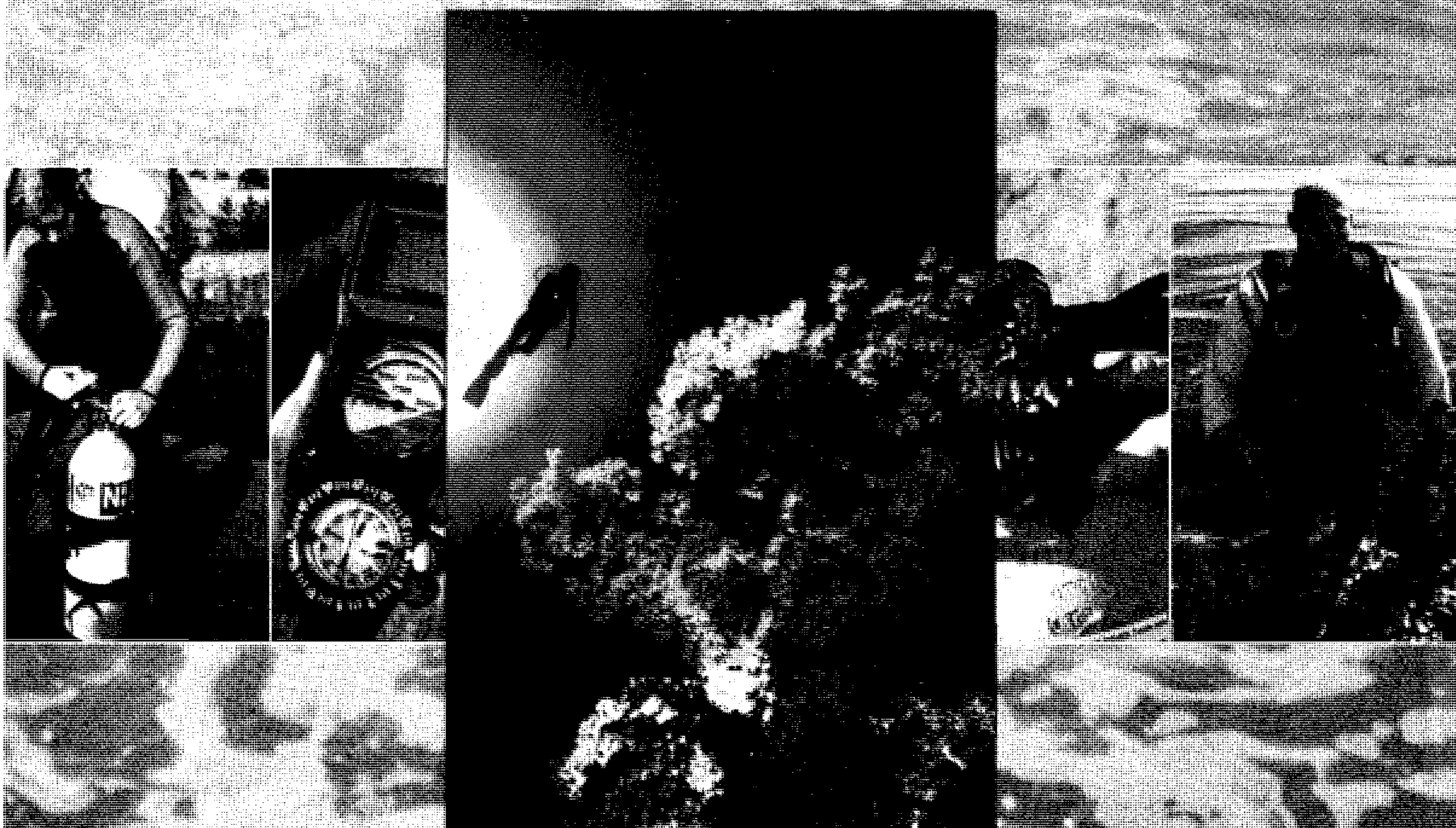
DAN Nitrox Workshop Proceedings



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DAN NITROX WORKSHOP PROCEEDINGS

November 3 and 4, 2000

Michael A. Lang, Editor
Nitrox Workshop Chair

Divers Alert Network
Durham, NC

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Opinions and data presented at the Workshop and in these Proceedings are those of the contributors, and do not necessarily reflect those of the Divers Alert Network.

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Contents

ABOUT DIVERS ALERT NETWORK
www.DiversAlertNetwork.org

Divers Alert Network (DAN®) is a 501(c)(3) non-profit organization associated with Duke University Medical Center in Durham, North Carolina. Since 1980, DAN has served as a lifeline for the scuba industry by operating the industry's only Diving Emergency Hotline, a lifesaving service for injured scuba divers, available 24 hours a day. Additionally, DAN operates a diving Medical Information Line, conducts vital diving medical research, and develops and provides a number of educational programs for everyone, from beginning divers to medical professionals.

Divers Alert Network is supported through membership dues and donations. In return, members receive a number of important benefits, including access to emergency medical evacuation, travel and personal assistance for both diving and non-diving needs, DAN educational publications, a subscription to *Alert Diver* magazine and access to diving's premier dive accident insurance coverage.

Your Dive Safety Association, DAN currently has more than 200,000 members worldwide.

The DAN Vision

The DAN vision is to be the most recognized and trusted organization worldwide in the fields of diver safety and emergency services, health, research and education by its members, instructors, supporters and recreational diving community at large.

The DAN Mission Statement

Divers Alert Network (DAN), a non-profit organization, exists to provide expert medical information and advice for the benefit of the diving public. DAN's historical and primary function is to provide emergency medical advice and assistance for underwater diving injuries and to promote diving safety.

Second, DAN promotes and supports underwater diving research and education, particularly as it relates to the improvement of diving safety, medical treatment and first aid.

Third, DAN strives to provide the most accurate, up-to-date and unbiased information on issues of common concern to the diving public, primarily, but not exclusively, for diving safety.

ACKNOWLEDGMENTS

I wish to extend sincere appreciation and acknowledgment to my colleagues on the 2000 DAN Board of Directors: Dr. Peter B. Bennett, Dr. Paul S. Auerbach, Mr. William M. Ziefle, Mr. Michael N. Emmerman, Dr. Alessandro Marroni and Dr. Karen Van Hoesen. This diving safety research effort would not have been possible without DAN financial support and the foresight of the Board in approving it. The Workshop's timely nature and the full cooperation of the participating diving experts have proven to be a significant contribution to the recreational diving industry.

Many thanks to the workshop papers' authors, especially Dr. Bill Hamilton, Dr. Richard Vann, Dr. Dan Kerem, Mr. Bill Oliver, Mr. Elliot Forsyth and Dr. Bruce Wienke, who helped tremendously by submitting their manuscripts on time. The short turn-around time for the production of proceedings for a workshop of this scope is unprecedented and could not have taken place without their full cooperation.

Of major significance is the collaboration of the principals of the recreational nitrox diving training organizations: Ed Betts, Bret Gilliam, Jon Hardy, Drew Richardson, Tom Mount and Bruce Wienke. ANDI, TDI, SSI, PADI, IANTD and NAUI assisted immeasurably in attaining workshop objectives by agreeing to contribute their agencies' nitrox diving and certification numbers, an exemplary cooperative industry effort.

Ms. Cathy Jones provided transcription services of the extended workshop discussions.

DAN Staff who were helpful during various phases of this workshop's organization and conduct deserve special recognition: Sherry Strickland and Cindy Duryea for logistical support, and Peter Winkler for his technical computer assistance during the workshop.

Finally, I thank Jennifer Dorton, Smithsonian Museum of Natural History Diving Officer, for her assistance with this project. The Smithsonian's Office of the Under Secretary for Science - Scientific Diving Program provided support for the editing, compilation and camera-ready production of these proceedings. Divers Alert Network funded this document's publication.

Michael A. Lang
Smithsonian Institution
DAN Board of Directors
DAN Nitrox Workshop Chair

DAN NITROX WORKSHOP INTRODUCTORY REMARKS

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As Workshop Chairman, and on behalf of the Divers Alert Network (DAN) Board of Directors, I take this opportunity to welcome you to the DAN Nitrox Workshop. I am pleased to acknowledge the Divers Alert Network for providing the financial support and sponsorship of this event. I also formally thank each of you for your participation and contribution to this diving safety effort.

The use of nitrox has vested itself as a mainstream recreational diving activity since it was first introduced to sport divers in 1985. How much so? PADI, SSI and NAUI now support recreational nitrox training programs in addition to their traditional open-circuit compressed air programs. The focused technical diving training agencies, IANTD, ANDI and TDI, have amassed several additional years of experience in providing nitrox training to the recreational diver.

Why was this diving safety project of interest to the industry and prioritized by means of DAN's support? As with any emerging technology that has found a broader market appeal, controversies invariably arise. Ignorance, myths and misconceptions often fuel opposite views. A critical examination of the current issues surrounding nitrox diving was in order to disseminate credible diving safety information. This forum was provided to objectively debate the issues and to discuss the available nitrox operational and physiological data, risk management, equipment and training parameters.

An approximation of the magnitude of nitrox consumption was essential. This seemed achievable by our ability to provide a denominator of nitrox divers and nitrox dives, as a sub-set of the overall level of recreational diving activity. Many other discussions of nitrox topics flow from these numbers, *e.g.*, nitrox DCS incidence rates compared to air, and nitrox training and equipment sales growth.

Physiological issues such as carbon dioxide retention and oxygen toxicity were also in need of critical examination. Consideration of nitrox training and equipment issues contributed were needed to comprehensively address risk management and legal considerations regarding the use of nitrox.

The recreational diver will be the ultimate beneficiary of our improved collective knowledge of the state of the art of nitrox diving in 2000. The intermediary beneficiaries of this information will be the providers and manufacturers of nitrox products (instructors, equipment, dive stores and nitrox dispensers). To these entities we collectively direct this up to date expert knowledge.

In effect, we are trying to paint a more accurate picture of nitrox diving in the year 2000 with specific emphasis on its use by the recreational diving community. In order for us to start on the same wave-length, a self-introduction of workshop participants and a review of the workshop agenda are in order (see Appendices). The development of this agenda was an iterative process that resulted in the main topics most participants felt were in need of discussion. The topic being nitrox, we're all going to look green and yellow after a day and a half of discussion, which is why all PowerPoint slides are those colors.

I invited Dr. Bill Hamilton to give us a brief historical overview of nitrox (oxygen enriched air) use. Next, one of the most important sessions is a review of the nitrox operational data. We are attempting to get a much better approximation of the amount of nitrox diving actually occurring in the recreational diving community. I wanted to not only examine the numbers of nitrox certifications of instructors and divers, but also make a first attempt to determine how much nitrox diving is taking place. Dr. Vann will then start with a factual presentation of the DAN database as it relates to nitrox diving.

The organizational data follows next, which I have separated into three groups: The first being the recreational nitrox training agencies. We have tabulated the submitted data and will project it on the screen for discussion. The second group represents the scientific diving community. I feel it is important to give this perspective and compare the recreational nitrox experience to more controlled programs that have done a significant amount of nitrox diving. Finally, we will get a glimpse of liveaboard nitrox diving, that deals with essentially a short-term captive population of recreational divers.

The third session is nitrox physiology. Dr. Kerem is here to discuss CO_2 retention as the first speaker. The second topic, maximum PO_2 limits, is a discussion session. I've asked Jon Hardy, who is currently performing a project on testing nitrox as a product, to share his preliminary results. For the discussion of risk management issues, we have Bill Turbeville and Karl Shreeves who will give us the milestones on the recreational nitrox variance from the Occupational Safety and Health Administration. Legal considerations and particular cases will be discussed by Bill Turbeville and Jon Hardy. Finally, the nitrox curriculum surfaced as a suggested topic of discussion.

In the nitrox equipment session tomorrow, Bill Oliver will inform us of what he is currently doing on behalf of the Diving and Equipment and Marketing Association (DEMA) with regards to the equipment manufacturers' nitrox issues. Elliot Forsyth is here to talk about oxygen compatibility and the 40 percent oxygen cleaning rule.

I appreciate that many of you have personal opinions on these topics, but we want to provide factual data, technical specifications, authoritative reports or reliable information that will assist in the separation of fact from fiction. A review is then provided of the currently available nitrox compatible dive computers. Finally, I have scheduled a roundtable workshop discussion for the promulgation of recommendations.

My objective is to prepare these workshop proceedings as a deliverable end product in time for public release at DEMA 2001 in New Orleans.

A self-introduction of workshop participants followed:

- Bruce Wienke, Los Alamos National Laboratories, also representing NAUI.
- Morgan Wells, Undersea Research Foundation.
- Dick Vann, Research Director of DAN.
- Karen Van Hoesen, UCSD Medical Center and DAN Board of Directors.
- Bill Turbeville, attorney at law specializing in diving legal matters.
- Ed Thalmann, Assistant Medical Director of DAN.
- Karl Shreeves, PADI and Diving Science and Technology (DSAT).
- Dick Rutkowski, Hyperbarics International and Undersea Research Foundation.
- Drew Richardson, PADI and Diving Science and Technology.
- Bill Oliver, representing DEMA.
- Tom Mount, IANTD.
- Richard Moon, Medical Director of DAN.
- Alessandro Marroni, President of DAN Europe and European Committee for Hyperbaric Medicine, DAN Board of Directors.
- Doug Kesling, National Undersea Research Center at the University of North Carolina, Wilmington.
- Dan Kerem, three years retired from Israeli Navy Medical Institute and President of Israel Marine Mammal Research and Assistance Center.
- Walt Jaap, American Academy of Underwater Sciences and Florida Marine Research Institute.
- Jon Hardy, representing SSI, and Rodale's Scuba Diving Magazine.
- Bret Gilliam, TDI.
- Evin Cotter, Aggressor Fleet.
- Elliot Forsyth, Wendell Hull & Associates.
- Mike Emmerman, Special Operations Support Group and Chairman, DAN Board of Directors.
- Dave Dinsmore, Director of the NOAA diving program.
- Petar Denoble, DAN Research.
- Chris Borne, Johnson Space Center Neutral Buoyancy Lab.
- Bart Bjorkman, EnviroDive Services.
- Ed Betts, ANDI International.
- Michael Lang, Smithsonian Institution, and DAN Board of Directors.
- Peter Bennett, President of DAN.

Observers:

- Jacob Freiberger, Duke Medical Center
- J. D. Hobbs, Duke Research.
- Klaus Torp, Duke Medical Center.
- Bill Clendenen, Training Director, DAN.
- Dan Orr, Executive Vice President, DAN.

A BRIEF HISTORY OF DIVING WITH OXYGEN-ENRICHED AIR USING OPEN-CIRCUIT APPARATUS

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Breathing mixtures of oxygen and nitrogen that have more oxygen than air were undoubtedly used by some of the developers of early diving equipment, and such mixes were studied by the U.S. Navy; most of these were oriented toward use with rebreathers. The first serious investigation of oxygen-enriched air as a breathing mixture for use with open circuit breathing apparatus was by Dr. Morgan Wells of NOAA, beginning in 1977. The benefit of such mixtures is only as an improvement of the decompression situation, manifested as longer no-stop times, shorter decompressions, or more conservative dives when used with tables designed for air. Techniques for making and using such mixtures, particularly 32% and 36% oxygen, were developed and promulgated by the NOAA Office of Undersea Research and its Center at the University of North Carolina at Wilmington. Terminology for use with these mixes has been confusing. The term "nitrox" introduced by Dr. Wells and widely adopted elsewhere was originally intended for mixtures lower in oxygen than air. Other terms are enriched air nitrox, EANx, and oxygen-enriched air (OEA). Although the use of OEA was accepted by the scientific diving community, when offered for recreational diving it met with considerable resistance and controversy. Realistic concerns were that mixing and handling the gas could be dangerous, and that using mixtures enriched in oxygen could invoke oxygen toxicity. Several methods for making OEA are now available without having to handle high pressure oxygen. Several organizations were set up primarily to provide training in diving with OEA, and recently the major recreational diving training "agencies" have embraced OEA.

Introduction

This workshop was convened to address the matter of recreational diving with a special category of breathing gas, described as oxygen-enriched air and popularly called "nitrox." For recreational diving the implication is that the divers are using open-circuit scuba apparatus. This paper reviews the history of the technology of using this set of gas mixes, beginning with a brief review of the practical considerations of what is needed to do it and how it is done, followed by a review of the milestones in its development.

I am indebted to many colleagues, some named and some not named here, for virtually all of the information collected over many years on this topic. Even so, these comments represent my own perspective and opinion, and no one else is to blame. My sincere apologies to anyone whose toes I tread upon.

This group was assembled to investigate many of the elements of the "practice" of recreational diving with oxygen-enriched air or "nitrox." The practice involves several aspects of diving that are not part of normal recreational diving, and because of this there was some early controversy about "nitrox" for use by recreational divers. Some doubt still persists as to how best manage the many steps and functions of recreational use of oxygen-enriched air breathing mixtures.

It might be useful to define "recreational" diving. Recreational diving in the USA is generally defined as the type of diving taught by the organizations or "agencies" that train these divers. Traditionally, this has been limited to open-circuit scuba diving with air as the breathing gas to a depth no greater than 40 msw (130 fsw), and without requiring decompression stops. (In other countries the limits may extend to 50 msw and allow limited decompression patterns.) These limits are not established by law, but rather by tradition; they just represent the scope of normal training activities. It should come as no surprise that the suggestion that divers breathe a mixed gas instead of air might not be well received by some people brought up in the recreational diving community.

Background Considerations: Physiology

By way of background information the physiology of diving in the recreational range with oxygen-enriched air (OEA) is reviewed.

Decompression

The incentive for using an oxygen-enriched breathing mixture is to improve decompression. This is not just the primary incentive, it is the only reason to do it. There are several facets to this. If the decompression obligation is based on the nitrogen fraction only, as seems to be the case, then a mix with more oxygen and less nitrogen should be better.

Although these are aspects of decompression, the use of such mixes has several manifestations. The most common situation is for no-stop dives (dives not requiring decompression stops), which allow for greater bottom times when oxygen-enriched air is used. If the dive is one where decompression stops are required, the total decompression time will be shorter with OEA. For repetitive dives, OEA may allow a shorter surface interval, and/or more no-stop time on the second dive.

These are cases where the no-stop time or decompression is based on the actual nitrogen partial pressure, determined by using the "equivalent air depth" or by calculations or tables designed for the appropriate gas mixture. Another situation prevails when enriched air is breathed and decompression tables for air are used. In this case, the decompression times are not affected, but the dives done with OEA are considered to be more conservative. This benefit can apply to repetitive dives, flying after diving, and diving at altitude.

Oxygen toxicity

Oxygen exerts its toxic effects on divers in two different ways . The first category is a set of effects on the central nervous system (CNS) from exposures to high levels of oxygen for relatively short times. The important manifestation of this CNS toxicity is an epileptic-like convulsion that may occur without warning. The other category is predominantly characterized by effects on the lungs (chest pain, coughing, and a reduction in vital capacity), and this category also includes a more diffuse set of symptoms (paresthesias, numbness of fingertips and toes, headache, dizziness, nausea, and a reduction in aerobic capacity). These symptoms collectively are called "whole-body" oxygen toxicity. They may develop after many hours of exposure to levels not high enough to invoke the CNS effects. Whole-body exposure is monitored in "units" (UPTD or OUT). Diving with OEA in the recreational mode is not at all likely to invoke the whole body syndrome, but the exposure can be tracked (the OTU count) and the chance of getting symptoms can be predicted (Hamilton, 1989).

CNS toxicity represents a very real and possibly very dangerous risk. It is a real risk because it is possible for divers on OEA to breathe gas mixtures high enough in oxygen to get a toxic dose. It is dangerous to a scuba diver because a convulsion usually causes a diver to spit out the mouthpiece, in which case the diver is quite likely to drown unless rescued. Fortunately, it is possible to eliminate or greatly reduce the risk of a convulsion by managing the diver's exposure to oxygen.

Narcosis

Another physiological effect of air or enriched-air mixtures is inert gas or nitrogen narcosis. Narcosis is not an important issue in enriched air diving because the depths where these mixes are efficient are too shallow to invoke serious narcosis in most divers. Even so, a claim made by some proponents of "nitrox" is that it reduces narcosis. There is no objective evidence that this is the case. It is not likely because the properties of oxygen suggest that this gas should be even more narcotic than nitrogen, and limited experimental work supports this idea (Bennett, 1970; Linnarsson *et al*, 1990).

Carbon dioxide buildup

Buildup of carbon dioxide is not really a unique concern of diving with nitrox mixes, but CO_2 has been cited as a hazard for divers in the deeper range of enriched air nitrox diving (Lanphier and Bookspan, 1996). One of those recognized as a pioneer of diving with oxygen-nitrogen mixtures is the late Dr. Ed Lanphier. While studying use of these mixes for diving he discovered the phenomenon of CO_2 retention. This condition causes a person to have a reduced ventilatory response to CO_2, such that breathing a dense mix while exercising can lead to unconsciousness. The conclusion is that these divers are better off with helium-based mixtures. A remaining problem is that it is not a trivial task to determine which divers are CO_2 retainers, and this begs the question of whether there should be screening for this condition.

Background Considerations: Making and Handling OEA Mixes

Before physiological issues can be of concern, it is necessary to prepare and handle the oxygen-enriched breathing mixtures. There are several aspects to this.

Air to be mixed with oxygen

Breathing mixtures for some of the early operational use of OEA at the NOAA Undersea Research Center at the University of North Carolina at Wilmington were made by mixing pure gases, oxygen and nitrogen, to form 32% or 36% oxygen-nitrogen mixes. This is expensive, and inherently dangerous because it involves using a pure inert gas. This was done because a source of air clean enough to mix with oxygen could not be identified or even specified. This was later resolved.

Use of mixes up to 40% oxygen

From the earliest use of oxygen-enriched mixtures it was considered that mixtures of up to 40% oxygen could be handled in the same way and with the same equipment configurations as for air. Although this "40% rule" has been widely disseminated (for example, it is in the OSHA standard for commercial diving), it appears that limited testing has been done to validate this, and it remains a matter of uncertainty in the minds of some.

Mixes should be analyzed

Unlike medical prescriptions, in the present-day recreational diving industry it is considered, and experience has shown, that the diver should check the analysis of tanks of mix prepared by a dive shop or gas supplier. The custom is for divers to confirm the analysis of the oxygen fraction in OEA mixes in their scuba tanks. Normally this is performed at the shop providing the "fill" at the time a tank is taken. When to do the analysis and the procedures to be followed should somehow meet some as-yet-undefined minimum standards.

Tanks should be properly and prominently labeled

The analysis has essentially no meaning unless the user of the tank is aware of it. To ensure this, it is essential that scuba tanks containing gas other than air be labeled unambiguously. Names such as "NNI" are not unambiguous. Some diving groups also label tanks with an indication of the maximum operating depth (MOD) for a given mix, based on the PO_2 selected as the "limit" of exposure. The MOD, in large letters, is visible to other divers for added safety. The MOD banner is useful, but the actual values of each of the major components should show on the tank.

History of Diving with Oxygen-Enriched Air

The history of diving with oxygen-enriched, nitrogen-based mixtures can be roughly divided into 3 phases. The first would include the early operations and studies that used rebreathers. This phase, as a part of the development of enriched air diving, goes to about the 1960s.

The next phase was commercial operations, most of which were using conventional hose and mask apparatus with on-line blenders. This was done mostly in the 1970s and 1980s.

The last phase, the use of enriched air mixtures in the open-circuit scuba mode began in the 1970s and continues today.

Early OEA work based on rebreathers

The great physiologist Paul Bert first suggested the use of oxygen to improve decompression in the 1870s (Bert, 1943). The early OEA diving was with a variety of different types of rebreathers (remember that open circuit apparatus was not widespread until the 1950s). For these, in virtually all cases the objective was to provide a gas for a diver to breathe under water, and decompression efficiency was not considered at all or was a secondary objective. Henry Fleuss probably made the first OEA dive somewhere around 1879. He developed a self-contained rebreather apparatus that used oxygen, and later made the transition to an air-based mix (Bachrach, 1975). His apparatus actually worked, and was used for at least one salvage job. Probably the first modern promotion of oxygen-rich mixtures was by Dr. Chris Lambertsen, who recommended this approach in the early 1940s (Lambertsen, 1947). His orientation on this topic was based on rebreather use, but there is no doubt he had a broader perspective.

Another widely recognized series of studies on oxygen-nitrogen mixtures was the work at the U.S. Navy Experimental Diving Unit during the 1950s by Dr. Ed Lanphier (1955a; 1955b; 1958). The Navy's original motivation to use oxygen-nitrogen mixtures (they called them "nitrogen-oxygen mixtures") was the same as ours today, to improve decompression. Lanphier described the equivalent air depth (equivalent PN_2) method for using a standard air table with an enriched air mix, and was well aware of the different benefits a lower nitrogen fraction might bring. However, Lanphier found an increased sensitivity to the toxicity of oxygen's partial pressure when the exposure was based on a mixture than when pure oxygen was breathed. PO_2s that were tolerable when pure oxygen was breathed seemed to cause more convulsions when breathed in oxygen-nitrogen mixes at greater depth.

Lanphier attributed the problems to CO_2, and set about to study that. He devoted the later phases of the project to methods of measuring CO_2 and to trying to screen out the "CO_2 retainers" in order to permit higher oxygen levels to be used and thus allow more aggressive decompressions. Lanphier also suggested both in his original reports and in a later analysis (Lanphier and Bookspan, 1996) that using helium or an oxygen-helium-nitrogen trimix would make the breathing gases less dense and would therefore cause less CO_2 buildup. The actual experiments were done with open circuit apparatus in the laboratory, but implementation of the results by the Navy would likely have been done mostly with rebreathers.

At about the same time Logan did some limited studies at the NEDU to evaluate the question of being able to ignore the oxygen in determining a decompression, and could not show statistically significant evidence that oxygen contributes to decompression in the range being used for OEA diving (Logan, 1961).

Commercial development of OEA

The benefits of decompression based only on the nitrogen fraction was not lost on the commercial diving industry. This was normally done using standard hose-supplied breathing gear with gas prepared by on-line blenders. One of the innovators was Andre Galerne, whose company IUC International used it as a "secret weapon" since other operators were not convinced that the equivalent air depth process would work (Galerne *et al*, 1984; Galerne, 1989). Andre had developed this technique as early as 1958 with colleagues in a French company Sogetram, who still use it. The OEA techniques were found to be most cost effective under special circumstances such as a need to dive during a tidal window.

A major diving job on a pipeline landfall was performed by a Norwegian construction company, F. Selmer, in 1982 and 1983. This operation used a Dräger Polycom on-line blender with standard surface-supplied masks and helmets (Hartung, 1982; Bøe and Hartung, 1983) and using tables developed by Arntzen and Eidsvik (1980). The outcome was quite satisfactory.

Commercial use of OEA in the offshore oil industry came more slowly. This was in part because of the formulas used for payment for diving services, which left less incentive for the contractor to use OEA. Oceaneering has done many thousands of OEA dives offshore on suitable projects, also using a Polycom blender but with the U.S. Navy Standard Air tables as the basis for equivalent air depths or equivalent PN_2 (Overland, 1989). A few other companies have done this sort of diving using similar procedures. An occasional operation is still done using this technique, but it is not widely used at the present time.

In 1989, a consortium of Swedish commercial ("civil") diving companies sponsored a proof of concept test program at the Swedish Naval Diving Center (Örnhagen and Hamilton, 1989). In a week of fairly stressful simulated diving, 8 commercial divers showed no decompression problems and tolerated the oxygen exposure well (although not without some effects), but since then the procedures have not been put to much productive use.

Scientific diving with OEA

The real development of diving with oxygen-enriched air as we know it was within the scientific diving community, and by far the bulk of this activity was specifically within the diving program of the National Oceanic and Atmospheric Administration (NOAA, 2001, in press). Dr. J. Morgan Wells, then Director of the NOAA Diving Program, felt that NOAA's scientific diving operations were quite limited when they were performed using the procedures in the U.S. Navy Diving Manual. In 1977, Dr. Wells proposed to use breathing mixtures enriched with extra oxygen for NOAA diving operations. The initial proposal was to use a fixed mixture of oxygen and nitrogen containing 32% oxygen. This was designated "NOAA Nitrox I", or more properly, "NN32." Using an upper partial pressure limit of oxygen of 1.6 atm this mix gave a maximum operating depth of 40 msw (130 fsw), which is the maximum depth limit for NOAA scuba diving.

Decompression tables were developed for both no-stop and decompression diving operations using the 32% mix, based on the U.S. Navy Standard Air Decompression Tables, and have a similar format. Limited testing using Doppler bubble-monitoring techniques tended to confirm the validity of the tables. NN32 was approved for NOAA-wide use in 1978. The decompression tables were published in the NOAA Diving Manual (1979). Later, NOAA authorized a second mix (36% oxygen) for use by NOAA divers.

The National Undersea Research Center at the University of North Carolina in Wilmington (NURC/UNCW), with the assistance of Dr. Wells, was the first to develop a comprehensive enriched air nitrox diving program to support their undersea research efforts. They developed standards and procedures, EAD tables, mixing capability, and a training program. This became and has remained the most active OEA nitrox diving program in the U.S. The NURC/UNCW program actively promoted the use of OEA in the scientific diving community, and they assisted other organizations in developing similar programs. Much of the credit for the recent widespread acceptance of enriched air nitrox in the scientific diving community belongs to NURC/UNCW. In due course the American Academy of Underwater Sciences (AAUS) issued standards for diving with oxygen enriched air, and the practice is now widespread.

The whole history of this diving technology has been threaded with gas and equipment development. UNCW originally began with partial pressure blending, mixing oxygen with pure nitrogen. They used pure N_2 because they did not have a source of oil-free air. Later, they implemented a continuous mixing system of the type developed by Wells (1989 patent). In 1992, UNCW collaborated with Florida State University in conducting a comprehensive program on blending of breathing gas mixes.

In addition to the partial pressure and continuous mixing methods and the more precise method of mixing by weight, two new methods of producing oxygen enriched air have come along recently (Wells and Phoel, 1996; Raftis, 2000). These methods both actually produce an oxygen-enriched mixture by removing some of the nitrogen. Both use atmospheric air as the feed gas, so neither require the use of high pressure oxygen. One method works by forcing a feed gas, here air, through a differentially permeable membrane. By adjusting flows and pressures, mixes of up to 40% oxygen can be prepared. The other method utilizes preferential adsorption on a clay-like mineral ("molecular sieve"). By sequencing the adsorption and evacuation stages of alternate beds of sieve, this method can produce mixtures of up to 95% oxygen.

One other element in the development of enriched air diving needs to be mentioned. Early in 1990, a new magazine, *aquaCorps*, appeared on the scene and addressed the new practice of "technical diving." Technical diving is extended range diving using advanced techniques and equipment to go well beyond the traditional recreational diving range, involving planned decompression and the use of more than one breathing mix on a dive. Although diving with enriched air is not itself technical diving, the concept of diving outside the normal range was becoming well established. This had a big impact on the spread of the practice of enriched air diving outside of the military and scientific communities.

Troubles with the Name

The word "nitrox" was originally used to describe the atmosphere in a seafloor habitat, where the oxygen has to be kept to a lower fraction than that in air because of oxygen toxicity concerns. Dr. Wells undoubtedly borrowed "nitrox" from habitat diving, but he might well have been the one who started using the term in that context, since NOAA was a leader in that technology (NOAA, 1979).

"Nitrox" is an unfortunate term because it emphasizes the nitrogen component and, in a sense, implies that nitrogen is the beneficial component, whereas it is the nitrogen that we are trying to get rid of. It sounds a bit strange when that word is used in a context of a high-oxygen mixture. Further, the term "nitrox" is not specific. However, it is in wide and general use, and despite this ambiguity, for the sort of diving addressed by this workshop it is well understood by almost everyone. Since the word is a compound contraction or coined word and not an acronym, it should not be written in all upper case characters as "NITROX."

Not so easily understood are terms like "NOAA Nitrox I" and "NNII." The chance that designations like this can lead to real problems is small, but since some fatal accidents with oxygen or oxygen-enriched mixtures have been attributed to the diver's breathing the wrong mix or the right mix at the wrong time, it is wise to label tanks with the actual composition as well as a code. NOAA has accepted new designations "NN32" and "NN36" for the 2001 edition of the NOAA Diving Manual.

One attempt at compromise with the term "nitrox" is the term "enriched air nitrox" (agreed on at the Harbor Branch Workshop, *vide infra*). This was abbreviated as EANx . The "x" was originally the "x" in "nitrox" but more recently it has been converted to a subscript with the oxygen percentage, *e.g.,* EAN36 is 36% oxygen enriched air.

The U.S. Navy and others have stated these as "nitrogen-oxygen" mixes whereas "oxygen-nitrogen" is now preferred; international convention recommends that the oxygen component in a mix be stated first.

Dick Rutkowski Took It Downtown

In 1985, Mr. Dick Rutkowski, retired Director of NOAA Diver Training, developed and began to market a "nitrox" training and certification program for recreational divers. This met with considerable resistance, but today most recreational scuba training agencies have some type of enriched air diver training program, and the gas mixtures are extremely fashionable and widely used by recreational divers.

Rutkowski's program was not well received, for several reasons. First, the concept was directly contradictory to the traditional and venerable limits of recreational diving. It was not well understood, and "Not invented here." The promotion was too strong, and included some benefits that were not well documented to say the least. To some, perhaps, "nitrox" posed a competitive threat, but the main objections were probably based on a perceived compromise of safety. Skin Diver magazine took an editorial stand against it, and heavyweights in the recreational diving community like Dr. Fred Bove and Dr. Peter Bennett (Bennett, 1991) felt it was too soon at best. Dr. Bove urged caution and said the UHMS Diving Committee was "not ready to recommend nitrox for recreational divers" (Bove, 1992). Dr. Bennett was quoted as saying that a diver who had been diving nitrox "could not be treated" (for decompression illness). A number of myths developed. It seems that those opposed to enriched air were just as imaginative as those promoting it.

Some Activities and Relevant Workshops

In 1988, at the Harbor Branch Oceanographic Institution, NOAA's Office of Undersea Research sponsored a workshop of experts to address some of the issues of enriched air. This group addressed experience within NOAA and its programs, commercial use of OEA, oxygen tolerance, physiology as related to decompression and the equivalent air depth, experience of the U.S. Navy and the Canadian Forces, use in rebreathers, a little about mixing, and activity summaries from diversified groups. This clarified for the first time many of the poorly understood issues, with generally favorable findings. The name "Harbor Branch Workshop" is not on the cover because of an administrative glitch, but this is the popular name for the proceedings (Hamilton *et al*, 1989).

During this time several organizations specializing in training for enriched air diving were formed. They had widely ranging philosophies, but all were able to function in this capacity. One company, ANDI, took the "high road" with a more conservative stance on oxygen safety, but uses an unrealistic term for enriched air, "SafeAir." Given the complexities of mixing, handling, analyzing, and using oxygen enriched air, it is hardly appropriate to consider that this is "safe" or even safer than diving with air. It has a decompression advantage, and that's it.

Harbor Branch and the intervening developments were not enough to silence the critics. As the 1992 DEMA show was organizing for its meeting in Houston, DEMA management rejected applications of those organizations wanting to promote "nitrox" at the show. They were told they could not participate. Seizing on this opportunity, Michael Menduno, publisher of the now defunct *aquaCorps*, organized a workshop at DEMA dedicated to oxygen enriched air for recreational diving. Dick Long, of The Scuba Diving Resources Group, who were behind the "Responsible Diver" program, provided funding, and once again a group of experts gathered to deal with the facts about OEA for recreational divers (Hamilton, 1992). While the Harbor Branch workshop concentrated on physiology and operations, this workshop focused more on mixing and handling. Not related to the workshop, DEMA relented and the OEA training organizations were permitted to show, but certainly without resolution of the concerns.

The group endorsed some existing concepts and practices, disapproved of some practices, and called for action on some issues. Endorsements included:

- the EAD principle,
- the NOAA limits for oxygen exposure (but lower limits were encouraged),
- using normal DCS treatment procedures for air diving after OEA dives,
- that oxygen exposure of recreational OEA dives should not affect treatment, and
- pending confirmatory testing, mixes up to 40% oxygen could be used in equipment suitable for air provided the equipment was clean and oxygen-compatible lubricants were used.
- dry OEA will not corrode tanks and other gear appreciably faster than air,
- air for mixing should be "oil free,"
- tanks used for OEA should be compatible with oxygen,
- mixes should be analyzed properly before use
- mixing in standard tanks by adding oxygen and topping with air is considered unsafe.

Among the needs were uniform standards for divers, instructors, and dispensers, but existing training agencies were accepted as adequate. Seriously needed was a specification for air to be mixed with oxygen, as well as a commodity standard for OEA in the range of 23.5% through 50% oxygen. Testing is needed for the "40% rule," that equipment suitable for air could be used safely with mixes in the range up to 40% oxygen, or preferably, to 50%. A unique tank connector for OEA was needed.

Other output from this meeting included that the hands-on training needed for actual OEA diving itself was minimal, "Breathe in, breathe out." (There is a little more to it than that . . . .) A statement attributed to this workshop was that enriched air could improve your sex life. Use of OEA really can improve the sex life - and many other aspects of life - for divers who are routinely getting inadequate decompression and therefore have subclinical DCS. Proper decompression can do wonders in this situation.

During this time the objections to enriched air nitrox began to dwindle. It became very fashionable and the market for training, equipment, gases, and dive computers continued to increase. In 1993 the Canadian Forces (DCIEM) issued enriched air tables as an appendix to their diving manual (DCIEM, 1993) . These are actually EAD (equivalent air depth) tables based on the standard DCIEM air tables. They use an upper oxygen limit of 1.5 atm PO_2 and both depth and time limits are more stringent than the air tables. When some dive shops attempted to move enriched air diving into Australia, it created lots of action and politics in much the same way as it had been in the USA.

One additional meeting had a significant impact on enriched air. As mentioned above, one uncertainty in mixing oxygen-enriched mixes was how to define the cleanliness of the air. A diver can tolerate a level of oil mist that is much higher than is safe to use with high pressure oxygen. The gas grades either allow a lot of oil (5 mg/m3) or do not address it at all. In order to fill this gap some of the "industry leaders" met during the tek93 technical diving conference and agreed on a level of 0.1 mg/m3 for air to be mixed with oxygen. This is a level that is low enough to be safe, yet high enough to measure, and available filtration can meet this requirement. This limit has been widely accepted.

NASA's Hubble Telescope Repair

NASA astronauts, when preparing for extravehicular activity (EVA), go through extensive training in a tank of clear water to rehearse the steps that will be used, with simulations often lasting many hours. While the rest of the world was learning to use OEA, NASA was busy thinking of reasons why it did not need to. Then they needed a 6.5 hr EVA to repair the Hubble telescope. A mission of this duration could not be simulated underwater with air as the breathing gas without invoking the need for decom-pres-sion. The tank is 40 feet deep, and the suit adds another 8 fsw or so of additional pressure, making this (worst case) situation impossible when breathing air without exceeding the no-stop limit; decom-pres-sion stops were considered to be out of the question. The problem was solved by using 46% oxygen enriched air (Hamilton, *et al,* 1994). At Marshall Space Flight Center interim facilities were installed to handle the mix obtained from a supplier, the crew was trained, and both the training and the mission went off without problems. NASA now has a much larger Neutral Buoyancy Laboratory near the

Johnson Space Center in Houston that is fully equipped with enriched air blending and handling capability.

Additional Developments

Another problem that could have become troublesome was the matter of OSHA compliance. Technically speaking, an instructor employed to teach diving would fall under the OSHA Commercial Diving Standard. However inappropriate this might be, it is federal law. This has recently been mitigated by a variance allowing instructors to breathe the enriched air mixtures and still fall under the exemption of recreational diving that is part of the OSHA standard (OSHA, 1999). Without the variance, a chamber would have to be on site where instructor-employees are breathing anything but air.

The development of technical trimix diving creates an interesting contrast. Extreme range technical diving has drawn much less flak from the recreational industry than enriched air did. Maybe it is perceived that it does not threaten the industry as "nitrox" did. It is just a lot further from home.

This creates a little mixup on what is "technical diving." The definitions above show clearly that diving with oxygen enriched air is not technical diving. OEA is, however, used in many deep technical trimix dives as a decom-pres-sion gas, but that is irrelevant to this argument.

The development of extended range technical diving has helped generate what I regard as the oxymoron of the day, "Technical nitrox." Bizarre as it may seem, many of the agencies teach this as a topic. It simply means diving with oxygen enriched air using mixes other than 32% and 36% oxygen, and doing dives that involve decom-pres-sion stops. Not a particularly threatening activity, but one that really has an inappropriate name.

Conclusion

In 1995, it became clear that enriched air diving had arrived when PADI took the plunge and began teaching it (PADI, 1995). NAUI had been doing it since 1992 with instructors furnishing their own teaching materials. In 1997, NAUI made a substantial investment in a new enriched air manual (Hamilton and Silverstein, 1997). Another organization that had resisted earlier, the British Sub-Aqua Club, has come around with its own new set of custom tables, which like the standard BSAC tables, were prepared with Dr. Tom Hennessy (BSAC, 1995). *Skin Diver* has even accepted enriched air, and the Divers Alert Network (DAN) has fully incorporated enriched air procedures into its records-keeping system.

A survey performed for the U.S. Navy in 1999, disclosed hundreds of thousands of open circuit dives with OEA. In general, except for those done by UNCW, most dives were not well documented. Commercial companies do not use OEA much these days. It is still VERY fashionable among recreational divers. The DCS record is actually quite good for OEA dives, as it should be for reasons given above. Most current dive computers allow for the use of one or more enriched air mixes.

The new NOAA Diving Manual, to be published in 2001, will include a chapter on diving with OEA, to be a complete "standalone" course guide for OEA diving. To embellish the section on terminology above, it can be noted that this chapter (at NOAA's insistence) calls oxygen enriched air "nitrox" except where the word implies more oxygen than air, then it is properly called OEA.

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NITROX DIVING DATA REVIEW

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Nitrogen-oxygen or "nitrox" diving is not new and has enjoyed some success. Experimental studies of nitrox diving conducted in the laboratory and field are reviewed below as an introduction to the recreational nitrox diving data collected by the Divers Alert Network.

Laboratory and Field Studies

From 1977-81, we conducted a series of nitrox chamber decompression trials using the Mark 15 Underwater Breathing Apparatus (Vann, 1982). The Mark 15 is a closed-circuit, mixed-gas, rebreather with an oxygen control system that maintains a constant inspired oxygen partial pressure (P_IO_2) set-point of 0.7 atm, independent of depth. We modified the oxygen control system to investigate the advantages of higher set-points for extending bottom time and reducing decompression time. With a 0.7 atm set-point at depths of 60-140 fsw (25-13.3% inspired oxygen fraction – F_IO_2), 114 no-decompression dives were conducted with a 3.5% incidence of decompression sickness (DCS). In addition, 193 decompression dives to 100 and 150 fsw (17 and 12.6% F_IO_2) were conducted with a DCS incidence of 6.2%. When the oxygen set-point was raised to 1.4 atm, there was no DCS in 17 no-decompression dives to 100 fsw for 40 min and 1.7% DCS in 58 decompression dives to 100 and 150 fsw for 60 min. At an oxygen set-point of 1.6 atm, there was no DCS or oxygen toxicity during 13 no-decompression dives to 150 fsw for 10 min, but an oxygen convulsion occurred after 40 min during a single dive to 100 fsw (40% F_IO_2). The diver had exercised underwater at a measured oxygen consumption of 1.6 Lpm and noted high breathing resistance that was confirmed during post-dive tests.

In 1991, a series of no-decompression nitrox dives was conducted with dry, resting divers to evaluate the feasibility of extending repetitive dive bottom times by breathing oxygen for 30 minutes during the surface intervals between dives (Surface Interval Oxygen – SIO_2; Vann, *et al.*, 1992a). There was no DCS or oxygen toxicity in 138 dives to 70 fsw with 36% oxygen (1.12 atm P_IO_2) and one DCS incident, but no oxygen toxicity, in 148 dives to 120 fsw with 32% oxygen (1.48 atm P_IO_2).

In 1992, an operational field study of SIO_2 was conducted in Wakulla Springs near Tallahassee, FL (Vann, *et al.*, 1992b). Volunteer divers made three dives per day for six consecutive days. Their mean air consumption at depth was equivalent to a swimming speed of 0.5 knots. There was one DCS incident in 383 no-decompression dives to 80 fsw with 36% oxygen (1.23 atm P_IO_2) and to 120 fsw with 32% oxygen (1.48 atm P_IO_2). There was no evidence of pulmonary oxygen toxicity in measurements of carbon monoxide diffusing capacity before and after diving. During a 80 fsw dive with 36.8% oxygen (1.26 atm P_IO_2), however, one diver had a seizure after 35 min at depth. He was rescued and recovered without further incident. ubsequently, he was found to have an unreported history of seizures and was taking anti-convulsant medication.

The Institute of Nautical Archaeology (INA) has excavated submerged shipwrecks for over 30 years. In 1985, 1987, and 1995, we provided INA with air diving tables to support two dives per day with a five-hour surface interval to depths of up to 200 fsw using oxygen decompression at 20 fsw (Fife, *et al.*, 1990; Fife, *et al.*, 1991; Vann, *et al.*, 1995). More than 22,755 dives have been conducted using these procedures with a 0.03% DCS incidence. In 1998, we provided INA with similar tables that used 32% nitrox to depths of 120 fsw (1.48 atm P_IO_2). There were 3,566 dives on these tables with a 0.03% DCS incidence (Vann, *et al.*, 1999). The divers were reported to have less fatigue after nitrox diving than after air diving (Charlton, 1998).

Recreational Diving Data

The use of mixed gases is becoming more common in recreational diving, but experience with this methodology is not well documented. This section compares the limited data collected by the Divers Alert Network to date for air and nitrox diving. The data were obtained from safe divers, injured divers, and diving fatalities. The three diving populations were subdivided by the breathing mixture they used – air or nitrox. The data reviewed included:

- *Project Dive Exploration* (*PDE*) for 1997-2000: 14,778 dives by 2,516 divers who dived safely and three divers who were recompressed.
- Diving injury data from 1995-2000: 11,781 dives by 2,480 divers, all of whom were recompressed.
- Diving fatalities from 1990-1999: 845 divers.

Figure 1 shows nitrox diving activity in DAN data from 1990 to 2000 as a fraction of all diving including air. In *PDE*, annual nitrox diving fluctuated between 10 and 20% since 1997. Nitrox injuries as a fraction of all annual injuries increased steadily from 2% in 1995 to 12% in 2000. The nitrox fatality fraction fluctuated between zero and 5% of total annual fatalities.

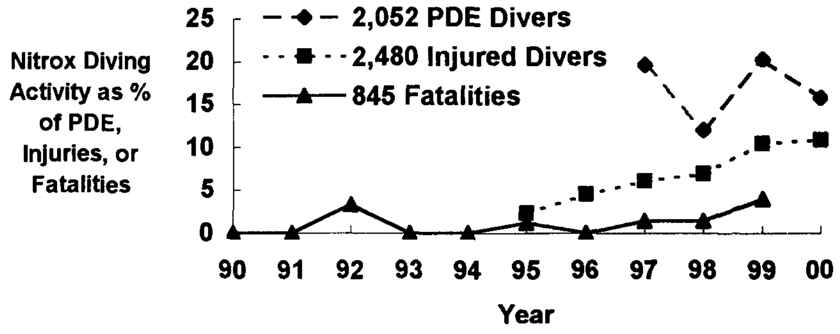


Figure 1. Nitrox diving activity.

Table 1 is a summary of *PDE* divers, injured divers, and diving fatalities over all years from 1990-2000 by gas mixture. Table 2 shows the same information expressed as percentages of the total *PDE* divers, injured divers, or diving fatalities. The greatest fraction of nitrox diving was by *PDE* divers while the lowest fraction was among fatalities.

Table 1. Number of *PDE* divers, injured divers, and diving fatalities by gas mixture.

	PDE	Injuries	Fatalities
Air	1741	2319	810
Nitrox	472	147	9

Table 2. Percentages of air and nitrox divers in the three populations.

	PDE	Injuries	Fatalities
Air	79%	95%	96%
Nitrox	14%	5%	1%

Table 3 shows the percentage of female divers. There was approximately the same fraction of female nitrox divers (11-13%) in each population.

Table 3. Percentage of female divers.

	PDE	Injuries	Fatalities
Air	27%	28%	18%
Nitrox	13%	14%	11%

Table 4 shows the mean diver age for the three populations and two gas mixes. Fatalities and *PDE* nitrox divers were the oldest ages. These differences are reflected in the age distributions of Fig. 2.

Table 4. Mean diver age (years).

	PDE	Injuries	Fatalities
Air	38	36	40
Nitrox	45	37	44

Figure 2 shows the distributions of diver age. *PDE* nitrox divers were disproportionately represented in the 60-69 age group. Injuries and fatalities were distributed more or less normally although injured divers and diving fatalities were older than the corresponding air divers.

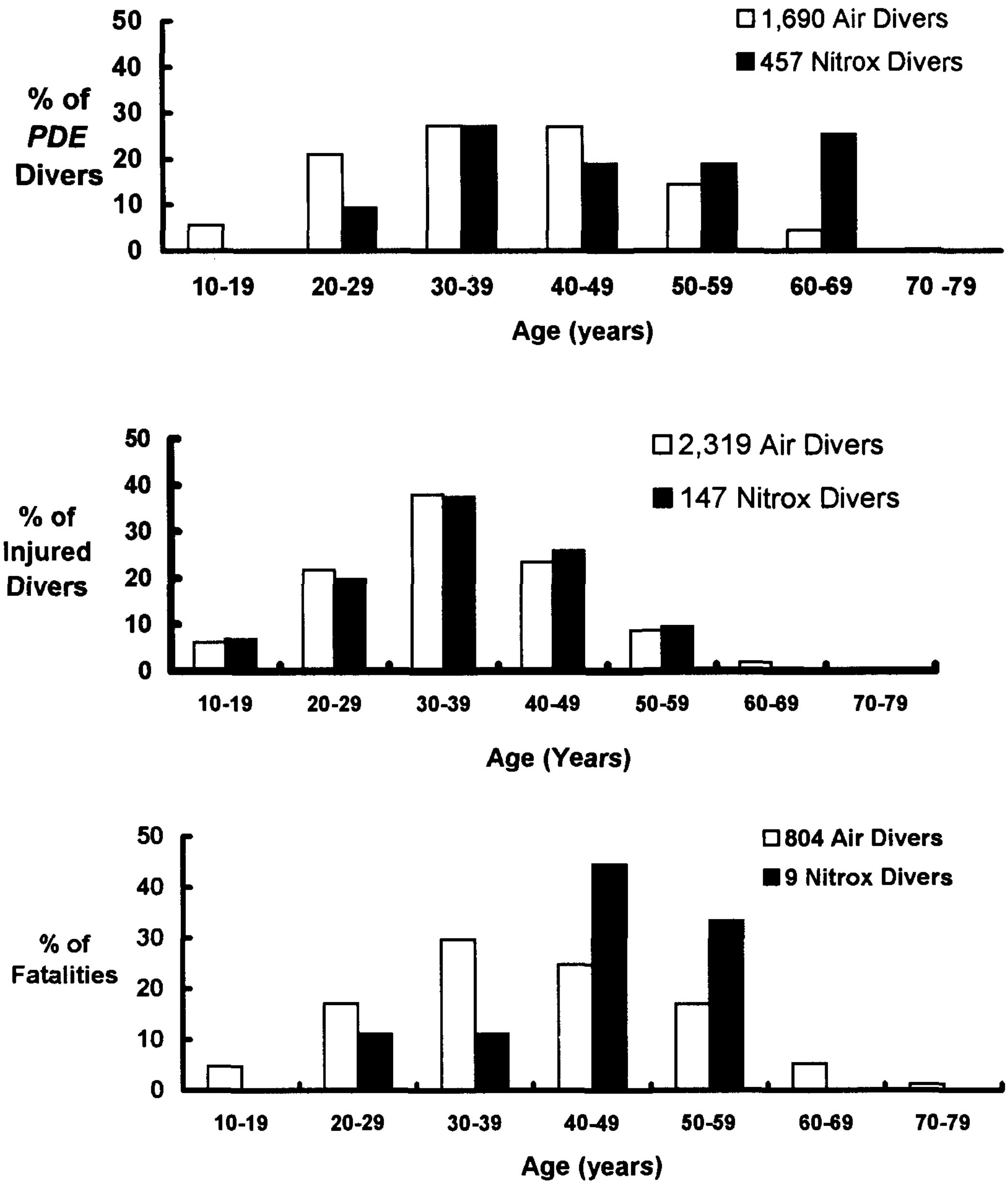


Figure 2. Distribution of diver age.

Figure 3 shows the distributions of certification for the three populations and the two gas mixes. For *PDE*, the highest proportions of divers held a 'Specialty' certification that included nitrox training. Air divers who were injured were more likely to have basic certification. Air and nitrox fatalities most often had basic certification.

