The people who think that DeepTech is not technical enough say that we should write about decompression theory, hogarthian gear configurations, and dive physiology topics like PFO and micro circulatory damage. This group will definitely like Dr. Weinke's article. These people are the movers and shakers in the sport of techdiving. These people lay new line in virgin caves, they research geomorphological phenomena, they locate and dive virgin wrecks. These people are the ones responsible for the current state of techdiving. Obviously this group should be included in DeepTech's plans for a future direction. Without them as both readers and contributors there would be no DeepTech Journal.

Not unlike the beer that strives to be both less filling and taste great we seem to be presented with diametrically opposed goals. If we succeed we can make a TV commercial with two groups of satisfied readers alternately shouting "Easy-to-Read " and "Technical-Articles."

Our philosophy has always been that if you don't get mail, you haven't done it right. We will probably continue to aim for mainstream techdivers by making our editorial content both more technical and easy to read.

One thing we want to acknowledge is our appreciation for our advertisers. These companies and organizations took a risk by placing an ad in a new magazine. This gamble, as it turns out, is paying off handsomely. Our circulation is 3,000 and we continue to add subscribers at the rate of 80-100 per month. Industry leaders have all expressed their support for DeepTech and many have written articles for us or are planning to write them over the coming months. We ask that you support our advertisers by taking your business to them. Or if you already do business with them let them know that you saw their ad in DeepTech.

The last thing we ask is that you continue to communicate with us. We commit to being responsive to reader feedback. DeepTech is a magazine written by divers for divers. We must know what you want and think if we are to direct our efforts in the right direction.

Curt Bowen
Co-Publisher

Win Remley
Co-Publisher

Cave Geomorphology

This weekend, Dave Young, Mike Wisenbaker and I made contact with the property owner of a sink hole that we're interested in exploring. To help explain our motives for diving the sink, we supplied the owner with a copy of the cave geomorphology article from DeepTech Issue 2. After reviewing the materials the owner enthusiastically agreed to let us dive. He appeared genuinely interested in learning how his sink hole fits into the big picture. This particular location, South of Crawfordville, is tidally influenced and is big enough to have an interesting cave. Thanks for the help that you didn't know you were providing. If we find something good, we'll let you know.

Christopher Brown
via the Internet
chbrown@freenet.fsu.edu

Women Tech Divers

Thought you might like to know that Tracy Weekley has just been certified as Australia's first female trimix diver. Her last checkout dive was at 78 metres and fulfilled the requirements of both her ANDI and TDI trimix courses. Her buddy on the dive was Grahame "Big Kahuna" Elliott, who was completing his TDI Trimix course. Tracy is one of the few women who have begun to explore beyond recreational depths. Unfortunately there is still a lot of sexism in Australia. "It's like a cone of silence descends on you when they find out you're a girl!" Tracy said. Tracy is also a PADI Divemaster and the first woman in Australia to receive the PADI Ice Diver certification.

Pat Bowring
Summer Hill, NSW

In the Women Tech Divers article you mentioned that Barb Lander has dived the U-550. This is an error. Nobody has dived the U-550 yet. Barb has been on both of John Chatterton's search attempts to look for the U-550, but so far only the Pan Pennsylvania, the tanker sunk by the U-550 just before the U-550 was sunk itself, has been located and dived. I was on the Andria Doria dive and the Norness dive with Barb and she filled me in on the details.

John Heimann
via the Internet
john.heimann@telops.gte.com

Jim Bowden's Record

With relief...The sidebar about Sheck Exley titled "With Respect" in the article on Jim Bowden's record dive tackled what I have grappled with in my own thoughts. I wondered when the cave diving community would acknowledge Bowden's achievement. Your handling of the issue was respectful and dignified. Congratulations to you Jim Bowden!

Steve Porter
St. Paul, Minnesota

Cancel my subscription to this self-congratulatory piece of shit. Are there tech divers other than contributing editors? I thought Bowden was Mr. Exley's safety diver. Matter of perspective? I won't waste my time with future issues.

Johnny Richards, P.C.
N. Richland Hills, Texas

[For the record, Bowden and Exley conducted separate explorations into Zacaton simultaneously. Their dives occurred on opposite sides of the sink which is over 300 feet in diameter. At no time during the dive could they see each other.-WR]

The Monitor

Whenever I can, I vacation in the Carolina's to dive the plethora of wrecks that dot the coast there. The Monitor has long since been a dream dive of mine. Your article gives the best description of the history of this ship that I've seen. I especially liked your Clancy style description of the battles. How about doing a piece on the incredible wrecks we have up here in the Union North.

Frank Deutchman
New York, New York

[If you liked our article you should check out Gary Gentile's book Iron Clad Legacy.-WR]

Part of what makes wreck diving so interesting is knowing the history behind the wreck. Your article on the Monitor was exceptional in every way. It gave me a real thirst to dive this piece of history.

Alan Johnson
Wilmington, North Carolina

Nice Job

As a professional writer and ex-magazine editor, I know that starting a magazine from scratch makes organizing an expedition to dive the Gunilda or Eagles Nest look like a stroll in the park, but you seem to have pulled it off. The articles on Bowden, the Monitor and karst geomorphology are useful references. Although, trying to run Bowden's record deep dive profile on my computer almost broke the motherboard. My only criticism is your choice of typeface for the body copy. Serif faces are much more legible. All the best for that critical first year.

Steve Lewis
via the Internet
diver@muskoka.net

I just received my first issue of DeepTech (issue 2) and I can only say one thing...awesome! Finally a magazine that has some useful information and not just a bunch of ads. Keep up the good work.

Ron Nad
via the Internet
wuhx73a@prodigy.com

Correction

In your glossary you state that 1 centimeter is equal to .155 inches. This is an error. 1 cm.=.3937 in.

Dan Fountain
via the Internet
dfountain@aol.com

[Thanks for the sharp eye Dan!-WR]

Letters to the Editor

We don't sugar-coat-it. If you send it, we'll print it. Send letters to:

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or e-mail to: deeptek@aol.com

Diving News, Exploration Updates, and Discoveries.

A dozen Atlantis I rebreathers were used in the first Drager and Uwatec Rebreather Instructor ITC in held in Nassau during the month of July.

Drager and Uwatec Host First Ever Rebreather ITC

Drager and Uwatec recently hosted their first western hemisphere Instructor Training Course (ITC) for the Atlantis I rebreather. The seven day intensive course was held July 9-14 at Stuart Cove's Dive South Ocean Resort in Nassau. Twenty dive professionals from the U.S., Australia, England, Egypt, Germany, and the Pacific Rim were invited to participate in the course. This select group shall become the nucleus for international Instructor Trainers.

The training curriculum was developed for Drager by Technical Diving International (TDI). Rob Palmer, internationally respected cave explorer and Director of TDI Europe, headed the staff which included: Christian Schult, Drager marketing manager; Sean Griffin, CEO Uwatec USA; and Bret Gilliam, President TDI. A comprehensive teaching manual in both metric and U.S. units plus an accompanying slide series is available for future students.

A dozen Atlantis I units were used during the week with few difficulties. This marked the largest ever gathering of functional commercial rebreathers in one location. Unlike other rebreathers that have been offered in limited editions, Drager intends to release two hundred Atlantis I units to the U.S. market in October 1995. These units will be distributed through a joint marketing venture with Uwatec who is supplying the nitrox dive computers that go with the Atlantis I rebreathers.

The Drager Atlantis I is a semi-closed circuit rebreather that uses a variable nitrox mixture of 60%, 50%, 40%, or 32%. The Atlantis I is compact and adjusts to fit different body sizes from smaller women to larger framed men. Weight of the unit is approximately 30 pounds and provides up to two hours of life support from a single 20 cubic foot cylinder. The small size and light weight make the Atlantis I easy to swim with and remarkably comfortable over extended use.

Maintenance is fairly simple requiring less than 20 minutes to service at the end of the diving day. The Atlantis I can be used to a depth of 150 fsw, and is ideal for extended dives in the 50-100 foot range where divers can optimize no decompression profiles with extraordinary bottom times.

For information regarding rebreather training and certification or instructor training courses on the Atlantis I contact TDI at 207-442-8391.

NACD Annual Workshop

NATIONAL ASSOCIATION FOR CAVE DIVING NACD

The National Association for Cave Divers (NACD) will host their annual cave divers workshop on November 10-12, 1995 at the Holiday Inn West in Gainsville, Florida. The program begins Friday the 10th at 8pm with a social gathering, followed by registration at 7:30 am on Saturday the

11th. Special guest speakers, presentations, and mini-workshops on several cave diving related topics will be presented. Cost for the workshop is $25 for members and $30 nonmembers. Send registration to NACD Committee, P.O. Box 14492, Gainesville, FL. 32604. For more information contact Lloyd Bailey at 904-332-0738. Drop by DeepTech's booth and say hello.

Tek96

The annual aquaCorps tek trade show will be held January 12-16, 1996 in New Orleans, just prior to the DEMA show. DeepTech Journal will be among the exhibitors at this years tek, so stop by and say hello. For more information regarding the show call 800-365-2655.

ADEC'96

The annual Asian Diver Exhibition and Conference (ADEC) will be held May 17-19, 1996 at the World Trade Centre in Singapore. For more information on ADEC'96 write to ADEC, 100 Beach Road, #26-00 Shaw Towers, Singapore 0718, or call +65-294-3366.

Doppler Diving Workshop

August 8, 1995 Dive USA announced a series of Doppler Diving workshops to be conducted at their Singer Island School. The first two workshops will be held November 4th and 5th at a cost of $150 per person. The workshop leader, Michael Emmerman, is a leading researcher in the field of hyperbaric and hypobaric environments and has published studies for the American Academy of Underwater Sciences, The Undersea and Hyperbaric Medical Society, and the Aerospace Medicine Association. The workshops consist of a morning academic session followed by two open water dives with doppler testing and analysis. Space is limited, early registration is recommended. For more information contact Dive USA at 800-348-3871.

Uwatec Beefs Up Marketing Team

On October 5, 1995 Uwatec announced a strategic alliance with Bret Gilliam, of TDI, and Mitch Skaggs, formerly of H2O Scuba. Gilliam and Skaggs will be assisting Uwatec in selling their products to North American markets. Gilliam will assist Uwatec in the Northeast USA, and Skaggs will focus on the Florida market. The announcement comes on the heels of the recent release of the Uwatec/Drager Atlantis I rebreather as a commercial product.

Regarding the announcement Gilliam said, "It's a natural alliance for me with Uwatec. I've used their instruments and computers exclusively as my personal gear since 1989. I have the highest regard for the quality and reliability of Uwatec gear, and that has been reflected in my own exploration projects and those of most technical divers. I've endorsed their products for years in my books and articles and it's very exciting for me to be representing the line officially now."

Skaggs underscored the announcement by saying, "I have always been impressed with Uwatec's products as well as their commitment to looking toward the future of diving and not just following other manufacturers."

WKPP Extends Wakulla 1,820 feet

Woodville Karst Plains Project (WKPP) divers have extended the Wakulla B tunnel with an additional 1,820 feet of surveyed passage at a depth of 300 feet. The team of divers currently working the Wakulla spring include George Irvine, the project director, Bill Main, Jarrod Jablonski, Casey McKinlay, Derek Hagler, Alex Hagler, Barry Miller, Steve Irving, Rick Sankey, Brent Scarabin, and Robbie McGuirre who has since died in a diving accident independent from WKPP activities.

Several set up dives were required by team members to strategically place deco gas and safety bottles at several locations throughout the cave. With preparations made and the safety divers in the water the push team consisting of Irvine, Jablonski and McKinley set out with McKinley taking the lead initially. The divers began on air which was planned for use in the event of any initial delay. The air was dropped quickly 3 minutes into the dive when

(continued next page)

DeepTech Glossary

ANDI
American Nitrox Divers, Inc.

ATA
Atmospheres Absolute

atm
Atmosphere

Bottom Mix
A breathing mixture used at the deepest portion of a dive

CO_2
Carbon Dioxide

CNS
Central Nervous System

DAN
Divers Alert Network

DCS
Decompression Sickness

EAN
Enriched Air Nitrox

EPA
Environmental Protection Agency

FFW
Feet of fresh water

FSW
Feet of sea water

ft/min
Feet per minute

HE
Helium

Heliair
A mixed gas created by blending helium and air

Heliox
A mixed gas containing helium and oxygen

HPNS
High Pressure Nervous Syndrome

IANTD
International Association of Nitrox and Technical Divers

ITC
Instructor Training Course

NACD
National Association for Cave Divers

NAUI
National Association of Underwater Instructors

Nitrox
Any mixture of nitrogen and oxygen above 20.9% O_2

NOAA
National Oceanic and Atmospheric Administration

NSS-CDS
National Speleological Society-Cave Diving Section

O_2
Oxygen

PADI
Professional Association of Diving Instructors

ppN_2
Partial Pressure of Nitrogen

ppO_2
Partial Pressure of Oxygen

PSA
Professional Scuba Association

psi
Pounds per square inch

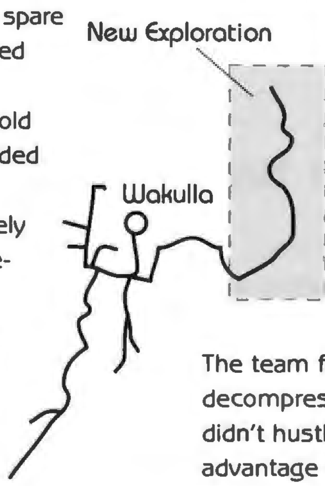
TDI
Technical Diving International

Trimix
Any mixture of oxygen, nitrogen, and helium

Unit Conversions

1 psi	= 2.31 ffw
	= 2.25 fsw
	= 0.068 ata
1 atm	= 14.696 psi
	= 33.9 ffw
	= 33 fsw
1 fsw	= 0.445 psi
1 ffw	= 0.434 psi
1 kg/cm^2	= 1000 gm/cm^2
	= 10 m of fresh water
	= 9.75 m of sea water
	= 14.22 psi
	= 32.8 ffw
	= 28.96 in of mercury
1 cm	= 0.394 inches
1 meter	= 39.37 inches
	= 3.28 feet
1 foot	= 0.305 meters
1 liter	= 33.81 fluid ounces

the team switched to trimix (13.5% O_2/50% He/36.5% N_2). The first stage drop occurred on schedule 1,700 feet in at a depth of 300 feet. The second stage drop also occurred as planned at the 360 foot pit about 2,500 feet into the cave. The third and last stage drop was made at the old end of the line 4,200 feet in at a depth of 300 feet. The spare scooter was also dropped here. McKinley quickly secured his reel to the old end of the line and headed down virgin tunnel. Jablonski followed closely assisting with line placements and Irvine took survey measurements and kept the books. About 900 feet later McKinley's reel ran out but Jablonski had his ready. Jablonski quickly secured his reel to McKinley's line and continued the push with less than 10 seconds delay. Irvine later remarked, "You should have seen those two. It looked like a relay race where one runner hands the baton to another. They didn't miss a beat!" With Jablonski now in the lead, McKinley followed, assisting with line placements. When Jablonski's reel ran out of line they tied it off 6,020 feet into Wakulla. They had pushed more than a mile at a depth of 300 feet.



The team faced a horrendous decompression schedule if they didn't hustle out so they took advantage of the flow and ran mid tunnel picking up stages along the way. They made it to the first deco stop at 190 feet in 30 minutes, an average of 200 feet per minute. Decompression was accomplished on air from 190-120 feet, EANx35 from 120-70 feet, EANx50 from 70-20 feet, and oxygen from 20 ft-surface. The custom decompression profile was calculated by Hamilton Research for an 85 minute dive at 300 feet. Total decompression was 360 minutes. Safety divers rotated with the push team monitoring for symptoms of DCS and oxygen toxicity. Full face masks were used at the shallower stops. George Irvine credits the entire team with the accomplishment, saying the dive could not have happened without many hours of planning and flawless execution.

The YSI-6000

Bleeding-Edge Technology for Research Divers

by Win Remley

Many technical divers have become involved in various aspects of water quality research. Pollution, storm water runoff, and water table problems are but a few of the reasons divers may be called upon to explore and analyze the water in underground systems. The Environmental Protection Agency (EPA), the Department of Environmental Protection (DEP), and state government organizations regularly establish and sponsor research into aquifer systems.

YSI, based out of Yellow Springs, Ohio, has just begun shipping the YSI-6000 Environmental Monitoring System. The YSI-6000 is about the same size as a typical cave light battery housing (3.5 in. diameter by 19.5 in. long) and can be deployed for water monitoring and data collection for several months at a time taking measurements at regular intervals.

The YSI-6000 is the most comprehensive data collection tool of its type. It has the ability to take 14 separate measurements and includes sensors for dissolved oxygen, conductivity, specific conductance, resistivity, temperature, pH, depth, ORP, turbidity, ammonia, and nitrate. It is fully programmable via a PC and can take up to eight measurements simultaneously. A fresh set of batteries (8 alkaline C-cells) will last four months taking a set of measurements every 15 minutes.

After retrieving the YSI-6000 it can be connected to a PC via an RS-232 interface to download collected measurement data. The data is stored in nonvolatile flash memory so that collected data will be preserved in the event of power failure or dead batteries. The unit's intelligence comes from EPROMS that can be updated with software from the manufacturer on disk. Calibration can be accomplished in the field while exposed to air making it easy to setup and use.

The YSI-6000 is easily configured for cave diving. It can withstand depths of 500 ft. and temperatures from -5° to 45° C.

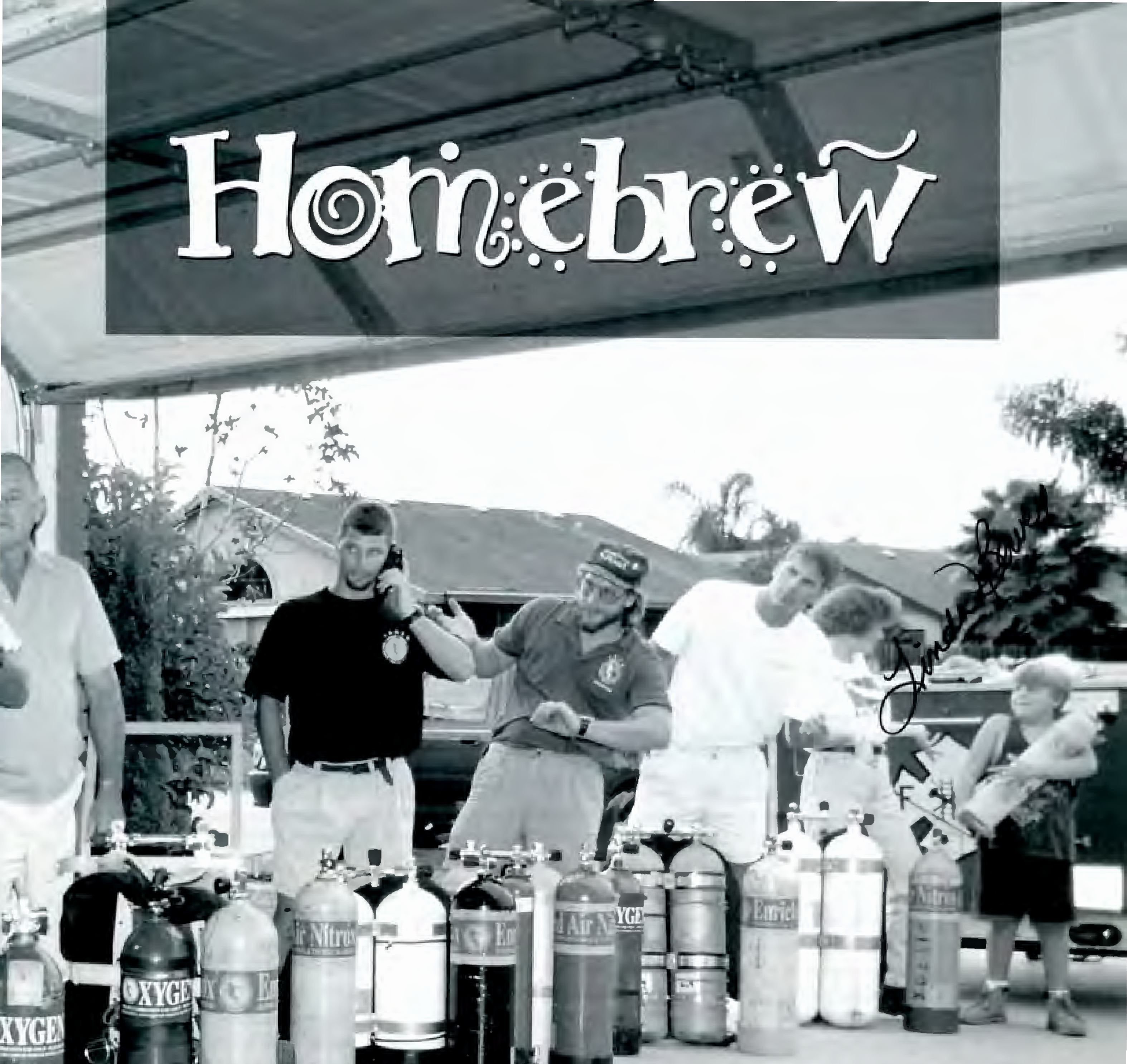
The YSI-6000 appears to be well engineered with tight fitting pressure seals. It is rated for a maximum depth of 500 feet and a temperature range of -5° to 45° C. The unit is fairly lightweight at 6.5 lbs. and can easily be attached to a diver via clips and D-rings.

