American Nitrox Divers, International.

Complete SafeAir© User

INSTRUCTORS
MANUAL

10

Author

Edward A. Betts

American
Nitrox
Divers
International

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FORWARD

"It's rare that a breakthrough in diving is implemented by an overnight invention. The practice of enriched air diving has been around for over two decades but it took the vision of a few dedicated professional instructors to introduce its benefits to sport divers. The work of Ed Betts and American Nitrox Divers, Inc. to produce this text and a national training network for ANDI divers will be remembered as one of the more progressive innovations of the 1990's. The SafeAir© program which you are currently enrolled in will open your eyes to the many operational and safety advantages over conventional air scuba diving. Consider yourself lucky to have obtained training from enlightened, progressive scuba professionals who are committed to making the best applications of available technology in the pursuit of increased diving safety and enjoyment."

Bret Gilliam
President, OCEAN TECH

"The knowledge and technology to improve diver performance and reduce the risk of decompression sickness has been available for years. Most of us simply did not have access to it. After reading this book, and hopefully attending an ANDI training program, you will become aware of one rather startling fact! If you had the choice, you would never again have your cylinders refilled with air. The availability of SafeAir© may slow you down for now, but as knowledge spreads and demand increases, your local scuba center will offer a variety of superior breathing gases. SafeAir© is finally here to stay! I certainly hope that this book becomes a useful tool to provide you with safer diving. It's the best source I have come across to date for both the sport diver and the instructor."

Dr. Lewis Kohl
Deputy Director
Dept of Emergency Medicine
Kings County Hospital Center
Brooklyn, New York

Instructors Manual

Prepared and edited

by

C. Douglas Pettit

Executive Vice President ANDI

ABOUT THE AUTHOR

ED BETTS

Ed Betts formed American Nitrox Divers, Inc. (ANDI) in 1987. He is Executive Vice President, Manager of operations and instructor trainer for oxygen enriched air diving programs and procedures. Ed is also founder and General Manager of Island Scuba Centers, inc.. Ed established Long Island's oldest full service scuba facility in 1968.

He is Executive Vice President of ISC Management Corp., a management and systems consulting firm. They are involved in all phases of computer hardware and software installation, also business management, consulting and training. The Corporation also designs and installs specialty gas delivery systems. During the period of 1984-1987 he engineered, fabricated and installed a high pressure, ultra dry, ultra pure gas distribution system for The Peoples Republic of China (on site for their high tech space optics program). This included training of “PRC” technical staff in the U.S.A. during 1986.

His diving experiences started in 1963 and he is now currently certified as an Open Water Instructor by: The National Association of Underwater Instructors (NAUI), Professional Association of Diving Instructors (PADI), Center for Underwater Research (CURE). He is also a NASDS Open Water Instructor Trainer #009, and American Nitrox Divers Inc. (ANDI) Instructor Trainer #001.

He also operated an ocean going salvage vessel and dive boat for ten years.

Ed has over 3700 logged dives and over 3200 hours of logged bottom time. He has personally certified over 2500 students to various levels of sport diving certification and is a certified instructor for almost every advanced specialty. Ed has considerable experience in the use of alternate breathing gases and teaches a Tri-mix program for "Deep Explorers".

ACKNOWLEDGEMENTS

Chris J. Lambertsen, M.D., Director
Institute for Environmental Medicine
University of Pennsylvania
Philadelphia PA 19104

Who first suggested as early as 1943 that mixtures of nitrogen and oxygen could be used to reduce decompression. He has been a pioneer in diving research for over 50 years.

J. Morgan Wells, Ph.D., Director
NOAA Diving Program - Room 304
6001 Executive Boulevard
Rockville MD 20852

He began to deploy this concept to the scientific community in the early 1970's. He also converted the EAD idea to a standard set of decompression tables known as NOAA NITROX I Tables, and has now developed the NOAA NITROX II Tables.

Richard Rutkowski
Hyperbarics International
490 Caribbean Drive
Key Largo FL 33037

For his guidance in bringing Enriched Air Technology to the sport diver.

The National Undersea Research Program, NOAA/NURP
Rockville MD 20852
David B. Duane, Director
Elliott Finkele, Past President
Bill Bush, Ph. D.

For their support and interest in this concept, through workshops and Doppler studies to verify the validity of this concept.

The United States Navy Department
Washington DC

For publishing this concept as early as 1959 in the USN Diving Manual for use with their MK-6, semi-closed rebreathers and to the Navy divers who have applied Enriched Air Technology.

American Nitrox Divers International
Freeport, NY 11520

For getting the concept out to sport divers,in a standardized format so that they can start using Enriched Air Mixtures.

Bill Hamilton Ph. D
Hamilton Research Ltd.
80 Grove Street
Tarrytown NY 10591-4138

For his Support and Advice.

Stephen Mastro
NOAA Undersea Research Program
University of North Carolina at Wilmington
Wilmington NC 28403

For his support of this concept from the onset, and his contributions and critique. NURP/UNCW has worked closely with NOAA to implement this technology.

ANDI INSTRUCTOR PROCEDURES

COURSE TITLE :

The Application of Enriched Air Mixtures

CERTIFICATION TITLE :

ANDI Complete SafeAir© User

ROLE DEFFINITION :

The ANDI Complete SafeAir© User can dive using any SafeAir© mixture and using any approved ANDI application.

LIMITATIONS :

The absolute maximum depth approved for use by ANDI Complete SafeAir© Users is 46 MSW (150 FSW). The absolute maximum exposure to oxygen, approved for normal dive (non-emergency) profiles is 1.6 BAR PO_2 (1.6 ata).

COURSE OVERVIEW :

The course consists of two parts. Part 1 is comprised of five theory modules and when completed, a Part 1 certificate is to be issued. The Class Modules are :

- CM 1) The History and Development of SafeAir©
- CM 2) Oxygen and the Diver : A Discussion of the Pathophysiology of Oxygen
- CM 3) Mathematical Principles of Gas Mixtures
- CM 4) The Equivelent Air Depth Formula and Mixture Application
- CM 5) SafeAir© Equipment Handling and Gas Analysis

Part 2 is comprised of the following practical application topics or exercises to be supervised and evaluated by the ANDI instructor :

- a) gas analysis and record keeping ,
- b) dive planning skills,
- c) a demonstration of a thorough understanding of the Part 1 information (exam) and to,
- d) enjoy two reccommended, ONE required open water experience utilising any of the approved applications detailed in CM 4 .

ANDI INSTRUCTOR PROCEDURES

APPROXIMATE THEORY TOPICS DURATION :

8 - 10 hours

MINIMUM INSTRUCTOR REQUIREMENTS :

ANDI Instructor with " Active Teaching " status.

INSTRUCTOR MATERIALS REQUIRED :

a) ANDI Complete SafeAir© Users Instructor Manual,
b) ANDI Complete SafeAir© Users OHP or 35mm slides set training aids,
c) ANDI Charts and Graphs as training aids,
d) ANDI sample kit of educational and promotional products,
e) SafeAir© cylinder, properly marked and labeled,
f) gas sampling device and oxygen analyser,
g) SafeAir© compatible breathing system with ANDI designation sleeves,
h) class roster with ANDI C - card registration forms,
i) Part 1 completion diploma for ANDI Complete SafeAir© User.

STUDENT PREREQUISITES :

Any certified diver holding certification, (open-water rated or equivelent) from any recognised training agency. The candidate should be able to present a log book showing current diving activity and diving experience of not less than 10 dives. This program may be combined with any other advanced level course or activity, i.e. wreck diving, cave diving, deep diving, etc.

STUDENT MATERIALS REQUIRED :

a) ANDI textbook/workbook entitled "The Application of Enriched Air Mixtures " by Edward A. Betts. An exception to this mandatory requirement would be offered if the ANDI text/workbook was not available in the students native language.
b) notepaper and writing implements
c) an electronic calculator
d) appropriate diving equipment and SafeAir© mixture for completion of Part 2
e) training and diving logbook.

ADMINISTRATION :

a) have the student complete the certification registration form
b) have the student sign the statement of understanding (transfer of liability)
c) include a student identification photo (3.6 x 3.6 cm or 1.5 x 1.5 in.). The instructor or facility should ask for the photo when the student first registers for the course.
d) collect all required course fees. Since the program consists of two parts, the certification fees SHOULD BE ADDED TO THE COST OF PART 2 . The section entitled "Referral Procedure" clarifies this procedure.
e) award a certificate of completion to all students successfullt completing PART 1 (classroom/theory).

f) the instructor is to have the students sign their completed exams. Instructors/ facilities should retain these completed exams for a period of not less than three years.
g) upon successful completion of all ANDI requirements , the instructor is to submit the completed application form, photo I.D. and appropriate payment to ANDI's regional representative or ANDI's Home Office for processing.
h) ANDI instructors and facilities agree to offer their students the opportunity to audit this class for no fee. Other ANDI facilities' students may attend this course at no more than 1/2 of the standard classroom fee. Proof of completion of this course's classroom attendance is required. Either a classroom certificate or a certification card is the only proof of completion acceptable.

PART 2 PROCEDURE :

Part 2 is comprised of the following practical application topics or exercises to be supervised and evaluated by the ANDI instructor :

a) gas analysis and record keeping. The ANDI Gas Mixture Validation Book, in the standard format is required at ANDI refill stations.
b) dive planning skills. The ANDI instructor is required to approve of the SafeAir© application chosen.

c) a demonstration of a thorough understanding of the Part 1 information. This is to be accomplished by completing the exam questions located at the back of the text/workbook. These questions are those that make up the final exam. This exam may be completed as an "open book test", a verbal discussion between the instructor and students or a closed book exam. In the event that the instructor elects to administer a formal exam, this exam must be reviewed by the student and all incorrect answers must be discussed and then corrected by the student. In any case, it is the responsibility of the certifying instructor to determine the students ability to employ all approved ANDI SafeAir© applications. Remember that the C Card being issued is "ANDI Complete SafeAir© User ". If the student cannot perform the mathematics or table usage required, the student should be certified as ANDI Limited SafeAir© User.

d) enjoy two reccommended, ONE required open water experience utilising any of the approved applications detailed in CM 4 . It is strongly suggested that two repetetive dives be completed using SafeAir© to effectively re-enforce the benefits of SafeAir© diving. If physical or environmental limitations do not permit the completion of the second dive, certification need not be witheld. However the ANDI instructor is required to organise the open water activity to encourage and permit the completion of the two reccommended repetetive dives.

REFERRAL PROCEDURE :

An ANDI classroom certificate was awarded to all students upon completion of the classroom/theory (Part 1) requirements. The candidate must present the Classroom Certificate to the training facility or instructor as a prerequisite to enrollment in Part 2 of this program. The time interval between the completion of Part 1 and the commencement of Part 2 must be 9 months or less.

If the above mentioned interval is greater than 9 months the student/candidate must re-attend a Part 1 session prior to the practical application portion (Part 2).

Part 2 must be conducted in the prescribed format. The certifying instructor is the instructor who conducts Part 2 training.

All certification fees should be included in the Part 2 retail fees and are the responsibility of the certifying instructor.

NOTE : The term " Part 2" is specifically used instead of the term "open water" to emphasise the fact that there is more to this procedure than "going diving". Refer to "Part 2 Procedure".

Classroom Module 1
The Development and History of Oxygen Enriched Air

Objective:

Instructor Note: The ANDI SafeAir© program. Is just a new specialty program. It is not focused on "technical diving" but is geared primarily for the recreational diver at all levels. Certainly if one has inclinations to pursue activities beyond the recreational guidelines then this program is a definite prerequisite.Remember that ALL LEVELS of divers may benefit from this information if it is presented properly.

A. Upon completion of this module, the students will be able to describe or define:

1. Why Sport Divers should use SafeAir©.
2. The evolution from Air to NOAA NITROX (SafeAir©).
3. The benefits of SafeAir©.
4. NOAA Nitrox I and NOAA Nitrox II.

Materials:

A. ANDI Instructors Manual.

B. Blackboard, chalk, eraser or substitute.

C. Class roster, student folders and test questions. Each student must have the ANDI text/workbook.

D. ANDI slide presentation (optional)

Introduction:

A. Establish Contact.

1. Introduce self.
2. Introduce subject - Introduction to Oxygen Enriched Air / "SafeAir©." Outline topics to be discussed.

B. Create Interest.

  1. We are now entering a new era in sport/recreational diving.....

C. Stress Value.

  1. Enhances diving safety and enjoyment.
  2. Applicability of SafeAir© for all sport diving situations (40 feet to 130 feet).

OVERVIEW:

INSTRUCTOR'S NOTE: suggested elapsed time - 75-90 minutes.

A. Subject Matter of the Class.

  1. Explanation and review of No Decompression Limits derivation.
  2. Ten factors that predispose a diver to decompression sickness.
  3. Explanation of the history of Oxygen Enriched Air. What is SafeAir
  4. Applicability of SafeAir© for sport diving with decompression computers.
  5. Explanation of the various mixtures of SafeAir© (NITROX I & II). Technically speaking there are 28 flavors of SafeAir©
  6. Benefits of Safeair© and future developments.

B. Student Conduct.

  1. Please take notes.
  2. Ask questions any time.
  3. There will be a written test developed from this material at the end of this course. We will be completing sample problems through-out the program.
  4. You should review the previous material at the end of the chapter.

Presentation:

(Instructor Note: Ask your students if they know how the "No Decompression Limits" were derived. Spend a little time to figure out if they know the basic diving physiology that applies to the No Decompression Limits. If possible, use this section to gauge the level of the class. this material has real value as a review and also to explain more fully information not covered or understood in their prior training.)

A. PHYSICS AND PHYSIOLOGY REVIEW OF THE NO DECOMPRESSION LIMITS

1. What does it mean to be saturated with nitrogen?

   THIS MEANS THAT THE INTERNAL PARTIAL PRESSURE OF NITROGEN IN YOUR TISSUES WILL EQUAL THE EXTERNAL PARTIAL PRESSURE OF NITROGEN IN THE SURROUNDING MEDIUM.

2. How long does it take a diver to become saturated with nitrogen at a given depth?

   24 HOURS

3. What does the term *gradient* mean?

   THE TERM GRADIENT REFERS TO THE DIFFERENCE BETWEEN THE INTERNAL PARTIAL PRESSURE AND THE EXTERNAL PARTIAL PRESSURE OF A GAS. THE GRADIENT IS EQUAL TO ZERO WHEN YOU ARE SATURATED.

4. What term describes the physiological condition of a diver ascending from depth with an internal partial pressure of nitrogen greater than the external partial pressure of nitrogen?

   SUPERSATURATION.

5. What would be the physiological effect of bringing a diver up from depth if the partial pressure gradient is too large?

   THE NITROGEN WILL COME OUT OF SOLUTION AS BUBBLES INTO THE TISSUES AND BLOOD STREAM RESULTING IN POTENTIALLY SERIOUS TISSUE DAMAGE.

6. Who discovered that the human body could withstand a certain level of supersaturation without ill effect?

   J. S. HALDANE

7. What was the nature of Haldane's discovery?

   HALDANE DISCOVERED THE TOLERANCE LEVEL FOR NITROGEN SUPERSATURATION IN THE HUMAN BODY. HE THEORIZED THAT THE BODY COULD ~~WITHSTAND A 2:1 TISSUE GRADIENT.~~

8. Based on Haldane's discovery, up to what depth could a diver stay for 24 hours and ascend without having to decompress?

   33 FEET OR 10 METERS (2 ATMOSPHERES ABSOLUTE).

DEVELOPMENT OF THE U.S. NAVY TABLES.

9. The 2:1 tissue gradient became the basis for the U.S. Navy basic tables' research.

10. clearly if a diver were to go deeper than 33 feet ,10 meters or 2 atmospheres,(all the same) the diver can no longer spend an unlimited amount of time underwater.

11. It is also clear that the deeper the diver operates underwater, the less time the diver can spend underwater and ascend safely without having to decompress.

12. The U.S. Navy then began empirical testing on human divers based on Haldane's principle.

13. Using the Experimental Diving Team (composed of male divers condition), the No Decompression Limits were established by placing divers at a given depth for a prescribed period of time, bringing the divers directly to the surface, and waiting to find if the divers had decompression sickness.

14. The amount of time a diver can spend at a given depth and proceed directly to the surface without having to decompress is based on the amount of time it takes for various body tissues to reach the 2:1 gradient.