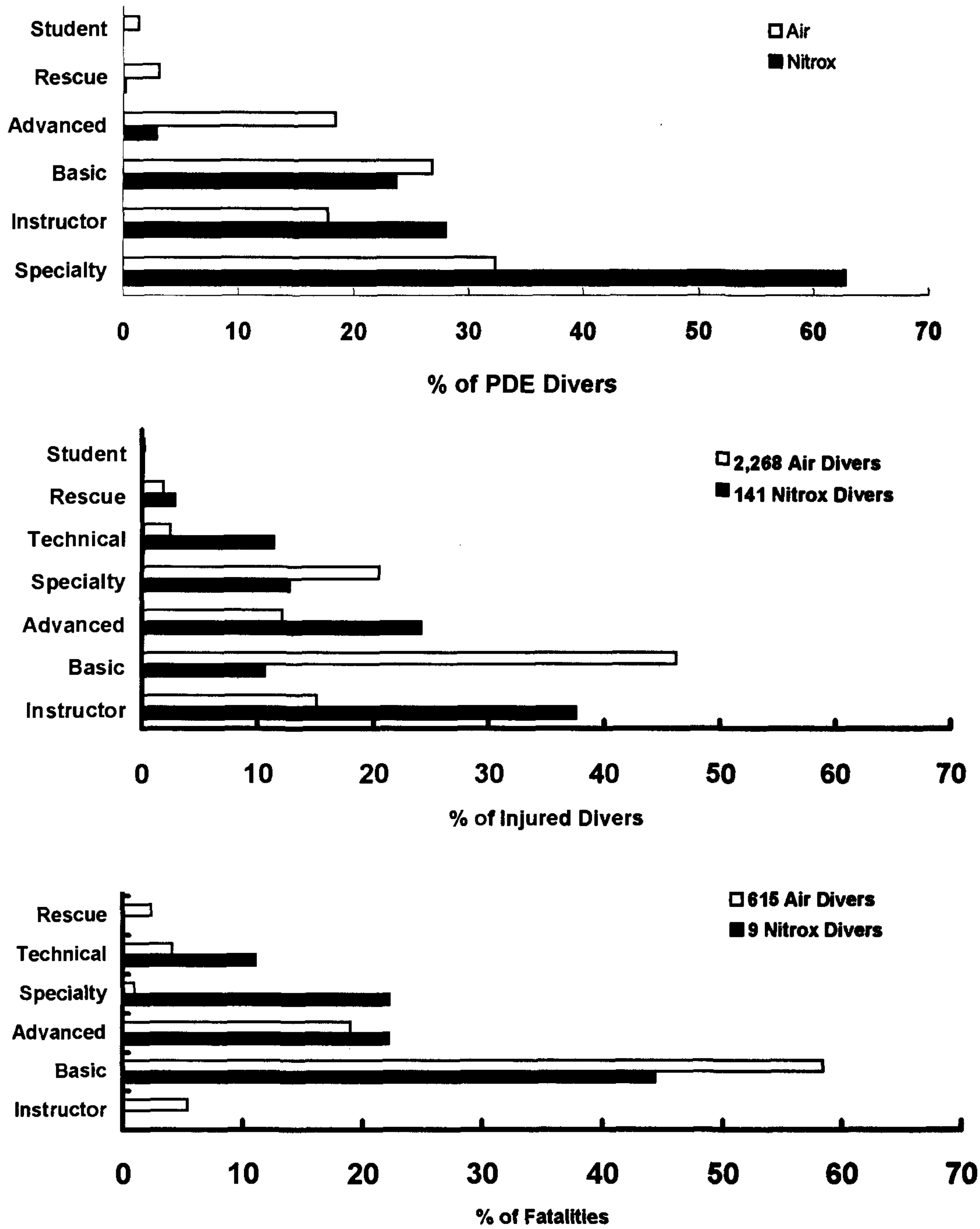


Figure 3. Diver certification.

Table 4 shows the mean years since initial diver certification. There was little difference in the time since certification between air and nitrox divers.

Table 4. Mean years since certification.

	PDE	Injuries	Fatalities
Air	9	9	7
Nitrox	11	10	7

Figure 4 shows the dive platform used by *PDE* divers and diving fatalities. (Dive platform information was not available for injuries.) For *PDE*, half the air diving was from liveaboards and half the nitrox diving was from charter boats. Shore dives were the most common starting point for both air and nitrox fatalities.

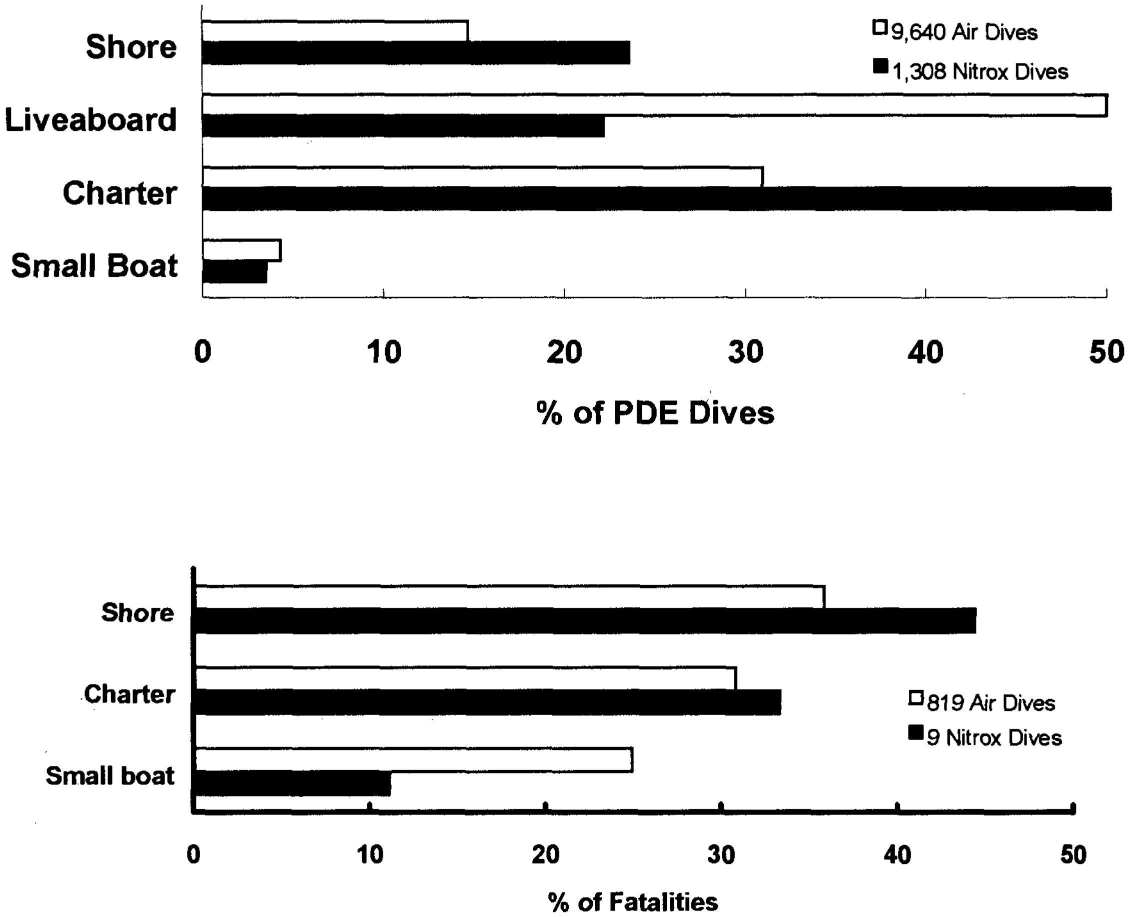


Figure 4. Dive platform.

Table 5 shows the mean days of diving and Table 6 shows the mean number of dives for the three populations. (For fatalities, information is available only for the day of the event.) In general, nitrox divers had longer trips but made fewer dives. For fatalities, the critical event usually occurred on the first dive.

Table 5. Mean days of diving.

	PDE	Injuries
Air	3	2
Nitrox	8	2

Table 6. Mean number of dives.

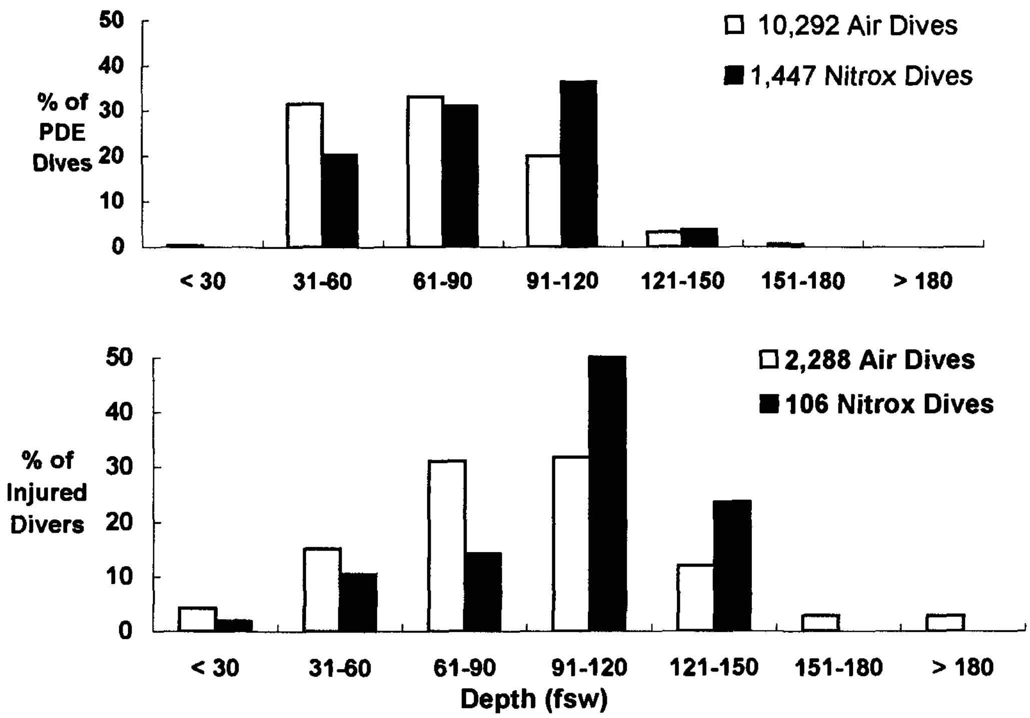
	PDE	Injuries	Fatalities
Air	7	5	1.3
Nitrox	5	4	1.2

Table 7 shows the mean maximum dive depth for the three populations. Injured divers had the greatest maximum depths while fatalities had the shallowest depths. The maximum depths for nitrox divers were greater than for air divers.

Table 7. Mean maximum dive depth.

	PDE	Injuries	Fatalities
Air	75	91	35
Nitrox	95	100	40

Figure 5 shows the distributions of maximum dive depth for the three populations. *PDE* nitrox divers rarely exceeded 120 fsw while deeper nitrox dives were more common for injured divers. Air fatalities were more common during shallow diving.



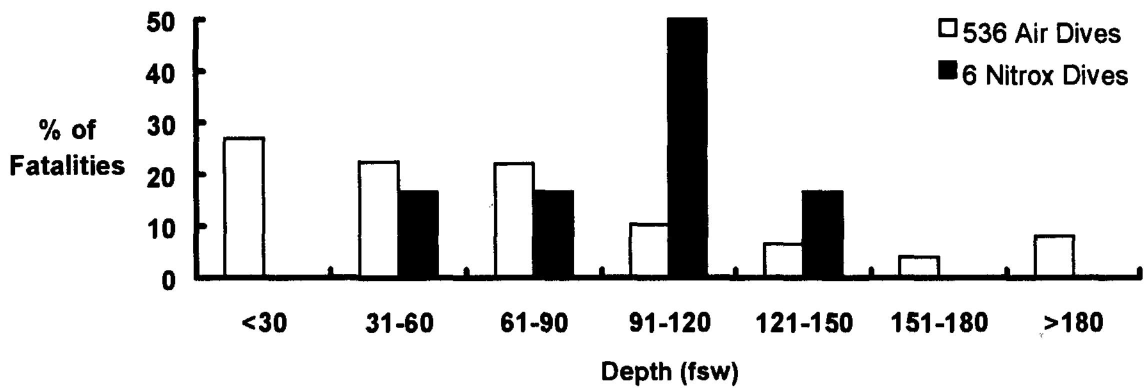


Figure 5. Distributions of maximum dive depths.

Table 8 shows dive computer use. For *PDE*, 90% of all divers used computers. All *PDE* divers wore a computer to record their depth-time profiles even if they did not dive according to the computer. For injuries, half the air divers used computers. Computer use was more common for nitrox fatalities than for air fatalities.

Table 8. Dive computer use.

	PDE	Injuries	Fatalities
Air	93%	53%	42%
Nitrox	92%	42%	89%

Tables 9 and 10 show the proportions of the three populations and gas mixes that reported rapid ascent or running out of gas. Both events were uncommon for *PDE* but common for fatalities and injuries.

Table 9. Rapid ascent.

	PDE	Injuries	Fatalities
Air	0.6%	23%	24%
Nitrox	0.7%	12%	22%

Table 10. Out of gas.

	PDE	Injuries	Fatalities
Air	0.2%	3.4%	44%
Nitrox	0.2%	4.8%	33%

Figure 6 shows the estimated maximum inspired oxygen partial pressure in 74 nitrox diving injuries. About 5% of these exposures had a maximum oxygen partial pressure of 1.71-1.8 atm, but the most common partial pressures (45%) were 1.21-1.4 atm.

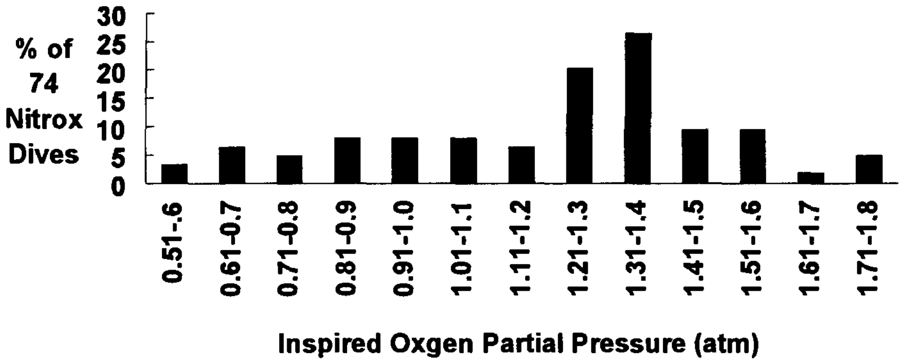


Figure 6. Maximum oxygen partial pressure and nitrox diving injuries.

Data were available for nine nitrox fatalities, but of these, only five had sufficient information for a minimal description of the dive profile. Table 11 summarizes information for three of the cases. The maximum oxygen partial pressure did not exceed 1.35 atm in these cases, and there was no indication of oxygen toxicity. The critical events appeared to be rapid ascent or running out of gas.

Table 11. Nitrox fatalities.

Depth (fsw)	Time (min)	% Oxygen	PIO2 (atm)	Comment
40	30	32	0.71	Rapid ascent
91	15	36	1.35	Rapid ascent
115	38	30	1.35	Out of Air

Two nitrox fatalities did have indications that oxygen convulsions may have occurred. In one case, an experienced diver was found unconscious at 135 fsw after about 45 min of breathing 38% oxygen in nitrogen with an inspired oxygen partial pressure of 1.93 atm. A seizure was not observed. The diver was not formally trained in nitrox diving but knew that the oxygen partial pressure was higher than recommended. He believed he could handle the mix and accepted the risk.

The second case involved an experienced cave diver who was observed to convulse during a cave dive. His dive profile involved 15 min on air at 80-104 fsw (0.87 atm maximum P_IO_2) followed by 45 min on 40% oxygen in nitrogen at the maximum depth of 84 fsw (maximum 1.42 atm P_IO_2).

Summary

Laboratory and open-water experience suggests that nitrox diving may be practiced with low risks of decompression sickness and oxygen toxicity. DAN has data on mixed gas diving dating from 1990 for diving fatalities, from 1995 for diving injuries, and from 1997 for safe dives. A higher proportion of safe divers used nitrox than of divers who were injured or died. Nitrox divers were older than air divers, and over 60% of nitrox divers who dived safely had specialty training. Safe nitrox diving was most common aboard charter boats, and there were no air or nitrox fatalities from liveaboards. Nitrox divers who dived safely dived less intensively (fewer dives over more days) than did air divers. In general, nitrox divers dived deeper than did air divers regardless of whether they dived safely, were injured, or died. For either air or nitrox, injured divers and diving fatalities had higher proportions of rapid ascent and running out of gas than did safe divers. The maximum oxygen partial pressures were above 1.3 atm for half of 74 injured nitrox divers. While the incidence of oxygen toxicity during nitrox diving is unknown, convulsions and/or unconsciousness was reported for three divers who had maximum oxygen partial pressures of 1.4, 1.6, and 1.9 atm. Careful depth control is important to avoid excessively high oxygen partial pressures during nitrox diving. In the future, DAN will increase its efforts to collect data about mixed gas divers who dive safely, are injured, or die.

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ANDI *SAFEAIR* TRAINING

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There are no reported incidents of DCS using SafeAir either during training or after certification. We sent a query to this effect as recently as 10 October, 2000.

SafeAir is a marketing term, but also an ANDI trademark that has more to it than a cute, non-intimidating name. The simple definition is that SafeAir is an oxygen-enriched air mixture between 22% and 50% oxygen, produced and dispensed according to ANDI standards.

This begins with an ANDI certified gas blender trained in correct oxygen handling protocols. The gas blender uses "oxygen service" equipment to mix oxygen compatible air with oxygen approved for breathing purposes and stores this product in clean, designated receivers after analysis. Oxygen service means more than cleaning: designed for oxygen use, compatible and cleaned.

Only oxy-compatible air is used in the process, not Grade E, which is the worst breathing gas standard known.

The air used to produce SafeAir must be analyzed quarterly by an independent federally licensed testing laboratory. ANDI receives a copy of the inspection report for the facilities' files. In addition, the gas is analyzed by the end user. We maintain that this product is by several standards safer than air when correctly used.

Oxygen enriched air? Yes, but if it is not SafeAir, it is only nitrox.

Every ANDI program uses a three-letter course code for identification. In order to better differentiate the programs and their scope of training ANDI attaches a "Level of Training", 1 through 5 for every program. All courses with the same matching level designation follow the same general scope of training and are geared for the same experience level of the participant. Level 1 designates an introductory program for new divers or divers-in-training. All Level 1 courses will follow the same limitations: 30m max depth, no-stop-required profiles, no decompression training, 1.45 atm PO_2, 4.0 atm PN_2 and information of a less complete or less technical nature. For example, only SafeAir 32 and 36 may be used by LSU students. All Level 2 courses can be expected to be of an "advanced recreational" scope of training. Only two cylinders and up to two gases may be employed to limit the task loading. This is essentially the recreational limits that are accepted world-wide: 40m maximum depth, no-stop-required profiles, no decompression training, 1.45 atm PO_2, 4.0 atm PN_2 and information content of a more complete or more technical nature. Other levels: Level 3 training encompasses the first level of what has become known as "technical diving". Training Level 4 is considered an "explorer's" program. All level 5 formats are exploration courses and involve the use of other inert gases (in addition to Nitrogen).

SafeAir Course Titles & Certifications (partial listing)

- Limited SafeAir User - (L1) LSU
- Complete SafeAir User - (L2) CSU

SafeAir Training Standards (partial listing), effective May 1999

Standard	LSU (L1)	CSU (L2)
Max. Course Depth	30 m	40 m
Min. Course Depth	10 m	20 m
Max Deco	N/A	N/A
Max PO_2 Deco	N/A	N/A
Gas Limits (PO_2)	1.45 atm	1.45 atm
Gas Limits (PN_2)	4.0 atm	4.0 atm
Theory Time	5-6 hrs	10-12 hrs
# of Dives	2	2
Min. Bottom Time	50 min	50 min
Min. Run Time incl. Safety Stops	60 min	60 min
Prerequisites	Diver-in-Training	OW certified

TECHNICAL DIVING INTERNATIONAL NITROX: AN AGENCY PERSPECTIVE

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Introduction

Looking back at the evolution of nitrox and its use by sport divers, it probably was unreasonable to hold out even the slimmest of hopes that this rather benign technology would be met without controversy. Apart from a small cadre of technical divers, the release of nitrox in 1985 was either greeted with outraged protest by ultra-conservatives or yawning indifference. Whichever response was received, nitrox could hardly be termed "welcome." Over the last decade the diving industry has witnessed a 100% about face and nitrox use in 2000 has become positively mainstream. So why are we still writing about it? If everyone is doing it, where's the story?

If ever one individual can be credited with a revolution in diving, it's Dick Rutkowski. Having developed a reputation as one of NOAA's shining stars during his long diving career there, he turned his attention to sport applications of nitrox following his retirement in 1985. Under Dick's guidance the first sport nitrox training emerged and began to catch on. He was quick to offer the hard facts and physiology that rebutted the misinformed, but publicized, critics. Irascible as always and not one to suffer fools gladly, Dick blazed a trail for the whole industry to follow.

Terminology

What's in a name? Nitrox, Enriched Air, EAN32, Oxy-Air, NOAA Nitrox I, or SafeAir? No wonder nitrox critics initially found an ear, since even the experts couldn't agree on what to call this alternative breathing gas. In spite of spirited discussion and a litany of arguments, the generic term "nitrox" has fallen into such widespread use that it's doubtful any name change will be forthcoming. The acronym EAN (enriched air nitrox) followed by a number representing the oxygen percentage (*i.e.,* EAN32, EAN36, etc.) is also widely used to more accurately describe the specific mix.

Evolution of Nitrox Popularity

It seems like only yesterday that nitrox was poking its head out of the closet only to be whacked on the nose and briefly banished from the 1992 DEMA show. The outcry that resulted ranged from threats of lawsuit on restraint of trade issues to simple faxes to the DEMA Board of Directors saying, in effect, get educated and stop making fools of yourselves. After a few meetings of nitrox community leaders and the DEMA brain trust, the hatchet was buried and business went on as usual.

Later the same year, Skin Diver magazine decided to make nitrox its soapbox sermon of the year. It blamed the gas and those who promoted it with about every thing imaginable, stopping just short of linking the whole lot to global warming, the introduction of rap music, and New Coke. After a passionate gnashing of teeth and damning editorials resulting in much heat but precious little light shed on a relatively benign technology, the diving consumer public elected to make up its own collective mind and nitrox popularity soared. There must be something about trying to remove the public's choice and censorship that stirs interest in everything from banned books to tanks with green and yellow bands.

When PADI announced that it would introduce its own nitrox training program in January 1996, the last bastion of resistance effectively fell. Now even the most strident opponents have eaten proverbial crow.

How could such a hot button item go from raging controversy to nearly universal acceptance in such a short time? It was probably due to a combination of circumstances. I always believed that the diving consumer was smarter than most give him credit for. Those divers who experimented with nitrox found out quickly that they didn't spontaneously combust from breathing a higher oxygen content, neither did they find themselves doing a convulsive tap dance with the grim reaper if they used the gas within the widely accepted depth and time limits. The hysterical scare tactics of a few partisans with a thinly veiled agenda simply didn't wash with the diving public capable of making their own intelligent decisions.

Nitrox Dive Computers

Another factor in the burgeoning business of nitrox has been the proliferation of support equipment by mainstream manufacturers. Perhaps the biggest breakthrough came with the introduction of programmable nitrox dive computers allowing divers to maximize the benefits of enriched air by incorporating all the elements of multilevel profiling. It was precisely those features that convinced so many divers to embrace computers in the first place. Those divers were an exact demographic fit for nitrox use. They wanted to increase their bottom time and add a safety margin over the tables. Nitrox offers many of the same advantages but divers were loath to return to tables for dive planning. With the advent of affordable nitrox computers, nitrox received a boost that pushed its popularity over the top. No longer confined to wrestling with tables, keeping convoluted records of bottom times, surface intervals and varying mixtures, today's modern nitrox diver can turn the process over to his micro-chip buddy and even program different mixes for each dive. Bingo, diving just got fun again.

Initially, these computers tended to be on the pricey side but market competitive influences have now brought nitrox computers down as low as $300 while offering more bells and whistles than ever before. Currently there are several dozen models offered in North America. Most require the diver to manually set his mix prior to the dive but some manufacturers have recently introduced computers with integral oxygen analyzers that automatically set the oxygen percentage. These were aimed at use in rebreathers but clever divers have adapted hardware to allow their use with regular open-circuit scuba gear. Manufacturers have also responded to the way nitrox is being used in the field by expanding the programmable range of their computers. The first nitrox computer produced by Orca Industries in 1992 allowed the use of only 32% nitrox mix. Later, Dive Rite and UWATEC introduced computers with ranges from 21% to 50%. UWATEC's latest offering allows the user to program any oxygen mix from 1% to 100%. That reflects the way divers have retreated from the idea that only a couple of mixes would be used.

Originally, NOAA published tables for mixes of 32% and 36% since those percentages matched up nicely to their scientific dive mission depths. Prior to the introduction of nitrox computers that allowed easy use of varied mixes, divers were stuck with those two options. That proved to be over-limiting for several reasons. The 32% mix was widely regarded as the perfect match for sport divers since its 1.6 atm PO_2 limit coincided with the 130 foot depth limit for divers in training. For those wanting to maximize dive profiles at lesser depths, it was desirable to use higher oxygen fractions and accept shallower depth limitations. Later, the use of semi-closed circuit rebreathers necessitated the use of varying nitrox mixtures based on both depth and gas flow through a restricted sonic orifice in the breathing loop. Clearly, one or two nitrox mixes would never satisfy the growing demand to adapt nitrox diving to a nearly infinite list of applications.

The good news is that the industry responded to give divers exactly what they needed: More flexibility and choice. Just as early satellite navigation systems (Sat-Nav) provided only latitude and longitude, global positioning systems (GPS) later incorporated multiple chart way points, automatic computation of all courses and even integration with radar and chart plotters. Nitrox computers now provide such a plethora of functions that the user manual can take a long time to read. It's worth taking the time to navigate your way through it. In addition to decompression functions, you can access depth limits based on mix, accumulation of oxygen loading measured as either central nervous system time allowances or longer term oxygen tolerance units (OTU's). An amazing series of PC integrated software features let you run pre-dive scenarios and download actual dive profiles in real time. You can even set variable oxygen PO_2 limits.

Nitrox has clearly found its place in sport diving and continues to gain popularity. Most liveaboard vessels have embraced nitrox and provide it to guests either at no cost or as a slight add-on to regular fees. It is in this application that vacationing divers have found its most worthy use. People dive from liveaboards mostly because they afford maximum diving potential in great locales. Nitrox and liveaboards go together like wine and cheese. With the right nitrox mix programmed in your computer, it's now possible to literally dive all day (and night sometimes) without ever incurring a decompression obligation.

Dive computers revolutionized how divers conducted themselves in the 1980's. Nitrox in the 1990's has forever changed the notion that compressed air was our only choice to breathe. The combination of the two technologies has maximized the options for divers worldwide while making dive planning easier, safer and more convenient coupled with another key breakthrough: Affordability.

The Diving Industry

In 1997 I authored a lengthy article in Deep Tech urging the diving industry to finally show some internal responsibility by organizing some formal fact-finding workshops to sort out the various policies, guidelines, standards and overlapping regulations that apply to the use of nitrox. At the time we hoped that DEMA might show some leadership in facilitating such meetings where a consensus agreement could be reached. The Recreational Scuba Training Council (RSTC) took a pro-active step to bring representatives from training agencies, manufacturers, and other concerned parties together in a special caucus held in Las Vegas on March 1, 1997. The day was spent identifying the key issues still remaining where controversy or disagreement was identified. The committee was charged with reviewing all existing policies and making a recommendation for guidelines to be approved by the diving industry. It was hoped that DEMA would provide the funding for the committee's preliminary work and would receive the final report and conclusions for consideration by DEMA's membership.

The train almost immediately went off the track. DEMA's Executive Director had since departed and the committee was passed off to DEMA's legal counsel who treated us to a textbook lesson in "how to say nothing meaningful in a thousand words or more." He explained that DEMA was not in the business of creating standards. That was an interesting perspective since a variety of DEMA members were engaged in litigation where other professional trade groups' standards were being applied to the diving industry even though such application did not fit our use. Due to lack of DEMA funding, the committee was forced to suspend its work and was placed on indefinite postponement.

I noted at the time: "In this type of workshop, all the domestic and international guidelines, laws, or standards can be examined and debated by the attendees to determine what makes sense for application in the *diving* industry. It's rather pointless for our industry to currently borrow a little from CGA, a little from NOAA, a piece here from the Navy, and maybe something from Europe. DEMA is an international trade association that can assume the responsibility for setting its own guidelines in much the same way that certification is currently self-enforced by industry agreement."

Let's examine the result of letting other professional trade groups extrapolate their standards to the diving industry. The Compressed Gas Association (CGA) promulgates standards for their members who dispense and handle gases and materials for uses such as welding, fire fighting, and hospital anesthesia. Over the years, CGA has come up with some excellent guidelines, many of which the diving industry has tacitly endorsed. On the other hand, some of their rules make no sense for divers. For instance, according to CGA the only approved color for compressed air cylinders is black with a white top. When was the last time you saw a scuba diving tank that conformed with that criterion? If the diving industry is forced to look to CGA for its standards, then anyone filling or selling an improperly color-coded cylinder is technically in violation and could be accused of negligence. Ridiculous? Not in the hands of a good plaintiff's attorney who will hang his case on any lapse of conduct.

Wouldn't it make more sense for DEMA, as diving's trade association, to take some pro-active steps to ensure that its members are afforded the protection of consensus standards and guidelines that are peer reviewed by its own technical people? It makes sense to see the value of controlling our own destiny, both in the legal arena and in dealings with the government.

Nitrox Variance Submission to OSHA

At the 1998 DEMA show a confrontational and bitter meeting was scheduled to explain the ongoing variance application submitted to OSHA. This variance application was initiated by Oceanic who intended to manufacture a closed circuit rebreather several years ago. PADI pursued a separate variance for nitrox use by sport divers using conventional scuba. The two efforts were well intended and privately financed by the two companies but miscommunications by DEMA fueled the debate once the final language of the variance was released. Unfortunately, the final language in the submission was hopelessly flawed from the perspective of other training agencies, dive operators and manufacturers. One cannot blame PADI and Oceanic, although many vocal critics wanted to. These companies represented their own corporate interests and much of the language contained in the variance reflected unit-specific equipment specifications and other proprietary materials that the wider DEMA membership either could not or did not want to be tied to. Those parties left out of the application process vented their frustration over what was perceived to be a potentially damaging document. DEMA should have made the effort to get informed and pro-actively manage the process for all its members. This would not have impeded the original variance applications by PADI and Oceanic and would have allowed the other concerned parties to be kept abreast of developments and make their submissions at the same time.

Meanwhile, a separate group of manufacturers and training agencies had formed another variance application group to protest the restrictions on the original application. This wasted time, resources, money and legal effort as well as confusing the issue for OSHA who indicated their preference to deal with one joint application. To further muddy the waters, Dr. Ed Thalmann from the Divers Alert Network (DAN) had officially filed an opinion against any increase in oxygen levels above 1.3 atm, thus confirming DAN's incomplete understanding of how sport divers use nitrox or rebreathers in short duration exposures. No wonder the bureaucrats in Washington have trouble dealing with issues from the diving industry: We seem incapable of speaking with one voice.

To Clean or Not to Clean?

The issue that ignites the most passion among parties seems to be a debate on what nitrox oxygen content should require "oxygen cleaning" of scuba equipment. The majority of the industry appears to support the traditionally accepted "40% rule", which does not require any special handling or cleaning for equipment in contact with mixtures up to, but not exceeding, 40% oxygen content. Other concerned parties have insisted on requiring cleaning for every mix over 23%, a decidedly conservative position that has fostered much debate.

The most accepted references for oxygen cleaning are provided as follows:

- Code of Federal Regulations, Part 1910.430 (i) - Commercial Diving Operations.

- OSHA Oxygen Specifications 1910.420 (1)
- NOAA Oxygen Specifications (appendix D)
- U.S. Navy Oxygen Specifications U.S. MIL-STD-777E (SH) Note K-6-4, Cat. K.6
- U.S. Coast Guard Oxygen Specifications Title 46: Shipping, revisions through 10-1-92. 197.452 Oxygen Cleaning 46 CFR 197.451

All of the above specifically cite the "over 40%" guideline that has been in widespread use since the 1960's. This was later confirmed for the diving industry at the 1992 Enriched Air Workshop. The consensus of attendees and professional panelists brought to that conference was to accept the "over 40%" guideline and continue the status quo.

Most of the confusion that seems to be promulgated is a result of misapplying PVHO (pressure vessel for human occupancy) guidelines. As anyone familiar with the operation of recompression chambers knows, these guidelines address a maximum oxygen content of 25% when a human is encapsulated in a pressure vessel (chamber). The concern here is for a fire hazard to a living person, not a piece of mechanical equipment. We suggest not trying to squeeze humans into nitrox cylinders. Additionally, the distinction has to be made between items of equipment that will be used in contact with a gas. For instance, scuba regulators are compatible according to the above-cited existing guidelines as long as they are used with enriched air mixtures of 40% oxygen content or less. The confusion invariably arises when dealing with cylinders and valves that may, or may not, be contacting enriched air mixtures with greater than 40% oxygen content.

Three commonly practiced methods of producing enriched air mixes exist:

- Continuous blend (with oxygen injection in conjunction with an oil-free compressor)
- Partial pressure blending (where low pressure oxygen is decanted into scuba cylinders and then topped with compressed air), and
- Membrane separation systems (where nitrogen is extracted from standard atmospheric air).

Of these three methods, only partial pressure blending would require the valve and cylinder components to be oxygen cleaned. The other two methods ensure that the equipment is never subjected to greater than 40% oxygen content.

There is more than ample history to support the responsible application of the "over 40% rule" that has been observed for several decades. Indeed, we are not aware of a single case of accident or incident when this guideline has been properly applied. Tens of thousands of enriched air divers are trained each year and the overwhelming majority of these divers are taught the "over 40% rule". Among training agencies, only ANDI subscribes to the more restrictive 23% guidelines. The champions of the 23% guideline are at odds with the USCG, NOAA, U.S. Navy, OSHA, and the other nitrox training agencies.

Manufacturers have produced programmable nitrox dive computers that allow the diver to select his oxygen content setting from normoxic air at 21% to 50%. The idea being that a diver can make one purchase that will allow him to use his computer in a variety of nitrox applications or simply plain old "air." The mentality that seeks to convince the consumer he needs to own at least two complete sets of scuba gear: one for air and for nitrox insults his intelligence and undermines the public's trust in the industry to set responsible safety guidelines.

TDI Record of Nitrox Certifications

1994	Instructors:	536	Divers:	3789
1995	"	789	"	5267
1996	"	1084	"	6863
1997	"	1897	"	8961
1998	"	2367	"	11,986
1999	"	2841	"	13,893
2000	"	3309	"	15,447 (Sept., 9 mos.)
Total: Instructors		12,843	Divers	66,206

TOTAL ALL LEVELS: 79,049 since program inception in 1994

TDI Operational Considerations

1. Max PO_2: 1.6 atm (EAN32 max depth 132 fsw; EAN36 max depth 110 fsw)
2. Nitrox compatibility of standard scuba equipment: up to 40% oxygen content
3. NOAA Oxygen Limits taught to all certified divers and instructors
4. Concept of OTU/UPTD tracking explained but not a factor in sport diving
5. Analysis of mix must be observed by diver to an accuracy of plus or minus 1%
6. Since 1996, the diver population using nitrox is overwhelmingly skewed towards programmable nitrox computers versus tables
7. Prerequisites for training entry: certified diver, 10 logged dives

NOTE: Within this time frame of 6 years and 9 months, TDI has not had an accident of any kind with any nitrox divers.

Conclusion

This DAN sponsored workshop in 2000 is a positive step to objectively re-visit a set agenda of nitrox issues that have been in debate for nearly fifteen years. For the first time, the real players are being brought together to share hard data on the numbers of divers and instructors trained and certified in nitrox by the various agencies. Input from operators will supply data on actual nitrox use in the field and the growing number of sport divers using nitrox mixes as their primary breathing gas of choice in scuba. Most importantly, an attempt will be made to confirm or rebut the presumptions of diver risk using nitrox.

Nitrox can dramatically increase no decompression times and shorten the necessary surface intervals between dives. With a bit of planning a nitrox diver could dive all day in depths of 60-80 feet and never run into required decompression. Even using the basic EAN 32 mix, a diver will be able to chalk up a major advantage on his air breathing brethren during a typical two to four dives a day schedule.

Another use of nitrox has been to dive EAN as "air" in conjunction with standard air tables or dive computers. This incorporates the *physiological advantage* of breathing the mixture, which contains 11% more oxygen and less nitrogen. This provides a significant safety factor since the divers' tables or computers assume he is breathing standard air. This has appealed to divers who may not be in the best shape, divers over 40, or anyone making a particularly arduous dive in colder water or when a higher workload is expected. Nitrox offers the diver another dimension by expanding the no-decompression window. Nitrox may well prove to be a milestone in diving as was the acceptance of dive computers. Those instruments were initially met with controversy by ultra-conservatives who predicted all sorts of accidents and dire happenings for those divers who dared to abandon dive tables. Of course, the record of success proved the doom-sayers wrong and now computers are standard equipment for the majority of divers.

Although subjective benefits are reported by many divers, nitrox should not be considered a miracle elixir that will increase sexual potency or promise renewed vigor as some over zealous proponents have suggested. It is reported that nitrox divers feel less fatigued at the end of a diving day and that headaches are eliminated. Anyone who has notched a full day of diving from a liveaboard knows the feeling of pleasant exhaustion that hits you right about the time dessert is served. Nitrox divers on the same schedule seem to have more energy (for whatever activities) and can at least enjoy the movie that evening on the VCR without doing a face plant on the dining table.

So what's the downside? Not much really. Because nitrox does contain more oxygen than regular air, there are depth limits that must be strictly observed to avoid any effects of oxygen toxicity. There are time limits associated with breathing oxygen at certain partial pressures. The good news is that the time limits take care of themselves if the diver remains within the no-decompression profiles. For EAN32 the depth limit is 130 feet, a limit that most sport divers are already conditioned to. As the oxygen percentage is increased, the depth limit is correspondingly reduced.

Will nitrox enjoy a similar embrace from the diving public? The best bet is yes considering the phenomenal growth in the last few years and the ever widening spread of availability. Liveaboards now routinely offer nitrox to all divers. Dive resorts now have nitrox available throughout the Caribbean, including the once super conservative Grand Cayman Island. Even the British Sub Aqua Club (BSAC) now offers nitrox training. The time is rapidly dwindling for you to be viewed as a dive rebel. It's all becoming too respectable...

NITROX AND ITS IMPACT ON THE DIVE INDUSTRY

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Nitrox was first introduced to the recreational market by Dick Rutkowski in 1985 after he retired from NOAA as the Deputy Diving Director. During his tenure at NOAA, Dick, along with Dr. Morgan Wells, had developed the use of Nitrox diving within NOAA and for scientific diving applications. Upon retirement Dick looked at all the many safety advantages of nitrox, which had proven to be true for NOAA Divers for 14 years, and he decided to introduce it to recreational divers. He did this by forming IAND (now IANTD), originally under his parent company Hyperbarics, International.

Recreational divers dive the ideal profile to enjoy all the benefits afforded by the use of nitrox. For a couple of years Dick was the only retail outlet pumping nitrox. Due to Dick's efforts, more instructors soon started teaching nitrox, which made it become more available at dive facilities.

Table 1. Yearly Totals for IANTD Certifications.

Years	Divers	Instructors	Facilities
1990-1991	157	147	7
1992-1993	4078	802	83
1994-1995	11576	1783	150
1996-1997	19021	2315	312
1998-1999	19669	2178	327
Jan. - Oct. 2000	9877	915	160
Totals	64,378	8,140	1,039

From the above it is evident how rapidly nitrox diving is growing. This community enjoys an extremely high safety record. It is also evident from the growth in the last three years that the use of nitrox is becoming more popular and will have a major financial impact on the dive industry. These figures are even more impressive when you realize that in the last few years many other agencies have also begun training nitrox divers.

It is hard to realize that in 1992 IANTD was required to have a sign at our booth at DEMA posting the perceived dangers of diving nitrox. During that period and up until the mid-nineties, nitrox was controversial. Most dive agencies denounced it, *Skin Diver* magazine called it "snake oil". It even had the Cayman Islands disclaiming it and declaring they would not treat divers who got a DCS hit while using it. DAN, by way of its publication Alert Diver, repeatedly presented nitrox as being unsafe for recreational divers and forecast death and destruction through its use.

From the mid-nineties onward, the benefits overcame the doubts. As Dick Rutkowski states "Science Overcomes Bull...". Today, every major training organization in the world provides nitrox courses. *Skin Diver* and all major diving publications are supportive of nitrox. The Cayman Islands became one of the first destinations to totally embrace not only nitrox diving but also even rebreathers and trimix diving. DAN also seems to be reevaluating its position on EANx and maybe its editorial policy in Alert Diver with regards to the use of nitrox.

Today nitrox is main stream, and a very viable part of the diving industry. Its use has not only made diving safer, but it has also stimulated the development of equipment by manufacturers dedicated for use with EANx. It has added safety for divers and produced income for manufacturers, training agencies, facilities, resorts, and instructors. All in all, nitrox diving has been a win-win situation for the dive industry.

In addition to nitrox, IANTD has certified Advanced EANx Divers, Rebreather Divers, Technical Divers, Trimix Divers, Technical Cave Divers, and Technical Wreck Divers in the use of EANx and helium based mixtures for a total of 16,519 certifications. This total does not include OW diver certifications.

From those facilities who track gas fills (many do not) and provided their reports on the number of nitrox fills (recreational mixes only) the following data has been compiled by IANTD:

1999-2000 current	800,321
1997-1998	404,811
1995-1996	125,132
1991 –1995	71,002
between 1985 and 1991 would estimate	10,000
Total recreational nitrox fills:	**1,411,266**

Note that this total does not include home brews. For instance, while making the decision to pump EANx, Ginnie Springs did a 3-month survey of the cylinders being filled at their facility. It was discovered that 95% of all doubles that were filled had 400 to 600 psig of oxygen in them. Thus 95% of the fills they were giving to cave divers was nitrox. If this is projected over a year, Ginnie Springs was (is) filling several thousand sets of doubles with nitrox. These numbers are not reflected in any surveys, as they are not official fills. However, this practice was, and to some degree still is, wide spread in much of the world today. If you add these numbers to the above total and use a little imagination, it is easy to conclude that many more nitrox fills than we have documented have been made. In fact, I would speculate that the number of fills actually made by IANTD Facilities alone would double the figures that have been reported to us.

There is a large population of Technical and Cave Instructors who make in excess of 300 dives a year and all of these dives are on EANx or helium-based mixtures. None of these have had DCS even though they are doing up to 4 dives per day or two really long dives with extensive decompression stops per day. For instance, I personally have made 750 dives in the last two years. All of these were on either EANx or helium-based mixtures with a slight majority of these on CCR with depths as great as 420 fsw and dive durations up to 5 hours. These dives have been on deep wrecks, in caves and on deep walls with a very few being on shallow reefs. I have not experienced DCS nor have the dive partners and students I have been diving with at the time.

From the facilities that reported, no incidence of DCS was returned. This does not necessarily mean that there were no hits but rather that the facilities have no reports of hits from their divers. From a training perspective, with the tens of thousands of training dives being made, many with considerable decompression-stop times involved, we have no incident reports involving DCS.

Today there are many divers who never dive air at any depth and I think this is an expected trend as air is the most unsafe gas one could dive. Of the divers I do know who have experienced DCS hits in the last few years, all were diving on air.

AN OVERVIEW OF THE PADI ENRICHED AIR DIVER PROGRAM AND ASSOCIATED DSAT OXYGEN EXPOSURE LIMITS

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Introduction

In January 1996, PADI International released an Enriched Air Nitrox dive training program, which is fully supported with educational materials for the student and instructor. This paper reviews some of the philosophy, highlights, content, and treatment of this topic found in the course, and will address the certification history and program growth since inception. The purpose of the course is to familiarize divers with the procedures, safety protocols, hazards, risks, benefits and theory of no-decompression diving with oxygen enriched air containing 22 percent to 40 percent oxygen. The emphasis is on diving with EANx32 and EANx36 (also known as NOAA Nitrox I and II). Training emphasizes the importance of proper procedures to ensure safety, and realistically balance the pros and cons of enriched air diving. Instructors are encouraged to elaborate beyond the material in the course outline to accommodate individual student interests, and aspects of enriched air diving unique to the local environment. The goals of this program are:

1. To enable a diver to plan and make no-decompression dives using enriched air blends containing 22 to 40 percent oxygen, remaining within accepted dive table and oxygen exposure limits,
2. To enable a diver to obtain and care for equipment used in enriched air diving; and,
3. To enable a diver to avoid possible operational hazards and underwater hazards associated with oxygen.

Two enriched air training dives required for certification. These may not exceed 30 metres/100 feet, or exceed a PO_2 of 1.4 atm., whichever is less.

An Overview of "Enriched Air"

Enriched air is any nitrogen/oxygen gas blend with more than 21 percent oxygen. Enriched air is sometimes called "nitrox." However, the term "nitrox" includes nitrogen/oxygen mixes with less than 21 percent oxygen. (These are used by divers to reduce oxygen exposure when remaining under pressure for days at a time.) For clarity, the terms "enriched air" or "enriched air nitrox" are preferred by PADI.

Most of the special training one needs to safely dive with, and handle, enriched air relates to its higher oxygen content. The primary application of enriched air is to extend no-decompression limits beyond those of normal air. Based on NOAA tests, Navy tests dating back more than 50 years, 20 years of field experience by scientific divers, plus field experience in thousands of recreational dives, the no decompression limits for enriched air are generally considered as reliable as those for normal air tables and computers. However, there is a trade off. As you reduce nitrogen exposure, you increase oxygen exposure. Therefore, much of what needs to be taught to students deals with keeping oxygen exposures within safe limits. Practically speaking, depending upon the dive depth and breathing rate, dives may be limited by enriched air supply rather than no-decompression limits. Therefore, planned dive profiles and planned repetitive dives may not be able to take advantage of the additional time enriched air offers in some cases.

Because you absorb less nitrogen using enriched air, you might expect that using enriched air within normal air no-decompression limits would substantially improve safety. This is probably *not* true. The decompression sickness (DCS) incidence rate is already so low that it's unlikely that simply reducing nitrogen can produce a *meaningful* risk reduction. Although there's been no study of this, statistical estimates suggest that using enriched air within normal air limits only reduces mathematical risk a fraction of a percent. After all, the DCS incident rate is estimated as .004 percent (one in 25,000 dives) to .001 percent (one in 100,000 dives). If you cut that rate by half, which is very unlikely, the best you could do is reduce incidence by .002 percent. Therefore, it's inaccurate to suggest that enriched air is "safer" than air in any meaningful way. Used properly, both are safe and have impressive safety records. Used *improperly,* enriched air has *more* potential risk due to oxygen toxicity. Safety stops, avoiding factors that predispose you to DCS (such as dehydration), avoiding sawtooth profiles and following other safe diving practices probably reduce your risk far more significantly than using enriched air within normal air limits. Admittedly, some divers feel any mathematical DCS incidence risk reduction, even though tiny, still makes it worthwhile to use enriched air for dives than can be expected to be made safely with normal air. This is a personal choice without any safety concerns, provided enriched air procedures are followed.

Although enriched air has a reduced nitrogen content, many diving physiologists don't believe enriched air significantly reduces narcosis when making deeper dives (Bennett, 1970; Linnarsson, *et al.*, 1990. This is because oxygen under pressure appears to have similar narcotic properties to nitrogen under pressure. Thus, while enriched air has less nitrogen, it has about the same potential for narcosis. Although some divers say they experience less narcosis with enriched air, it's wisest to assume enriched air will not reduce narcosis. Some divers claim they "feel better" after a dive with enriched air. There is little objective evidence for feeling less tired or "better" after diving with enriched air, but it has been cited frequently. This may simply be a psychological effect.

In comparison to air diving, diving with enriched air offers longer no-decompression times, but it also has five disadvantages and potential hazards:

1. Potential for oxygen toxicity - Much of what is taught is the PADI EAN_X program deals with staying within oxygen time and depth limits. Exceeding safe oxygen limits can be

extremely dangerous. This is the most serious of the potential hazards unique to enriched air diving.

2. Special equipment - Because of the higher oxygen content, enriched air diving requires a dedicated cylinder and may require other equipment exclusively for enriched air diving. It can also be very hazardous to fill an enriched air cylinder from a conventional air source. Special equipment also includes a properly calibrated oxygen analyzer to verify cylinder content. Enriched air equipment also requires special maintenance.
3. Availability - Enriched air is readily available in some areas, in others you won't find it at all.
4. Proper gas blending and handling - You must ensure that you're diving with the blend of enriched air you intend to, and that neither you, nor anyone else, confuses one enriched air or normal air cylinder for another. It can be very hazardous for someone to use enriched air, or the wrong blend accidentally.
5. More complex dive planning - Enriched air diving requires more planning steps, with more potential for error, and less tolerance for error if you make one. You must use care and double check you dive table and oxygen calculations to avoid both DCS and oxygen toxicity. Monitoring your depth becomes more critical.

Equipment for Enriched Air Diving

The primary concern regarding enriched air and dive equipment is the high oxygen content. Pure oxygen and high oxygen mixes cause materials to burn/explode more readily, even at normal temperatures. High oxygen content may also cause equipment to deteriorate rapidly.

A common guideline in diving is that standard scuba regulators, BCDs, SPGs and alternate air sources may be used for enriched air blends up to 40 percent. This is based on recommendations, standards and field experience by NOAA, the U.S. Navy and the National Institute of Safety and Health. In practice, this guideline has a good record. However, local law may require that all equipment used with enriched air be cleaned to oxygen service specifications, and local practice may also require that specific equipment meet oxygen service standards and include specific marketing or tags. Regulators rated for 300 bar/4500 psi must meet oxygen service standards. Some groups within the diving community advocate oxygen service standards for all equipment used with more than 23 percent oxygen.

Most scuba equipment manufacturers have recommendations and/or modifications for their equipment when it is used with enriched air. Others state that their equipment shouldn't be used for enriched air. Follow recommendations of all manufacturer's guidelines and contact the manufacturer for information as necessary, since recommendations may change over time. In all cases, gas mixes with more than 40 percent oxygen (used outside of recreational diving and beyond the scope of PADI's course) *require* the equipment to meet oxygen service specifications.

Enriched air requires a cylinder dedicated specifically for use with enriched air for two reasons:

1. It's critical for safety that no one accidentally confuses the nitrox cylinder for one containing standard air. Therefore, the cylinder must be clearly marked.
2. One method of blending enriched air requires putting pure oxygen in the cylinder. This is called "partial pressure" blending. When *partial pressure blending with pure oxygen will be used, the tank and valve must meet oxygen service standards even though the final enriched air blend will have less than 40 percent oxygen.*

As a result, enriched air cylinders have standardized decals and/or tags and color coding generally agreed upon by the international diving community. These markings assure that you can readily identify an enriched air tank, determine its contents and determine whether the cylinder can be used for partial pressure blending.

Yellow cylinders should have a 10 centimetre/4 inch green band around the tank shoulder with yellow or white lettering reading "Enriched Air," "Enriched Air Nitrox," "Nitrox," or a similar designation.

Non-yellow cylinders should have a 15 centimetre/6 inch band around the tank shoulder. The top and bottom of this band should be a yellow 2.5 centimetre/1 inch band, with a 10 centimetres/4 inches green center. The green portion should have yellow or white lettering reading "Enriched Air," "Enriched Air Nitrox," "Nitrox," or a similar designation.

Enriched air cylinders should have a dated annual visual inspection decal stating that the cylinder has been serviced and inspected for enriched air use. The decal should also indicate that the cylinder does, or does not, meet oxygen service standards for partial pressure blending.

Additionally, enriched air cylinders should have a contents decal or permanent tag. This decal/tag should, at a minimum, list the oxygen content of the blend the cylinder currently holds, the fill date, the maximum depth for the blend, and the name of the person who analyzed the oxygen content to verify the blender's analysis (this should be the diver who will use the tank). Decals are replaced and tags rewritten when the cylinder is refilled.

Besides these markings above, local laws and regulations may require additional or modified markings on enriched air cylinders. Some areas have recommendations or requirements that an enriched air cylinder be used within a given period, such as within 30 days of filling, and the cylinder may be marked accordingly. In other areas, standard air cylinders are stamped "air only," highlighting the need for a dedicated cylinder.

Concerns Associated with Filling Enriched Air Cylinders

The first is a fire/explosion hazard. As mentioned, some substances readily burn or explode in the presence of high oxygen concentrations. This includes trace hydrocarbons (lubricants) that may be found in standard compressed air. These trace lubricants may accumulate over time in a compressed air cylinder, raising the potential for fire or explosion hazard if the cylinder is exposed to high oxygen percentages. Similarly, during the filling process compressed gases can back flow into the filling system from an enriched air cylinder. This also poses a potential fire/explosion hazard in the presence of high oxygen concentrations.

The second concern is the percentage of oxygen in the blend. The amount of oxygen in an enriched air blend is critical. If the percent of oxygen varies by more than one percent, oxygen exposure, maximum allowable dive depth and no-decompression limits will be affected.

To handle these concerns: If partial pressure mixing in the cylinder will be used, air used in filling enriched air cylinders must meet oxygen compatibility requirements. Oxygen compatible air is produced by using special oil-free compressors, special filtration, or a combination of both. This is crucial because even trace oil or contaminants may create explosion/fire hazard. Other, more preferred methods of producing enriched air do not require putting pure oxygen in the cylinder. These methods greatly reduce filling hazards, but nonetheless, the cylinder must be dedicated for enriched air use and serviced accordingly.

Enriched air blending and filling requires keeping records of system maintenance and fills beyond those required for a conventional compressed air system. To manage these concerns, enriched air cylinders should only be filled by reputable, qualified enriched air blenders. Qualified blenders have the proper equipment for producing oxygen-compatible air and minimizing contamination of equipment that must remain in oxygen service and/or enriched air service. Qualified blenders have the special training required to produce accurate enriched air blends and confirm the accuracy. Qualified blenders have been trained to follow the operational procedures and maintain the necessary records.