The list of capabilities and features of the YSI-6000 are seemingly endless including the capability to be connected by wire to a transmitter at the surface, so that measurement data can be broadcast to a central location via satellite telemetry. In this way several YSI-6000s could be deployed at different locations throughout a water system with real-time data being simultaneously collected from each one.

Anyone desiring more information on the YSI-6000 or its applicability to a specific project is invited to call YSI at 800-765-4974.

This article is presented for informational purposes only. DeepTech Journal does not recommend gas mixing by anyone not specifically trained for this activity.

Homebrew



by Curt Bowen and Win Remley

Joe Techdiver pushes the button on his automatic garage door opener. The door slowly rises revealing a cadre of friends eagerly awaiting gas fills for the days diving activities. Joe has built his own mixing station in his garage using equipment similar to that he examined in the local dive shop. Joe is an experienced diver and his buddies trust him to give them what they want—nitrox and trimix for deep dives. What Joe and his buddies may or may not know, is that this practice can be fatal unless strict safety rules are learned and rigorously followed.

For the buddies it means they get gas fills at reduced prices, if indeed they pay at all. Plus, they don't necessarily need the proper training, certification, and experience to use the gas they are mixing. If Joe thinks they can "handle it" then he will probably give it to them. For Joe it means significantly reduced prices on mixed gas fills. Plus he becomes very popular on Saturday mornings. The problem is that if

(continued next page)

Partial pressure filling is accomplished by partially filling a scuba cylinder with one or more gases by connecting it to larger cylinders via a fill whip and opening the valves of both cylinders. The gas flows from the cylinder with the greatest pressure, the supply cylinder, to the cylinder being filled, the scuba cylinder.

something goes wrong divers can die and Joe may lose his garage as well as the rest of his house in an expensive liability lawsuit. Make no mistake about it, mixing gas at home in your garage is dangerous for two reasons. The first is the risk of fire and explosion from high pressure oxygen. The second is incorrectly blended gas which may lead to breathing a mixture at an inappropriate depth for its contents.

Gas mixing is better left to those who have the right equipment, the necessary training, and the experience to blend and analyze gas correctly. The technical dive shops in your area are the best place to buy gas—without exception.

Nevertheless, many divers do mix gas at home. From the discussions DeepTech has had with some of these homebrewers there is some misinformation out there regarding gas blending. This article is written to, hopefully, increase knowledge about gas mixing and promote safer blending practices among divers who mix at home.

The practice of homebrew began with the early technical divers who wanted to explore beyond the limits of nitrogen narcosis and oxygen toxicity. They discovered that custom blended fills using combinations of oxygen, nitrogen and helium provided distinct physiological advantages at certain depths. At that time it was not possible to buy mixed gas fills in dive shops so there was no alternative except to devise ways to brew your own mix at home. These homebrewers typically used a process that is now called partial pressure filling.

Partial Pressure Filling

Partial pressure filling usually begins with a completely drained, or empty, scuba cylinder. The scuba cylinder is partially filled with one or more gases by connecting it to larger supply cylinders via a fill whip and opening the valves of both cylinders. The gas flows from the cylinder with the greatest pressure, the supply cylinder, to the cylinder being filled, the scuba cylinder. The

The Fire Triangle
Oxygen is a colorless, odorless, and tasteless gas. Higher concentrations of oxygen greatly accelerate the burning process, sometimes to the point of being explosive. Fire science gave us the fire triangle which graphically shows the three elements required for a fire to exist, heat, oxygen, and fuel. A fire (or explosion) cannot ignite without all three components being present.

Partial pressure filling with oxygen introduces the high concentrations of oxygen required for a fire. Oil deposits or hydrocarbon based lubricants in the cylinder and valves provide the fuel. And compressing the gas (filling the scuba cylinder) provides the heat (Charles Law).

The reason for oxygen cleaning all components (removing all hydrocarbon based materials) in a partial pressure fill station is to remove the fuel side of the fire triangle thereby minimizing the possibility of fire or explosion.

scuba cylinder is then topped off with air using a compressor to complete the fill. This "topping off" with air is typically done at the local scuba shop although some homebrewers have acquired their own air compressor as well. The exact amount of gas to use at each step in the fill process is calculated in advance using the principals of Henry's law of partial pressures.

Mixing gas in your garage (homebrew) is discouraged by virtually all of the training agencies and equipment manufacturers for two reasons:

- Anytime high pressure oxygen is used in a mixing process there exists the possibility for explosion and fire (see fire triangle sidebar). Strict safety standards for minimizing this possibility have been set by many organizations including TDI, IANTD, Luxfer, Catalina, and several government organizations, among others.

- Correct mixing and analyzing of the completed gas mixture is essential since breathing a constituent gas at a physiologically inappropriate partial pressure can cause, hypoxia, oxygen toxicity, blackouts, convulsions and other physiological unpleasantness. Again, strict safety standards have been established by relevant organizations regarding mixing and analyzing procedures to ensure accurate gas blending.

There are four main components to a partial pressure fill station: the supply cylinder, the fill whip, the scuba cylinder, and the oxygen analyzer. Supply cylinders are typically large, 300 cu. ft. cylinders that stand about 4-1/2 feet tall. They are typically constructed of steel and are pressurized to around 2250 psi. The fill whips are usually 3-5 feet long with high pressure connectors at each end plus an in-line valve and pressure gauge. The scuba cylinders vary widely in size and service pressure ratings.

Supply Cylinders
Although some divers are experimenting with other gases, most homebrewers buy only oxygen and helium supply cylinders for the purpose of mixing nitrox, heliair, and

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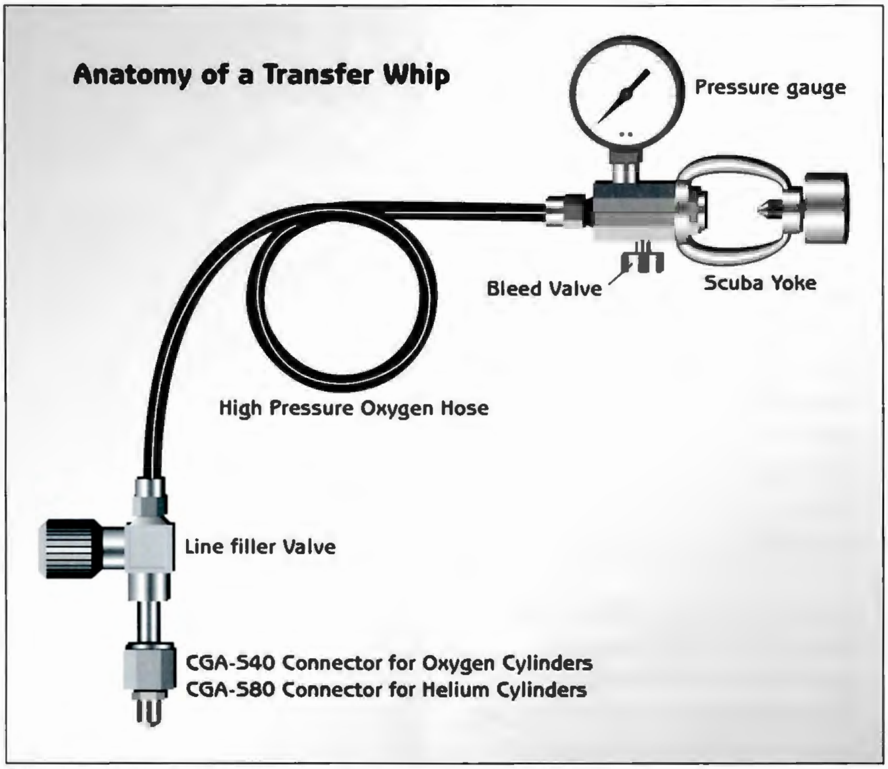


Fill whips can either be purchased whole and ready for use or separately as components and assembled by the user. All whip components must be free of hydrocarbons and rated for use at the maximum service pressure planned.

trimix. Homebrewers should be aware, however, that the exact makeup of these supply gases vary depending upon the supplier and grade that is purchased. Helium supply cylinders may contain small amounts of oxygen and nitrogen if a vacuum wasn't applied to the cylinder prior to filling. Likewise, oxygen supply cylinders may contain small amounts of nitrogen. Suppliers can usually tell you what percentage of trace elements their gas contains.

Helium and oxygen supply cylinders can be rented or purchased from local welding and medical supply facilities. A medical prescription may be required to purchase medical grade oxygen depending on state laws. Most suppliers offer three grades of oxygen: industrial, aviation, and medical. The difference between these grades is only in the procedures used for filling.

Medical and aviation grade oxygen cylinders are first completely drained, then a vacuum is applied to the cylinder to remove all gases. The cylinder is then filled to its working pressure with oxygen. One cylinder from each lot of medical and aviation grade cylinders is analyzed for purity. The rest of the lot is assumed to be the same as the analyzed cylinder since they are filled simultaneously from the same source. The only difference between medical and aviation grade oxygen seems to be the price. For those who can't obtain a prescription for medical grade oxygen, the exact same cylinder can be purchased as aviation grade for roughly twice the price.

Industrial grade cylinders do not have a vacuum applied prior to filling nor are they analyzed by the supplier. At best, industrial grade cylinders have a trace amount of nitrogen from the air that was in the cylinder prior to filling. At worse, there may be small amounts of other gases, for example, acetylene from an improperly configured welding system. Acetylene welding systems operate by blending oxygen and acetylene in a nozzle that is then ignited with a spark. The hoses leading to the nozzle have check valves (special one-way valves) that prevent one gas from backflowing into the other cylinder. The reality is that when these valves fail in the field welders simply bypass the check valve by removing it from the hose. Under these circumstances there is a small chance that acetylene could backflow into the oxygen cylinder. Since industrial grade cylinders are not evacuated prior to filling there may be trace elements of acetylene in the O2 supply cylinder. Granted, this possibility is remote, but possible nevertheless. We were not able to locate any information regarding what partial pressure of acetylene is considered harmful to humans.

Transfer Whip

A transfer, or fill whip is required to transfer oxygen or helium from the supply cylinder to the scuba cylinder. All components of the whip must be designed for high pressure service and be compatible with high pressure oxygen. All components must be properly cleaned and totally free of hydrocarbons (petroleum based materials like grease, oil, and rubber), including the lubricants and o-rings.

A fill whip can be either be purchased whole and ready for use, or the components can be purchased separately, properly prepared, and assembled by the homebrewer. All components must be rated for use at the maximum pressure they will be used at. Fill whip components are typically constructed of copper or brass. The following is a list of whip components:

Connectors—An industry standard CGA-540 style connector is required for connection to an oxygen supply cylinder, while a CGA-580 style connector is required for connection to helium supply cylinders. A CGA-540 to CGA-580 adaptor can also be purchased to convert an oxygen whip to fit a helium cylinder.

Line Filler Valve—A Line filler Valve is used to control the rate of filling. When filling oxygen the rate should not exceed 300 psi per minute to prevent excessive heat build up in the scuba cylinder. A good technique is to gently open the fill valve until you can barely hear the gas filling. Filling the scuba cylinder in cool water also helps to dissipate heat.

High Pressure Hose—High pressure teflon oxygen hoses should be used to fill oxygen. A 3-5 foot length is sufficient. These hoses are constructed of a teflon inner hose with an outer reinforced jacket of stainless steel braid.

Pressure Gauge—Pressure gauges come in many sizes, styles, and pressure ratings. Analog gauges are more difficult to read than digital gauges, but digital gauges are more expensive. Gauges with less than 2% error over the full range of measurement are best. Some homebrewers use a digital, air integrated dive computer as their pressure gauge. These units work well but all components must be free of hydrocarbons before use with oxygen.

Scuba Yoke—Scuba yoke and din fittings are standard per the scuba industry. Like all other whip components they must be free of hydrocarbons and rated for high pressure use.

Check Valve (optional)—A check Valve can optionally be used to prevent backflow of gas into the supply cylinders in the event the scuba cylinder contains more pressure than the supply cylinder.

Quick Disconnects (optional)—Quick Disconnects are quick release fittings that enable the whip to be quickly connected and disconnected.

Flow Restrictor (optional)—Flow Restrictors prevent the fill rate from exceeding a set value thereby preventing excessive heat buildup due to gas transfer.

Scuba Cylinders

Scuba Cylinders must also be free of hydrocarbons if high pressure oxygen is to be introduced into the cylinder. New scuba cylinders do not come from the manufacturer oxygen clean (free of hydrocarbons). They must be cleaned of petroleum based grease and oil deposits, and the rubber o-rings must be removed and replaced with Viton o-rings. Care should be exercised to not top off oxygen clean scuba cylinders at air fill stations (compressors) that have not also been oxygen cleaned. A non-oxygen cleaned compressor can introduce small amounts of oil into the scuba cylinder thereby contaminating it and requiring oxygen cleaning again.

Oxygen Cleaning

All components of a partial pressure fill station must be cleaned of hydrocarbons to minimize the risk of fire and explosion. The basic process of O2 cleaning is fairly simple (see side-bar). The equipment is first disassembled. All petroleum based components are removed and discarded. The remaining compo-

(continued page 19)

Oxygen Cleaning Scuba Cylinders

1) Remove valve;
2) Inspect cylinder for contaminates and cracks in accordance with standard inspection procedures;
3) If large amounts of oils or rust are found, tumble the cylinder;
4) Hydrostatic test the cylinder if tumbling is required;
5) Clean cylinder threads with chemical and a tooth brush;
6) Mix one gallon of SD-113 or TSP according to directions. Pour into cylinder and replace valve. Roll cylinder back and forth for 3-4 minutes;
7) Remove valve, empty contents into a bucket and reinspect cylinder. Repeat step 6 if needed;
8) Rinse thoroughly with clean water until no foaming can be detected;
9) Turn cylinder upside down and blow dry;
10) When cylinder is fully dry, follow the valve cleaning instructions and replace.

Oxygen Cleaning Cylinder Valves and Whip Components

1) Disassemble valve or whip component;
2) Manually remove all visible corrosion and grease;
3) Soak all parts in SD-113 or TSP and scrub with tooth brush if needed;
4) Rinse all parts in clean water and reinspect;
5) Blow dry or let air dry;
6) Replace all O-rings with Viton O-rings;
7) Reassemble and grease threads and O-rings with non-petroleum based grease;

Nitrox PPO2 and EADs

Percent Oxygen

Depth		25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	50%	60%	70%	80%	90%
30	Po2	0.48	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.74	0.76	0.95	1.15	1.34	1.53	1.72
	EAD	27	26	25	24	24	23	22	21	20	20	19	18	17	16	16	15	7	0	0	0	0
40	Po2	0.55	0.58	0.60	0.62	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88	1.11	1.33	1.55	1.77	1.99
	EAD	36	35	34	34	33	32	31	30	29	28	27	26	25	24	23	22	13	4	0	-0	0
50	Po2	0.63	0.65	0.68	0.70	0.73	0.75	0.78	0.80	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.01	1.26	1.51	1.76	2.01	
	EAD	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	20	9	0	0	
60	Po2	0.70	0.73	0.76	0.79	0.82	0.85	0.87	0.90	0.93	0.96	0.99	1.01	1.04	1.07	1.10	1.13	1.41	1.69	1.97		
	EAD	55	54	53	52	51	49	48	47	46	45	44	42	41	40	39	38	26	14	2		
70	Po2	0.78	0.81	0.84	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.19	1.22	1.25	1.56	1.87			
	EAD	65	63	62	61	60	58	57	56	54	53	52	50	49	48	47	45	32	19			
80	Po2	0.86	0.89	0.92	0.96	0.99	1.03	1.06	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.37	1.71	2.05			
	EAD	74	73	71	70	69	67	66	64	63	61	60	59	57	56	54	53	39	24			
90	Po2	0.93	0.97	1.01	1.04	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.42	1.45	1.49	1.86				
	EAD	84	82	81	79	78	76	74	73	71	70	68	67	65	64	62	60	45				
100	Po2	1.01	1.05	1.09	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.45	1.49	1.53	1.57	1.61	2.02				
	EAD	93	92	90	88	87	85	83	81	80	78	76	75	73	71	70	68	51				
110	Po2	1.08	1.13	1.17	1.21	1.26	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60	1.65	1.69	1.73					
	EAD	103	101	99	97	96	94	92	90	88	86	85	83	81	79	77	76					
120	Po2	1.16	1.21	1.25	1.30	1.34	1.39	1.44	1.48	1.53	1.58	1.62	1.67	1.72	1.76	1.81	1.85					
	EAD	112	110	108	106	105	103	101	99	97	95	93	91	89	87	85	83					
130	Po2	1.23	1.28	1.33	1.38	1.43	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93	1.98					
	EAD	122	120	118	116	113	111	109	107	105	103	101	99	97	95	93	91					
140	Po2	1.31	1.36	1.42	1.47	1.52	1.57	1.63	1.68	1.73	1.78	1.83	1.89	1.94	1.99	2.04						
	EAD	131	129	127	125	122	120	118	116	114	112	109	107	105	103	101						

Chart 1—The above chart gives the Equivalent Air Depth (EAD) in feet sea water, and partial pressure of oxygen (ppO2) in atmospheres absolute for various nitrox mixtures at depth. To use the chart find the desired maximum depth (fsw) in the left column, follow the column to the right until the desired ppO2 or EAD is located. Follow that column upwards to the top row to find the percentage of oxygen required to give the desired results. Note that the dark colored squares indicate partial pressures of oxygen greater than 1.6 ATA and that these percentages should be avoided due to the increased risk of oxygen toxicity.