15. It must again be highlighted that the No Decompression Limits were established by U.S. Navy divers who were all males of various ages and body types. No testing of females was ever performed.

16. The Navy also discovered some divers (approximately 5% to 7%) contracted decompression sickness when they dived to the No Decompression Limit performing full square profile dives.

In 1976 Dr. Merrill Spenser of the Institute of Applied Physiology and Medicine in Seattle published a report recommending that the present no decompression limits be reduced. This was based upon ultrasonic bubble detection studies (Spenser 1976).

Further studies by Dr. Andrew Pilmanis at Catalina Marine Science Center supported this recommendation. He found venous gas emboli or silent bubbles (VGE) in 100% of subjects exposed to 100 FSW (33 MSW) for 25 minutes. (From Karl E. Huggins "Doppler evaluations of Multilevel Dive Profiles" 14th International Conference of Underwater Educators 1983). The term VGE was subsequently changed to venous gas event as no blockage occurs.

We must therefore be conservative in our dive planning to ensure a certain time cushion (at least 5 minutes) so that we do not push the No Decompression Limits.

B. Here are other factors to consider in your approach to providing yourself with a time "safety cushion." Consider your physical condition carefully. Here are some factors predisposing a diver to decompression sickness:

1. Poor or impaired circulation or any factor that contributes to the condition. Factors such as obesity, higher lipid content, physiologic ageing, prior history of DCS, prior trauma (injury), smoking and excessive cold are among these factors.

2. Excessive carbon dioxide build-up (hypercapnia) is a prime factor to be considered. Some causes may be from poor physical condition, excessive exertion or inefficient and/or improperly tuned breathing equipment.

Instructor Note: do everyone a favor and stress the importance of preventative maintenance on life support equipment.

3. Forceful movement of muscles and joints under increased ambient pressure.

4. Consumption of alcoholic beverages before the dive and upon completion of the dive.(Alcoholic consumption should be stopped at least 12 hours before the dive and at least 12 hours after the dive.) Alcohol reduces surface tension of the blood and its presence alone can cause bubbling that would not otherwise not occur.

5. Loss of body fluids. Dehydration caused by any of the following:

    a. Seawater immersion. This dehydrates through osmosis.

    b. Production of urine - immersion diuresis

    c. Breathing dry air

    d. Perspiration and evaporation

    d. Cold. When a diver gets cold blood is shunted from the extremities

    e. Caffeine and alcohol. Both, but by different mechanisms.

    f. Drugs and medication. Many are diuretics and one should check with a physician on whether it would contribute to dehydration

    g. Seasickness. This rapid loss of body fluids is very serious and should be prevented whenever possible

    It is important to intake fluids, but the type of liquid should be chosen to limit caffeine. Soft drinks are often composed of carbonic acid, phosphoric acid and caffeine. Drinking "Gatorade" is usually putting back more salts and electrolytes than diving removes. If you choose to drink these types of fluid, drink plenty of water to keep things in balance. Drink water BEFORE going diving to allow the body time to distribute the fluid.

6. Ignorance of or lack of knowledge about any of the forgoing. The motto "Safety through Education" certainly applies here.

Obviously, from all this we can easily understand why we would want to reduce the partial pressure of nitrogen. Safer dive profiles or longer bottom times are the result of lowering the internal tissue gradient of nitrogen.

C. THE HISTORY OF OXYGEN-ENRICHED AIR

1. It has been long understood that by lowering the nitrogen content, divers could extend the no Decompression Limits and reduce the time needed for decompression.

The use of oxygen to shorten the time required for decompression was first mentioned by Paul Bert in 1878. It was investigated further by Ham and Hill in 1905.

1939! Christian J. Lambertsen Ph.D. designed the first oxygen rebreather. 1939 began the use of oxygen enriched air in diving applications. Dr. Lambertsen is still affiliated with the Institute of Environmental Medicine at the University of Pennsylvania.

The U.S. Navy has used oxygen enriched air in the MK6 diving system since 1962.

In fact, in relation to Sport Diving instruction, one of the first training manuals used in Scuba instruction mentions in its 1957 edition on page 77:

"Of course, air is a nitrogen-oxygen mixture. Its main drawback is the amount of nitrogen it contains and what this means in terms of decompression. The most obvious way to remedy this is to boost the amount of oxygen present. If you cut the nitrogen percentage in half (40 percent nitrogen - 60 per cent oxygen), you could theoretically double your absolute depth* as far as decompression limits are concerned." (New Science of Skin & Scuba. 1957, copyright Association Press.)

* It states absolute depth, but it should refer to time.

The primary question was how much oxygen to add and, of course, what effects it would have.

In 1970, Dr. Morgan Wells, Ph.D., Diving Officer for the National Oceanographic and Atmospheric Administration (NOAA) began experimenting with oxygen enriched air during diving operations. He standardized the mixture and called it NOAA NITROX I and developed the standard NITROX diving tables. NITROX II tables are also currently available. They were published in 1990 by NOAA through the efforts of Dr. Wells.

Richard Rutkowski retired from NOAA with 33 years of service in 1985. He has served as Deputy Diving Coordinator. He was founder and director of the NOAA Diving/Hyperbaric Training and Diver Treatment Facility. He began teaching what he called "Nitrox Diving" for sport divers in 1987 and is directly responsible for this major advancement in the Sport Diving Industry.

Ed Betts and Doug Pettit joined Dick Rutkowski in 1988 and formed American Nitrox Divers, Inc. ("ANDI") to standardizing Instructor Training, Sport Diver Training, and refill station dispensing procedures. Ed Betts, a multi certified Scuba Instructor since 1970, has worked to take this program nation wide. This training program is a result of his efforts. In 1989, the National Association of Scuba Diving Schools ("NASDS") became the first national training agency to endorse this training program due to Ed's efforts..

D. DIVING COMPUTERS and SafeAir©

Sport Diving has undergone a major advancement with the introduction of the various types of Diving Computers. These computers are true microprocessors that do literally thousands of calculations per dive. They calculate the tissue gradients at each depth attained, not the maximum depth attained. This results in two significant factors:

a. The No Decompression Limits extended beyond the U.S. Navy tables for the same dive profile.

b. The 2:1 tissue gradient is more closely approximated.

The computer dive profiles are definitely not considered **SAFER** than the same dive profiles derived from the U.S. Navy Diving Manual. Table rounding rules are, of course included in computer profiles.

Computers are now a reality in today's diving. Many concerned Instructors feel that they do nothing more than move the divers closer to the 2:1 gradient and therefore minimize the safety factors built into our table usage rules. As we will learn later in the training program, divers using SafeAir with dive computers are adding back far more safety factors than the computer takes away. It should be obvious from this that using a dive computer with SafeAir© is a reliable way to extend bottom times beyond the standard NO DECOMPRESSION LIMITS without eliminating the safety margins that table rounding practices provide.

E. WHAT IS NITROX?

1. Any mixture of nitrogen and oxygen is Nitrox. The term "NITROX" was always used to describe mixtures containing LESS OXYGEN than air. Many today use NITROX as a general term for oxygen enriched air. This is not technically correct. Any mixture of nitrogen and oxygen is nitrox, just as any mixture of helium and oxygen is called heli-ox. The term "OXYGEN ENRICHED AIR" is the most correct term to describe what it is we are talking about. EAN (Enriched Air Nitrox) is now becoming the general term most used to mean "nitrogen/oxygen mixtures containing oxygen percentages between 22 and 50%". This training program will teach how to practically apply these mixtures to sport diving situations.

2. Air is a nitrox mixture consisting of:

78.05%	nitrogen
20.95%	oxygen
1.00%	rare and other inert gases

Instructor note : trace gases in air are Argon, 9340 ppm - Carbon dioxide, 314 ppm - Neon, 18 ppm - Helium, 5 ppm - Krypton, 1 ppm - Xenon, .09 ppm and varying amounts of water vapor.

F. WHAT IS SafeAir©

1. Any mixture of NITROX with O_2 concentrations from 22% to 50%. (Enriched Air Nitrox) Technically there are 28 flavors of SafeAir©. In 1989 ANDI copyrighted the term, SafeAir©. This was a reaction to the mis-information that "NITROX" was for deep diving, mixed gas diving or "the dentist's stuff". SafeAir is for recreational use and definitely not just high tech. ANDI instructors may accurately state:

   "It may be NITROX but if it isn't ANDI ....it isn't SafeAir© "

   a. NOAA Nitrox I is air to which the oxygen concentration has been increased to 32 %. That results in mix containing 68% nitrogen and inert gases and 32% oxygen. The tolerance level allowed for oxygen is ± 1%. We include the 1.05% rare and other inert gases as part of the nitrogen content. This rounding up of the nitrogen content adds a slight but additional safety factor to the dive calculations, which we will be learning further on in the training program. NITROX 32, SafeAir© 32 and EAN 32 is the same gas as NOAA NITROX I.

b. NOAA Nitrox II is air to which the concentration of oxygen has been increased to 36%. We have with 64.0% nitrogen and inert gases, and 36% oxygen. The tolerance level of oxygen is also ± 1%. NITROX 36, SafeAir© 36 and EAN 36 are the same gas as NOAA NITROX II.

c. When gas mixtures are discussed, the inert gases are discussed first. 64-36 means the inert gas is 64%. In our specific application, our nitrox formula would be N_2 / O_2. SafeAir© 28, SafeAir© 40 and SafeAir© 50 are all different mixes of EAN that contain 28, 40 and 50 % oxygen concentration.

G. BENEFITS OF SafeAir©

1. We now know the answers to many questions that plagued the Nitrox pioneers!

   a. What changes in dive tables would be permitted by lowering the nitrogen content?

   Consider the following Charts

   b. What are the true limits of oxygen partial pressures?

   The answer to this question will be fully discussed in Class Room Module 2, "OXYGEN AND THE DIVER", our next classroom topic.

CHART 1 - 1

NO DECOMPRESSION LIMITS
SafeAir© - NOAA NITROX I & II AND AIR

		NO DECOMPRESSION LIMITSNO DECOMPRESSION LIMITS		
DEPTH FSW	**DEPTH MSW**	**AIR**	**NOAA NITROX I**	**NOAA NITROX II**
40	12	200	400+	400+
45	14	100	310+	400+
50	15	100	200	200
60	18	60	100	100
70	21	50	60	60
80	24	40	50	60
90	27	30	40	50
100	30	25	30	40
110	33	20	25	30
120	36	10	25	0
130	40	10	20	0

CHART 1-2

BREATHING MEDIA COMPARISON
Time limited by O_2 or N_2 limits - US Navy and NOAA Dive Tables

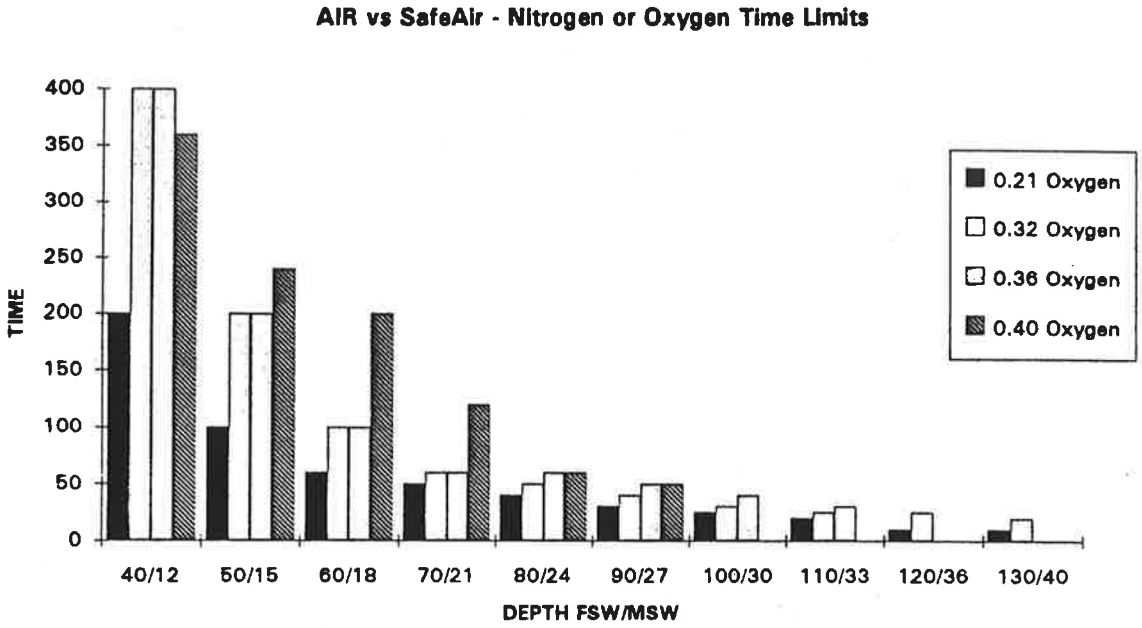
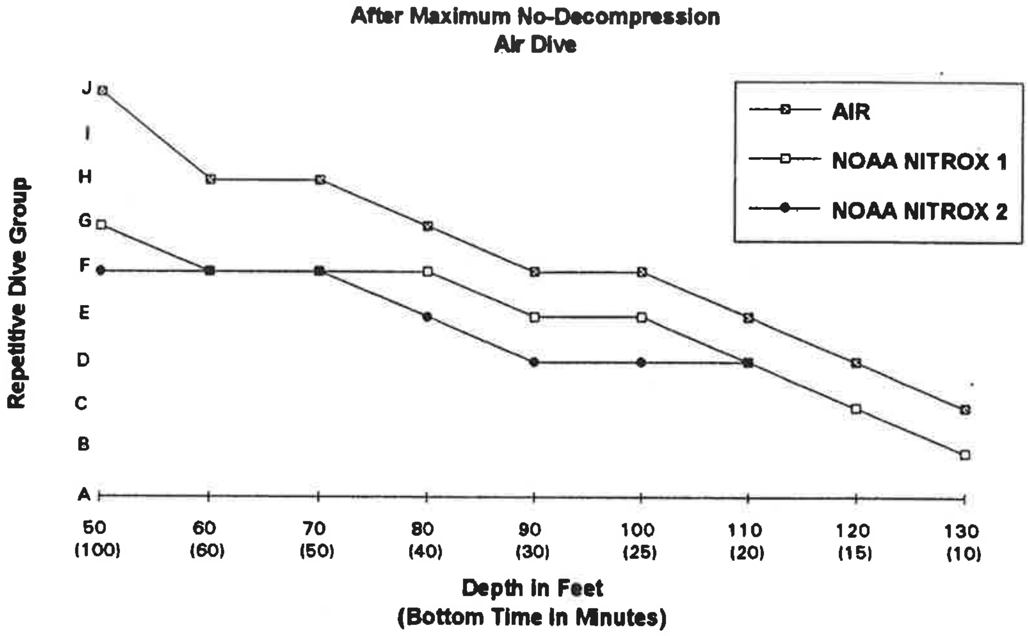


CHART 1-3

REPETITIVE DIVE GROUPS AFTER MAXIMUM NO-DECOMPRESSION DIVES



Instructor's Note: Discuss the charts with the class to affirm comprehension.

2. The effects of using oxygen enriched mixtures are:

   a. Extension of no decompression limits, which also reduces the probability of decompression illness (DCI) during no decompression diving.

   b. A reduction of required decompression time for dives exceeding the no decompression limits.

   c. A reduction of residual nitrogen within the body thereby reducing the required surface interval or increasing the allowable repetitive dive time or both.

   d. A marked reduction in the narcotic effects of nitrogen. This is especially noticeable in the 100 FSW (33 MSW) depths and deeper. This is subjective and requires more research. It is a fact that oxygen is more soluble than nitrogen in lipid tissue. This would seem to contradict the subjective reports. This is to be discussed further in the next section.

   e. A lower gas consumption rate may be noticed. Findings vary but, be aware that the savings are not due to physiology. Perhaps the calmer, more relaxed dive is the answer. Newer divers report greater savings. If breathing SafeAir© is perceived as a safer activity than the result may be a lower anxiety level in newer divers.

   f. The effects of any barotrauma may be reduced due to the improved microcirculation, enhanced oxygen - loading of blood plasma and a lower inert gas content of any free bubbles. More research is needed to properly identify the specific benefits with regard to pressure related injuries. It is believed by many that the diver would benefit from the higher oxygen concentrations.

   g. Most diver's report a post dive feeling of reduced fatigue levels and a calmer more relaxed dive. This subjective information suggests that sub-clinical decompression sickness (non-symptomatic) is reduced.

h. For dive profiles that require decompression, a more reliable decompression process will occur if the diver breathes a gas with a higher concentration of oxygen. "SafeAir© 50" is employed for this purpose.