Qualified enriched air blenders and service are identified by checking the following:

- Gas verification -- The operation should be able to show regular analysis of the air it uses for enriched air blending. This air should meet local standards for oxygen compatible air, such as Compressed Gas Association (CGA) Grade E air standards, modified to have no more than 0.1 milligram per cubic metre of detectable hydrocarbons or 10 parts per million of carbon monoxide (many operations try to limit it to two parts per million), or Grade J standards.
- In all cases, the air should be filtered to eliminate detectable particles (dust, etc.).
- Proper procedures for cylinder marking, analysis, and record keeping -- A lack of these may indicate that the operation isn't qualified or prepared to properly support enriched air diving.

Oxygen Analysis

Enriched air is analyzed by the blender after blending. Nonetheless, the diver who will be using a cylinder of enriched air must also personally verify the oxygen analysis of the cylinder. Do not dive with a cylinder of enriched air if you have not personally verified its contents. Failure to verify cylinder contents could lead to DCS or drowning due to oxygen toxicity if the cylinder contains an enriched air blend different from what you believe it to be. This is an important safety principle that avoids problems by double checking the initial analysis, verifying that the cylinder has been correctly marked for that blend, and confirming that the cylinder wasn't accidentally confused with another.

As stated, enriched air must be within 1 percent of the desired oxygen content. If the blend varies more than 1 percent from the desired oxygen content, you must recalculate your EADs and oxygen exposure based on the actual content, or have the cylinder refilled with the desired blend.

Oxygen Toxicity

Exceeding oxygen limits can cause central nervous system oxygen toxicity (CNS toxicity). CNS toxicity may cause a diver to convulse. Convulsions are not usually harmful by themselves, but underwater the diver is almost certain to lose the regulator and drown. This is the primary serious hazard of exceeding safe oxygen limits resulting in a fatal accident. Warning signs and symptoms may precede a CNS convulsion, but most of the time, it occurs without warning.

Warning signs and symptoms, if they do occur, include:

1. visual disturbances, including tunnel vision
2. ears ringing
3. nausea
4. twitching or muscle spasms, especially in the face
5. irritability, restlessness, euphoria or anxiety
6. dizziness

Note: PADI teaches divers the mnemonic VENTID -- vision, ears, nausea, twitching, irritability and dizziness and to ascend and end the dive immediately in the presence of any of these symptoms.

Heavy exercise is thought to be a predisposition to CNS toxicity, and should be avoided if you will near oxygen exposure limits, especially if your dive accidentally exceeds 1.4 atm. Some drugs, including the decongestant pseudoephedrine (found in Sudafed® and other products), are CNS exciters believed to predispose to CNS toxicity. It's generally recommended that divers avoid decongestants when diving (because they may wear off during the dive, leading to a reverse block). If taking a prescription, divers are instructed to consult with a physician knowledgeable in diving medicine before using the drug while diving (with air or enriched air).

Carbon dioxide accumulation in the body is believed to predispose oxygen toxicity (Lanphier, 1955). It's important to breathe continuously (do not skip breathe) to avoid retaining carbon dioxide. If you experience headaches after a dive, as a precaution, consult a physician familiar with diving to make sure you don't retain carbon dioxide.

Pulmonary or *whole body* oxygen toxicity is caused by prolonged exposure to high oxygen partial pressures. Exposures of several hours long are necessary to develop whole body oxygen toxicity, and are highly unlikely to occur within the oxygen exposure limits in the PADI EANx program. Symptoms include burning in the throat and chest, coughing and shortness of breath. Pulmonary oxygen toxicity is more of a concern in technical and commercial dives that require long decompression stops using pure or high amounts of oxygen (50 percent or more). Nonetheless, divers are advised to discontinue diving for a few days if symptoms are experienced that could indicate pulmonary oxygen toxicity.

Managing Oxygen Exposure

The high oxygen partial pressures experienced with enriched air must be kept within limits or they pose serious hazards to the diver. The higher the partial pressure, the shorter you can safely be exposed to it. Therefore, you must track your oxygen exposure with tables much as you track your nitrogen exposure. Oxygen exposure limits are independent of depth; they relate entirely to partial pressure. The oxygen partial pressure is .80 atm at 10 metres/33 feet using EANx 40. Using EANx 36, you have the same partial pressure at 12 metres/40 feet. Your oxygen exposure limits are the same for both dives.

The maximum oxygen partial pressure for PADI enriched air diving is 1.4 atm. 1.4 atm is the recommended maximum because it keeps you well within established oxygen limits appropriate for recreational diving. Planning a dive within 1.4 atm partial pressure also provides for margin of error. Some evidence suggests that as oxygen partial pressure exceeds the 1.3 atm to 1.4 atm range, the EAD concept becomes less reliable. Staying within 1.4 atm partial pressure reduces the likelihood of problems with this. If the planned dive depth would exceed 1.4 atm, either switch to an enriched air blend with less oxygen, or plan a shallower dive.

The contingency oxygen partial pressure limit is 1.6 atm. PADI discourages planning dives with a partial pressure this high because there is no room for error. Partial pressures between 1.4 and 1.6 atm should be considered a margin for error only. Divers at work have had oxygen toxicity (convulsions) near 1.6 atm while at work. Exceeding safe oxygen limits poses a high risk of oxygen toxicity.

Dive Planning Tips for PADI EANx

Treat the entire dive as though it were made at the deepest depth/highest partial pressure. Although NOAA limits don't specify minimum surface intervals, and there is no measurable credit for surface interval, it's recommended that you have a surface interval of at least an hour between enriched air dives whenever possible, especially if you exceed more than *50* percent of allowable exposure. This is believed to further reduce the likelihood of oxygen toxicity.

Do not exceed 100 percent of allowable exposure in 24 hours. Doing so, even at lower oxygen partial pressures, puts you at risk of oxygen toxicity. It is recommended for extra conservatism that you limit your exposure to 90 percent. If your planned dives would cause you to approach or exceed oxygen exposure limits, switch to an enriched air with less oxygen and/or plan your dives to shallower depths. Maximum allowable dive time is always the shorter of the no-decompression time or remaining oxygen exposure time. Always check both.

After a dive in which you were to accidentally exceed the contingency oxygen partial pressure limit of 1.6 atm, your oxygen exposure is considered 100 percent. It is recommended that you do not dive for at least 12 hours. The Oxygen Exposure Table allows you to track your accumulating oxygen exposure when making repetitive and multilevel dives with differing oxygen partial pressures (this is sometimes called the "oxygen clock"). Because people differ in their physiology, no table, computer or other method of measuring oxygen exposure can guarantee that oxygen toxicity will never occur, even within accepted oxygen limits. In rare instances, oxygen toxicity has occurred within the NOAA limits. Stay well within oxygen limits. It's easy to keep your oxygen partial pressure well within 1.4 atm by using an enriched air with less oxygen and/or by limiting depth.

Analysis of Oxygen Exposure Limits for DSAT Oxygen Exposure Table Against Existing Database of Manned Oxygen Test Dives

The PADI Enriched Air Diver course makes use of a new Diving Science and Technology (DSAT) Oxygen Exposure Table, distributed by PADI. This table is based on the commonly accepted National Oceanic and Atmospheric Administration (NOAA) single exposure limits:

NOAA Oxygen Limits for single exposures

PO_2 in atm	Time
0.6	720 min
0.7	570 min
0.8	450 min
0.9	360 min
1.0	300 min
1.1	240 min
1.2	210 min
1.3	180 min
1.4	150 min
1.5	120 min
1.6	45 min

The DSAT Oxygen Exposure Table allows the user to convert time at particular PO_2s to a percent of allowable exposure. Exposure in 24 hours may not exceed 100 percent. This methodology makes it practical in the field to track exposure during repetitive dives, multilevel dives, and when using more than one blend of enriched air.

NOAA limits extend total exposures for PO_2s from 1.6 atm through 1.1 atm with a minimum surface interval of two hours between exposures. The DSAT Oxygen Exposure Table doesn't allow this additional exposure time and limits 24-hour exposure to the single exposure limits for the following reasons:

- The PADI course emphasizes keeping PO_2s below 1.4 atm, which is an appropriately conservative level for recreational divers. The significantly reduced time at higher PO_2s encourages this, plus maintains conservatism if 1.4 atm is exceeded.

- Within the realm of no-decompression diving with enriched air, there's little need for greater exposure. Divers who stay within 1.4 atm and make progressively shallower dives will not often find themselves limited by oxygen exposure, even with the existing limits.
- From a training and educational viewpoint, building in the two-hour credit would complicate the table and field use. This increases the possibility of error with little real benefit in the majority of diving situations.

Although the NOAA limits have been widely accepted within the technical, and scientific diving communities, DSAT could not simply accept the limits on that basis alone. Of particular concern were the old U.S. Navy limits, which are more conservative.

US Navy Oxygen Limits for single exposures

PO_2 in atm	Time
1.0	240 min
11	120 min
1.2	80 min
1.3	60 min
1.4	50 min
1.5	40 min
1.6	30 min

Another concern was that much of the testing that led to the NOAA limits was conducted using pure oxygen closed circuit scuba. Tests using semiclosed nitrogen/oxygen mixes suggest that the presence of nitrogen might contribute to the onset of oxygen toxicity.

On the advice of Dr. Des Gorman (pers. comm.), DSAT compared the NOAA limits against the existing body of manned test dives of oxygen exposure, and against the published analysis of those tests by Professor Kenneth Donald of the Royal Navy. Donald (1942) is widely regarded as a leading authority on hyperbaric oxygen exposure, having begun ground-breaking research into this field in 1942. In particular, DSAT (1992) compared the NOAA limits to Donald's data and comments in his work.

Based on Dr. Donald's findings, the NOAA limits employed in the Oxygen Exposure Table seem reasonable and well within the limits of manned tests. In particular:

1. The limit of 45 minutes at 1.6 atm seems very conservative and appropriate. Most of the published body of testing oxygen exposure involves PO_2s greater than 1.6 atm. This makes extrapolating to lower PO_2s difficult, but there is a significant (approximate) overlap at the range edge that supports the NOAA limits. Tests by Donald using pure oxygen at 25 fsw (PO_2 1.75 atm) resulted in few cases of oxygen toxicity, and with only one exception, those that did occur involved underwater exercise and durations beyond 45 minutes. Further, Donald reports that "The Admiralty Experimental Diving Unit was unable to demonstrate oxygen poisoning in the range of 0 to 20 fsw." Using pure oxygen, this is the PO_2 range of 1.0 to 1.6 atm. Against this data set, a shorter time limit of 45 minutes at the lower PO_2s limit of 1.6 atm, certainly seems reasonable. With the emphasis on a maximum PO_2 of 1.4 atm, the exposure in the DSAT table seems

appropriate. The time limits for PO_2s below 1.4 atm stem more from pulmonary oxygen toxicity concerns than from CNS (acute) toxicity (Hamilton, 1989). An analysis of the exposure limits on the DSAT table when calculated as Oxygen Tolerance Units (OTUs) shows a maximum of approximately 300 OTUs at a PO_2 of 1.0 atm., which conforms with the daily OTU dose recommended by the Repex oxygen exposure limits for repeated daily exposure to oxygen. (Kenyon and Hamilton, 1988).

2. Dr. Donald discounts the old Navy limits as unrealistically conservative. In *Oxygen and the Diver,* he says "... Time limits were also given from 30 minutes at 1.6 atm to 240 minutes at 1.0 atm. These time limits appear to have been quite arbitrary and unrelated to acute or pulmonary oxygen poisoning... These restrictions cause a considerable limitation in the scope of mixture diving..." According to Dr. Donald, the Navy limits may have resulted because tests by Lanphier (1954) seemed to show a possible reduction in oxygen tolerance when breathing nitrogen/oxygen mixtures.
3. Dr. Donald doesn't believe the evidence supports the notion that nitrogen/oxygen mixtures increase the probability of oxygen toxicity. He cites the limited data that Lanphier based his conclusion on, and further cites experiments that show that nitrogen has neither a positive nor negative effect (Dickens, 1945). Says Donald, "Thus [Lanphier's] total evidence that, contrary to the Royal Naval findings (Donald, 1943 (i) & (ii)) and experience, oxygen was more toxic when breathed in oxygen-nitrogen mixtures is of little formal significance."
4. A more recent question involves the role of carbon dioxide retention in causing oxygen toxicity. Although few individuals retain carbon dioxide, especially when using conventional open circuit scuba equipment, recent tests support the limit of 1.4 atm as appropriate when an individual's carbon dioxide retention isn't known. (Kerem *et al.*, 1995).

Field data support both the limits and Dr. Donald's research and experience. The NOAA limits have been in use for more than a decade, with virtually no incidence of oxygen toxicity reported within the proposed range. With the additional conservatism built in, the DSAT Oxygen Exposure Table appears to be well suited for use by recreational divers.

Computer Dives Using Enriched Air

The optimum method for diving enriched air with a computer is to use an enriched air computer. Following the manufacturer's instructions, you program these computers with the blend you're using, they track your no-decompression status and oxygen exposure. If you already own an air dive computer, you can use enriched air with it, too. The simplest way is to plan your dive as a standard single depth enriched air dive using EADs and tables. Then, make your dive with your air computer. During the dive, you can use whichever gives you more no-decompression time, your computer or the EADs and tables. Remember, however, that repetitive dives must be calculated based on what you follow in the first dive.

It's important to plan and track oxygen exposure, especially for long multilevel dives. Planning dives so you ascend in levels, calculating each level's oxygen exposure separately and adding them together. Start at the deepest point of your dive and progressively work shallower, stay at or above the depth levels upon which you base your oxygen exposure. If you don't track levels, you must base your oxygen exposure on the deepest depth and total dive time. If you're only making one or two dives, you may find this much simpler anyway.

Diving Emergencies and Enriched Air

If a diver convulses underwater (possibly due to oxygen toxicity), the generally recommended action is to handle the emergency as you would for an unconscious diver underwater. (Note: This recommendation is based on the U.S. Navy procedures, which the Divers Alert Network defers to in this situation because there's been little study of this in recreational diving.)

a. Hold the diver's mouthpiece in (if still retained). Do not attempt to replace it if it is out of the mouth.
b. Immediately bring the diver to the surface and check for breathing.
c. Establish ample positive buoyancy for both you and the victim.
d. Call for assistance as needed and available and begin in-water rescue breaths if the victim isn't breathing. Take the diver to the boat or shore, and help remove the diver from the water.
e. Once out of the water, check for a pulse and breathing. If they're absent, begin/ continue rescue breaths and/or CPR. In any case, contact emergency medical care. If the diver is breathing, begin first aid for DCI as a precaution.
f. Even if the diver appears fully recovered, the patient should be examined by a physician.

Note: Some experts recommend that if a diver's mouthpiece is in place, to hold it in there and not begin the ascent until the convulsion subsides. After the convulsion ends, bring the diver immediately to the surface. This recommendation is based on the fact that a convulsing diver may hold his breath. In any case, the primary concern is getting the diver to the surface to prevent drowning, so you can begin first aid and get help.

If a diver is suspected of having decompression sickness after an enriched air dive, administer oxygen, first aid, and obtain emergency help exactly as you would if the diver had been diving with air. If possible, inform emergency personnel and the recompression facility of what the diver's time and depth was, that the diver was using enriched air, and what the blend was. In a DCI emergency, if you run out of emergency oxygen before you can get a breathing patient into emergency medical care, have the patient breathe any enriched air available. While not as beneficial as 100 percent oxygen, enriched air has more oxygen than air.

PADI EANx: Certification Numbers History

1. PADI EANx Instructor Certifications Issued 1996 - 2000 (YTD Sept) - 7,274
2. PADI EANx Instructor Trainer Certifications Issued 1996 - 2000 (YTD Sept) - 418
3. PADI EANx Diver Certifications issued 1996 - 2000 (YTD Sept) - 46,788
4. Number of Reported DCS Incidents Involving EANx 1996 - 2000 (YTD Sept) – 17

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NAUI NITROX DIVING STATISTICS

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Overview

NAUI began training and certifying nitrox divers/instructors in 1992. In 1998, NAUI Technical Diving Operations formed to establish standards and procedures for recreational and technical nitrox diving, as well as mixed gases such as heliox, trimix, helitrox, and to formally certify divers/instructors in recreational, extended range, decompression, and mixed gas diving activities. Across programs, maximum oxygen partial pressure, PO_2, is 1.4 atm, except at decompression stops where 1.6 atm is permitted. NAUI has traditionally employed an EAD approach to nitrox tables in the past, but is switching to phase RGBM tables now, to smoothly transition recreational and decompression nitrox diving. With trimix, helitrox, and heliox, NAUI already uses, and has released, RGBM tables coupled to pure O_2 at 20 fsw. Nitrox computers are an integral part of NAUI nitrox training, as necessary component of sensible dive planning and diver staging strategems. Diveware (Explorer, ABYSS, Proplanner, Decoplanner, etc.) is also an integral part of mixed gas dive planning and profile assessment. NAUI encourages "nitrox add on" to all of its curricula by making an additional 2 dives beyond core requirements. Plans are in the works to make all courses nitrox based, with air as a default, or standard case. NAUI employs a mixed gas blending and oxygen service procedure in all enriched oxygen and mixed gas activities and nitrox diving. The manual is also the basis of a gas-blending course.

Training Statistics

To date, NAUI has trained 4412 recreational nitrox divers, 784 technical nitrox divers (staged deco), and 317 trimix divers (staged deco) without incidence of DCS. Some 878 recreational instructors, 322 technical nitrox instructors, and 35 trimix instructors have been certified and trained by NAUI Technical Diving Operations without a single training incident of DCS. Overall, across all NAUI diving programs (recreational and technical), the annual DCS incidence rate for the past 10 years has been below 1/100,000. For all above training dives, some 32,198 tanks have been filled with mixtures up to 100% without mishap. Just for recreational nitrox, the tank total is 17,604 fills. Both EAN32 and EAN36 are standard NAUI training mixtures.

The yearly breakdown for recreational nitrox is as follows below:

Years	Numbers
92-97	1552 divers
	256 instructors
	5664 dives/fills
	0 DCS hits
	0 explosions
98	921 divers
	214 instructors
	3982 dives/fills
	0 DCS hits
	0 explosions
99	969 divers
	240 instructors
	4438 dives/fills
	0 DCS hits
	0 explosions
00	970 divers
	165 instructors
	3620 dives/fills
	0 DCS hits
	0 explosions
	0 DCS hit/17604
	0 explosions/17604

NAUI Technical Diving Operations shows zero DCS hits and oxygen mishaps. And, across all diving, NAUI statistics suggest DCS incidence rate well below 1/100,000 for the past 10 yrs, and no tank/regulator oxygen explosions. These statistics are for NAUI training activities only. NAUI has officially adopted the RGBM for all recreational and technical diving, having already released trimix, helitrox, and high altitude air tables. Nitrox and recreational air tables will soon replace the older Haldane-based tables for recreational diving. Over the past 4 yrs, many 1000s of RGBM dives have been logged without incidence of DCS (dive computers, trimix and helitrox NAUI tables, ABYSS, and altitude exposures).

On oxygen cleaning issues, NAUI adheres to the 40% or greater cleaning rule for enriched mixtures.

RECREATIONAL NITROX BASED ON COMMERCIAL DIVING CONCLUSIONS

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Introduction

Fish farmers are at risk. Using SCUBA, these commercial divers perform repeated bounce dives in frigid Canadian waters. With classic spike profiles, day in and day out, this group of divers is particularly susceptible to decompression sickness. Since their dives are relatively shallow (to 90 feet), these working divers are perfect candidates for nitrox. Using nitrox in the conditions this group dive under presents its own set of unique problems, ironically not unlike recreational divers using nitrox. While researching solutions for diving fish farmers, a new nitrox concept was developed.

Issues

The benefits of using nitrox in relatively shallow water is universally understood and accepted. The downside to enriching air with oxygen is the potential for oxygen toxicity events and decompression sickness remains an issue. These problems are exacerbated primarily from a lack of information retention; divers simply forget their theoretical nitrox training.

Experience has shown that when tested, few divers successfully pass a retest, even two weeks after taking a nitrox course. The result is divers who are certified for a lifetime but are unable to remember the math formulas required to safely perform a nitrox dive. Unfortunately, these divers often devolve to the potentially dangerous situation where they continue to dive nitrox even though they don't remember how.

Nitrox Table Development

Divers are familiar with the concept of dive tables. We felt that if we could develop a single, easy to understand and use nitrox table, it would solve the problem of divers forgetting formulas. In other words, we would do the math, then train the divers to understand the table.

For the nitrox table to be effective, it also had to incorporate oxygen toxicity information. Research indicated that pulmonary oxygen toxicity was not an issue below a PO_2 of 1.3 atm. A scuba diver just simply could not get the time/dose required to be at risk. The lowest PO_2 at which a CNS oxygen toxicity event was noted was at 1.3 atm. We explored the viability of using a maximum PO_2 of 1.2 atm and 90 fsw as the maximum depth.

At first the idea sounded preposterous. It was felt that bottom times would be diminished to the point that we might as well just use air. The big surprise came when we ran the numbers. Incredibly, the limiting factor is air consumption/cylinder volume, not bottom time. Working scuba divers, much like the majority of recreational divers, favor the ubiquitous aluminum 80 cu ft cylinder.

The worst DCS case scenario is multiple repetitive dives at the maximum dive table limit. DCS considerations are largely addressed by the unused allowable bottom time. For example, if an air dive table allows 60 minutes of bottom time at a given depth, whereas the same exposure with nitrox allows 200 minutes, the diver is still limited by air consumption/gas volume carried. If the dive actually lasts 50 minutes, this leaves 150 minutes of unused bottom time. The body does not absorb that amount of nitrogen time. Unfortunately, as a diver goes deeper, the unused bottom time advantage diminishes.

Pulmonary and CNS oxygen toxicity are not an issue at a PO_2 of 1.2 atm or less. The final hurdle was how to track the total accumulated oxygen exposure. We found that by color coding the nitrox table, it would depict the maximum allowed 24-hour exposure at a glance. The value assigned for each color was based on the maximum total duration for any 24-hour day for the PO_2s from .6 atm to 1.2 atm on the NOAA "Oxygen Partial Pressure Table".

The end result is a simple nitrox table that provides the diver with all of the information to conduct a nitrox dive at a glance with no equations or formulas required. With UPTD's and CNS% tracking factored in and an easy to use color code for tracking daily oxygen dose, the nitrox table is simple to use and easy to remember.

Conclusion

On presentation to the Workers Compensation Board of British Columbia, Canada it was immediately accepted as the required training for working scuba divers that choose to use nitrox. Furthermore, the largest commercial diver training school in Canada, the "Commercial Diving Group" has incorporated it as a core program in their curriculum.

Indeed, fish farmers are at risk, but armed with nitrox training developed specifically for them, perhaps they can dive safer. This concept is easily transferred to the public safety and recreational diving communities, without modification. Imagine all of the benefits of diving Nitrox without a downside.

AMERICAN ACADEMY OF UNDERWATER SCIENCES' NITROX USE

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Introduction

The American Academy of Underwater Sciences (AAUS) is a not-for-profit corporation. We are twenty years old and represent 72 universities, government agencies, consulting companies, and independent institutions that engage in underwater science, education and exploration. The AAUS publishes and maintains standards in scientific diving that comply with the OSHA exemption for scientific diving.

Our experience with nitrox began in government-sponsored workshops at Harbor Branch Oceanographic Institution in 1988 and at Florida State University in 1989. These workshops resulted in written standards for diver certification and gas mixing that were published in 1991. The AAUS Nitrox Standards were revised in 1999. The National Undersea Research Center (NURC) at the University of North Carolina, Wilmington, was the organization that provided most of the initial training and nitrox gas for member organizations. Until 1994, most of the nitrox training was provided through the NOAA/NURC facility in Wilmington, NC and Key Largo, FL. This provided a core group of Diving Officers, knowledgeable and experienced in nitrox operations. Currently, nitrox training is provided through nitrox training agencies represented at this workshop. Some programs train and fill nitrox cylinders in-house, while others are using dive shops and outside instructors for training and to obtain gas.

Operational Nitrox Statistics

The AAUS requires member organizations to report diving activity statistics annually. Our nitrox data accumulation began in 1987 and shows that nitrox use has steadily increased (Table 1). In the early years, the typical operation was an expedition on a NURC or NOAA ship, operationally managed by NURC staff.

In 1998, AAUS organizations reported 65,558 air dives compared to 4,880 nitrox dives (7.44%) and in 1999 the number of air dives was 61,522 and nitrox dives 4,385 (7.13%). In 1998, 393 researchers used nitrox and in 1999, 443 were diving nitrox.

Table 1. Summary of AAUS Nitrox Use.

Year	No. of Organizations reporting nitrox use	No. of nitrox dives	Bottom Time (minutes)
1987	3	254	1,435
1988	5	507	8,011
1989*	4	261	4,998
1990*	4	446	7,480
1991	5	414	14,245
1992	6	1,016	26,920
1993	7	632	21,155
1994	14	2,702	77,150
1995	12	1,215	46,346
1997	18	1,749	64,163
1998	35	4,880	185,175
1999	33	4,385	144,896
Totals	48	18,461	[10,033 hours]

*Organization reported number of dives, but no time.
Data for 1996 was omitted because of processing challenges.

In conjunction with the annual AAUS Symposium, we conducted an informal survey of AAUS members to obtain more details on nitrox diving. Of the 38 responding organizations, 33 were AAUS organizational members. Twenty-five of the OMs offer certification training in nitrox; certifications are through recreational training programs including: ANDI, IANTD, NAUI, PADI, SSI, TDI, and YMCA. Decompression management includes: Air and Nitrox Tables, air and nitrox computers, and custom software for decompression diving using nitrox as a stage-decompression gas. Twenty-nine organizations are using 32% and 36% oxygen mixtures, and 22 organizations are also using custom blending. Organizations most commonly use a PO_2 of 1.4 atm, and 1.6 atm was the second most common limit. Several organizations reported that they impose different partial pressure limits depending on depth, mixture, and operation. All of the respondents reported that divers are required to test the cylinder oxygen percentage before the dive and the majority was satisfied with testing equipment.

Oxygen cleaning of cylinders is standard procedure for 21 respondents (9 reported no cleaning) and many reported that if the percent oxygen was less than 40% they did not oxygen clean, but if the percentage exceeded 40% they did require oxygen cleaning of the cylinder. Scuba regulators designed for nitrox use is required by 14 organizations, and not required by 13. The greater than 40% oxygen limit was frequently invoked as the need to use a regulator designed for nitrox.

Fourteen organizations have mixing/filling systems for nitrox. Seven programs use partial pressure blending, 6 use blending with an oxygen source or a gas separation membrane, and one used another undefined mixing method. Only two of the 14 organizations that operate systems use oil-free compressors. Nine of the organizations report HAZMAT training for operators, three do not require training, and two did not respond. It is a DOT-OSHA requirement for fill station operators to receive HAZMAT training relative to the fill station and high-pressure cylinders within thirty days of hiring.

Reported Incidents and Rates

None of the organizations reported an oxygen toxicity problem. When asked if a PO_2 limit of 1.6 atm was dangerous, the DSOs responded that 1.6 atm was not a risky limit. The AAUS organizations are required to report diving incidents. Since 1987, the incident reports involving nitrox include:

- barotrauma: 1
- near drowning: 1
- injury caused by cnidarian stings: 1
- DCS incidents requiring chamber treatment: 6.

The barotrauma incident resulted from a stuck inflation valve in a dry suit training exercise. The individual was hospitalized, provided chamber treatment, and recovered fully after a month. The DCS cases were not severe and the individuals were reported to be fully recovered following recompression. Symptoms included pain in the shoulder, elbow, knee, hip, ankle, back, and fatigue and nausea. The near drowning was the result of a diver concealing information about epilepsy; the individual did not honestly report this condition on the medical history form and failed to take seizure-control medication.

Three of the nine incidents were not the result of nitrox use. The six DCS incidents compute to a cumulative (1987 to 1999) incident rate of 0.03. The DCS incidents occurred in 1991 (2), 1992 (3), and 1993 (1). The six incidents occurred in depths of 50 to 120 ft; some profiles had three repetitive dives, two were multiday operations, and one was a staged decompression operation. When comparing AAUS nitrox and air diving activity from 1997-1999, there were no nitrox DCS incidents, and for air diving there was one incident in 1997, one in 1998, and six incidents in 1999. The DCS incident rate ranges from 0.00002 to 0.00009 for air. The incident rate for nitrox diving for 1997-1999 was 0. Several of the DCS incidents have multiple dives to depths deeper than 70 ft. in common.

I. NITROX OPERATIONAL DATA

A. Nitrox Certification Data

M. Lang: I again thank all training associations for sharing their nitrox data for the common good. Instead of having every agency representative provide a "death by PowerPoint" presentation for twenty minutes, we have tabulated the nitrox certification data that was submitted to us. I wish to review this information and give everyone a few minutes to either elaborate on, or modify your submissions. The first spreadsheet is only for the certification data. The second one shows the reported DCS incidences of nitrox versus air. Initially, our intent was to get a hard count of numbers of nitrox dives. Barring every nitrox diver having a logbook to submit, that objective was not promising. Several groups did provide nitrox certification numbers but some had no way of tracking numbers of dives. Next, we opted to look at numbers of nitrox fills and made the reasonable assumption for recreational nitrox diving that one fill would equal one dive. I understand that for some cave diving operations the same cylinder gets partially refilled, which would not quite work for our assumption here. The first thing I want to accomplish is to verify the submitted data.

Table 1. Recreational Nitrox Certification Data

Organization	Instructors	Divers	Since
NAUI	878	4472	1992
PADI	7274	46788	1996
SSI	605	1570	1996
IANTD	8140	64378	1991
TDI	12823	66206	1994
ANDI	3196	49118	1989
UNCW	N/A	803	1986
NOAA	N/A	139	1981
NASA	8	384	1996
AAUS	N/A	N/A	1987
Aggressors	N/A	N/A	1997
Sea Hunter	N/A	N/A	1997
TOTAL	**32,924**	**233,798**	

B. Wienke: Those are the NAUI data and the information is only for diving instructors and recreational nitrox students certified. NAUI came on line with the nitrox program in 1992 as a specialty course. In 1998, NAUI Technical Diving Operations was formed to include recreational nitrox and technical diving, which is extended range diving, deco-diving, and tri-mix.

D. Richardson: Those are the data that PADI submitted. We differentiated (did not include) the instructor-trainer group (418) from the instructors at large. That might affect your bottom line. If it has any relevance, that would be the only difference. The data are from January 1996 through September 2000.

J. Hardy: Those are the SSI numbers. The program was put together in 1996, but those figures only represent 1997, 1998, and 1999. I would like to come back to Drew for a moment.

When I reviewed the figures, I saw that the first year of the program had higher number of certifications than the second year of the program. It was high, went down and went up again. Drew, did you find that same thing for PADI, an initial influx and then a drop off?

D. Richardson: Yes, Jon, basically the same experience. We viewed that as a pipeline of interest, if you will. It didn't drop off a lot, but it did somewhat and since then it's been a steady upward growth if you look at it on a curve.

J. Hardy: Exactly the same with SSI.

T. Mount: That is the IANTD submitted data and it is current through the end of October. We also have instructor trainers who aren't listed there, but it wouldn't change the numbers because they have instructor numbers prior to becoming instructor trainers.

B. Gilliam: Yes, TDI is exactly the same. As represented, our instructor trainers would be included in the instructor group anyway so those numbers wouldn't change. Our numbers are accurate through the end of the third quarter.

E. Betts: The ANDI numbers confirm what we submitted. Probably the only comment to make is that the number of instructors represents nitrox instructors and nitrox instructor trainers only. Instructors with other ratings are not included, for example, an open water instructor who is not a certified nitrox instructor. To get some validity to the data, since that's what we're looking for, it would be fair to comment that there has to be a tremendous number of duplicate certifications. This might possibly explain the sudden influx of numbers with, for example, PADI's data and SSI's data, followed by the drop-off. Crossover certifications and multiple certifications are frequently the case.

M. Lang: Do you have any feel for what the overlap might be?

E. Betts: It's an appropriate question to ask. If we're trying to validate data, I really couldn't offer a conjecture. There is a reasonable number of ANDI instructors who also hold other agency's instructor numbers. I would probably estimate that number to be as high as 25 percent.

B. Gilliam: Ed may be right in regards to the possible cross-certification of instructors. I doubt if you're seeing any of that skewing the diver statistics because I don't really see anything that has the tendency for a regular diver to end up with multiple certifications. Although that may be true at the instructor level, I think the other numbers are pretty hard.

M. Lang: For nitrox?

B. Gilliam: Yes, for nitrox.

T. Mount: I would concur with what Bret said. We actually sent a survey out to instructors at one point to know if they cross-certified students and very few of them do. Most of them certify with one agency or another. Many of the instructors obviously are multi-agency certified.

M. Lang: Drew, would you want to comment on that?

D. Richardson: That's consistent with our analysis.

J. Hardy: What Bret is saying is true. There are a lot of crossovers at the instructor level, particularly at first. These instructors may have already held a certification from a technical diving association, but as far as I can tell, we have very little crossover at the student diver level.

B. Wienke: I would concur with that and as the cost of certification goes up for divers with the agencies, you'll see less multiple certifications for divers.

M. Lang: As there are no more comments on this first section of operational data, we'll proceed with the rest of the data submissions.

D. Kesling: The UNC numbers are what we submitted. My main comment is under number of instructors. We have instructors teaching under NAUI, PADI and IANTD programs. That's the only comment about issuing recognition material certifications for the scientific diving nitrox study and those 803 divers.

M. Lang: They are IANTD certified?

D. Kesling: Those are scientific nitrox divers within our program who might receive recognition materials or meet the prerequisites for NAUI, PADI or an IANTD certification based on what they select or what the instructor offers.

M. Lang: Those numbers may actually already be accounted for in NAUI, PADI, or IANTD?

D. Kesling: Right.

M. Lang: I'll make a note of that.

D. Dinsmore: Those numbers are correct. The "2" represents instructors at the NOAA Diving Center. Besides being NOAA instructors, they are also NAUI nitrox instructors. The number "139", if you realize we have got about 300 NOAA divers, represents over one third of our total who are nitrox certified.

M. Lang: Are these yearly recertifications or are these one-time certifications?

D. Dinsmore: Those would be one-time certifications.

C. Borne: The numbers haven't changed. I need to point out that at the NASA facility, we don't certify divers, they're not given a card. They're not doing any kind of open water checkout dives, it's a facility-specific qualification. The number "384" is what is on my current roster. There have probably been approximately 250 divers deleted from that roster. As far as certification or qualification, we're close to a 600 diver total. My instructors are with IANTD, NAUI and PADI. Sixty to seventy percent of my staff of 70 have gone on to get the nitrox certification, but some of my staff members do not hold the cards, they're just qualified to dive in our facility.

W. Jaap: If you look at the "non-available" entry under the instructor heading, we have 24 organizations at AAUS that do teach a nitrox course and certify through probably PADI, NAUI and IANTD. As far as numbers of divers last year, we had 442 nitrox divers in AAUS organizations. The typical percentage of nitrox diving compared to air diving is about seven percent at this point in time. Nitrox is showing a slight gain on air diving. Other than that, it shows we have been doing quite a bit of nitrox diving.

M. Lang: The next operational data section is from liveaboard nitrox diving. We thought we might be able to get a good handle on the number of nitrox dives that actually occur among captive liveaboard diver populations. The problem we ran into was that some operations don't track numbers of dives because they felt there wasn't a need to. The only way for them to track nitrox divers at all would be to physically count the release and waivers signed specifically for nitrox. Peter Hughes, for example, even though he was interested and wanted to contribute numbers, felt he could not allocate the staff time to trace this. The next option I pursued was to try to get an idea of the number of nitrox dives by overlaying a formula on the cubic footage of oxygen consumed; however, several liveaboard operations use gas separation membranes so we could not answer how many 80 cu.ft. aluminum nitrox cylinders were filled.

B. Gilliam: Michael, Evin Cotter asked me to report on this since TDI pulled the hard records for the Aggressor Fleet. Their numbers are underreported because only eight of their 13 vessels were able to report, so their number of divers would be higher. Because their divers are certified through our agency, TDI, they are replicated in our numbers above. The number of instructors entered as "n/a" would actually be approximately 80 instructors during that period. Those numbers would probably be higher, but you would be getting into duplicate reporting there.

M. Lang: Alright, and the same for the other liveaboard operations, they're in the TDI numbers?

B. Gilliam: Yes.

D. Rutkowski: I'd like to make the following comment: Not included in this table is Hyperbarics International. I'm sorry, I didn't realize the importance of it. In 1985, I started teaching recreational nitrox diving at Ocean Divers in Key Largo. Eventually we became so busy as an organization just teaching nitrox and fighting battles with the pseudo experts, that in 1991 I had to bring in Tom Mount and formed a company call IANTD. There is a lot of history there between '85 and '91 that should be included, but I think I turned most of my data over to Tom when we formed IANTD.

T. Mount: The number of divers and instructors is included in the IANTD data I submitted.

A. Marroni: Do the data, NAUI down to ANDI, refer to America only or are they worldwide data?

B. Wienke: NAUI data are worldwide.

D. Richardson: PADI data are worldwide with the exception of Japan, which has some strange gas laws making nitrox not very popular. PADI nitrox certifications worldwide are about two percent of total diver certifications. Jon, for further clarification, the only setback in the second year was really in the Nordic region, they must have had a winter? The northern European market did dip, the rest have met a steady climb since inception.

J. Hardy: SSI nitrox figures only reflect those processed through the United States. If they were processed in another region, they're not reflected in those numbers.

T. Mount: IANTD numbers are international.

B. Gilliam: TDI numbers are international as well.

E. Betts: The ANDI numbers reflect, to the best of our ability, worldwide values. However, we did have some aberrations on reporting especially from Australia and Japan. From a few third world countries, we couldn't get back timely data. There are a couple of ANDI regional headquarters that process certifications individually. For example, in Thailand and Philippines, the numbers are certainly accurate and I don't think that there'd be any skewing at all.

M. Lang: Let me ask, Bart, are your numbers included in IANTD, is that correct?

B. Bjorkman: Yes, because we're primarily a commercial diving operation, if anybody wanted to take a recreational IANTD nitrox course, we would train them to that standard and certify them.

D. Richardson: Just for Dr. Marroni's interest, continental Europe would be about 6,072 of that total number. If you look at greater Europe, out of the PADI U.K. facility, nitrox certifications are around 13,297.

B. Nitrox Dive Data

M. Lang: We'll continue with the submitted dive data discussion.

Table 2. DCS Incidents: Nitrox and Air

	Nitrox Fills	Nitrox DCS	Air Fills	Air DCS
NAUI	17604	0	N/A	N/A
PADI	N/A	17	N/A	N/A
SSI	N/A	0	N/A	N/A
IANTD	1411266	0	N/A	N/A
TDI	N/A	0	N/A	N/A
ANDI	967450	0	N/A	N/A
Ocean Divers	26000	N/A	235504	N/A
UNCW	23407	5	21201	N/A
NOAA	4894	1	156697	22
NASA	34651	0	N/A	N/A
AAUS	18461	1	442679*	27**
Aggressors	33778	1	N/A	11
Sea Hunter	30400	0	N/A	N/A
TOTAL	**2,567,911**	**25**	**856,081**	**60**

* Based on AAUS 1987 to 1999 air dive data
** Based on 1990-1999 data.

B. Wienke: Those numbers are correct. We estimate those nitrox fills based on the number of dives that a diver has to do for nitrox certification, same for the instructor. One tank per dive.

M. Lang: Zero reported DCS incidences during training, or reported cases to NAUI after training was completed?

B. Wienke: No reported cases of DCS for any of our nitrox instructors, and/or divers. Two nitrox dives per NAUI certification. In the NAUI curriculum, nitrox can be embedded in any of the air open water or advanced diving courses. NAUI has plans to make their curricula all nitrox and compressed air would be a subcase or the usual default case.

D. Richardson: There is really no way for PADI to keep track of fills. The only thing that we could attest to is the two-dive requirement per nitrox certification. If you double the certification number for number of dives, it would still give you a gross underestimation. I should elaborate on the nitrox DCS incidences. Of our total incidence reports for the period since 1996, that's about .14 percent of all reports. Those 17 cases aren't in training *per se*. There were three working dives, about twelve divers utilizing enriched air and then three dives in training. One of those was PADI enriched air and two were not. They were in other training schemes. That's what that "17" represents. Of course, there were some other factors, which Dick Vann mentioned earlier, for example, multiple dives and rapid asçents. Perhaps they had nothing to do with enriched air, it just happened to be the medium they were breathing.

T. Mount: On the number of dives that IANTD has as nitrox fills there, those are dives that are actually logged and can be traced to a given facility. Many of our facilities log the dives. They are all supposed to. About 30 percent of them did not respond. Basically, they said they didn't have logs and would have to guess, which I did not accept. The interesting thing about it though to me, because of the influence of everyone getting into nitrox since 1998, is that 800,000 of those nitrox fills were in that short time period. This gives us an idea of how fast this industry is growing. On the decompression sickness rate, zero has been reported through the facilities. I used to run chambers, as did Dick Rutkowski, and admit that the facilities don't always know when divers get bent, but it's the best reporting I can submit to you.

B. Gilliam: TDI has no way of tracking cylinder fills or logged dives at the certification agency level, we did not submit any data there. TDI has no nitrox DCS incidents of any kind during training and we have no knowledge of any other accidents from our certified divers that we've been able to track from the sampling that we did. We think those numbers are accurate.

M. Lang: For clarification, does TDI have facilities like PADI and IANTD?

B. Gilliam: Yes, we do.

E. Betts: The number of nitrox fills is specifically tied to the number of pages completed with the facility-required mix validation books. One nitrox fill per sign off. There are 25 fills on a page and every ANDI training facility, including educational affiliates such as, for example, University of California Davis, are required to have a mix validation book. They're reported quarterly. Only 7.5% were not reported for the current quarter.

D. Rutkowski: We started pumping nitrox at Ocean Divers in 1985. Every one of those nitrox fills are logged by the user's name, percentage of oxygen, and maximum depth that mix can be used to. Those fills are all verifiable by log. However, as Tom said, it's hard for any of us at facilities to know if anybody is really bent or injured. When I operated the Miami chamber for many years, I'd call up a local dive shop and ask if they've ever had anybody bend. They'd respond "Oh no, we never have any diver bend." Well, I've got five of your people in the chamber right now, I'd inform them. That's the story there.

B. Wienke: Over the past 10 years, the reported DCS rate at NAUI headquarters is less than one in 100,000 for all air diving, technical diving, and nitrox diving.

D. Richardson: PADI has a pretty strong capture mechanism for a couple of simple reasons. One, it's required through our standards that members report any kind of incident. It's a litigious society and they routinely do. That would include any incident, even if they have dual certification, or if they're involved in something that may not be a PADI program. In terms of those DCS numbers, again, there were three in training, not exclusively for PADI enriched air, three working instructors doing multiple dives and the balance were divers. We feel confident that if they don't report, they don't have insurance coverage. Typically, that's an accurate reflection of what's been going on since 1996 through our data collection.

T. Mount: We can say it's valid, as far as training and working instructors, that there may have been no decompression sickness. What both Dick and I were referring to is the Joe Blow who goes on a boat to dive nitrox, goes home, gets bent and goes to a chamber somewhere. He has no reason to report it. It would be nice if he would so that your guys would have the record of that, not us.

D. Kesling: Those are the numbers UNCW submitted. It is actually the number of dives, 23,470. It's hard to estimate the number of fills because in probably 25% of the dives we're using twin cylinders. But we do make the assumption of one diver, one cylinder. Those are essentially our numbers of dives, not accurate fill statistics.

M. Lang: Do you want to elaborate on the five cases?

D. Kesling: They were operational, scientific diving cases: Type one, Type two DCS, and probable DCS with recompression therapy. The only other note would be that there is probably some overlap in terms of reporting under the American Academy of Underwater Sciences. These are dives that are captured in our database on exposures and it's not unlike the individual scientists to report those back to their host institution too and they're also captured in the AAUS database.

D. Dinsmore: Those are the numbers that go back to 1981 that NOAA has in its database. The one nitrox bends case occurred in 1997. White female in her 20s on a NoD Nitrox 36 dive, well within the nitrox no-decompression limits. She was involved in a fairly arduous dive catching and tagging turtles underwater. Symptoms were nausea, fatigue, and mood shift. There was a delay in treatment until the next day in a mono-place chamber in Savannah, Georgia where she was treated successfully.

C. Borne: The JSC Neutral Buoyancy Lab doesn't have the capability to even fill compressed air other than for the Russian space suit. These numbers are the number of dives that we're figuring based on one fill per dive. We fill an average of 50 cylinders per day. This data was submitted through 8 October, 2000, so it's climbing as we speak. We've had four incidents at NASA, none of which were nitrox DCS-related. One was a subcutaneous event, not biased to the gas mix. The diving medical requirements for NASA are Air Force Class III flying physicals.

K. Van Hoesen: Michael, if you want to keep track of DCS data, you should probably delete all four of those cases from your database because they really don't represent true DCS, which is what you're looking for up there.

C. Borne: Right. They're not listed here in the next slide.

W. Jaap: Doug's already told you that those six AAUS cases that we have there, five are also reported by UNCW so there's duplication. Dick Vann has also talked about them because several of them were part of that experiment where they were testing use of surface oxygen. In the last three years, if we compare air and nitrox, AAUS has had zero reports of nitrox DCS cases. For air, in 1997 we had one and that results to a .0002 rate. In 1998, we also show one that results in a .0003 rate and in 1999, there are six reported. These six reported air cases contain several that are probably suspect because a facility decided to admit a diver to a chamber just to protect themselves from a legal standpoint. The person may not have really presented with DCS symptoms, but we have received a report of it. Therefore, in 1999, AAUS has a .009 rate for air.

P. Denoble: How is it possible that UNCW reported more nitrox fills than AAUS? Is there not mandatory reporting?

D. Kesling: UNCW has many visiting temporary divers using our facility who are not members of an AAUS organizational member, so their numbers would be reflected in our data and may not necessarily be in the AAUS data.

B. Gilliam: Reporting for the Aggressor Fleet, the nitrox fill data that's entered is only reflective of 5 of the 13 vessels. That number would reasonably be doubled to get the total numbers of fills, which would be dives.

M. Lang: All 13 vessels have nitrox on board now?

B. Gilliam: Yes. That number is skewed just because of the logistics of reporting. The nitrox DCS case remains one. However, the air DCS case that's reported in the far right column, Evin doesn't know where that number came from. Five of the eight boats had eleven cases of DCS for air divers and that number probably would be at least twice that amongst the entire fleet. It's significant that those numbers be reflected that way.

C. Borne: Fore the NASA Space Lab, the 34,000 is for scuba dives only. I'm not sure if we were going to talk about the number of dives or hours that we spend in the space suits? Those dives are logged as event hours. I didn't have the time to get together the man hours or person hours in the water. Since 1996, event hours total over 5,000 hours in the suits alone, that's in addition to the totals, with no DCS reported.

B. Gilliam: With the scientific groups, are those guys primarily diving on tables or on computers? The reason I ask is look at the numbers of DCS in the relatively small population of scientific divers, as opposed to those in the recreational group, which are very low. I know that the recreational group and liveaboards are almost exclusively diving on computers.

W. Jaap: The AAUS nitrox data for dives in 1991 and 1992 were probably table dives and they were controlled experiments for some of those incidents. I don't believe computers were available for nitrox back then. Right now, the way AAUS' tracking of statistics goes, we do not separate computer from table use in terms of reporting from the organizational member programs. From my own experience, at the very least about half of the nitrox dives being made in the U.S. are probably done on computers.

M. Lang: I would support that.

D. Kesling: Until 1997, all UNCW dives were USN table-based dives using the EAD concept. After 1997, we introduced dive computers. One or two of those incidents reflected a dive computer profile. For the question of high incidence relative to the number of dive exposures, in our operation, we have a Divemaster on-site. In some cases, we have chambers on site with DMTs in the field, so we're more attuned to looking at problems post-dive than maybe some of the other recreational type situations and/or the denial situation in DCS and then, the non-treatment type situation. We're pretty aggressive in terms of identifying a problem. Once the individual is turned over to a medical facility, then you normally can't rule out DCS. They go through a full treatment and that's why I put the caveat out there of probabilistic DCS (one or two) based on data that we have from the medical facility, post treatment.

M. Lang: Are these all table treatments, or a test of pressure or diagnostic event?

D. Kesling: These are all full table treatments.

B. Hamilton: Before Dick Vann jumps up over there, we have to be extremely careful interpreting this information. The problem is outcome. You've gone a long way to come up with a denominator, the fills, and that's a fairly good estimate given the caveats we've heard. As you've heard people say, almost nobody has a really clear outcome coverage. You can't really count treatments because cases that aren't decompression sickness get treated and a lot of people sneak away and go to the bar. The number one symptom is denial. Report the information, but try not to connect the cases with the number of dives. For one thing, you can see that the very well organized operation has a fairly high incidence of DCS and the ones with lots and lots of dives have none at all. Something's going on here and we should be very cautious in interpreting this report.

M. Lang: Bill, your point is well taken. It's a given that the analysis is not going to be connecting the dots.

D. Rutkowski: As far as the high incidence at UNCW, these are mainly scientific divers. As Doug mentioned, most of these people are wearing doubles. What these people do is spend many hours a day diving over many days and they have a higher DCS incidence due to that fact. A lot of people don't realize that shallow long dives can be more hazardous than deep quick dives. That's where that higher number comes from.

M. Lang: That was why I had hoped to get hard liveaboard dive data because those divers are a temporarily captive population. If somebody's going to have a problem on day three of a seven-day trip, you're going to know about it as skipper. That population, in general, enjoys essentially unlimited diving. Few restrictions have been offered as far as number of dives per day for a consecutive number of days.

B. Gilliam: True.

W. Jaap: Just to follow up a bit on those six AAUS cases. The earlier ones were multi-day and there were in some cases three dives per day. They were rather aggressive and in one case, there was an error in interpreting a depth that they were supposed to go to, which was exceeded. There are some things going on there that were probably beyond what would be normal recreational, single day dives.

D. Richardson: On the multiple day dives, some of these do include liveaboards. In 12 of those 17 cases, that was perhaps a related factor, which is about 71 percent of that number. There were other related factors, such as rapid ascent and missed stops. That was the next highest category of perhaps a related factor. On the tables versus computer users, about 65 percent of those divers and/or instructors, had computers strapped to them somewhere. This may not have had any bearing at all though considering the other factors.

P. Denoble: Before we continue the discussion of incidents, I would like to remind you that DAN presents for one year more nitrox cases of DCI than there is shown here for several years, not mentioning air DCS. We can say that we probably include in our report about one third of all cases treated. We really shouldn't discuss incidence rates based on these data.

D. Dinsmore: Regarding the NOAA statistics, those 23 cases were all table based. We do not use computers.

B. Gilliam: With regards to the liveaboard populations, for the sake of discussion, the Aggressor numbers alone are worth taking a look at. You've got approximately 60,000 dives that are reflected up there as 33,000, with one attributable DCS hit. In the same population, you have approximately 20 air DCS hits. Their population that is diving nitrox now is approximately 60 to 70 percent of the total numbers of divers on the boat. Most of them are diving on computers. What's also interesting about this population is that those numbers are from higher age groups simply because there's an economic barrier for people who can't afford to dive and spend that money for this particular activity in the sampling group represented there. It's interesting to see that an older population diving three to four dives a day is producing such a small incidence rate. Those numbers are hard. I find that to be a rather remarkable indicator that nitrox is dropping the number of DCS cases in that particular population. The Sea Hunter population, with two vessels operating at Costa Rica's Cocos Island, where Medevac is almost not even a consideration, look what it's done to their numbers. Finally, most of their rebreather dives have nitrox gas that's being used.

M. Lang: Avi Klapfer and Peter Kragh are believers in nitrox diving as can be evidenced by the SEA HUNTER and UNDERSEA HUNTER's consumption of oxygen, by far the most cubic footage in the entire country of Costa Rica.

D. Rutkowski: Our philosophy at Ocean Divers is a little different because we have better control of our divers. People come to Ocean Divers, they want to breathe nitrox and they're going to dive the wreck. They get one tank on the wreck. The tank duration on nitrox doesn't last them any longer than it would if it were air. We encourage everybody to use that 32 mix on the wreck on their air tables or their air computer. Once they do that, everything they learned for air diving applies. When the divers come to me, they analyze the gas, they sign out for the mix by percent. They also sign out for the mix by the maximum depth they can dive that mix to. If they're going to use it as air, I say, take the tank offshore, breathe in, breathe out and bring the tank back. That's all they really have to know. That's where that statement came from. They can only get one tank and they use it as air.

M. Lang: I would like to engage the group in discussion of how much compressed air versus nitrox diving is going on within these groups. Some of you mentioned this, but it has not been consistent throughout the discussions.

B. Wienke: For NAUI, it's probably a four to five percent nitrox use versus air.

D. Richardson: The only numbers I would have for PADI to address that would be certification based. Enriched air is approximately two percent of our total certification base and for that same period, about .14 percent of reported DCS.

J. Hardy: SSI doesn't have a handle on these numbers, they don't have records on that. I would like to make a point to Drew. What the number 17 there is showing is the significant size of PADI compared to all these other organizations and also the good recordkeeping and reporting system. I happen to have the opportunity to serve as a defense expert for NAUI, PADI and SSI. I realize that oftentimes PADI's getting a report that actually happened in one of the other agency's instructor programs. I would like to reinforce what Drew's been saying. This shows the significant size of PADI and the thoroughness of their reporting and recordkeeping system and their influence where an instructor of another agency may actually have PADI insurance.