Oxygen Fill Pressures for Nitrox

Percent Oxygen

Desired Fill Pressure	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	50%	60%	70%	80%	90%
2200	84	111	139	167	195	223	251	278	306	334	362	390	418	446	473	501	529	808	1086	1365	1643	1922
2300	87	116	146	175	204	233	262	291	320	349	378	408	437	466	495	524	553	844	1135	1427	1718	2009
2400	91	122	152	182	213	243	273	304	334	365	395	425	456	486	516	547	577	881	1185	1489	1792	2096
2500	95	127	158	190	222	253	285	316	348	380	411	443	475	506	538	570	601	918	1234	1551	1867	2184
2600	99	132	165	197	230	263	296	329	362	395	428	461	494	527	559	592	625	954	1284	1613	1942	2271
2700	103	137	171	205	239	273	308	342	376	410	444	478	513	547	581	615	649	991	1333	1675	2016	2358
2800	106	142	177	213	248	284	319	354	390	425	461	496	532	567	603	638	673	1028	1382	1737	2091	2446
2900	110	147	184	220	257	294	330	367	404	441	477	514	551	587	624	661	697	1065	1432	1799	2166	2533
3000	114	152	190	228	266	304	342	380	418	456	494	532	570	608	646	684	722	1101	1481	1861	2241	2620
3100	118	157	196	235	275	314	353	392	432	471	510	549	589	628	667	706	746	1138	1530	1923	2315	2708
3200	122	162	203	243	284	324	365	405	446	486	527	567	608	648	689	729	770	1175	1580	1985	2390	2795
3300	125	167	209	251	292	334	376	418	459	501	543	585	627	668	710	752	794	1211	1629	2047	2465	2882
3400	129	172	215	258	301	344	387	430	473	516	559	603	646	689	732	775	818	1248	1678	2109	2539	2970
3500	133	177	222	266	310	354	399	443	487	532	576	620	665	709	753	797	842	1285	1728	2171	2614	3057
3600	137	182	228	273	319	365	410	456	501	547	592	638	684	729	775	820	866	1322	1777	2233	2689	3144
3700	141	187	234	281	328	375	422	468	515	562	609	656	703	749	796	843	890	1358	1827	2295	2763	3232
3800	144	192	241	289	337	385	433	481	529	577	625	673	722	770	818	866	914	1395	1876	2357	2838	3319
3900	148	197	247	296	346	395	444	494	543	592	642	691	741	790	839	889	938	1432	1925	2419	2913	3406
4000	152	203	253	304	354	405	456	506	557	608	658	709	759	810	861	911	962	1468	1975	2481	2987	3494

Chart 2—The above chart provides the amount of oxygen to add (in psi) to an empty scuba cylinder to create the various nitrox mixtures. To use the chart find intersection of the row containing the desired ending cylinder pressure (at left), and the column containing the desired percentage of oxygen (at top).

Heliair PPO2 and ENDs

Depth	Heliair Mix (O2%/He%)	18/14	17/19	16/24	15/28	14/33	13/38	12/43	11/49	10/52	9/57	8/62	7/67	6/72
160	PO2	1.05	0.99	0.94	0.88	0.82	0.76	0.70	0.64	0.58	0.53	0.47	0.41	0.35
	END	133	123	114	106	96	87	77	65	60	50	40	31	21
180	PO2	1.16	1.10	1.03	0.97	0.90	0.84	0.77	0.71	0.65	0.58	0.52	0.45	0.39
	END	150	140	129	121	110	99	88	75	69	59	48	37	26
200	PO2	1.27	1.20	1.13	1.06	0.99	0.92	0.85	0.78	0.71	0.64	0.56	0.49	0.42
	END	168	156	144	135	123	112	100	85	79	67	55	44	32
220	PO2	1.38	1.30	1.23	1.15	1.07	1.00	0.92	0.84	0.77	0.69	0.61	0.54	0.46
	END	185	172	159	150	137	124	111	95	89	76	63	50	37
240	PO2	1.49	1.41	1.32	1.24	1.16	1.08	0.99	0.91	0.83	0.74	0.66	0.58	0.50
	END	202	188	174	164	150	136	123	105	98	84	71	57	43
260	PO2	1.60	1.51	1.42	1.33	1.24	1.15	1.07	0.98	0.89	0.80	0.71	0.62	0.53
	END	219	204	190	178	164	149	134	115	108	93	78	63	49
280	PO2	1.71	1.61	1.52	1.42	1.33	1.23	1.14	1.04	0.95	0.85	0.76	0.66	0.57
	END	236	221	205	193	177	161	145	125	118	102	86	70	54
300	PO2	1.82	1.72	1.61	1.51	1.41	1.31	1.21	1.11	1.01	0.91	0.81	0.71	0.61
	END	254	237	220	207	190	174	157	136	127	110	93	77	60
320	PO2	1.93	1.82	1.71	1.60	1.50	1.39	1.28	1.18	1.07	0.96	0.86	0.75	0.64
	END	271	253	235	222	204	186	168	146	137	119	101	83	65
340	PO2		1.92	1.81	1.70	1.58	1.47	1.36	1.24	1.13	1.02	0.90	0.79	0.68
	END		269	250	236	217	198	179	156	146	128	109	90	71
360	PO2			1.91	1.79	1.67	1.55	1.43	1.31	1.19	1.07	0.95	0.83	0.71
	END			265	251	231	211	191	166	156	136	116	96	76
380	PO2				1.88	1.75	1.63	1.50	1.38	1.25	1.13	1.00	0.88	0.75
	END				265	244	223	202	176	166	145	124	103	82
400	PO2				1.97	1.84	1.71	1.57	1.44	1.31	1.18	1.05	0.92	0.79
	END				279	257	236	214	186	175	153	131	110	88
420	PO2					1.92	1.78	1.65	1.51	1.37	1.24	1.10	0.96	0.82
	END					271	248	225	196	185	162	139	116	93
440	PO2						1.86	1.72	1.58	1.43	1.29	1.15	1.00	0.86
	END						260	236	206	195	171	147	123	99
460	PO2						1.94	1.79	1.64	1.49	1.34	1.20	1.05	0.90
	END						273	248	217	204	179	154	129	104
480	PO2							1.87	1.71	1.55	1.40	1.24	1.09	0.93
	END							259	227	214	188	162	136	110
500	PO2							1.94	1.78	1.62	1.45	1.29	1.13	0.97
	END							271	237	223	196	169	142	115

Chart 3—The above chart gives the Equivalent Narcosis Depth (END) in feet sea water, and partial pressure of oxygen (ppO2) in atmospheres absolute for various heliair mixtures at depth. To use the chart find the desired maximum depth (fsw) in the left column, follow the column to the right until the desired ppO2 or END is located. Follow that column upwards to the top row to find the percentage of oxygen and helium (O2/He) required to give the desired results. Note that the dark colored squares indicate partial pressures of oxygen greater than 1.6 ATA and that these percentages should be avoided due to the increased risk of oxygen toxicity. Also note that ENDs greater than 130 fsw are not recommended due to impairment from nitrogen narcosis.

Helium Fill Pressures for Heliair

Heliair Mix (O2/He/N2) \ Desired Fill Pressure	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000
18/14/68	286	300	314	329	343	357	371	386	400	414	429	443	457	471	486	500	514	529	543	557	571
17/19/64	381	400	419	438	457	476	495	514	533	552	571	590	610	629	648	667	686	705	724	743	762
16/24/60	476	500	524	548	571	595	619	643	667	690	714	738	762	786	810	833	857	881	905	929	952
15/28/57	571	600	629	657	686	714	743	771	800	829	857	886	914	943	971	1000	1029	1057	1086	1114	1143
14/33/53	667	700	733	767	800	833	867	900	933	967	1000	1033	1067	1100	1133	1167	1200	1233	1267	1300	1333
13/38/49	762	800	838	876	914	952	990	1029	1067	1105	1143	1181	1219	1257	1295	1333	1371	1410	1448	1486	1524
12/43/45	857	900	943	986	1029	1071	1114	1157	1200	1243	1286	1329	1371	1414	1457	1500	1543	1586	1629	1671	1714
11/49/40	952	1000	1048	1095	1143	1190	1238	1286	1333	1381	1429	1476	1524	1571	1619	1667	1714	1762	1810	1857	1905
10/52/38	1048	1100	1152	1205	1257	1310	1362	1414	1467	1519	1571	1624	1676	1729	1781	1833	1886	1938	1990	2043	2095
9/57/34	1143	1200	1257	1314	1371	1429	1486	1543	1600	1657	1714	1771	1829	1886	1943	2000	2057	2114	2171	2229	2286
8/62/30	1238	1300	1362	1424	1486	1548	1610	1671	1733	1795	1857	1919	1981	2043	2105	2167	2229	2290	2352	2414	2476
7/67/26	1333	1400	1467	1533	1600	1667	1733	1800	1867	1933	2000	2067	2133	2200	2267	2333	2400	2467	2533	2600	2667
6/72/22	1429	1500	1571	1643	1714	1786	1857	1929	2000	2071	2143	2214	2286	2357	2429	2500	2571	2643	2714	2786	2857

Chart 4—The above chart provides the amount of helium to add (in psi) to an empty scuba cylinder to create the various heliair mixtures. To use the chart find intersection of the row containing the desired ending cylinder pressure (at left), and the column containing the desired heliair mixture (at top).

Trimix Best-Mix Fill Pressures

Best Mix Defined as ppO2=1.4 ATA, END=130 fsw

Depth	Best Mix		2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000
160 fsw	9% He	psi He	224	234	243	252	262	271	280	290	299	308	318	327	336	346	355	364	374
	24% O2	psi O2	149	155	161	167	174	180	186	192	198	205	211	217	223	229	236	242	248
	67% N2	psi Air	2027	2111	2196	2280	2365	2449	2534	2618	2703	2787	2872	2956	3040	3125	3209	3294	3378
180 fsw	18% He	psi He	429	446	464	482	500	518	536	553	571	589	607	625	643	661	678	696	714
	22% O2	psi O2	135	140	146	152	157	163	169	174	180	185	191	197	202	208	214	219	225
	60% N2	psi Air	1837	1913	1990	2066	2143	2219	2296	2372	2449	2525	2602	2678	2755	2831	2908	2985	3061
200 fsw	25% He	psi He	598	623	648	672	697	722	747	772	797	822	847	872	897	922	946	971	996
	20% O2	psi O2	123	128	134	139	144	149	154	159	164	170	175	180	185	190	195	200	205
	55% N2	psi Air	1679	1749	1819	1889	1959	2029	2099	2169	2239	2309	2379	2448	2518	2588	2658	2728	2798
220 fsw	31% He	psi He	740	771	802	833	864	894	925	956	987	1018	1049	1079	1110	1141	1172	1203	1234
	18% O2	psi O2	114	118	123	128	132	137	142	147	151	156	161	166	170	175	180	185	189
	51% N2	psi Air	1546	1611	1675	1740	1804	1868	1933	1997	2062	2126	2191	2255	2319	2384	2448	2513	2577
240 fsw	36% He	psi He	862	898	934	970	1005	1041	1077	1113	1149	1185	1221	1257	1293	1329	1365	1400	1436
	17% O2	psi O2	105	110	114	118	123	127	132	136	140	145	149	153	158	162	167	171	175
	47% N2	psi Air	1433	1493	1552	1612	1672	1732	1791	1851	1911	1970	2030	2090	2149	2209	2269	2329	2388
260 fsw	40% He	psi He	967	1007	1047	1088	1128	1168	1208	1249	1289	1329	1370	1410	1450	1490	1531	1571	1611
	16% O2	psi O2	98	102	106	110	114	118	123	127	131	135	139	143	147	151	155	159	163
	44% N2	psi Air	1335	1391	1446	1502	1558	1613	1669	1725	1780	1836	1891	1947	2003	2058	2114	2170	2225
280 fsw	44% He	psi He	1058	1102	1147	1191	1235	1279	1323	1367	1411	1455	1499	1543	1588	1632	1676	1720	1764
	15% O2	psi O2	92	96	99	103	107	111	115	119	122	126	130	134	138	141	145	149	153
	41% N2	psi Air	1250	1302	1354	1406	1458	1510	1562	1614	1666	1719	1771	1823	1875	1927	1979	2031	2083
300 fsw	47% He	psi He	1139	1186	1234	1281	1329	1376	1424	1471	1519	1566	1614	1661	1708	1756	1803	1851	1898
	14% O2	psi O2	86	90	93	97	101	104	108	111	115	119	122	126	129	133	137	140	144
	39% N2	psi Air	1175	1224	1273	1322	1371	1420	1468	1517	1566	1615	1664	1713	1762	1811	1860	1909	1958
320 fsw	50% He	psi He	1210	1261	1311	1362	1412	1463	1513	1563	1614	1664	1715	1765	1816	1866	1916	1967	2017
	13% O2	psi O2	81	85	88	92	95	98	102	105	109	112	115	119	122	125	129	132	136
	36% N2	psi Air	1108	1154	1201	1247	1293	1339	1385	1431	1478	1524	1570	1616	1662	1708	1755	1801	1847
340 fsw	53% He	psi He	1274	1327	1380	1433	1487	1540	1593	1646	1699	1752	1805	1858	1911	1964	2017	2071	2124
	12% O2	psi O2	77	80	83	87	90	93	96	99	103	106	109	112	116	119	122	125	128
	35% N2	psi Air	1049	1092	1136	1180	1224	1267	1311	1355	1398	1442	1486	1529	1573	1617	1661	1704	1748
360 fsw	55% He	psi He	1331	1387	1442	1498	1553	1609	1664	1720	1775	1831	1886	1942	1997	2053	2108	2164	2219
	12% O2	psi O2	73	76	79	82	85	88	91	94	97	101	104	107	110	113	116	119	122
	33% N2	psi Air	995	1037	1078	1120	1161	1203	1244	1286	1327	1369	1410	1452	1493	1535	1576	1618	1659
380 fsw	58% He	psi He	1383	1441	1498	1556	1614	1671	1729	1787	1844	1902	1960	2017	2075	2132	2190	2248	2305
	11% O2	psi O2	70	72	75	78	81	84	87	90	93	96	99	101	104	107	110	113	116
	31% N2	psi Air	947	987	1026	1066	1105	1145	1184	1223	1263	1302	1342	1381	1421	1460	1500	1539	1579
400 fsw	60% He	psi He	1430	1490	1549	1609	1669	1728	1788	1847	1907	1967	2026	2086	2145	2205	2264	2324	2384
	11% O2	psi O2	66	69	72	75	77	80	83	86	88	91	94	97	100	102	105	108	111
	30% N2	psi Air	903	941	979	1016	1054	1092	1129	1167	1205	1242	1280	1318	1355	1393	1430	1468	1506
420 fsw	61% He	psi He	1473	1534	1596	1657	1719	1780	1841	1903	1964	2025	2087	2148	2210	2271	2332	2394	2455
	10% O2	psi O2	63	66	69	71	74	77	79	82	85	87	90	92	95	98	100	103	106
	28% N2	psi Air	864	900	936	972	1008	1043	1079	1115	1151	1187	1223	1259	1295	1331	1367	1403	1439
440 fsw	63% He	psi He	1512	1575	1638	1701	1764	1827	1890	1953	2016	2079	2142	2205	2268	2331	2394	2457	2520
	10% O2	psi O2	61	63	66	68	71	73	76	78	81	84	86	89	91	94	96	99	101
	27% N2	psi Air	827	862	896	930	965	999	1034	1068	1103	1137	1172	1206	1241	1275	1310	1344	1378
460 fsw	65% He	psi He	1548	1613	1677	1742	1806	1871	1935	2000	2064	2129	2193	2258	2322	2387	2451	2516	2580
	9% O2	psi O2	58	61	63	66	68	70	73	75	78	80	83	85	87	90	92	95	97
	26% N2	psi Air	794	827	860	893	926	959	992	1025	1058	1091	1124	1157	1190	1223	1256	1289	1323
480 fsw	66% He	psi He	1581	1647	1713	1779	1845	1911	1977	2043	2109	2174	2240	2306	2372	2438	2504	2570	2636
	9% O2	psi O2	56	58	61	63	65	68	70	72	75	77	79	82	84	86	89	91	93
	25% N2	psi Air	763	794	826	858	890	921	953	985	1017	1049	1080	1112	1144	1176	1207	1239	1271
500 fsw	67% He	psi He	1612	1679	1746	1814	1881	1948	2015	2082	2150	2217	2284	2351	2418	2485	2553	2620	2687
	9% O2	psi O2	54	56	58	61	63	65	67	70	72	74	76	79	81	83	85	88	90
	24% N2	psi Air	734	765	795	826	856	887	917	948	979	1009	1040	1070	1101	1132	1162	1193	1223

Chart 5—The above chart provides the amount of helium and oxygen to add (in psi) to an empty scuba cylinder to create the best-mix for a given depth. All above mixtures yield a ppO2 of 1.4 ATA and an END of 130 fsw. To use the chart locate the maximum planned depth on the left and the desired fill pressure of the cylinder on the top. The intersection of that column and row gives the amount of helium and oxygen to use to create the best-mix for the planned depth.

nents are cleaned with a mild degreaser. Non-petroleum based lubricants are added. Viton O-rings are inserted and the components are reassembled. Two chemicals are especially good for removing oil based contaminates from scuba tanks, valves, and fill whip components: 1) SD-113, A water soluble, biodegradable, degreaser that is safe for all metals; and 2) Tribasic Sodium Phosphate (TSP), A mild degreaser that comes in a powder form and requires mixing.

All rubber O-rings used in partial pressure filling of oxygen must be removed and replaced with Viton O-rings. Viton O-rings can be easily purchased by taking all of the O-rings that were removed from the valves and fittings to a local supply company. The supply company can match virtually any rubber O-ring with a Viton equivalent.

Only non-petroleum based grease can be used on threads, fittings and Viton O-rings. The following products are recommended: Halocarbon Grease; Fluorolube; Krytox; and Chrisolube.

The Mixing Process

The mixing process is relatively straightforward. The first thing to do is open the cylinder valve and drain the cylinder completely. Remember that the cylinder won't really be empty though. It will contain 14.7 psi of air or some combination of air and the last gas the cylinder was filled with. In most cases this small amount of gas will have a negligible affect on the final gas mixture.

When partial pressure mixing any combination of helium, oxygen and air, the helium should be added first, followed by oxygen, and then topped off with air from an oil free compressor. Oil free air is especially important to prevent contamination of oxygen cleaned components. The exact percentage of each constituent gas is calculated in advance. Tables for gas mixing are located on pages 12-14.

After adding each gas to the scuba cylinder, the scuba cylinder should be left to cool to room temperature before continuing with the mixing. This will give more accurate pressure readings for calculating the percentages of each constituent gas. When topping off with air, the most accurate mixing occurs by filling to the planned pressure, letting the scuba cylinder fully cool to room temperature, then measuring the cool pressure with a gauge and slowly topping off again to the planned pressure. If all phases of the fill are begun at a constant room temperature, very accurate partial pressure blending is possible.

Gas Analysis

The most important phase of any gas mixing process is the analysis. Without analysis there is no way to accurately determine appropriate breathing depths for each cylinder nor can you determine proper decompression profiles since the exact ratio of each constituent gas is not known. Especially unsettling is the fact that many homebrewers don't analyze their gas. They, instead, rely on the partial pressures used in blending the gas to calculate the ratios. This is a dangerous practice. Divers have died because they breathed gas from a cylinder that was blended incorrectly and not analyzed. Temperature variances during filling can play a significant role in altering the final mixture. Divers who don't analyze their gas are playing Russian Roulette with their cylinders in a very real sense.

All that's required to analyze gas is a simple oxygen analyzer. These devices can be purchased for as little as $250 U.S. A constant flow regulator with scuba yoke, similar to those used on medical oxygen cylinders, is also required. These regulators can be purchased for as little as $50 U.S. The analyzer you select should have no more than 1% error over the full range of measurement. The small digital analyzers seem to be best suited for diver use.

The procedure for analyzing gas is simple. First the analyzer is calibrated, then the gas is analyzed. When mixing nitrox or heliair, only one analysis is required per cylinder. When mixing trimix two separate analyses are required per cylinder at different stages of the blending process.

(continued next page)

What is Heliair?

Heliair is a term coined by Sheck Exley for a trimix derived by mixing helium and air. Heliair is the easiest and cheapest way to blend trimix and eliminates the fire hazard of blending pure oxygen. Another advantage is that only one analysis is required since the precise percentage of nitrogen, helium, and oxygen can be determined by knowing only the percentage of oxygen.