3. The principal areas of SafeAir© usage

   a. Advanced level sport divers are currently taking advantage of the benefits of Safeair in the following areas:

      1. Wreck diving

      2. Cave diving

      3. Altitude diving

      4. Recreational diving (0 to 130 FSW in the U.S.A.) 0 to 50 MSW.

      5. Deep Diving (deeper than recreational limits) using EAN as a decompression gas.

   b. Other areas of diving have already benefitted from the safety and operational advantages offered by SafeAir©:

      1. Military operations

      2. Marine sciences

      3. Marine harvesting and Maraculturing

      4. Commercial diving operations

4. Future uses of SafeAir©:

   a. SafeAir© will be the breathing gas of choice for sport dives deeper than 40 FSW - 13 MSW.

   b. Dive computer capabilities will be expanded to be used with several nitrox mixtures. Orca Industries developed a "Delphi Nitrox II" in October 1990 and other models will follow. Dive-Rite began marketing the "Bridge" in 1993. Oceanic will be offering a full function EAN computer beginning in late 1993.

c. Additional tables will be developed to fit a wide range of Nitrox mixtures. ANDI has available a computer program that generates tables for every possible profile and mix. This material and procedures are discussed in ANDI's "Extended Range Diver" program.

d. ANDI refill stations will provide multiple SafeAir© mixtures.

e. All breathing gas for divers will be oil free, and produced in cleaner systems than ever before. Oil-less and oil-free compressors will become more commonplace.

f. Diving gases will be routinely analyzed for safety and efficiency.

g. In 1993 several equipment manufacturers began marketing EAN compatible equipment. The future is here.

h. SafeAir© usage will expand into aviation, tunneling, and other hypo/hyperbaric areas.

i. Tri-mix (N_2 / He / O_2) will become routine for moderate/deep diving. (160+ FSW- 48+ MSW)

j. Safe and effective methods for in water SafeAir© and oxygen decompression will be developed. The tables are already in use. (See "c" above).

k. Closed circuit rebreather systems will be available for both bi-mix (EAN) and TRI-MIX gases in the near future.

We are truly embarking on a new era in diving with the application of this technology.

Application:

A. Describe ten factors predisposing a diver to decompression sickness.

B. When was oxygen enriched air first used?

C. What is SafeAir©?

D. Define NITROX I . Define NITROX II. Define SafeAir© 32. Define SafeAir© 36.

E. What are the benefits of using SafeAir©?

Summary:

A. How the No Decompression Limits were derived.

B. Why sport divers may be predisposed to decompression sickness.

C. Applicability of SafeAir© for sport diving situations.

D. How SafeAir© can be used with computers.

E. Definitions of Nitrox I and Nitrox II and SafeAir© mixtures.

F. Benefits of using Safeair©.

Chart 1-4 US - METRIC - IMPERIAL MEASUREMENTS

NASA metric/Imperial equivalents

ATA	PSA	kPa	FSW	MSW	PO_2	Bar
1	14.696	101.33	0	0	0.209	0.98692
2	29.392	202.66	33	10.132	0.419	1.97384
3	44.088	303.98	66	20.265	0.628	2.96076

1 MSW =1/10 Bar

1 Bar = 1.01325 ATA

1 MSW = 0.101 ATA

1 MSW = 3.2568 FSW

1.0 Cubic ft = 28.311 Liters
1 Atmosphere = 760 mm Hg (mercury)

FSW ÷ 3.2568 = MSW

MSW × 3.2568 = FSW

1 kPa ~ 1/100 Atmosphere

33 FSW = 10.1326 MSW Pressure

1 FOOT = .3048 METER (DISTANCE NOT PRESSURE)

1 METER = 3.28 FEET (DISTANCE NOT PRESSURE)

INSTRUCTOR NOTE - DUE TO THE UNIVERSAL VALUE OF THIS INFORMATION WE ARE INSERTING MATHEMATICAL CONVERSIONS AND FORMULAS FOR YOUR REFERENCE

NITROX CLASSROOM MODULE 1
QUIZ

1. **List ten conditions or factors that predispose divers to decompression sickness.**

1)	6)
2)	7)
3)	8)
4)	9)
5)	10)

2. **When were enriched air mixtures first used?** ________________________

3. **What is SafeAir©?** ____

4. **What is Nitrox I?** _____________________________

5. **What is Nitrox II?** _____________________________

6. **What are the benefits of using SafeAir©?**

A) ____

B) ____

C) ____

D) ____

E) ____

F) ____

G) ____

CLASSROOM MODULE 1
QUIZ ANSWER SHEET

1. List ten conditions or factors that predispose divers to decompression sickness.

1) **OBESITY / HIGHER LIPID CONTENT**	6) **CO_2 LEVELS INCREASED**
2) **REDUCED CIRCULATION BY COLD, AGE, ETC.**	7) **ALCOHOL / DRUGS IN THE SYSTEM**
3) **EXCESSIVE EXERTION**	8) **DEHYDRATION / LOSS OF FLUIDS**
4) **POOR PHYSICAL CONDITION**	9) **COLD**
5) **FORCEFUL MOVEMENT**	10) **IGNORANCE**

2. When were enriched air mixtures first used? **1939 IN REBREATHERS**

3. What is SafeAir©? **ENRICHED AIR MIXTURES BETWEEN 22% AND 50%**

4. What is Nitrox I? **68% NITROGEN AND 32% OXYGEN**

5. What is Nitrox II? **64% NITROGEN AND 36% OXYGEN**

6. What are the benefits of using SafeAir©?

A) **EXTENSION OF NDC LIMITS**

B) **REDUCED DECOMPRESSION TIME**

C) **SHORTER SURFACE INTERVALS**

D) **EXTENDED REPETITIVE DIVE TIME**

E) **REDUCED NARCOTIC EFFECT**

F) **SAFER IF BAROTRAUMA EVER DID OCCUR**

G) **REDUCED SUB-CLINICAL DCS**

Classroom Module 2
Oxygen and the Diver - A Discussion of the Pathophysiology of Oxygen

OBJECTIVES:

A. Upon the completion of this module the students will have expanded their understanding of oxygen's effect upon divers. Nitrogen Narcosis and depth limits will also be discussed. Specifically:

1. Nitrogen Narcosis, Oxygen toxicity and their symptoms
2. Dalton's Law of Partial Pressure as the basis for varied gas mixtures
3. Oxygen life support ranges
4. Why SafeAir© 50 may be preferred to 100% oxygen when used as an in-water decompression aid.

MATERIALS:

A. ANDI Instructors Manual.

B. Blackboard, chalk, eraser or substitute.

C. Class roster, student folders and test questions. Instructors may wish to have a calculator at hand to increase the speed and accuracy of conversions and computations.

D. Students are required to have the ANDI text/workbook. A calculator will aid with all mathematical computations.

INTRODUCTION:

A. Establish Contact

1. Introduce self
2. Introduce subject - "Oxygen and the Diver"

B. Create interest

1. We will now correct some misinformation, and

2. Now *correctly* diagnose certain diving maladies.

C. Stress value

1. You will become safer divers as a direct result of this expanded understanding.

OVERVIEW:

INSTRUCTOR'S NOTE : elapsed time- 135-180 minutes.

A. Subject Matter of class

1. Nitrogen narcosis symptoms and nitrogen limits.

2. Dalton's Law.

3. Oxygen toxicity symptoms and exposure limits.

4. Oxygen clock and life support ranges.

5. CNS and Whole body toxicity.

6. Deep diving and Oxygen.

7. Application of SafeAir© 50.

B. Student conduct

1. Please take notes. There is room provided in your text/workbook to allow you to write in the margins. You may follow along with the presentation.

2. Ask questions at any time.

3. There will be a written test developed from this material at the end of this course. We will be completing sample problems through-out the program.

PRESENTATION:

BACKGROUND

A. In various training programs, student divers were told that:

1. 100 FSW (30 MSW) is to be considered the safe dive limit.
2. Other divers were taught that after experience 130 FSW (40 MSW) is the maximum limit.(European instructors are quite comfortable teaching a 50 MSW (163 FSW) limit.

These numbers were not arrived at arbitrarily or capriciously. They are based upon the real physiological responses of divers at those depths. Depth is relative to experience and training but limits ARE based upon physiology.

More accurately they are derived from the effects of increased partial pressures of nitrogen. When breathing *air*, nitrogen becomes narcotic at depths below 100 FSW-30 MSW

At 130 FSW (40 MSW) all divers have been affected. The extent is dependent upon many variables.

It is the author's opinion that Nitrogen Narcosis is the *real underlying cause* of most deep diving accidents performed on air.

INSTRUCTOR NOTE : We surely could spend more time developing and expanding the information on Nitrogen Narcosis. However the emphasis is to reenforce the concept of limits and why they are necessary.

Beyond 130 FSW (40 MSW) the narcotic effect is extreme. Divers judgement, reaction time, sensory perception and muscle coordination are severely impaired. Divers become significantly less concerned with their own welfare. Perception is distorted by narcosis. Many divers believe that they are not effected. They may PERCEIVE no ill effects and report that fact accurately. The effects of narcosis may vary from day to day within the same individual. The exact mechanisms and the factors causing narcosis are not completely understood. The above limits should be strictly adhered to by the average diver using air. We know that these depths are stressful on human physiology. Divers are now learning of ways to handle greater depth or time exposures by changing the breathing medium.

We have known for quite some time that *air* is the *worst* gas mixture for divers with regard to the physiological penalties. We have been correctly taught that Nitrogen is the "bad guy." We have 2 gases to consider when discussing true limits.

These studies have provided the information we will be sharing in this module and through out the course.

PRESSURE

Before we may continue a discussion of gas pressures and depth limits we must understand what IS pressure!

1. Pressure is defined as a force applied upon an area.

$$P = \frac{F}{A}$$

Any force - any area

where:

P = total pressure
F = force applied
A = unit of area

2 To continue, we must now review Dalton's Law of Partial Pressure.

a) $P = P_1 + P_2 + P_3 + P_4$ etc.

where:

P = total pressure
P_1 = pressure of gas 1
P_2 = pressure of gas 2
P_3 = pressure of gas 3
P_4 = pressure of gas 4, etc.

Simply stated, the whole is equal to the sum of the parts. John Dalton discovered that each molecule exerts an individual pressure. Total pressure is merely the sum of these individual pressures. In a mixture of gases, the pressure exerted by each gas is directly proportional to the gases percentage in the mixture.This percentage relates to the *fractional equivalent* of the gas in the mixture. For example: if we approximated air to contain 21 molecules of oxygen for every 100 molecules, it would follow that the *fractional equivalent* of oxygen would be 21/100. Of course there would be 79/100 of something else in this mixture. The **fg** of a gas is derived in this manner. The fractional equivalent of oxygen in this mixture may also be expressed as a decimal, in this case .21. Now we are referring to a *specific gas*, oxygen. We now have identified the "g" as O_2, therefore the nomenclature is **fO_2**. The pressure exerted by all of the molecules of any one gas is called the *partial pressure* of that gas.

b) When we analyze "God's Nitrox" (AIR) with regards to Dalton's Law it looks like this in ATA's or BARS.

$P = P_1 + P_2 + P_3 \ (+ P_4 + P_5 \text{ etc.})$ or,

Expressed in ATA or BAR $1.0 = 0.7805 + 0.2095 + 0.01$

Expressed in p.s.i.a. $14.696 = 11.47 + 3.078 + 0.147$

This is why we will not be using the Imperial System's psi values in discussing partial pressures..... but consider how these values were derived. This is all demonstrating the relationship known as Dalton's law.

INSTRUCTOR'S NOTE: For the purposes of simplicity ATA and BAR may be used interchangeably. Be aware that the two terms are not precisely equivalents. 1 ATA = 0.98692 BAR and 1 BAR = 1.01325 ATA. this small difference of slightly more than 1% does not significantly change the oxygen dosages discussed shortly.

The concept of "partial" pressure may be better understood after studying CHART 2-1

CHART 2 - 1

PARTIAL PRESSURES OF GASES IN AIR AT DEPTH

ATMOSPHERES ABSOLUTE (P)*	DEPTH FSW (Gauge)	DEPTH MSW (Gauge)	PARTIAL PRESSURE OF OXYGEN* PO_2 (fO_2 x P)	PARTIAL PRESSURES OF NITROGEN* PN_2 (fN_2 x P)
1	0	0	0.21	0.79
2	33	10	0.42	1.58
3	66	20	0.63	2.37
4	99	30	0.84	3.16
5	132	40	1.05	3.95
6	165	50	1.26	4.74
7	198	60	1.47	5.53
8	231	70	1.68	6.32
9	264	80	1.89	7.11
10	297	90	2.10	7.90

* Trace gases included in PN_2; Pressure expressed in ATA\BAR

INSTRUCTOR'S NOTE : A physics review....As the density of the gas and the pressure contained in a full diving cylinder remains constant, the % of the individual gases remain constant but their individual pressures change as the total pressure changes.

OXYGEN AND OXYGEN TOXICITY

Let us look at some misinformation that has been offered as fact concerning oxygen. Many of us were taught that the toxic level of oxygen was **2.0 ATA** and the depth limit for a working diver was **297 FSW**. This information is incorrect because of several factors:

a. Mathematically computed by rounding down of PO_2 to 20.0 %. 20.95 % (toxic gases should be rounded up) it should be 21.0% not 20.0%

b. Most working divers experience oxygen toxicity symptoms at a depth much shallower than 297 FSW (90 MSW.) Actually oxygen toxicity may easily occur at a depth closer to 200 FSW (60 MSW.) In fact, the U.S. Navy has always stated that the PRACTICAL LIMIT of an air dive is 190 FSW (58 MSW) (About 6.75 ATA.) This is due to several considerations, namely the partial pressure of oxygen (PO_2), the partial pressure of nitrogen (PN_2), the time of oxygen exposure (tO_2), the time of nitrogen exposure (tN_2) and the available gas supply.

INSTRUCTOR'S NOTE: Introduce the above nomenclature, tO_2 and tN_2 now.

c. Oxygen toxicity symptoms overlap many Nitrogen Narcosis symptoms and may easily be incorrectly diagnosed. Refer to CHART 2-2 for a list of oxygen toxicity symptoms. Now compare this to a list of Nitrogen Narcosis symptoms.

INSTRUCTOR'S NOTE: The symptoms listed below in BOLD FONT are nitrogen narcosis symptoms as well as **CNS oxygen toxicity symptoms. Identify for your students how the Central Nervous System type toxicity symptoms very neatly overlap. In earlier editions of the student text/workbook the older term "VENTID" was used but that term did not address the full range of symptoms. ANDI Instructor Trainer # 13, Mark Caney, contributed this useful teaching tool. thank you Mark .**

CHART 2 -2

CENTRAL NERVOUS SYSTEM SYMPTOMS

1. CENTRAL NERVOUS SYSTEM:

C	**CONVULSIONS**	**Convulsions and Unconsciousness**
E	**EUPHORIA**	**Greater Risk Taking - Less Feelings of Danger**
N	**NAUSEA**	**May be Intermittent**
T	**TWITCHES**	**Muscle Spasms (Usually Facial and Lip Muscles First)**
A	**ANXIETY**	**Anxiety level increases**
D	**DIZZINESS**	**Dizziness and Vertigo**
I	**IRRATIONAL**	**Irrational and irresponsible behavior**
V	**VISION**	**Peripheral Shunts to Tunnel Vision and other visual distortions**
E	**EARS AND**	**Tinnitus (Ringing in the Ears) - Sound Distortion**

These Symptoms can Occur in any Order

d. The Navy *always* said 2.0 ata was "exceptional exposure."

INSTRUCTOR'S NOTE: Refer to CHART 2-4 to note that the maximum NORMAL EXPOSURE has long been considered to be 1.6 ATA PO_2.

Referring to CHART 2-5 the acronym "CENT A DIVE" may be useful in remembering the CNS type symptoms. If high PN_2 is gradually reduced and PO_2 increased Nitrogen narcosis symptoms MAY not disappear. We now understand better the role of oxygen in this equation. Oxygen is the cause of many of the symptoms attributable to nitrogen. Nitrogen acts as a narcotic and a CNS depressant. Oxygen MAY be narcotic but does act as a CNS *stimulant*. This is an area that requires more research. The administration of high doses of 100 % oxygen during therapy (between 1.0 ATA and 2.4 ATA) does not mandate a narcotic or euphoric response in patients.