T. Mount: I don't have anything to add right now.

B. Gilliam: Nothing here.

E. Betts: The only comment I would make is that we have several very large resorts, especially in Israel. Eilat, for example, where one of our facilities does somewhere around a thousand fills in a day seems remarkable, in addition to being responsible for administering and operating the hyperbaric chamber. These people are very attuned to identifying any DCS symptoms. This does not fall in the category of a dive center that doesn't see their divers at the end of the dive day. Pursuant to that, it's interesting to note that they have substantial numbers of cases of DCS from air diving and have yet to have a single case of DCS associated with enriched air diving. Although I can accept comments made regarding the validity of data, there still is some variation in the numbers that needs to be looked at. I don't think it's fair to say that there is less DCS reported with nitrox diving only because there is less correct reporting. For our training agency, we request each ANDI facility to prepare an accident report. A level three report is something that you have second-hand information about. A level two report is a report for which you've got first-hand information. The level one report is a report made out by a witness. I feel that we've made an effort to produce as accurate a data representation as possible stating that no incidence of DCS is associated with enriched air diving. To answer the question concerning air fills versus enriched air fills, for ANDI, according to the last time we asked that question in January, 2000, the numbers are running about 85 percent enriched air fills versus air fills for all of our training scenarios. At the facilities themselves they are pumping just a little under 50 percent enriched air versus air.

M. Lang: I'd like a number from TDI and IANTD.

B. Gilliam: On what?

M. Lang: Percentage of nitrox versus compressed air.

B. Gilliam: 100 percent of our nitrox courses are all nitrox.

M. Lang: What was that middle thing? We actually got that part and are with you all the way. Do you not provide air programs?

B. Gilliam, Yes, we do. The division of our company that teaches entry-level programs in the traditional sport market is SDI. I didn't report on that because it's all air-based stuff. Our technical material includes extended range diving, which is deeper diving on air, but we weren't asked to report on that. We do have it, but those numbers are very small. The preponderance of our business is in the nitrox market and that's the largest database that we have. From our follow-ups, the incidence rate within training is still zero. Obviously, you're going to see more DCS in the extended range type programs than the others, but the numbers are still very small. We do have air-based programs, but they would be in our division known as Scuba Diving International in that much broader-based sport diving market.

T. Mount: About 75 percent of our training is on nitrox. We have a few people who do the open water diving courses on air, but even the majority of them have done it on nitrox now for three years.

E. Thalmann: Before anybody jumps up and down about these numbers, what we're looking at here really are nitrox decompression procedures versus air decompression procedures. I submit that the air decompression data could be made as low as nitrox presumably if you wanted to spend a lot more time in the water. What we're seeing here is that for whatever procedures are being used, nobody's really getting hit. There are probably many different decompression methods being used for the nitrox diving. Nobody's mentioned what those are, but it appears in general they result in a lower DCS incidence for the simple reason that for a given depth you can spend more time in the water on nitrox. We all agree that the increased oxygen percentage is going to give you a lower incidence of decompression sickness. There's really nothing about this data that says anything other than for recreational divers using nitrox the incidence is lower simply because the procedures in use are more conservative than the ones being used for air. It's probably reasonable to say that the type of diving they're doing as reflected here may not really be all that different. As Bret Gilliam said, once you get into aggressive diving, where you're into the long bottom times and lots of decompression, you're probably going to start to see the incident events go up with any type of diving whether it be nitrox or other gas.

D. Richardson: Just one more point. We haven't really addressed behavioral issues but they are a factor. It doesn't really matter what the divers were breathing if they've done a panic ascent. Behavioral issues are a whole other topic, but have something to do with reporting cases of DCS here, irrespective of compressed air or enriched air.

B. Gilliam: Drew's point is interesting. Within TDI, the prerequisite to taking a nitrox program is that you have to be a certified diver and have logged ten dives. Some of the initial anxieties and mistakes that divers might make with regards to being low on gas or rapid ascents would be eliminated in our particular group because they're required to come in with a bit more actual experience. Other agencies that mainstream the divers on nitrox right from the start would be more skewed in the other direction. Ed was saying that people are approaching the decompression differently. The diver groups on air and nitrox are actually approaching it similarly. Most always people are using the gas to maintain no decompression profiles. There's nothing particularly different there in the mainstream nitrox diver use.

D. Kesling: We're right at about a 50-50 split in numbers of nitrox versus air dives and about the same for DCS incidents. About five for both the nitrox and the air. As for decompression obligations, we're using tables or dive computers for scientific productivity. The risk is about the same because with decompression obligations, whether it's a 21 percent mix or a 36 percent mix, we will take it to the maximum No-D limit. As far as procedural practice, the encouragement of the safety stops at 15 feet for three to five minutes is for both forms of gases and diving procedures within our database.

D. Dinsmore: Clearly, the majority of the dives being done by NOAA are on air. Although the numbers are changing as we get more and more people trained, nitrox is now being taught as part of our regular training program, which was not the case in the past. This has only been within the past four years that nitrox has been offered as part of our three week standard NOAA working diver course. We're going to see our numbers increasing in the number of nitrox dives. In 1999, we had 9281 air dives and 1104 nitrox dives. In September 2000, thus far we have 7500 air and about 1200 nitrox dives.

M. Lang: Morgan, maybe you can provide a clarification. The nitrox program that was published in the 1979 NOAA Diving Manual, was that for use at the NOAA Undersea Research Centers (NURC)?

M. Wells: Negative. It was developed for in-house use and spread then to the University NURC Centers supported by NOAA.

C. Borne: NASA's dives are all nitrox.

W. Jaap: For AAUS, between seven and eight percent of all the dives made by the reporting organizations were on nitrox. Two other points I'd like to make. The outcome of those six DCS incidents was good. All those people recovered and most of them reported going back to diving. EPA manages 32 percent nitrox by diving it as air.

B. Gilliam: In the case of the SEA HUNTER fleet, their use of nitrox is nearly 100 percent. In the case of the Aggressor Fleet, it's tending towards 70 percent and will probably increase. They dropped the price of nitrox fills again so that whatever even minor financial barrier was there will have been eliminated. The program is becoming more popular.

C. Nitrox Training Requirements

M. Lang: I would like to proceed to the next topic and am asking the nitrox training agencies for assistance. There is a logical flow to this agenda. We started by highlighting and discussing the operational nitrox certification and nitrox dive data. The following exercise is a sort of mitigation for not allotting each representative a 20-minute dose of "death by PowerPoint". Since the agency heads are all present here, we will proceed with the completion of this comparative table. Please remember to only present values for recreational nitrox diving.

Table 3. Recreational, Scientific and Governmental Nitrox Diving Training Requirements

Recreational Nitrox Training Requirements

	IANTD	ANDI	TDI	PADI	NAUI	SSI
Max PO_2 limit (atm)	1.6	1.6	1.6	1.4	1.4	1.6
O_2 Content Range	22-40%	22-50%	22-40%	22-40%	22-40%	22-40%
O_2 Cleaning	>40%	>21%	>40%	Mfr.	>40%	>40%
O_2 Limits (atm)	NOAA	NOAA	NOAA	NOAA	NOAA	NOAA
OTU/UPTD	300/day	N/A	N/A	N/A	350/day	NOAA
Mix Analysis Accuracy	± 1%	± 1%	± 1%	± 1%	± 1%	± 1%
EANx Table/DC*	T/DC	T/DC	T/DC	T/DC	T/DC	T/DC
Agency Tables	Y	Y	NOAA	Y	Y	Y
Table Model	B-PiN_2	B-PiN_2	USN-EAD**	Rogers/RDP	mUSN-EAD	USN-EAD
Encourage DC	Y	Y	Y	Y	Y	Y
Prerequisites	none	none	OW	OW	none	OW

Government and Scientific Nitrox Training Requirements

	NOAA	NASA	AAUS	UNCW
Max PO_2 Limit (atm)	1.6	1.6	1.6	1.6
O2 Content Range	32% & 36%	46%	22-40%	28-40%
O2 Cleaning	>40%	>23%	na	>40%
O2 Limits (atm)	NOAA	NOAA	NOAA	NOAA
OTU/UPTD	Repex	415/day	Repex	Repex
Mix Analysis Accuracy	± 1%	± 1%	± 1%	± 1%
EANx Table/DC*	T	T	T/DC	T/DC
Agency Tables	NOAA	USN	NOAA	USN
Table Model	USN99-EAD	USN-EAD	mUSN99-EAD	mUSN99-EAD
Encourage DC Use	N	N/A	N/A	N/A

*DC = Dive Computer

** m=modified; USN=United States Navy; EAD=Equivalent Air Depth

USN99=United States Navy 1999 Dive Tables which have not been published at time of this proceeding.

M. Lang: Discussion of table entries.

B. Gilliam: We found out a long time ago that if you keep the divers within the CNS limits, the OTU/UPTD count doesn't make any difference. You can't obtain numbers that are worth mentioning.

K. Shreeves: PADI recognizes the track record of the 40 percent guideline, but we defer to the manufacturer's recommendation.

C. Borne: OTU's are 415 for the suited subject. We take the divers in with a recreational diver's certification and then put them through NASA's training program. Most of my population is former commercial or ex-military, except for the scuba instructors.

D. Rutkowski: The mix analysis should read +/- 1 percent.

E. Thalmann: The NOAA tables and USN tables are the same. The NOAA tables just continue what the EAD already is. If you look at the NDL's, these are just the USN tables converted to the EAD's. If you're using USN tables, you're using NOAA tables.
D. Kesling: That's not the case. You aren't rounding off the ten-foot increments or going to the actual depth for the maximum allowable bottom time.
E. Thalmann: That's a small detail and you're really very close. One of the problems with that column is there's a lot of non-information there. If you say USN, what do you mean? Are you using U.S. Navy air tables with EAD conversion? Do you mean a table in which the actual oxygen percentage is used to compute the decompression? There's a big difference. I'm going to guess that most of the people are referring to the 1955 U.S. Navy air tables using an EAD conversion factor. Are they using air tables with an EAD conversion or using the actual inspired oxygen PO_2 to compute the tables (PiO_2)?
T. Mount: IANTD uses the actual oxygen fraction. They are not rounded off on an EAD. They are actually calculated from the oxygen fraction.
D. Kesling: As far as the U.S. Navy tables, UNCW is using the 1999 edition that has not been released yet. We also have modified our tables to reflect the points that were made in a report from the NEDU in 1993, which found some errors in tabulation when those tables were generated.

B. Wienke: NAUI has mUSN (small m for modified).

P. Denoble: What is the maximum range of mixtures that you are teaching?
J. Hardy: 22 to 40%. There is no 21% in the nitrox system.

D. Kerem: Can anyone report on incidences of oxygen seizures in recreational nitrox diving over and above what Dick Vann reported earlier?
M. Lang: Nothing to report. There is not a single response from the audience, so the answer to that question is zero incidents.

M. Wells: Under table model, PiO_2 should really be PiN_2.

R. Moon: I presume that mix analysis means absolute value rather than percent of target concentration, is that correct? What does one percent mean?

E. Betts: It's one percent by volume.

D. Kesling: If your target mix is 36, is it a range from 35 to 37, or is it 35.5 to 36.5?

B. Gilliam: They're all one percent absolutes.

B. Hamilton: In other words, if it says 36 percent, the range is from 35 percent to 37 percent rather than the fraction of 36 percent.

B. Gilliam: That's the way we all do it.

M. Lang: That's a general agreement by everyone.

B. Bjorkman: For those who teach outside of the United States, do these values hold true for international communities?

B. Gilliam: TDI, yes

B. Wienke: NAUI, yes.

T. Mount: IANTD, yes.

E. Betts: ANDI, yes. I'd like to point out that for international marketplaces worldwide cleaning is required either by local ordinances or law for 21 percent or greater.

K. Shreeves: PADI, if there's a local regulation, obviously then the instructor has to conform to that, but otherwise, yes.

J. Hardy: SSI, yes, because the materials are simply translated directly and converted to the metric system.

NITROX AND CO_2 RETENTION

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Introduction

Breathing hyperoxic nitrox ("nitrox") entails a tradeoff between the benefits of a reduced nitrogen tension and the hazards of an increased oxygen tension. Of the latter, pulmonary and/or whole body oxygen toxicity need not concern sport divers who should only worry about central nervous system (CNS) toxicity. When the risk of CNS toxicity is compared for nitrox versus pure oxygen, at an equivalent PO_2, the former is potentially riskier on account of two factors:

1. The presence of nitrogen (and seemingly of any "inert" gas) on top of toxic O_2 levels hastens the toxic manifestations in several experimental systems:
   - *In vitro* free radical formation
   - Survival of fruit flies
   - Appearance of seizure activity in the EEG of rats.
2. The increased density of the mixture and the increased work of breathing it, favor hypoventilation and CO_2 buildup (see below).

It falls to reason that safe PO_2 limits would be more conservative with nitrox, as reflected by the NOAA limits, which are universally adopted by the recreational and scientific nitrox diving communities.

The threshold of CNS oxygen toxicity is notorious for its inter- and intra-subject variability and unpredictability and safe PO_2 limits are aimed below the threshold of the most sensitive breathers, on their "worst day". This paper reassesses the attempt to identify individuals with an allegedly inherent and expected increased risk and to tailor-make them individual PO_2 limits, for their own safety as well as for possible liberalization of the global limits.

The inherent risk alluded to is that of CO_2 retention resulting from exercise hypoventilation, a term that describes a situation where the increase in ventilation does not match that of CO_2 production. In this case, CO_2 is temporarily "retained" until a new steady state is reached where the product of (the lower) alveolar ventilation and (the higher) alveolar CO_2 again equals CO_2 production.

Diving hypoventilation can ensue from either one or any combination of the following, all of which pertain to nitrox diving:

1. A depth-related increase in gas density and work of breathing,
2. A PO_2 -related blunting of ventilatory drive,
3. A dive-related individual trait, which could be one or both of:
   - Inborn – the diving vocation selects natural exercise hypoventilators, who feel more comfortable under water.
   - Acquired – being the only aerobic sport limited by the quantity of breathing gas, a gas-saving breathing pattern is adopted with time.

There is individual variability of the ventilatory response to all 3 factors and the actual degree of hypoventilation resulting from their combination is subject-specific. However, compared to the sensitivity to CNS O_2 toxicity, it is much more consistent and reproducible in a given subject.

The rationale for CO_2 retention exacerbating CNS O_2 toxicity is given below:

Hypoventilation

↓

Arterial hypercapnia (↑ P_aCO_2)

↓

Cerebral vasodilation

↓

↑Cerebral tissue PO_2

↓

↓ CNS oxygen toxicity threshold

The weakest link in the above chain, where individual traits are concerned, is that the cerebro-vascular response to CO_2 has not been measured during exercise in known "normal chronic hypoventilators", alias "CO_2 retainers", and not shown to behave in accord with the general population. Frequent complaints of immediate and transient post-dive headaches in established retainers (who usually "learn how to live with it") may hint that vasodilation indeed exists, at least in some subjects.

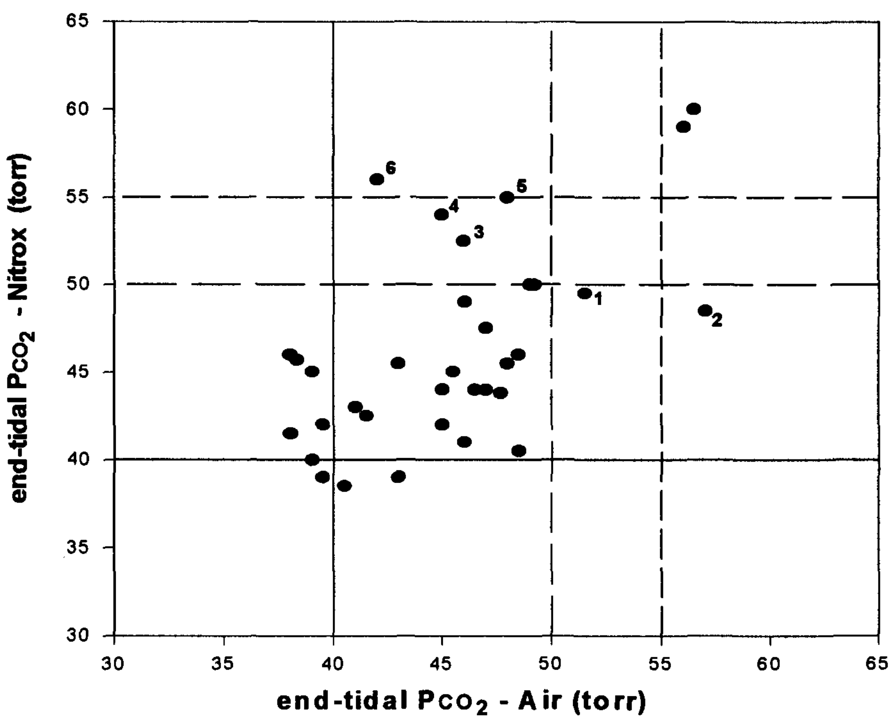
Scanning Nitrox Divers For Degree Of CO_2 Retention

Professional Divers

Screening for CO_2 retention during nitrox breathing is more readily justified in select small groups, backed by a hyperbaric physiological research facility. The Israeli Navy opted to test its construction divers, immersed at their current maximal operational depth, using the O_2-richest nitrox mixture, their personal regulators and at a realistic exercise level (1.2-1.4 L O_2 /min). Specialized equipment required includes a wet pressure chamber and a fast-response CO_2 analyzer or, better still, a mass spectrometer to accurately measure end-tidal CO_2 tension in lieu of the more pertinent arterial tensions.

Measurements were also made, at the same exercise level, breathing air at 1 ATA. This attempted to isolate the contribution of the third hypoventilation promoter from that of the first (depth related) two and also to devise a much simpler test that may predict the response at the above-listed conditions. The figure below shows the correlation of exercise end-tidal PCO_2 while breathing air at 1 ATA and 40% nitrox at 4 ATA, in 34 professional Navy divers.

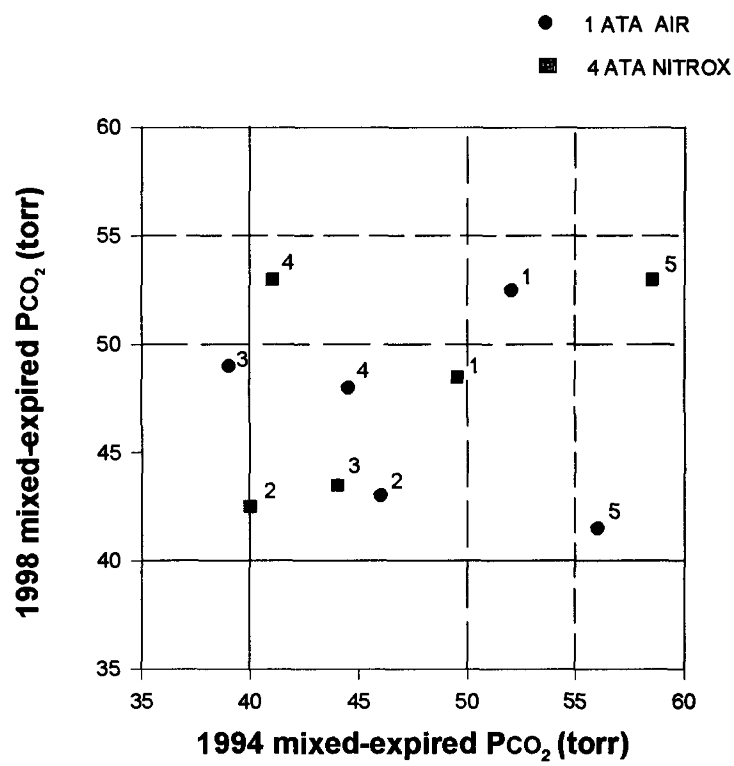
The 40 torr mark line in the figure is the mean end-tidal PCO_2 for several hundred young novice divers exercising on 1 ATA air. The 50 torr line marks 2 SD above this mean and the defined upper limit for end-tidal PCO_2 of "*non-retainers*". The 55 torr (3 SD above the mean) line brackets the defined range of "*moderate CO_2 retainers*", whilst anything above it is defined as an "*extreme CO_2 retainer*":



CORRELATION BETWEEN END-TIDAL Pco_2
IN I ATA AIR & IN 4 ATA NITROX

It will be seen that as a whole, group values tend to lie above the 40 torr mean, during both 1 ATA air and, especially, during nitrox breathing at depth. The group mean end-tidal PCO_2 was not significantly higher with the latter, attesting to the dominance of the depth-unrelated individual trait in determining the degree of hypoventilation. Four non-retainers on air became so on nitrox (3-6) and two went the other way (1-2). For a small select group, this rather high percent of false negatives in the air-predictor test is unacceptable and the simulation of actual conditions is called for.

We had occasion to test 5 of the above subjects again after four years. The comparison between the two time-spaced measurements for both air and nitrox is shown in the figure below. Numbers 1-5 identify air-Nitrox pairs for each of the 5 subjects. The 1 ATA air values for 4 subjects (2-5) have maintained their definition (3 non-retainers and one moderate retainer) over the years. Subject 2, with time, became a moderate retainer on nitrox and subject 1, a very experienced diver who of late very rarely dives, has moved from being an extreme retainer on both mixtures to being a moderate one on nitrox and a non-retainer on air.

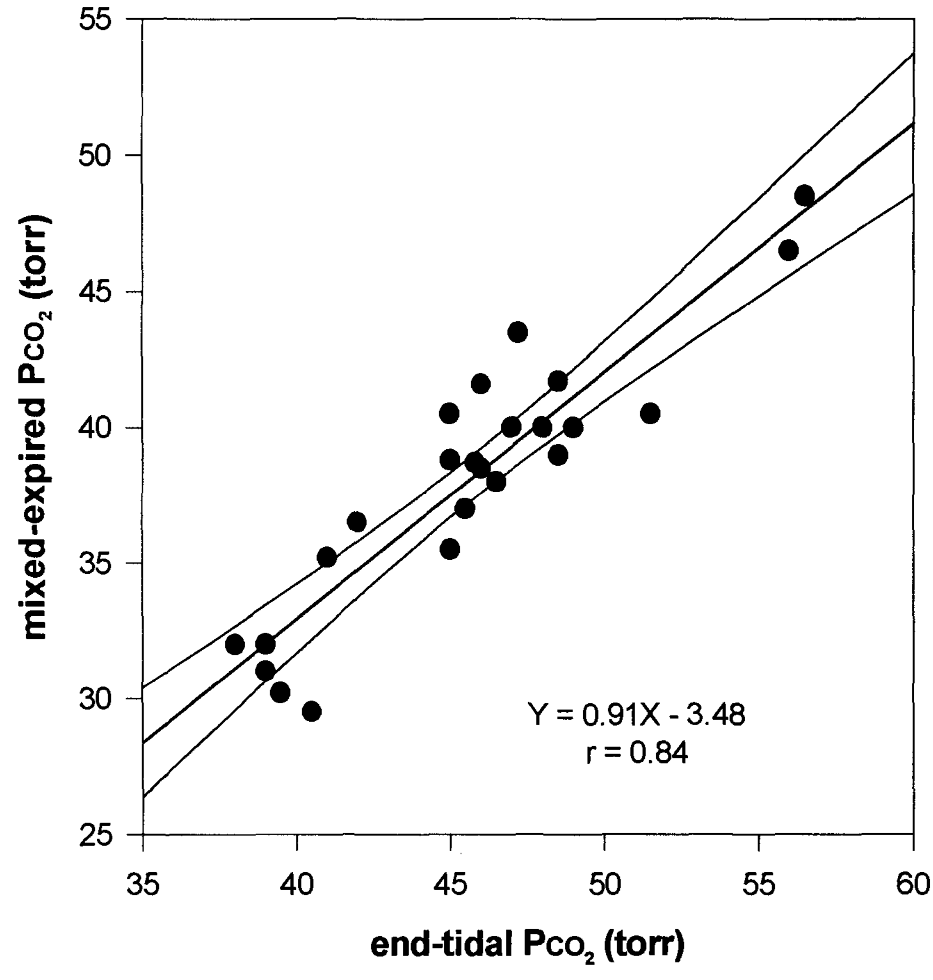


4-YEAR REPEAT TEST OF CO2 RETENTION IN 5 PROFESSIONAL DIVERS

Recreational Divers

The first questions that come to mind are "why bother?" and if we do bother, "is it realistic?". Let me address the second question first in saying: "It is". A nitrox diving club may, at a modest cost, maintain a facility, which will provide a simple if not conclusive test for CO_2 retention. The required equipment is a simple graded bicycle ergometer, a hose connecting the exhaust of a scuba regulator to the inlet of a mixing box and a simple CO_2 analyzer, the probe of which resides in a "flow container" at the outlet of the box. A thermometer (tested gas is assumed to be fully saturated), barometer and a conversion chart from $\%CO_2$ to CO_2 tension completes the list.

The relevant physiological measurement is that of exercise mixed-expired CO_2 tension, which is generally highly correlated with end-tidal CO_2 tension, as seen in the next figure, constructed with available data from 24 of the 34 construction divers in the first figure:



CORRELATION BETWEEN MIXED-EXPIRED AND END-TIDAL P_{CO_2}: 1 ATA AIR

Mixed-expired PCO_2 while exercising on air at 1 ATA is as good (or not too good) a predictor as end-tidal PCO_2 for retention at depth. In the group of 24 divers, there were 3 false negatives and 2 false positives. Two of the three extreme retainers at depth were detected by the test. Even on the basis of this limited data, which as yet precludes saying anything meaningful on the usefulness of the test, a subject found by it to be an extreme retainer should suspect that he remains so during his nitrox dives.

We now come to the first question of: "why bother at all to screen recreational nitrox divers for CO_2 retention", given the near perfect record, *i.e.*, near zero incidence of CNS oxygen toxicity in the entire history of this industry? The answer here is that the specter of incurring a seizure at considerable depth should put the fear of God in any serious and educated diver and should make him want to know of any personal extra risk. The scene of the seemingly only documented (and fatal) incidence of CNS toxicity in an "open" sea dive breathing nitrox was in a cave.

Are the cerebral CO_2 levels caused by even extreme retention indeed risky, when abiding by the current global nitrox PO_2 limits? The apparent impunity of recreational nitrox divers to CNS toxicity is backed by the Israeli Navy experience with pure oxygen rebreathers (in preparation for publication), which shows victims of CNS O_2 toxicity to be both retainers and late detectors of buildup of inspired CO_2/malfunctioning absorbers. Thus, the invasion of closed and semi-closed systems with CO_2 scrubbers and O_2-enriched mixtures into recreational diving poses a very real risk.

To the final question of: "now that I know that I am a higher risk extreme CO_2 retainer, what should I do about it?", the following guidelines for using more conservative PO_2 limits (adopted in the Israeli Navy) are proposed:

DEGREE OF RETENTION	**END-TIDAL CO_2 (torr)**	**MIXED-EXP. CO_2(torr)**	**Max PO_2 (ATA)**
NONE	<50	<41	1.6
MODERATE	50-55	41-45	1.4
EXTREME	>55	>45	·1.2

Disclaimer: The views expressed in this paper are those of the authors and do not represent the official views of the Israeli Navy.

II. NITROX PHYSIOLOGY

A. Discussion of Kerem paper

B. Wienke: From your experiences, what percentage of divers would you estimate is in the extreme CO_2 retention category?
D. Kerem: Below five percent.
B. Wienke: What would you estimate for the moderate category?
D. Kerem: For the professional navy divers, that would be approximately 25%.

M. Wells: Dan, could you comment on the NOAA oxygen limits, for example, 1.6 atm for 45 minutes? Could you give us some insight into what time duration dives are common for your divers?
D. Kerem: These guys we're asking to work with nitrox using just one scuba tank. Going by the times that we allow for pure oxygen, the combat divers use the same limits for several hours of strenuous swimming underwater. We didn't actually specify time limits on that.
M. Wells: I understand then in practice your combat divers go 1.6 atm for several hours is that correct?
D. Kerem: Affirmative.

D. Richardson: Would you say that, for an individual whose CO_2 retention level isn't known, the limits of 1.4 up to 1.6 atm are reasonable?
D. Kerem: On the whole, I would say so.

R. Moon: Dan, I think those are very nice data. In using those data to construct guidelines, it's important to note that the end-tidal CO_2 may both overestimate and underestimate the arterial PCO_2. Whereas your divers were probably relatively young with no lung disease, there is an aging component in recreational divers for whom pulmonary dead space increases. Therefore I would hypothesize that it would be more difficult to detect CO_2 retainers using end-tidal CO_2 groups.
D. Kerem: Your point is well taken.

T. Mount: In your opening slide you mentioned CO_2 limits being affected by both helium and nitrogen. However, none of your data reflected the use of helium. I'm curious what you may have found out as far as helium is concerned because it's always been my understanding that the use of helium reduces CO_2 retention.
D. Kerem: The only mention I made about helium is that test that examined the influence of an inert gas on oxygen toxicity, not on CO_2 retention. Those were *in vitro*, not in people. This was on pure oxygen on top of which you added a few atmospheres of either nitrogen or helium that would exacerbate the oxygen toxicity. Helium should be better (CO_2 retention-wise) in people because of its lower density.

D. Vann: Can you comment on the increase in CO_2 retention that occurs as depth and density increases?

D. Kerem: Not much more than what I have shown. There were people for whom, at 1 atm of air, the CO_2 retention was not even in existence. When they were taken to 30 meters, they suddenly showed either a moderate or an extreme retention. You would probably want to say that it was the increased density caused mainly by depth.

D. Vann: Richard, aren't there data from Swedish workers that address that question?
R. Moon: Well, almost all the data in the literature have been based on end-tidal CO_2. I think it's the easiest measurement to make, but it's also fraught with a lot of difficulty.

A. Marroni: There is a growing interest in Europe for deep air diving and our multiple agencies are about to start certification at the 50 and 60 meters level on air for deco diving. Do you think that there is a role for a research project to screen for carbon dioxide retention in this kind of deep air diving?
D. Kerem: Probably not, unless you want to start consideration of wash-in and wash-out of gases that could be different with CO_2 retention. You have increased CO_2 during your dive and less when you are decompressing, nor a narcosis effect. There could be some synergism, but not regarding oxygen toxicity.

B. Hamilton: Dan, if you drew a best fit line through your data points, it would be very close to a 45-degree slope, or slope of one, which is what you would expect. For this particular measurement, air and enriched air, you would expect to see an end-tidal PCO_2, wouldn't you? It's going to affect them both in the same way isn't it, as they are the same densities?
D. Kerem: No, the air is at 1 atm and the enriched air at 4 atm. We just wanted to see if we could do a simple air test and predict who is going to be the CO_2 retainer. Most of them continued to show the same degree of retention when you took them to depth, but some of them only appeared as retainers at depth.

R. Moon: Dan, what was the PO_2 in the group breathing nitrox?
D. Kerem: For this particular one it was 40 percent, so at 4 atm, 1.6 atm.

D. Vann: Alessandro, regarding your question about deep air diving, there are a number of reports in the literature. I have also seen a case in the lab of people just going to sleep at 150 to 180 feet and there have been a number of fatalities there. That's a mighty difficult topic to study in the laboratory for ethical reasons. But I think there are certainly anecdotes.
D. Kerem: Were they resting or exercising?
D. Vann: They were exercising. The one that I'm familiar with personally, divers were swimming in open water. At some point, it might be reasonable to think about switching from nitrogen to helium to get rid of the narcosis and also the increased density, which would appear to increase CO_2 retention.

B. Maximum PO_2 Limits Discussion

M. Lang: The next topic under physiology actually provides for a discussion session. It was included because it surfaced repeatedly from several of you as a topic in need of discussion, *i.e.,* the continually shrinking maximum PO_2 limit.

B. Gilliam: I've been doing this for a while. When I was a Navy diver, our operational limits were a maximum 2.0 atm and they've been revised downward steadily since then. At 1.6 atm, it seems that we've struck a balance that seems to work overwhelming well in this sport diving population we're addressing here. The database that we presented here today includes nearly 80,000 instructors and divers that were trained under the 1.6 atm rule. Obviously, that PO_2 is reduced as the length of the dive dictates, for longer dives it's going to decrease. It's interesting to note again how most of these divers are using nitrox as a technology and performing no-decompression, repetitive diving. If you take even the most liberal algorithm that is in place now, the no-decompression limit on a 32 percent mix (depth limit of 132 feet) still doesn't even get you to 40 percent of the CNS limit. Considering this as an oxygen-dose relationship, I'm trying to understand why there is this continuing resistance to the acceptance of 1.6 atm. We've heard positions that we should go to 1.4 atm. Nobody seems to have any reported oxygen toxicity incidents at all. It's not too likely that we will see any because of the methodology that's being used. The science divers are using 1.6 atm, as I understand it. We've been using it at TDI for nearly seven years now without incident. I can also tell you as the former President and CEO of Uwatec for four years that we shipped every one of our dive computers worldwide with a PO_2 alarm set at 1.5 atm. With our software program, the divers could go in and change that set point at will from a high of 1.95 atm to a low of 1.0 atm. When these computers would come back to us for battery changes or other service, about 95 percent of these computers were set at 1.6 atm. This means this diver population has decided that this limit is what they were going to dive at and they were not having problems with it. I would really like to hear from the naysayers as to why we think we need to mess with this limit that's worked well for NOAA, the Navy, the science divers, NASA, and for the largest population of nitrox sport divers who have been trained at this 1.6 atm limit.

D. Rutkowski: There's a lot of myth and misconception out there about the use of oxygen. You hear that commercial divers are routinely using PO_2's of 1.8 atm. Navy SPECWAR are using 1.9 atm. NOAA and some of our training agencies here use 1.6 atm. PADI went to 1.4 atm. Dr. Wells could best explain how this 1.6 atm came up as an administrative appeasement number. It was between the professionals who wanted much higher PO_2's and the recreational diving community. If I dive a PO_2 of 1.6 atm for 20 minutes at 130 feet, I'd be using 43 percent of my oxygen toxicity clock. I can dive 1.4 atm and use 100 percent of the oxygen toxicity clock and be in more danger than the individual pushing 1.6 atm. Many people will say that these working divers got to use 1.3 or 1.4 atm. The issue is not the PO_2; it's the time at the PO_2. If I'm going to make a 20 minute dive at 240 feet, I've got 120 minutes of decompression for which I'm going to need 140 minutes of my CNS clock. If I use a PO_2 of 1.4 atm, I will be using 93 percent of that clock. I'd be at much higher risk for a seizure than a diver pushing 1.6 atm and using only 43 percent of the CNS clock would. I could lower my PO_2 to 1.3 atm for that 140 minute dive, which would lower my CNS clock to 76 percent of running time rather than 93 percent. You've got to understand that it's the time at these PO_2's that is important, not the PO_2 by itself.

B. Bjorkman: We run across this situation in Canada where we're allowed a PO_2 of 1.5 atm through DCIEM. Working divers are in very cold water and exerting themselves. We found that wasn't really the issue. The issue was that our divers were forgetting everything they were learning. Our instructors could teach them well for the day, but two weeks later would fail if they were retested. We had to come up with a way for people to remember all the formulas. The only way we could come up with was to develop a table. We found that if we went to a PO_2 of 1.2 atm, because keep in mind that our occupational divers in Canada can commercially dive with scuba, we didn't have the problems of tracking OTU's or CNS percentages. Most of the dives are done in relatively shallow water of 60 to 70 feet, perhaps as much as 90 feet. People ran out of air or bladder capacity long before they ran out of bottom time. If you notice on everybody's table or those working with equivalent air depths, down to about 60 feet it's pretty hard to get over a 1.2 atm in any event. For shallow water dives, we found that limiting nitrox to 1.2 atm for occupational scuba divers allowed us to put it all on a simple table that was very easy for people to track. They didn't have to remember any formulas, just looked at the table, and six months post-training could figure out exactly what PO_2 to use for the depth and the fraction of oxygen in their cylinder.

D. Rutkowski: Since you're doing shallow work, your PO_2 isn't significant. In Key Largo, we have two wrecks that range anywhere from 20 to 40 meters. We give somebody a 32 mix and they're going to go to 130 feet and be pushing a PO_2 of 1.6 atm. If we were to lower that to 1.2 atm, there would be no sense in having these artificial wrecks out there. People wouldn't be able to stay on them.

B. Bjorkman: We certainly agree with you on deeper depths. The only problem is if you have to go beyond a 1.2 atm, we have to start getting back into the formulas and this is where we're running into problems. They'll dive regardless, with a lifetime certification, but their knowledge is no longer there.

D. Rutkowski: Dr. Vann did a lot of research in this area. When you came up with some of these numbers you had these people on ergometers, didn't you, working in hot water and cold water?

D. Vann. Right, our 1.6 atm exposures were for divers working in 70 degree water. We were fine at 1.6 atm with working divers and I should say a lot of CO_2 retention in the equipment they were using until I got up to 40 minutes, when we had one seizure. We really have very poor data on oxygen toxicity in comparison to decompression where we don't have really good data. One of the things to bear in mind is what is risk? Risk depends upon two things. It depends upon the probability of an injury and it also depends upon the severity of an injury. For decompression sickness, for example, when we're doing altitude studies for the space station, we don't mind 50 to 80 percent incidence of decompression sickness if the symptoms are simply knee pain. If we get into a situation where we get paralysis, then we have to have a very low risk of decompression sickness. One of the things that you want to ask yourself in this discussion of oxygen toxicity it looks like the probability is really low of having a problem at 1.6 atm oxygen partial pressure. The severity of the injury that can occur with unconsciousness underwater is potentially pretty high, which should be considered in your decision about what you want to do.

B. Gilliam: One of the reasons that the 32 percent mix became so popular was because at a 1.6 atm oxygen exposure, it matched up exactly to the traditional training limits and the recommended sport diving limit of 130 feet. It was an easy match for divers to remember their limits. It also gave enough benefits for nitrox that people could maximize what they were trying to do by getting longer bottom times, shorter decompression and shorter surface intervals. I'm certain that everybody in this room understands the difference that Dick was trying to illustrate that it's not the PO_2 all by itself that's a problem, it's the dose, the time in minutes at that particular PO_2. Trying to artificially limit the sport diver's activities without some reasonable justification is what I'm trying to get at here today. We've seen this data of over a quarter of a million divers trained mostly in the last four years. There have been no oxygen incidents. There are no problems here. I have personally seen people who are incompletely trained and don't understand on the diver level, because the materials are not explaining to them that the dose is the combination of these two effects. I've seen divers who have almost precipitated themselves into panic situations because their computer tells them that they went from 1.4 to 1.45 atm all of a sudden and they think they're going to spontaneously combust. Again, I'm asking for somebody to enlighten me as to why we think we have a problem at 1.6 atm. None of our data shows that we do. I'd like to know why we should be moving in this direction with this discussion. Drew, why did PADI decide to go with 1.4 atm as opposed to a 1.5 or a 1.6 atm?

D. Richardson: We should look at the database and known outcomes to answer that question. For this whole discussion, if you look at Kenneth Donald's work from 1942 to 1945, working with the Royal Navy, they did about 2,000 test dives using oxygen breathing. If you compare that database to NOAA's dose duration, it falls right in between 1.4 and 1.6 atm. PADI had no objection to 1.6 atm. We set it at 1.4 atm for recreational divers as a margin of safety for diver error. However, 1.6 atm fits very nicely under the Donald data set as well. He did make a few mentions in his findings about individual variability. He spoke about temperature being a factor and an increase in susceptibility in 'cooler' water. Generally, the NOAA limits up to and including 1.6 atm at the 45-minute limit, also fall very nicely under Kenneth Donald's work, done so long ago in the war effort.

K. Shreeves: You'll notice that all our tables actually do include numbers up to 1.6 atm; PADI has never been against 1.6 atm. We're thinking more in terms of the recreational versus the technical diver. Speaking of Ken Donald's work, I'd appreciate some feedback from the researchers in this room. We tried to find a correlation between exposure and time to onset of CNS. We're not talking about whole body or pulmonary, but just convulsion and weren't able to find a correlation. I'd like to know where the data is that says there is a tight time-exposure relationship with regard to CNS toxicity.

E. Thalmann: You obviously haven't read Donald's book. First of all, he made a great point of the individual variation to time-quantitative symptoms. There's the classic plot of the diver who was exposed to a fixed oxygen partial pressure day after day and his time quantitative symptoms ranged from five minutes to several hours. What we've got is a bunch of people quoting the literature very superficially without really having spent enough time reading the material in depth to find out where Donald was coming from. The depth-time limits were simply derived from what was considered safe for the majority of exposures for a single bounce dive to that depth for the time as published. If you go back and read Ed Lanphier's original work, he basically did his exposures deep and then extrapolated them shallow to come up with his O_2 limits. But the point that Donald made was there was such a wide variation and that's why we can see oxygen toxicity at 20 feet. There have been reported convulsions at 20 feet and some even shallower than that because you have this wide individual variation. That is the problem with oxygen.

B. Hamilton: Donald did all of his studies on pure oxygen, which meant they were all shallow and they didn't have a lot of CO_2 retention or breathing gas density factors for what that's worth. On the dose matter that Bret asked about, the curve of susceptibility goes sharply upward a little after 1.6 atm. It's not linear. You can go all day at 40 feet at 1.4 atm. You go until you have a pulmonary problem and you're not going to get a convulsion. Whereas at 1.6 atm, the 45 minute limit is a workable value, but you have to realize that's for a not very hard working diver. That's not very deep in terms of the breathing mix and, we've tried to make the NOAA Manual reflect as much as we could that this 1.6 atm doesn't cover all bases. With regard to the operational data set of numbers, the system is geared to look at decompression sickness. Nothing is there to catch O_2 hits. The fact that we didn't show any hits on all those dives doesn't mean there weren't any. In fact, there have been some. The other factor is in supporting what Drew said why PADI sets PO_2 at 1.4 atm, because, for one thing, it does deal with the huge individual variability and the variability of the conditions at a very low cost. You don't give up very much when you cut the oxygen limit from 1.6 to 1.4 atm. You do see it somewhat, but it's not a big cost.

M. Lang: Bill, a clarification, please. When you say there have been some hits, what does that refer to? One of the objectives of this exercise is to factually document whether or not there have been documented O_2 hits.

B. Hamilton: I know of a couple. These people have taken oxygen hits at 1.6 atm.

M. Lang: Recreational nitrox divers, technical, commercial or military?

B. Hamilton: Technical. One was on the Lusitania that was written up extensively and studied thoroughly.

B. Gilliam: That was not on nitrox.

B. Hamilton: That was a hit after a tri-mix dive breathing pure oxygen at 1.6 atm during decompression.

M. Lang: Those are the kinds of events that we need to clarify for the record. Is there a reference that we can cite?

B. Hamilton: It's written up in *aquaCorps*, if you can call that a reference.

D. Vann: That's not fair because you've got a multi-level oxygen exposure there. When you're talking about a multi-level oxygen exposure as you are after a long decompression dive, it's a whole new ballgame. You can't compare that with a single limit. That's probably what Ed Thalmann was referring to as well. The exposures in which there was a seizure at less than 1.6 atm were all multilevel. I don't know of any others that weren't and I would be very interested in hearing from this group of any oxygen seizures that occurred at 1.6 atm or less without multilevel exposures.

M. Lang: Let's go through that exercise just for the record to document any seizures at 1.6 atm or less on single exposures.

E. Betts: The simple answer is no, I don't have any documented data.

C. Borne: None.

B. Bjorkman: No.

D. Dinsmore: Not that I know of.

B. Gilliam: TDI has none either.

J. Hardy: SSI has none, but also in my legal consulting, I have none.

W. Jaap: AAUS reports zero.

D. Kerem: I'll stress again that with pure oxygen diving, as long as your gear is okay and there is no CO_2 buildup in the system, divers routinely dive for hours at 1.6 atm with no incidence of oxygen convulsion.

D. Kesling: None at UNCW.

T. Mount: None at IANTD.

D. Richardson: Zero at PADI.

D. Rutkowski: Hyperbarics zero.

B. Wienke: Zero at NAUI and I would point out that in the last couple of years there's been a lot of decompression diving with O_2 washout at 20 feet at 1.6 atm and we've had no problem.

B. Hamilton: Dick, you reported two incidences.

D. Vann: One in the chamber and then one in the DAN data, which was a multilevel exposure. It was 15 minutes on air between 80 and 104 feet with a maximum PO_2 of 0.87 atm. The other was 45 minutes on 40 percent nitrox at a maximum depth of 84 feet and that was 1.42 atm. That's a case reported from the field, but the report was actually the most complete that I've seen.

T. Mount: May I comment on that particular one? That case was of a cave diver if I'm not mistaken. When they did his blood gases he also had twice the prescription dosage allotment in his blood and he'd also taken six Advil prior to the dive.

M. Lang: It's duly noted. The conclusion then is that there are no documented oxygen seizures from recreational nitrox diving at 1.6 atm or less on single exposures.

D. Rutkowski: At Ocean Divers in Key Largo, divers are diving air more than nitrox. There are often emergencies that arise with divers offshore. When the rescue people go out there, the first thing I have them ask divers is what drugs they took before diving and how soon before diving. Even the air divers may have what you call drug-drug interaction. If a diver had a tank of nitrox on his back, you could bet they'd call it an oxygen seizure. The PO_2 of 1.6 atm only uses 43 percent of its clock. We used to have a NOAA Nitrox II mix of 37.5 percent. At 100 feet that mix would have pushed a PO_2 of 1.6 atm. A guy diving at 100 feet on that mix would have a 40-minute no-decompression time limit. That would put him at 96 percent of his CNS clock. Dr. Wells knocked the mix down to 36 percent, which at 100 feet gives a PO_2 of 1.5 atm and only 33 percent of the CNS clock. These PO_2's are not just numbers that somebody grabbed out of a hat.

T. Mount: Another important consideration to remember is you're talking about recreational diving not technical diving. Most organizations that do technical diving use 1.4 atm for technical mix because you do spike on multilevel exposures and come back on oxygen. In technical diving, there have been some oxygen seizures, that's undeniable, in recreational diving there have not. Dick uses the example of the two USCG cutter wrecks in Key Largo. Most recreational divers do not go down to a fixed depth and remain there. Most of them either drop to sand beside the wreck at 130 feet, and then swim back onto the deck, which is 110 feet deep. Very few of the people ever actually operate at their maximum PO_2's. The important thing to emphasize is the maximum operating depth, not the dive duration that most people do there.

E. Thalmann: First of all, I know of no regulation or body that is telling the recreational diving community what PO_2 they should be diving. If they want to dive 1.6, 1.8, 2.0 atm as far as I know, they're welcome to do it and there's nobody around here that can tell them to do it differently. Second of all, I want to quote something that says that multiple anecdotes do not make data. Here we have got at least a half a million anecdotes if I totaled all those dives up correctly. That does not constitute data. It appears that a lot of individuals are not really willing to look at the data, and number two figure out what the data really say. The U.S. Navy picked 1.3 atm. Why would an organization that has a much higher vested interest in minimizing their decompression time pick a lower PO_2 than recreational divers? These guys fight wars and want to get out of the water quickly. The reason is that one O_2 incident in the water gets ten million "oh no's", no matter how many "atta boy's" you get. Where did that come from? There were a series of dives done at the Navy Experimental Diving Unit, which is quoted in Donald's book, if you read it carefully. They were all multiple level dives that tended to simulate the kind of oxygen dives that an actual combat swimmer would do. The depths of these dives range from 50 feet to as shallow as 20 feet. What was found was that out to four hours, which was the longest time tested, there were no O_2 hits at 20 feet. Therefore, it appeared that not only the lack of convulsions, but the lack of symptoms overall, gave the impression that 1.3 atm was something you could probably breathe forever and not have a problem. There was one documented incidence of an O_2 convulsion after 75 minutes at 25 feet. Even so, the Navy picked a 4-hour limit at 25 feet based on operational considerations and based on the fact that all of these other dives were done without incident. The other comment is that I'm glad that the recreational dive community has come up with a nice mathematical way of integrating oxygen exposures for multi-depth dives. The best brains in the U.S. Navy, after a million dollars of funding, have been unable to do that. If somebody could please show me the data on which they based this, I would be happy to bring it to the attention of the Supervisor of Diving so we can catch up with you guys. The point is that the hundreds of dives that were done at NEDU using multiple level techniques were analyzed by the best minds we could find and they were unable to come up with any method of integrating the PO_2's to explain the observed outcome. Now, does that mean that what the recreational people are doing is bad? No, it doesn't. Does anybody want to change that? No. It depends on your philosophy. Nobody is telling the recreational dive community you can't dive 1.6 atm. They turn around to the Navy and ask why they picked 1.3 atm? Because it can be dived all day long. It doesn't impact Navy operations all that much and they don't want any O_2 hits in the water. The Navy has within the last month rewritten its helium tables to eliminate 100 percent oxygen in the water. Why? In the last two years there have been two O_2 incidents. They don't want any of them, they've eliminated O_2 in the water and everybody's happy with that. Looking at this data and trying to draw conclusions about O_2 toxicity is much like looking at raw decompression data and trying to decide whether or not the current decompression tables are safe. A classic example: The Navy, in developing a decompression computer, was looking at the shallow air no D limits. I'm sure everybody here would say that these are just fine, we dived them forever. Nobody's having any problem with these NDLs. The Navy did two hundred 40 foot dives for 200 minutes that resulted in two hits. Based on two hits, both fairly mild, they said that's unacceptable. It depends on your philosophy of what you want to do. If you want to be aggressive, fine. 1.6 atm is probably okay as long as you stay within the O_2 depth-time limits. The beauty of going shallower is it's almost fail safe. The question is do you want to be fail safe or do you want to have procedures that require a lot of attention on the diver's part. As far as I know, there is nobody here to stand up and tell any recreational diver what PO_2 he ought to dive. If you want to cast aspersions on opinions based on data, that's a different story. The point I'm making is that the 1.3 atm comes from looking at real data. This is a recommendation of a PO_2 that is almost never going to get you in trouble no matter how long you breathe it. If you want to look at other data, you could say, that's right, there's no data to suggest that 1.6

atm is unsafe. Do you want to make sure a diver can't get in trouble or do you want to have a PO_2 that is going to require him to follow a specific procedure to not get into trouble? It all depends on your philosophy.

M. Wells: A lot has been made of the NOAA limits and since they don't exactly match the Navy limits, you ought to understand where they come from. Bret mentioned that a lot of people now have independently discovered that 32 percent at 130 feet yields 1.6 atm. I'd like to point out that's precisely why it was chosen. 1.6 atm was the normal working limit for Navy mixed gas diving when I was doing this in the '70's and 130 feet was the normal scuba limit. If you put that into the equation the Canadian divers can't remember, you come up with 32 percent, which I called NOAA Nitrox I for a very good reason for Bill Hamilton's information. Those tables were designed so that they could be handed to a diver and said, follow these tables. These were NOAA divers and NOAA divers can in fact read and follow instructions. If one followed those tables, the diver would not have to think of oxygen partial pressure limits whatsoever, because they were built into the tables. That build-in is why I called it NOAA Nitrox I, referencing the content of the mix because I didn't want the divers messing around with that. It was all prepackaged and later NOAA Nitrox II came along (36%). The content was non-essential after the analysis was done if you follow these tables. In the late '80's we were presented with a bit of a dilemma caused by the Navy and Ed has mentioned that. We were preparing the third edition of the NOAA Diving Manual, which eventually came out in 1991. The Navy reduced their limits from 1.6 atm. Someone mentioned that this did not have a great impact. It had a great impact on the way NOAA and the Undersea Research Centers were diving. It dramatically reduced the allowable bottom time available for the nitrox divers. Thanks to the fine work of Butler and Thalmann that had been published a couple of years ago, you will notice reference to that publication in that edition of the NOAA Diving Manual: "based on the work of..." I've been asked many times why the Manual doesn't match the numbers in the Butler and Thalmann paper. It was considerably less than they had recommended in their paper. As you remember, the Navy cut back from 1.6 atm for 30 minutes. We wound up increasing it to 1.6 atm for 45 minutes based on Thalmann's work. After consultation with the best experts I could get a hold of and putting our heads together for a consensus opinion, there was a dramatic effect on the effectiveness and acceptable risk we were willing to take at the time. The 1.6 atm for 45 minutes fell within what we considered a quite acceptable risk and that's been in effect now for well over a decade. Judging from what I've heard here today, it is quite acceptable. That 1.6 atm, by the way, was for working dives. People seem to have forgotten that 60 years ago, before I was born, pure oxygen was used for in-water decompression at 50 and 40 feet. They used it heavily throughout my entire lifetime and there have been some incidences, but that's a PO_2 well in excess of 1.6 atm. We have a very reasonable number that has been extended from the original Navy limit of 1.6 atm for 30 minutes to 1.6 atm for 45 minutes. That, by the way, was the only significant deviation from Navy policy that NOAA made. I thought, Thalmann, you would be proud of us for doing that based just on your work.