A disadvantage of heliair is that the diver must compromise either equivalent narcosis depths or oxygen partial pressures. The best mix of 1.4 ppO2 ATA will require the diver to withstand a equivalent narcosis depths of about 180 feet. If an END of 130 feet is desired the ppO2 is lowered to 1.05 ATA. With these limitations heliair mixtures are usually not the best mix available. To blend the best mix containing a ppO2 of 1.4 ATA and an END of 130 feet trimix will have to be blended by filling with helium first, then oxygen, then topping off with air.

The most important phase of any gas mixing process is the analysis. Without analysis there is no way to accurately determine appropriate breathing depths for each cylinder nor can you determine proper decompression profiles.

Calibration

Analyzer calibration is simple. After assembling the analyzer, connect it to a cylinder containing a known percentage of oxygen—like air (20.9% O2), or pure oxygen (99.9% O2—few sources of oxygen actually contain 100% O2, ask your supplier for the exact percentage to use). Turn the analyzer on, give it a few minutes to stabilize, then adjust the display via the calibration knob to read the correct value (i.e., 20.9 or 99.9). Disconnect the analyzer from the calibration source, then reconnect it to the same cylinder and check the calibration. It should read within .2% of the initial reading to be considered calibrated. When mixing gas with a desired final percentage of oxygen greater than 60% it is best to calibrate using pure oxygen to minimize errors in the reading. When mixing gas with a desired final percentage less than 60% O2 air is best for calibration.

Analyzer elements last from 9 to 24 months. When they are reaching the end of their useful life the analyzer will take longer to stabilize and maintaining a calibration may become more difficult. Analyzer elements cost around $75 U.S. Plan on replacing them regularly.

Nitrox Analysis

After filling your cylinder with the correct percentages of oxygen and air, connect the analyzer to the cylinder, open the cylinder valve, and adjust the flow to 2-4 cu. ft. per minute. Wait 2-3 minutes for the reading to stabilize then check the display. If there is too much oxygen in your gas you can slowly add small amounts of air to bring it down to the desired reading. Be careful to not overpressurize the cylinder though. If there is too little oxygen in your final mix you will either have to use it the way it is, dump it and start over, or add small amounts of oxygen using an oil free Haskel pump or similar device.

Heliair Analysis

Heliair analysis is the same as that for nitrox. If the analyzed gas contains too little oxygen you can slowly add small amounts of air to bring the O2 content up. Be careful to not overpressurize the cylinder though. If there is too much oxygen you will either have to use it the way it is, dump it and start over, or add small amounts of helium using a Haskel pump or similar device.

Trimix Analysis

Trimix is analyzed twice. Once after the helium and oxygen have been added to ensure the correct ratio of these two gasses. Then analyzed a second time after the air has been added to ensure accurate mixtures. Beginning each stage of trimix blending with the cylinders at a constant temperature, (room temperature) is essential to minimize blending errors due to temperature variance. Small adjustments at each step in filling can correct for slight errors in the mix as with nitrox and heliair analysis.

Gas Diffusion

In researching for this article we came across passionate differences of opinion regarding diffusion. Diffusion is the process whereby two constituent gasses intermix throughout the cylinder. Some persons claim that you have to roll a cylinder to mix the gasses after filling or you have to wait 24 hours before analyzing to give the gasses time to mix. However, virtually everyone we spoke to in the gas blending industry says this is hogwash. Representatives say that by the time you finish filling your cylinder and connect the analyzer, the gasses will be 99.9% diffused.

Cylinder Marking

Proper cylinder identification is imperative. Switching to the wrong mix at depth can be fatal due to oxygen toxicity or nitrogen narcosis. All cylinders should be clearly marked with the contents and the maximum safe depth for the gas. Three inch grey duct tape written on with a black heavy Sharpie™ pen works well. The tape should be run lengthwise down the cylinder. This marking should be placed on each cylinder twice, once on each side of the cylinder. This way a buddy can instantly see if you are breathing from the wrong cylinder and intervene.

Summary

If you insist on blending your own gas, then safety measures, like proper cleaning of the equipment, mixing techniques, and gas analysis are essential. Technical diving is not about who can step farther out over the edge. Rather, it's about fun, exploration, and excitement. If you are not prepared to invest the time and money (and space in your garage) required to develop a homebrew fill station then we'll see you at the tech dive shop, where we can shoot the breeze while we wait for our fills.

Gas Blending Manuals

Gas Diving Technician's Handbook
T.D.I.
9 Coastal Plaza, Suite 300
Bath, Maine USA 04530
(207) 442-8391

Blending and Partial Pressure methods of Mixing Nitrox
I.A.N.T.D.
9628 NE 2nd Ave. Suite D
Miami Shores, FL USA 33138-2767
(305) 751-3958

Whips, Lubricants and Accessories

Amron International
759 West Fourth Ave
Escondido, CA USA 92025-4089
(619) 746-1508

Global Manufacturing Company
1829 South 68th Street
West Allis, WI USA 53214
(414) 774-1616

Underwater Applications
15 Brewster Road
Framingham, MA USA 01701-6217
(508) 628-9520

MDA, Producers of SD-13
1515 W MacArther Blvd., Suite 5
Costa Mesa, CA USA 92626-1414
(714) 966-0659

Christolube
Lubrication Technologies Inc.
310 Morton Street
Jackson, OH USA 45640
(614) 286-2644

Oil Free Compressors

Rix Industries
6460 Hollis Street
Oakland, CA USA 94608
(510) 658-5275

Gas Boosters

Haskel Manufacturing
100 East Grakm Pl
Burbank, CA USA 91502
(818) 843-4000

Oxygen Analyzers

MERS
6092 Clark Center Avenue
Sarasota, FL USA 34238
(800) 451-4379

DeepTech offers the above company listings as a resource only, without recommendation with respect to quality, price, customer service or other criteria. There may also be local vendors in your area that can supply the components described in this article.

The Awesome Photography of Wes Skiles

To most divers the name Wes Skiles is as familiar as Dacor or Scubapro. His photos of underwater caves, sumps and dry caves have appeared in virtually every dive and cave related publication in existence.

Wes's films are also becoming as legendary as his still photography. He routinely dives with explorers as they make record pushes into some of the world's longest caves in Florida, Mexico, and the Caribbean. He films these events real-time as they happen. This means, of course, that Wes's own diving skills are refined to the explorer level. His newest film "Ocean Spirit", airing soon on PBS, differs from his past work in that most of it was shot in open water. Interestingly, the film features Grateful Dead drummer Bill Kreutzmann as one of the divers.

Wes is 37 years old. He lives in the cave-holy-land of North Central Florida. He's an instructor for both the NSSCDS and PADI, and he has been diving since he was ten years old.

Recently Wes was kind enough to take time out of his busy schedule to talk with DeepTech about his life, diving and, of course, his awesome photography.

DT: How and when did you get started in diving Wes?

Wes: I've had a strong fascination for the underwater world ever since I was a kid. The thing that influenced me most, cliche as it sounds, is all those old episodes of Sea Hunt. I remember jumping out of the tree in my front yard onto the ground and then swimming across the grass visualizing what it would be like to be a diver. I dove for an entire year as a kid in pools with a mask skirt, no face plate, just the skirt and mask strap. I thought it was totally cool just to have the skirt.

DT: How old were you then?

Wes: I was probably about seven at that time. When I was eight, the YMCA offered a skin diving course and I signed up. The instructor, Bob Axlrod, took an interest in me. After completing the course he started calling my parents and saying "we're going out to the springs for scuba checkouts and if Wes wants to come along we'd love to have him. I know how much he loves the springs." I would go with Bob and the scuba classes, but I would just go as a snorkeler. After awhile Bob started letting me use scuba and he started showing me how to breath off a regulator. I made my first dive when I was ten using a little set of tiny doubles in Troy springs.

DT: How did you get into technical diving?

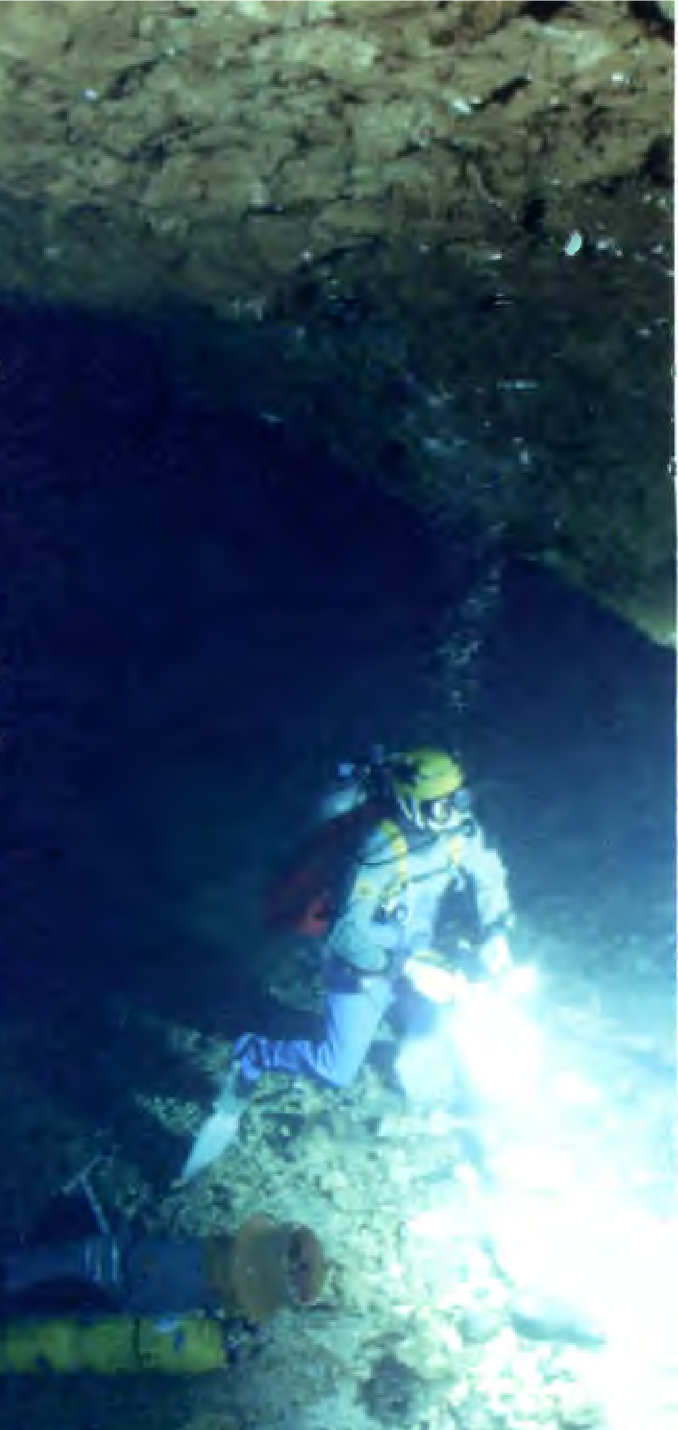
Wes: In the late 60s and early 70s I had a neighbor down the street, Kent Markum, who was an inventor of underwater stuff. He built small submarines and other gadgets. Many of his inventions were featured in various publications like Skin Diver and Popular Mechanics. His first subs were small one and two man wet/dry subs. I totally got into helping him build them. I was still a kid, but I was fixated on Kent Markum's house. Other kids were running around and playing Cowboys and Indians while I was sanding fiber glass in Kent's garage. Kent also built an early scooter that he called a Scuba-Tow. This predated even Farallon's stuff.

When I was old enough to go to the springs I went to Ginnie. I was twelve or thirteen then. The photographer from Popular Mechanics had a bunch of scuba gear and he was going to photograph my brother and I using Kent's Scuba-Tows and he said there's the stuff, pointing to the scuba gear. I put it on and jumped in the water and dove all day long in Ginnie. This was back when Ginnie was a back woods hole, completely surrounded by forest. My brother said, "Don't go in the cave." I said,

(continued page 27)

Photo by Noel Sloan

Wes Skiles after a dive on a Mk IV rebreather.



"I remember having agonizingly sore muscles from hanging on to an aquazep with my legs. I had a light in one hand a camera in the other, scootering down the tunnel filming the push team 4,000 feet into Wakulla at a depth of 320 feet. You know what I mean If you've ever seen divers on aquazeps with their tanks attached under the scooter and they're hanging on with one hand and driving the scooter with the other, plus all their regulators and reels. I'm behind them or in front of them, geared the same way, only I'm driving my scooter with no hands taking pictures."

Explorer Liz Wight explores within the underwater passages beyond the Concorde chamber.

Lamar Hires explores cave passage in Peacock Cave wearing his new TransPac Side Mounts.

All photos by Wes Skiles

Mark Long and Tom Morris pause briefly at the bone bed during a deep penetration into Wakulla.

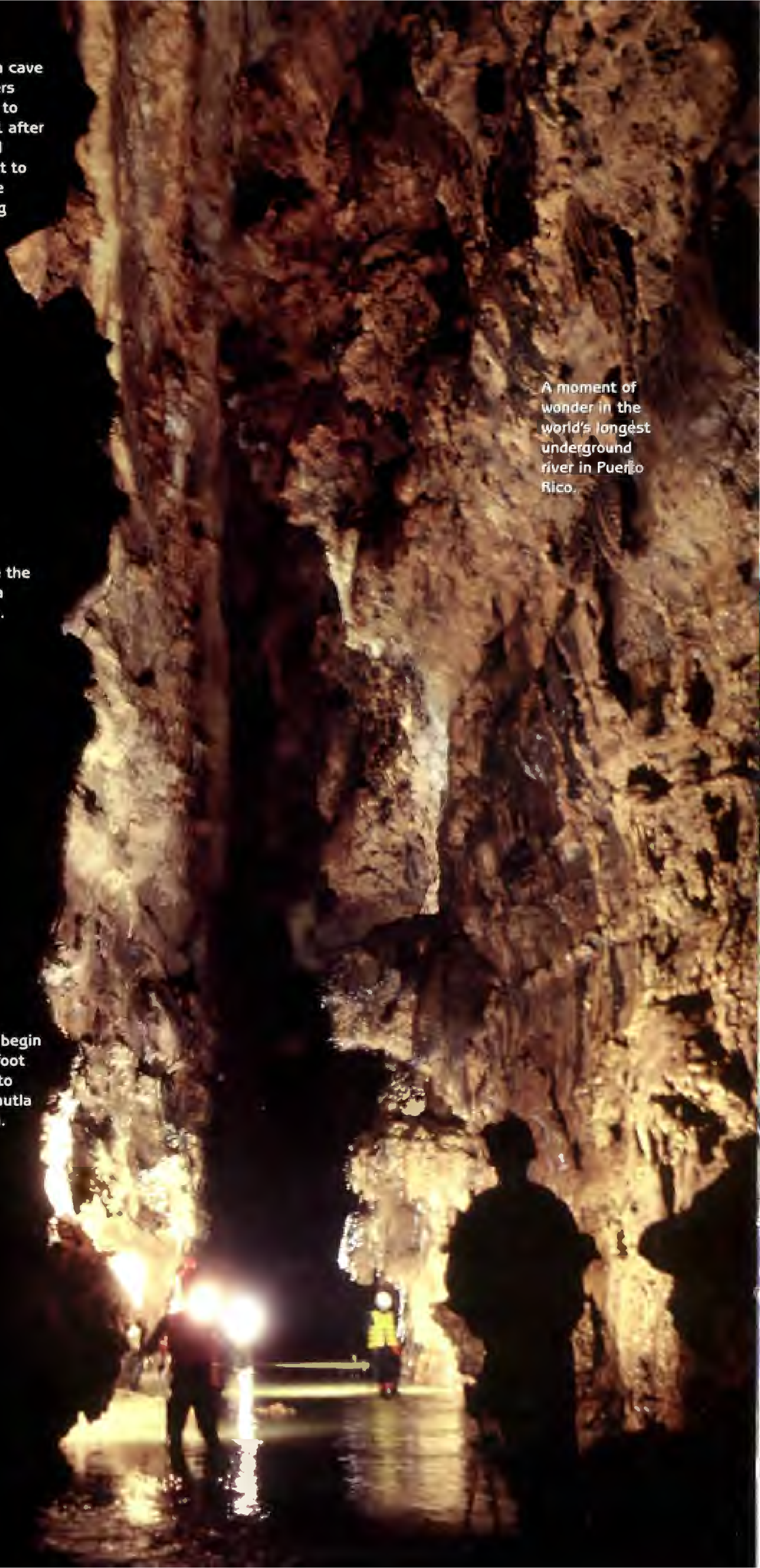
Bill Stone pushes the limits of the Huautla Cave System using his MkIV Rebreather.

In swimming-pool-clear water, Jeffrey and Ruby Haupt begin a scooter cave dive at Blue Spring.

Huautla cave explorers retreat to Camp-1 after a failed attempt to exit the flooding cave.

Cavers explore the Huautla system.

Cavers begin a 360 foot drop into the Huautla System.



A moment of wonder in the world's longest underground river in Puerto Rico.

All photos by Wes Skiles

"Oh, everybody's worried about the caves." I went down and peeked into the cave until my eyes got adjusted. It was strange. The bottom was covered with long blade ribbon grass all around the entrance. Inside the cave was just a black hole. Now, of course, there's white sand and clear rock, but back then it was just this black hole that you had to go through this grass to get into. I couldn't see very much, but for me it's the imagination. "Man how far does this go? Where is this water coming from? This is so cool!" I came back and started drawing pictures of what I saw and even trying to sketch the cavern just so that I could imagine myself being back there. It was a real strong hook for me. By the time my buddies and I were old enough to drive we had regular excursions going to the springs.

DT: What type of diving are you doing now? Nitrox and trimix?

Wes: Yes. I have always used whatever technology I needed to use to do the things I wanted to do. I have never gotten into technology just for the sake of technology. I'm not into having a bank of tanks and all the gauges and all the computer programs so I can bounce around the planet in high-tech gear. I am a project to project type of person. I love exploration and I consider what I do to be wholistic exploration. I'm not interested in seeing how far I can go. However, when I find a place that I like, I am into all aspects of it. Where does the water come from? What lives in here? How many water sources are there? Where does this little tunnel go? Where does this big tunnel go? Wholistic, looking at all aspects of it. When something takes me to the point where I need more technology, then I use it. I live a very technologically burdened life-style as it is. My real idea of fun is surfing. Bathing suits, surfboards and water. That's what I do when I want to get away from it all.

Back in 1987, we did an 82 minute dive in Wakulla with max depths of 340 feet. At that time, penetrating over 4,000 feet at a depth of 320 feet had never been done. No one had ever been that far, at that depth, in an underwater cave. We wanted to see where the tunnel went and to map and film it. I've done a lot of that kind of diving with the main thrust being accomplishing goals like mapping or filming. That's what I'm really into.

DT: Did that project go with all the technology from Hamilton and his decompression models?

Wes: Yes. That was the first real project in which Hamilton crossed over to the sport diving community. Hamilton was into consulting for the big deep sea exploration projects, and he started to play with the idea of supporting the technical diving community. It wasn't even called technical diving back then. It was just groups of people doing meaningful explorations and projects in which Bill thought he could contribute. Parker Turner played a big role in getting Bill Stone and Bill Hamilton together. Hamilton agreed to fashion a set of tables that allowed us to really soar and cut the decompressions we were going to have to do. It made what we did in Wakulla a reality.

DT: What made you decide to get into underwater photography?

Wes: I started as a kid with 8mm and super 8 cameras. I shot stop action films and surfing films with my brother. My brother was real hard-core about getting the surfing images. I would help him and then I would edit the films. I really got into it. Then I bought a Nikonis II when they were new and got into still photography while diving the springs in the early 70s. I have a strong number of images starting about 1972 or 1973. My interest in photography has always been from a documentary point of view. Now I'm a film maker full time. It's what I do for a living. I now produce, direct, write and shoot films for networks as well as what they call "acquisition work" with my partner Jeffrey Haupt.