The confusion occurs when we discuss the Meyer-Overton Theory. This refers to the relationship between solubility in lipid tissue and narcotic effect.

As the solubility of a gas in lipid tissue increases its enhancement of the narcotic effect also increases. This statement appears to be true for all breathable gas mixtures. Because oxygen and carbon dioxide are almost twice as soluble in lipid tissue as nitrogen, it would appear logical to presume that oxygen is more narcotic than nitrogen and therefore would enhance narcosis as the PO_2 increases. However with regard to oxygen the human body is a unique container. A diver breathing 100% oxygen at 1.6 ATA does not appear to be impaired. More research needs to be performed to better address this issue.

INSTRUCTOR NOTE: nitrogen's lipid solubility is 66.129 ml/liter while oxygen's lipid solubility is 110.535 ml/liter using olive oil as the solute at a temperature of 37 degrees C and a pressure of 1 Bar.

The U.S. Navy and NOAA

The U.S. Navy and the other large commercial diving enterprises backed the exposure limit of oxygen down to 1.6 ATA partial pressure. If this were 1972 maybe we would be saying that this is "new" information, but today for everyone except the sport diving industry, this is historical background. Why can't the sport diving industry take advantage of new information?

Pathophysiology of Oxygen

The mechanisms of oxygen toxicity and its ranges are not entirely clear. We do know that CNS type toxicity can be traced to a disturbance in the synaptic area. The synapse is the area where one nerve ending meets another. High oxygen pressure disrupts the transmission of electrical impulses across this area. In this respect nitrogen narcosis and oxygen toxicity are similar. However nitrogen apparently suppresses the impulse as a depressant while oxygen excites the process. An analogy that is not exactly correct but sufficient to aid in understanding: N_2 ups the resistance, O_2 ups the voltage.

Although the biochemistry is not precisely clear, what we do know is that O_2 is an incredibly active molecule and readily combines with other substances both organically and inorganically. Within our bodies organic compounds are frequently damaged as they combine with oxygen producing corrosive substances called oxidants. These oxidants include such substances as hydrogen peroxide, epoxides and superoxides. Even monatomic oxygen (un-combined), the super oxidant called "free radicals" briefly exist. The body counters by producing antioxidants like vitamin E, superoxide dismutase and others. Higher partial pressures produce higher levels of oxidants. At some point, the body's ability to buffer the oxidants will be exceeded. Since our body is "tuned" for one ATA, this situation requires both time and elevated pressure. It is a very complex relationship with perhaps dozens of chemical reactions occurring simultaneously.

Interestingly, our cells have harnessed this highly reactive molecule oxygen, for the purpose of producing energy. Carbohydrates, fats and proteins react with oxygen to produce energy CO_2 and water. The more energy we require the more oxygen we use. Also, as we use more oxygen the more CO_2 we produce. This CO_2 would simply be exhaled under normal conditions. At high workloads, especially under increased partial pressure, we begin to build up carbon dioxide in the bloodstream. This has a twofold effect upon the diver who exceeds the limits of oxygen. Firstly, increased levels of CO_2 dilates blood vessels aiding them in their quest for more oxygen. Especially the blood vessels in the brain. This elevates oxygen delivery and exposes the brain to even higher levels of oxygen. Secondly, the blood becomes more acidic. This causes the hemoglobin to lose oxygen faster and expose the brain to even more elevated levels of oxygen.

Carbon dioxide is the prime catalyst for CNS type oxygen toxicity. It is imperative to realize that high workload dives must be accompanied with more conservative dosages of oxygen.

It is of no small significance to note that all breathing equipment be selected and properly maintained to reduce CO_2 buildup (hypercapnia). Whether air or enriched air, divers should be utilizing the best breathing systems possible, and kept in tune..

To understand the mechanics of what transpires, we need to consider the following:

1. The pathophysiology of oxygen cell energy - Energy is provided by fuel (fat, carbohydrates, protein and oxygen.)
2. The result of the chemical process is heat + CO_2 + H_2O.
3. CO_2 and H_2O are both present, individually and as a compound., $H_2 CO_3$, carbonic acid.
4. CO_2 must be kept in balance.
   As CO_2 increases, we have the formation of:

$$2CO_2 + 2H_2O \rightarrow 2H + 2HCO_3$$

This causes a shift in pH balance in our body fluids and tissues. Other acids are produced as well as carbonic acid (lactic et.al.) This process eventually results in acidosis and a higher susceptibility to oxygen toxicity. ***This shift does require time, but is speeded up by exertion.*** The probability of O_2 toxicity (CNS) occurring is very high if the exceptional exposure limits are reached during a working dive. There are no additional safety margins factored in. These are the REAL NUMBERS. High work load dives require lowering the PO_2. ANDI recommends that the PO_2 not exceed 1.45 for high work load dives. Once again, since elevated levels of CO_2 initiate CNS O_2 toxicity, it is important that breathing equipment be properly tuned to avoid breathing resistance. When operating at the maximum limits it is extremely important that only the highest quality Air Delivery Equipment be employed.

The Oxygen Clock

The need for monitoring nitrogen time (tN_2) has long been established. Oxygen has a similar time/partial pressure relationship. When breathing oxygen above .5 ATA, tO_2 must also be monitored.

As the nitrogen partial pressure goes up the exposure time permitted goes down. As the oxygen partial pressure goes up the exposure time permitted goes down.

We use charts and time to tract BOTH nitrogen and oxygen exposures. The U.S. Navy listed oxygen exposure times since before scuba diving was born. NOAA revised and updated the limits in April 1990. These exposures are listed on ANDI charts 2-2 and 2-4. The oxygen time limits must be treated with respect. These limits are at least as important as nitrogen exposure limits. They should be part of every dive plan utilizing enriched air. Chart 2-4 is available from ANDI instructors and training facilities.

INSTRUCTOR'S NOTE: U.S. Navy Manual - 1973 Table 9-20 - maximum oxygen partial pressure 1.6 ata for 30 minutes (April 1, 1990 changed to 1.6 ata for 45 minutes) - See ANDI CHART 2 - 4 NOAA Diving Manual table 11-1 (NOAA 1973 11-2 & US NAVY 1973 11-1) ANDI - CHART 2 - 4

CHART 2 - 3

OXYGEN EXPOSURE LIMITS
United States Navy

NORMAL EXPOSURE		EXCEPTIONAL EXPOSURE	
EXPOSURE TIME IN MINUTES	MAXIMUM OXYGEN PARTIAL PRESSURE ATA	EXPOSURE TIME IN MINUTES	MAXIMUM OXYGEN PARTIAL PRESSURE ATA
30	1.6	30	2.0
40	1.5	40	1.9
50	1.4	60	1.8
60	1.3	80	1.7
80	1.2	100	1.6
120	1.1	120	1.5
		180	1.4
240	1.0	240	1.3

U.S. Navy Diving Manual [1973], Change 1 Table 9-20.

Limits revised 1990 - See **(CHART 2 -4 NOAA Limits)**

CHART 2 - 4

OXYGEN EXPOSURE LIMITS - NOAA

NOAA Oxygen Partial Pressure and Exposure Time Limits for Nitrogen-Oxygen Mixed Gas Working Dives

Normal Exposure Oxygen Partial Pressure Limits						
Oxygen Partial Pressure (PO_2) in ATA		Maximum Duration for a Single Exposure			Maximum Total Duration for Any 24 Hour Day	
		(min)	(hrs)		(min)	(hrs)
1.6		45	0.75		150	2.5
1.5		120	2.0		180	3.0
1.4		150	2.5		180	3.0
1.3		180	3.0		210	3.5
1.2		210	3.5		240	4.0
1.1		240	4.0		270	4.5
1.0		300	5.0		300	5.0
0.9		360	6.0		360	6.0
0.8		450	7.5		450	7.5
0.7		570	9.5		570	9.5
0.6		720	12.0		720	12.0
Exceptional Exposure Limits						
2.0		30	0.50			
1.9		45	0.75			
1.8		60	1.00			
1.7		75	1.25			
1.6		120	2.00			
1.5		150	2.50			
1.4		180	3.00			
1.3		240	4.00			

INSTRUCTOR NOTE: Discuss Chart 2-4 thoroughly. Ask the class sufficient questions to establish a familiarity with the layout. The exceptional exposure limits do cause confusion in the students mind. Explain that these numbers ONLY relate to life threatening or mission critical situations. These extended time values are survivable only if the other factors are in balance.

Once again , ANDI wishes to stress that the probability of CNS toxicity occurring is very high if the exposure limits are exceeded during a high workload dive. There are no safety margins factored in. These are the real numbers. There are variables however. The variables are due to the extremely complex nature of oxygen's pathophysiology. Higher workloads mean higher CO_2 production. As we have previously discussed, CO_2 is the prime catalyst for inducing CNS toxicity reactions. Therefore if we plan higher workload dives or encounter conditions that cause extended respiration elevation we should not be operating at the maximum exposure limits. Back-off on the partial pressure or the time of exposure or both. ANDI recommends that the PO_2 not exceed 1.45 ATA during these higher CO_2 generating dives.

We must be aware of the fact that any value listed above 1.6 ATA for any purpose whether extreme exposures or in water decompression from heliox dives are intended for systems other than open circuit scuba. Convulsions occurring while underwater using conventional open circuit scuba would most probably result in death by drowning.

Oxygen Life Support Ranges

When discussing breathing mixtures we may have three possible conditions of oxygen concentration:

<.21 ATA = hypo-oxic

.21 ATA = norm-oxic

>.21 ATA = hyper-oxic

INSTRUCTORS NOTE: This section should be taught as a narrative using chart #2-3 as reference.

CHART 2-5 PARTIAL PRESSURE OF OXYGEN AS DOSAGE (IN ATA)

0.10 -	Not enough - death is eventual result
0.12 -	Borderline function - asleep - body functions shift hypoxic
0.16 -	Minimum necessary to sustain work - resting function OK
0.21 -	Norm-oxic - we exhale 15% to 17% oxygen and 4% to 6%CO_2 in normal conditions.
0.30 -	Normal saturation dive doses. Exposures are usually 24 hours or more.
0.35 to 0.50 -	Chambers and bells - low dose/long term - less than 24 hours
0.50 -	Maximum saturation dive dosages - Lorraine/Smith effect symptoms begins to manifest.
0.60 -	Pulmonary/whole body stress loads may be clocked by utilizing Oxygen Tolerance Unit (OTU) values.
1.40 -	Maximum dosage for extreme workload dives. Paul Bert effect becomes more likely above this value
1.45 -	Begins the caution zone for normal exposures and the limit for high workload dives with regard to CNS toxicity - Paul Bert effect
1.60 -	Maximum dosage for normal dives or "open-water" decompression Only 45 minutes single dive exposure as the limit
1.60+ -	CNS toxicity becomes a very likely occurrence - Paul Bert effect. Dosages in this range are very dependent upon time and CO_2 loading
2.0 -	100% oxygen at two ATA (optimize out gassing of nitrogen) For "at rest" only situations - Hyperbaric therapy.
2.40 to 2.80 -	Oxygen therapy at 6 ATA (to reduce bubble size and prevent bubble formation)
3.0 -	50 % oxygen therapy at 6 ATA (reduce bubble size - maximum oxygen dosage) Short duration dosages- chamber therapy only.

INSTRUCTOR NOTE: "CENT A DIVE" symptoms are not a serious problem when occurring in a chamber. Even convulsions are not life threatening in themselves. Also seizures can be made to disappear quickly by lowering the partial pressure of oxygen. Of course drowning is not an issue.Seizures have occurred after high dosage levels were reduced. As much as 3 to 5 minutes after reduction, but only after very high doses, 2.4 and above. Be sure that students are aware of the difference between convulsions occurring during therapy or breathing via helmets or band masks and seizures in open water on open circuit scuba.

Pulmonary/Whole Body Toxicity

During very long exposures to elevated partial pressures of oxygen at ranges approaching 24 hours, it was discovered that there was an adverse physiological effect. This is called the Lorrain Smith effect after the researcher who investigated this malady in the early 1960's. Also called "whole body toxicity" or "pulmonary oxygen toxicity", some of the symptoms are similar to pneumonia. **Although pulmonary oxygen toxicity is well beyond the range of recreational/sport divers exposure, no discussion of oxygen would be complete without mention of this side effect of "too much" oxygen.** The symptoms of pulmonary toxicity are listed on chart 2-2 but as we will learn, play a very small role in the oxygen issue for sport diving. However for the sake of completeness and for those who anticipate extreme exposures let us discuss a method of tracking low dose exposures as they relate to the oxygen clock.

As noted above and in CHART 2-2, we see that there are two types of oxygen toxicity predominately associated with short and long term exposures. It is normal to consider the amount of nitrogen the body is absorbing by monitoring the time of nitrogen pressure exposure (tN_2). As the partial pressure of oxygen is increased it is also necessary to monitor the time of oxygen pressure exposure (tO_2).

Chart 2-6

PULMONARY TOXICITY SYMPTOMS

- **NON PRODUCTIVE COUGH - Coughing with no Phlegm**
- **INCREASE IN BREATHING RESISTANCE**
- **DIFFICULTY IN TAKING A COMPLETE BREATH**
  Reduction of Vital Capacity

- **NOTICEABLE CLUMSINESS AND/OR LACK OF COORDINATION**

These Symptoms can Occur in any Order
For the purpose of review consider the following:

1. **Short term - Central nervous system toxicity**

   High dose - short term - Paul Bert effect

   We have some understanding of this, especially when considered with the "CENT A DIVE" symptoms. Refer to CHARTS 2 - 2, 2 - 4 and 2 - 5

2. **Long term - Pulmonary oxygen toxicity or whole body toxicity**

   long term - low dose - Lorraine/Smith effect

Formulated in the late 1960's, *a unit of pulmonary toxic dose* or (UPTD) is a time-pressure unit. It may also be called an OTU (oxygen tolerance unit) or CPTD (cumulative pulmonary toxic dose.) One (1) OTU is *approximately equal* (see table) to the application of 1 ata of O_2 for 1 minute, 1 OTU = 1 ata/minute. For example, 1.5 ata PO_2 for 30 minutes is equal to 53 OTU.

INSTRUCTORS NOTE: The formula for calculating OTU's is NOT a student requirement but is added for instructor information. It is not a linear relationship as the formula demonstrates.

$$\boxed{OTU = t\left[\left(\frac{PO_2 - .5}{.5}\right)^{.83}\right]}$$

Schedule of unit dosage per ata of O_2 exposure

ATA	OTU/MIN	ATA	OTU/MIN
0.5	0	1.6	1.92
0.6	0.265	1.7	2.010
0.7	0.490	1.8	2.20
0.8	0.656	1.9	2.34
0.9	0.831	2.0	2.48
1.0	1.00	2.1	2.61
1.1	1.16	2.2	2.74
1.2	1.32	2.3	2.88
1.3	1.47	2.4	3.00
1.4	1.62	2.5	3.14
1.5	1.77		

Maximum 1 day dose = 850 units

Maximum 2 day dose = 700 units average per day (1400 total)

Maximum 3 day dose = 620 units average per day (1860 total)

Maximum 4 day dose = 525 units average per day (2100 total)

Maximum 5 day dose = 460 units average per day (2300 total)

Maximum 6 day dose = 420 units average per day (2520 total)

Maximum 7 day dose = 380 units average per day (2660 total)

INSTRUCTORS NOTE: Because OTU's or UPTD's were originated to integrate or quantify oxygen exposures for low dose/long term effects they do not answer all of the questions regarding quantifying high dose /short term exposures. For example, if we compare three different multiple exposures totaling 75 minutes at 1.6 ata, 90 minutes at 1.5 ata, and 120 minutes at 1.2 ata, they all equal one half of the maximum total duration for a single 24 hour exposure (Refer to chart 2-4) but, the OTU/UPTD values are 144, 139.5, and 158.4 respectively. So although the only method presently standardized is OTU/UPTD values, they are just a guide and no absolute values can be placed upon them. In the range of technical/scientific diving they can be an effective tool to monitor cumulative exposures but have little use in the exposure ranges encountered in the recreational/sport diving community.