E. Thalmann: This is not really funny, but exactly what should happen. NOAA set its PO_2 limits based on two things: Its operational requirement and the amount of risk they were willing to take. The Navy does not canvas the commercial diving industry before it sets its policy. We used to point this out all the time. Someone would invariably get up and complain you guys changed this in your diving procedures and are causing us another heartburn. We'd turn around and say, write your own diving manual, this is the Navy's

Diving Manual. Navy policy is made for Navy divers. All I was doing was explaining why the Navy chose such a conservative limit. What NOAA did is exactly what you're supposed to do. What risks do you want to take and what are your operational requirements? The recreational diving community needs to do the same thing. What are the risks and what are the operational requirements? I would say that the risks-benefit ratio for recreational diving should be as close to zero as you can get because there is no reason that these guys have to get in the water. On any given Sunday, they can stay home and watch football versus commercial divers and military divers who may be required to get in the water, have a mission, or scientists who have an experiment to do. You have to set your risk benefit for the community. NOAA has gone forward and come up with its limits. There is no reason why the recreational divers can't say those are fine. This is a testament to the things you're willing to say. We're willing to recommend that our recreational divers take the same risk as NOAA divers, that's exactly the way it is. You read the data and you make your decision based on them, there's nothing wrong with that

B. Gilliam: We haven't had much comment on this side of the room for a little while. Ed, you've made a bunch of pretty sweeping statements on why the Navy picked 1.3 atm. Obviously the Navy picked that because of their operational tactical requirements. They can't put a combat swimmer in the water and expect him to go over and accomplish a mission in 45 minutes which would be the limit at 1.6 atm. Let's get a grip on the realities of what we're talking about here. Secondly, you've criticized the data that's been brought here today, but absent this data there aren't any other data. This is a relatively new technology. The agencies have been teaching it for less than a decade in most cases and there has been an overwhelming amount of very hard numbers put up here today that are just as hard as anything that DAN has tried to go out and accumulate on their own. A lot of the information that we brought here today has been offered in the past to DAN and in many cases has simply been ignored or distorted. When you say that nobody is trying to tell the sport diving industry what to do, that's really a bit of an understatement, because that is exactly what has happened to us in several situations. That is one of the reasons we're all sitting in this room today. There have been some very speculative and presumptive statements made about the safety of this particular technology in the hands of sport divers that has been flat out wrong. The focus of this workshop has been on what our sport divers are doing with this technology. We can learn a lot from the closest other relative that we've got in this group, the science divers, who have been diving nitrox since the mid '70's with excellent results. We've all been around the room on this 1.6 atm, with no documented oxygen incident. A sport diver using this technology is typified by a guy in a relatively benign environment. He is not threatened, he is not a working diver. In fact, if you take just about any measurable limits of what the performance characteristics of the sport diver are, they're what we would consider to be almost at rest by comparison to a science diver or a Navy tactical diver. Their risk benefit of operating at a maximum PO_2 of 1.6 atm is much different than that of diver who's in the water slinging wrenches around or swimming at a sustained speed over a longer distance to perform a work function in a tactical mission. This doesn't add up. There's a bit of resentment when people fail to take fully into consideration what it is the sport diving community is trying to do and how they are doing it. We are doing it with a reasonable degree of responsibility. There are a quarter of a million nitrox divers that have been produced in the last four years. No one is having oxygen problems that any of us can identify. A lot of speculation and presumption has been thrown out there, which if we operated under all of our lives, we'd never get in airplanes or boats. The risk would simply be too great because we don't know what the risk really is. I'm still coming back to the fact that there are an awful lot of good numbers that have been put up here today that suggest that divers using nitrox in the applications that sport divers are using it in, are doing it without problems. Remember as well that most of their equipment packages have a limit to the point that they'll never even get to the no-decompression limit anyway, much less get anywhere close to a threshold of vulnerability on the oxygen-dose exposure. To focus on the real target group we're trying to assess here: It's the Joe Diver with an 80 cubic foot aluminum tank on his back, typically diving in a situation where he's moving around on a reef and perhaps taking pictures. He is not exactly a hard working guy who's at some sort of threat and risk. That's who we should be concentrating on, not on why the Navy did it a certain way, because their mission and goals are completely different than what these people are trying to do. These analogies do not necessarily cross over.

E. Thalmann: First of all, I applaud Mr. Gilliam for being privy to Navy policy discussions, which I obviously missed while I was in the Navy. I don't think he has any idea what went into the 1.3 atm decision. Second of all, what we've seen today is not data, it's anecdote or call it what you will. I think that Mr. Gilliam doesn't know what real data is. Third of all, the Navy is not telling the recreational diving community what to do. If you want your divers to dive 1.6 atm, then why don't you do it? What is stopping you? Why don't you just get up and say I am going to teach it this way? This is the way I want to do it. I have got data to back it up. I can justify it. If called to task, I can produce evidence to say that this should be reasonably safe. Why don't you do it?

B. Gilliam: I think that what we've just seen is exactly why we're in a room like this today because it's that type of attitude, Ed, that gets people pretty upset. Now why is this data that you guys speculatively generate from time to time at DAN any more consequential or any more efficacious than the data that's been put up here today? That data that we put up there today are hard numbers of divers and instructors trained. How many incidents of DCS resulted from that? How many oxygen incidents resulted from that? Those numbers are just as hard as the numbers you guys are trying to assess over at DAN. Remember also that DAN has made sweeping indictments of the nitrox community and have accused us of using a technology improperly at times. You have predicted decompression sickness incidence rates twice that of the air diving community. These statements are largely unsupported by any scientific, medical or anecdotal data. The reason all these people are in this room today is to try to get an objective assessment of what is really going on. Bombastic statements like you've just made are not helping the situation any.

E. Thalmann: Can I separate Thalmann from DAN a minute, please? I've got to make something clear here. Thalmann, 20 years in the Navy, was talking about U.S. Navy generated oxygen exposure data when I talked about data. I don't give any more credence to the DAN data than the data that you've presented. It's still anecdote. It is not based on direct observation and it's not based on controlled conditions. It is still anecdote. When you say me, make sure you understand what me is. I've never made a statement about decompression sickness. If Dr. Bennett wants to get up and say what DAN thinks about it, that's fine. I don't ever recall saying that. Everything that I've ever written or said about oxygen exposure limits has always been referenced to published data and experiments under controlled conditions. If you are you willing to accept that half a million clean dives is evidence that 1.6 atm is okay, you're certainly welcome to do it. I don't think I would particularly object to it. I don't see what the problem is.

C. Testing Nitrox as a Product

Jon Hardy: I'm now wearing my Rodale's Scuba Diving Magazine hat and also remind you that I am not an employee of any company. I'm an independent contractor to all the people that I work for. About 50 percent of all my work effort goes into testing equipment, procedures or the situations from legal cases. When I talk about the work that I do with Rodale's, please remember that it's as an independent contractor. I'm held at arm's length from the magazine because I have nothing to do with the advertising or marketing.

Given that, every year for the last nine years I have proposed the tests that we do for the magazine. The equipment testing articles are the most expensive articles published in any magazine in the diving field. I've been saying each year that we ought to test nitrox as a product as opposed to a procedure. We finally convinced Rodale's to do it this year and just about the time Michael contacted me we had just started our initial testing. What we do for all our testing and these tests are not just jump in the swimming pool and swim around. The BC, dive computer, and regulator testing is done in labs with breathing simulators and hyperbaric chambers. Then we dive in the ocean and test them with real people. We have logged thousands of dives over the last nine years on these projects.

We went around the nitrox community and asked what human functional aspects we could test and how we should test them. We are not testing DCS or oxygen toxicity. We're talking about those elements that many of us are going to say are urban myths about nitrox.

We have a procedure called the test of the test. Every regulator test, every BC test, every computer test we do has been first tested to see if it is repeatable. That we can follow the scientific method and on a different day can get the same results as we did on a previous day. That 15 different testers can come up with the same result.

The nitrox community offered the following assertions: Diving nitrox causes less narcosis, less fatigue, less gas consumption, and better thermal balance. Those are four areas that some divers believe are true. At this workshop you have heard things said that refute most of these already. These are the four that we found and I am certainly open for any other suggestions. The magazine is going to spend a good deal of time, money and effort for about a three to six month period trying to analyze these. As Michael said, we're going to take a look at some initial results.

We have been testing the gas consumption factor. Of those four human aspects, we know a lot about testing gas consumption because we use it regularly in our controlled swims for testing the efficiency of various equipment. From our initial test, not yet completed or ready for publication, we have found no variation between air and nitrox in the consumption of the gas under the same set of conditions. The numbers are so close that they vary by hundredths of a cubic foot permitted. The variance is completely lost by doing the math and rounding off the numbers.

We are really in a quandary to figure out the testing of the fatigue aspect. Any suggestions of how to measure this are welcome. We heard some good statements about less decompression stress while diving nitrox. But how, in fact, would we measure that? We're going to examine the narcosis aspect. Most of the knowledgeable people state that there is no difference, but we haven't tried that test yet. Our initial consideration of the thermal balance aspect is that there are so many other variables that we can't differentiate that one.

D. Kerem: Probably the way to do it is either a blind, or preferably a double-blind experiment. You could have people breathe from a nitrox tank that would be labeled as nitrox and have 22 percent, almost air, and another higher percent of oxygen and then test underwater with a psychological performance test for narcosis. Give them a questionnaire after they come out of the dive for the fatigue assessment and compare it that way.

R. Moon: I'd like to ask Jon Hardy an unrelated question and that is do you know if there has been any random quality assessment as to the concentrations of oxygen amongst various vendors in the nitrox business?

J. Hardy: Are you referring to how accurate the oxygen contents are?

R. Moon: Yes.

J. Hardy: I don't know of any.

D. Nitrox Mix Analysis Discussion

M. Wells: Since very early in this nitrox business, the things that have concerned me about the safety of diving these mixtures is not so much what limits we set here, but more conventional operational limits. I noticed it was bothering Richard Moon too when he asked about what percentage we were talking about. Certainly we were talking about plus or minus one percent by volume. That value got on the original NOAA nitrox specification for the gas because that's exactly what it is for compressed air. The CGA has a commodity specification and that's what it is for air. If you go home and read the instruction booklets that come in the box with the analyzer, you will find that these analyzers have, according to the manufacturers, an accuracy of plus or minus one percent. This is not really so good if we analyze our mixture for plus or minus one percent by volume absolute and measure it with a device that in itself has only plus or minus one percent accuracy. That could lead us to errors of several percent. Jon, I've worried about this and did some experiments of my own within NOAA testing both the person and the analyzer. We're dealing with the capability of the instrument and the capability of the normal diver to use that instrument. Say I studied a dive class where I had three Teledyne analyzers calibrated on a much expanded scale on strip chart recorders, mixed the gas personally and sent it out with a class. Part of the procedure would be for each diver to analyze his own gas and record it in a logbook. I would retrieve the cylinders after they were used and reanalyze the balance of the gas. I would be attempting to do a blind study on myself there. The results would be rather striking. At least I can speak for NOAA divers that the diver-analyzer complex was not very good. Some real surprises would come back when the divers had some hints we were using two standard mixtures and they would actually confuse a 32 percent with a 36 percent mix. That's pretty bad, isn't it? I have never done that study, but I predict we would find, based on the analyses that students perform on known gas mixtures in classes and such experiments I just mentioned, dramatic differences in the gas content. A lot of the variability we may see in certain parameters we're trying to measure here may in fact be due to divers breathing different gases than we think they're breathing.

B. Bjorkman: If you look at those instruction booklets that Dr. Wells just referred to, you'll also find that the analyzers work on partial pressures or fractions of gas. They all recommend the use of a flow restrictor or at least to get the flow down to a consistent 2-3 liter/minute flow rate. What we're finding when we work with people in this industry is that if you just hold the analyzer up to the valve and open it up, everybody's going to get a different reading. It's very important to use a flow restrictor. If perhaps the industry recommended that a flow restrictor be used that's suitable for the analyzer, I think we'd get much more consistent results.

B. Gilliam: I was going to say exactly the same thing, Bart. Although in their nitrox classes divers are typically exposed to watching an instructor demonstrate a nitrox analysis, the problems are exactly as you've stated. There are many different types of analyzers, especially some that are specifically designed and can't even be put on a flow restrictor. We've deviated from that at TDI and gone back to asking our students to observe the analysis of the mix rather than doing it themselves because they make too many mistakes. The mistakes are related to the flow and they end up reading partial pressures that are fractions. We have edited our books to specifically recommend flow restrictors and that the gas dispenser is probably far more qualified in doing the analysis; the diver should observe as opposed to doing it himself. Realistically speaking, the average diver doesn't own his own oxygen analyzer anyway and he's probably better off doing it that way.

T. Mount: At IANTD we have noticed that when you have someone doing gas analysis, if you have a flow restrictor, the readings come out remarkably close. If you do not adjust the flow, 32, 38, 40% is read wherever the guy happens to adjust it at. We agree that the person doing the mixing should actually perform the analysis, but we think that the students should also do it because they learn the technique by doing it themselves.

D. Rutkowski: At Ocean Divers I do most of the mixing. In the earlier days, we used to mix by the NOAA continuous blending method, but now we use the gas separation membrane. It's very easy to analyze the gas when it's coming out of the compressor. That's one analysis. When the guy is filling the storage tank out in the cage, the person who works for the dive shop is analyzing the gas as it goes into the tank. Not only is he analyzing the gas that's going into the tank, but he analyzes the gas that the guy brought back after his analysis. In addition to that, the user has to analyze the gas. We know when the user is off by not having the proper flow rate.

C. Borne: At NASA, we're at the opposite end of that spectrum. At the NBL, our mixers have five analyzation cells within each blender. We also have analyzers at the station deck that is feeding the suits as well as our scuba fill station. At no time do any of the individual users analyze the gas or log it. We have logistically and operationally a different situation here, but it's all done totally unknown to the end user on scuba and those subject to the suit. We probably have some of the most analyzed gas in the world by the time it goes through seven cells before it gets to the user.

E. Betts: Everybody here can agree that if the diver doesn't really know what the gas is that they're using then the entire concept is flawed. For that reason in our ANDI program from the very beginning, Dick and I agreed that there was supposed to be a standard procedure for analyzing the gas. Within ANDI it is a requirement that the instructor actually teach gas analysis within a very specific and prescribed format and it is a requirement that the student analyze the gas based upon that training scenario. We are very specific that waving the analyzer in front of a cracked valve is probably the fastest way to dive the wrong mix. Probably more so than an error in blending. We can also all agree that there are probably a lot fewer errors in blending than there are in analysis. We tried to tighten up where the most likely problem would be, the actual end user analysis. Of course it's great when an instructor hands somebody a cylinder and says this is 36%. We don't think that's the end result we're looking for. It is a requirement that the gas user actually analyzes the gas.

D. Kerem: Other than confusing the user when he's breathing, the whole idea of him analyzing the gas is to have redundancy and it should be analyzed at least twice. Have the dive club analyze it, tag it and if the user tests it and it doesn't fall within one percent of what's written on it, then there's a problem.

R. Moon: Are there any standards for the conditions under which the analyzers must be kept and calibrated?

C. Borne: At NASA we have pretty strict standards through the testing program invoked by the NASA safety standard manual. They are very close tolerances and done on a very frequent basis, tagged and available for review by any individual walking by to look at that equipment. We have pretty tight control and it's not by our organization, but an independent organization testing that equipment through the calibration lab.

B. Wienke: At NAUI we assume that diver responsibility starts with the diver so we require that the diver analyze all of his mixes. I can't imagine anybody in this room ever going diving without knowing what the mixes are themselves.

D. Rutkowski: Standards for the analyzers are unit specific. When you buy an analyzer, a book comes with it. Do you have a calibration gas? That's probably not necessary. You've got one of the best calibration gases in the world right here, 20.94% O_2 in this atmosphere. Standardize your analyzer, exhale on it with your CO_2, if it goes to 16 or so it should come back to 21. If it comes back to 21, then the analyzer's probably working. If the numbers are fluctuating and bouncing around, then the cell or the battery are going bad. When we talk about analyzing for nitrox, every time I treated a diver and he was diving air I analyzed his gas for CO, CO_2 and for oxygen. Often the oxygen was low because it got oxidized out of that tank and converted into iron oxide. The Dade County medical examiner has on record at least two fatalities of divers, one whose oxygen was 3 percent and the other one whose oxygen was 6 percent because they left these tanks sitting in the closet for a long time. A number of these guys that I've analyzed gas for, the oxygen was 16, 17 percent. It stands to reason that if the oxygen percentage goes down, the inert gas content goes up and the algorithms are off. I would go nowhere in the world without sniffing my gas if I bought a tank of gas from a dive shop.

M. Lang: We got that on the record. Richard, that still is not a satisfactory answer for the standards for gas analyzers.

R. Moon: I've heard a number of different opinions around the table. From where I sit, I end up evaluating a number of divers after having experienced decompression sickness and a very common question is: Should I switch to nitrox and should I use more conservative tables? The answer is: I don't know. Although theoretically and largely in practice, nitrox may be at least as safe and probably safer than air diving. The issue is where do you get your nitrox and how can you be sure that the content is what is labeled on the tank? A large number of the divers that I have treated for decompression illness that have been using nitrox have no idea what the concentration was. The remainder simply accepted what the dispenser told them. I would argue very strongly for some kind of multi-institutional voluntary standard that one could put on one's shop window so that the consumer can have some assurance that when he gets his tank filled in that location, that it's filled with some kind of quality control.

T. Mount: For anyone here who is really interested in oxygen sensors and analyzers, there's a book by John Lamb that I highly recommend you read. It's probably as definitive as anyone has ever written on a broad scale about all sensors. Reference: Lamb, J.S. 1999. "The Practice of Oxygen Measurement For Divers." Best Publishing Company, Flagstaff. 120 pp.

B. Bjorkman: We're very fortunate here today that we've got representatives from scientific, military, commercial, technical and recreational diving and are getting a good overview of what's happening. It's really important that we remember that this is about an open water diver who's all excited about diving, still wants to get a little bit more training and become a nitrox diver. The heads of the different organizations here actually still teach and that's important because they don't lose sight of who their customer really is. The question I pose is if we retested a diver who just took a recreational nitrox course, two weeks later, what do you think the results would be of their exam? Would they be able to calculate the formulas? Would they understand the CNS percent? Would they understand the basic things that will pertain to their safety?

T. Mount: I think two things would happen. Most of them would understand the time limits because they're pretty straight forward and tabulated. Many of the dive tables are cut off at the limits so the diver can't exceed the tables. They could pass the exam, except most of them would probably get messed up on the mathematical equations.

B. Gilliam: I agree with Tom that the shift to nitrox tables provides a quick reference that eliminates most of the mathematical calculations where people will make mistakes if given a chance. The essence of what a nitrox diver really has to assimilate and retain is really very simple stuff, MOD's and gas analysis. We have done some retesting to find out if our materials were suitable for instruction over the internet where they could be completely self taught. We've had very good luck with it. You can apply it to almost anything, though. Bruce and Michael would remember the survey that Kelly Hill did in 1988 where they gave a whole bunch of instructors, instructor trainers and new divers five repetitive dive calculations to do. Less than half of them could pass the test. What Tom was emphasizing, and we did it too, is if you can make it as simple as you can and go to a simplified look up table, you'll eliminate the human error that's so prone here. With nitrox today, especially with most of its use now being done with dive computers, a lot of that error factor has gone away. The nitrox computers, once they've set their mix and the PO_2 is in there, are going to tell the diver their MOD. They will give them a warning on approaching that threshold. They are going to calculate CNS loading by percentage. We're not really seeing much of a problem with rapidly lost retention.

E. Betts: Everybody would agree with Bart's comment that six months after an enriched air class, divers would not be able to run through all of the mathematics. My comment here is why do they have to? The second comment is in an entry-level nitrox program there is no more math involved than you're going to teach in an open water course. Calculate the PSI at 83 feet. Who's going to be able to do that six months after they do their open water course? Why do they have to? Everybody would agree that the way we were teaching decompression was not by memorizing the no-decompression limits, but by using a table. We certainly wouldn't consider teaching oxygen limits by memorizing NOAA limits, any more than we would suggest selecting PO_2's for this entry-level diver by solving multiple mathematical equations. Look it up on the table. All the training agencies have tables, charts, and graphs in order to make this a teachable subject. One of the first obstacles that Dick and I had when we started talking about nitrox training were all of the recreational scuba agencies who didn't have a clue about oxygen limits and assumed that this concept was unteachable to recreational divers. The fact that we're all here today supports that some of these preconceived notions were incorrect. On one hand, I don't think entry-level divers could do the mathematical calculations, on the other, I don't think it's a requirement or an obstacle to teach this nitrox technology to entry-level divers.

M. Lang: This is the discussion I had envisioned for the nitrox curriculum session. We'll pick this line up here and look at some of the common elements that are already in place and what should or maybe should not be reinforced in the actual teaching of nitrox.

D. Richardson: Bart, did I understand you said six weeks or six months?

B. Bjorkman: Drew, actually two days.

D. Richardson: I would predict that if we did a proper educational research study, assuming they demonstrated mastery of the performance objectives, we'd have a similar outcome. I would say the same for six weeks. In terms of the general public, nobody loves math. However, if they're demonstrating mastery of the performance requirements on the assessment instruments, that's not a long of period of time for any kind of long-term memory erosion. I would be a lot more optimistic about that especially if there were a practical application of it. The longer you go without utilizing a piece of information, the weaker the result you're going to get. I don't think it's all that dismal quite frankly.

B. Wienke: In New Mexico they have dive programs at the University of New Mexico and the College of Santa Fe and nitrox is in the entry-level curricula. When divers come back into the next level classes, even if they haven't been diving, the first thing that they're tested on is basic diving physics and physiology. The loss of nitrox content is actually very minimal. Divers that have been trained in New Mexico in these programs are facile at diving math and are using tables as Bret and Tom point out just as the average air diver. I don't think there's a big deal about adding nitrox into a basic curriculum.

III. NITROX RISK MANAGEMENT

M. Lang: The first discussion will be a brief overview of the OSHA nitrox variance for recreational nitrox instructors. The second part will discuss several prioritized legal considerations for nitrox as we know them to date.

A. OSHA Recreational Nitrox Variance

K. Shreeves: We'll provide a quick update on the OSHA variance and try to make a long story short as to how we got to where we are. I'll start with the outcome first because many of you are already familiar with the OSHA variances. The OSHA variance is in effect on a federal level and has been in place for just over a year now. We're currently in the process of working on it on a state-by-state basis. In 1995, when PADI was about to introduce its enriched air program, we realized that the existing exemption for recreational dive instruction would not cover the use of enriched air nitrox. We asked OSHA for a change to the exemption and found out very quickly that it literally took an Act of Congress. To change a standing regulatory exemption, it actually goes through Congress. OSHA proposed what's called a variance. The way a variance works is an employer applies with a mechanism to meet the philosophy or the spirit of the regulation in a different way. OSHA reviews it, publishes it in the Federal Register, then presumably accepts it. Originally, this was intended to be on a case-by-case basis, but very quickly OSHA found that when a variance was published the other employers would say that's a better way to do it. Rather than making everybody submit the same paperwork, OSHA established a policy that once a variance was in place, any employer who followed the letter of that variance was also covered. The variance pathway took us a little over four years. At OSHA's request we combined our efforts with Oceanic. It's been a very long, interesting process to say the least. After four years and more than a quarter of a million dollars on our part and who knows how much Oceanic has put into it, the variance is in place. That's the good news. The bad news is when we start talking more broadly about technical diving, we've barely scratched the surface.

B. Turbeville: What are the parameters for the variance?

K. Shreeves: The variance is for enriched air use by an instructor teaching recreational diving down to 130 feet within no-stop limits with a maximum PO_2 of 1.4 atm. Incidentally, OSHA wanted 1.3 atm, based on the U.S. Navy limits. We actually had to argue for 1.4 atm and they accepted our arguments. There are some logistical requirements that we didn't want, but OSHA insisted on. For example, there needs to be a stand-by diver, but that's very loosely interpreted. It can be your Divemaster and it does not have to be an employee. There is a provision for access to a recompression chamber, which has to be within one hour. It need not be on-site, but within reasonable access. The whole document is available on-line at OSHA's web site or you can also contact PADI.

B. Turbeville: It's important to realize that OSHA only has regulatory authority over those individuals in an employer/employee relationship. If you're not employing someone using these gases, it isn't an issue. For the typical sport diver, if you're not working as an instructor for a shop, this doesn't really matter. Where this does matter, and why PADI spearheaded this effort, is where you have a dive shop employed instructor who's teaching someone how to use nitrox and there's an accident. Then OSHA may have an issue. I will tell you from personal experience, however, that regardless of what the variance says, the fact is that

OSHA does not want to get involved. I know this for two reasons. One, Steve Butler, OSHA Division of Maritime Compliance, told me he does not want to be forced to become involved. Only if I he is forced to become involved would he recommend any prosecution even if there was an accident that occurred outside of these parameters. Second, there have been two cases that I've been involved in where I've represented individuals, agencies or companies that have been sued where OSHA has stepped in. In these two particular cases, the instructor died along with the student. One was a sport diving case within commonly defined recreational limits, about a 70 foot dive. The other case, which is in ongoing litigation was a technical diving situation. In the first case, the OSHA regulator was very interested in bringing an action. It was not until the Department of Justice got involved and spoke to a U.S. attorney that I could turn the dogs off and get the case dismissed. The regulator didn't understand what was going on in scuba diving. This happened to be in Wisconsin. The second case is more interesting, a technical tri-mix dive, where clearly it was beyond the scope of the variance or the original exemption for sport diving. There was a dual fatality, a student and an instructor. One phone call was made by OSHA, they knew about it. They spoke to the proprietor of the store and knew there was an employer/employee relationship in January of 1998. There has not been any follow-up whatsoever in nearly three years. We doubt there will be. OSHA simply doesn't want to get involved. I should say from a legal perspective that if you are outside the parameter of the variance and you are teaching nitrox diving in an employer/employee relationship, you might be outside of the "law". The fact is even if there were an accident, the odds of there being serious repercussions are not very great from what we've seen so far.

K. Shreeves: The employer relationship is interesting with respect to the variances. For example, it's not only if your instructor is teaching an enriched air class. It's if your instructor is breathing enriched air no matter what he's teaching. On the other hand, the instructor could be teaching an enriched air class, but using air, in which case it's not an issue at all. The other area where the industry might have some concern with regard to OSHA is not an accident, but a complaint. OSHA is required to investigate a complaint. Were there to be an employee who, say, is terminated and wants to get back at the employer, looking for an angle, such a hot-headed employee could create some issue by alleging that there's a problem with following the exemption or the variance, depending on situation. How far and seriously OSHA would take that we don't know.

B. Gilliam: It was reported to the TDI headquarters office that the state of Hawaii is not recognizing this variance. Do you know anything about that?

K. Shreeves: The person at PADI who would be following that would be Jeff Nadler. You highlight the point that once OSHA puts a variance into place, that's on the federal level. Every state implements it on its own. Some states literally copy what OSHA says word for word and adopt the federal guidelines as theirs. Other states, California and Hawaii among them, look at it separately. I haven't heard anything in particular about Hawaii saying no, but it doesn't surprise me that they're not automatically accepting it because they usually don't.

D. Dinsmore: Does the variance specifically talk about instructional purposes?

K. Shreeves: Yes, and this has nothing to do with scientific diving. This has to do with recreational scuba instruction.

D. Dinsmore: Does it state that right in there, recreational and for instruction only?

M. Lang: Of the four exemptions from the commercial diving standards this variance only applies to the first one, which reads: "However, this standard does not apply to any diving operation performed solely for instructional purposes, using open-circuit, compressed air scuba and conducted within the no-decompression limits." The variance was filed to modify the exemption for the recreational diving community to include a) nitrox, and b) rebreathers.

K. Shreeves: We did try to wrap in language that was implied in the original exemption that OSHA has accepted a philosophy on. A Divemaster leading an underwater tour for recreational divers is not specifically listed under the exemption as it was written in the '70's. OSHA has always recognized part of the intent as that Divemaster working in the same safety envelope; he's providing education and information about the environment. We tried to put some language in the variance that was a little more specific to cover that activity as well.

B. Turbeville: That brings us to the point of administrative and prosecutorial discretion, which is that while there may be a strict reading of the rule, the variance may not allow supervision of recreational divers. The fact is OSHA doesn't want to get involved in that much of a knit picking of a variance because it causes too much work for them. They're rather understaffed and overworked as it is right now. The bottom line is if we don't make this an issue for them, they're not going to follow up on it.

K. Shreeves: That is the best form of risk protection we can have on a legal basis, good education and good diving practices. If you don't have accidents, you don't have problems.

M. Lang: There were qualifiers in the variance, such as the CO_2 analyzers. Do you want to cover some of those for discussion?

K. Shreeves: There were several on the rebreather side. Since I was working primarily on the open-circuit side, I don't have all that information. It is published in the variance. Most of it did stay unfortunately for those who produce closed-circuit equipment. The bullets for nitrox were: PO_2 of 1.4 atm, 130 feet maximum depth, dives within the no-stop limits, a maximum 40 percent mix, a stand-by diver and within one hour of a chamber.

B. Turbeville: The 1.4 atm came as a result of a compromise because at first OSHA wanted 1.3 atm. Where did OSHA find the 1.3 atm? From the U.S. Navy. Earlier there was a discussion of standards of care and community practice. Ed Thalmann indicated that this is what the Navy wants to do and it was just for Navy divers. Well, it's not that simple. The problem is, as a trial lawyer, I will be faced with expert witnesses saying, you think the standard of care is 1.6 atm, but guess what? Here is the U.S. Navy Diving Manual and by God, that's the bible for divers. This says 1.3 atm. Now we have OSHA saying it's 1.4 atm. It's very important that if you're going to make a statement, or publish a standard based upon what you assume to be accurate data, that you make it very specific to the community to which it's directed. Otherwise, it will affect every other community out there at least on the legal end if there's a lawsuit. The way these standards are created within a courtroom is based upon which expert witness the jury believes is the most honest and the most experienced. We have a certain tool now that the Supreme Court has given us to keep out really ridiculous opinions, which is called a challenge. However, it doesn't weed all this nonsense out. The fact is we're going to see cases, not on the specific 1.3 versus 1.6 atm standard, but similar types of issues. If the Navy or NOAA wants to set up a particular standard of care for itself and it's much stricter than the community as a whole thinks is necessary, suddenly we have to defend in a microcosm in a courtroom that less strict standard that we think applies to recreational sport users. Somebody else, the plaintiff's side in this particular case, can point to a document and to other experts saying that's far too risky because at the Navy it says 1.3 atm. Theoretically, that is a potential problem.

B. Nitrox Community Standard Of Care

M. Lang: Is it your opinion that among recreational agencies that teach and certify nitrox divers there is enough of a commonality in standards to constitute a standard of practice for the nitrox community in the recreational industry?

B. Turbeville: Absolutely yes. I have no problem at all with the standard as it's created so far mainly because the soul of the law is not theory. It's not even science. It's experience. Granted you might say that the data that have been shown here today are not the type of data that would pass peer review. The may not be from double-blinded experiments. It may be that they have some deficiencies if you look at a close statistical analysis, but the fact is it is the experience of the industry over a number of years and there are literally hundreds of thousands of dives. We can point to that and say we have had a safety record, which at least for the PO_2 of 1.6 atm, is perfect in the sport industry. I have no problem defending that. However, if we do have an accident and there is a lawsuit, I can assure you that someone's going to point to the Navy standards and say you should have followed that. To a certain extent a central nervous system hit is sort of like decompression sickness in that it's a probabilistic phenomenon. It happens in odd little clusters or based upon individual exposure and individual tolerances. Even though operationally the PO_2 limits are different, we'll have to explain and maybe I'll be successful. The fact is I don't know that because I don't make the decision. It's going to be six or eight or twelve people so ignorant they couldn't get out of jury service. Those are the people who make that standard of care for you.

D. Rutkowski: The Navy's 1.3 number is an operational consideration number. It's not a physiological number. The deepest the Navy uses air is about 170 feet. Figure out the PO_2, .21 times 6.17 atm, the PO_2 is 1.3 atm. That's where the 1.3 came up.

E. Thalmann: You weren't paying attention. That's not where it came from. I told you 1.3 came from somebody analyzing all the oxygen exposures that the Navy did back in the '80's and applying the best mathematical model they could come up with. They were trying to figure out at what PO_2 there was less than a five percent chance of any oxygen toxicity occurring and the answer came out to be 1.3. This was made completely independent of any consideration for either the PO_2 limits or helium oxygen partial pressures. Recently they reissued nitrox diving procedures, which I'm not really that familiar with because I wasn't around. If you noticed, the last several editions of the U.S. Navy Diving Manual contained no nitrox. The only other partial pressure limits that were stated in the Diving Manual were for helium oxygen surface-supplied diving. I can assure you that that's where the 1.3 atm came from. I was there and participated in the discussions. It had nothing to do with either the helium oxygen partial pressure limits, which nobody wanted to change or any partial pressure limits that had to do with nitrox diving.

D. Rutkowski: If the Navy would have increased that PO_2 a little bit on the TWA 800 dives, they wouldn't have had so many hits. The Navy would have wished they had nitrox.

E. Thalmann: First of all, the Navy writes its procedures for the Navy. The last meeting we had with the Navy master divers was not more than six months ago. They are all very happy with the air tables as they exist and that's what they're using. The Navy didn't dive nitrox on the TWA flight 800 recovery. They were diving heliox and air. This wouldn't have made any difference any way. The Navy develops its procedures for the Navy. Everybody has to understand that. The Navy Diving Manual is a Navy publication which, by law, has to be made available as a public document. The Navy does not canvas other organizations when it changes its procedures. This is in stark contrast to the Royal Navy, where their diving manual is an official document that is not available for that exact reason. They have the advantage of being able to change their procedures and theoretically nobody else is allowed access to that document. If you have it and you want to use it, that's fine, but you're not supposed to have it.

M. Emmerman: To clarify the comment on the TWA dives, the Navy divers were using mix. The SUBSALV commander actually denied us the right of using nitrox on that operation.

B. Oliver: I want to suggest a hypothetical scenario and this is the one in which Bill said that the plaintiff is going to hold up the existing standard, which in this case is the U.S. Navy limit. You will defend that by using the practical standard that is derived from the scientists and the individuals that comprise this group. Would you be better served if you had a formal standard drafted by this group or would that standard also be challenged against the Navy standard by the plaintiff?

B. Turbeville: I don't think it would matter that much. I think we still have the Navy standard out there and that's still an issue we have to deal with. All that any attorney defending a sued individual instructor, agency or dive charter can do is point to the standard of care that's been followed by the recreational/sport community so successfully for more than a decade now. If the standard is in writing and it says U.S. Navy, certain jurors and certain judges will think that's got to be the bible. Dr. Thalmann is right that the Navy is free to not canvas other agencies and to set standards for its own operations. My only wish would be they would make that clear in their manual. What they are doing is very specific for their operations and for the concerns they have for their divers for what they have to do. It does not apply to what we in the recreational/sport or even technical community have to do. In the same vein, no one thinks of applying Association of Diving Contractor standards to recreational or technical diving. We don't have diving bells. We don't have surface supplied gas. Yet I have still seen some of those issues come up, for instance, in live boat diving procedures. Experts will bring in ADC standards because they're out there and they're in print and other people follow them. It's our job to state what operational limitations or differentials there are between that community and ours. Can it be won? Absolutely, it just takes time to explain it.

K. Shreeves: Dr. Thalmann was saying that we have to say, as a sport diving community, that the Navy standard is their standard, it's not our standard. If we can do that in our communications to the dive community, we lessen the probability that Bill Turbeville will have to defend against it in a court of law.

B. Turbeville: That's absolutely right, Karl. By no means am I suggesting the Navy standard is wrong or it should be changed, that's not the point. It has to be made clear somehow through the publications themselves or perhaps through groups like this that different communities are freely entitled to have different standards based on their separate operational characteristics. Is there a cost-benefit analysis here and a risk-benefit analysis? Of course.

There always is. The question is then what is it based upon, what are your data? Why do you have operational differences and how can you explain that to a lay public or in my case, a lay jury, in a way that makes sense when a diver has a problem diving nitrox at 1.6 atm, has a seizure, goes unconscious and drowns. I have to defend the standard of whatever agency it is. I have to say it's been a safe standard for the past million plus dives. But poor Mrs. Goldberg, bought the farm diving on this so-called safe standard. That may happen and probably will happen because statistically someone's going to have a problem at some point in time using nitrox.

T. Mount: Bill, if the new Navy manual does have 1.6 atm for nitrox, that solves that problem anyway, right?

B. Turbeville: Absolutely. That solves the problem, yes.

E. Thalmann: Most decompression computers predict repetitive dives that are much longer in available bottom time than the Navy tables. As I understand it, nobody has yet been successfully sued for an accident on a decompression computer. Doesn't the same situation apply that somebody can go to the Navy tables and say this individual was using a gizmo that recommended much more bottom time than the Navy standard, that's the reason he got bent and therefore the manufacturer is held liable for an unsafe apparatus?

B. Turbeville: To my knowledge, no one has gotten a jury verdict against any manufacturer, but they certainly have extracted a lot of money in settlement. The only case I know wasn't even a trial, it was binding arbitration, about five years ago. Bill Oliver was at the time both my client and one of my expert witnesses. We won that one on the basis that the law does not say you must make a perfect machine. It says only that you must design out those risks you can reasonably design out and then warn against the remainder. With decompression sickness, since we know it's a probabilistic phenomenon, we don't know enough about it to say we can make a perfect device to guarantee that you won't get bent. All we can do is make the computer as safe as the community standard will allow it to be and then warn against the residual risk. In this particular case, the arbitrator, who was an attorney acting like a judge, said this guy got bent. He was following the computer, but the fact is the warnings were very clear. You might get decompression sickness even if you do everything we tell you to do. Therefore, you must be alert to the signs and symptoms and seek treatment immediately. This guy flew back to California from Cozumel after he got bent, so he lost. The lawsuit was brought based upon the fact that he followed the computer and still got bent. Even with nitrox, we can design out a certain amount of risk. We can't design out all risk. Therefore, whatever residual risk there remains must be warned against and that's what the instructional agencies do.

J. Hardy: In serving on many of these computer cases in the diving field, we have the Navy tables thrown up at us constantly. I hope you caught the fact that Bill Turbeville pointed out that it has cost the industry a tremendous amount of money in out of court settlements. In fact, some of the computer programs have been changed based on considerations of the out of court settlements. It's still costing us dearly even if the case isn't getting all the way to trial.

D. Rutkowski: We keep mentioning the Navy tables and 1.3 atm. Whatever happened to the other government document, the NOAA Diving Manual? Can't you use that for defense, Bill?

B. Turbeville. Absolutely. I have used it in the past and I'll use it in the future. The question is what are the community standards of care? I'd be careful there, though, because the NOAA Dive Manual also says some things that are fairly harmful to some of my clients' interests. For instance, that buoyancy compensators must act as personal flotation devices and keep your head and face up under all circumstances. The problem is none can do it. None have ever been able to do it. None will be able to do it at least in the foreseeable future. I've got to say, that's what NOAA says, but that's not necessarily what the manufacturers can do. They can't produce such a device. The NOAA Manual is one of the documents that I use occasionally, but it's used against me occasionally as well.

D. Rutkowski: The nitrox concept's been around for over 30 years. Dr. Morgan Wells started open circuit demand nitrox in 1970. In fact, Wells and I have been at NEDU teaching courses for the Navy four years ago. I don't see where you can justify going to the Navy Manual 1.3 atm when all their stuff is operational air diving, not nitrox itself.

M. Lang: Alright, let's do one more round on this 1.3 atm and then I'm cutting that off.

D. Rutkowski: 1.3 atm is for the Navy's closed circuit UBA, which is used by SPECWAR diving and trust me, it's got nothing to do with us.

M. Lang: Uncle Dick, don't make me come over there.

D. Rutkowski: I'll tell you what, let me buy shots of Scotch. The last one standing wins.

C. Nitrox Legal Considerations

J. Hardy: Let me suggest that I give a prelude and a transition and then put up an issue to let Bill Turbeville comment on. I would like to point out that another paper in these workshop proceedings will be a reprint of one of the "Lessons for life" that I prepared for Rodale's Scuba Diving Magazine. These are analyses of actual cases where I've served as an expert witness. Dick Vann set the stage this morning with one of the DAN cases he put up, which is the one that I wrote about. It was about a diver on a wreck dive chasing lobsters with home brewed nitrox. He was diving at 2.0 atm on his 39 percent mix, operating at about 135 feet. The first issue I would put forward to let Bill give you legal insight on is the supplying of nitrox. In other words, the manufacture of nitrox as a product by the store.

B. Turbeville: That's actually the most theoretically interesting issue of all. When you look at liability issues in the diving field, there are two that you have to be concerned with. The first is negligence. That is, whether there was a duty of care, a breach of that duty of care, a proximate or legal causation, which actually equals foreseeability for our purposes and then, were there damages? That's the one common standard. The other standard is strict liability/product liability. If you have a product, a dive computer or a gas, *i.e.*, enriched air nitrox, and it's found to be defective, which means unreasonably dangerous, you have faultless based liability. You don't need to prove negligence. You can't meet the standard of care for the community if it's found to be defective. Nitrox is a product. A supplier who produces or blends nitrox has just made himself or herself into a manufacturer. When they supply that product, two interesting things will occur. Number one, you lose the issue of fault. It's a strict liability question. That makes it easier for the plaintiffs to win. More importantly, for the practical purposes that I have to face, the liability waivers are no good anymore. The liability waivers work extremely well against negligence-based claims. They don't work against product liability claims. If the smart plaintiff's lawyer realizes that they can call nitrox a product, claim that it was "manufactured" improperly, they've just gotten around the waiver, which is our first and most important line of defense.

J. Hardy: The next issue is O_2 cleaning of equipment by the dive store in their repair and service department.

B. Turbeville: That's more on the negligence side. This is nothing that's terribly new. I don't know of any significant cases that have come out of any of these issues yet, frankly. As far as an overall view, I should have probably said up front that I don't believe nitrox is a legal issue at all. It really isn't. It is a very minor portion of what I have to do in my practice, which is 100 percent in the diving field. Of much greater concern to me are things like not running out of air, not holding your breath going to the surface, and making sure that students are under the control of an instructor at all times. If you don't O_2 clean properly, you're back in the same boat as a dive shop that doesn't do good maintenance on the regulators. You are now liable, not for product liability, but for negligence. That's something, by the way, that you can probably get around with a waiver.

J. Hardy: The next item would be training in nitrox use.

B. Turbeville: If there's ever any litigation that's going to center on the training aspect, assuming that they get past the release somehow, teaching nitrox or teaching air would be the same. That is, what is the standard of care and was is it reasonably followed in this particular case? That's where I get back to the concern we've just addressed about what is the standard of care for our community. Is it appropriate or even proper to bring in the standard of care from other communities? If so, why? There's no easy answer to this. All I can tell you is that it simply isn't even a blip on the radar screen yet. The operational use of nitrox is not posing any significant problems for us in the legal field to defend. We just don't see the cases.

M. Lang: You don't see the cases because they don't go to trial due to pre-trial settlements?

B. Turbeville: No. There have been claims filed. In fact, I'm defending a couple where nitrox is at issue, but only on the technical end where everyone agrees that somebody breathing 32 percent at 220 feet is a problem. But that's not an issue of nitrox as we're discussing it here. That's an operational and a supervisory consideration.

J. Hardy: The supervision of nitrox divers gets complicated because you have, for example, a Divemaster on the vessel supervising some people diving air and some diving nitrox. What are the potential implications of that?

B. Turbeville: That could be a tricky issue depending upon the standard of care for the charter. Divemasters are an area of the diving field that I don't think anyone's ever gotten a handle on, because Divemasters wear so many different hats. The obligation of a Divemaster depends on whether he is assisting a class, is the on-board individual responsible for checking people off and checking them back in, or is an underwater tour or group leader. Let's say you have a Divemaster on one of the California charter boats with 25 or 30 divers going in the water. On this particular boat they've always had the Divemaster record times in and out. Unless those divers are following computers, they're basically following the tables based upon the times given to them by their Divemaster. If some are using nitrox and some are using air, that becomes a very difficult situation for that Divemaster. Is that a particularly heinous problem? I don't think so. I think you break it down into individual cases. But theoretically, if you're making a law school exam, you could make a pretty intriguing problem there.

J. Hardy: Let me press you a little bit further, Bill. I've served on cases, going back on air now, where they said the Divemaster took the time in the water, took the time out and recorded the depth of the dive. By doing so, the Divemaster has now taken responsibility for that dive. Lo and behold, the dive was executed on a computer, but what was thrown up in our face were the dive tables.

B. Turbeville: That is absolutely a problem, Jon. It's one of those situations that you can never really get around. The fact is either the Divemaster is going to do too little or too much, depending on which way the plaintiff's lawyer wants to bring the case. If you make this Divemaster the be-all and end-all for dive safety, you've put an enormous burden in his or her lap, one that cannot be maintained. Some operations have taken the opposite tack and they simply say our Divemaster is basically a deckhand. The Coast Guard requires a deckhand, which is what our Divemaster does. He will help you on and off the boat, assemble tanks, pick up dive weights if you need them, but, folks, once you get to the dive platform, you're on your own. Now if that's made clear, that is a defensible standard. I can also guarantee you that we'll have someone come up there and say, wait a second. In this other community we have back in California or Hawaii the Divemasters typically are group leaders, tour leaders and they follow you like hawks under the water. They are the Dive Gestapo. That is one standard of care. Unfortunately, the Dive Gestapo have been thrown in our faces before when other operators wanted to give people the ability to do what certified divers should be able to do, which is dive by themselves. But you're right, Jon, no matter which way you go, there is always an opposing viewpoint.

J. Hardy: After we've sorted our way through all this and the plaintiff can't find any other way to sue us, they come up with the theory that no matter what happened with nitrox or air, the failure to rescue becomes an issue.

B. Turbeville: The failure to rescue is like failure to warn in product cases. That's where bad cases go to die. It's really a bad claim for the most part because the fact is that most people who are dead, stay dead. It's hard to revive the dead. We've had lots of cases where people have been dead for some period of time and then the plaintiff's expert will say, but if only you'd done CPR in this fashion, if only you'd added oxygen to the CPR equation, perhaps we would have revived this person. Ladies and gentlemen, I'm no doctor, but I do know this: typically people don't rise from the dead. If you look at the statistics that we've put in front of judges and juries, such as the one done in Seattle recently, the fact is that those who are already unconscious, are not breathing and don't have a heart rate, are clinically dead for all practical purposes. With the failure to rescue, if the person is struggling on the surface and while they're struggling there's a problem with getting the tow rope out or the boat can't break anchor and they drown while they are under view, that's different. That is probably a good claim depending upon the circumstances. When you find somebody on the bottom with regulator out of their mouth and for all intents and purposes they're no longer alive, to say that if only you had done something more, is very rare to lose a case like that. The data that I have seen show that you don't revive many of these victims.

J. Hardy: To round it out, we have the sale and rental of "O_2 clean" nitrox equipment.

B. Turbeville: That gets you back to the manufacturing standard. Product liability in this country is governed by Restatement of Torts, Section 402(a), a 1964 standard of the

American Law Institute, developed for what product liability should cover. They decided that it isn't just the sale of a product that should be covered, it's the rental also. If you rent a product, you step into the shoes of the manufacturer. The product here is enriched air nitrox. If that was not blended or analyzed properly you may have what's called a defective product. Now you no longer have a release and you have a guaranteed lawsuit, which will get you to a trier of fact, either the judge or the jury. You're not going to get out early, that is a difficult case. You're probably going to settle it just to avoid the costs of litigation depending upon the individual facts.

M. Lang: The floor is now open for further discussion of any additional risk management issues.

B. Bjorkman: Oxygen cleanliness is a very static situation. You can certainly oxygen clean something, but as soon as you put it into use, it quickly becomes oxygen un-clean and it's almost impossible to quantify. Where does that stand from a legal point of view?

B. Turbeville: I have no idea. That's one of those issues that hasn't been tested yet. We now have the first claim that I'm aware of where that very issue will probably come to bear. In fact, Elliot Forsyth is involved and it is in active litigation. It's odd because while, theoretically, oxygen fires should be fairly common at least with 100 percent oxygen, which we use in the technical diving field, not in recreational sport diving, we don't see many. At least not any that result in any type of injury. Through the comprehensive reporting of the various insurance carriers for the entities that I represent, I've never seen an incident yet using oxygen of 40 percent or less. There just hasn't been one. That doesn't mean there couldn't be one although I understand it's kind of hard to make that happen at those lower percentages. If there were a fire that occurred with somebody using recreational nitrox of 40 percent or less, we could find plenty of experts to state that the experience in the industry for the past 12 years has been over a million fills with no incidents. None. We could probably find some theoretical data to support that. Manufacturers have a bit of different perspective on that. Some of it is driven by people like me who say, you better be careful and warn that if you're going to use regulators with more than 22 percent O_2, go ahead and clean it. It can't hurt. If you over-warn, sometimes you invite problems. Our experience has been that 40 percent and below does work.

E. Betts: This room is not filled with the general diving public, everybody here understands what you mean when you say the 40 percent rule does work. However, I think somebody more qualified than I should perhaps clarify that when you paint with such a broad brush, you're covering 40 percent in what? All cases of compressors, booster pumps, blending systems, membrane systems, and regulators? We need to define what we are talking about when we say 40 percent works.

M. Lang: The actual oxygen cleaning discussion will be addressed in the nitrox equipment section tomorrow, so please focus questions as they refer to the legal implications.

B. Turbeville: That's all I'm going to say. Ed, you are right. I don't know all the parameters. I don't even begin to pretend that I'm an expert in these areas. All I can tell you is that from a legal perspective, and knowing which claims are coming up, from what we've seen so far, there hasn't been a claim on anything involving 40 percent or below for any kind of application.

B. Gilliam: We have three different grades of oxygen that are dispensed routinely in the United States. Has there been any issue with people who are using commercial grade oxygen as opposed to medical grade oxygen for blending purposes?

B. Turbeville: I've had a lot of phone calls on that from operators who have been wondering that same question. I tell them that there are no specific rules. The people from DAN might know more about that than I do because they've had to field a lot more of these issues than I have and worked with regulators in various states on the oxygen issue. The community practice has been that regardless of the source of oxygen, you're going to get a clean breathable source. Even industrial welding oxygen is typically very clean. The only difference relates to how the cylinders are handled or cleaned, I believe. Aviation grade oxygen, for instance, is the same thing as medical or even welding grade, but it's drier. The dew point is minus 65 degrees, and that's perfectly appropriate as well. There are no legal claims, to my knowledge, that have ever been brought on that issue.

B. Clendenen: I serve for DAN on the Compressed Gas Association medical equipment and medical gases group. The big concern from a legal standpoint is operators or retailers using medical grade oxygen to mix nitrox. What you're doing in that situation is using a DAN oxygen provider card to purchase a prescription drug and then you're adulterating it, which is against federal law. I don't know what the implications would be from a personal or store standpoint, but from the CGA's and the FDA's standpoint, that is probably the biggest risk for the operator using medical grade oxygen to do that. The FDA, like OSHA, is very aware of that practice going on. Their concern is that they hope nothing happens because it might impact our ability to get emergency oxygen for scuba diving accidents, which provides a great outcome for injured divers.

D. Rutkowski: All oxygen is distilled from the atmosphere. Chemically, in your body, there is no difference between any grade of oxygen. The government required a prescription to get medical grade oxygen. It's just your government working for you again trying to cause you a problem. Use aviation grade oxygen. There are welding or industrial grades of oxygen that are purer than medical grade. They have to be. The only difference between medical grade is that the tank is put on a double vacuum, taken down twice supposedly. A lot number is also recorded on that bottle. That's the only difference between any grade of oxygen.

M. Lang: Is there not also a humidity specification involved?

D. Rutkowski: Aviation grade oxygen is a little drier. But if you're a diver in water, it doesn't take much to let a little water in your mouth.

M. Lang: My thoughts exactly.

T. Mount: If you use medical grade oxygen to mix gas in the state of Florida and disburse it to other people, you've just committed three Class II felonies. That's how you don't want to use medical grade oxygen in the State of Florida. Aviation grade oxygen is fine. Theoretically, if you use welding grade oxygen and they don't vacuum the bottle, it may contain contaminants. Nevertheless, many divers use it.

R. Moon: Regarding the quality of the nitrox that is being dispensed, we've already heard that there are several potential inaccuracies in mixing nitrox and analyzing oxygen content. Although your last comment implied if it ain't broke, don't fix it, is it not only a matter of time before there is an action related to someone breathing a gas that was incorrectly mixed?

B. Turbeville: I hope I was not too glib. I don't want to suggest that if it ain't broke, don't fix it because I think that is a legitimate problem. I was suggesting that I don't know the answer. I can suggest to use medical grade, welding grade or preferably aviation grade oxygen, but if that oxygen is not pure and that product leads to injury or death, it may be considered defective in which case the release is no good. You don't have to prove fault. It's strict liability and it's a much tougher case to win. I don't know of any cases that have come up where there's been bad oxygen. I've certainly had cases where there's been bad air, usually from a compressor defect. Clearly, if there's ever an issue with oxygen that is somehow not pure, whoever supplied that, all along the chain from the person who first manufactured it to the person who sold it, are all considered manufacturers under the law. They've got strict liability. That's a big problem.

R. Moon: The issue is not so much a matter of purity, but rather accuracy in delivering the oxygen percentage that is requested.

B. Turbeville: You could look at it in two different ways. On the one hand, if you are the supplier and you have misanalyzed the mix that you have sold me and I get hurt or I die, you've sold me a product that is defective. There is also the issue of whether it was just a defective product or an error on the part of the operator. Did I not do my job as end user, following the community standard of care, in analyzing it properly? There has not been a case like that yet, but it's an interesting issue. It behooves the community to come up with some consensus on how nitrox should be analyzed. Clearly, if it's not analyzed properly, all bets are off. If I were on the plaintiff's side, the first thing I would do is make the argument that if you don't analyze it properly and you sell it, you've just sold a defective product by definition. That does an end run right around the release, you go straight to court, forget negligence. You can prove defectiveness fairly easily in that case.

R. Moon: If I interpreted your last couple of sentences correctly, were you urging a voluntary standard from the training agencies?

B. Turbeville: If they haven't done that already, they need to do it. In the shops I frequent, flow restrictors are the norm now. Every time I use a Mini-Ox I get a different reading for the same tank. It's hard to use. My understanding is if you have an operator who's experienced in using a flow restrictor, they typically get very close readings. There has not been a person hurt to the extent where a suit was filed because they had a poorly blended gas in recreational nitrox.

E. Betts: Isn't there a reasonable transfer of liability when the end user actually analyzes gas in accordance with the way he was taught?

B. Turbeville: Yes. That's why you have that interesting dichotomy and liabilities there. The standard of care in the industry is that the user is required to analyze the gas and sign off on a gas log.

E. Betts: Not all agencies and practices follow through that way. That is not what you'd call a community standard. It may be a recommendation by training agencies that the end user analyze the gas, but in actual practice, I don't think anybody here would admit that that's the way it is. Most of the time you'll see an instructor handing somebody a cylinder saying this tank is 36 percent. The big case occurred in Australia where they were using a membrane system and had the oxygen connection feed to the compressor come off. They were using a membrane and figured everything before this was 36 percent, therefore it's 36 percent. They had six rebreather divers ready to flop off the boat with air in the rebreather. Shouldn't there be a community standard that says the end user has the ultimate responsibility to analyze the gas? If they choose not to, that's not the dispenser's fault.