DT: What type of photo and video equipment do you use?

WES: I use whatever is the best for the job. It's just like dive technology. When it's time to do a deep exploration dive, I use the best that is available today. In motion picture film work it's the same thing. Technology changes rapidly, though. You buy a 30lb camera that costs more than your house and a year later that camera is obsolete. Unfortunately, I do have to buy these cameras. They are my work tools. I am continually upgrading. We're now shooting digital. We have several digital cameras in addition to our 16mm and 35mm film cameras.

DT: If I were a diver wanting to get into cave photography, what kind of equipment would you suggest?

Wes: I think the best formula for getting into underwater cave photography is the Nikonis V, with a 15mm underwater lens by Nikor, and a minimum of three strobes, one or two on the camera one or two off camera with slave syncs.

DT: What were a couple of your favorite projects?

Wes: The world's longest underground river is in Puerto Rico and it's called the Enchanted River. It is certainly one of the high points of my career. We explored almost 15 miles underground in a continuous under-

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ground river with 28 waterfalls. We discovered it by cave diving looking for a body. This was a pretty interesting way to begin an exploration project, I was flown to Puerto Rico in a jet to try and do a rescue. They dropped Henry Nicholson and I in a river canyon by helicopter to look for Tito Vasques underwater in a spring with low visibility on the Rio Manatee. We popped up 1200 feet back in this big room with this river running through it. That was the beginning of a series of expeditions where we pushed further into the cave.

Director/Cameraman Wes Skiles and Producer Jeffrey Haupt on the site of their latest Florida Film.

DT: So you discovered it?

Wes: Yes, then after that the next big thing was Wakulla. We had two push teams and I got to shoot the film that was shown on the Best of National Geographic Explorer. There is also a one-hour version that was shown on PBS called Wakulla. This was not such a big deal to shoot, it just takes just an enormous commitment. These are big cameras. I remember having agonizingly sore muscles from hanging on to an aquazep with my legs. I had a light in one hand a camera in the other, scootering down the tunnel filming the push team 4,000 feet into Wakulla at a depth of 320 feet. You know what I mean If you've ever seen divers on aquazeps with their tanks attached under the scooter and they're hanging on with one hand and driving the scooter with the other, plus all their regulators and reels. I'm behind them or in front of them, geared the same way, only I'm driving my scooter with no hands taking pictures.

DT: How did you hold on to the zep?

WES: I built a system that kind of held me down in the back and I used my leg muscles and my calves and pulled the scooter just like you would climb a telephone pole. I just held onto it. It takes really wanting it. You really got to want it to get out there and get the footage.

DT: Do you have anything interesting going on now?

Wes: Jeffrey Haupt and I are working on a new episode of Bill Curtis's New Explorers featuring Eric Hutcheson and Mike Madden. I think this will be the finest underwater cave film ever made. We went to the Yucatan and stayed 20 days and shot 16mm film of virgin exploration dives. We discovered bone beds of Manatees and other sea creatures. We worked on connecting the system from eight kilometers inland all the way to the ocean. It's the most beautiful underwater cave I've ever seen. There are lots of caves that get me going but I've never dived a cave with so many different things to see and do.

DT: If you had a dream project, what would it be?

WES: The thing I want more than anything is a one atmosphere suit. I believe that the key to the secrets of what is to be discovered underwater are going to be discovered with one atmosphere suit exploration. I met with Phil Nuytten personally and I'm currently training in a Newt Suit. I've learned how to take things apart, how to size the suit for myself, how to operate it, and getting in and using it. I really would like to mount a set of cameras on a Newt Suit and go flying underwater in the coolest places on the planet. That's what I'd like to do more than anything. I'd love to think that it's going to have no umbilical cord as well. The day that you don't need an umbilical cord and you can just cruise in these suits is the day we will begin to do some really neat things.

DT: Do you have any advice for apprentice underwater photographers and videographers?

Wes: What I've discovered is that if you're a diver first, and you really understand diving well, and then you embrace photography or videography, I think you can do a jam up job of it. If you're a photographer or videographer first and you get into scuba diving to take your work to a new a dimension then it's more difficult. In my field I'm competing against thousands of film makers and camera men who learned to dive so they can shoot underwater. Or rather, they are competing against me. I have 22 years of cave diving experience. I'm able to think about the shot because I am not worried about whether or not I'm going to die. This is to my advantage and to the advantage of others who are comfortable underwater. That's what it's all about, being comfortable. Both disciplines, however, require a tremendous amount of experience.

Wes Skiles is the owner of Karst Productions, Inc. in High Springs, Florida For information write or call: 7500 County Road 340, High Springs, Florida 32643, 904-454-3556.

the reduced gradient bubble model and phase mechanics

by Dr. Bruce Weinke

Modeling of decompression phenomena in the body is a difficult task, and existing models are incomplete at best. With these caveats, models and underpinning physical principles of decompression are the focus of this article. Free and dissolved gas phases, and transfer mechanisms are pinpointed. Differences between dissolved and free phase models are contrasted.

Introduction

Modeling of decompression phenomena in the human body is, at times, more of an artform than a science. Some take the view that deterministic modeling can only be fortuitous. Technological advance, elucidation of competing mechanisms, and resolution of model issues over the past 80 years has not been rapid. Model applications tend to be ad hoc, tied to data fits, and difficult to quantify on first principles. Almost any description of decompression processes in tissue and blood can

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Sea Level Surfacing Ratios and Critical Tensions			
halftime τ (min)	Critical Ratio R_0	Critical Tension M_0 (fsw)	Tension Change ΔM
5	3.15	104	2.27
10	2.67	88	2.01
20	2.18	72	1.67
40	1.76	58	1.34
80	1.58	52	1.26
120	1.55	51	1.19

Table 1—Sea Level Surfacing Ratios and Critical Tensions

Critical Phase Volume Time Limits			
Depth d (fsw)	Nonstop Limit t_n (min)	Depth d (fsw)	Nonstop Limit t_n (min)
30	250	130	9
40	130	140	8
50	73	150	7
60	52	160	6.5
70	39	170	5.8
80	27	180	5.3
90	22	190	4.6
100	18	200	4.1
110	15	210	3.7
120	12	220	3.1

Table 2—Critical Phase Volume Time Limits

Critical Phase Volume Gradients			
halftime τ (min)	Threshold Depth δ (fsw)	Surface Gradient G_0 (fsw)	Gradient Change ΔG
2	190	151	.518
5	135	95	.515
10	95	67	.511
20	65	49	.506
40	40	36	.468
80	30	27	.417
120	28	24	.379
240	16	23	.329
480	12	22	.312

Table 3—Critical Phase Volume Gradients

be disputed, and turned around on itself. The fact that decompression takes place in metabolic and perfused matter makes it difficult to design and analyze experiments outside living matter. Yet, for application to safe diving, we need models to build tables and meters. And deterministic models, not discounting shortcomings, are the subject of this discourse.

Models

Most believe that the pathophysiology of decompression sickness syndrome follows formation of a gas phase after decompression. Yet, the physiological evolution of the gas phase is poorly understood. Bubble detection technology has established that moving and stationary bubbles do occur following decompression, that the risk of decompression sickness increases with the magnitude of detected bubbles, that symptomless, or silent, bubbles are also common following decompression, and that the variability in gas phase formation is less likely than the variability in symptom generation. Taken together, gas phase formation is not only important to the understanding of decompression sickness, but is also a crucial model element in theory and computation.

Bubbles can form in tissue and blood when ambient pressure drops below tissue tensions, according to dissolved-free phase mechanics. Trying to track free and dissolved gas buildup and elimination in tissue and blood, especially their interplay, is extremely complex, beyond the capabilities of today's supercomputers. But safe computational prescriptions are necessary in the formulation of dive tables and digital meter algorithms. The simplest way to stage decompression, following extended exposures to high pressure with commensurate dissolved gas buildup, is to limit tissue tensions. Historically, Haldane first employed the approach, and it persists today in modified form.

History

Tables and schedules for diving at sea level can be traced to a model proposed in 1908 by the eminent English physiologist, John Scott Haldane. He observed that goats, saturated to depths of 165 feet of sea water (fsw), did not develop decompression sickness (DCS) if subsequent decompression was limited to half the ambient pressure. Extrapolating to humans, researchers reckoned that tissues tolerate elevated dissolved gas pressures (tensions), greater than ambient by a factor of two, before the onset of DCS symptoms. Haldane then constructed schedules which limited the critical supersaturation ratio to two in hypothetical tissue compartments. Tissue compartments were characterized by their halftime, τ. Halftime is also termed half-life when linked to exponential processes, such as radioactive decay. Five compartments (5, 10, 20, 40, and 75 minutes) were employed in decompression calculations and staged procedures for fifty years.

Some years following, in performing deep diving and expanding existing table ranges in the 1930s, U.S. Navy investigators assigned separate limiting tensions (M-values) to each tissue compartment. Later in the 1950s and early 1960s, other US Navy investigators, in addressing repetitive exposures for the first time, advocated the use of six tissues (5, 10, 20, 40, 80, and 120 minutes) in constructing decompression schedules, with each tissue compartment again possessing its own limiting tension. Temporal uptake and elimination of inert gas was based on mechanics addressing only the macroscopic aspects of gas exchange between blood and tissue. Exact bubble production mechanisms, interplay of free and dissolved gas phases, and related transport phenomena were not quantified, since they were neither known nor understood. Today, we know much more about dissolved and free phase dynamics, bubbles, and transport mechanisms, but still rely heavily on the Haldane model. Inertia and simplicity tend to sustain its popularity and use, and it has been a workhorse.

To maximize the rate of uptake or elimination of dissolved gases, the gradient is maximized by pulling the diver as close to the surface as possible. Exposures are limited by requiring that the tissue tensions never exceed limits (called M-values), for instance, written for each compartment in the US Navy approach (5, 10, 20, 40, 80, and 120 minute tissue halftimes) τ, as, $M = M_0 + \Delta Md$, with, $M_0 = 152.7\tau^{-1/4}$, and, $\Delta M = 3.25\tau^{-1/4}$, as a function of depth, d, for ΔM the change per unit depth. Obviously, M, is largest for fast tissue compartments (τ small), and smallest for slow tissue compartments (τ large). Fast compartments control short deep excursions, while slow compartments control long shallow excursions. Surfacing values, M_0, are principal concerns in nonstop diving, while values at depth, ΔMd , concern decompression diving. In both cases, the staging regimen tries to pull the diver as close to the surface as possible, in as short a time as possible. By contrast, free phase (bubble) elimination gradients, as seen, increase with depth, directly opposite to dissolved gas elimination gradients which decrease with depth. In actuality, decompression is a playoff between dissolved gas buildup and free phase growth, tempered by body ability to eliminate both. But dissolved gas models cannot handle both, so there are problems when extrapolating outside tested ranges.

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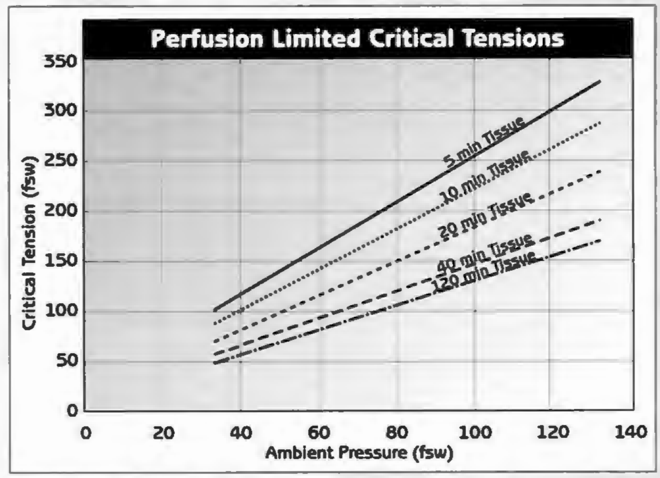

Figure 1—Critical tensions are linear functions of pressure in the Haldane scheme, obviously increasing with ambient pressure. Faster compartments permit larger amounts of dissolved nitrogen, slower compartments less.

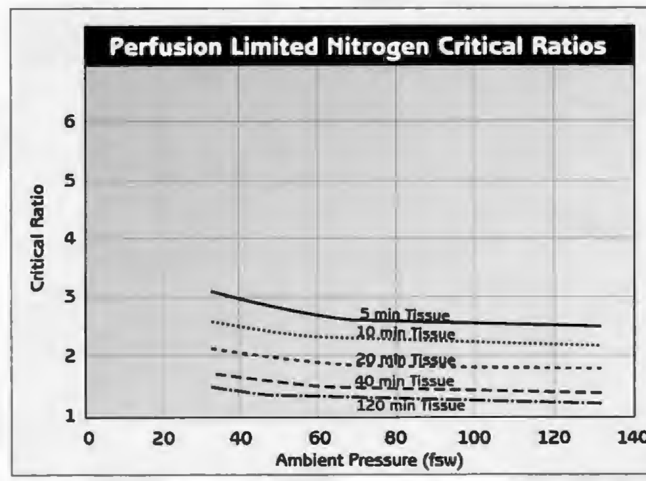

Figure 2—Critical ratios, R, are simply the critical tensions, M, divided by the ambient pressure, P, and are seen to be hyperbolic functions of pressure. Faster compartments support larger critical ratios, and slower compartments smaller critical ratios.

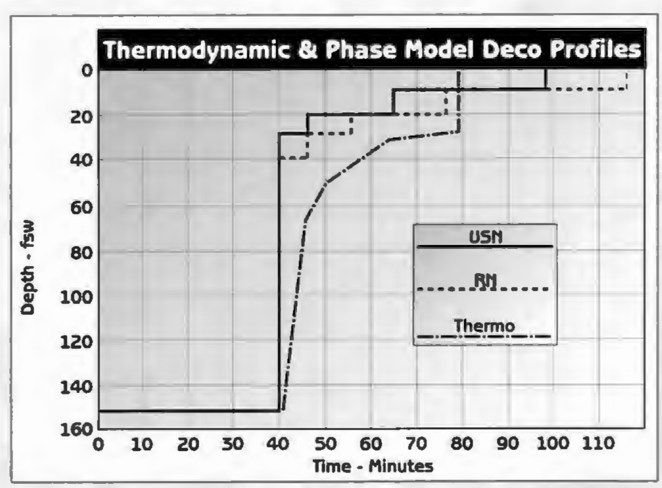

Figure 3—Decompression profiles for a dive to 150 fsw for 40 minutes are depicted according to supersaturation and phase decompression formats. Differences between supersaturation schedules (USN and RN) and the phase format schedule (thermo) are generic to bubble models vs. critical tension models, and are based on the fundamental differences between eliminating free and dissolved gas phases. Decompression staging is a playoff in trying to eliminate both.

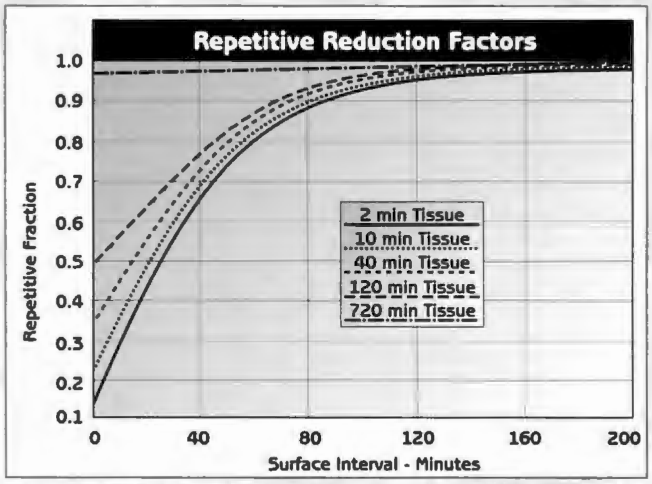

Figure 4—Within the phase volume constraint, bubble elimination periods are shortened over repetitive diving, compared to bounce diving. Faster compartments are impacted the most, but all fractions relax to one after a few hours.

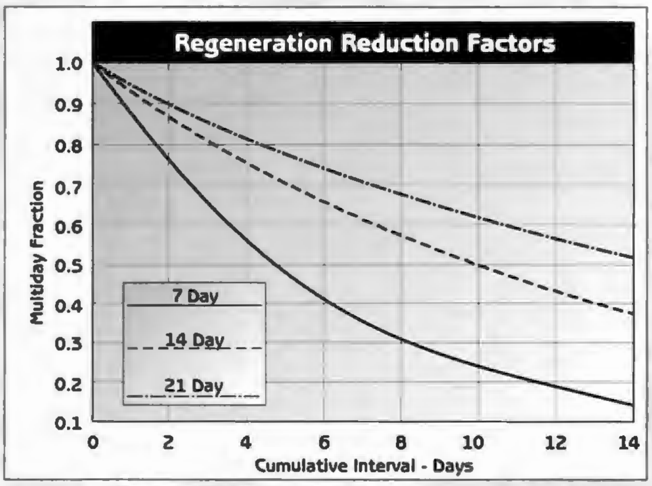

Figure 5—Micronuclei are thought to regenerate over adaptation time scales (days), replenishing existing pools of gas seeds. A factor η^{reg}, accounting for creation of new micronuclei, reduces permissible gradients by the creation rate, thus maintaining the phase volume constraint over multiday diving.

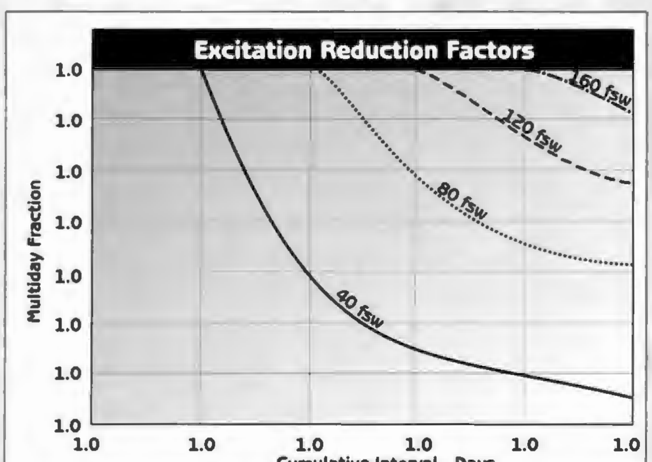

Figure 6—Deeper-than-previous diving activity stimulates smaller bubble seeds into growth according to the varying permeability and reduced gradient bubble models. Scaling gradients by the ratio of bubble excess on the deepest points of earlier dives, η^{exc}, maintains the phase volume constraint for multidiving. Shallow dives followed by deeper dives incur the largest reductions in permissible gradients.

A popular set of (surfacing) critical tensions, M_0, and corresponding critical ratios, $R_0 = M_0 / P_0$, and changes per foot of depth, ΔM , are listed in Table 1 under appropriate headings. Critical parameters, according to the U.S. Navy, are also plotted in Figures 1 and 2. In absolute pressure units, the corresponding critical gradient, $G = Q - P$, is related to ambient pressure, P, and critical nitrogen pressure, M, with, $Q = 1.27\ M$. In bubble theories, supersaturation is limited by the critical gradient, G. In decompressed gel experiments, Strauss suggested that G 20 fsw at ambient pressures less than a few atmospheres. Other studies suggest, 14 G 30 fsw , as a range of critical gradients (G-values). In diffusion-dominated approaches, the tissue tension can be limited by a single, pressure criterion, such as, $M = 709P / P + 404$.

Blood rich, well-perfused, aqueous tissues are usually thought to be fast (small τ), while blood poor, scarcely-perfused, lipid tissues are thought to be slow (large τ), though the spectrum of halftimes is not correlated with actual perfusion rates in critical tissues. As reflected in relationship above, critical parameters are obviously larger for faster tissues. The range of variation with compartment and depth is not insignificant. Fast compartments control short deep exposures, while slow compartments control long shallow, decompression, and saturation exposures.