Working Limits of Oxygen

In the range between .5 and 1.45 ata PO_2 the recreational /sport diver receives a major physiological benefit by breathing these hyper-oxic mixtures. The oxygen time limits, or tO_2's established for single exposures allow for extremely extended dive profiles (2½ to 6+ hours) and present no oxygen hazards.

Repetitive dives may be made within safe limits by allowing the body to "reset" the oxygen clock. The minimum recommended surface interval for this purpose is 45 minutes, breathing air, to allow the body to stabilize the oxidants formed by elevated O_2 partial pressures. Considering the nitrogen clock as well, it is prudent to allow 1 hour between dives. The surface interval should also be used to re-hydrate. This takes into account the major changes that occur and allows the body to self regulate and re-adjust to the changes.

Caution Zone

The area between 1.45 and 1.6 ata PO_2 is considered to be within the "caution zone". Care should be taken to monitor the tO_2 (oxygen time/dosage exposure) as well as your physical condition throughout the dive. Understand that high work loads and CO_2 buildup can enhance the likelihood of CNS toxicity problems. The exposure times listed in chart 2-4 are considered the real work numbers and have an excellent history of problem free dives. In fact, the oxygen exposure times used prior to 1990 were felt to be far too conservative. NOAA published the oxygen exposure times for nitrogen-oxygen working dives in 1990. These are the times and limits that ANDI has been teaching and diving. However, do not take that as a license to carelessly operate at the edge or beyond these limits. Oxygen tolerance is a very complex issue. Great care should be taken not to exchange one problem (DCS) for another (CNS O_2 toxicity.) Refer again to chart 2-2 for reference to the symptoms of CNS O_2 toxicity.

Rarely are there any indications of oxygen problems during normal workload dives at 1.6 ATA exposures. High workload dives should be shortened in duration from the 45 minute maximum single exposure or the partial pressure of O_2 should be reduced if the exposure time is to be maintained at 45 minutes. If your dive plan was to be for 45 minutes at 1.5 ata or higher (but less than 1.6!) it would be prudent to shorten or abort the dive should you find that you have been breathing hard or have elevated your respiration rate appreciably. ***There is no rule that is perfect for operating in this exposure range, just as there are no perfect decompression tables.*** Beyond 1.6 ata PO_2, CNS oxygen toxicity is more likely to occur. This is often referred to as the Paul Bert effect after the scientist who first investigated the condition. Exposures above 1.6 ata may be tolerated for short durations without toxicity symptoms appearing if the balance of the physiological equation permits. Normally this only works for "at rest" situations.Dosages of 2.0 ata PO_2 are routinely administered during hyperbaric therapy with out ill effect.Be aware that there are no permanent adverse effects of CNS O_2 toxicity induced seizures, as long as adequate respiration is maintained. ***Of course***

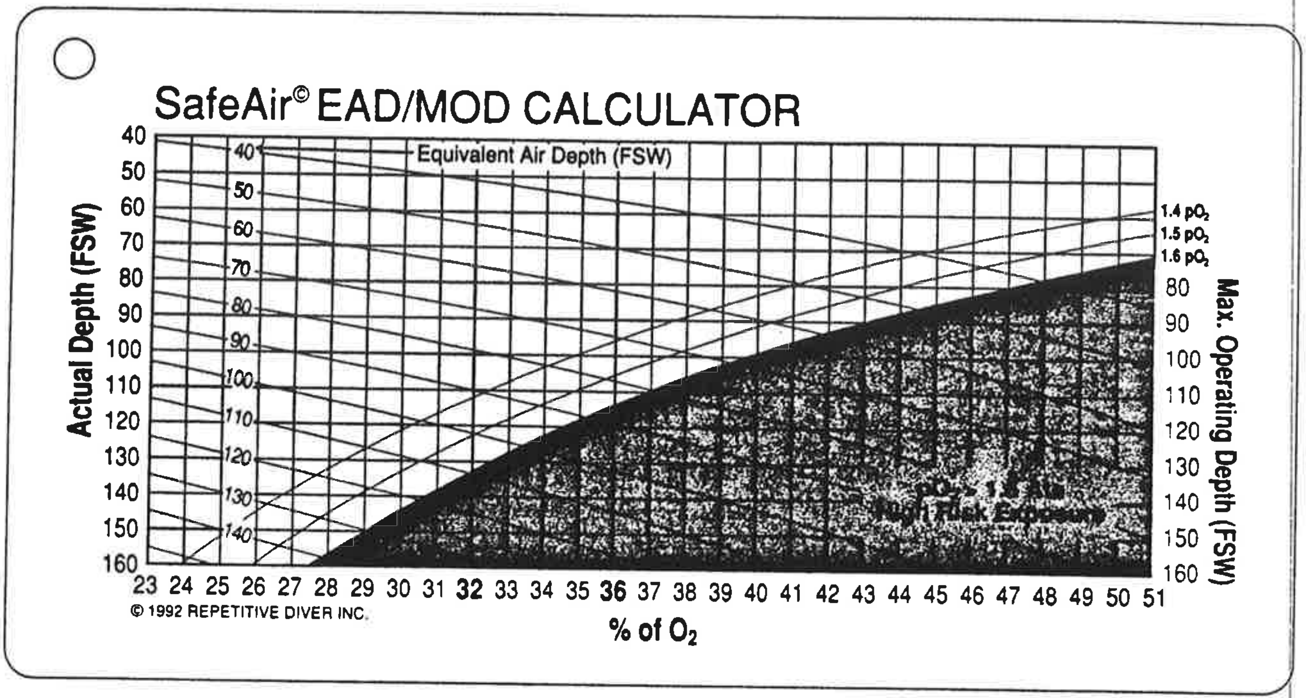
convulsions occurring while underwater using conventional SCUBA would most probably result in death by drowning.

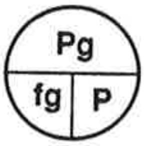
SafeAir© EAD/MOD CALCULATOR

ANDI and Repetitive Diver have developed the **SafeAir© EAD/MOD CALCULATOR**. This flexible, waterproof chart is used for dive planning. It provides for monitoring OTU's, tO_2's, and PO_2 dosages as previously discussed. It also list best mix values, and Equivalent Air Depths (EAD) which will be discussed in Chapters 3 and 4.

CHART 2 - 6

SafeAir© EAD/MOD CALCULATOR





Oxygen partial pressure in ATA	Maximun minutes for single exposure	Maximum minutes for any 24 hr exposure
1.6	45	150
1.5	120	180
1.4	150	180
1.3	180	210
1.2	210	240
1.1	240	270
1.0	300	300
0.9	360	360
0.8	450	450
0.7	570	570
0.6	720	720

ATA (pO₂)	OTU/MIN
0.5	0
0.6	0.265
0.7	0.490
0.8	0.656
0.9	0.831
1.0	1.00
1.1	1.16
1.2	1.32
1.3	1.47
1.4	1.62
1.5	1.77
1.6	1.92
1.7	2.01
1.8	2.20
1.9	2.34
2.0	2.48
2.1	2.61
2.2	2.74
2.3	2.88
2.4	3.00
2.5	3.14

WARNING

The use of oxygen enriched air requires specialized training and equipment. Do not attempt to apply this technology until you have received proper training in these procedures.

For more information contact:

American
Nitrox
Divers
Inc

516-546-2026

INSTRUCTOR NOTE: Mention that these are available for sale at ANDI Facilities or from ANDI Instructors.

Oxygen and Deep Diving

Although deep air divers ....very deep air divers, frequently exceed the maximum oxygen exposure limits without incident, most are right on the edge of major toxicity problems (217.6) FSW [66.75 MSW] is 1.6 ata PO_2 on an air dive.) Many do not distinguish the symptoms of oxygen problems from that of "normal" narcosis. Intermittent nausea, tunnel vision, tinnitus, momentary dizziness and euphoria usually precede muscle spasms and grand mal type seizures, ***but not always***. 200+ FSW (61+ MSW) on air is far too great a risk to sensibly undertake (If these depths are to be explored the breathing mixture should be adjusted to reduce the O_2 partial pressures encountered.) Too many "un-explained" deaths occur from this folly.

Often the question arises as to the validity of the oxygen limits when taken in light of many successful deep dives. Dives on air to extreme depths have been achieved such as Bret Gilliam's current record of 452 FSW (137.8 MSW.) The fact is that many divers have died in deep dive attempts. The people that complete these dives are well aware of the extreme risk involved and prepare for them with great care. Good diet, not smoking, good physical condition, extremely rapid descents, very short exposures (≈5 minutes), minimal CO_2 buildup or no exertion at all and rapid ascents to quickly reduce PO_2 are all part of the scenario. Still deaths occur. This does not invalidate the numbers but support them further.

INSTRUCTOR NOTE: Many times students ask how a person can dive to depths, such as Bret Gilliam's current record of 452 FSW. The fact is, many divers have died in attempting these deep dives. The people that do the deep dives are well aware of the problems involved and they prepare for them with great care. They control their diets. Do nothing to exert energy on the dive to avoid creation of excess CO_2. They fall like a stone and start up immediately. Dive times are often ten minutes or less.

In-water Decompression Using Oxygen

Commercial, scientific and technical divers have been using pure oxygen, for years, to improve and make safer in-water decompression schedules. The more advanced members of the recreational/sport community are exploring this technique. The level of education is way behind, considering the number of divers using O_2 for decompression. Several recent studies have indicated that long decompression stops utilizing 100% O_2 may not be the best way of reducing inert gas tension. Due to the vascular constriction caused by high PO_2 many have suggested that an 85% to 90% O_2 concentration in a helium/oxygen mixture may be more beneficial. The big picture of oxygen is well understood; but, this is a very complex problem with information frequently being updated. To many, the concept of "if a little O_2 is good, a lot must be better", is the extent of their knowledge. Many do not understand the physiology involved and often experience problems as a result of violating the oxygen clock. Nausea during the decompression hang may not be "just sea sickness." Education as to safe methods and appropriate exposure limits is mandatory and overdue. (DCIEM and the Australian Navy are completing development of in-water deco tables utilizing pure oxygen.)

There is no faster practical method to eliminate dissolved nitrogen from tissues than by inspiring 100% (85% to 90% - see above) oxygen. Usually the application of pure oxygen follows long deep excursions where the limits of oxygen are approached ***before*** the diver ascends and begins the decompression schedule. Many scientific/technical deep dive operations are conducted using air as the breathing gas. This shows an ignorance of, or a disregard for the physiology of the gases involved. This is where most of the oxygen exposure abuses occur.

For example at 240 FSW (73 MSW) the diver breathing air is taking a dosage of oxygen equal to 1.73 PO_2 usually for 25 or 30 minutes. This diver then ascends and switches to 100% O_2 and begins the decompression schedule. Even by restricting the use of 100% O_2 to the 20 FSW (6 MSW) level the clock is running full speed. 20 FSW (6 MSW) is 1.6 ata and all of the pressure exerted by the breathing gas ***is oxygen***. The partial pressure of oxygen is the ***total*** pressure. Referring to chart 2-4 it shows that the ***recommended total*** single exposure time at 1.6 ata PO_2 is 45 minutes. Therefore the total time spent breathing 1.6 ata PO_2 ***or higher*** should not exceed 45 minutes. This dive easily equals or exceeds that limit. When divers choose to perform decompression dives, using oxygen for decompression is one method for added safety. This should only be done if the diver understands the physiology. For "at rest situations" there are other studies supporting considerably longer exposures at 1.6 ata PO_2.

Many other oxygen users, lacking complete information, believe that ***air breaks*** for 5 minutes every 25 minutes of O_2 use are required to prevent whole body oxygen toxicity. It is surmised, that after reading the U.S.Navy manual's discussion of air breaks during chamber therapy, it can be assumed that this procedure is required to prevent pulmonary problems associated with oxygen. Air breaks ***ARE*** beneficial and worthwhile, but the physiological function is to "relax the oxygen clock". This is primarily to prevent ***CNS*** toxicity symptoms. It does allow pulmonary recovery and extends exposure limits significantly. ***If the decompression schedule calls for oxygen, use it!*** If oxygen is not required, and is being used to increase the safety factor, consider breathing SafeAir© 50 instead. In several areas it has physiological and operational advantages over 100% oxygen.

INSTRUCTOR NOTE: The average diver should NOT be using pure oxygen. The need does not exist therefore why assume the risk? The use of SafeAir© 50 however , does offer significant advantages. Its use also supports the entire concept of enriched air

usage. Stress the fact that all divers have the opportunity for added safety during ascents (both decompression dives and no-stop required dives) by using SafeAir©

SafeAir© 50

This gas mixture can solve the problems of CNS O_2 toxicity normally associated with long dives that approach the limits of the oxygen clock. Consider the dosages of oxygen in air, SafeAir© 50 and oxygen while surfacing/decompressing from a deep operation. Examine the tO_2's listed in the following chart. Using SafeAir© 50 the diver can still realize a very significant increase in the out gassing gradient of the inert gases over air, without the negatives associated with using pure O_2 in these decompression situations. Also note the extreme exposure times permitted. This gives all divers the opportunity for increased safety as a result of SafeAir© usage.

MSW	FSW	ABSOLUTE PRESSURE	100% OXYGEN PO_2 - tO_2	SafeAir© 50 PO_2 - tO_2
15	50	2.5	2.5 - *	1.25 - 180 min
12	40	2.2	2.2 - *	1.1 - 240 min
9	30	1.9	1.9 - *	.95 - 300 min
6	20	1.6	1.6 - 45 min	.80 - 450 min
3	10	1.3	1.3 - 180 min	.65 - 570 min

*** Exceeds recommended exposure limits.**

Pony Cylinders and SafeAir©

Advanced level sport divers can also receive additional benefits from utilizing SafeAir© 50 as the breathing medium during the "safety stop", Safe Scuba Ascent Method or S.A.F.E. procedure. By switching to a smaller safety/bailout cylinder, commonly called a "pony", filled with SafeAir© 50 the diver elevates oxygen levels and lowers inspired nitrogen thereby eliminating nitrogen faster. Safer ascents are the result.

It is necessary to expand further on the of use of ponys and the concept of bailout gas and bottom gas. A bottom gas is a gas breathable at its maximum operating depth which limits the PO_2 to 1.6 ata. A bailout gas is a gas breathed during emergency ascent. It is not acceptable for horizontal escape (ie. cave or wreck penetration.) It is recommended that the PO_2 contained in a bailout gas should never exceed 2.0 ata PO_2 (ie. SafeAir© 50 as a bailout gas has a maximum operational depth limit of 100 FSW (30 MSW.)

It has been an unanswered question as to why the use of the pony cylinder is almost exclusively limited to the northeast area of the United States. Primarily New York and New Jersey wreck divers incorporate the pony cylinder as standard equipment for ocean diving. It is a totally redundant system of gas supply, valve, regulator first stage and second stage. This ***truly independent air supply*** offers a degree of redundancy that is required for all advanced level diving situations. It is much more reliable than other out of air and emergency sharing systems. Pony cylinders usually contain 13 to 40 cubic feet of gas and therefore are likely to provide more gas than other methods.

Utilizing pony cylinders filled with enriched air mixtures, all divers (not just wreck divers), can combine a 30 year old diving practice and 30 year old technology to achieve safer more enjoyable diving experiences.

Advantages of SafeAir© 50 over Pure Oxygen

1. Cost and accessibility of oxygen. Some states require a prescription and access is even denied in some countries. Japan for example requires an industrial or medical permit to purchase oxygen! SafeAir© can be dispensed without these concerns.

2. Oxygen has specific depth limits based on the accepted maximum dosage of 1.6 ata limit (20 FSW [6 MSW]). For "at rest situations" there are studies supporting considerably longer exposures than 45 minutes at 1.6 ata PO_2. If the decompression stop is stressful such as rough water, currents or very cold, the maximum dosage should be reduced to 1.45 ATA. Air breaks are required to prevent CNS O_2 toxicity. The oxygen clock is running so we need to monitor the tO_2 just as closely as we monitor the tN_2. Breathing SafeAir© 50/50 for all decompression stops of 70 FSW (21 MSW) and shallower is a reasonable alternative.

3. Oxygen is not compatible with standard scuba equipment. Very few scuba regulators can be completely converted for use with O_2. ***Valves must be converted*** to prevent failure and accidents. Only O_2 compatible lubricants may be used. Cylinders must be cleaned for O_2 use.

4. There is increased risk in handling and transporting cylinders containing pure oxygen. This risk is alleviated with SafeAir©.