B. Turbeville: I'm not going to say what the industry should do in this case. That's a matter of philosophy. I can tell you that you're right that if you have a community standard that the end user must analyze a gas, at a minimum what you've done is added some comparative fault, as the term is used, for that user if there's a problem with the gas. No question about it. You can't reduce some of the strict liability at the product end, but you certainly can on the negligence end. If you leave it up to the operator to provide the gas analysis, that makes the operator more liable, period. Whether they do a good job or a bad job is up to the individual operator.

K. Shreeves: Ed, we have a community standard. Every training organization teaches the diver to analyze the mix or observe a professional analyzing the mix. What you described seems to be a different problem, one of people not following that standard.

E. Forsyth: We actually have seen a number of fires in systems less than 40 percent oxygen. They tend not to get publicized too much as with most fires and many of them never make it to the point where litigation is involved. Is there a reason perhaps that we don't hear more about these things and could it be that what's happening is that manufacturers say send us your equipment and we'll send you a replacement? They quickly take the evidence and sweep it under the carpet. I'm not necessarily pointing blame, but by and large the things that we do hear about tend to be the most serious incidents where people actually get hurt.

B. Turbeville: There might be incidents out there, but they're not being reported. Having represented most of the major manufacturers in this community, I don't know of a single case where they've had a fire with a 40 percent or under mix. That's not saying it didn't happen, but they are not reported to the agencies or to the manufacturer's insurance carriers either. They're just not brought up.

E. Forsyth: Ever since we were at DEMA last year we have become somewhat of a repository for people's war stories regarding fires and have started a database. It's our hope that we can get this up on the internet and provide an environment where people can get good information and provide experiences that occurred without legal ramifications. It's quite interesting to know that there are a lot more things happening than are actually reported.

T. Mount: It would be nice to have some of the information fed back to the training agencies because we don't have any reports of any problem under 40 percent, period.

NO SUCH THING AS "SAFE" AIR?

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Reprinted with permission from Rodale's Scuba Diving Vol. 7, Number 7, Issue 57, August 1998. *Ed.'s note: This regular column presents the anatomy of a diving accident and the lessons to be learned from it. The incidents described are real. Names of locations and people have been changed or deleted.*

Setting the Stage

He had been diving all over the world and made many deep technical dives. He regularly pushed the limits on wreck dives and mixed-gas dives. He was a strong diver and a risk taker who often ignored the rules and recommendations of recreational diving. He had little formal training beyond the basics, but he blended his own gases and believed that the limits concerning oxygen toxicity were not meant for him. The dive sites on this occasion were to be deep offshore wrecks. The trip was sponsored through his local dive store and was made up of regular customers of the dive store, as well as store and boat dive pros.

Dive Details

Because he had blended his own nitrox at home, no one from the dive store or boat knew the oxygen content of his tanks. When asked before the dive what gas he was diving, he brushed off the question, saying, "the usual." The dive was on a wreck in 135 feet of water. His descent and initial exploration of the wreck were apparently uneventful; he was observed by other divers to be actively swimming about hunting for lobsters.

Rescue Attempt

During the dive, one of the dive professionals who was also exploring the wreck observed him not moving, went to him, got no response and proceeded to take him up the anchor line. Arriving in shallow water, the dive pro--knowing the dive boat was immediately above them and that he had to make a decompression stop--inflated the victim's dry suit and sent him to the surface. There, he was immediately spotted by another dive pro who towed him the short distance to the boat, where CPR was performed to no avail.

Investigation and Legal Action

Analysis of the diver's breathing gas found an oxygen content near 39 percent. The depth of the dive was 125 to 135 feet. It was also discovered that the victim was not trained in deep, decompression, wreck, nitrox or technical diving. On this dive and on other dives before this, he dived beyond 130 feet, used mixed gases he had prepared himself, made required deco stops, penetrated wrecks, did not plan his dives, did not use complete equipment, dived alone and did not keep a log. An estranged family member brought a legal action against the boat, store and dive pros. The insurance company settled out of court, so there was no trial and no legal ruling.

Analysis

The accepted limits for oxygen partial pressure are 1.4 to 1.6 atm, depending on how conservative you wish to be. The higher limits, if used, are more often for short periods during emergencies or for decompression. On this dive, oxygen partial pressure was near 2.0 atm. This diver was also engaged in heavy work, which increases the impact of the oxygen and the likelihood of oxygen toxicity. He did not understand or respect well-established oxygen limits. The maximum operating depth for this gas mixture should have been 102 feet using an oxygen partial pressure of 1.6 atm or 85 feet using 1.4 atm.

There is no such thing as safe air or a safe procedure or a safe piece of dive equipment. There are ways of doing things that are safer than others, but no absolute guarantees. Degree of safety is determined by how individuals behave given certain variables--equipment, environment, experience, fitness, procedures, skills and the actual conduct of the dive. This diver clearly suffered oxygen toxicity that led to convulsions, drowning and gas embolism. He put himself above reasonable conduct and paid the ultimate price. The dive community then paid a financial price for his behavior. Much of what we all shell out for scuba diving products and services goes toward insurance.

Lessons For Life

- Training in specialty diving activities greatly increases the effectiveness and safety of such diving.

- Mixed gases should be prepared by reputable businesses that have the training and equipment to do so properly.

- The maximum operating depths for nitrox mixtures are based on significant medical research, are reasonable and need to be followed.

- By diving with a buddy, you will have a person to provide assistance or help and, in a worst-case situation, a person to perform a rescue.

- Part of what divers learn in training is that proper, complete, well cared for dive gear increases the safety of diving.

EXPERT WITNESS REPORT BY JON HARDY

The following is an edited version of the Expert Witness Report by Jon Hardy in support of the defense of the legal action, based on the accident described in this "Lesson for Life" as it appeared in RSD Magazine.

Issues

1. Use of nitrox

Nitrox or EAN is simply an alternative gas for scuba divers to breathe; it provides both advantages and disadvantages. By decreasing the nitrogen content of the air and increasing the oxygen content, decompression requirements are lessened, but the risk of oxygen toxicity is increased. In 1992, nitrox was still considered a technical diving technique, but training was easily available particularly on the East Coast. Today nitrox is considered part of general recreational diving.

[The Victim] violated several commonly accepted safe practices of nitrox diving:

- He was not trained or certified for nitrox diving
- He did not acquire his nitrox from a reputable source, but made a home brew of unknown quality
- He knowingly exceeded the maximum operating depth (MOD) for the nitrox he was using by going to 125-135 feet with 38.8% oxygen
- He did not use oxygen clean tanks that were properly labeled, plus he regularly misled or hid this from others.

By being irresponsible he put others who would later attempt to rescue him at risk. His disregard for the reasonable and accepted oxygen limits (1.4 to 1.6 atm) caused him to have oxygen toxicity that lead to convulsions, drowning and finally a gas embolism.

2. Divemaster duties

The common practice in the diving field is for dive boats to supply the divemaster when conducting an open boat trip (the boat sells individual spots directly to divers) or when a charter group requests a divemaster. Otherwise, as was the case here, the charter group is to supply the divemaster if in fact one is even needed. The primary duties of a divemaster are to assist divers and the skipper of the vessel in the conduct of dive operations. There is absolutely no way a divemaster can control divers in the water. There also is no standard:

1. That a divemaster is to, or can, ensure the safety of divers
2. That a divemaster is to check the contents of tanks
3. That a divemaster has the power to enforce safe diving practices.

There is nothing a divemaster could have done to prevent or change the outcome of this accident.

In fact the skipper, mates and charterer covered all the needed duties of a divemaster on the date of this accident. They:

- Collected money
- Assured the forms and lists were complete

- Set the anchor
- Briefed the divers on the water conditions
- Helped divers in and out of the water
- Conducted the rescue
- Provided first aid, CPR and oxygen
- Acquired outside help from USCG
- Accounted for all divers
- Kept records.

3. Buddy system

The buddy system is a recommended and common practice among recreational divers and is a requirement of instructor training standards during the conduct of open water training dives. It is also common practice to solo dive throughout the diving community, particularly during certain types of diving, such as game taking, underwater photography, spearfishing, river diving, free diving, search dives, artifact diving, and extended range or technical diving. Solo diving is also much more common in certain areas or among certain groups, as was the case here. There was nothing that barred these divers from diving together if they wished.

[The Victim] had the experience, equipment and training to dive alone if he wished. Diving alone does not cause accidents. Buddy diving does provide someone to share the experience, help with planning, equipment, etc., and assist in an emergency. In this case there is no evidence that a buddy could have prevented, stopped or solved [the victim's] oxygen convulsion. After the convulsion was over the buddy could have done no more than [the Rescuer] did to assist [the Victim].

4. Diving deeper than 130 feet

For many years the most commonly accepted recommendation for general recreational divers has been a depth limit of 130 feet. This has been based on air supplies, need for decompression, equipment limitations, increased risks, and the ability to deal with emergencies, including emergency ascents.

At the same time improving equipment, procedures and techniques have made possible safer extended range or tech diving, that increases the commonly used limits to 190 feet and provides for even greater depths.

Although [the Victim] had not taken deep or wreck diving courses, he was highly experienced and well equipped for this type of diving.

5. Decompression diving

Beginning recreational divers are taught to do "no decompression" diving. Actually all diving using compressed gases requires decompression, but the concept of "no decompression" is used to mean dives that do not require staged stops to decompress on the way to the surface. Decompression during this so called "no decompression" diving is accomplished by the slow rate of ascent and the common practice of making safety stops.

Experienced divers, particularly those who do deep wreck dives regularly do decompression stops. This is the norm with mid-Atlantic wreck diving.

6. Waiver and release forms

It is common practice to use and rely on these forms in the recreational diving community. It is clear that [the Victim] had signed these forms before and that the other paid divers also signed them on this trip. If anyone had refused to sign the form they would not have been permitted to dive.

Aside from the legal implications of these forms, it is clear that any scuba diver who signed the form would understand that the intent is for the diver to personally accept the responsibility for the known risks of scuba diving and by so doing release the boat and its operators of this responsibility.

7. Dive planning and dive profiles

It is clearly understood throughout the recreational diving community that unless a diver is on a guided tour by a dive professional the dive plan, including the actual dive profile is the individual responsibility of each diver.

8. Dive briefing

Dive briefings can be formal or informal, detailed or very short. With this group of experienced divers the simple report on water conditions given by the mate who set the anchor was all that was expected or needed.

9. Personal responsibility

[The Victim] was completely responsible for his own actions. His behavior, in this case his serious human error of diving too deep on an enriched oxygen mixture directly caused his death. He alone had the information and control over the dive to make it safe or not. He had not been trained in wreck, deep, mixed gas or tech diving, yet his years of experience and self teaching served him well except for his incorrect view of oxygen toxicity, which was counter to medical research and the standard of care in the diving field.

[The Victim] was clearly a risk taker, having done many dives that were way beyond the range of normal recreational diving. He had repeatedly done all of the following, which are all outside normal recreational diving:

- Decompression diving
- Diving well beyond 130 feet
- Not planning dives
- Mixed gas diving with no training
- Wreck diving with no training
- Deep diving with no training
- Not carrying a back up light
- Not using a reel
- No training for tech diving
- Diving alone
- Mixing his own gases

- Doing oxygen decompression
- Not using a full face mask
- Not keeping a log
- Not understanding or respecting oxygen limits.

Expert Opinion

This accident was solely the fault of [the Victim]. None of the defendants did anything to cause or contribute to the accident. The defendants did all that was possible, given [the Victim's] errors, to rescue him. The defendants did not violate any standard of care and are not negligent in any way.

IV. NITROX TRAINING CURRICULUM

M. Lang: I was asked to schedule some time for discussion of the entry-level, recreational nitrox-training curriculum. The first topic that surfaced was OTU/UPTD tracking. The second topic was the gas analysis training and the third was the necessity of the mathematical formulas. Any others?

D. Kesling: CNS tracking.

B. Gilliam: The CNS threat is far greater than that of OTU's.

W. Jaap: Decompression protocols.

D. Kesling: Written exam.

M. Lang: Number of nitrox dives required for certification.

B. Bjorkman: Nitrox cylinder labeling and how to analyze gases.

M. Lang: Gas handling. If we take the table of contents of recreational nitrox course training manuals and overlay them, do they all have the same topics?

B. Gilliam: Yes.

M. Lang: Should something be added or deleted from those for not being an absolute requirement or a necessity?

B. Gilliam: At TDI we explain the theory of OTU tracking and then discount it completely by saying that if we stay within the CNS limits, the OTU's don't make any difference. Everybody's covering the same nitrox material, perhaps in different ways. The time is long gone when everybody was going to require cylinders to be green and yellow. Now people are just using all cylinders and putting various different bands on them to designate the mix. This is another interesting legal discussion because we're all in violation of CGA standards because the only CGA accepted cylinder color for compressed air cylinders is black with a white top. When was the last time you saw one of those in the scuba industry?

D. Dinsmore: This may not be applicable to everybody, but recordkeeping or documentation of the dives and the gases.

M. Lang: Does everybody recommend keeping a personal log book for nitrox dives and gas analysis.

D. Dinsmore: Yes.

M. Lang: It is required in the training standards that you log this information to get your certification, it appears that is in place.

D. Richardson: Emergency procedures.

E. Betts: We can take the table of contents of each training manual and show where each agency discusses the limitations of the CNS clock and discusses risk management and why these numbers are used. Every responsible training program is discussing possible consequences of not following the recommendations. This discussion started out as whether or not the recreational community needs to teach certain issues, for example, the OTU tracking. Of course Bret chimed in that CNS reporting was more important. It's certainly more important, but everybody's already doing that. That wasn't the basis of the discussion. As I understood it, the basis of the discussion was we've got certain topics we're teaching, do we need to do that? What is the justification for it?

D. Richardson: That certainly is one area to examine. This is a workshop. We want to look at areas that perhaps are omitted, if any. At the end of the day this document will stand for itself so people will see that this community got together and established some minimum content that they agreed on should be included in this type of training. I don't see any harm in that. I see value in that.

T. Mount: When you're teaching CNS, you're teaching risk management of nitrox. They are one and the same topics.

D. Kesling: Accident management instead of risk management?

M. Lang: Now that we have this spreadsheet, what do we want to do with it?

B. Gilliam: Michael, I appreciate what you're trying to do, but at the end of this exercise we'll have neat little checks in all those boxes. You might almost decide that you did a good day's work and let us go home early.

M. Lang: We just got a nod that everyone is teaching these things, right? Yes?

K. Shreeves: Except everybody's not teaching OTU's to entry-level enriched air divers, is that correct?

T. Mount: Correct for IANTD.

E. Betts: Correct for ANDI. It's a non-issue following no D dives within the CNS time limits.

B. Gilliam: If you wanted to really get an accurate census, just make up a form, pass it out tomorrow morning and let everybody fill it out and give it back to you.

M. Lang: I can already get that information from the content page of your training manuals.

E. Betts: The table of content from the training manuals certainly would show what the curriculum is about.

M. Lang: I'll include the six Tables of Contents at the end of this discussion session.

D. Kesling: Is everybody requiring dives as part of nitrox certification? It's gone back and forth in the industry. If so, how many dives? Is there anyone not requiring dives?

B. Gilliam: TDI does not. We have a recommendation of two dives. When we first started teaching nitrox this was something that was embraced by many retailers, especially in the Midwest. We discussed it with our risk management people, lawyers and key instructor trainers. Since nitrox is basically an academic transfer of knowledge, there is no diving skill assessment involved. We didn't feel that the inclusion and then firm requirement of dives was necessary. Students are going to be required to do the dive planning and are required to demonstrate understanding of analysis, all of which can be done in a classroom. We left the dives as a recommendation and not a requirement.

D. Richardson: PADI requires two dives. Everybody else does, TDI may be the exception.

C. Borne: At NASA we're not certifying anyone. We're covering all that information for potential users at our facilities in about an hour and a half long nitrox briefing. It's more of an informed consent and then breathe in and breathe out. We do not require dives. We place more emphasis on the handling of the equipment that they're using, flammability, the closeness to the suits, more so than on the nitrox concept itself.

D. Rutkowski: IANTD has a policy that leaves it up to the instructor. If a guy comes in and he's an advanced level diver, why should I have to go out and blow bubbles with him?

T. Mount: The IANTD policy that was voted in by everybody is two required dives. We did a survey before nitrox was widespread when it wasn't as available and was more expensive. We discovered that 95 percent of the divers who had taken nitrox courses and dived during the courses never dived the gas. We also found that 90 percent of the divers who had dived nitrox during the course continued to dive it. That may be antiquated reasoning today because you can get nitrox more readily and there's product recognition. In essence, you've received this education, now go dive the gas.

M. Lang: Fair enough.

D. Rutkowski: Requiring the dives is a great thing, that's where the dive shop makes its money. If you run a dive shop, you need to make money. Take them out to blow nitrox bubbles.

E. Betts: ANDI chose to require two dives for enriched air certification. We've broken the course down into two parts. A part two program is actually a hands-on practical application in which the student is required to analyze gas, handle cylinders, sign out cylinders and mix validation books, and sign off a checklist affirming the contents of the cylinder. These are practical applications. We never felt it appropriate for somebody to have a certification card that says Nitrox Diver and they've never analyzed gas, signed out a cylinder or ever actually breathed the gas. It just seemed to be an oxymoron. Bret's point is well taken that there is no difference in diving air or nitrox and that's true. ANDI would not have made the choice to require diving because there is a difference breathing under water. The problem is that the practical application needs to be driven home. The student needs practice in gas handling, gas analysis and proper protocols that are of a practical application nature as opposed to a theoretical nature. It was never possible with a classroom of 18 or 20 people to let each person analyze gas in the classroom. Consequently, you were turning them loose without them ever handling an analyzer or handling cylinders or a mix validation book. We decided that we needed a part two practical application. That was the justification for the dives that ANDI required when others said that's an absurdity.

B. Gilliam: I should have noted when I made my original comments that about 90 percent of TDI people do the recommended dives, it's just that it's not a requirement. The evolution of the people coming in to take the programs is not so much as a matter of curiosity like it was in the early '90's. These divers are coming in to take courses and simultaneously investing several hundred dollars in a nitrox dive computer. Their intent is specifically to participate in nitrox when they go dive with the Aggressor Fleet. We know this because it's filled out on the forms returned to us that divers are doing the dives. In many cases, they're doing a lot more than two. We have divers who go out directly from that nitrox class and make 24 dives a week on a liveaboard. The issue is not that they're not getting the practical exposure to it, they are.

J. Hardy: I'd like to note that when we switched from nitrox being the sole territory of technical diving to general recreational diving, there was a significant simplification of the nitrox curriculum. We're seeing that curriculum simplified even more as we go along. Part of that is because the manufacturers are responding with better nitrox dive computers that are easier to use and do their jobs very well. It's kind of naïve to think that divers are going to continue to use these laborious tables that we have in our books, but we all have them. This is not rocket science and these nitrox dive computers are getting extremely capable at doing what they do.

M. Wells: In this case, I'll be NOAA retired and my comments go from the '70's up through 1995 and Dave Dinsmore can add on to this. I also want to defend Bret's point of view and sound like Ed Thalmann if I can get that tone in my voice when I say "applies to NOAA and only NOAA." Training for NOAA working level divers in the use of nitrox did not necessarily involve actually breathing in and breathing out nitrox. It was a published list of things that were required. To address Ed Betts' concern, it most certainly did require lots of gas analysis. I would also express my very strong opinion that any time taken away from such things as safe handling of the equipment, filling of cylinders and especially gas analysis, and devoted to breathing in and out, would be considered negligent in my opinion.

SSI – Enriched Air Nitrox Specialty Diver

Foreword

1. Introduction to Nitrox
   What is nitrox?
   - Enriched air nitrox
   - Nitrox I and II
   - Misperceptions regarding nitrox

   The benefits and limitations of nitrox use
   - The advantages of nitrox
   - The limitations of nitrox

   Becoming a nitrox diver
   What you will find in this manual
   Chapter 1 Review

2. Physics and Physiology of Nitrox
   The benefits of breathing less nitrogen
   - Equivalent air depths
   - Nitrox use and bottom time
   - Nitrox and narcosis
   - Using nitrox to increase safety margins
   - Is richer better?

   The disadvantages of breathing more oxygen
   - The concept of partial pressure
   - Limiting PO_2s
   - CNS oxygen toxicity
   - Contributing factors
   - Recognizing and responding to CNS oxygen toxicity
   - Preventing CNS oxygen toxicity
   - Establishing and remaining within maximum operating depths (MODs)
   - Limiting total O_2 exposure to safe, CNS "clock" values
   - Limiting depth
   - Reducing CO_2 levels

   Chapter 2 Review

3. Equipment for Nitrox Diving
   How nitrox use impacts dive equipment
   - Increased oxidation and wear
   - The risk of fire or explosion

   Using standard scuba equipment with nitrox
   - The 40 percent rule
   - What rules should you follow?

   Nitrox and scuba cylinders
   - The significance of blending methods
   - What do the terms "O_2 Clean" and "O_2 Service Rated" mean?
   - The significance of oxygen compatible air

- Nitrox cylinder markings

Analyzing nitrox cylinder content
- Protocols for dispensing nitrox
- The need to analyze
- O_2 analysis hardware
- Analysis procedures

Chapter 3 Review

4. Planning Nitrox Dives

Managing exposure to nitrogen
- Using air-based dive tables or computers with nitrox
- Using nitrox-programmable dive computers
- Using equivalent air depths
- Using the SSI combined Air/EANx dive tables

Managing exposure to oxygen
- A simplified approach to tracking O_2 exposure
- Tracking CNS "clock" values
- Other considerations

The nitrox dive planning and decision making process
- Define your goal
- Managing oxygen exposure

Chapter 4 Review

Appendix
1. Partial Pressure of Oxygen (PO_2)
2. Equivalent Air Depth (EAD)
3. Actual Depth (From EAD)
4. Maximum Operating Depth (MOD)

PADI – Enriched Air Diver Manual

Introduction
Course Overview
The Advantages and Disadvantages of Diving with Enriched Air
- The definition and purpose of diving with enriched air
- Enriched air and safety
- Enriched air and narcosis
- Disadvantages and potential hazards of enriched air

Equipment for Enriched Air Diving
- Equipment other than cylinders
- Cylinders used for enriched air diving
- Filling enriched air cylinders

Using the RDP with Enriched Air
- Equivalent Air Depth (EAD)
- Using EADs with the RDP
- Planning repetitive enriched air dives with the RDP

Managing Oxygen Exposure
- Oxygen partial pressure
- Oxygen exposure limits
- Oxygen toxicity
- Determining the maximum and contingency depth limits for enriched air
- Calculating your oxygen exposure
- Repetitive dive planning with the RDP and the oxygen exposure table

Using the Enriched Air RDPs
Special Applications in Enriched Air Diving
- Using the wheel for multilevel enriched air dives
- Using computers for multilevel enriched air dives

Diving Emergencies and Enriched Air
Obtaining Enriched Air Fills
- Oxygen analysis
- Stickers (decals), tags and the fill log

The Equivalent Air Depth Formula
The Oxygen Partial Pressure Formula
The Maximum Depth Formula
Enriched Air and You
- Enriched air diver course training dives

Knowledge Reviews

NAUI - Nitrox: A Guide to Diving with Oxygen Enriched Air

- Diving at altitude
- Dive computers and enriched air
- Dive planning software
- Knowledge review

8. Using NAUI Diving Tables with Enriched Air Nitrox
    - Selecting the appropriate diving table
    - Repetitive diving
    - Dive computers
    - Knowledge review
9. Overview of Gas Mixing
    - Oxygen handling
    - Cleaning for oxygen service
    - Preparing enriched air nitrox
    - Knowledge review
10. Obtaining and Analyzing Enriched Air Nitrox
    - Obtaining nitrox fills
    - Performing gas analysis
    - Cylinder labeling
    - Fill station log
    - Knowledge review
11. Diving Equipment Considerations
    - Cleanliness
    - What is done during cleaning and conversion to EAN service?
    - Scuba cylinders
    - Identification of enriched air cylinders
    - What about new equipment?
    - Routine care and maintenance
    - Knowledge review
12. Having Enough to Breathe and Staying Warm
    - Normal respiration
    - How much gas is needed?
    - Modifying factors
    - Finding the personal RMV
    - Converting pressure to cubic feet
    - Calculating the standard RMV
    - Thermal protection: Staying warm
    - Types of protection
    - Knowledge review
13. Contingencies: If Things Don't Go as Planned
    - Contingencies
    - Oxygen supply
    - Out of gas, out of life
    - What if a decompression stop is required?
    - Omitted decompression
    - Decompression sickness
    - Oxygen toxicity

- Knowledge review

14. Technical Diving Overview
Bibliography
Glossary
Reference Section
About NAUI

IANTD - Enriched Air Nitrox Diver Student Manual and Workbook

Introduction
Foreword
Nitrox comes of Age
About the Author
Acknowledgments

- Introduction to EANx Diving
  - What is Nitrox?
  - Nitrox Advantages and Limitations
  - Enriched Air Nitrox History
  - Current Trends in Enriched Air Nitrox Use
  - The Future
- Physiological Implications of Oxygen
  - Partial Pressure Considerations
  - Central Nervous System (CNS) Oxygen Toxicity
- Physics for EANx Divers
  - Force/Unit Area or Pressure
  - Dalton's Law
  - Oxygen Exposure (PO_2)
  - Maximum Operating Depth
  - Best Mix Equation (FO_2)
  - Equation Summary
- EANx Dive tables
  - Equivalent Air Depth Concept (EAD)
  - IANTD Nitrox Tables
- Operational Implications of Oxygen and Oxygen Safety
  - Review of EANx Advantages
  - Mixing EANx
  - Training for EANx Blenders
  - Training for EANx Users
  - Equipment
  - Analysis of EANx Mixtures
  - Repetitive Dive Worksheet

Membership Application
Waiver and Release of Liability
Medical Questionnaire
Student Verification
Final Exam Answer Sheet
Student Workbook and Notes
Appendices

- Air and EANx Diving and Decompression Tables
- Quiz Answers
- References

TDI – Nitrox: A User Friendly Guide to Enriched Air Mixtures

ANDI – The Application of Enriched Air Mixtures

Forward
About the Author
Charts, Figures and Tables
Acknowledgments

1. The History and Development of SafeAir
   - Objective
   - Background
   - Predisposition factors
   - The history of oxygen-enriched air
   - Diving computers and SafeAir
   - What is nitrox?
   - What is SafeAir?
   - Air is Nitrox!
   - Benefits of SafeAir
   - Review
   - Quiz
2. Oxygen and the Diver – A Discussion of the Pathophysiology of Oxygen
   - Objective
   - Background
   - Pressure
   - Oxygen and oxygen toxicity
   - Pathophysiology of oxygen
   - The oxygen clock
   - Oxygen life support ranges
   - Pulmonary/Whole body toxicity
   - Working limits of oxygen
   - Caution zone
   - Oxygen and deep diving
   - Oxygen limits summary
   - In-water decompression using oxygen
   - SafeAir 50
   - Pony cylinders and SafeAir
   - Advantages of SafeAir 50 over pure oxygen
   - Review
   - Quiz
3. Mathematical principles of gas mixtures
   - Objective
   - Symbols required
   - Equations and relationships
   - Variations in the breathing mixtures
   - Complete a few problems for practice
   - Review
   - Quiz

4. The Equivalent Air Depth Formula and Mixture Application
   - Objective
   - Introduction
   - Equivalent air depth (EAD) formula
   - Examples of EAD calculations
   - SafeAir EAD/MOD graph calculator
   - Applications of enriched air
   - Review
   - Quiz
5. Oxygen Handling and SafeAir Dispensing Procedures
   - Objective
   - Oxygen reactions
   - Properties of oxygen
   - Oxygen clean
   - Oxygen compatible
   - Oxygen service
   - Oxygen clean and SafeAir equipment
   - Diving equipment and SafeAir
   - Dedicated cylinder – marking and labeling
   - Color coding
   - Cylinder contents tag
   - Cylinder inspection sticker
   - Proper gas analysis and record keeping
   - Methods of refilling cylinders
   - Breathing gas purity standards
   - Partial pressure blending
   - Oxygen booster pump
   - Pre-mixed SafeAir
   - Continuous blending system
   - Quiz

Appendix
- ANDI DivePlanner software
- NOAA Nitrox I Dive Tables
- NOAA Nitrox II Dive tables
- Buhlmann Nitrox Dive tables
- ANDI Standards for Gas Users
- Tear-out/Hand-in Quizzes

NITROX AND RECREATIONAL DIVING EQUIPMENT COMPATIBILITY: PRELIMINARY FINDINGS BY DEMA MANUFACTURERS COMMITTEE.

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Introduction

In June 2000, a diving instructor was injured when his equipment caught fire as he was preparing to use an oxygen-enriched breathing air mixture (nitrox). The term "nitrox" technically refers to any combination of oxygen and nitrogen, including mixtures that contain less oxygen than air. It has been proposed that more accurate terminology such as "Enriched Air Nitrox" (EAN) or "Oxygen Enriched Air" (OEA) be used to distinguish mixtures with an oxygen content greater than air since these are the mixtures of interest for recreational diving. However, the proposed substitute terms have not gained wide acceptance. "Nitrox" has become accepted to mean EAN or OEA in recreational diving, hence within the context of this report at least, the terms are synonymous.

This incident raised the attention of the recreational diving community because it is thought to represent the first instance of an injury to a recreational diver related to a reaction between scuba equipment and nitrox. It was soon learned that the nitrox mix in this case contained nearly 80% oxygen and it is believed that the high percentage of oxygen was a significant contributing factor to the accident. The vast majority of experience with recreational use of nitrox is with gas mixes containing less than 40 % oxygen. Complete details of the incident are not available due to pending litigation, but it is known that the circumstances in this event were not typical of recreational use of nitrox.

Although this event involved special circumstances because of the unusually high percentage of oxygen in the mix, it did arouse interest and concern within the recreational diving community regarding the compatibility of nitrox and recreational scuba equipment. A specific concern was expressed that not all training agencies and equipment manufacturers are in agreement with respect to the preparation and maintenance of recreational scuba equipment for nitrox use. It was suggested that the Diving Equipment and Marketing Association (DEMA) should aid in the development of a unified policy to address this issue.

DEMA Findings

After looking into the matter, DEMA offers the following summary of its findings:

- The safety record for nitrox use with recreational scuba equipment has been excellent since its introduction to the recreational community in the mid 1980's. Dick Rutkowski, former Deputy Diving Coordinator for the National Oceanographic and Atmospheric Administration (NOAA), introduced nitrox to recreational diving. Rutkowski and others developed training programs adapted from the operational experience of NOAA and there have been literally millions of dives performed with no reported incidence of injury related to compatibility of nitrox with scuba equipment.
- When nitrox was introduced to recreational diving it was greeted with much skepticism. Judgments were made that nitrox diving was either too complex or risky for recreational diving and that it more appropriately be confined to the realm of technical diving. Early supporters of nitrox have demonstrated that these judgments were incorrect and recreational nitrox diving is now accepted as a mainstream activity with at least six training agencies now providing nitrox instruction for recreational divers and dispensers of nitrox mixes. The six training agencies include the International Association of Nitrox and Technical Divers (IANTD), American Nitrox Divers International (ANDI), Technical Diving International/Sport Diving International (TDI/SDI), Professional Association of Diving Instructors (PADI), National Association of Underwater Instructors (NAUI), and Scuba Schools International (SSI).
- Nitrox training is still generally presented as an advanced topic because of the need to understand physiological limitations not encountered with standard air diving. However it is clearly distinct from technical diving and the level of risk, when the activity is performed within the prescribed limits, is not considered any greater than with air diving. In fact, there is support for the proposition that there is a decreased risk of decompression sickness (DCS) for divers who use nitrox and conduct their dive plans as if they were using air.
- Basic training for nitrox diving also includes information pertaining to the increased potential risk of fire associated with handling gas mixes with elevated concentrations of oxygen. The training advises that the risk of ignition and support of combustion increases as oxygen concentration and pressures increase and that the procedures for blending nitrox should only be attempted by those who have access to the proper equipment and have received specialized training in approved handling techniques. Improper blending can place the user of the nitrox gas at serious physiological risk, and blending procedures that require handling of pure oxygen require specific measures to reduce the significant risk of fire.
- The recommended measures include verification that the equipment design is suitable for exposure to oxygen-rich atmospheres, cleaning to remove combustible contaminants such as lint, oil residue and other particles, and substitution of some components (usually seals) and lubricants with oxygen-compatible materials.
- Follow-up measures must also be taken to avoid recontamination of the equipment in use. Generally, this means that the equipment must be dedicated to use with similarly cleaned systems.
- All of the recreational diving training agencies are in agreement that these measures are necessary for equipment exposed to pressures greater than 200 psi and nitrox mixes containing more than 40% oxygen. Where there is disagreement is with regard to equipment exposed to less than 41% oxygen. One view is that standard scuba equipment may be used interchangeably with standard air and nitrox containing 40% or less oxygen. This view has been represented by IANTD and TDI/SDI citing their favorable safety record coupled with the operational experience of NOAA. Supporters of this view further point to U.S

Occupational Safety and Health Administration (OSHA) and U.S. Navy practices that only specify an oxygen-cleaning requirement for diving system components exposed to oxygen mixes that exceed 40% by volume. Supporters of this view acknowledge that in industrial applications outside of diving, there are requirements that any gas mix containing more oxygen than 23.5% be treated with the same consideration as pure oxygen. However, these supporters also believe that because there are few industrial uses for gas mixes with less than 40% oxygen, the limitations imposed are derived from a theoretical risk, are contrary to actual experience and are unnecessarily conservative. In contrast, there is an opinion held by ANDI that the standards and practices of industries with broader experience in handling oxygen and other gases should be respected. It is further argued that the conditions for use for nitrox in the recreational community may likely be broader than that experienced by NOAA and others in the past. As examples, higher operating pressures, new equipment design and materials are cited and that until proven otherwise, the more conservative practices should be followed.

- In order to gain another perspective on the issue, DEMA consulted Elliot Forsyth, a former NASA engineer with experience in evaluating equipment for exposure to oxygen-rich atmospheres. Forsyth indicates that the probability of ignition and combustion in the presence of an oxygen-rich environment is highly dependent on the configuration of the equipment and the operating pressure of the system. While the probability of ignition is lower, fires have occurred in systems exposed to gas mixes containing less than 40% oxygen. In light of this statement, it would seem inappropriate to assume that all scuba equipment intended for use with air would necessarily be compatible with nitrox mixes containing oxygen in the 23.5% to 40% range.
- An important item to note is that while there remains an open debate as to whether it is necessary to clean equipment for exposures to gas mixes containing less than 41% oxygen, the official policy statements of all the training agencies is to follow the equipment manufacturer's recommendations regarding use restrictions.
- DEMA also contacted several manufacturers of recreational scuba equipment to obtain their positions on nitrox. Sixteen manufacturers were contacted and none condoned the use of products that have not been evaluated and prepared for nitrox applications, regardless of the percentage of oxygen in the oxygen-enriched nitrox mixture. At least two of the larger companies have performed adiabatic compression tests to assess nitrox compatibility of specific equipment and have relied on these test results as a basis for their recommendations. The overwhelming majority of manufacturers offer at least one product that has been specifically prepared and designated as suitable for nitrox use. Most of the manufacturers specify that even with nitrox compatible products, exposure should be limited to mixes containing 40% or less oxygen and that the equipment be dedicated to nitrox use to minimize opportunities for recontamination. Several manufacturers will approve exposure to mixes with a greater oxygen content provided that specific instructions are followed. The appropriate manufacturer should be consulted for details.
- In many cases, manufacturers will approve conversion of earlier models of their products for nitrox use. Generally, conversion involves cleaning, replacement of seals with oxygen compatible materials, and use of oxygen compatible lubricants. All of this can be performed when normal regulator or valve service is due, but should be performed by a technician specifically trained in nitrox applications.

Conclusions

After carefully considering the issues, DEMA has concluded the following:

- All of the manufacturers consulted in this survey recommend that use of their products with high-pressure nitrox be restricted to only those products that have been prepared and designated for such use. Nitrox for the purposes of this instruction is defined as any nitrox mixture with an oxygen content greater than 23.5%.
- The manufacturers recognize the favorable safety record associated with past use of standard equipment and nitrox, but also feel that the measures recommended to further reduce risk for present and future applications are prudent and are not unduly burdensome.
- Although some training agencies present persuasive arguments that specific cleaning should not be necessary for exposures to less than 41% oxygen, these same agencies specify that manufacturer's recommendations should be followed. The recommendations appearing in this report are those reported to DEMA by the manufacturer as of September 2000.
- Given the current positions of the manufacturers and training agencies, there is, in fact, a unified community standard in place.
- It is important to recognize that community standards for this and other issues may change as the experience of the manufacturers and training agencies continues to evolve. Risk factors concerning the compatibility of standard scuba equipment with nitrox may be reevaluated in the future and may justify changes to the current community standard. However, until a change is presented, DEMA recommends that the current community standard be followed. Further, if there is any question regarding changes to the manufacturer's policy, DEMA recommends that the manufacturer of the specific equipment be contacted directly.

Discussion after Oliver presentation

B. Oliver: Cressisub has an "X" at the air equivalent of the gas and stands alone in not recommending nitrox at all. The companies that list a "2" have designated some models for nitrox use. Others have nitrox conversion components available and recommend that the equipment not be used with nitrox unless it is converted. A "1" means that all of the models produced have been prepared for nitrox use. Prepared for nitrox use is understood to mean nitrox-clean, not oxygen-clean. This mean that hydrocarbons have been removed through some cleaning processes at their factory, but they have not followed through with documentation and specific packaging that normally is required with oxygen cleaning. Most of the companies still limit the use of their equipment to no greater than 40 percent oxygen. They're taking a very conservative position. Three companies exceeded that limit. Oceanic's equipment is good to 50 percent O_2. OMS and Scubapro have at least one model that is good to 100 percent O_2. Aqua-Lung is owned by Air Liquide, the largest industrial gas company in the world with 100 years experience in handling oxygen. They emphatically stated: "You will follow our policies; if it's not air, it's oxygen and you have to treat it as such." Aqua-Lung was able to persuade them to reconsider. They said: "If we test your regulators and you follow our recommendations, we will give you an allowance to meet this nitrox need."

Table 1. Manufacturer's recommendations regarding nitrox and equipment use.

	Maximum fO_2 Authorized				
Company	**23.5%**	**<41%**	**<51%**	**100%**	**Comment**
Aqua-Lung		2			
Atomic		1			
Beuchat			2		
Cressi-Sub	x				
Dacor		2			Policy conforms with parent company.
Dive-Rite		2			
Genesis		4			
International Divers Inc.		1			
Kirby-Morgan			1		
Mares America		2			
Oceanic			2		
Ocean Management Systems				1	
Sherwood Scuba		4			
Scubapro				2,4	
Thermo valve		2			
Zeagle		3		4	Policy is being reevaluated.

key code - Enriched Air Nitrox (EAN) Sep 00

- x Maximum limit. EAN not recommended.
- 1 All models are factory-prepared for EAN using oxygen compatible materials.
- 2 Designated models factory-prepared for EAN using oxygen compatible materials.
- 3 Standard air components declared acceptable. Viton o-rings available.
- 4 Conversion components available for installation by technician qualified to prepare for oxygen service.

B. Oliver: Aqua-Lung did some testing on regulators and although they didn't share with us the exact details, said, "Some of your regulators are okay for 40 percent nitrox and some aren't." Aqua-Lung made some changes in the regulators that weren't and brought them up to the level for approval, but they wouldn't approve anything for 100 percent oxygen. Some smaller manufacturers changed their positions to Aqua-Lung's.

J. Hardy: Bill, could you clarify the Scubapro line?

B. Oliver: Scubapro has one unit that is good for 100 percent oxygen. They were qualifying that regulator at the time that I was talking to them and the X on the table just meant that all other equipment that they have is only good for air.

M. Lang: Allow me to introduce Dr. Sergio Angelini, Director of Technical Development at Scubapro, who is joining us this morning.

S. Angelini: Molte grazie. This is derived from testing of the Mk 20 first stage to 3600 psi at 100 percent O_2 by the German agency B.A.M. (Bundesanstalt Für Materialprüfung). This is not a value that comes from some empirical guessing, it has been tested and we're comfortable with that. We have not extended it to our other models because we did not test them and don't know what the results would have been. The particular Mk 20 that passed the test had the nitrox kit and therefore Viton o-rings and a special high-pressure seat. We just recently approved the Mk 20UL (ultralight), which has the aluminum body with the nitrox kit, to 40 percent O_2 taking a more conservative position.

T. Mount: Does this mean that the Mk 20 Nitrox, which we've been using for the last couple of years, is now approved for 100 percent O_2? Is that what you're saying?

S. Angelini: Every Scubapro Mk 20 with a nitrox kit (oxygen clean and with the kit installed) is approved for 100 percent O_2.

T. Mount: That's reassuring to know because we've all been using it with 100 percent.

B. Turbeville: What is Scubapro's position on continuing maintenance and cleaning of the regulator once it's first been nitrox cleaned?

S. Angelini: That's a very good question because we don't sell a Mk 20 that's ready out of the factory for 100 percent O_2 use. We only sell it with a normal high pressure seat and regular o-rings. We sell the kit separately to the dealers and they have to install it. We have to trust them to do a good job. That may be somewhat of a delicate position, but then again, after a year you have to perform the servicing and have to trust your dealers anyway.

B. Turbeville: Do you have a recommendation as a manufacturer on how the regulator should be treated or stored between dives? Should it be bagged in plastic or how do you keep it from being re-contaminated?

S. Angelini: We only say that it has to be used on tanks and valves that are oxygen clean. There is absolutely no way that you can track that though.

CLEANING TO AVOID FIRES IN NITROX SCUBA AND FILL SYSTEMS

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Cleaning systems and components for nitrox service has been a highly controversial issue in the recreational diving industry. It has divided the industry into two main factions: those who support a special-cleaning threshold for oxygen service at 40 percent oxygen, and those who support a threshold of 21-25 percent, or standard air. The objective of this paper is to communicate a broader perspective on the issue, that is, to assess the risk of fire in these systems and how cleaning affects this risk. The risk of fire in nitrox systems is real and requires special consideration, different from standard air systems. Materials are more flammable and ignition mechanisms are more active in oxygen-enriched environments. A risk management approach is presented that shows many factors must be considered to avoid fires, including system design, operations and maintenance, and cleaning. Because all these factors require consideration to avoid fires, it is difficult to specify a single value where special cleaning is required for all scuba and fill systems. Standard practice in most industries is to be conservative in these situations. The bottom line is that technical judgment is the key. The limitations of history of use are also discussed as they apply to the risk management approach. Some final recommendations are presented that may prove helpful concerning the topic of cleaning to avoid fires in nitrox scuba and fill systems.

Introduction

As the use of nitrox as a breathing gas continues to increase in the recreational diving industry, questions concerning the requirements to clean these systems are rampant. There are many reasons to desire a "clean" nitrox system, one free of contaminants, including proper function and physiological safety. But the most immediate and critical reason to clean nitrox systems is to minimize potential fire hazards.

The topic of cleaning systems to avoid fires can be complex and controversial. Our organization spends two full days teaching an ASTM course focused on minimizing fire hazards in oxygen systems. I will not even begin to address all the issues, much less begin to lessen the emotional distress that I know many in the industry have suffered over the past 10 years regarding this topic! But I do hope to present an unbiased and objective look at the real issues of fire hazards in nitrox systems and how cleaning affects them.

Further, the recreational diving industry is not alone in its struggle for definition regarding thresholds for cleaning nitrox systems. Just within the past month, the Atmospheric Gases Committee of the Compressed Gas Association, Inc. (CGA) submitted a draft of a Position Statement on the "Definition of a Threshold Oxygen-Mixture Concentration Requiring Special Cleaning of Equipment" (CGA PS-13, 2000). The draft, expecting to be approved and released within six months, is an attempt within CGA to provide a single definition for an oxygen-cleaning threshold. It states that equipment systems exposed to 23.5 mole percent oxygen or greater should be specially cleaned to reduce the risk of fire. In addition, industries that routinely use oxygen-enriched gas mixtures generally advocate that in cases where special cleaning thresholds exceed 21-25 percent oxygen there be a well-defined basis for allowing it, including such things as oxygen hazards analyses per accepted ASTM practices.

The primary objective of this paper is not to debate numbers concerning oxygen concentration, but instead to communicate a broader perspective on the issue, that is, to assess the risk of fire in these systems and how cleaning affects this risk. To properly address this topic, it is necessary to first put aside any emotional attachment to a favorite oxygen concentration value. Then we can gain a perspective of the specific issues at hand and develop an understanding as to how these issues relate to the diving industry. Next, we need to identify and characterize the specific hazards, if any, of *not* cleaning nitrox systems. It is also necessary to define the risk involved and decide what level of risk is tolerable in the recreational diving industry, realizing that it can differ between industries, and even between organizations within an industry. Only then can we ultimately decide which specific systems require cleaning and when cleaning is appropriate. The bottom line is that technical judgment is the key.

The Great Divide

Though my professional involvement with the recreational diving industry only spans a few years, qualifying me as a neophyte compared to the pioneers who established nitrox diving, I have become keenly aware of the division within the recreational industry regarding oxygen-cleaning thresholds, which I have entitled, "The Great Divide."

It is widely accepted in the diving industry that systems that contain oxygen concentrations greater than 41 percent oxygen are treated as 100 percent oxygen systems regarding their need to be cleaned for oxygen service to minimize the risk of fire. It is also widely accepted in the diving industry that systems containing oxygen concentrations approximately equivalent to air, from 21-25 percent oxygen, require no special cleaning for oxygen service. The Great Divide, however, occurs in systems with less than or equal to 40 percent oxygen, where there exists a major difference in opinion regarding the need to clean nitrox scuba and fill systems.

The majority follow a rather obscure but popular approach known as the "40 Percent Rule," based on an OSHA standard written for commercial diving. This faction boldly states that scuba and fill systems traditionally used for air service can be used for nitrox service up to 40 percent oxygen with no modifications or special cleaning required. They tend to rely on a vast experience base, or history of use, as their rationale for adopting this threshold.

Others follow approaches based on industry standards from CGA, NFPA, NASA, US Navy, or other OSHA standards, which typically recommend cleaning any system exposed to oxygen concentrations higher than standard air, from 21 to 25 percent oxygen. This faction takes a more conservative approach to nitrox safety, as they require systems to be cleaned and dedicated only for nitrox use to avoid contamination. The rationale used for this approach is based on materials flammability data and recommendations from other industries that have a long history of using oxygen systems.

Figure 1 illustrates The Great Divide as I've interpreted it. Systems employing oxygen concentrations less than 21-25 percent do not require special cleaning, which pleases everyone. Systems that contain over 40 percent oxygen require cleaning and everyone calls upon Mr. Clean without hesitation. However, systems that use between 25 and 40 percent oxygen still deliberate, "To clean or not to clean, that is the question."

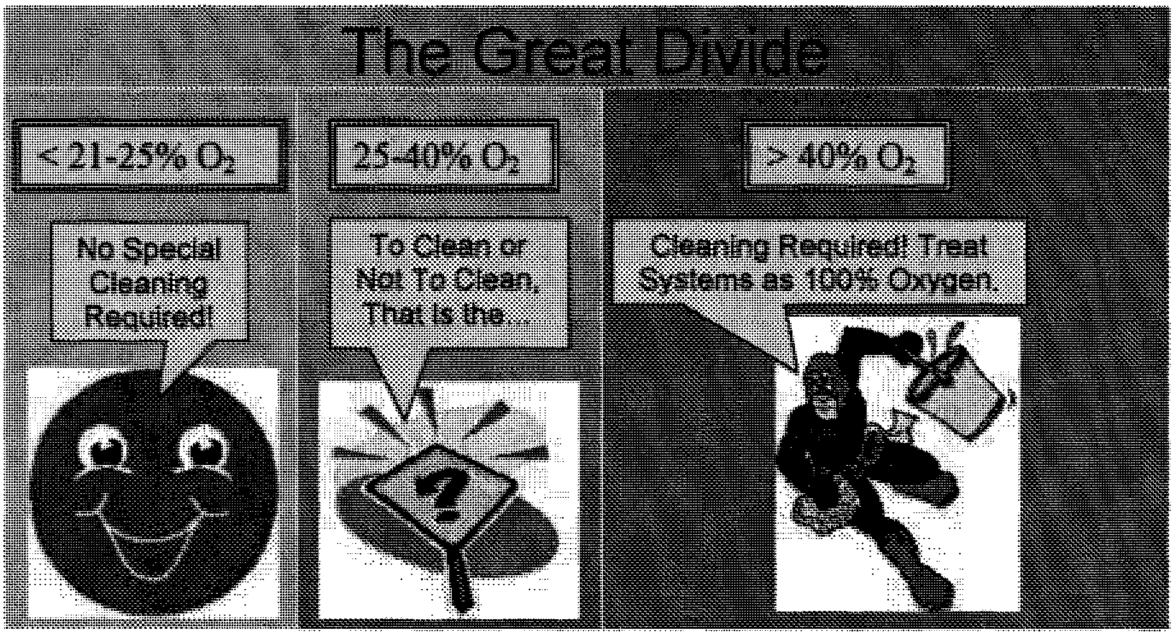


Figure 1. Illustration of The Great Divide regarding oxygen cleaning thresholds

The Fire Hazard Defined

Now that the dividing point regarding oxygen-cleaning thresholds has been put into perspective, it is important to define the immediate fire hazards of using nitrox. First, nitrox contains oxygen, an agent that supports combustion. Oxygen by itself will not burn, but, generally, it makes other materials in its presence more flammable and ignitable. Increasing the oxygen concentration above that found in standard air will make the materials in those systems more flammable and more easily ignited than they would be in air. Furthermore, if a fire were to occur in a system with an increased oxygen concentration, the flame spread rate and combustion rate would be increased over normal air environments.

The nature of fires that occur in oxygen and nitrox systems also contribute to the hazard. Fires in these systems tend to be subtle and erratic, exhibiting themselves infrequently and usually without warning. Many systems that experience a fire have been in operation for years without incident. In training courses, we commonly use the analogy of a cigarette lighter to describe the erratic nature of oxygen fires: in a system designed to create a small fire (the flame), with all the elements required to sustain a fire present (the oxidizer, fuel and ignition source), how many attempts does it take to get ignition from the lighter? Sometimes ignition occurs on the first try; sometimes it takes two flicks of the lighter; but sometimes it requires several attempts to "flick your Bic" to get ignition. Oxygen and nitrox fires are similar. Ignition, in itself, is a low-probability event and, as such, does not exhibit itself often. This aspect of the hazard can lull users to sleep, making them lose awareness and even forget the hazard is real.

Complicating the problem is the fact that in most oxygen or nitrox systems, the potential ignition sources cannot simply be "turned-off," as they can in other environments. This makes the fire hazard and its associated risk inherent to these systems. This concept is counter to the traditional "fire triangle" prevention method, where removing a leg of the triangle (either the fuel, the oxidizer, or the ignition source) "prevents" a fire. Most people relate to Smokey the Bear when he "prevents" fires by extinguishing campfires, or simply removes the ignition source. However, in most oxygen or nitrox systems, one can't remove the oxidizer leg (it's the oxygen itself), one can't remove the fuel (as nearly all materials can be ignited in high pressure nitrox or oxygen), and finally, one can't completely remove potential sources of ignition as heat-generating sources are always present (like adiabatic compression heating from cylinder valves and frictional heating in compressors). In short, all the elements necessary to create a fire are present in our systems in one form or another, making the hazard difficult to completely eliminate. Because of this, fires have occurred in nitrox and oxygen systems, from compressed air to 100 percent oxygen.

Fires in Oxygen-Enriched Environments

Most people who routinely use enriched-oxygen gas mixtures are aware that fires occur in systems using 100 percent oxygen. They have either heard or seen first-hand evidence of these fires in industrial gas systems, aerospace oxygen systems, medical oxygen applications, or even recreational diving applications using 100 percent oxygen in oxygen booster pumps or partial pressure blending systems. The awareness of fires in these systems explains the universal acceptance by the recreational diving industry to clean systems using high concentrations of oxygen.

However, less common is the understanding that fires occur even in systems using lower oxygen concentrations. For example, at least two fires in cylinder valve seats have been investigated at NASA's Neutral Buoyancy Lab (NBL) in 46 percent nitrox scuba systems. Figure 2 shows the crown orifice of the valve from one of the incidents. Figure 3 shows the seat retainer of the valve and the combustion remains of the nylon seat. Some would question if this same ignition is possible in a 36 or 40 percent oxygen environment. The answer is, "Yes!" Nylon is flammable under these conditions and similar fires have been reported in cylinder valves using even standard breathing air.