Multitissue Model

Multitissue models, variations of the original Haldane model, assume that dissolved gas exchange, controlled by blood flow across regions of varying concentration, is driven by the local gradient, that is, the difference between the arterial blood tension and the instantaneous tissue tension. Tissue response is modeled by exponential functions, bounded by arterial and initial tensions, and perfusion constants, lambda , linked to the tissue halftimes, τ, for instance, 1, 2, 5, 10, 20, 40, 80, 120, 180, 240, 360, 480, and 720 minute compartments assumed to be independent of pressure.

In a series of dives or multiple stages, initial and arterial tensions represent extremes for each stage, or more precisely, the initial tension and the arterial tension at the beginning of the next stage. Stages are treated sequentially, with finishing tensions at one step representing initial tensions for the next step, and so on. To maximize the rate of uptake or elimination of dissolved gases the gradient, simply the difference between arterial and tissue tensions is maximized by pulling the diver as close to the surface as possible. Exposures are limited by requiring that the tissue tensions never exceed $M = M_0 + \Delta M d$, as a function of depth, d, for ΔM the change per unit depth. A set of M_0 and ΔM are listed in Table 1.

At altitude, some critical tensions have been correlated with actual testing, in which case, an effective depth, $d = P - 33$, is referenced to the absolute pressure, P, with surface pressure, $P_h = 33 \exp(-0.0381\ h)$, at elevation, h, and h in multiples of 1,000 ft. However, in those cases where critical tensions have not been tested, nor extended, to altitude, an exponentially decreasing extrapolation scheme, called similarity, has been employed. Extrapolations of critical tensions, below P = 33 fsw, then fall off more rapidly then in the linear case. A similarity extrapolation holds the ratio, $R = M/P$, constant at altitude. Estimating minimum surface tension pressure of bubbles near 10 fsw, as a limit point, the similarity extrapolation might be limited to 10,000 ft in elevation, and neither for decompression nor heavy repetitive diving.

Models of dissolved gas transport and coupled bubble formation are not complete, and all need correlation with experiment and wet testing. Extensions of basic (perfusion and diffusion) models can redress some of the difficulties and deficiencies, both in theory and application. Concerns about microbubbles in the blood impacting gas elimination, geometry of the tissue region with respect to gas exchange, penetration depths for gas diffusion, nerve deformation trigger points for pain, gas uptake and elimination asymmetry, effective gas exchange with flowing blood, and perfusion versus diffusion limited gas exchange, to name but a few, motivate a number of extensions of dissolved gas models.

The multitissue model addresses dissolved gas transport with saturation gradients driving the elimination. In the presence of free phases, free-dissolved and free-blood elimination gradients can compete with dissolved-blood gradients. One suggestion is that the gradient be split into two weighted parts, the free blood and dissolved-blood gradients, with the weighting fraction proportional to the amount of separated gas per unit tissue volume. Use of a split gradient is consistent with multiphase flow partitioning, and implies that only a portion of tissue gas has separated, with the remainder dissolved. Such a split representation can replace any of the gradient terms in tissue response functions.

If gas nuclei are entrained in the circulatory system, blood perfusion rates are effectively lowered, an impairment with impact on all gas exchange processes. This suggests a possible lengthening of tissue halftimes for elimination over those for uptake, for instance, a 10 minute compartment for uptake becomes a 12 minute compartment on elimination. Such lengthening procedure and the split elimination gradient obviously render gas uptake and

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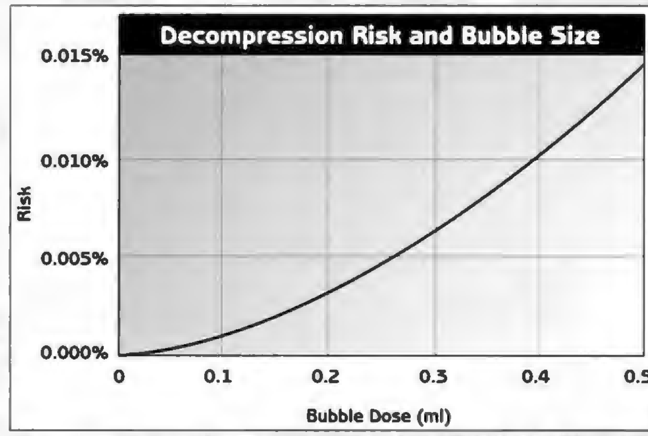

Figure 7—It is possible to correlate model parameters with experimental diving data. The above relationship correlates risk with computed model bubble size, that is, theoretically computed bubble dose (ml) is linked to incidence of decompression sickness in the sigmoidal dose curve. Dose is a measure of separated gas volume, a natural trigger point in phase models.

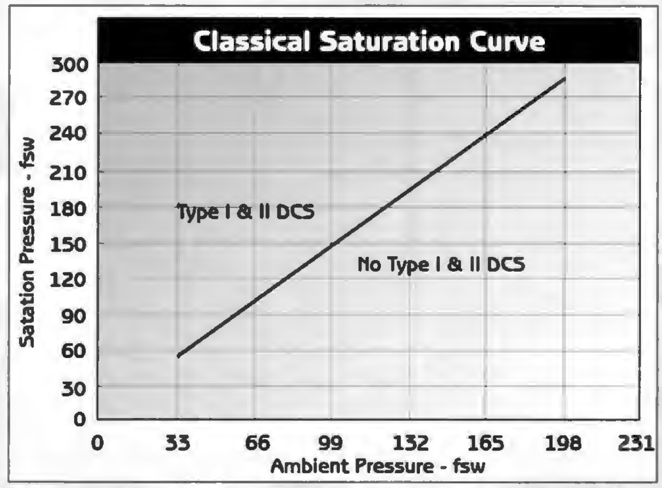

Figure 8—The classical saturation curve relates saturated tissue tension, Q, to permissible pressure on decompression, P, in linear fashion with, $Q = 1.37P + 11.1$, holding in the hyperbaric region, P 33 fsw, but questionable in the hypobaric region, $P < 33$ fsw, especially as P drops below 16 fsw.

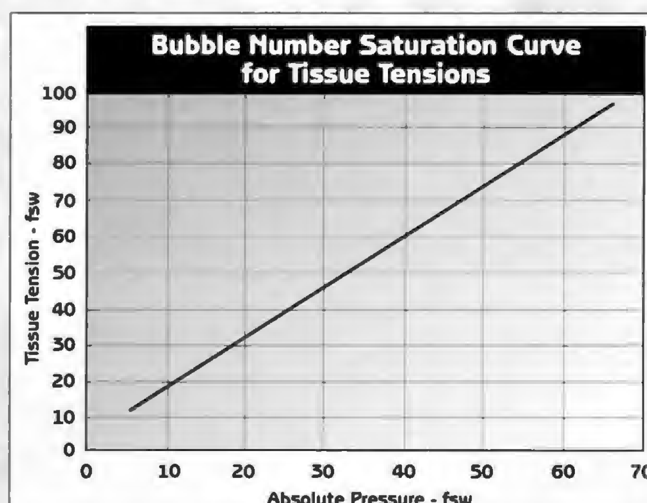

Figure 9—In exponentially decreasing bubble size models, such as the VPM and RGBM, with excitation radii inversely proportional to compression-decompression pressures, the saturated tissue tension, Q, in absolute units satisfies, $Q = [2.31 - \exp(-11.3/P)]P$, exhibiting a linear behavior for large P, and passing through the origin as P approaches zero. The curve thus possesses the desired hyperbaric and hypobaric form across a broad pressure range.

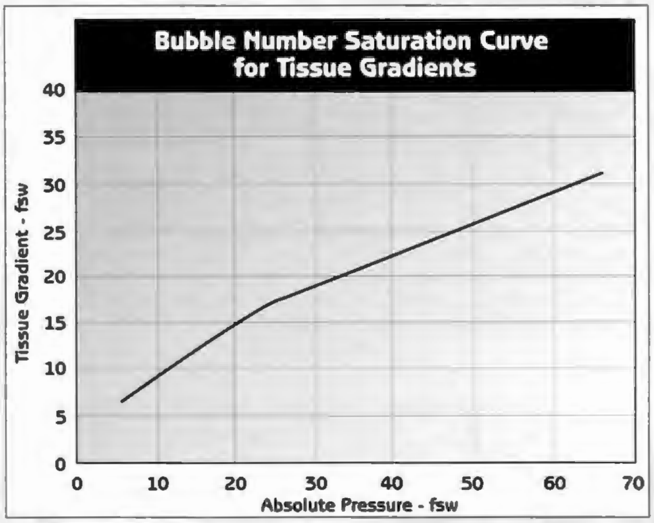

Figure 10—In analogy with the tension, the saturated tissue gradient, G, exhibits similar behavior, Permissible saturation gradient, G, is given by, G = [1.31 - exp(-11.3/P)]P, another curve approximating a straight line for large P, and passing through the origin as P gets small.

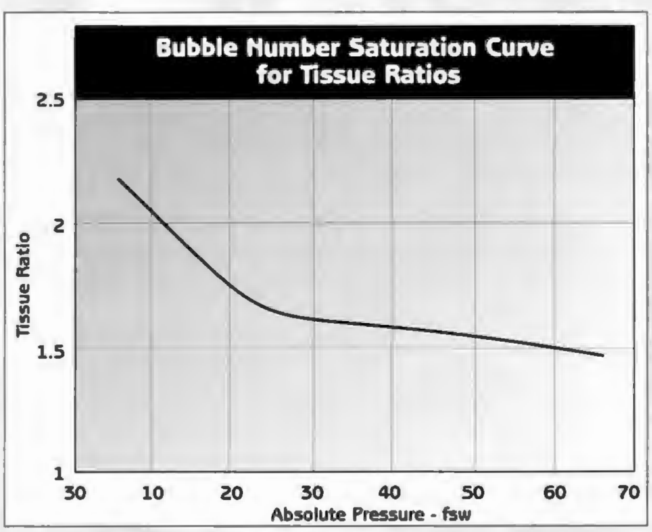

Figure 11—The saturated tissue ratio, R, approaches a near constant value in both the large and small P limits in exponentially decreasing seed models, specifically in the VPM and RGBM, of the form in absolute pressure units, R = 2.31 - exp(-11.3/P), that is, 2.31 for small P and 1.31 for large P. Tissue ratios are thus bounded for all pressures.

elimination processes asymmetric. Instead of both exponential uptake and elimination, exponential uptake and linear elimination response functions can be used. Such modifications can again be employed in any perfusion model easily, and tuned to the data.

Thermodynamic Model

The thermodynamic approach suggested by Hills, and extended by others, is more comprehensive than earlier models, addressing a number of issues simultaneously, such as tissue gas exchange, phase separation, and phase volume trigger points. This model is based on phase equilibration of dissolved and separated gas phases, with temporal uptake and elimination of inert gas controlled by perfusion and diffusion. From a boundary (vascular) zone of thickness, a, gases diffuse into the cellular region. Radial, one dimensional, cylindrical geometry is assumed as a starting point, though the extension to higher dimensionality is straightforward. As with all dissolved gas transfer, diffusion is controlled by the difference between the instantaneous tissue tension and the venous tension, and perfusion is controlled by the difference between the arterial and venous tension. A mass balance for gas flow at the vascular cellular interface, a, enforces the perfusion limit when appropriate, linking the diffusion and perfusion equations directly. Blood and tissue tensions are joined in a complex feedback loop. The trigger point in the thermodynamic model is the separated phase volume, related to a set of mechanical pain thresholds for fluid injected into connective tissue.

The full thermodynamic model is complex, though Hills has performed massive computations correlating with the data, underscoring basic model validity. One of its more significant features can be seen in Figure 3. Considerations of free phase dynamics (phase volume trigger point) require deeper decompression staging formats, compared to considerations of critical tensions, and are characteristic of phase models. Full blown bubble models require the same, simply to minimize bubble excitation and growth.

Reduced Gradient Bubble Model

The reduced gradient bubble model (RGBM), developed by Wienke, treats both dissolved and free phase transfer mechanisms, postulating the existence of gas seeds (micronuclei) with permeable skins of surface active molecules, small enough to remain in solution and strong enough to resist collapse. The model is based upon laboratory studies of bubble growth and nucleation, and grew from a similar model, the varying permeability model (VPM), treating bubble seeds as gas micropockets contained by pressure permeable elastic skins

Inert gas exchange is driven by the local gradient, the difference between the arterial blood tension and the instantaneous tissue tension. Compartments with 1, 2, 5, 10, 20, 40, 80, 120, 240, 480, and 720 halftimes, τ, are again employed. While, classical (Haldane) models limit exposures by requiring that the tissue tensions never exceed the critical tensions, fitted to the US Navy nonstop limits, for example. The reduced gradient bubble model, however, limits the supersaturation gradient, through the phase volume constraint. An exponential distribution of bubble seeds, falling off with increasing bubble size is assumed to be excited into growth by compression-decompression. A critical radius, r sub c , separates growing from contracting micronuclei for given ambient pressure, P_c. At sea level, P_c = 33 fsw , r_c = .8 microns, and ΔP = d. Deeper decompressions excite smaller, more stable, nuclei.

Within a phase volume constraint for exposures, a set of nonstop limits, t_n, at depth, d, satisfy a modified law, $dt_n^{1/2}$ = 400 fsw $min^{1/2}$, with gradient, G, extracted for each compartment, τ, using the nonstop limits and excitation radius, at generalized depth, d = P - 33 fsw. Tables 2 and 3 summarize t_n, G_0 , ΔG , and δ, the depth at which the compartment begins to control exposures.

Gas filled crevices can also facilitate nucleation by cavitation. The mechanism is responsible for bubble formation occurring on solid surfaces and container walls. In gel experiments, though, solid particles and ragged surfaces were seldom seen, suggesting other nucleation mechanisms. The existence of stable gas nuclei is paradoxical. Gas bubbles larger than 1 micron should float to the surface of a standing liquid or gel, while smaller ones should dissolve in a few seconds. In a liquid supersaturated with gas, only bubbles at the critical radius, r_c, would be in equilibrium (and very unstable equilibrium at best). Bubbles larger than the critical radius should grow larger, and bubbles smaller than the critical radius should collapse. Yet, the Yount gel experiments confirm the existence of stable gas phases, so no matter what the mechanism, effective surface tension must be zero.

Although the actual size distribution of gas nuclei in humans is unknown, these experiments in gels have been correlated with a decaying exponential (radial) distribution function. For a stabilized distribution accommodated by the body at fixed pressure, P_c , the excess number of nuclei excited by compression-decompression must be removed from the body. The rate at which gas inflates in tissue depends upon both the excess bubble number, and the supersaturation gradient, G. The critical volume hypothesis requires that the integral of the product of the two must always remain less than some volume limit point, α V , with α, a proportionality constant. A conservative set of bounce gradients, $\bar{G}$, can be also be extracted for multiday and repetitive diving, provided they are multiplicatively reduced by a set of bubble factors, η^{rep}, η^{reg}, η^{exc}, all less than one, such that $\bar{G} = \eta^{rep}\, \eta^{reg}\, \eta^{exc}\, G$.

These three bubble factors reduce the driving gradients to maintain the phases volume constraint. The first bubble factor reduces G to account for creation of new stabilized micronuclei over time scales of days. The second factor accounts for additional micronuclei excitation on deeper-than-previous dives. The third bubble factor accounts for bubble growth over repetitive exposures on time scales of hours. These repetitive, multiday, and excitation factors, η^{rep}, η^{reg}, and η^{exc}, are drawn in Figures 4, 5, and 6, using conservative parameter values. Clearly, the repetitive factors, η^{rep}, relax to one after about 2 hours, while the multiday factors, η^{reg}, continue to decrease with increasing repetitive activity, though at very slow rate. Increases in bubble elimination halftime and nuclei regeneration halftime will tend to decrease η^{rep} and increase η^{reg}. Figure 4 plots η^{rep} as a function of surface interval in minutes for the 2, 10, 40, 120, and 720 minute tissue compartments, while Figure 5 depicts η^{reg} as a function of cumulative exposure in days for 7, 14, and 21 days. The repetitive fractions, η^{rep}, restrict back to back repetitive activity considerably for short surface intervals. The multiday fractions get small as multiday activities increase continuously beyond 2 weeks. Excitation factors, η^{exc}, are collected in Figure 6 for exposures in the range 40-200 fsw. Deeper-than-previous excursions incur the greatest reductions in permissible gradients (smallest η^{exc}) as the depth of the exposure exceeds previous maximum depth. Figure 6 depicts η^{exc} for various combinations of depths, using 40, 80, 120, 160, and 200 fsw as the depth of the first dive.

Tissue Bubble Diffusion Model

The tissue bubble diffusion model (TBDM), according to Gernhardt and Vann, considers the diffusive growth of an extravascular bubble under arbitrary hyperbaric loadings. The approach incorporates inert gas diffusion across the tissue-bubble interface, tissue elasticity, gas solubility and diffusivity, bubble surface tension, and perfusion limited transport to the tissues. Tracking bubble growth over a range of exposures, the model can be extended to oxygen breathing and inert gas switching. As a starting

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point, the TBDM assumes that, through some process, stable gas nuclei form in the tissues during decompression, and subsequently tracks bubble growth with dynamical equations. Diffusion limited exchange is invoked at the tissue-bubble interface, and perfusion limited exchange is assumed between tissue and blood, very similar to the thermodynamic model, but with free phase mechanics. Across the extravascular region, gas exchange is driven by the pressure difference between dissolved gas in the tissue and free gas in the bubble, treating the free gas as an ideal. Initial nuclei in the TBDM have assumed radii near 3 microns at sea level, to be compared with .8 microns in the RGBM.

As in any free phase model, bubble volume changes become more significant at lower ambient pressure, suggesting a mechanism for enhancement of hypobaric bends, where constricting surface tension pressures are smaller than those encountered in hyperbaric cases.

As seen in Figure 7, the model has been coupled to statistical likelihood, correlating bubble size with decompression risk, a topic discussed in a few chapters. For instance, a theoretical bubble dose of 5 ml correlates with a 20% risk of decompression sickness, while a 35 ml dose correlates with a 90% risk, with the bubble dose representing an unnormalized measure of the separated phase volume. Coupling bubble volume to risk represents yet another extension of the phase volume hypothesis, a trigger point mechanism for mends incidence.

Saturation Curve

The saturation curve, relating permissible gas tension, Q, as a function of ambient pressure, P, depicted in Figure 8 for air, sets a lower bound, so to speak, on decompression staging. All staging models and algorithms must collapse to the saturation curve as exposure times increase in duration. In short, the saturation curve represents one extreme for any staging model. Bounce curves represent the other extreme. Joining them together for diving activities in between is a model task, as well as joining the same sets of curves over varying ambient pressure ranges. In the latter case, extending bounce and saturation curves to altitude is just such an endeavor.

Models for controlling hypobaric and hyperbaric exposures have long differed over range of applicability. Recent analyses of very high altitude washout data question linear extrapolations of the hyperbaric saturation curve, Figure 8, to hypobaric exposures, pointing instead to correlation of data with constant decompression ratios in animals and humans. Correlations of hypobaric and hyperbaric data, however, can be effected with a more general form of the saturation curve, one exhibiting the proper behavior in both limits. Closure of hypobaric and hyperbaric diving data can be managed with one curve, exhibiting linear behavior in the hyperbaric regime, and bending through the origin in the hypobaric regime. Using the RGBM and a basic experimental fact that the number of bubble seeds in tissue increase exponentially with decreasing bubble radius, just such a single expression can be obtained. The limiting forms are exponential decrease with decreasing ambient pressure (actually through zero pressure), and linear behavior with increasing ambient pressure. Accordingly, Figures 9, 10, and 11 exhibit Q, G, and R as a function of P for the expression (in terms of parameters ζ and ξ. Asymptotic forms are quite evident. Such general forms derive from the RGBM, depending on a coupled treatment of both dissolved and free gas phases. Coupled to the phase volume constraint, these models suggest a consistent means to closure of hypobaric and hyperbaric data.