5. If oxygen is carried in aluminum scuba cylinders the capacity of most cylinders is reduced since few scuba facilities are capable of filling oxygen above about 2000 PSI. Because, the higher the pressure of pure O_2 the more unstable and reactive it becomes. The standard "Aluminum 80" contains only 53.3 cubic feet at 2000 PSI.

6. In the event of necessary oxygen therapy a 50/50 mix provides a larger "window" than pure O_2 by providing a lot of tO_2. This should be important to those opposed to the proliferation of this technology to the recreational/sport community, because of their concern for whole body pulmonary problems. The case for whole body/pulmonary toxicity is difficult to justify under these applications using SafeAir©. Several individuals, including The Divers Alert Network (DAN) have gone on record expressing concern as to successful treatment outcome when the patient has prior exposure to elevated levels of oxygen. Table 6 accounts for 655 UPTD and more than allows for a "large treatment window". This "position statement" by DAN, unsupported by any clinical evidence, is another example of "theoretically possible" but highly unlikely positions. A patient at rest may show no signs or symptoms of substernal discomfort, cough, and mild dyspnea after 8 hours exposure at 1.5 ata PO_2. The use of SafeAir© mixtures instead of air during normal recreational/sport diving activities can add a major safety factor in

reducing DCS incidence. As of December 1991 few cases of DCS have been documented for dives using SafeAir© mixtures. Further, no indication of pulmonary O_2 toxicity symptoms have been reported.

The use of SafeAir© 50 is more beneficial than 100% O_2 after long air exposures with high PO_2, because of CNS O_2 toxicity and not due to any pulmonary problems that might occur during therapy.

8. SafeAir© 50 may be used at a deeper depth than 100% O_2 and therefore more justification for carrying a pony or stage cylinder is realized. 1.6 ata $P0_2$ is not reached until 70+ FSW. Switching over to 50/50 as the ascent gas from deep or tri-mix dives at 70 FSW (21.336 MSW) may be more practical than ***carrying*** oxygen, which can only be used at 20 FSW **if the hang is not stressful.**

INSTRUCTOR NOTE: The whole discussion on hyperbaric treatment is of general student interest. It also addresses some of the controversy surrounding oxygen and hyperbaric treatment.

Hyperbaric treatment of diving accidents

The operator must consider many things in formulating the treatment plan, among them are the following:

1. Elevating the amount of O_2 dissolved in the tissue and blood within certain limits: Hyperbaric oxygen levels in tissues and CNS improves microcirculation. It also arrests and/or reduces CNS edema (swelling).

2. Increase the hydrostatic pressure to provide sufficient pressure to slow or stop outgassing of inert gasses. This also reduces the embolus effect by reducing the diameter of the actual gas bubbles that are present. Even 2.8 ata PO_2 is frequently administered for short periods. Usually the patient is in a supine position (lying on the back), totally at rest and not speaking. This is to keep the CO_2 at manageable levels. Should toxicity symptoms manifest themselves, the operator would reduce the O_2 dosage until the symptoms disappear. Convulsions can occur, up to several minutes, after the high dosage is stopped. However, the concern for possible onset of convulsion is minimal as the condition can be made to disappear quite rapidly.

INSTRUCTOR NOTE: In the treatment of arterial gas embolism (AGE) and decompression sickness (DCS) it is important that Boyles Law be thoroughly understood. Most instructors and divers learned that the volume varies inversely with

pressure in exact proportion. Double the pressure halve the volume. In arterial and capillary blockage the concern is really bubble diameter. Bubble diameter (a sphere) does not reduce in a directly proportional relationship. The actual reduction in a spheres diameter with a doubling of pressure would be approximately 21%.

Instructors Note: The formulas needed for the radius (½ the diameter) of a sphere are as follows:

$$\textit{Radius} = 3\sqrt{\frac{3V}{4\Pi}}$$

or

$$\textit{Radius} = (.6204)\ 3\sqrt{V}$$

and

$$\textit{Volume} = \frac{4\ \Pi r^3}{3}$$

or

$$\textit{Volume} = (.5236)\ r^3$$

The normal response to the question - what happens to a sphere when the pressure is doubled? is that its size is reduced to one half. The answer is that the volume is one half. The bubble diameter at 2 ata = 0.793. At 8 Ata the bubble size is approximately halved. Most chamber treatments are at 6 ata which is very close to halving bubble diameter.

3. Control of N_2 debt and narcosis of the chamber observer - tender.

    a) Use other SafeAir© mixtures within acceptable guidelines, ie.

        6 ATA required for hydrostatic cap but symptoms indicate high PO_2 is required.

        Pure O_2 can not be used as 6 ATA is not reasonable.

        50% N_2 and 50% O_2 is 3 ATA PO_2 and 6 ATA of total pressure.

60% N_2 and 40% O_2 is 2.4 ATA PO_2 and 6 ATA total pressure, but only 3.6 ATA of PN_2 instead of 4.68 ATA PN_2 in air.

This results in decreased narcosis and N_2 debt for the tender observer as well as the patient.

Various other mixtures can be used with the same type of variations. 2.8 ATA's of O_2 is the optimum number for maximum elimination of inert gases.

INSTRUCTORS NOTE:

Further education in advanced diving concepts should be taken before diving deep, using oxygen in water for either decompression or for the treatment of diving accident victims in water.

As technology advances man must advance his knowledge in the use of diving gases. To say that it is unsafe for sport scuba divers to use gases other than air is probably not very smart as divers are learning there are better mixtures than air, and that they are a lot safer. We have used our technology to push air to the limits, with new tables and decompression computers. If we could throw these away or use nitrox computers and nitrox mixes we could immediately double no decompression time over air.

NITROX CLASSROOM MODULE 2

QUIZ

1. What are the percentages of nitrogen and oxygen in the NITROX mixture called AIR?

1) 2)

2. Fill in the numbers in the following chart.

ATA\BAR	FSW	MSW	PSI	PO_2	PN_2
1	0	0		.21	.78
	33		29.4		1.56
	66	20		.63	
4	99		58.8		3.12
5	132	40	73.5		

3. Fill in the "CENT A DIVE" symptoms

C ____________________
E ____________________
N ____________________
T ____________________

A ____________________

D ____________________
I ____________________
V ____________________
E ____________________

4. What is the normal maximum exposure limit of oxygen expressed in ATA's

5. What gas that is present in our bodies, if allowed to increase, accelerates the "CENT A DIVE" symptoms?

NITROX CLASSROOM MODULE 2
QUIZ ANSWER SHEET

1. What are the percentages of nitrogen and oxygen in the NITROX mixture called AIR?

1) 78.05% 2) 20.95%

3. Fill in the numbers in the following chart.

ATA\BAR	FSW	MSW	PSI	PO_2	PN_2
1	0	0	14.7	.21	.78
2	33	10	29.4	.42	1.56
3	66	20	44.1	.63	2.34
4	99	30	58.8	.84	3.12
5	132	40	73.5	1.05	3.90

3. Fill in the "CENT A DIVE" symptoms

C CONVULSIONS	Convulsions and Unconsciousness
E EUPHORIA	Greater Risk Taking - Less Feelings of Danger
N NAUSEA	May be Intermittent
T TWITCHES	Muscle Spasms (Usually Facial and Lip Muscles First)
A ANXIETY	Anxiety level increases
D DIZZINESS	Dizziness and Vertigo
I IRRATIONAL	Irrational and irresponsible behavior
V VISION	Peripheral Shunts to Tunnel Vision and other visual distortions
E EARS AND	Tinnitus (Ringing in the Ears) - Sound Distortion

4. What is the normal maximum exposure limit of oxygen expressed in ATA's

1.6 ATA's

5. What gas that is present in our bodies, if allowed to increase, accelerates the "CENT A DIVE" symptoms? CARBON DIOXIDE

Classroom Module 3

Mathematical Principles of Gas Mixtures

OBJECTIVES:

A. Upon completion of this module the student will have learned a through mastery of the formulas and math related to gas mixtures.

MATERIALS:

A. ANDI Instructors Manual.

B. Blackboard, chalk, eraser or substitute.

C. Class roster, student folders and test questions.

D. Students need workbook, calculator and notebook

INTRODUCTION:

A. Establish Contact

1. Introduce self

2. Introduce subject - "Mathematical Principles of Gas Mixtures"

B. Create interest

1. This information is the basis for all gas mixes including; air, SafeAir©, and tri-mix diving.

C. Stress value

1. We need to understand the math relationships between; partial pressures, total pressure and depth in order to obtain the full benefits of enriched diving.

OVERVIEW:

INSTRUCTOR'S NOTE: **elapsed time 90-120 minutes: students who are unable understand the following mathematical principles may still be certified as a limited user.**

A. You will learn the math to use to determine the limits of allowable depths and dosages of various gas mixtures.

B. Student conduct

1. Please take notes.
2. Ask questions at any time.
3. There will be a written test developed from this material at the end of this course. We will also be completing sample problems through-out this module.

PRESENTATION

A. Review Dalton's Law and look at some of the Symbols used in gas mixture principles.

1. $P = P1 + P2 +$ etc.

Air (1.0 ata) = .79 ata (nitrogen) + .21 ata (oxygen)

We have rounded slightly by adding the trace elements to the nitrogen. Please note that we are using decimals instead of percentages. This will make our later calculations more unit consistent and easier to handle.

2. In order to continue further, we need to identify the rest of the symbols we will be using in the following formulas:

P = total pressure (usually in ata but remember, depth can also be pressure.)

ATA = atmospheres absolute

D = depth or gauge pressure (usually in sea water)

FSW = feet of sea water

MSW = meters of sea water

NOTE - The above are all expressions or variations of pressure

fg = fractional equivalent of a gas

fO_2 = fractional equivalent of the specified gas (fN_2 or fH_2 or fHe)

Pg = pressure of a gas

PO_2 = partial pressure of the specified gas (PN_2 etc.)

There are a total of seven (7) formulas in this program. (4 are just variations of Dalton's Law.

1. Dalton's Law - with which we are familiar.

2. Convert ata's into FSW or MSW:

   FSW = (ata - 1) (33)

   MSW = (ata - 1) (10.0)

3. Convert FSW or MSW into ata's

INSTRUCTOR'S NOTE : You will need to leave formulas # 2 & # 3 on the board for those less familiar with the math and physics involved.

Now we are ready to discuss the PHYSIOLOGICAL and OPERATIONAL limitations of any gas mixture by utilizing the variations of Dalton's Law.

Examples:

Limitations of a dive planned for 100 FSW (30 MSW) utilizing Nitrox fO2 .21 and a 100 cubic foot cylinder* are;

1. Decompression time
2. Gas supply
3. Nitrogen narcosis
4. Oxygen toxicity

* 100 cubic ft is approximately equivalent to 2800 liters of free gas

Limitations of a dive planned to 130 FSW (40 MSW) utilizing Nitrox fO2 .21 and a 100 cubic foot cylinder are;

1. Nitrogen narcosis
2. Decompression time
3. Gas supply
4. Oxygen toxicity

As we change the gas mix these limitations also change. When working with various gas mixes we need to start thinking about the limiting factors of the dive.

Examples:

SafeAir© mixtures:

N_2 problems are greatly diminished.

O_2 problems are enhanced and the numbers need to be monitored more carefully.

Helium mixes:

Narcosis is greatly reduced

Smaller molecular size creates rapid diffusion into the system requiring decompression on virtually every dive, but also defuses out of the system very rapidly.

From the above we can see that in order to study the variations of gas mix formulas we need to able to determine:

1. Depth limit of a mix
2. Dosage of gas or total pressure of a specific gas
3. The best mix to use to limit dosage

As stated these are all variations of Dalton's law. We can solve for:

1. Pg

2. P

3. fg

NOTE: Write this on the board in the circular style shown below

To solve for one of the three
Cover the unknown

The mathematical expression shown by the two known numbers, is the equation to use.

1. How deep can we dive with this mix?

$$P = \frac{Pg}{fg}$$

Determining the limits of O_2. The limiting amount of the Pg is 1.6 ata.

Determining the limits of N_2. The limiting amounts are as follows:

a) 3.2 ata to eliminate the effects of Nitrogen narcosis.

b) Never exceed 4.0 ata to minimize the narcotic effects of Nitrogen.

Now examine the following gas mixes:

AIR -

$$P = \frac{1.6}{.21}$$

$$P \ \cancel{P} = 7.6\ ata \qquad (7.62)$$

Change 7.6 ata to FSW (How Deep)

$$P = (7.6\ ata - 1.0\ ata)\ 33 \qquad P = (7.6\ ata - 1.0\ ata)\ 10$$

$$P = 218\ FSW \qquad P = 66\ MSW \qquad (66,2)$$

The formula could look like this:

$$FSW = \left[\left(\frac{1.6}{.21}\right) - 1.0\right] 33 \qquad MSW = \left[\left(\frac{1.6}{.21}\right) - 1.0\right] 10$$

INSTRUCTOR NOTE: We use .79 as the PN_2 because in air the sum of the PN_2 + P of all the other inert is rounded to this value.

Checking the limits of N_2 use

$$Pg = 4.0\ ata$$

$$FSW = \left[\left(\frac{4.0}{.79}\right) - 1.0\right] 33 \qquad MSW = \left[\left(\frac{4.0}{.79}\right) - 1.0\right] 10$$

$$FSW = (\overset{5}{\cancel{6}}.06 - 1.0)\ 33 \qquad MSW = (\overset{5}{\cancel{6}}.06 - 1.0)\ 10$$

40,63 ✓

$$FSW = 134 ✓ \qquad MSW = \cancel{51}$$

To eliminate the narcotic effect of nitrogen we would use 3.2 ata:

$$FSW = \left[\left(\frac{3.2}{.79}\right) - 1.0\right] 33 \qquad MSW = \left[\left(\frac{3.2}{.79}\right) - 1.0\right] 10$$

$$FSW = (4.05 - 1.0)\ 33 \qquad MSW = (\overset{✓}{4.05} - 1.0)\ 10$$

$$FSW = 100\ ✓ \qquad MSW = 31MSW\ ✓ \qquad (30.51)$$

Summary:

Using AIR as the gas mix;

The depth limit with regard to oxygen is 218 FSW

The depth limit with regard to nitrogen is 100 to 130 FSW. Nitrogen acts as a narcotic. Its effect is variable and subjective. Many divers that they perceive no symptoms at 100 to 150 FSW. This perception may be correct, but remember perception is distorted by the narcosis. Nitrogen narcosis may be tolerated in higher dosages by more experienced and strong willed individuals.

Examine several other gas mixes.

SafeAir© 32

$$P = \frac{Pg}{fg}$$

$$FSW = \left[\frac{1.6}{.32} - 1\right] 33 \qquad MSW = \left[\frac{1.6}{.32} - 1\right] 10$$

$$FSW = (5.0 - 1)\ 33 \qquad MSW = (5.0 - 1)\ 10$$

$$FSW = 13\underset{4}{\cancel{2}}\ ✓ \qquad MSW = 40\ ✓$$

SafeAir© 36

$$FSW = \left[\frac{1.6}{.36} - 1\right] 33 \qquad MSW = \left[\frac{1.6}{.36} - 1\right] 10$$

$$FSW = (4.4444 - 1)\ 33 \qquad MSW = (4.4444 - 1)\ 10$$

$$FSW = 11\cancel{3}2{,}67 \qquad MSW = 34{,}4 \quad \checkmark$$

ANY GAS MIX:

$$P = \frac{Pg}{fg}$$

$$FSW = \left[\frac{1.6}{(ANY\ fO_2)} - 1\right] 33$$

OR

$$MSW = \left[\frac{1.6}{(ANY\ fO_2)} - 1\right] 10$$

5. What is the BEST mix for a given depth?

$$fg = \frac{Pg}{P} \qquad \left[\frac{Pg}{P}\right]$$

To minimize the effects of N_2 increase the O_2 to the maximum dosage allowable.

What is the max dosage of O_2 allowable? 1.6 ata.

Examples:

4.96

130 FSW (39.6 MSW) = 4.939 ata

$$fg = \frac{1.6}{4.939} = .32\ fO_2$$

105 FSW (32 MSW) = 4.181 ata (4.2)

$$fg = \frac{1.6}{4.181} = .38\ fO_2$$

218 FSW (66.4 MSW) = 7.606 ata 7,644

$$fg = \frac{1.6}{7.606} = .21\ fO_2$$

80 FSW (24.4 MSW) = 3.424 ata (3.44)

$$fg = \frac{1.6}{3.424} = .46\ fO_2 \quad (0,47)$$

6. Central Nervous System Maximum O_2 Dosage

INSTRUCTORS NOTE: Pg could be any gas. For O_2 dosage use PO_2.

$$Pg = fg \times P$$

We now know that we also need to monitor our CNS-O_2 clock to prevent O_2 toxicity. The limits should be made part of our dive plan.