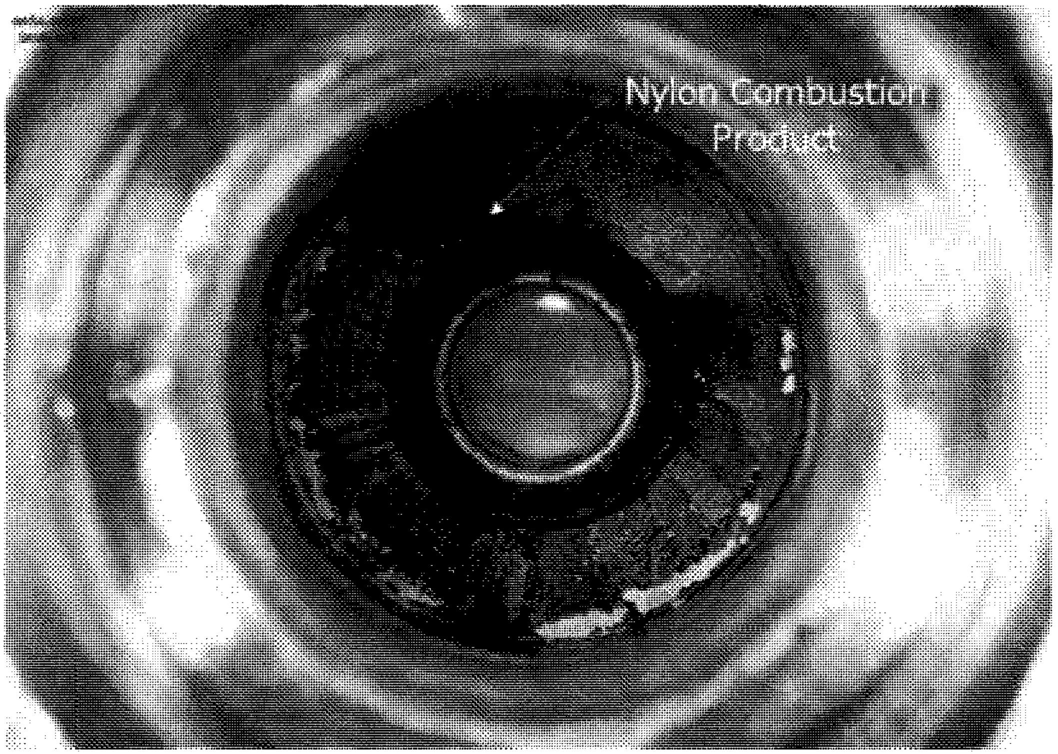


Figure 2. Crown orifice from burned cylinder valve seat in 46 percent nitrox

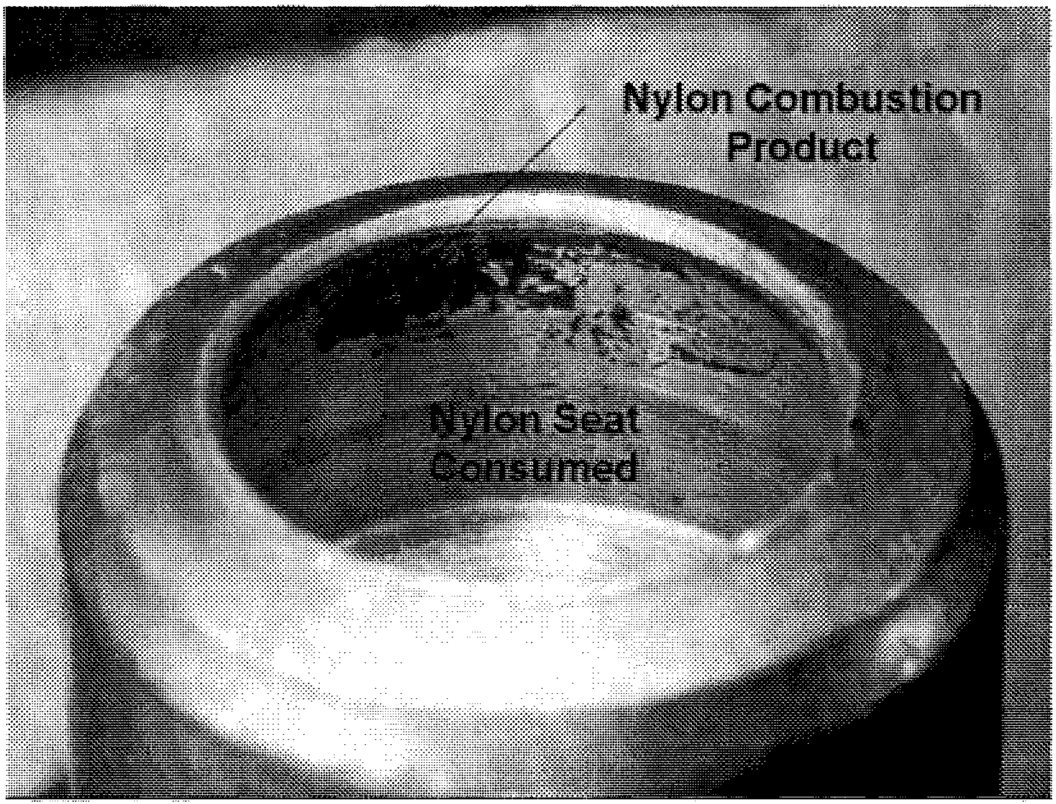


Figure 3. Valve seat retainer with nylon seat consumed in 46 percent nitrox

The most misunderstood concept regarding nitrox fire hazards is that many materials in scuba and fill systems that are *not* flammable in air *will burn* in oxygen-enriched environments, even up to 40 percent oxygen. Table 1 lists the oxygen index (OI) of several common polymeric materials used in scuba and fill systems. The OI values given are per ASTM standard test D 2863, measuring the minimum oxygen concentration required to support combustion at atmospheric pressure.

Per this table, PEEK, neoprene, PVC, silicone rubber, nitrile rubber, nylon, and EPDM may not support combustion in ambient air, but would in a 40-percent oxygen environment. Furthermore, as the pressure increases up to a point, OI values generally decrease, meaning that in typical scuba systems some of the best materials, like PTFE and PCTFE, may be considered flammable.

Though the frequency of nitrox fires, especially those in environments with less than 40 percent oxygen, is fewer than those in 100 percent oxygen, many have been reported. Perhaps the most common equipment experiencing nitrox fires in the recreational diving industry is fill

Table 1. Oxygen index values of selected polymeric materials per ASTM D2863

Material	Oxygen Index
EPR	21
EPDM	20-25
Nylon	21-38
Nitrile Rubber (Buna-N®)	22
Silicone Rubber	25-39
PVC	31
Neoprene®	32-35
PEEK	35
Vespel SP21®	53-61
FKM (Viton A®)	56
PCTFE (Kel-F 81®)	95-100
PTFE (Teflon®)	95-100

stations. Fire incidents in systems using less than 40 percent oxygen are known to have occurred in aluminum and carbon steel compressor blocks, aluminum-bodied filter towers, fill station panel valves and regulators, and some pre-compression nitrox generating equipment used for continuous blending. The cause of these fires varies, but many are related to hydrocarbon or particulate contamination, be it from poor maintenance or otherwise, that may have been avoided through proper cleaning. Hyperbaric chambers are other nitrox systems that have experienced fires. One of the most tragic chamber fires occurred in a 1.8-atmosphere air chamber (21 percent oxygen) in Milan, Italy, in 1997, killing 11 people.

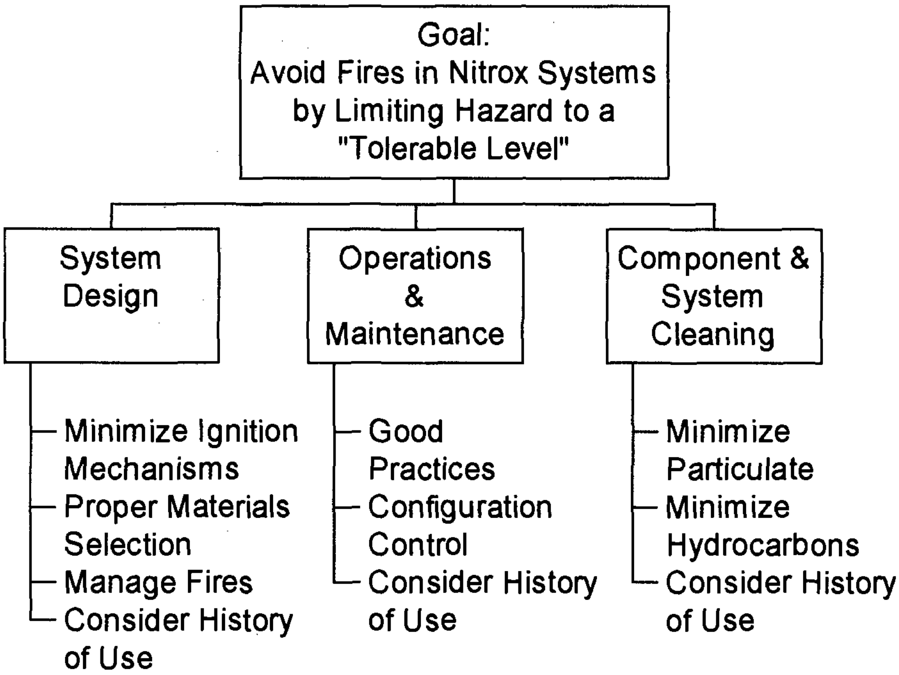
The Risk Defined

Thus, fire hazards are real, even in systems using less than 40 percent oxygen, and the reality of fires presents a risk to the user. But, *managing the risk is possible*, as has been shown by the many years of nitrox usage with relatively few incidents of fire. To manage the risk of fire effectively, though, requires a different approach than is typically employed for standard air. It also requires a systematic analysis of the hazards present, and above all, requires technical judgment.

Figure 4 is a flowchart that shows a risk management approach specific to nitrox and oxygen systems. The end goal is to avoid fires in nitrox systems by reducing the hazards to a tolerable level. The model is applicable because it allows those in a specific industry to define what "tolerable" means for them, understanding that risk tolerance is different for different industries. This may be especially true for the recreational diving industry.

The purpose of this chart is simply to convey that many factors are required to accomplish the goal. If any one of these factors is compromised, it can defeat the other two and, ultimately, lead to a fire. Our organization teaches entire courses on the details of this approach, based on ASTM standard and guidelines. The first box, system design, considers how systems and components need to be designed to avoid fires. This box is aimed primarily at equipment manu-

Figure 4. Model for fire hazard risk management in oxygen and nitrox systems.



facturers and system engineers. It encompasses many things including minimizing active ignition mechanisms in a system, choosing proper materials, and designing a system to handle a potential fire. History of use is a consideration is each step of the risk management approach and is discussed below. The second box aims to stress the importance of operations and maintenance of oxygen or nitrox systems to avoid fires. Things like good practices and controlling the configuration of a system are imperative to avoiding fires. Both manufacturers and end users have a responsibility in understanding these principles. The third box shows where cleaning fits into the risk management approach. Through minimizing particulates and hydrocarbons, the hazard of igniting these contaminants is reduced. Again, responsibilities in this area lie with both the manufacturer and the end user. If a system is not well designed, or is improperly operated and maintained, the cleaning aspect of the risk management approach becomes critical. Cleaning may not completely prevent a fire, but it will certainly reduce the risk.

Is Cleaning Required?

To help evaluate the risk of fire and ultimately determine whether cleaning is required, it is beneficial to understand the oxygen-enrichment thresholds imposed by the professional organizations that routinely use oxygen-enriched gas systems. Table 2 gives a listing of some organizations and the oxygen-enrichment thresholds, with references, that have been established.

It is important to remember that oxygen-enrichment thresholds are simply used as a dividing line, identifying the point where these systems are treated differently to avoid fires, including system design, operations and maintenance, and cleaning. It is the point where industries define "tolerable risk" in their risk management approach. The values themselves are not "magic," whereby just above the threshold value spontaneous combustion is inevitable and below it nothing ever burns! They are *simply limiting values for treating systems differently than* standard air.

Table 2. Oxygen-Enrichment Threshold Values from Various Organizations.

Organization	Threshold Value	Reference
U.S. Navy	>25% oxygen	Mil-Std-1330D
CGA	>23.5% oxygen	CGA Pamphlet 4.4
NFPA	>21-25% oxygen	Various
ASTM	>25% oxygen	G 126, G 128, G 63, G 94
NASA	>21% oxygen, >100 psig air	Various KSC, JSC refs
OSHA	>23.5% oxygen	29 CFR1910.146, 29 CFR 1910.134
OSHA	>40% oxygen	29 CFR 1910.430

The faction of the recreational diving industry that holds fast to the "40 percent rule" for special-cleaning of nitrox systems references the OSHA document 29 CFR 1910.430 as its basis. Because this threshold is significantly higher than the others traditionally adopted by other industries and because it has such wide subscription in the recreational industry, it bares further study. First, all of 29 CFR 1910 subpart T applies to commercial diving operations. In section 1910.430, under "Equipment," and specifically under section (i) "Oxygen Safety," the standard states that equipment used with oxygen or mixtures over 40 percent shall be designed and cleaned for oxygen service. The validity of its application to the recreational diving industry can be debated, and it has been for some time. This is because the standard contains much information not practiced by the recreational diving industry, does not directly address systems with equal to or less than 40 percent oxygen, and is considered such a "black sheep" compared to other oxygen-enrichment thresholds in other industries. Furthermore, the rationale behind the 40 percent value has been lost, though it is believed to be based on the commercial diving industry's *experience* with standard scuba equipment many years ago at the time the standard was written.

Despite these factors, the 40 percent oxygen-cleaning threshold *may not* be unreasonable for the recreational diving industry. It may be that the industry concludes that the risk of fire without cleaning systems up to a 40 percent oxygen threshold is "tolerable." This argument can only be supported, however, if individuals truly understand the level of risk that they deem "tolerable," and if the risk is properly communicated to others in the industry, including the fact that fires are still possible in this environment.

Is cleaning required? The unsatisfying but truthful answer to this question is a definite "maybe!" Because of the number of factors that contribute to a fire and the inherent risk of ignition in most nitrox systems, it is very difficult to specify a single value where special cleaning is required for all scuba and fill systems, especially if the only factor considered is oxygen concentration. There may well exist systems that are well designed and are properly operated and maintained that can tolerate reasonable amounts of contamination without incident, even in a 40 percent oxygen environment. This must be true to some degree, in fact, or the number of fire incidents in the recreational diving industry would be higher. However, not all systems are this way.

More test data and scientific study are needed before we can ultimately predict when and where a fire will occur. Standard industry practice is to be conservative in applications where scientific data and understanding are limited. This explains why most industries set their oxygen-enrichment threshold values close to that of standard air. They have used technical understanding and judgment as a rationale for decisions, not just experience.

What About History of Use?

History of use is a credible part of the risk management approach shown above. It provides a starting point for hazards analyses and gives both designers and end-users a sense of comfort with equipment. The recreational diving industry relies heavily on a "successful" history of use as a rationale for decisions.

But, as the model shown above indicates, history of use is only a small part of the risk management approach. Though always considered, history of use is only used to support one or more of the main elements of risk management, not as a stand-alone. The reason for this is that history of use can often provide a false sense of comfort that a fire will not occur, especially if the system hasn't been effectively analyzed for hazards. Also, history of use is only applicable if all system conditions are comparable over time, including the application, operating environment, system design and materials selection, and type of contaminants the system is exposed to. For example, the commercial and scientific diving industries have built the bulk of their nitrox history with brass-bodied components operating in 2500-psi maximum systems. By contrast, today's recreational diver or nitrox blender may use components built from aluminum, titanium, or other exotic alloys at pressures up to 4500 psi. These systems may still be safe, but they have a limited history of use, which must be considered when evaluating risk level.

A "successful" history of use requires a large database of relevant applications. It also requires a low ignition probability and a low ignition consequence. Even then, for a history of use to be "successful," it is critical to understand *why* fires haven't occurred. Is it luck? Or is it because the risk of fire has been minimized through proper design, operation and maintenance, and cleaning?

Recommendations For Consideration

As an unbiased, objective "outsider" to the recreational diving industry, I am not in a position to mandate changes, nor do I have the intention of doing so. However, considering my background in oxygen system design and safety, I will propose some recommendations for consideration that may prove helpful concerning the topic of cleaning to avoid fires in nitrox scuba and fill systems.

1. *Allow diving equipment manufacturers to define oxygen or nitrox compatibility for, as well as set guidelines for, their own equipment.* This may already be the accepted practice as most training and certifying agencies refer to the manufacturer regarding specific compatibility issues with equipment. However, this point needs to be stressed more fully to ensure that end-users are not defining whether equipment can or can't be used in nitrox and whether specific concentrations of oxygen are acceptable. Guidelines for use also need to be supplied and emphasized by the manufacturer, such as maximum use conditions and environments, operation and maintenance, and cleaning processes and frequency. Only the manufacturer is in this position of authority, and understands their equipment sufficiently, to recommend compatibility of their equipment. Also, since the manufacturers design and test their own equipment, they understand the equipment limitations and are qualified to specify guidelines for use. This requires, however, that the manufacturer fully analyzes and understands the fire hazards in their equipment, and that they test their equipment for ignition mechanisms in the worst-case environment. Specific guidelines to aid manufacturers in this assessment could be established, as discussed below.

2. *Establish industry-specific guidelines or standards for nitrox use.* Though manufacturers' recommendations would still have final authority for a given product, the entire industry would benefit if common guidelines were established regarding the use of nitrox equipment, system operation and maintenance, cleaning, gas blending, and other issues. Single definitions for oxygen-enrichment could be developed and substantiated based on a risk "tolerance" level acceptable to all. Similar to the medical oxygen industry, standard tests developed for nitrox scuba and fill system components would help validate them for nitrox or even 100 percent oxygen service. For these standards and guidelines to be most effective, they would have to be established by manufacturers, training agencies, and end-users alike, and be universally accepted and practiced. The recreational diving industry already has representation within the ASTM G-4 committee on "Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres," which could act as a vehicle to develop the guidelines and standards. The ASTM G-4 committee is open to anyone desiring membership and encourages participation from all industries with an interest in these issues.

3. *Implement oxygen and nitrox fire hazards training programs for nitrox users.* Most training agencies currently include a section on oxygen hazards as part of their nitrox certification. However, very few nitrox training manuals present accurate and thorough information regarding the risk of fire in nitrox systems. It is the nitrox blender's and diver's right to

know the level of risk associated with their activity, not just the risk of physical harm from oxygen toxicity, but also the increased risk of fire in elevated oxygen concentrations. This information needs to come from a reliable source that understands oxygen fire hazards and be consistent from agency to agency. A multi-tiered system may be appropriate, similar to other diving courses, where courses could range from introductory to advanced and be specific for different audiences, including manufacturers, certifying agencies, instructors, and divers. Topics would depend on the target audience but could include design, testing, materials selection, operation and maintenance, and fire history.

EVALUATION OF CONTAMINANT-PROMOTED IGNITION IN SCUBA EQUIPMENT AND BREATHING-GAS DELIVERY SYSTEMS

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As the underwater diving industry continues to use greater concentrations of oxygen in its scuba systems, contaminant ignition becomes of greater concern. In this study, several scuba component assemblies from the Neutral Buoyancy Lab at NASA Johnson Space Center were tested after 1 year of use. They were pneumatically impacted with 50 percent nitrox gas at 20.7 MPa (3000 psi) to evaluate their ignition resistance then disassembled to assess their cleanliness. A follow-up study was then conducted on the ignition thresholds of hydrocarbon-based oil films in oxygen and nitrox environments to characterize the cleaning requirements for these systems. Stainless steel tubes were contaminated to known levels and tested by pneumatic impact. Ignition was determined with a photocell connected to the end of the contaminated tube. The results of the scuba component tests, cleanliness evaluation, and contaminant ignition study are discussed and compared for 50 percent nitrox and 100 percent oxygen environments.

Introduction

Since the inception of scuba diving, breathing-gas mixtures for these applications have traditionally been pressurized air. However, in recent years, as the various advantages of oxygen-enriched gas mixtures for scuba have been discovered, more systems are being developed and implemented that produce, transport, or supply oxygen-enriched gas mixtures for scuba applications. Along with the growing popularity of these systems is the growing concern of contaminant ignition in these systems, specifically hydrocarbon contaminant.

The concern is legitimate for at least two reasons. First, it is commonly known that materials are generally more flammable and more easily ignited as oxygen concentration increases. Second, it is also known that many systems in the diving industry that were designed only for high-pressure air service are now being used for oxygen-enriched gas mixtures without any modifications. Although not widely reported, several fire incidents are known to have occurred in systems that had operated successfully for years in high-pressure air service but failed when operated at higher oxygen concentrations.

The NASA White Sands Test Facility (WSTF) was tasked by the NASA Johnson Space Center (JSC) Neutral Buoyancy Lab (NBL) to attempt to define the threshold limits for contaminant ignition in environments typical of NBL diving operations. The question of contaminant ignition thresholds surfaced as the NBL was developing cleaning requirements for its scuba equipment and breathing-gas delivery system. The NBL sought to define initial cleanliness requirements for its hardware and to develop a reasonable timetable for recleaning these system components.

The NBL uses scuba equipment and filling techniques similar to those used in most diving industries. NBL divers commonly breathe nitrox1 mixtures with greater than 21 percent oxygen, often called enriched air nitrox (EAN) mixes. Common EAN mixes include 32, 36, and 40 percent oxygen for the recreational diving industry, but other military and technical diving applications may increase oxygen concentrations up to 80 percent or more. The NBL uses a partial-pressure mixing technique to prepare its breathing gas, nominally at 45 percent oxygen but at a maximum of 50 percent. Pure oxygen and compressed air are flowed from tube banks and gas cylinders into a blender, which combines these gases at the required percentages and then pumps them into individual diving cylinders.

Previous Studies

The ignition of oil contaminants in pure oxygen systems has been widely studied for various ignition mechanisms. A review published by Werley (1983) documents several of these studies. Werley refers to data published by Walde (1965) showing ignition of oil films by a hot wire at 10.5 MPa (1500 psi). The lowest ignition threshold of a hydrocarbon-based oil film was 151 mg/m^2 (14 mg/ft^2). Mixed units for hydrocarbon contamination levels are common units used in industry and will be used throughout this paper. Werley also refers to a study by Presti and DeSimone (1967) showing oil-contaminant ignition thresholds by pneumatic impact at 20.7 MPa (3000 psi). These data showed a lower ignition threshold of organic oil to be 1180 mg/m^2 (110 mg/ft^2) and of petroleum lubricating oil to be 1720 mg/m^2 (160 mg/ft^2). Another study that evaluated oil contaminant ignition by various ignition mechanisms in pure oxygen was conducted by Shelley *et al.* (1993). PTFE tape, contaminated with hydrocarbon oil, was found to ignite by mechanical impact at contaminant levels between 130 and 260 mg/m^2 (12 to 24 mg/ft^2). In that same study, pneumatic impact tests showed that 5 mg of oil added to the tape caused the tape to burn longer and with more intensity than it did without the oil. Finally, ignition thresholds of hydrocarbon oil by mechanical impact in liquid oxygen were evaluated by Bryan (1971). The oil was shown to be reactive when impacted on a Teflon surface at a concentration as low as 230 mg/m^2 (21.6 mg/ft^2).

Studies evaluating the ignition thresholds of oil in mixed gases are few. Generally, ignition thresholds in these environments have been found to be much greater than those found in pure oxygen. Werley (1983) refers to a study by Burgoyne, *et al.* (1973) in which a model was developed to predict the oil film concentration required for detonation in air. At 100 atmospheres of pressure, the predicted concentration level was 30.6 g/m^2 (2840 mg/ft^2).

Recently, the ignition of hydrocarbon-based oil films in high-pressure oxygen was studied by Pedley, *et al.* (1987). Stainless steel lines were contaminated with hydrocarbon oil in levels ranging from 25 to 9000 mg/m^2 (2.3 to 836 mg/ft^2) and pneumatically impacted at pressures ranging from 6.9 to 41 MPa (1000 to 6000 psi). Pedley, *et al.* (1987) observed ignitions with contaminant concentration as low as 65 mg/m^2 (6.0 mg/ft^2) and 6.9 MPa (1000 psi), but they observed no ignitions with 25 mg/m^2 (2.3 mg/ft^2) at any pressure. Although these data were helpful in evaluating the cleaning requirements of high-pressure oxygen systems, the study did not consider contaminant ignitability in lower pressure, pure oxygen environments and in high-pressure oxygen-enriched gas mixtures, environments more typical of scuba equipment and breathing-gas delivery systems.

In the present study, scuba component assemblies were tested after 1 year of use at the NBL. They were rapidly impacted with 50 percent nitrox gas to demonstrate their ignition resistance, and then disassembled to evaluate their cleanliness. This study also attempts to expand the work of Pedley, *et al.* (1987), using a similar test approach and the same hydrocarbon oil, to evaluate hydrocarbon oil ignition in lower pressure oxygen and high-pressure, 50 percent nitrox.

Test Approach

The NBL randomly selected from its inventory four scuba assemblies that were due for annual servicing and sent them to WSTF for testing. Three of the assemblies were tested by pneumatic impact for their resistance to ignition with their given contaminant level. Each of the three was pneumatically impacted for 60 consecutive cycles at 20.7 MPa (3000 psi) in a 50 percent nitrox gas mixture.

Following the impact tests, all four scuba assemblies were disassembled and their respective contaminant levels determined through standard clean room verification techniques. The data were used to characterize the contamination levels inherent in NBL dive equipment after a year of service. Results of the scuba component tests and contaminant evaluation were previously reported (WSTF, 1997) and are therefore only summarized and briefly discussed in the experimental and results sections of this study.

For contaminant ignition threshold tests, stainless steel tubes were contaminated with a hydrocarbon oil film and then pneumatically impacted. Pneumatic impact was selected as the ignition mechanism because it has been shown to be a credible, and potentially the most common, ignition mechanism for nonmetallic materials (Moffett, *et al.* 1987). Contaminant level and impact pressure were varied in an attempt to define the lower ignition threshold for these contaminants at given pressures (Table 1). Tests were conducted in pure oxygen (aviator's breathing grade) at pressures of 6.9 MPa (1000 psi) and lower to represent the oxygen pressures found in the NBL breathing-gas delivery system. Tests were conducted in 50 percent nitrox at pressures up to 27.5 MPa (4000 psi) to represent the maximum nitrox pressure pumped into the NBL diving cylinders

Table 1. Test Matrix Used for Contaminant Ignition Study.

Pressure MPa (psi)	Contaminant Level mg/m^2 (mg/ft^2)			
	<10 (<1)	110 (10)	538 (50)	1080 (100)
27.5 (4000)	100,[1] 50[2]	50	50	50
17.1 (2500)	50	50	50	50
6.9 (1000)	50	100, 50	100, 50	100, 50
5.2 (750)	Not Tested	100	100	100
3.4 (500)	50	100, 50	100, 50	100, 50

[1]100 percent (aviator's breathing grade) oxygen concentration test conditions.
[2]50 percent nitrox concentration test conditions.

Experimental Procedures

Test System Description

The WSTF test system used for the scuba equipment pneumatic impact tests was also used for the contamination ignition threshold study, with slight variations to accommodate specific instrumentation and test article configurations. Also, high-pressure 50 percent nitrox was used in addition to the oxygen media for some tests. The test gas was compressed into a high-pressure accumulator before each impact. An isolation valve and fast-acting impact valve isolated the accumulator pressure from the test article. A vent valve located just upstream of the test article vented the system pressure after each impact.

System instrumentation included a Clairex® CL707L photocell enclosed behind a sapphire window and attached to the end of the test article to detect any visible light from a reaction. The photocell proved to be sensitive enough to detect contaminant combustion. Two strain gauge pressure transducers were located at the test article interface to record pressurization time and track system pressure. For the contaminant levels used in this test program, the pressure transducers were not sufficiently sensitive to detect a pressure increase from the combustion event separately from the pressurization event. The thermocouple used by Pedley, *et al.* (1987) was removed in this test series because it was ineffective at tracking the heat rise associated from oil combustion separately from the heat associated with the compression event. Data from most instrumentation channels were recorded at a 50 ms sampling rate by a Versa-Module Europa bus data acquisition system. The pressure and photocell channels, however, were sampled at a 1 ms rate for the first second of each impact. Standard video recorded each test to document any potential burnthrough of the stainless steel tubing.

Test Article Description

The four scuba assemblies included a first-stage regulator with two flex hoses connected to second-stage regulators, a flex hose connected to a submersible pressure gauge, and a buoyancy control device. Two of the three scuba assemblies tested by pneumatic impact had nitrox O-ring kits, made of Viton,® installed in the regulators before delivery to WSTF. The third assembly tested by pneumatic impact had the original O-rings left installed. Finally, the one scuba assembly not tested by pneumatic impact was a demonstration unit that had been ultrasonically cleaned and a nitrox O-ring kit installed. The scuba assemblies were tested in the "as received" condition.

The test articles for the contaminant ignition threshold study were 304 stainless steel tubes, each 61 cm (24 in.) long with a wall thickness of 0.089 cm (0.035 in.) and a nominal diameter of 0.64 cm (0.25 in.). Individual tubes were cut and flared, then cleaned with alkaline and acidic cleaning solutions, rinsed with deionized water, and verified clean to level 50 A per NASA JHB 5322 C (1994). The hydrocarbon oil used to contaminate the tubes was Mobile DTE 24, which has been shown to ignite readily in oxygen systems (Pedley *et al.*, 1987).

Solutions of the oil mixed with Freon 113® were prepared at various concentrations to match the contaminant levels shown in Table 1. The oil concentration in each solution was verified by dipping test coupons of known surface area in the solution and evaporating off the Freon 113®; the coupon was then flushed, the solution boiled off, and the remaining nonvolatile residue (NVR) weighed to give a contamination level per unit of surface area.

The test articles were similarly prepared before test. The tubes were dipped in the solution, placed on a shelf under a fume hood to evaporate the Freon 113®, then individually bagged. The test articles were prepared within 24 hours of their testing to reduce the chance of oil evaporating from the tube or migrating to a single point on the inside of the tube.

Test Procedure

The scuba assembly pneumatic impact tests followed procedures similar to those outlined in previous pneumatic impact component tests (Newton, *et al.*, 1997). Each of three test articles was installed and purged with the test gas, then pneumatically impacted 60 times at 20.7 MPa (3000 psi) in a 50 percent nitrox gas mixture.

For the contaminant ignition threshold tests, system checkout tests were conducted before placing the contaminated test articles into the test system. System instrumentation was verified as functional; several baseline tests were run on the photocell to characterize its sensitivity to light. A flashlight was placed directly behind a fan blade, and the photocell was placed directly in front of the fan blade. The fan blade was then rotated at various velocities to ensure that the photocell accurately traced the amplitude and frequency of the intermittent light source. Control group test articles, cleaned to level 50 A per NASA JHB 5322 C and not subjected to contaminant, were installed at the test article interface. The control group test articles were impacted at various pressures to ensure that no false positives were detected by the photocell and that pressurization rates were consistent at approximately 20 ms.

The contaminated test article was installed and carefully purged with the test gas at a very low pressure so as not to remove any oil. The test gas was pressurized in the accumulator to the required impact pressure. A software program remotely controlled the operation of the system valves during test. First, the computer opened the isolation valve to pressurize the fast-acting impact valve to system pressure. Shortly thereafter, the impact valve was opened to rapidly pressurize the test article. The impact valve was left open for 100 ms, then the impact and isolation valves were closed and the vent valve opened to vent the test gas. At least three consecutive impacts were conducted on a given test article, with a 30-second interval between impacts, even if the photocell sensed an ignition. In many cases, more impacts were conducted on a given test article if no ignitions were detected during the first three impacts.

Test Results and Discussion

Scuba Equipment Component Tests and Contaminant Level Evaluation

Results of the scuba equipment pneumatic impact tests and contamination evaluation were previously reported (WSTF, 1997) and are summarized below.

A. *Results and Indications*.

No evidence of ignition was found in the three scuba assemblies when subjected to multiple pressurization cycles with 50 percent nitrox at 20.7 MPa (3000 psi) (WSTF, 1997). Each assembly passed a posttest leak-check test with gaseous nitrogen. When the scuba equipment was disassembled to the piece-part level, the contaminant level evaluation showed gross amounts of particulate and nonvolatiles in the oxygen-wetted portions of the assemblies, indicative of the "dirty" environment that this equipment is exposed to daily. Most of the contaminant materials were identified as chrome, brass, and stainless steel, but some plastics and lubricant were also found. In some cases, the particles were very large, failing level 1000 per NASA JHB 5322 C. The NVR levels, taken only from the oxygen-wetted metallic surfaces, ranged from 260 to 5060 mg/m^2 (24 to 470 mg/ft^2), but the NVR composition was not determined.

The data from the component tests and posttest evaluation indicate that the NBL scuba assemblies were highly contaminated after one year of service but that ignition by pneumatic impact was not observed in 50 percent nitrox at 20.7 MPa (3000 psi). The data do not imply, however, that the scuba assemblies are impervious to ignition. Experience shows that ignition can be an unpredictable, highly erratic, and low-probability event (ASTM, 1991). Some oxygen and nitrox systems that have functioned without incident for years have become fire casualties (Dicker and Wharton, 1988). Furthermore, specific laboratory tests designed to evaluate materials ignition or to replicate fire scenarios have either shown poor repeatability or failed to reproduce ignition (Moffett, *et al.*, 1989;

Schmidt, *et al.*, 1989; Newton, *et al.*, 1989). A classic example of this comes from the particle impact testing NASA conducted on the oxygen flow control valve (Plante and Pippen, 1989), in which ignition did not occur until the 63rd test in a 80-test matrix, showing how difficult predicting ignition can be (Joel Stoltzfus, pers. comm.). Finally, these scuba assemblies may be vulnerable to ignition mechanisms other than adiabatic compression. Gabel and Janoff (1997) present a detailed discussion of additional ignition hazards that may occur in recreational scuba equipment used in oxygen-enriched environments.

B. Data Limitations.

It is critical to note the following limitations when applying the component test data:

1) Pneumatic impact ignition in components is highly configuration dependent (Newton, *et al.*, 1997). The fact that the scuba assemblies tested showed no ignitions does not suggest that other components with slightly different configurations, even first-stage scuba regulators, will withstand ignition under the same conditions. In these tests, the gas temperature generated by adiabatic compression on the first-stage regulator theoretically would exceed the autogenous ignition temperature (AIT) of the polymer seat material (assuming AIT data in 100 percent oxygen). However, in this configuration, the softgoods did not ignite for several possible reasons. First, the gas was a 50 percent oxygen concentration, which decreased the severity of the test environment and may have limited the amount of oxygen available for reaction. Second, the first-stage regulator in scuba equipment allows flow-through upon impact, up to approximately 1.0 MPa (150 psi), before closing. Therefore, the compression event was not at a true dead end, and the resulting pressure ratio from 1.0 to 20.7 MPa (150 to 3000 psi) generated less heat. Third, the robust, thick-bodied, chrome-plated brass design readily dissipates heat in these regulators, making them tolerant to pneumatic impact heating. Finally, the softgood portions of these components are small, which limits the exposed surface area to impact and allows very little heat to concentrate in these areas
2) The contaminant level for the test articles evaluated was specific to the NBL and may not accurately represent the contamination types or quantities found in other scuba applications, such as that encountered by the recreational diving industry. It is reasonable to assume that such contamination, if evaluated, may differ greatly from that found in the NBL's controlled, swimming pool environment. Thus, the no-ignition results of the three scuba assemblies tested does not imply in any way that cleaning these systems, initially and during periodic maintenance, is unnecessary.
3) From a statistical standpoint, a sample size of only three test articles provides a low level of confidence that ignitions will not occur in these assemblies under these conditions.
4) Pure no-ignition results can provide only a level of confidence regarding a no-ignition scenario. It cannot provide any information pertaining to either the ignition threshold or the safety factor between the operating conditions and the point where ignition occurs. Without positive ignition data, the safety margin and ignition risk involved in using contaminated scuba assemblies under typical nitrox conditions are unknown.

C. Recommendations and Conclusions.

It is recommended to always use a conservative approach when applying these data. For example, the high contaminant levels found in the four scuba assemblies should, at a minimum, cause users of this equipment to be alert to potential ignition mechanisms. Also, because these contaminants are flammable in most nitrox environments, users should take special precautions to initially clean their equipment and protect their equipment from contaminants. It was recommended to the NBL that they disassemble and clean scuba equipment during annual maintenance and maintain component cleanliness as best as practical during use.

Finally, to better evaluate the safety margin or ignition risk in these systems, it is recommended that testing be conducted to determine if ignition mechanisms other than adiabatic compression will ignite the contaminants found in scuba assemblies. Also needed is a test to determine how much contaminant is required before ignition occurs by adiabatic compression or another mechanism.

Contaminant Ignition Threshold Tests

The results of the tests conducted in both 100 percent oxygen and 50 percent nitrox are summarized in Table 2.

A. 100 Percent Oxygen.

For the 100 percent oxygen condition, tests were conducted at pressures of 6.9 MPa (1000 psi) and lower, except in the checkout tests with no contaminants, to simulate one environment found in the NBL breathing-gas delivery system. Reactions were observed at pressures as low as 5.2 MPa (750 psi) and contaminant levels as low as 110 mg/m^2 (10 mg/ft^2). No contaminant ignitions were observed at 3.4 MPa (500 psi), even at contaminant levels as high as 1080 mg/m^2 (100 mg/ft^2). Generally, the ignition frequency increased with increasing pressure and contaminant concentration.

Figure 1 shows a typical data trace for a no-ignition test run at 6.9 MPa (1000 psi). Pressure traces of three different impacts and the corresponding photocell output represent only the "fast" data collected at a 1 ms sampling rate for the first second of each impact. After the first second of each impact, the data were then recorded on a separate channel at a 50 ms rate. The photocell baseline, when sensing no light, was about 1700 mV. Figure 1 shows that no light emissions were detected by the photocell for any of the three impacts. During an ignition event, the photocell data paralleled that of the pressure transducer, though with a slight delay, and peaked at levels of between 3500 and 5000 mV. The photocell read 5000 mV maximum when completely saturated with light.

All tests for which the photocell peaked between 3500 and 5000 mV were considered "reactions," or evidence of contaminant combustion. The photocell was the only method of detecting a reaction in these tests because posttest analysis showed no physical evidence of combustion, such as charring, discoloration, odor, or residue in the stainless tubing, even in heavily contaminated samples. Other attempts to confirm that combustion had occurred, such as pre- and posttest gravimetric and NVR analyses, proved unsuccessful because of the comparatively small amounts of contaminant in the tubing.

Table 2. Results of the Contaminant Ignition Threshold Tests.

		100 Percent Oxygen		50 Percent Nitrox	
Contaminant Level mg/m^2 (mg/ft^2)	Test Pressure MPa (psi)	Number of Impacts	Number of Reactions[a]	Number of Impacts	Number of Reactions[a]
1080 (100)	27.5 (4000)	Not Tested	Not Tested	21	8
	17.2 (2500)	Not Tested	Not Tested	15	8
	6.9 (1000)	45	1	15	3
	5.2 (750)	60	1	Not Tested	Not Tested
	3.4 (500)	45	0	60	0
540 (50)	27.5 (4000)	Not Tested	Not Tested	15	5
	17.2 (2500)	Not Tested	Not Tested	15	2
	6.9 (1000)	30	2	60	0
	5.2 (750)	30	1	Not Tested	Not Tested
	3.4 (500)	75	0	27	0
110 (10)	27.5 (4000)	Not Tested	Not Tested	45	15
	17.2 (2500)	Not Tested	Not Tested	60	6
	6.9 (1000)	63	2	60	1
	5.2 (750)	9	1	Not Tested	Not Tested
	3.4 (500)	15	0	60	0
<10 (<1)	27.5 (4000)	100	5	515	30
	17.2 (2500)	Not Tested	Not Tested	160	4
	6.9 (1000)	Not Tested	Not Tested	100	2
	3.4 (500)	Not Tested	Not Tested	60	0

[a] Number of reactions as indicated by the photocell.

B. 50 Percent Nitrox.

Results from the 50 percent nitrox tests show ignitions occurred with concentrations as low as 110 mg/m^2 (10 mg/ft^2) and pressures as low as 6.9 MPa (1000 psi) (Table 2). No tests were conducted at 5.2 MPa (750 psi). Similar to the 100 percent oxygen data, no ignitions occurred at 3.4 MPa (500 psi) at any contamination level. Again, the data show the ignition frequency increased with increasing pressure and contaminant concentration

Anomalies were observed while conducting baseline tests with the system at 27.5 MPa (4000 psi) and using a contaminant-free test article that had been cleaned to level 50 A per NASA JHB 5322 C. The photocell indicated a reaction had occurred after some impacts with a clean test article. Initially these tests were discounted because it was thought that the tube must have been unintentionally contaminated. Pedley, *et al.* (1987) also observed these "false" reactions in their study and discounted those tests. However, when multiple false reactions were observed during this test series with clean test articles, including those with 50 percent nitrox, a more detailed investigation was conducted in an attempt to identify the cause. Because of the frequency of this phenomenon, it was hypothesized that the photocell was actually sensing a light emittance other than a combustion reaction during impact.

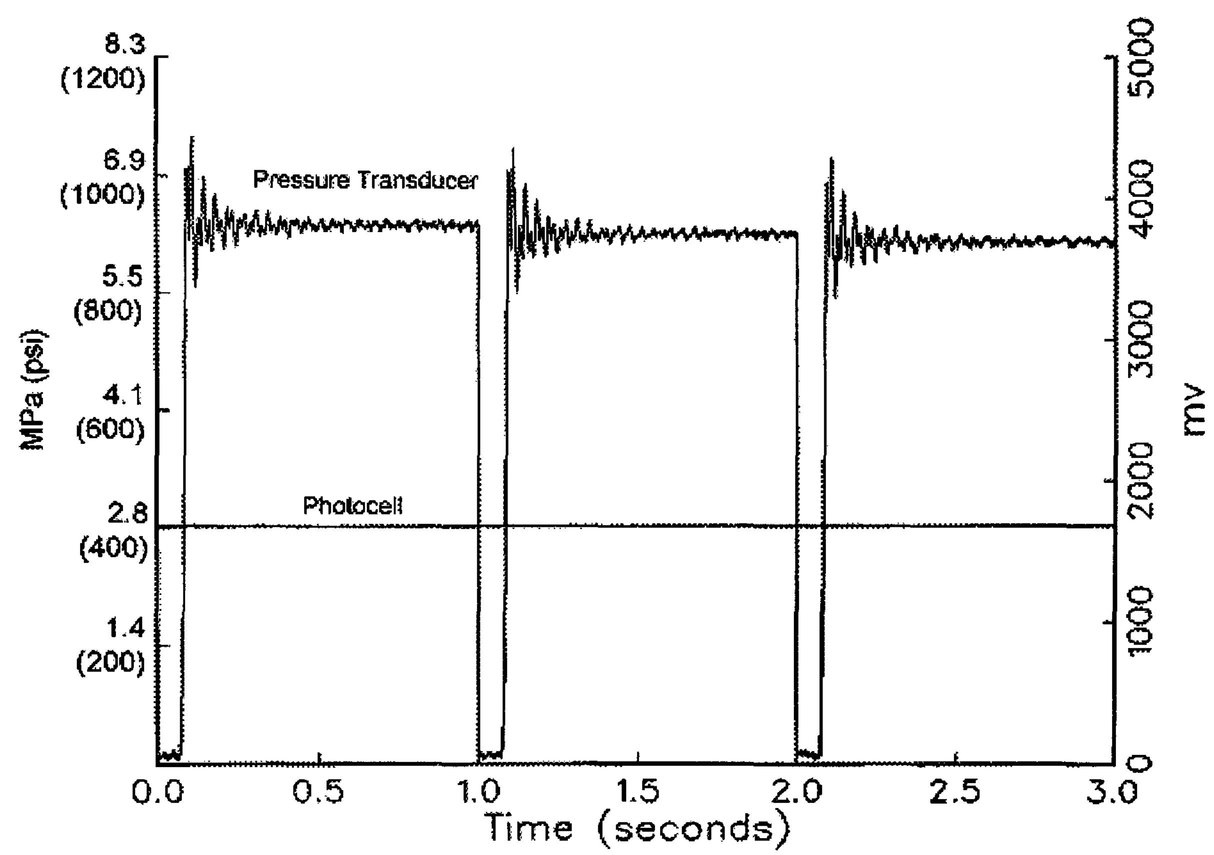

Figure 1. Pressure Transducer and Photocell Data for Three Impact Cycles with 1080 mg/m² (100 mg/ft²) in 100 Percent Oxygen at 6.9 MPa (1000 psi).

First, the cleaning process was investigated to determine if ignition was caused by residual cleaning solvent left on the samples. This possibility was quickly ruled out after confirming that the precleaned samples contained no residual hydrocarbons. Another potential cause that was investigated was the emittance of sodium or potassium spectra, in visible wavelengths, from the cleaned stainless tubes. A related cause is a phenomenon known as "double electron transfer," or the release of energy, possibly in the form of photons, resulting from the electrons in the closely packed oxygen molecules changing transition states. This phenomenon has been theorized to occur in oxygen at pressures above 6.9 MPa (1000 psi) (Ralph Tapphorn, pers.

comm.). Despite exhaustive efforts to characterize the emittance, including installation of band pass filters of various wavelengths in front of the photocell, the detection of the phenomenon was too inconsistent to characterize.

Thus, the percentage of false reactions detected in tests with clean test articles must be considered in the uncertainty of the ignition data, especially at low contaminant levels and high pressures. Because no reactions were observed at pressures lower than 3.4 MPa (500 psi), the mechanism creating the false reactions was considered inactive at these pressures. Finally, the use of a photocell to detect contaminant ignition was successful at higher contaminant levels but proved unsuccessful in defining the lower ignition threshold.

The results of this contaminant ignition study may allow the NBL to relax its cleaning level requirements for 50 percent nitrox applications at pressures below 3.4 MPa (500 psi). For systems with pressures higher than 3.4 MPa (500 psi), the ignition data from Table 2 can be applied conservatively with some level of risk. Further testing is recommended, perhaps using a different ignition-detection method, to determine the absolute lower ignition threshold for contaminant concentration and pressure.

Summary

The NASA JSC NBL tasked WSTF with evaluating the contaminant ignition hazards of its scuba assemblies and breathing-gas delivery systems in low-pressure 100 percent oxygen and high-pressure 50 percent nitrox. Four scuba assemblies, selected at random from the NBL inventory requiring annual service, were sent to WSTF for testing and analysis. Pneumatic impact ignition testing was conducted on three of the assemblies, and contaminant levels were determined for all four assemblies. No ignitions occurred during any of the pneumatic impact tests on the component assemblies. The components were disassembled and shown to contain gross quantities of particulate and hydrocarbon. Finally, a contaminant ignition study was conducted in an attempt to identify the lower ignition threshold for contamination and pressure. Stainless steel tubes contaminated with hydrocarbon oil were pneumatically impacted, and ignitions were observed in both 100 percent oxygen and 50 percent nitrox in concentrations as low as 110 mg/m^2 (10 mg/ft^2) and pressures as low as 6.9 MPa (1000 psi). No ignitions were observed at any contaminant level at a test pressure of 3.4 MPa (500 psi). The results from this study may allow the NBL to relax its cleaning requirements for systems with maximum pressures below 3.4 MPa (500 psi) in oxygen or nitrox.

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HIGH PRESSURE COMBUSTIVE OXYGEN FLOW SIMULATIONS

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Introduction

Using 3D hydrodynamics simulation codes with oxygen combustion chemistry imbedded, we have simulated explosion scenarios under high pressure pneumatic impacts. Mixed gas flows (variable oxygen fractions) down a short stopped tube were analyzed for variable volatile and non-volatile particle densities in the impact region (stopped end with a small opening simulating the first stage seat of a regulator). Drive pressures were varied from 50 psi up to 5000 psi, with dirt particle densities ranging 5 mg/ft^2 up to 300 mg/ft^2. Oxygen fractions varied from 0.21 up to 1.00 (air to pure oxygen).

The flow schemes are typical of impacted pneumatic gas hydrodynamics. At the stopped orifice, a slug of compressed gas is heated by both shock formation and inertial implosion (both compressive and non-adiabatic). Dust is assumed to be metal, plastic, glass, grit, rubber, and fiber, with particle sizes ranging from 5 microns up to 250 microns. Combinations with plastic, fiber, and rubber are combustive. Reaction oxygen chemistry is assigned to the dust, and rapid heat conduction from the slug ignites assembly constituents when appropriate. Obviously, the process is very complicated, but some simple results are suggested by simulations.

For drive pressures in the 3000 psi and above range, and across all dust densities supporting combustion, oxygen mixtures below 70% (oxygen content) did not ignite in these simple simulations. Above 70%, impurity densities around 200 mg/ft^2 were requisite to support combustion in the 3000 psi range. Below 3000 psi, ignition and burn were only sustained with high oxygen fractions (90%).

These are ignition studies. Deflagration and sustained burn are not guaranteed following ignition. For sample cases above, sustained burn requires rich oxygen mixtures, somewhere in the 70% range and above, with dirt densities above 200 mg/ft^2 requisite.

Combustion Equations

Combustion phenomena invoke mass balance, heat transfer, and chemical kinetics equations, nothing more than total conservation statements for species of reacting gas and dirt mixtures. The mass balance connects particle mass, momentum, and energy via the usual fluid equations. That is, mass continuity takes the form,

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = \Pi$$

for ρ the fluid density, u the fluid speed, and Π the net production rate of new fluid. Momentum continuity is written, with g the acceleration of gravity,

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u u) + \nabla p = \rho g + F + \nabla \cdot \sigma$$

with F any forces, p the pressure, and σ the viscous stress tensor. Energy continuity takes similar form,

$$\frac{\partial (\rho I)}{\partial t} + \nabla \cdot (\rho u I) + p \nabla \cdot u = Q - \nabla \cdot J$$

for I the internal energy, Q the combustion heats, and J the heat transfer flux. Heat flux results from heat conduction and changes in specific enthalpy of combustion products,

$$J = -K \nabla T - \rho D h \nabla$$

for temperature T, diffusion coefficient D, enthalpy h, and heat transfer coefficient K. These are the mass and heat transfer equations for the pneumatic gas, leaving the reaction source, Q, given by (with m a sum over reaction species),

$$Q = \sum_m a_m h_m$$

for a combustion reaction rates, and h heats of formation. In terms of Prandt and Schmidt coefficients, P and S, diffusion and heat transfer coefficients take the usual form, for μ a phenomenological flow coefficient approximately equal to the temperature,

$$D = \frac{\mu}{\rho S}$$

$$K = \frac{\mu}{cP}$$

Dirt Distributions

Solving the equations for the actual density (surface) is also complicated. To calculate mass, momentum, and total energy exchange between the flowing gas and the surface particulates, one needs account for the distribution of dust sizes, compositions, velocities, and temperatures, a

$$\frac{\partial f}{\partial t} + \nabla \cdot (f v) + \nabla_v \cdot (f \eta) + \frac{\partial (f R)}{\partial r} + \frac{\partial (f \tau)}{\partial T} = \phi$$

difficult task without prior knowledge. To simplify, we will only consider two component (or one) distributions, with particle sizes all the same to yield the total surface density, f. Particulate coalescence and collisions under impact loading need also be accounted in the analysis. Accordingly, an evolution equation for particulates is solved at each time step, with mass and heat balance equations, with ϕ the collision rate, τ the temperature change rate, R the radial change rate, and η the velocity change rate.

Numerical Scheme

The above set is finite differenced with respect to time and space. The LANL code, KIVA, used for designing gas and diesel combustion engines is employed. Cylindrical 3D geometry is assumed for the test configuration. All data comes from the LANL combustion libraries, well represented and validated from experiment, design, and other applications.

Results

Five drive pressures, 1000 psi up to 5000 psi, were considered for ignition and burn. Particulate densities ranged 50 mg/ft^2 up to 300 mg/ft^2 for the tabulation. Only hydrocarbons (plastic, silicone, nylon) ignited in the study. Glass, titanium, aluminum, and fiber did not ignite. For drive pressures above 3000 psi, only 70% oxygen and above ignited the hydrocarbon assemblies, provided the assembly densities were greater than 200 mg/ft^2. Below 3000 psi, high oxygen fractions (90%) were necessary for ignition and burn, with the same particulate distributions. Two component mixtures, with hydrocarbon particulate density above 200 mg/ft^2, ignited but the quenching component of the distribution (metal, glass) reduced the burn wave intensity. Below 5 mg/ft^2 dust density, ignition and burn were not observed.

The Tables below summarize ignition and burn for varying drive pressure, dirt density, and oxygen fraction.

Table 1. Drive Pressure 1000 psi

f(mg/ft^2)	fO_2 20%	40%	60%	80%	100%
50	n	n	n	n	n
100	n	n	n	n	n
150	n	n	n	n	n
200	n	n	n	n	n
250	n	n	n	n	n
300	n	n	n	n	y

Table 2. Drive Pressure 3000 psi

f(mg/ft^2)	fO_2 20%	40%	60%	80%	100%
50	n	n	n	n	n
100	n	n	n	n	n
150	n	n	n	n	n
200	n	n	n	y	y
250	n	n	n	y	y
300	n	n	y	y	y

Table 3. Drive Pressure 5000 psi

$f(mg/ft^2)$	fO_2 20%	40%	60%	80%	100%
50	n	n	n	n	y
100	n	n	n	n	y
150	n	n	n	y	y
200	n	n	n	y	y
250	n	n	n	y	y
300	n	n	y	y	y

Ignition and sustained burn required 90% burn-up of the particulate matter.

Clearly, these studies suggest trends for particulate ignition on the end of the stopped tube. Other scenarios also present themselves, in the form of distributed dirt near the end of the tube, dirt in the entering drive stream impacting the stopped end, and combinations thereof. Questions of ignition and burn for particulates of different size need also be answered.

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V. NITROX EQUIPMENT

J. Hardy: I'm going to share what I did based on the nine years and several hundred dive computers we've tested for Rodale's Scuba Diving Magazine. I've compiled a nitrox compatible dive computer list (10.25.00) of what is currently available. This list is not going to be perfect, but as of the end of last month, includes 13 different manufacturers with 35 models of dive computers. I may have missed a few in the process, but these computers have all been included in tests that we've done over the last nine years and are still in distribution. I've noted the distributors Aqua-Lung, SeaQuest or Scubapro because of the various different brand names.