The Abyss RGBM Implementation

As of this writing the only commercially available decompression software that incorporates the reduced gradient bubble model (RGBM) is Abyss. The RGBM is a dual phase (dissolved and free gas) algorithm for diving calculations. Incorporating and coupling historical Haldanean dissolved gas transport with bubble excitation and growth, the RGBM extends the range of computational applicability of traditional methods. The RGBM is correlated with diving and exposure data on more complete physical principles. Much is new in the RGBM algorithm, and troublesome multidiving profiles with higher incidence of DCS are a target here. Some highlighted extensions for the ABYSS implementation of the Buhlmann basic algorithm include:

- ❑ Restricted repetitive exposures, particularly beyond 100 ft, based on reduction in permissible bubble diffusion gradients within 2 hr time spans;
- ❑ Restricted yo-yo and spike (multiple ascents and descents) dives based on excitation of new bubble seeds;
- ❑ Restricted deeper-than-previous dives based on excitation of very small bubble seeds over 2 hr time spans:
- ❑ Restricted multiday diving based on adaptation and regrowth of new bubble seeds;
- ❑ Smooth coalescence of bounce and saturation limit points using 32 tissue compartments;
- ❑ Consistent treatment of altitude diving, with proper zero point extrapolation of limiting tensions and permissible bubble gradients (through zero as pressure approaches zero);
- ❑ Algorithm linked to diving data (tests), Doppler bubble, and laboratory micronuclei experiments;
- ❑ Additional parameters reducing exposure time accounting for fitness, work load, and water temperature.

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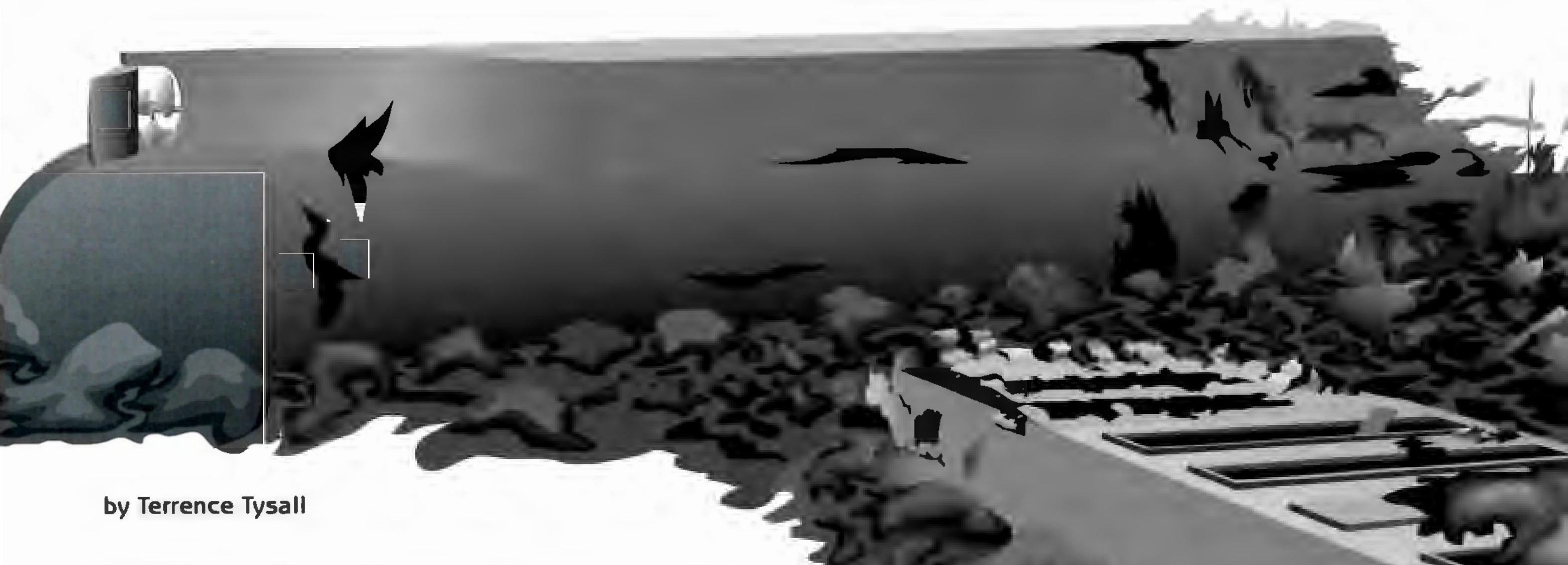

by Terrence Tysall

The Edmund Fitzgerald sank on November 10th, 1975 seventeen miles northwest of White Fish Point in Lake Superior. The Fitzgerald, a 729 foot iron-ore carrier, was loaded with 27,300 tons of taconite ore and was headed for Detroit, Michigan. At 2:00 a.m. the Fitzgerald slammed into a severe weather mass. The Fitzgerald's captain tried to avoid the worst of the storm by steering towards the north. The ship held its own for a while but the pumps, capable of pumping 32,000 gallon per minute, proved inadequate for the tremendous amount of water pouring in from the rain and crashing waves. By 3:30 p.m. the Fitzgerald developed a list. Trailing behind the Fitzgerald was another freighter, the 767 foot Arthur M. Anderson, also trying to survive the storm. At 7:10 p.m. Captain McSorley of the Fitzgerald radioed to Captain Cooper of the Anderson, calmly saying, "We're holding our own." Ten minutes later, the Anderson's radar showed no image of the Fitzgerald. The vessel had vanished

The loss of the Fitzgerald and the entire crew of twenty nine, represents one of the most tragic shipwrecks in modern history. I contemplated this loss while standing on a jetty reaching out into Lake Superior. The jetty was shaking from the impact of the colliding waves. I could hardly believe that this was the same body of water that only hours before had reflected, mirror like, the canopy of stars overhead. There would be no diving today. Once again Gitchegumee, as Lake Superior is known in Indian legend, had taught a human the meaning of the word humility.

How did I, a confirmed warm water lover, find himself standing on the shore of the largest of the great lakes? Two persons were responsible, Gordon Lightfoot, and Mike Zee. Gordon Lightfoot's influence was felt first, when he recorded his number one hit in 1977, The Wreck of The Edmund Fitzgerald. As an eleven year old boy, who was already addicted to water and diving, the song fascinated me with it's tale of the powerful lake and it's hapless victims. I recall listening to the song, picturing in my young mind a mighty ship being torn asunder by a vicious gale, and the fate of the twenty-nine crewmen.

Mike Zee's influence was first felt when I met him three years ago. I was struck by his extreme focus, and drive towards an unspoken goal. Little did I realize the goal he had in mind at that time.

Mike decided that 1995 was the year he would touch the Edmund Fitzgerald with his gloved hand as the first scuba diver to reach the wreck. No small feat considering the Fitzgerald lays under 540 feet of 36°F water in Lake Superior. For reasons known only to Mike, he decided to extend to me, the undeserved invitation to make the attempt with him. Needless to say I jumped at the opportunity.

After months of secretive planning and Mike's patient attempts to track me down via phone, we arrived at a tentative dive plan. We agreed to meet for this undertaking in the waning days of August. The original plan called for the team to assemble the third week of the month, but last minute delays prevented my departure for nearly a week.

Mike journeyed from Chicago, his home town. The rest of the small team traveled from Ontario, Canada; Orlando, Florida; and Ocala, Florida. Mike brought with him the bulk of the gas required for the multiday opera-

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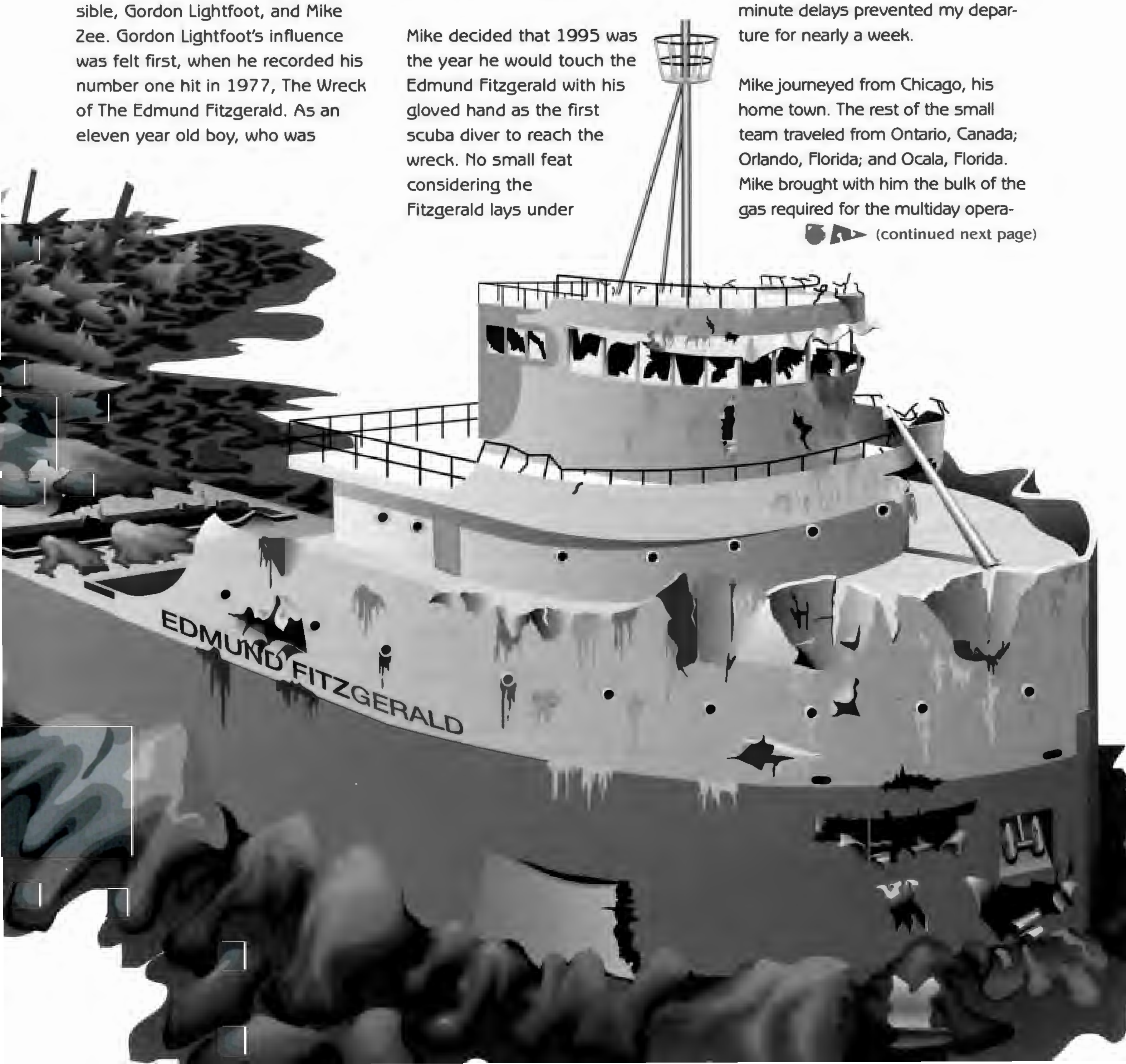
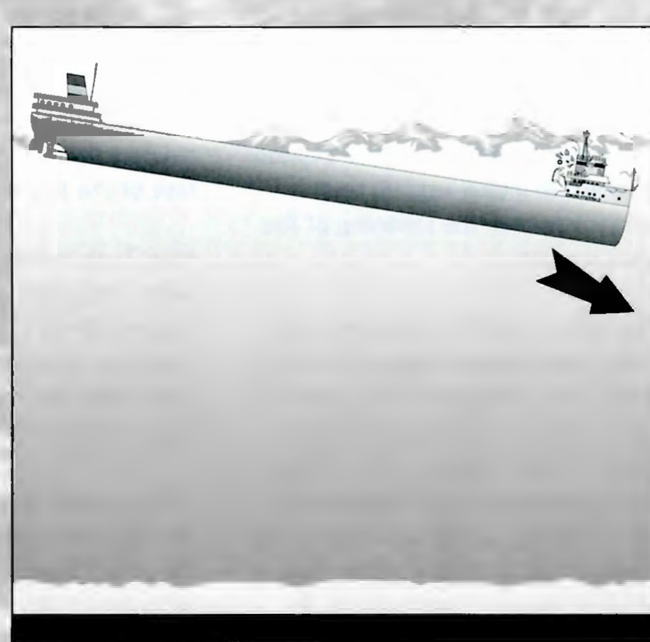


The Wreck of The Edmund Fitzgerald—A Theory

With Lake Superior winds gusting to 90 miles per hour and the waves cresting 25 feet the Fitzgerald began taking on water and listing to the left. The captain maintained power and tried to keep the bow pointed into the wind and the breaking waves.



The Fitzgerald bit deeply into an especially huge wave. The bow was driven completely underwater. The weight of the flooding water, combined with the engines and forward momentum drove the vessel underwater like a torpedo. It is believed that the Fitzgerald sank in less than a minute.

tion. I brought the two in-water support divers, Ken Furman and Mauro Porcelli. Our long journey from Florida was made in a compact pickup truck. We survived the trip by having one of us sleep in the bed of the truck, buried in stage bottles and doubles, while the other two drove in relative comfort. We rotated driving duty throughout the 27 hour nonstop trip.

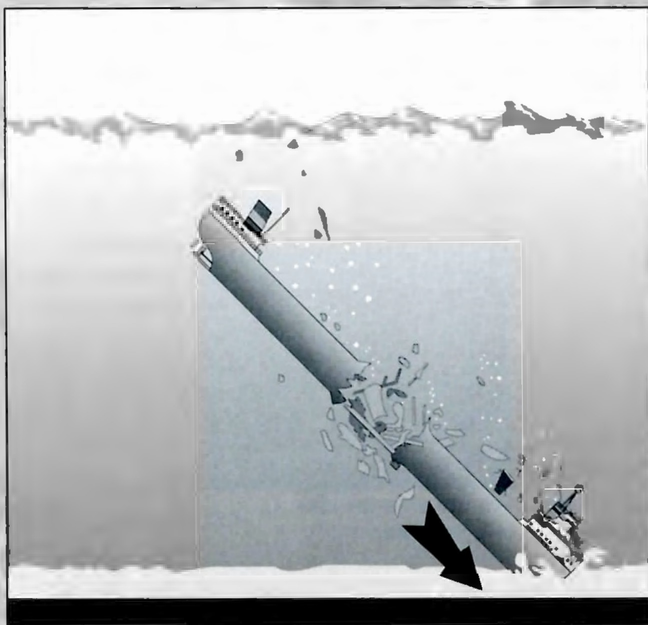
We arrived in the town of Paradise, Michigan at 3 a.m. where we met our gracious hosts for the week, Chris and Debbie of Heidi's Traveler's Motel. These generous people donated the accommodations for the whole team at there own expense. It was during this initial late night meeting that we met Mike's business partner and Captain of the R/V First One; Randy Sullivan of Lake Superior Dive Tours.

The first impression I received of Lake Superior was that of a large, calm lake. It looked as if the objective would come off without a hitch, so we chose the first day for a tune up dive. The main concern for the tune up dives was getting everyone accustomed to the low water temperatures (36°F). The wreck that Mike chose for the first dive was the S.S. Osbourn a steamship that sunk after a collision. We conducted a complete run through of the Fitzgerald dive simulating the descent and bottom phases, including support team activities. We learned a great deal from this practice.

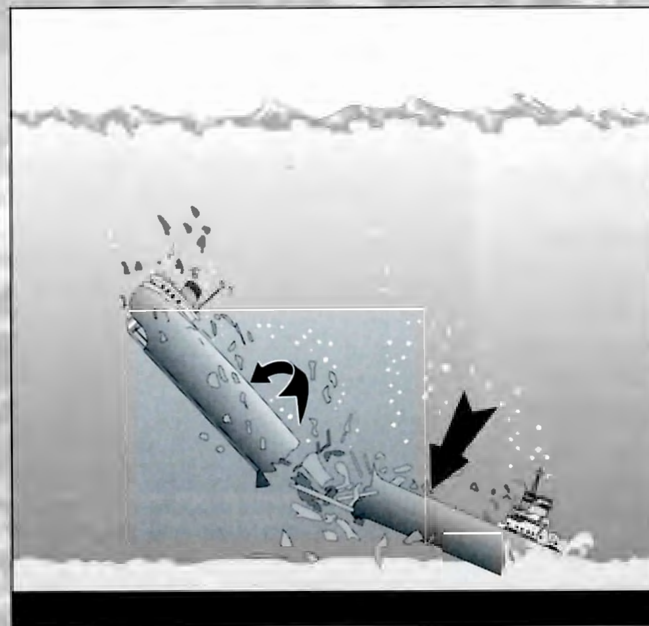
Upon reaching the Osbourn it became obvious what Charlie Tulip, Greg Zambeck, Mike, and the other veteran Great Lake divers had been telling me for years—that the wrecks located in their backyard are absolutely without comparison. I was absolutely awed viewing wrecks sunk in the 1800's with the rigging still in place. To see china, silverware, and other artifacts still resting undisturbed had a profound impact on me.

What I didn't know at the time, is that the lake had a small demonstration of her famed fury in store for us. Within hours of the completion of our first practice dive the weather changed the lake from millpond calm to ten foot, close set, steep faced waves, the likes of which I had never before seen. With winds gusting at thirty knots, the goal of our journey seemed as far away as ever.

Since there was no chance of diving during this storm, which was only average by Great Lakes standards, we used the opportunity to debrief the tune up dive and conduct a second simulated dry run of the planned dive, this time in the motel courtyard. This raised a few eyebrows from the other patrons of the motel but it tightened up the team, and gave everyone a chance to ask questions and offer suggestions. We decided if the weather cleared we would make the first available attempt to reach the Edmund Fitzgerald.



Plunging down at a steep angle the bow was driven 25 feet into Lake Superior's mud bottom until it hit bed rock. Approximately 200 feet of the ships mid section completely disintegrated from the tremendous impact.



With the ship torn in half the stern section rolled to port and landed upside down approximately 170 feet from the bow. The bow settled into the mud upright.

When we woke up the next morning, the winds had slowed a little but they were still in the twenty knot range, the chances of diving the Fitzgerald did not look good for the third day in a row. The team, however, gamely decided to make the attempt anyway. We left the dock in marginal conditions and were holding are own until our boat, the First One, rounded Whitefish Point. I have no doubt that the boat could have made it to the wreck site, but none of us would have been in any shape to conduct the dive. Suitably humbled, I realized I was unable to fathom what the men on the Fitzgerald had experienced in their final hours.

The only hope we had of pulling off the dive was a break in the weather expected the next morning. This would be our last chance, since Randy and the boat were needed elsewhere, and I had to leave that next afternoon as well.

Gloriously, the next morning, September 1, 1995, was a day made to order. There was a slight breeze out of the west, and bright sunlight dancing off the six-inch waves. Our opportunity had arrived. We were out of the harbor and rounding the point by 9:30 a.m. At 11:00 am we found ourselves seventeen miles from Whitefish Point, floating motionless above the most famous of the Great Lakes Wrecks, the S.S. Edmund Fitzgerald.

The team worked quickly until everything was ready for the dive to begin. Randy deftly kept the boat positioned above the wreck, and simultaneously lowered the special deep camera that would confirm our position over the wreck, as well as serve as our descent and ascent line. Mike and I were wearing similar gear configurations consisting of doubles (120 cu. ft. cylinders for Mike, 104 cu. ft. cylinders for me) filled with bottom mix, and an air filled 120 cu. ft. cylinder mounted pyramid triple fashion between our doubles—to be used as our travel gas. On our left we carried a 45 cu. ft. cylinder filled with a transitional mix that we hoped would help us combat counter diffusion problems on ascent. On my right side I decided to carry a spare 80 cu. ft. cylinder of air in the event one of us developed a malfunction in one of our triples. The only other cylinder we carried was our precious Argon for suit inflation.