Examples:

5.45

130 FSW (39.6 MSW) = 4.939 ata

$(4.939\ ata)\ X\ (.32\ fO_2) = 1.6\ PO_2$ (45 *Minutes*) (1.58)

80 FSW (24.4 MSW) = 3.424 ata

$(3.424)\ x\ (.36\ fO_2) = 1.2\ PO_2$ (210 *Minutes*) (1.23)

60 FSW (18.3 MSW) = 2.8 ata

$(2.8\ ata)\ X\ (.40\ fO_2) = 1.1\ PO_2$ (240 *Minutes*) 1.12

105 FSW (32.0 MSW) = 4.181 ata

$(4.1\ ata)\ X\ (.36\ fO_2) = 1.5\ PO_2$ (120 *Minutes*) (1.48)

* 20 FSW (6.0 MSW) = 1.6 ata

(1.6 *ata*) X (1.0 fO_2) = 1.6 PO_2 (45 *Minutes*)

(1.6 *ata*) X (.50 fO_2) = .8 PO_2 (450 *Minutes*)

* Compare these two examples to illustrate the expanded oxygen window using SafeAir©50 and Pure Oxygen.

In summary look at the diagram of our mathimatical expression of Dalton's Law, we should readily see that by covering up the "Unknown\Solve for" value, the equation we want is present. Try to use the diagram instead of memorizing the formulas. It's easier to remember that Pg is on top, then fill in the other values and all variations of Daton's Law are displayed. We have now come a long way in our understanding of gas mix variations and have answered most of the questions pertaining to dive planning utilizing enriched air mixtures. What is still missing from the complete concept of SafeAir© diving is how to calculate the tN_2 for various mixtures. This aspect will be discussed in Chapter 4.

SafeAir© CLASSROOM MODULE 3
QUIZ

1. Complete the following conversions:

2 ATA's = ______________FSW

4 ATA's =_______________FSW

7 ATA's =______________FSW

2 BAR's =__________MSW

4 BAR's =__________MSW

7 BAR's =__________MSW

2. Complete the following conversions:

47 FSW =_______________ATA's

79 FSW =_______________ATA's

262 FSW =______________ATA's

16 MSW =_________BAR's

25 MSW =_________BAR's

85 MSW =_________BAR's

3. List the formulae for:

Depth Limit

Best Mix (Smallest PN_2)

CNS O_2 Dosage

4. What is the maximum PN_2 dosage recommended?

5. List the primary physiological and operational limitations considered in dive planning?

1)

2)

3)

4)

SafeAir© CLASSROOM MODULE 3 (cont)
QUIZ

6. **Fill in the maximum single dive time fO2 the following dives.**

55 FSW (17 MSW) fO2 = .40 **Maximum time**

75 FSW (23 MSW) fO2 = .36 **Maximum time**

110 FSW (33 MSW) fO2 = .36 **Maximum time**

125 FSW (38 MSW) fO2 = .33 **Maximum time**

American Nitrox Divers Inc.

SafeAir© CLASSROOM MODULE 3
QUIZ ANSWER SHEET

1. Complete the following conversions:

2 ATA's = 33 FSW
2 Bar's= 20 MSW

4 ATA's = 99 FSW
4 Bar's= 40 MSW

7 ATA's = 198 FSW
7 Bar's= 70 MSW

2. Complete the following conversions:

47 FSW = 2.424 ATA's
16 MSW = 1.6 BAR's

79 FSW = 3.393 ATA's
25 MSW = 2.5 BAR's

262 FSW = 8.939 ATA's
85 MSW = 8.5 BAR's

3. List the formulae for:

Depth Limit

$$P = \frac{Pg}{fg}$$

Best Mix (Smallest PN_2)

$$fO_2 = \frac{Pg}{P}$$

CNS O_2 Dosage

$$Pg = fg \times P$$

4. What is the maximum PN_2 dosage recommended? 4.0

5. List the primary physiological and operational limitations considered in dive planning?

1) GAS SUPPLY
2) NITROGEN NARCOSIS
3) DECOMPRESSION LIMITS (tN_2)
4) OXYGEN TOXICITY (tO_2)

American Nitrox Divers Inc.

SafeAir© CLASSROOM MODULE 3 (cont)
QUIZ ANSWER SHEET

6. Fill in the maximum single dive time fO2 the following dives.

55 FSW (17 MSW)	fO_2 = .40	Maximum time 240 (tO_2
75 FSW (23 MSW)	fO_2 = .36	Maximum time 210 c tO_2
110 FSW (33 MSW)	fO_2 = .36	Maximum time 45 c tO_2
125 FSW (38 MSW)	fO_2 = .33	Maximum time 45 c tO_2

a_z [illegible]

				pO_2 =	tO_2
17m	≙	2,7 b	✱	0,4	1.08 → 1.1 / 240
23m		3,3 b		0,36	1.19 → 1.2 / 210
33m		4,3 b		0,36	1.55 → 1.6 / 45
38m		4,8 b		0,33	1.58 → 1.6 / 45

Classroom Module 4
The Equivalent Air Depth Concept and Mixture Application

OBJECTIVES:

A. Will be able to compute the equivalent air depth for any mix of SafeAir©

MATERIALS:

A. ANDI Instructors Manual.

B. Blackboard, chalk, eraser or substitute.

C. Class roster, student folders and test questions.

D. Students need calculator and notebook

INTRODUCTION:

A. Establish Contact

  1. Introduce self

  2. Introduce subject - "The Equivalent Air Depth Concept and Mixture Application"

B. Create interest

  1. This formula will enable the choice of maximum bottom time for a given gas mix.

C. Stress value

  1. Now the diver can determine the maximum amount of O_2 that can be added for a given depth and also determine the maximum time at that depth using the EAD formula.

OVERVIEW

INSTRUCTOR'S NOTE: elapsed time 75-90 min

A. You will learn the mathematical formula used to determine equivalent air depths.

B. Student conduct

1. Please take notes.
2. Ask questions at any time.
3. There will be a written test developed from this material at the end of this course. We will be completing sample problems through-out the program.

PRESENTATION

The Equivalent Air Depth (EAD) Formula

When the amount of nitrogen in the breathing mixtures changes the amount of nitrogen absorbed by the body's tissue changes.

The EAD formula uses the amount of nitrogen in the breathing mixture and the depth of a dive to determine how deep an air dive would have to be to have the same nitrogen tissue loading as this dives mixture.

Generally the formula is calculated with an increase in O_2 an therefore a decrease in nitrogen. This results in an EAD less than the actual depth.

If, for some reason, the amount of nitrogen was increased the formula would work and an EAD could be calculated.

Example:

> A 40 foot dive and an increased amount of nitrogen worked in the EAD formula would result in a depth greater than 40 feet.

The amount of nitrogen that is used in the formula is 79%. This is a conservative number as it is determined by subtracting the amount of oxygen in the mixture from 100%. This is an additional safety factor as there is only 78% nitrogen in air.

Example:

> Analyze the gas in a cylinder and it has a 32% O_2 content. The 32 is subtracted from 100 and the result is a 68% content. If an actual measurement of the nitrogen in the cylinder was made it would show a lower percentage of nitrogen but it is rounded up to be conservative.

The EAD formula works.

$$EAD(FSW) = \left[\frac{(1.0-FO_2)}{.79}(D+33)\right] - 33$$

OR

$$EAD(MSW) = \left[\frac{(1.0-FO_2)}{.79}(D+10)\right] - 10$$

An example of a dive situation:

SafeAir©32 ($N_2 = 68\%$ $O_2 = 32\%$) Depth 130 feet.
No special considerations.

$$EAD(FSW) = \left[\frac{(1.0-.32)}{.79}(130+33)\right] - 33 = 107.3\ FSW$$

OR

$$EAD(MSW) = \left[\frac{(1.0-.32)}{.79}(40+10)\right] - 10 = 33\ MSW$$ ✓ (33,04)

The answer is equivalent air depth.

The formula establishes a ratio between the amount of nitrogen in air and the actual breathing mixture and applies this ratio to ATA. The -33 adjusts the number to FSW.

What is the purpose of this?

This formula provides a way to dive the standard Navy air tables with any blend of O_2 and N_2 in the cylinder.

1. A 130 foot dive on Nitrox I has the same nitrogen absorption as a 107 foot dive on air.
2. The are also safety factors which work as follows:

A. It is stated that 130 foot dive depth is the maximum depth. Your average depth is something less which is another built in safety factor.

B. Using .79 for the nitrox number instead of .78 is a second safety factor.

C. At a depth of 107 FSW on the air tables, it is rounded up to 110 FSW. This provides an additional 3/10ths of one stop safety factor.

The formula allows you to use any number .26 .24 .23 .39 .36 .31 up to .50. As this is a mathematical formula and uses all numbers, it is only necessary to know the gas percentages in the cylinder.

To do EAD calculations, there must be assurance that the oxygen percentage is plus or minus one percent. If number used is a percent and one half off and the dive is planned on the 110 table there is no safety factor. In fact the actual EAD of 112 feet would put the air table at the 120 feet.
It is much easier if the gas mix is SafeAir© 32 or SafeAir © because then the NOAA tables are available which provides for more bottom time than using the EAD formula.

Examine a few more examples:

Dive SafeAir© at a Depth 115 feet (35 MSW) - No special considerations.
What is the maximum amount of Oxygen? Use the best mix calculation as
it is necessary to find maximum fO_2 allowable for this dive.

To solve for fO_2use:

$$\frac{PO_2}{P}$$

$\nearrow$ 0,36

$$115 = \left[\left(\frac{1.6}{fg}\right) - 1\right] 33 = 35.67\ O_2\ \%$$

f02 is PG over P which equals the maximum f02 for that depth.

P expressed as FSW or MSW needs to be converted to ATA\ BAR.

PO_2 is always 1.6 as maximum O_2 exposure. PO_2 could be set as 1.45 or any other value. The user selects the value; the rest is just math.

fO_2 = 35.67 or 35.5 percent O_2. In fact any mix less than 36% would be the maximum amount of oxygen that would use to dive to this depth.

When the cylinder contents are analyzed, and the gas in the cylinder is 36% or more, the fill would need to be adjusted by adding air. Anything less than 36 is an acceptable number.

The important thing is for the user to analyze the gas before the cylinder is used. Remember that the gas is homogeneous and remains so.

Aplications of Enriched Air

Application 1 - The Four Rule Procedure

The easiest way to use Enriched Air Mixtures is to use the four rule program. Every recreational diver, even the occasional diver or infrequent resort visitor can apply SafeAir© in this manner.

It's as simple as:

- Do not dive deeper than 130 FSW (40 MSW)
- Do not exceed 45 minutes bottom time
- Use the standard mix 68/32 SafeAir©
- Do everything else the same as air diving

By doing everything else the same (same tables as usual, same instruments as usual) no change in dive skill levels or in dive planning procedures need to be learned. Any dive tables being used are O.K. since the use of SafeAir© is only adding a major level of safty with regards to nitrogen levels. ***Any*** certified or resort diver will benefit from the reduced nitrogen levels in SafeAir© mixtures by utilizing this application. This application was the original program offered to the recreational diving community in 1988 by ANDI.

Application 2 - SafeAir© with Air Computer

Use a dive computer that is programmed for "air". The computer can be used the same as with normal air dive planning. This maximizes the divers' safety and still offers bottom times that are extended beyond the standard air tables. The computer can be dived to the air limits with very large safety margins. No alteration in the dive plan is necessary other than checking the tO_2 if the dive is to be longer than 45 minutes. Refer to chart 2-4. There is no concern about the nitrogen clock if the computer is properly used. Back-up procedures are the same as those used for normal air diving.

The computer is not aware of the breathing mixture. It is programmed to think the mix is 78% nitrogen, and it calculates accordingly. In fact, there is reduced inert gas "ingassing" and the diver has "programmed in" his own safety factor. If an increase in the tN_2 error margin is the desired objective you could use ***any*** SafeAir© mixture dive within the oxygen limits and do everything else the same.

Application 3 - SafeAir© Programmed or Programmable Computer

Use an "enriched air" programmed computer. Match the mix to the computer's specified fO_2. Maximize bottom time, use the shortest surface interval available and maximize bottom time on the next dive. Perform the normal safety and ascent procedures according to the manufacturer's instructions, and add an additional measure of safety. ie: a safty stop at 15-10 ft (5-3 MSW). In this case the objective is to obtain the full bottom time benefit of the SafeAir© mixture.

More safty may be added by using a fO_2 higher tan the program in the computer. The MOD of this gas must be of course respecteed.

Application 4 - Use The Dive Table That Corresponds To The Mix

Use the dive table that corresponds to the mix used. Be aware that you can switch between tables as you switch gas mixes. The only requirement is that you end each surface interval with a known "repetitive group letter".

Repetitive group letters represent a quantitative amount of nitrogen and are consistent between the three standard dive tables we are using. The US Navy standard air decompression tables, NOAA NITROX I and NOAA NITROX II all use the same letter to represent the same amount of dissolved nitrogen. ***Do not switch tables until you are breathing the gas mixture designated by that table.*** Do follow the standard rule of performing the "***deepest dive first.***" When using enriched air mixtures always select the mix that yields the deepest EAD value. This would require you to use the mix with the **smallest fO_2 first.** Remember that the NOAA tables assume that ascents and decents are performed breathing air. Using SafeAir© as the breathing medium adds to the reliability of the tables. Therefore, using the NOAA tables it can be stated that they are more conservative than the air tables upon which they are based.

Application 5 - Calculate The EAD Formula

Calculate and use the EAD formula. For example, select another cylinder gauge the gas and find that the gas is actually 34% O_2.

The EAD of 89.8 FSW (27.34 MSW) corresponds to the 90 FSW table. Check the standard air table for the tN_2. The US Navy tables indicate 30 minutes of "no decompression time." This is substantially different than the 15 minutes that the air dive to 115 FSW would allow.

$$EAD = \left[\frac{(1.0-.34)}{.79}(115+\underbrace{33}_{})\right] - \underbrace{33}_{} = \overset{90,65}{\cancel{89.8}}\ FSW$$

OR

$$EAD = \left[\frac{(1.0-.34)}{.79}(35+10)\right] - 10 = 27.6\ MSW_{c} \cong 89,87\ ft.$$

Of course it is much easier to use the NOAA Nitrox I or the NOAA Nitrox II tables or Buhlman EAN tables and eliminate the need for calculation. If you need to use the formula, it is nice to know that you can! Be sure to apply the correct dive plan parameters. The formula can not determine the safe limits for oxygen, nitrogen or gas supply. Decompression using EAD and air tables does assume the use of air for ascent and decompression. Using SafeAir© for ascents and any required decompression adds considerable safety margins and provides more reliable decompression. If further clarification is required be sure to consult with your ANDI instructor.

Application 6 - Optimize The Gas Mix For A Desired Result

Optimize the gas mix. Plan a dive to 85 FSW (26 MSW). Using a gas mix that yields an O_2 dosage of less than 1.45 ata, (this is a work dive), we wish to maximize the allowable bottom time. Use the "best mix" formula but use the value of 1.45 PO_2 for the Pg value instead of the standard maximum exposure of 1.6 ata that we would usually use. (PO_2)

85 FSW (26 MSW) is 3.5757 ata (3.6 BAR)

$$fO_2 = \left(\frac{Pg}{P}\right)$$

$$fO_2 = \left(\frac{PO_2}{3.5757}\right)$$

= 0,40

$$fO_2 = \left(\frac{1.45}{3.5757}\right) = 40.6\, fO_2 (\%)$$

Round down. **40.0 fO_2**

Now calculate an EAD for SafeAir© 40 at 85 FSW (28 MSW)

$$EAD = \left[\frac{(1.0-.40)}{.79}(85+33)\right] - 33 = 56.6\ FSW$$

OR

18,86

$$EAD = \left[\frac{(1.0-.40)}{.79}(28+10)\right] - 10 = 18.9\ MSW$$

Use CHART 4-5 to look up the conversion factor for SafeAir© 40. This eliminates the need to perform the division by .79 for each fO_2 mix. The result of the formula is 56.6 FSW (17.3 MSW). This enables you to use the 60 FSW (18 MSW) air table instead of the 90 FSW (27 MSW) table, providing substantial additional bottom time.