Table 1. Nitrox Compatible Dive Computers

MANUFACTURER	MODEL
AERIS	300G
AERIS	500 AI
AERIS	750GT
AERIS	Atmos Pro
AERIS	Savant
COCHRAN	Commander
COCHRAN	Commander Nitrox
COCHRAN	Nemesis +
COCHRAN	Nemesis IIa Nitrox
DACOR	Equano2X
DACOR	Transcend
DIVE RITE	NiTek
DIVE RITE	NiTek3
DIVE RITE	NiTek C
GENESIS SCUBA	Nitrox Resource
GENESIS SCUBA	React
MARES	Surveyor Nitrox
OCEANIC	Data Plus
OCEANIC	Data Plus 2
OCEANIC	Datamax Pro Plus
OCEANIC	Datatrans Plus
OCEANIC	XTC-100
OCEAN REEF	Ocean O2 Nitrox
SHERWOOD SCUBA	Logic
SUUNTO*	Cobra
SUUNTO*	Solution Nitrox
SUUNTO*	Vyper
UBS	Chameleon
UBS	Nitrox Pro2
UWATEC**	Aladin Air X Nitrox
UWATEC**	Aladin Air Z O_2
UWATEC**	Aladin Pro Nitrox
UWATEC**	Aladin Pro Ultra
ZEAGLE	Stratus I
ZEAGLE	Stratus II

* Distributed by Aqua Lung & Sea Quest
** Distributed by Scubapro

J. Hardy: It is very simple math for a dive computer to handle nitrox. It is not complicated for that microchip to do the job. What it is essentially doing, at the risk of oversimplification, is moving the no-decompression line over based on NOAA's materials. Virtually all computers say that in their literature. Most of them have a way to adjust the PO_2 either on the fly or beforehand. The typical range is from .21 to 1.6 atm. Many computers will have a demarcation at 1.4 and 1.6 atm. Others must be preset before the dive. You set the O_2 percentage, which can be anything from 21 (air) up to 50 percent. A few models go all the way to 99 or 100 percent. Variability comes in what the manufacturers share with us and what we're able to test, which is, what the computers track and how they track it. That is not clear among the manufacturers. You should also realize that practically all manufacturers are moving towards nitrox computers. You're going to see an era when all computers have a nitrox program. It's simply a function that you call up when you want to use it. On the face of the computer it has air and if you want nitrox, you simply punch up that screen and go with nitrox. I also predict that all dive computers will eventually interface with desktop computers.

NITROX EQUIPMENT DISCUSSION

M. Lang: As we start this discussion, I ask that you be very crisp and precise in your comments so that we can most effectively use the remaining time.

T. Mount: We're discussing something already involved in the standards. The manufacturers are producing nitrox regulators, which takes precedence to what the training agencies say anyway. IANTD says anything up to 46 percent can be used without special cleaning provided it meets the specifications of the manufacturer. We default to the manufacturer.

B. Gilliam: I agree completely with Tom that the agencies would really like to have the onus put on the manufacturers. The one thing that would help all of us is if there was consistency and common sense throughout the process. We all can see where the potential fire hazards are in the high pressure side of the first stage of a regulator. Is it necessary for us to get very concerned about the second stage where the low pressure is really not much of a fire hazard? We get very passionate at times in these discussions about "to clean or not to clean", but nobody ever brings up the issue of cleaning the other components. If you have to clean the second stage of the regulator then you also have to clean the low-pressure inflator that inflates the BC. I don't know anyone who's ever taken that path. What about HP hoses and submersible pressure gauges? If you were ever going to have a fire, it would probably happen right there in the SPG. The whole equipment package should be looked at, which would help everybody come to agreement

B. Wienke: I agree with Jon's comment that all dive computers are probably going to be nitrox. Some dive computer manufacturers (*e.g.*, Suunto and Cochran) are also going to include tri-mix. The reason why they haven't gotten into the tri-mix business to date is because of liability. The technical diving community is driving that. Presently, all computers, except for a very few, are typically Haldanean models. These are dissolved gas models with M-values if they're U.S. Navy, or Bühlmann values. That's going to change in the future to dual phase models brought up on risk computers because the computing power and the memory is sufficient to perform phase calculations.

B. Wienke: On the oxygen combustion issue, it's not really hard to model with high surety oxygen combustion flows in any type of system. We have done such calculations. To do this, it's fairly easy to draw on combustion technology that is used for designing engines in Detroit and at Los Alamos National Laboratory. The whole oxygen combustion issue can be correlated with experiments to a very high degree. We can come up with probabilistic curves for ignition. Ignition doesn't always mean burn propagation, but we can come up with ignition criteria as a function of configuration whether it's a first stage of a regulator or a tank valve. The important unknown factor is the nature of the dirt that you're trying to ignite. Is it hydrocarbons, plastics, pyrotechs or rubber or do we have titanium or titanium oxide particles? The combustion chemistry is really the important consideration. We did 3D simulations with a simple configuration. An overdrive gas with a variable fraction of oxygen slams up against a stopped end. The stopped end has a hole in a model of a regulator first stage with gas flowing out of the tank tube. Viscous equations are employed. We vary the drive pressure between 50 to 5,000 psi. As this pneumatic gas slug forms in the region in and around the first stage of the regulator and the seat or the hole in the stop end, a shock pattern is generated that is strong enough to ignite some of the dust in there. The dust can be hydrocarbons, nylon or teflon, which doesn't burn very well, rubber or fabric, plastic, metal or glass. The result is shock heating plus implosive compression. The whole process is highly non-adiabatic, so there is heat transfer mainly by shock heating. We looked at dust densities between 50 and 350 mg, distributed evenly across the face or the stopped end of the regulator. These are typical dust densities that are described in the literature. With flammable dust densities around 100 mg per square foot on the regulator surface stop end, we needed 70 percent oxygen to ignite and burn the assembly. You can get a spot ignition and not necessarily have combustion waves or reaction waves propagating through the gas. If we drop the drive pressure to 2,000 psi, we need a high amount of fairly dirty dust distributed over the stopped end to get the assembly material to ignite and burn. By dropping even highly combustible dust densities below 10 milligrams per square foot, we don't get ignition even up to 99 percent oxygen. The question of metals is interesting because in this particular simulation, if you take only small titanium or aluminum particles on the order of a micron size and spread them across the stopped end, they don't necessarily ignite. However, if you ignite metal such as titanium and aluminum by impact, that's a different story. If it's pure titanium surrounded by other kinds of containment, it's not clear that you will always ignite the titanium. Igniting a local hot spot does not mean that you're going to have an explosion propagating through the gas. You could have a "whoosh" sound and nothing happens or an explosion could follow it. Calibration comes from experiments that are done in shock tubes. The calibration is used to dial in the reaction chemistry for the combustion. The expertise for the combustion chemistry is drawn from studies and designs that are done for Detroit on combustion engines. The model there is what they call a droplet model. With fuel (gas) injection, your carburetor or igniter fires material into the combustion chamber in droplet form. That is a very good model for doing these tests.

B. Gilliam: From your experience and knowledge of the components that are being put into regulators today, do you think that we have just been lucky or are we on solid ground with the 40 percent rule?

B. Wienke: I believe that 40 percent is quite conservative from the simulations we've done. It's like decompression sickness, it doesn't mean to say that you are not ever going to get hit. The track record of nitrox diving is excellent and it's not just 30 to 38 percent O_2. We're also talking about stage decompression diving where people are using 100 percent mixtures of oxygen and have no problems.

S. Angelini: As a manufacturer, it would be nice for us to be able to test every single configuration of regulators we have to 100 percent O_2 to establish what functions at what levels. It would not be a definitive answer, but at least it would give us some kind of quantification of the risk, what we accept and what we do not. Of course, liability is always there and you only need one person to get hurt to be in trouble with a big lawsuit. At least you can show that you've done the best you can. We've done it with only a small fraction of the regulators because financially, it becomes a burden. The diving industry is not a very rich industry. The risk level that you tolerate is really what matters. There should be different standards for nitrox fillers and the scuba diver end user. As you fill, you heat up the components as the gas is flowing through. It's not the opening of the tank valve that is necessarily the most crucial moment. From the professionals in the field you can expect more rigor in what they do and more training in how they do it. On the other hand, the scuba diver does not have any technical knowledge. He faces the risk of a problem only as he opens the valve because that's when the heating taking place inside the first stage. We don't necessarily need to make it mandatory that people open the valve very slowly, although that would take away most of the problems. In most instances you would burn the seat, empty your tank and miss the dive. If you have a titanium body or some other exotic material, you may run into more problems. The bottom line is that the diver is faced with a lot less risk in the case of an ignition because it will only happen when the tank valve is opened. The diver himself does not need to be perfectly trained and knowledgeable about all these aspects, which makes this easier. You cannot expect the whole diving community to know everything. We're also talking about bagging regulators and whether the low pressure side needs to be cleaned. This is not necessary because it's not just the concentration that drives the whole process, it's also the pressure. Concentration times absolute pressure results in a partial pressure that you need to worry about. Under 500 psi it's a consensus that there's nothing happening, thus there is no need to worry about cleaning the low pressure side. There's really no need to bag the regulator as long as you clean your dust cap and close your regulator after diving. It's very improbable that a particle of dust will travel up the second stage into the first stage. Even in a piston first stage that is not perfectly sealed, the only part that is in contact between the inside and the outside is a low pressure o-ring, at which point you've already reduce the pressure and do not have that risk. The point is that we have data that show that people don't necessarily clean their regulators and they're fine. On the other hand, we have liability as manufacturers. One of the points that Elliot made was that the manufacturers have to assume the liability. That's a big issue when you look at what the lawyers make these days, no offense.

B. Turbeville: I resemble that remark.

S. Angelini: We want to have testing to back these data, which is why we stand with 23.5 percent on anything that's not tested. The fact that people in the field use it to a higher level therefore eliminates a liability if we don't support it, but at the same time we're comfortable that we don't have a bomb out there waiting to go off. If it is going to happen, it will be at the very beginning of opening a tank valve. The diver will be on the surface and it will very likely to fizzle into nothing.

B. Bjorkman: As an industry we have this fixation with oxygen cleaning. The overall picture emphasizes operating pressure, temperature, ignition sources, and velocity of gases. We can pour 100 percent pure oxygen through a horribly contaminated tube without real risk at all if there's no ignition source. Especially when you consider 'oxygen clean' as a transitory state. A regulator can be cleaned thoroughly and tested for cleanliness, but how long will it remain clean while in use? It's very important for the dive shop blender to realize that if they're dealing with a horribly contaminated system that is not designed for oxygen service, they probably shouldn't be using it.

B. Oliver: I've had the misfortune to be involved in some litigation. Invariably, no matter how benign the risk might be, the plaintiff's attorney will ask whether there is a better alternative design that could be used. The cost impact of going to that alternative design puts the manufacturer in a tough spot by responding that it would cost too much to install Viton o-rings, clean the regulators and put Christolube in them when they are shipped. It's not a very defensible position. What you will see is that the manufacturers are going to start doing this to all of their regulators just to cover their bases, which is probably going to answer this 40 percent issue.

D. Rutkowski: I was pleased to hear Forsyth's and Wienke's presentations, two opposing situations. Forsyth's presentation was mainly concerned with flammability. Wienke was talking about chemical ignition. In this business we are more concerned with chemical ignition than we are with flammability. If we're talking about oxygen percentages for physiology then it's 21. If a fire started in this room, where would you rather have the oxygen percentage? Twelve, twenty-one or 40 percent? I would rather have a 12 percent oxygen mixture in this room if a fire started. History shows that it's improbable to have chemical ignition up to 40 percent O_2. Forsyth authored a paper for NASA showing that pneumatic pressurization of the first stage of a regulator in 20 milliseconds, resulted no problems using up to 50 percent oxygen. If you reference OSHA 1910.430(c), that test was conducted before 1974. This community has proven by the millions of tanks that have been filled with up to 40 percent nitrox that there has not been a problem.

E. Forsyth: That paper did show, in fact, that we did not get any ignitions (see Forsyth's referenced paper first published by ASTM with some supplementary data in this volume). It puts into proper context what that particular group of tests did. Unfortunately, it's been abused in the sense that it's a test that showed no ignitions, but the scope and the applicability of that particular test needs to be taken into consideration if it's going to be used. Second of all, there is not a difference in opinion here, despite what Mr. Rutkowski said. Bruce Wienke and I are literally talking about the same thing. Ignition is different than propagation and those are the terms that are commonly used in industry. Whether you can ignite something is totally different than whether it propagates after you get it ignited. Bruce's data showed ignitions of the dust between 70 and 90 percent O_2. I have some data from follow-up tests on hydrocarbon oil that show ignition down to 10 milligrams per square foot. These are levels that are quite a bit lower than what Bruce was showing with particles of dust down to 50 percent oxygen. We tested that at 50 percent and 100 percent O_2. It is an ignition problem, however the issue that needs to be addressed is whether it's a propagation problem. In none of those tests did we see propagation. Is ignition in and of itself tolerable? What Sergio said was very insightful regarding the differences between a high-pressure regulator and the low pressure side. There is merit in two different standards in terms of how a regulator is cleaned. To NASA's Neutral Buoyancy Lab we recommended that they fully oxygen-clean their first stage regulators used in their 46 percent nitrox systems. All the second stage equipment is still clean, but it's only done via a visual inspection. Typically, NASA does take the conservative approach because their level of risk acceptance is different from that expressed in this forum.

E. Betts: The data presented here is an illustration of what goes on in the real world of the dive store concerning cleaning low pressure equipment. The recommendation that ANDI follows is that the low pressure equipment is certainly far less of a consideration. Nevertheless, in the actual servicing procedure, it's extremely difficult for the service technician to use oxygen clean capabilities and oxygen clean lubricants on the high pressure side and then switch over to standard protocol using non-compatible lubricants and materials on the second stage. In my experience, one of the issues is cross-contamination. It becomes quite an embarrassment to see a non-compatible lubricant on significant surfaces of equipment that was intended to be oxygen clean. The simple recommendation is, if you have decided to oxygen clean a regulator and put correct lubricants in, to not use silicone grease on low pressure equipment. This reduces cross contamination on the technician's side at the dive store level.

B. Hamilton: Let me brief this group on what the new NOAA diving Manual will say. We talked about oxygen cleaning at two levels. There is formal oxygen cleaning and informal oxygen cleaning. Formal oxygen cleaning is what Elliot referred to what CGA and ASTM want and it's mostly a matter of paperwork. There is an enormous amount of documentation involved. That's what NASA does and that's one of the reasons why it's so expensive. I used to work for Union Carbide and I know what this is all about, it was a lot of trouble. But informal oxygen cleaning is what Sergio referred to, you make sure that the regulator is clean, that it doesn't have any garbage in it and that it has a proper lubricant. That should be done with the second stage as well even though it is a very low risk area. If you're using 40 percent and clean it to the dishwasher standard, that's clean enough. That's oxygen clean, but it doesn't follow the protocol, the paperwork trail. Therefore, make it clean, inspect it and make sure that you don't contaminate it again with silicone lubricants.

T. Mount: Every training agency insists that when oxygen cleaning is taking place oxygen compatible lubricants be used throughout the regulator's first and second stages. The real problem is even if the second stage were oxygen clean, you would need oxygen compatible diaphragms, which there aren't many of on the market. There'd be no reason for manufacturing them. It would be a waste of money because it wouldn't accomplish anything.

S. Angelini: My comment earlier about not cleaning the second stage took some things for granted. What I meant is that we don't use Viton o-rings in second stages. We only use oxygen-compatible lubricants. Some of these lubricants work better than the non-oxygen compatible ones anyway. They're a little bit more expensive, but it is actually simpler having just one type. We recommend Viton o-rings for the first stages and on the second stages, we have EPDM. We know that EPDM works better even for first stages because when you go into very cold environments, the Viton will basically not hold up its properties and the EPDM will. There was also some controversial statement made by PADI or DSAT that Viton should not be used.

K. Shreeves: We didn't make that statement. What happened was another manufacturer that has a large gas company behind it, had experienced a problem and told us that they were going to discontinue Viton. It had to do with medical equipment. PADI, as a matter of policy, always informs its retailers when it gets information like this. We posted that information on our member web site. It wasn't open to the general public, but it inadvertently came across as an indictment against Viton, which was not what we intended. After several calls from Scubapro and other companies, we deleted it. That was never our statement, it was based on information we got from another manufacturer.

S. Angelini: I would endorse that Viton is a little bit of a problematic material. A regulator taken into freezing water has to perform and with Viton, it will not. You're preventing one problem, not eliminating it, because it may not exist with the EPDM anyway, but you're creating another one. I would like to take regulators, possibly with steel metal shavings inside from the machining process, with the standard materials, EPDM, regular high pressure seats and oxygen compatible lubricants such as Christolube or Kytox, and have them tested. If we want to declare it good for 40 percent, let's test it at 60 or 80 percent at maybe 4000 psi and reduce our risk level to something that we consider acceptable. The question is whether that is not already being done in the field with the years of experience that we have had and then also corroborated by the calculations that, for instance, Bruce has done.

M. Wells: My own first exposure to this 40 percent rule came not in the context of diving, but when filling and developing breathing apparatus for people at reduced atmospheric pressure in the early '70s. Obviously, I had the need to use mixtures with higher oxygen concentration than that of air. Faced with this problem of a potential fire, I went to a very logical place. I walked down the street to the fire department and talked to a very knowledgeable young lieutenant there who reached over on his bookshelf and pulled out some literature that contained the 40 percent rule. It had been in effect for some time and is included in the new NOAA Diving Manual. It has a long history. Remember that every time one turns on the valve for oxygen decompression, all this stuff goes roaring down the hose. Behnke and Lanphier developed oxygen decompression before I was born. They were opening valves fast, firing oxygen down hoses across dirty decks into the diving helmets full of fur, lard and clothing. That's my definition of a dressed human being in this oxygen environment. I would also like to suggest that every stroke of the cylinder of a compressor pumping this stuff is in effect a test, isn't it? We're using the ignition system of a diesel engine. I'm slightly emotional about this especially when I see a whole page full of references that are not applicable to this situation. We're talking about very specific situations when we see that whole list referring to confined spaces. I've timed myself cleaning cylinders that I used for oxygen service at the rate of ten per hour. If we want to oppose "oxygen cleaning", what happened to the simple kind of cleaning that our mothers taught us when we were kids? In most cases that's oxygen clean. Have you ever seen the sparkling glasses on the TV ads for dishwashing liquid? That's called the water-drop test. It is much more specific than ultraviolet light. What I'm suggesting is that we have done a lot more, have a lot more experience, and do not seem to be having significant problems. We should not try and reinvent something here.

B. Oliver: I want to add something to the record regarding the Viton versus EPDM o-rings. I was at Aqua-Lung when that decision came from Air Liquide. Their concern was that Viton, if it does ignite, has a potential for releasing some toxic gases. The concern was brought to them from the medical industry regarding use of 100 percent oxygen. On the other hand, EPDM has a lower oxygen index than Viton. As an engineer, you can look at the tradeoff between would I rather have it ignite at a higher temperature and oxygen concentration, or, if it does ignite, do I want to avoid the toxic gases? What I'm saying is that there's a justification for EPDM as well as Viton depending on where you want to make the tradeoff.

VI. FINAL DISCUSSION AND RECOMMENDATIONS

M. Lang: I would like to discuss as a priority those points where there was no disagreement, based on presentations and the discussion sessions. We start with a blank sheet. Let's try to summarize in an efficient manner what we've all agreed on and then we might also outline those points that need more work or that were inconclusive.

B. Gilliam: Maximum PO_2 of 1.6 atm.
K. Shreeves: We heard the whole group saying that the 1.4 to 1.6 atm range is suitable.
M. Lang: Do we want to use a range or a maximum value?
T. Mount: A range is ambiguous. Nothing prevents me from using 1.4 or 1.2 atm, but if we have a range, someone is going to question what this range is based on.
B. Turbeville: You need to agree on a maximum value.
M. Lang: The suggestion is a maximum value of 1.6 atm. Can we live with that as a workshop recommendation? Raise your hand, please. Alright. Next bullet.

D. Richardson: Michael, you might want to add "based on the history of use presented", because that's significant. That's the first time this industry has ever gotten together and shown what their certification base has been and what their experience with DCS and oxygen was.
M. Lang: I agree.
D. Richardson: There's been a significant history of nitrox use up to 1.6 atm with zero incidents of CNS problems reported.
M. Lang: Raise your hand everybody. Next bullet, please.

B. Wienke: No increased DCI risk for nitrox diving compared to air, based on the statistics that were filed here.
E. Betts: No apparent evidence for an increased risk in the use of oxygen enriched air as opposed to air.
B. Turbeville: I would use no evidence as opposed to no apparent evidence. Apparent evidence is a little bit too ambiguous for what we've seen here today.
M. Lang: No evidence was presented that would show an increased risk in nitrox use versus compressed air.
R. Moon: I thought we did away with nitrox in the first presentation.
M. Lang: Is that a consensus? Did we do away with the term nitrox? I don't believe it was. It was suggested, but it wasn't actually a consensus. Do you disagree?
R. Moon: There needs to be a modifier as to the kind of nitrox we are talking about.
M. Lang: Fair enough.
R. Moon: Enriched oxygen mix.
A. Marroni: We should define the risk. Is it general risk or are we talking about DCS?
M. Lang: That's a good point. DCS needs to be specifically mentioned.
B. Wienke: DCI.
B. Turbeville: It should be DCS.
M. Lang: It should be DCS, we didn't talk about embolism or other barotrauma. Oxygen enriched air use versus compressed air?
B. Gilliam: Put nitrox in parentheses because that is the term by which this gas is generally referred to.

B. Wienke: Put the second bullet first.

M. Lang: Everyone agrees with that? Raise your hands please. Thank you. Oxygen flow restrictors for gas analysis. Was that something we agreed on?

B. Gilliam: Oxygen analyzers should be used with a flow restrictor, not to exceed three liters per minute.

M. Lang: We didn't present flow rate data for oxygen analysis. I would suggest we leave the rate out.

B. Gilliam: Fine.

E. Betts: How about a controlled flow sampling device? Can everybody go with that?

M. Lang: A controlled flow sampling device. Does anybody have major heart burn with that? Raise your hands. We all agree on that. Good. We've reached three consensus recommendations on the workshop list.

R. Moon: I would strongly push for some statement about when and how the gas analysis should be performed, by whom and something about calibration of the oxygen analyzer.

M. Lang: Discussion of that proposition?

E. Betts: Everybody here has already agreed that it's certainly most appropriate that the end user analyze the gas.

R. Moon: What about the mixer analyzing the gas? Should that not be in there as well?

E. Betts: I certainly would agree that that's appropriate. There needs to be a redundant test someplace in here.

M. Lang: Do we agree that there should be a redundant chain of testing of the gas? That's the question, right?

B. Gilliam: By the end user is what we discussed.

M. Lang: We discussed the end user. Did we also agree that there should be a redundant analysis of the gas at the pumping end and at the end user end? Did we agree on that, yes or no?

T. Mount: What we agreed on is that the end user or redundant source would verify the gas. Some of us require the end user to do it, some don't, but he should at least verify it so it's analyzed twice.

M. Lang: Should we say end user verification of gas?

D. Richardson: What we want to do is show good practice in mixing the gas, but each individual user needs to take final responsibility to analyze the gas that they're breathing. That's inescapable. It's a responsibility that's placed on every end user in the whole training process.

B. Wienke: End user verification of gas analysis.

E. Betts: Required.

B. Bjorkman: It's very important too that the mixer, as part of their process, analyzes the gas. Otherwise, he has no idea if he's produced the correct mix.

D. Kerem: Verification implies that someone has tested it earlier.

M. Lang: That's an implied definition. Can we live with that fourth bullet, end user is required to verify gas analysis? Raise your hand, please. Done.

J. Hardy: How about the training agencies' encouragement of dive computer use? The transition from tables to dive computers? Do we have any agreement on that? We had general nodding of heads when that came up, but do we have agreement that the direction we should take is from tables to computers?

M. Lang: Please propose the wording of that recommendation.

J. Hardy: The wording being that the training agencies encourage the use of dive computers over the use of tables.

T. Mount: I'm one of the world's greatest believers in, and user of, dive computers. Many of my instructors feel very negatively about them. We also have agencies here that do not use them, NOAA, for instance. We should not recommend that we encourage dive computer use. Most of us do it anyway. We should not prohibit them either. 95 percent of my students use computers where they're applicable. I'm concerned about becoming 100 percent dependent on computers. I've owned just about every computer on the market that supports technical diving and I've never had one that did not quit in the middle of a dive at some point where I had to fall back on tables.

D. Dinsmore: I mentioned that NOAA does not use dive computers. We may in the future, but that statement would not reflect how NOAA feels. Perhaps you could say something about dive computers can be used effectively with nitrox.

E. Betts: I would accept that.

J. Hardy: We might change that to recognize the usefulness of dive computers.

M. Lang: Effectiveness?

J. Hardy: Yes.

M. Lang: Training agencies recognize the effectiveness of dive computers, is that better? Tom, is that okay with you?

T. Mount: That's excellent.

K. Shreeves: Agreed.

M. Lang: Can everybody live with that? Show of hands, please. Very good.

J. Hardy: Can we say something about not spending a whole bunch of time tracking long-term oxygen exposure?

B. Hamilton: There's no need to. For recreational diving with oxygen enriched air, there is no need to track whole body or long-duration oxygen exposure. At some point here we need to talk about tracking exposures to high oxygen contents. That's not part of this statement though, that's good.

K. Shreeves: In a sense, the so-called "CNS clock" does that. Shouldn't we be more specific and state that in recreational diving of oxygen enriched air, there's no need to track OTU's?

B. Hamilton: Use a parenthesis after whole body, yes.

T. Mount: I would also add UPTD because that's still a common end.

M. Lang: Can we live with this? Show of hands please. Very good, and counting.

B. Gilliam: Something to the effect of teaching NOAA CNS limits. We don't have that addressed yet. We have a maximum PO_2.

M. Lang: Would you re-word that please?

B. Gilliam: Recognize NOAA oxygen limits in teaching exposures.

M. Lang: Oxygen exposure limits.

T. Mount: Tracking oxygen clocks may be based on NOAA exposure limits. We have repetitive tracking now thanks to Dr. Bill Hamilton and some other people who have been using dive computers. The way the NOAA table is written, it doesn't explicitly imply that. It doesn't give you half times for oxygen tracking. You need to consider it because all the dive computers use that technology. All our tables do when we plan dives. I would say change use of an oxygen clock based on NOAA.

B. Hamilton: NOAA exposure limits. I would put oxygen clock in quotes since that's only one way to express it.

M. Lang: Concept after that?

B. Hamilton: That's good, with the word concept there.

D. Kesling: Add a CNS component to that just to differentiate.

B. Hamilton: CNS oxygen clock.

R. Moon: There's a bit of a danger in putting that down there because that implies that there is a well established relationship between time of exposure and CNS O_2 toxicity, which there is not. I'm not sure exactly what we're trying to impart by that bullet. I would say the opposite: Teach the fact that CNS O_2 toxicity can be sudden and unexpected rather than predictable based upon time of exposure.

D. Kerem: I second that.

B. Hamilton: Michael, why don't you just add that on? CNS oxygen toxicity can occur suddenly and unexpectedly. I entirely agree with Richard Moon.

M. Lang: Okay Richard?

R. Moon: Fine.

M. Lang: Good. Can everybody agree to that? Hands up, wait, hands down.

D. Dinsmore: Does everybody teach the oxygen clock or do they teach the NOAA exposure limits?

B. Hamilton: They're taught simultaneously.

M. Lang: Let's find that out.

T. Mount: IANTD teaches the clock.

J. Hardy: SSI, yes.

B. Gilliam: TDI, yes.

E. Betts: ANDI, yes.

B. Wienke: NAUI, yes.

D. Richardson: PADI, yes.

M. Lang: There's the answer. Any other bullets?

B. Gilliam: Do we have a consensus on the 40 percent oxygen-cleaning rule?

M. Lang: We need to address the 40 percent rule.

E. Betts: I certainly would suggest a 40 percent value. We need to say something about its applicability. I am opposed to the broad stroke approach that it's applicable for everything. That's the problem that's occurring with the ignition fires with regard to pumps, compressors, and filtration equipment. If we're going to make a statement about 40 percent, I don't think it's prudent to say it's a 40 percent rule across the board that applies to "recreational diving."

J. Hardy: I suggest that we separate the user from the provider. Would that help out then? We're more concerned about the end user and what happens to the end user. For the professionals in the dive store, as Sergio separated those two entities, apparently the risks are different. The volume handled is different. Would that satisfy your needs to talk only about the end user as a recommendation to the field?

E. Betts: I'm concerned about the liability of our ANDI dealers as we distribute enriched air as a product. There's a liability involved with dispensing procedures and proper gas analysis. For the end user to use or treat enriched air as if it were air, unless you're under 40 percent, I've always felt was a simplistic comment and needed some form of clarification. To make that statement to the user you're creating an aura that this is applicable throughout the industry. I can't live with that.

M. Lang: Alright, fair enough. How about if we term it something like the first bullet that no evidence was presented that the 40 percent oxygen cleaning rule has been a problem?

E. Betts: With regard to what?

B. Gilliam: I'm with Michael. In talking about the end user we should state that no evidence was presented to suggest that the use of standard scuba equipment regulators, inflators, etc., up to 40 percent, is unacceptable. Then we're not getting into the dispensing or manufacturing of the gas.

M. Lang: Does that meet your concerns?

B. Gilliam: That's what you were trying to say, weren't you, Ed?

E. Betts: That's all I'm trying to say. Let's get some science here instead of a broad paintbrush stroke.

T. Mount: No evidence that would prohibit the use of up to 40 percent nitrox with standard scuba equipment.

E. Betts: Is it not appropriate to cover the manufacturers here, although they are the final word on this issue?

T. Mount: If we, largely a body of training organizations, make a statement like this we take any burden off the manufacturers. The manufacturer is the one that's going to have to take the burden on this. As in our standard, it says, we default to manufacturer's recommendations.

M. Lang: It seems that we need a modification of this recommendation.

B. Turbeville: Michael, evidence doesn't prohibit anything. You might want to state that the evidence suggests there is no need to prohibit it. But evidence in and of itself does not prohibit. It can't. No evidence suggests that the use of a maximum of 40 percent nitrox with standard scuba equipment presents an unreasonable risk to the user.

S. Angelini: I'd say we just stick with what we said in the other point. No evidence shows increased risk because we have not seen any increased risk. We're stating the obvious, but we're formulating it in a way that should really address this point without exposing it to ambiguity of any sort.

B. Turbeville: That is sufficient. What Sergio said is fine.

S. Angelini: No evidence was presented to show an increase in risk when using 40 percent nitrox with standard scuba equipment. Of course, we have to qualify this in terms of the risk, not DCS in this case, but ignition, flammability, and explosion.

D. Richardson: Two months from now at DEMA we'd like to remember the specifics. We're talking about two different things here. The reader might look into that and wonder why we're covering oxygen to DCS and now mechanical interfacing. We need to clarify this.

B. Gilliam: Equipment compatibility is what you're really talking about.

B. Turbeville: You might want to put in increased risk of fire or explosion.

D. Richardson: That addresses it, thank you.

T. Mount: Let us qualify something. Use the word ignition instead of explosion.

E. Forsyth: First of all, I like the word unreasonable because I did show that there is an increased risk of material flammability and ignitability that increases with oxygen concentration. There's hard data to support that there is an increased risk of fire. What the level of risk is when you state it's unreasonable better reflects the attitude.

B. Turbeville: The term unreasonable risk is a legal standard.

E. Forsyth: What that infers is that you've actually thought about it and made an assessment. The second thing is that I did show that we have seen ignitions and seat burns. Whether or not you term that a fire or an explosion is a matter of opinion. At 46 percent nitrox, we've seen three fires that we've been working with NBL on.

M. Lang: The statement reads up to 40 percent.

E. Forsyth: I know. We have vast experience of cylinder valve fires at less than 40 percent. I didn't show any because I didn't have the time. I'm hesitant, as an outsider here, to vote on this because I don't feel like I have a say here, because this is your industry. I have a difficulty with this statement in the sense that I know the fires are occurring at less than 40 percent. We do see cylinder valve seat ignitions at less than that.

S. Angelini: The fires and the ignitions that you have observed, were they in scuba equipment or in applications that don't necessarily apply? We're not saying that it doesn't happen. We're commenting on what was presented and what we did not observe.

E. Forsyth: The answer is both. Within scuba and within other applications of cylinder valves. Cylinder valve configurations do not vary very much at all.

E. Betts: Several of the valve manufacturers have taken big issue over this and they have in fact had ignitions. This was one of the original problems that ANDI had when we were trying to present the nitrox concept to the diving industry. Valve manufacturers said unequivocally not to tell me there is not a problem here. They'll dump a coffee can full of valve seats in your lap and show you all the burns that we've got. That was an issue that absolutely closed their mind to the proliferation of enriched air using their standard equipment. I'm not sure that the valve situation has changed very much. We even had a discussion where a nitrox-specific, or breathing gases other than air, valve and valve configuration needed to be addressed. I don't think the manufacturers were comfortable with the statement that nobody died yet.

D. Richardson: Do we want to say based on the history of use?

M. Lang: Operational history indicates no problem with a maximum 40 percent nitrox use.

D. Richardson: That seems generally to be the case.

M. Lang: We have, in fact, presented and discussed that.

E. Forsyth: I guess I'm not sure what you mean. Operational history of what?

M. Lang: Standard scuba use of nitrox up to 40 percent nitrox.

E. Forsyth: I didn't present any pictures of fires here today so I guess your statement is correct in that sense, but we do know that they have occurred.

B. Gilliam: It's also within the context of what Bill Turbeville suggested to show unreasonable risk. Within the context of use, I think we're completely covered.

R. Moon: Elliot, you also made the point that you've seen these ignitions on high-pressure air too. If we were to go where there's no risk, we couldn't use air or anything else in our valves.

E. Forsyth: Right. My issue then would be more with "no evidence was presented." I really like the terminology of unreasonable risk because what that does is say that this community of people has assessed this issue and they've determined it not to be an unreasonable risk

S. Angelini: I'd like to add one thing. The history of use is important and it's the one piece of evidence that we have. However, it applies 99 percent to brass regulators. New materials are coming along. We only had one big accident and it was outside of the 40 percent limit, but we cannot say that we have a history of data on these materials. We have some information, but it's not a lot. I certainly don't want to exclude them because Scubapro also uses exotic materials in the product line. I wonder whether this message is a little bit too broad in how it's stated now.

D. Kesling: Add "to date" because equipment is going to change.

S. Angelini: The history of use is always "to date."

B. Hamilton: I appreciate what Sergio is saying, but I wonder if we could say that standards for scuba equipment as of the date of this meeting don't include the exotic materials you're talking about?

S. Angelini: There is between two and three years of experience with probably hundreds of dives. These materials are lighter and are meant for traveling. On travel is when most of the recreational nitrox diving is done. One could say that there is a history of data. I don't want to push it too far because these recommendations are being written for a purpose. Although I would certainly like to get the liability off of our chest and use something like this, I don't want to be unfair to the end user.

B. Oliver: Michael, I have a suggestion that might help. You might just add another sentence that says that the level of risk is related to specific equipment configurations and that you should rely on the manufacturer's recommendations.

M. Lang: Sergio, does that put you at ease?

S. Angelini: Absolutely.

M. Lang: Alright. With no more discussion on this, all those in favor, a show of hands, please. Very good.

D. Richardson: Would it be appropriate to add a statement that when an individual's CO_2 retention status isn't known, it seems the limit of 1.6 atm is appropriate with open circuit scuba? There was a session on CO_2 retention for open circuit scuba at 1.6 atm that would seem an appropriate limit if we're not going to be screening for retention.

M. Lang: Let me ask Dan to respond. Is that a statement you'd want to make?

D. Kerem: Right now I wouldn't change the limits, but maybe encourage the mentioning of the ratio of CO_2 retention in the curriculum.

D. Richardson: I'm suggesting a separate bullet.

M. Lang: A separate bullet is alright.

T. Mount: My concern here is that we may be indirectly implying that we should be testing everybody's CO_2 retention. Most facilities don't have the ability to do that.

D. Richardson: I'm saying just the opposite. That we shouldn't be testing, there is no reason to. Basically, you're setting a limit. We have a history of use to that limit. We're not screening for CO_2 retention, but that's not necessarily a problem using open circuit nitrox at 1.6 atm. Can we say that?

B. Wienke: We ought not to be making medical judgments because none of us, except for a few people in this room, are qualified to make such statements.

D. Richardson: There was medical evidence presented though that would suggest it's not a problem. Why was the question even raised and put on the agenda? It should be addressed by this workshop.

M. Lang: That's true. Some bullet about the CO_2 retention issue needs to go up here. Dan, did you want to finish any comments?

D. Kerem: I can't argue with the fact that the 1.6 atm limit seems very safe. Apparently, even CO_2 retainers get away with it. Notwithstanding the anecdotal cases that we still have of people convulsing on apparently safe PO_2's, I would at least educate people to this possibility. Suggest to the guys who finish the dives with a lot of gas in the tank after the buddy emptied their tank to perhaps take more conservative measures with the use of the PO_2 limit.

B. Hamilton: Could we add to the bullet "based on the history of use and assuming no excessive CO_2 accumulation"? That deals with heavy exercise and with the CO_2 retainer and it makes me a lot happier.

A. Marroni: In one of the two papers that we are referring to, it is said that in the case of the unknown CO_2 retainer, a maximum PO_2 of 1.4 atm is advised. This has been written and is something that we should consider.

R. Moon: I would make some statement about the possibility that there is physiological variability and susceptibility to CNS O_2 toxicity, but that the methods do not yet exist to reliably predict whether somebody is in that subgroup. Simply make the point that there may be people who are more susceptible for whom 1.6 atm is not appropriate, but at present there is no reliable way to identify such individuals.

M. Lang: Do we want to necessarily tag in the CO_2 retention, link it with the maximum PO_2 of 1.6 atm, or should the CO_2 retention be framed as there not being an excessive problem with it as a separate bullet?

R. Moon: I would make it a separate bullet.

D. Richardson: For open circuit.

B. Gilliam: Let me suggest that we're peeling back the layers of the onion pretty far now. If we got into this same discussion of air, we could be talking about PFO's and all kinds of sub-bullets. Yes, there are going to be exceptions from the general population rule, but we're going way overboard here to try to identify these at such a level right now. From Dan's talk, he identified CO_2 retainers as being maybe five percent of the population. We don't have screening methods to even begin to identify them. This is something that is being excessively minutiaed here.

M. Lang: Simply stating that CO_2 retention might be an issue doesn't say much at all.

B. Hamilton: Didn't what we said about using the NOAA limits cover that? Can we just delete this whole bullet?

M. Lang: Which bullet?

B. Hamilton: The one about using the NOAA oxygen exposure limits. That's the one that says 1.6 atm and a lot of other things too. Does that not meet the requirement right there?

M. Lang: For CO_2 retention?

B. Hamilton: No, just NOAA limits.

M. Lang: We're going to leave unchanged what we already agreed upon as consensus statement and that was a maximum PO_2 of 1.6 atm. Now we're dealing with the CO_2 retention issue and it's been suggested that we create a separate bullet for that.

A. Marroni: I would suggest to not mention it here unless it is implicitly defined for open circuit nitrox. Otherwise, we leave the door open for rebreathers and that's a different story altogether for which we would have to add multiple other bullets.

M. Lang: The overarching factor here is open circuit, entry-level, recreational nitrox. You're right in pointing out that maybe we need to put a qualifying statement to that effect up front.

T. Mount: There are several issues that get involved here. Why do we want to create a liability by talking about CO_2 retention in the first place? Leave the maximum PO_2 at 1.6 atm. That is a recognized limit. We don't have a way to screen CO_2 retaining divers who would get a headache all the time, therefore reduce their PO_2 limit. That's not practical. One other thing being overlooked is that most of us here do teach rebreathers and dive students do come into entry-level nitrox on rebreathers today.

B. Turbeville: Alessandro and Tom are absolutely right. You're going to open up a bucket of worms if you bring in a recommendation from this workshop on a non-quantifiable physiological factor. We can't screen it out and can't create a duty of care here.

M. Lang: We have a suggestion now that we remain mute on the CO_2 retention issue.

D. Richardson: I'm happy with that, but the PO_2 limit of 1.6 atm is also a physiological factor. I'm suggesting that I've heard that CO_2 retention is not a problem. Everyone has advised us that we don't need to screen for CO_2 retention on open circuit enriched air. We have that medical advice in our pocket anyway. This topic was on the agenda under physiology, it was discussed and Dr. Kerem's paper will appear in these workshop proceedings. It seems like we should say that we don't need to screen for this application. I don't see how that's creating any duty of care.

M. Lang: I agree with you Drew. A reconfirmation that CO_2 retention screening is not required for open circuit nitrox up to 1.6 atm. That's what I mentioned earlier that should be considered as a workshop recommendation.

A. Marroni: Isn't that more or less implicit in the bullet "CNS toxicity can occur suddenly and unexpectedly?"

W. Jaap: I assume that these recommendations are going into the proceedings along with the papers, so anybody who wants to get into this retention issue can read about it, right?

M. Lang: I've never done it any other way with these types of projects.

W. Jaap: Then it seems to me it may not be necessary to actually have a bullet up there about it.

M. Lang: This effort is to formulate a consensual summary, a synthesis, of the workshop presentations and discussions. If there's no consensus on the CO_2 retention issue, we can state that no consensus was reached.

A. Marroni: Medically, I'm not happy with CO_2 retention screening is not necessary, period. That's not true. There is research going on there. Is it really necessary we mention it now?

B. Hamilton: Not practical.

M. Lang: I have a simple solution. An entry-level nitrox diver comes to your office for medical clearance prior to taking the course. As a physician, are you going to screen him for CO_2 retention, yes or no?

A. Marroni: No.

M. Lang: Should we consider routine screening as not necessary?

M. Emmerman: No evidence was presented that all divers need to be CO_2 screened. That's truthful.

B. Hamilton: There wasn't much evidence on that topic presented at all.

R. Moon: I recommend "a simple routine CO_2 retention screening is not necessary."

M. Lang: Any more discussion of routine CO_2 retention screening not being necessary?

M. Wells: The maximum PO_2 limit of 1.6 atm is based on more than history of use. I'm going to suggest the fine scientific studies of Dr. Thalmann contributed to that limit.

M. Lang: Are you suggesting to delete "based on the history of use?"

M. Wells: From my perspective, add "and scientific studies." That's why it's in the NOAA Diving Manual today. The decision was made decades ago, not on history of use.

M. Lang: Right, back to the CO_2 retention issue. Can we live with that? Raise your hands. Yes? Okay, we're going to leave that on then as a workshop recommendation.

R. Moon: One last point. This has been a bit of a bee in my bonnet. I would like to do something to get rid of the fly by night mixers which, despite what has been said in this workshop, do exist. I would add to the oxygen analysis bullet, which is the fifth one down, that oxygen analysis should be performed by the dispenser and verified by the end user.

M. Lang: Does everybody operate that way?

R. Moon: Verification I think we understood did not necessarily mean analysis, but the gas should be verified in some way by either observing the analysis or performing it oneself.

M. Lang: Care to re-phrase that suggestion?

R. Moon: Oxygen analysis of the breathing gas should be performed by the dispenser and verified by the end user.

D. Rutkowski: IANTD will agree with that statement from Richard Moon.

E. Betts: That's a standard procedure. ANDI agrees with that.

D. Kesling: Sometimes those two processes don't happen simultaneously. That's the only caveat that I would try to clarify.

B. Bjorkman: The person mixing the gas isn't necessarily the person dispensing it.

M. Lang: Should dispenser be changed to mixer?

B. Bjorkman: Or blender.

M. Lang: Blender/dispenser/mixer.

J. Hardy: Provider?

M. Lang: Provider is not necessarily the person who mixed the gas. You always have to have the person mixing the gas analyzing the gas.

J. Hardy: Bill could probably talk to that, but from a legal point of view, the dispenser would be the shop owner.

M. Lang: Bill Turbeville, which term would you prefer? Blender, dispenser or mixer?

T. Mount: The point is the mixer has to verify it, but the dispenser is the person who would probably be legally liable.

B. Turbeville: They're all legally liable at some level. The question is on whom do you want to place the greater burden? If we say that the end user has to verify, that places some of the burden upon the end user, but by no means all of it. The fact is that they're creating a product. They cannot get rid of all the liability. They can only get rid of some liability. In terms of the definitions, that's not for the lawyers to say, that's for the training agencies and for the participants to define.

D. Kesling: There are three phases that now come to mind. You can have the glass blended and delivered by a supplier. You can have a person in the next phase dispense that gas to an end user and then, of course, the end user. Operationally, there could potentially be a potentially three-level process.

K. Shreeves: Let me suggest then that the way it's written right now is exactly what we need to say.

E. Betts: The possibility that the dispenser and the blender is one and the same person, is covered there. We want to say that the gas mixer or the one who creates the breathing medium analyzes the gas. Then we're attempting to transfer liability to the end user by saying the end user has to verify the mix. We are trying to cover the ground, but I want to acknowledge the fact that you could have three different phases here.

A. Marroni: Why don't you simply word it by the blender, the dispenser, and verified by the end user?

M. Lang: That then automatically puts three phases in the process. Does everybody recognize three phases in their operations?
A. Marroni: They can coincide.
D. Kesling: Put blender and/or dispenser and then verified by the end user.
M. Lang: Would that work?
E. Betts: That would work.
M. Lang: Show of hands, alright. Is there anything anyone would like to suggest that we haven't covered in the recommendations? Otherwise, we're going to close this file and solicit any final comments.
D. Kesling: The sequence in the analysis process should be blender, dispenser, and verified by end user.
M. Lang: Fair enough. That concludes this part of the recommendations.

E. Forsyth: When we refer to standard scuba equipment, could we add the words "with traditional materials"? We don't necessarily have to say, *e.g.*, brass, but that's what we're talking about. We've done tests on some of the new lighter metals, aluminum and titanium. They're going to support combustion at concentrations below 40 percent at pressures in the 300 to 400 psi range. I would recommend saying standard scuba equipment using traditional materials.
M. Lang: No? Some heads are shaking no. We have to recognize that we've already been through these as consensus recommendations and we're starting to lose people now from this workshop.
S. Angelini: The one thing we are not addressing there is whether it has to be cleaned, aside from being standard.
B. Hamilton: Can we insert the word "cleaned" in front of standard scuba equipment?
M. Lang: How do you define clean? Elliot, sorry, but this was a process and it was a minor point you brought up. We've been through these recommendation bullets and have agreed on them. We're at the point in this workshop where we can't modify them.
T. Mount: I was going to say we've already voted on them.

M. Lang: Any final comments or suggestions? With regards to the DAN Nitrox Workshop Proceedings. I have most papers on file electronically. If there are other items or revisions for consideration, they need to reach me within one week. Otherwise, we're not going to be able to keep our schedule of having this document available for DAN distribution at DEMA.

M. Emmerman: The statistics shown yesterday indicate a non-issue with reference to DCS and nitrox diving. However, I believe that both Ed Thalmann and Bret Gilliam are correct. Ed is correct that the statistics are not scientific data. Bret is correct in that the statistics paint a clear picture of a non-issue. If the industry desires to have scientific data to hang our hats on, we have two major road blocks. First, there's not enough money in the industry to support lab tests and secondly, the Institutional Review Board's protocols on testing certain dive sequences would restrict our testing. However, we do already have in place a qualified method for gathering data. DAN's Project Dive Exploration effort has trained Field Data Coordinators who could focus on specific nitrox-related questions.

R. Vann: We have heard from a number of people that decompression is a non-problem. I've heard that from Bret Gilliam and also from Peter Bennett. That's a nice point of agreement. No matter how you spin it, the reason we are here today is because there aren't enough data to clarify the issue in the minds of reasonable people that nitrox is a problem. This also exists for other areas in decompression. Reverse dive profiles were examined recently. Flying after diving, dive computers and rates of ascent are all decompression-related issues that are non-problems. This is not just limited to the recreational and scientific communities. This is also true for the U.S. Navy. For the last 10 or 15 years, I've heard from the Navy that the Navy is no longer funding decompression research because it is a non-problem. Nevertheless, for the last 20 years the Navy has spent millions of dollars of your taxpayer money, and employed the best minds to come out with new tables in 1992, which were rejected by the master divers because decompression is not a problem. In spite of all this, we still see at UHMS meetings and at the Aerospace Medical meetings that decompression is always on the agenda in a big way. Decompression is the non-problem that doesn't seem to want to go away. Why is this? It's because the incidence of decompression sickness is very low as long as we dive in the area of 60 feet for 30 minutes. The problem comes up when we get towards the limits of the algorithms or when we try to do something new and different like nitrox, reverse dive profiles, flying after diving, dive computers or slower ascent rates. There's another part of this whole issue that really hasn't been addressed and that has been the sniffing of the green gas after diving. I first learned about this from Bret Gilliam in 1991 at the Repetitive Dive Workshop when he presented the Ocean Quest data and how little decompression illness there was. He had quite a few people who were sniffing that green gas and I certainly hope it was DAN oxygen that he was using. I've also learned more recently that there are other folks who are doing this. A large liveaboard diving operation and a cave diving operation. Since this is anecdotal, I'm not going to mention who these people are. These are significant issues that suggest that maybe there's something there that's been swept under the rug. Decompression is a non-problem that won't go away. We can continue these meetings and continue the exchange of the thousands of expert opinions, or we can begin to work together to collect data under Project Dive Exploration. I should also mention Project Safe Dive that Alessandro Marroni is running in Europe, which is effectively very similar. We have to decide if we want to do it and how to do it so it's done practically and economically. I offer this modest proposal: I would suggest a training meeting to discuss how training should be done and how the whole project should be run in February. I also suggest that training agencies might pick your respective data collectors. They must be computer literate, motivated and enthusiastic. Also, select your collection sites. We could discuss how it would be done as well as train in February with the goal in mind of beginning data collection in the next diving season in the summer. If we can't agree to do something like this, I certainly will enjoy seeing you again at meetings of this nature in the future.

B. Wienke: On NAUI's behalf, I would like to strongly endorse that suggestion.

R. Moon: All the computers I use do not use the file you use for downloading.

R. Vann: I should add that the other computer manufacturers are coming along. It's unfortunate we didn't have representation from more of the computer folks here because they're getting there. They will be here and this would encourage them. In the meantime, we can work with computers from Uwatec, Suunto, and Cochran, expecting the others to be on board. It's such a huge data management problem.

A. Marroni: Thank you for mentioning Project Safe Dive. As you know, we've changed the name as well to DSL, Diving Safety Lab. We are doing it with the help and support of Uwatec that's supplying us with 300 computers. We are already doing a sub-project of the research that concerns nitrox and are collecting nitrox dives.

DAN Nitrox Workshop Consensus Recommendations

For entry-level, recreational open-circuit nitrox diving:

- No evidence was presented that showed an increased risk of DCS from the use of oxygen enriched air (nitrox) versus compressed air.
- A maximum PO_2 of 1.6 atm was accepted based on its history of use and scientific studies.
- Routine CO_2 retention screening is not necessary.
- Oxygen analyzers should use a controlled-flow sampling device.
- Oxygen analysis of the breathing gas should be performed by the blender and/or dispenser and verified by the end user.
- Training agencies recognize the effectiveness of dive computers.
- For recreational diving, there is no need to track whole body exposure to oxygen (OTU/UPTD).
- Use of the "CNS Oxygen Clock" concept, based on NOAA oxygen exposure limits, should be taught. However, it should be noted that CNS Oxygen toxicity could occur suddenly and unexpectedly.
- No evidence was presented, based on history of use, to show an unreasonable risk of fire or ignition when using up to 40% nitrox with standard scuba equipment. The level of risk is related to specific equipment configurations and the user should rely on the manufacturer's recommendations.

M. Lang: Barring any other comments, I want to thank you again, on behalf of the Divers Alert Network Board of Directors, for your participation. This has been a successful use of our time and we look forward to the proceedings publication. Thank you for your support.

Appendix A. DAN NITROX WORKSHOP PARTICIPANTS

Name	Organization	e-mail address	phone number
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Dan Orr	DAN		
Klaus Torp	Duke Medical Center		

APPENDIX B. DAN NITROX WORKSHOP AGENDA

Divers Alert Network

NITROX WORKSHOP

AGENDA

Friday, November 3, 2000

I. Introduction

9:00 - 9:10	*Welcoming Remarks*	Michael A. Lang
9:10 - 9:25	*Enriched Air Nitrox History*	R.W. Bill Hamilton

II. Nitrox Operational Data

9:25 - 9:45	*Nitrox Data Review*	Richard D. Vann
9:45 - 11:30	Nitrox Organizations	
	A. *Recreational Training*	Ed Betts, Bret Gilliam, Jon Hardy, Tom Mount, Drew Richardson, Dick Rutkowski, Bruce Wienke
	B. *Other Organizations*	Bart Bjorkman, Chris Borne, Dave Dinsmore, Doug Kesling, Walt Jaap.
	C. *Liveaboard Diving*	Evin Cotter, Avi Klapfer (data).
11:30 -12:00	**DISCUSSION**	
12:00 - 1:00	Lunch	

III. Nitrox Physiology

1:00 - 1:30	*Nitrox and CO_2 Retention*	Dan H. Kerem
1:30 - 2:00	*Maximum PO_2 Limits Discussion*	Michael Lang
2:00 - 2:30	*Testing Nitrox as a Product: Effects*	Jon Hardy
2:30 - 3:00	**DISCUSSION**	
3:00 - 3:20	Break	

IV. Risk Management Issues

3:20 - 3:40	*OSHA Nitrox Variance*	Bill Turbeville and Karl Shreeves
3:40 - 4:00	*Nitrox Legal Considerations*	Jon Hardy and Bill Turbeville
4:00 - 4:20	**DISCUSSION**	

V. Nitrox Curriculum

4:20 - 5:00	**WORKSHOP DISCUSSION**	Michael Lang
5:30 - 8:00	***Reception at Divers Alert Network***	

Saturday, November 4, 2000

VI. Nitrox Equipment

9:00 - 9:10	*Equipment Manufacturers Issues*	Bill Oliver
9:10 - 9:40	*Oxygen Compatibility - 40% rule*	Elliot Forsyth
9:40 - 10:00	*Nitrox Compatible Dive Computers*	Jon Hardy
10:00 - 10:20	**DISCUSSION**	
10:20 - 10:40	Break	

VII. 10:40 – 12:00 **Final Discussion & Recommendations**

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