All of the bottom mix regulators were Poseidon's. On our triples we carried Scubapro Mk15 D400's. All decompression bottles carried either Poseidon or Scubapro regulators. All connectors were DIN style.

After entering the water Mike and I proceeded to the camera line. Randy notified us of the camera location which was just off the bottom next to the port bow of the Fitzgerald. Upon completion of our

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surface checks, and Ken's studied approval, we turned on our lights, gave the nod, and thumbs down.


The Fitzgerald deep team and in-water support divers celebrate after the dive. Left to right: Mike Zee, Mauro Porcelli, Terrence Tysall, Ken Furman.

Initially we were breathing air from the triples on our backs. This was planned for a three minute descent to 250 feet where we would switch to our bottom mix, trimix 9.6/62. The first glitch appeared at 180 feet when Mike's Scubapro regulator began free flowing. Mike reacted coolly by switching on the fly to his bottom mix while I quickly shut the leaking regulator off. We quickly confirmed that we were OK, and that with the extra bottle I was carrying we still had the appropriate gas reserves necessary to continue our descent. Fortunately, as we continued our descent we were able to reactivate his air regulator for later use. At 250 feet I switched to bottom mix as well and we continued to fall into the blackness. Mike and I descended face to face so we could monitor each other for signs of High Pressure Nervous Syndrome (HPNS).

With the approach of 400 feet in depth the delicate process of slowing our descent began. I personally owe a huge debt of thanks to Jim Bowden, and Dr. Ann Kristovich for sharing their incredible power inflator concept with me. Of course, the depths Mike and I were diving is shallow stuff for those two.

When Mike and I first saw the Fitzgerald our depth was 490 feet. We descended slowly to 530 feet. I illuminated the hull and superstructure with my light. Mike and I slowly made our way along the wreck being careful not to disturb anything out of respect for the lost crewmen. These first glimpses of the Fitzgerald gave the feeling of extreme darkness, cold, and isolation. Mike and I looked at each other, and then we gently gripped the ghostly rail with both hands. For the first time in almost 20 years living hands were touching the Edmund Fitzgerald.

After exploring for twelve minutes it was time to say good-bye and begin the long trip back to the surface. The Dr. X software that we chose for the dive gave us two minutes to get to our first decompression stop at 310 feet, where we would switch to our transitional mix (trimix 16/35). Using Sheck Exley's recommended back-switching technique we hoped the transitional mix would give us a smoother physiologic transition to a lower helium mix. The first gas switch was followed by a 30 ft. per min. ascent to our next stop at 210 feet where we switched to air. The deep stops went smoothly, so much so that Mike and I allowed ourselves the luxury of a congratulatory handshake at 180 feet.

The next critical step came when the deep support diver, Ken Furman, would meet us 25 minutes into the dive with our EANx40. Waiting as if it were just another tune up dive, Ken immediately helped Mike attach his nitrox to his right side and settle into the next phase of decompression. Ken then relieved me of my extra air bottle and gave me my EANx40 as well. Ken returned to the surface to don an extra bottle of EANx40 to have ready in the event of equipment failure. This was accomplished in record time followed by Ken floating effortlessly above us, watching. It was shortly after our ascent to our 80 foot stop that Mike's nitrox regulator decided to grenade. Mike and Ken reacted so quickly and smoothly that it was a lesson just to watch. Ken had Mike's bottles switched so quickly that we lost only a minute from our run time.

Ken then went to the surface to get another EANx40 cylinder (yes—we had four ready to go—remember those what-ifs). It was while Ken was on the surface that my nitrox regulator decided to freeze and free flow. I began to doubt the wisdom of the earlier congratulatory handshake. After shutting down the free flow I signaled the surface via the underwater camera Randy was watching us with. Ken grabbed the other EANx bottle and headed back down, this time with Mauro. Presumably, the two of them arrived at our location thinking that Mike and I were incapable of decompressing without embarrassing ourselves. I had managed to temporarily solve my problem by breathing directly from the nitrox cylinder valve. I opened the valve and sipped some nitrox when I needed to inhale and then immediately closed it while exhaling. By the time we arrived in the balmy 40 degree water of the shallower stops, the regulator had thawed enough for me to open the valve and the regulator functioned flawlessly from that point forward.

Meanwhile, Mauro and Randy had deployed the surface supplied oxygen so we could begin the final phase of the decompression. We took air breaks every 25 minutes to limit our Central Nervous System (CNS) exposure. Mauro then took over baby-sitting duty, relieving Mike and myself of our extra stage bottles to make our longer decompression stops more comfortable. One of the handy things about hanging in the lake was that when you got thirsty at least you had water readily available to drink.

Once we had completed the required stops Mike and I slowly surfaced, where Ken and Mauro helped us remove our triples in the water with as little exertion as possible. Then, we added our own safety factor by breathing oxygen for thirty more minutes while lazily floating on the surface.

Reflecting back on the dive I am left with a couple of impressions and thoughts. The first is that of gratitude: gratitude for Mike asking me to accompany him, gratitude for surviving a dive where sucking gas from a cylinder valve became necessary, and especially gratitude for Ken, Mauro and Randy who made the dive possible with their expert support. I've thought often of the Fitzgerald since the dive. The mighty ship seems lonely in the cold dark water beneath Lake Superior. It is astonishing to think that an enormous ship like the Fitzgerald can be sunk by a storm on a lake. Gordon Lightfoot was right when he said that Superior never gives up her dead.

Terrence Tysall is an explorer, a former U.S. Navy Seal, and the co-owner of the Orlando Dive Center (ODC) in Orlando, Florida. He conducts special dive expeditions throughout the United States, Mexico, South America, and the Caribbean through the ODC.

DIVING THE SCALES OF JUSTICE

An Overview of the Legal Aspects of Risk Management (Part 1)

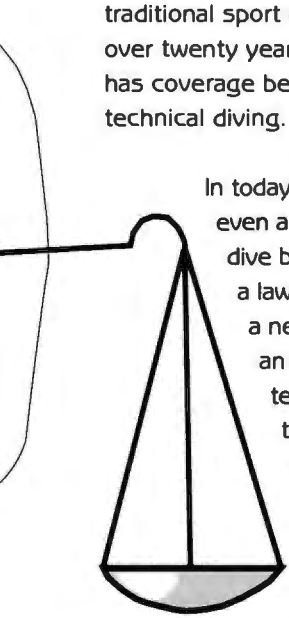
by Bret Gilliam

Did you ever tell someone that diving is a safe sport? Big mistake, you weren't being accurate. Safe means "without risk". Nothing in life is safe. And ultimately it all comes down to dealing with the reality of risk in business, sport, love and especially when ordering take out food.

There are few buzzwords to come into widespread use more important to professional instructors than "risk management" in today's society of litigation. Let's face it, a jury recently gave almost ten million dollars to a woman who was stupid enough to put a boiling cup of McDonald's coffee between her legs and then was surprised that it burned her when it spilled. Jackpot! It's easier than winning the lottery.

Insurance

Luckily there are some relatively simple steps that dive instructors can take to help balance the odds in their favor. The obvious first step is to acquire professional instructor liability insurance. Insurance has been available to cover traditional sport diving training for over twenty years but only recently has coverage been available for technical diving.



In today's society where even a stubbed toe on a dive boat is an excuse for a lawsuit, the spectre of a negligence claim from an accident in a technical diving training program is simply too horrible to contemplate for several reasons. First of all, every nutcase that doesn't approve of tech diving in general (a la Skindiver magazine) will fall over themselves wanting to testify as experts against the poor instructor who ran the class. Secondly, by definition, tech diving is outside the traditional limits envelope and does not, therefore, meet that standard of instruction. Lastly, without specific insurance coverage for our particular and very esoteric needs, our butts are swinging in the wind with no guarantee of defense costs. Indeed, the cost for a successful defense for an innocent instructor could very well bankrupt the individual or his business.

Part of my business is legal consulting in precisely this arena. I've been involved in nearly 200 cases, on both defense and plaintiff sides, since 1972. One thing I can tell you for certain is that it doesn't make one bit of difference whether you are Sister Theresa, and Jesus Christ himself appears as a character witness for you...if you haven't got insurance you are going to be staring down the face of some serious bills—even if you did nothing wrong.

Of course, there were plenty of pious "experts" out there who were quick to jump on their soapboxes and proclaim that technical diving activities could never obtain insurance at any cost! That notion was shot to hell after I met with Peter Meyer of Jardine Rolfe Ltd. in 1993. Peter is a senior vice president who specializes in coverage for the diving industry. He has handled programs for NAUI, SRA, retail and resort facilities, and a variety of liveaboard and day dive vessels. It also helps that Peter is a dive instructor himself.

Peter was willing to make a presentation on behalf of the tech training agencies and was able to secure insurance coverage that was, in essence, identical to regular sport instructor coverage including expanded limits to 5 million dollars. This would provide coverage for decompression diving, mixed gas, rebreathers, nitrox, and deep air diving to 220 fsw. This year he also was able to add a combined policy option that would provide coverage for both traditional sport training and tech courses for one premium. Variations of this same policy can be purchased through TDI and IANTD.

It doesn't make one bit of difference whether you are Sister Theresa, and Jesus Christ himself appears as a character witness for you...if you haven't got insurance you are going to be staring down the face of some serious bills—even if you did nothing wrong.

At TDI, we went one step farther to have our combined policy cover not only NAUI, PADI, SSI, NASDS, YMCA, L.A. County etc., but also NACD and NSS-CDS. This was accomplished by officially sanctioning the course standards and curricula of each agency. As long as instructors are on active teaching status with TDI and with the other agency they wish to certify through, they may train divers and be fully covered. And TDI doesn't require duplicate certification cards to be issued like other agencies have done.

If you own a home or a business and teach technical diving you would have to be nuts not to want this insurance protection. Even if your total net worth consists of a 1975 Ford pickup truck, six sets of doubles, and a dog with a bent tail, you are not immune to a lawsuit. Your future earnings and property can be attached for the rest of your life. And you will pay.

I appeal to every instructor to sit down and consider the sobering circumstances for all of the tech community if we were to lose a lawsuit. Then consider your own personal loss if it happens to you. For less than $600 you can buy a million dollars of coverage that guarantees to defend you and pay out in the event of a plaintiff's verdict. How much justice can you afford on your own? Not much.

Law Primer

It would be great if we could just buy insurance and then teach the best course we are capable of with the

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confidence that if an accident happened, the insurance company would pay for a top notch defense and the jury would be convinced that we did the best job of training that we could and acquit of us any wrongdoing. Yeah, right! And the strongest drugs Keith Richards ever did were No-Doz and black coffee!

Okay, time for Basic Personal Injury Law 101. Pay attention, there could be a real life quiz later that will really empty your wallet. Four things basically have to happen to allow a plaintiff (the guy who's suing you) to recover money:

1) He must be able to show damages, either financial or physical or both.
2) He must be able to show that you had a duty to provide training in an atmosphere of reasonable safety and...
3) That, by acts of commission or omission, you breached that duty.
4) Finally, that his damages were the proximate (direct) cause of your negligent performance.

I could make it sound a lot more complicated and throw in some flowery legalese that would send you running for a dictionary, but this pretty much sums things up. And remember another part of the personal injury equation: you will be judged by what the community believes to be conduct that a reasonably prudent dive instructor would display in similar circumstances.

So let's take a practical example: Jack Smith signs up for a basic dive course. He has never dived before and wants to learn. Bob Jones accepts him as a student. A payment in the form of a course fee is exchanged. At this time, a basic contract exists between these two persons that Jones will teach Smith to dive and look after his well being and safety during all aspects of that course.

However, Smith misses the class about the consequences of holding his breath on ascent and Jones never covers the material with him when he shows up for the first pool session. Sure enough, he holds his breath from the deep end of the pool when he accidentally floods his mask and panics. Smith suffers a fatal arterial air embolism and his family sues Jones.

1) Has Smith got damages? You bet, he's deader than the Buffalo Bills' chance at another Super Bowl.
2) Did Jones have a duty to provide a reasonable environment of safety for the dive course.
   Bet your ass.
3) Did Jones breach that duty. Right again, grasshopper. Smith never knew he shouldn't hold his breath while

breathing from scuba because Jones never told him so.

4) Did Smith die because of Jone's negligence? Bingo! You win the personal injury lottery and collect a million dollars.

I chose this example to hammer home a point. In entry level scuba instruction, the students really don't know anything at the outset. They are blissfully unaware of the hazards of diving until you, as the instructor, explain things like bends, embolism, sea urchins, and hot coffee. They are, to draw an elemental analogy, a blank slate that you will fill in with information from which they can make decisions about how to conduct themselves while enjoying the sport.

Of course, you give them a waiver to sign in which they are asked to assume the risk for the activities they will take part in. Are they capable of understanding and assuming that risk as neophytes? Arguably not in many situations.

Herein lies one of the fundamental differences between technical dive training and entry level open water training. Tech students have already been certified and had the chance to acquire some experience. They understand the consequences of breath holding on ascent, of decompression sickness, of running out of air and drowning. They are legally capable of understanding and assuming the risk of the training they are signing up for. That's why a properly executed waiver and release form is absolutely vital as part of your risk management. Because it may kick a lawsuit out of court on summary motions effectively telling the plaintiff to take a hike.

Look at this tool as your first line of defense. It's a contract between you and your student that says "hey, diving is potentially dangerous, here's a nice list of all the ways you can kill or injure yourself, you understand these risks and agree not to sue me even if I screw up and something nasty happens to you".

Is it really that simple? Not quite, but we're getting there. Tune in next issue for Dr. Gilliam's prescription for waivers and how to make them work for you.

Bret Gilliam is the President of TDI and ex-Chairman of NAUI's Board of Directors. He pioneered much of the risk management programs for technical diving and collaborated on writing defensible standards for technical dive training. He is actively involved in defending law suits against the diving industry as a consultant and expert witness on liability issues. He even unabashedly admits to having lawyers as friends.

Do it Right, Or Don't Do it!

by George Irvine

A dive instructor I know recently had a student show up for a cave diving course with a rectangular dive light, a scooter cage, a helmet, and a convoluted independent doubles rig. This student already knew what he wanted from his cave course presumably from reading the advertisements. His first comment to his amused instructor was that he was not quite ready to try a 1,000 foot penetration dive, but his cave diving merit badge would be a good start. He never once asked for his instructor's opinion. And his instructor happens to be one of the most experienced cave divers around. Unfortunately, much of the day was spent teaching buoyancy control to this new "tech-diver."

On the technical diving discussion groups, that are popular on the internet (techdiver, cavers, etc.), I routinely see recommendations for gas mixtures known to cause seizures and heavy narcosis by people who boast every qualification except having been there or done it themselves. I read comments from people who claim to have the ability to dive deep-on-air and "handle" the narcosis. I read justifications for dangerous gear configurations under the guise of personal preference. I read report after report of deaths of "tech-divers" who apparently believe that technical diving means depth. I read about training agencies who sell certifications for asinine specialties, like "technical deep air", or "advanced technical nitrox." Especially insidious are the rebreather pushers, who offer the desperate techdiver the diving equivalent of a cure for AIDS, but like the elixir salesmen of the wild west will leave death and destruction in their wake and leave us with regulation from the likes of the FDA. If people really understood these devices, they would run screaming from the room, and would certainly not take instruction on so sophisticated a device from someone with no engineering or technical background, let alone the cadre of under educated instructors who apparently don't understand high school math judging from their performance in teaching dive academics.

Diving is a wonderful sport that can be enjoyed your whole life. Why not just do it right? It is a physical activity that is best enjoyed if one is in good shape. After all, the finest piece of dive gear you own is you! Get in shape, get a physical, and have your doctor check you for predispositions to DCS and other dive related problems before you dive.

When the time comes to gear-up for a dive, remember that less is always best. Why encumber yourself with excess underwater baggage. Less gear is more streamlined, more comfortable, more effective, and therefore more safe. If you don't need it, don't take it. Keep it simple. There are no unseen demons in diving. Rigging your gear to prevent non-problems is counterproductive. For example, independent valves are an attempt to avoid a failure in the manifold. Manifold failures seldom, if ever, occur. Independents add complexity and risk due to the air management rules required to use them effectively. Not to mention the difficulty in sharing gas with another diver in an emergency. Remember the buddy system? Remember the basics? When the shit hits the fan, they're the only thing that will save you, so you had better get them mastered.

I am fortunate to be the director of a research and exploration organization called the Woodville Karst Plain Project (WKPP). Our group conducts research dives around Tallahassee, Florida. One member of the WKPP, William Hogarth Main, happens to be the person for whom the Hogarthian system of gear configuration is named.

The Hogarthian system has a few simple tenets and principles. It relies on simplicity and skill rather than complexity and equipment. The primary piece of equipment is the mind and body of the diver, which must be in excellent condition. The next most important piece of equipment is the buddy, who must likewise be fit and configured the same, since it is the buddy's job to provide redundancy.

The Hogarthian diver's gear is in perfect condition from maintenance and is clean and streamlined, with no elbows, swivels or convolutions of hose routing or anything else that is not absolutely necessary. It is proven gear of the highest quality with no consoles, computers, gadgets, widgets, or dangling nonsense of any kind. There is nothing in front of the diver. Everything is hidden away neatly. All of the diver's motions are unencumbered and his solutions to every contingency are simple and straight forward.

With all of the macho deep-air divers and officious nouveau techies running around, it is easy to lose sight of the basics, and the objective, which is to have fun. If it doesn't feel like fun, then it's not. If it's not clean and simple, it's not Hogarthian. If it's not Hogarthian, it's not right. If you're not doing it right, don't do it at all!

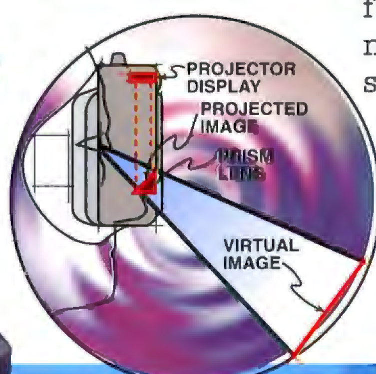
en·a·bling tech·nol·o·gy (en ā´bling tek nol´ə jē), noun 1. An applied science or engineering that, by its very existence, empowers a person to do what he otherwise would be incapable of doing. 2. A scientific or technical breakthrough that lays the foundation for entirely new activities and groups of products.

A Peek Inside the Lab at Cochran Undersea Technology

Cochran's patented hoseless dive computer technology is a classic example of an "enabling technology". The exclusive Cochran Nemesis dive data telemetry methodology provides a high-throughput data path, rapid data sample rates, extreme reliability and display independence.

The unique ability of the Nemesis to work with multiple displays lays the foundation for more exciting new products... like Cochran's Dive Master™ group diver management system. Dive Master, which allows a dive leader to track key dive telemetry from up to ten neighboring Nemesis series computers, is already in use today by progressive student training operations around the world.

And even more exciting products are being tested now in the laboratories at Cochran Undersea Technology. What would trip *your* trigger? How 'bout a small, low profile dive mask with integrated "heads up" display?



We've seen one under development in the Cochran lab! Codenamed "Spectacle", this mask displays all mission dive information directly at the bottom of the

Spectacle is being developed as part of the growing family of alternate displays for existing Nemesis series dive computers. Insiders expect it to be on the market next year.

Dive Master™ and the Spectacle™ are two more reasons to make your next dive computer a Nemesis II. From Cochran Undersea Technology. World leaders in dive instrument science.

To preview the latest Cochran enabling technology call 1.800.856.DIVE for the name of a Team Cochran retailer near you.

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