Refer to the charts at the end end of this chapter which illuststate numerous variations already calculated.

After several practice problems the EAD/ "best mix" scenario becomes quite easy for those who wish to apply this application of SafeAir© diving.

***Application* 7** - Pony System containing a richer miture than bottom mix.

Use a gas mix with a higher fO_2 than the bottom mix for all ascents. Both safety stops and required stage stops and required stops will be more reliable. The easiest way to do this is to use a pony bottle as an independent gas supply. Since the pony bottle may be used for emergency ascent consider the MOD of the gas in the pony.

For horizontal escape from an overhead environment do not exceed 1.6 ata PO_2 dosage. For vertical ascents in MOD based upon 2.0 ata may be used as the gas would be breathed for extremely brief exposures.

For Example:

We plan a wreck dive or reef dive to 100 FSW (30 MSW). We plan to use SafeAir© as our bottom mix. We have a 15 cu/ft (320 L) volume pony system . We should be using a gas mix in the pony between SafeAir© 36 and SafeAir© 50. 100 FSW (30 MSW) is 4ata by. By using SafeAir© 50 in the emergency bailout system we would be able to switch to the higher fO_2 and begin our ascent.

For enhanced safety use the SafeAir© 50 to more effectively off gassing during an ascent. For dive profiles requiring decompression stops the SafeAir© 50 should be the obvious best choice.

Application 8 - Pony Systems Containing Air - SafeAir© bottom mix.

Many times instructors or Dive guides express concern regarding the limiting factor of shallower MOD's for SafeAir© diving. "What happens if I have to go after some diver who is swimming around deeper than my MOD allows?" Use SafeAir© as bottom mix to enjoy the benefits. Use an **Air filled** pony system to allow for brief excursions beyond the MOD of your bottom mix. Also by diving with a pony system as a rule the "out of air emergency" should be virtually eliminated

Instructor note: Instructor should take the class through some examples of dive planning and table usage. Switching gas mixes during repetitive dives can be confusing to many students. Show how a repetitive group letter is constant for all US Navy Based Air, NOAA I, NOAA II and NASDS tables and can be utilized to switch between air NNI and NNII tables.

CHART 4 - 1

EQUIVALENT AIR DEPTH (EAD) CONVERSION FACTORS

fO_2	fN_2	CONVERSION FACTOR
.22	.78	.98734
.23	.77	.97468
.24	.76	.96202
.25	.75	.94936
.26	.74	.93670
.27	.73	.92405
.28	.72	.91139
.29	.71	.89873
.30	.70	.88607
.31	.69	.87341
.32	.68	.86075
.33	.67	.84810
.34	.66	.83544
.35	.65	.82278
.36	.64	.81012
.37	.63	.79746
.38	.62	.78481
.39	.61	.77215
.40	.60	.75949
.41	.59	.74683

fO_2	fN_2	CONVERSION FACTOR
.42	.58	.73417
.43	.57	.72151
.44	.56	.70886
.45	.55	.69620
.46	.54	.68354
.47	.53	.67088
.48	.52	.65822
.49	.51	.64556
.50	.50	.63291

CHART 4 - 2

EQUIVALENT AIR DEPTH (EAD) BASED ON SafeAir© MIXTURES AT DEPTH

SafeAir© 32 (68% NITROGEN 32% OXYGEN)

DEPTH		EAD		AIR TABLE		OXYGEN PARTIAL PRESSURE ATA /BAR	MAXIMUM NORMAL O_2 EXPOSURE (CHART 2-4)
FSW	MSW	FSW	MSW	FSW	MSW		
20	6	12.62	3.75	-	-	0.51	-
30	9	21.23	6.33	-	-	0.61	720
40	12	29.84	8.92	-	-	0.71	570
45		34.14		40	12	0.76	450
50	15	38.44	11.50	40	12	0.80	450
60	18	47.05	14.08	50	15	0.90	360
70	21	55.66	16.66	60	18	1.00	300
80	24	64.27	19.25	70	21	1.10	240
90	27	72.87	21.82	80	24	1.19	210
100	30	81.48	24.41	90	27	1.29	180
110	33	90.09	26.99	100	30	1.39	150
120	36	98.70	30.44	100	30	1.48	120
130	39	107.30	33.02	110	33	1.58	45
140	42	115.91	35.02	120	36	1.66*	-
150	45	124.52	38.18	130	39	1.77*	-

* Exceeds maximum recommended exposure.

CHART 4 - 3

EQUIVALENT AIR DEPTH (EAD) BASED ON SafeAir© MIXTURES AT DEPTH

SafeAir© 36 (64% NITROGEN 36% OXYGEN)

DEPTH		EAD		AIR TABLE		OXYGEN PARTIAL PRESSURE ATA	MAXIMUM NORMAL O_2 EXPOSURE (CHART 2-4)
FSW	MSW	FSW	MSW	FSW	MSW		
30	9	18.04	5.37	-	-	0.69	570
40	12	26.14	7.80	-	-	0.79	450
45		30.19		40	-	0.85	360
50	15	34.24	10.23	40	12	0.90	360
60	18	42.34	12.66	50	15	1.01	300
70	21	50.44	15.09	60	18	1.12	210
80	24	58.54	17.52	60	18	1.23	180
90	27	66.64	19.95	70	21	1.34	150
100	30	74.75	22.38	80	24	1.45	120
110	33	82.85	24.81	90	27	1.56	45
120	36	90.94	27.24	100	30	1.67*	-

* Exceeds maximum recommended exposure.

CHART 4 - 4

EQUIVALENT AIR DEPTHS (EAD) BASED ON AIR DEPTHS

SafeAir© 32 (68% NITROX 32% OXYGEN)

Actual Depth		EAD		PO_2
FSW	MSW	FSW	MSW	
5	1.6	0	0	0.38
16	5.1	10	3	0.48
28	8.6	20	6	0.60
40	12.0	30	9	0.71
46	14.4	35	12	0.77
51	15.6	40	15	0.82
63	19.1	50	18	0.94
75	22.6	60	21	1.05
86	26.0	70	24	1.16
98	29.5	80	27	1.27
109	33.0	90	30	1.39
121	36.5	100	33	1.50
132	40.0	109	36	1.60
133	40.8	110	36.7	1.61*

SafeAir© 36 (64% NITROX 36% OXYGEN)

Actual Depth		EAD		PO_2
FSW	MSW	FSW	MSW	
7	2.4	0	0	0.45
20	6.1	10	3	0.58
32	9.8	20	6	0.72
44	13.5	30	9	0.85
50	16.0	35	12	0.92
57	17.2	40	15	0.99
69	20.9	50	18	1.12
81	24.6	60	21	1.26
94	28.1	70	24	1.39
106	32.0	80	27	1.53
113	34.5	85	30	1.60
118	35.7	90	33	1.66*
131	39.4	100	36	1.80*
143	44.0	110	36.7	1.93*

* EXCEEDS NORMAL OXYGEN PARTIAL PRESSURE LIMIT OF 1.6 ATA

CHART 4 - 5

BEST MIX FOR SHALLOWEST EQUIVALENT AIR DEPTH (EAD)

DEPTH		ATA/BAR	fO_2	PO_2	EAD	
FSW	MSW				FSW	MSW
70	21	3.12	.513	1.6	30.5	9.4
75		3.27	.489	1.6	36.9	
80	24	3.42	.467	1.6	43.2	13.3
85		3.58	.447	1.6	49.5	
90	27	3.73	.429	1.6	55.9	17.2
95		3.88	.413	1.6	62.2	
100	30	4.03	.397	1.6	68.5	21.0
105		4.18	.383	1.6	74.8	
110	33	4.33	.369	1.6	81.2	24.9
115		4.48	.357	1.6	87.5	
120	36	4.64	.345	1.6	93.8	28.8
125		4.79	.334	1.6	100.2	
130	39	4.94	.324	1.6	106.5	31.2
135		5.09	.314	1.6	112.8	
140	42	5.24	.305	1.6	119.1	36.6
145		5.39	.297	1.6	125.4	
150	45	5.55	.287	1.6	131.8	40.5
155		5.70	.281	1.6	138.1	
160	48	5.85	.274	1.6	144.4	44.3
165		6.00	.267	1.6	150.8	
170	51	6.15	.260	1.6	157.1	48.3

CHART 4 - 6

PARTIAL PRESSURES OF NITROGEN AND OXYGEN IN VARIOUS SafeAir© MIXTURES

SafeAir© 32 (NITROGEN 68% OXYGEN 32%)

ATA /BAR	Depth		Depth		PO_2	PN_2
	FSW	MSW	FSW	MSW		
2.2121	40	12	29.84	8.92	.7079	1.5042
2.3636	45		34.15		.7564	1.6073
2.5152	50	15	38.44	11.50	.8048	1.7103
2.6667	55		42.75		.8533	1.8133
2.8182	60	18	47.05	14.08	.9018	1.9164
2.9670	65		51.35		.9503	2.0194
3.1212	70	21	55.66	16.66	.9988	2.1224
3.2727	75		59.96		1.0473	2.2255
3.4242	80	24	64.27	19.25	1.0958	2.3285
3.5758	85		68.57		1.1442	2.4315
3.7273	90	27	72.87	21.82	1.1927	2.5345
3.8788	95		77.18		1.2412	2.6376
4.0303	100	30	81.48	24.41	1.2897	2.7406
4.1818	105		85.79		1.3382	2.8436
4.3333	110	33	90.09	26.99	1.3867	2.9467
4.4849	115		94.39		1.4352	3.0497
4.6364	120	36	98.70	29.58	1.4836	3.1527
4.7879	125		103.00		1.5321	3.2558
4.9394	130	39	107.30	33.02	1.5806	3.3588
5.0909	135*		111.61		1.6291*	3.4618

***exceeds normal oxygen partial pressure limit of 1.6 ata**

CHART 4 - 6 *(CONT)*

PARTIAL PRESSURES OF NITROGEN AND OXYGEN IN VARIOUS SafeAir© MIXTURES

SafeAir© 36 (NITROGEN 64% OXYGEN 36%)

ATA /BAR	Depth		Depth		PO_2	PN_2
	FSW	MSW	FSW	MSW		
2.3637	45		30.19		.8509	1.5127
2.5152	50	15	34.24	10.23	.9055	1.6097
2.6667	55		38.29		.9600	1.7067
2.8182	60	18	42.34	12.66	1.0145	1.8036
2.9697	65		46.39		1.0691	1.9006
3.1212	70	21	50.44	15.09	1.1236	1.9976
3.2727	75		54.49		1.1782	2.0945
3.4242	80	24	58.54	17.52	1.2327	2.1915
3.5758	85		62.59		1.2873	2.2885
3.7273	90	27	66.65	19.95	1.3418	2.3855
3.8788	95		70.70		1.3964	2.4824
4.0303	100	30	74.75	22.38	1.4509	2.5794
4.1818	105		78.80		1.5055	2.6764
4.3333	110	33	82.85	24.81	1.5600	2.7733
4.4849	115*		86.90		1.6145*	2.8703

***exceeds normal oxygen pertial pressure limits of 1.6 ata**

CHART 4 - 6 *(CONT)*

PARTIAL PRESSURES OF NITROGEN AND OXYGEN IN VARIOUS SafeAir© MIXTURES

SafeAir© 50 (NITROGEN 50% OXYGEN 50%)

ATA /BAR	Depth		Depth		PO_2	PN_2
	FSW	MSW	FSW	MSW		
1.6061	20	6	.5443	.08	.8030	.8030
1.7576	25		3.7089		.8788	.8788
1.9091	30	9	6.8734	1.98	.95455	.9855
2.0606	35		10.0380		1.0303	1.0303
2.2121	40	12	13.2025	3.87	1.1061	1.1061
2.3637	45		16.3671		1.1818	1.1818
2.5152	50	15	19.5317	5.77	1.2576	1.2576
2.6667	55		22.6962		1.3333	1.3333
2.8182	60	18	25.8608	7.67	1.4091	1.4091
2.9697	65		29.0253		1.4849	1.4848
3.1212	70	21	32.1899	9.57	1.5606	1.5606
3.2727	75*		35.3544		1.6364*	1.6364

***exceeds normal oxygen partial pressure limit of 1.6 ata**

CHART 4 - 7

GAS MIX - MOD (Maximum Operating Depth - FSW)

fO_2	MOD*		EAD		'NDL** No Decompression Limit of EAD
	FSW	MSW	FSW	MSW	
.50	72.6	22.3	33.83	10.39	No Limit
.49	74.7	23.0	36.52	11.23	200
.48	77.0	23.7	39.40	12.10	200
.47	79.3	24.4	42.33	13.01	100
.46	81.8	25.1	45.47	13.96	100
.45	84.3	25.9	48.66	14.95	100
.44	87.0	26.7	52.06	15.99	60
.43	89.8	27.6	55.60	17.07	60
.42	92.7	28.5	59.29	18.21	60
.41	95.8	29.4	63.19	19.40	50
.40	99.0	30.4	67.25	20.65	50
.39	102.4	31.5	71.55	21.97	40
.38	105.9	32.5	76.01	23.36	40
.37	109.7	33.7	80.80	24.81	30
.36	113.7	34.9	85.84	26.36	30
.35	117.8	36.2	91.08	29.11	25
.34	122.3	37.5	96.74	30.92	25
.33	127.0	39.0	102.70	31.54	20
.32	132.0	40.5	109.02	33.48	20
.31	137.3	42.2	115.74	35.55	15
.30	143.0	43.9	122.95	37.76	10
.29	149.1	45.8	130.66	40.12	10
.28	155.6	47.8	138.89	42.65	10
.27	162.5	49.9	147.65	45.36	5
.26	170.1	52.2	157.24	48.27	5

* **Based upon 1.6 ATA (Atmospheres Absolute) Dosage of Oxygen**

** **Based upon U.S. Navy Tables**

SafeAir©
CHAPTER 4 QUIZ

1. State the EAD formula.

2. Solve for EAD.

FSW	EAD	fO_2	EAD	MSW
58		.40		18
52		.33		16
113		.36		34
148		.29		45
105		.36		32

3. Why would we want to use the EAD formula?

4. What piece of information do we need in order to be able to switch between tables?

5. List the various ways of applying SafeAir© mixtures:

1.	5.
2.	6.
3.	7.
4.	8.

SafeAir© CLASSROOM MODULE 4
QUIZ ANSWER SHEET

1. State the EAD formula.

$$EAD = \left[\frac{(1.0-FO_2)}{.79}\ (D+33)\right] - 33$$

2. Solve for EAD.

FSW	f02	EAD
58	.40	36
52	.33	40
113	.36	85
148	.29	130
105	.36	79

3. Why would we want to use the EAD formula?

IF A GAS MIX DID NOT MATCH OUR STANDARD TABLES

4. What piece of information do we need in order to be able to switch between tables?

REPETITIVE GROUP LETTER

5. List the various ways of applying SafeAir© mixtures:

1.Four Rule Procudure	5.EAD Formula
2.Air Compter	6.Optimize Gas Mix
3.Programed Or Programmable Computer	7.Pony System Containing Richer Mixture than Bottom
4.Corresponding Mix Dive Tables	8.Pony System Containing Air

Classroom Module 5

O_2 Handling and Nitrox Dispensing Procedures

Objective:

Upon completion of this module the students will know the proper procedure for marking, handling and sampling of NITROX (SAFEAIR) cylinders. The students will also better understand the proper procedures for handling pure oxygen.

Materials:

1) A.N.D.I. instructor's manual
2) Blackboard, chalk and eraser or substitute
3) Class roster , attendance list
4) Properly marked NITROX (SAFEAIR) cylinder
5) Oxygen analyzer and sampling device
6) Sample of refill log

Introduction:

A) Establish contact

    1) Introduce self

    2) Introduce the subject, "O Handling and Dispensing Procedures".

B) Create interest.
Because SafeAir© contains more oxygen, we can not treat the refill process as we would an air refill. As safe divers we must know what the oxygen content is in the NITROX mix that we're breathing. It is up to us, the end user, to do a final check.

C) Stress value.
Oxygen has unique properties that require specific procedures to prevent accidental damage and personal injury.

D) Overview

    1) Subject matter of this module

        A) Properties of oxygen as related to cylinder handling and suitability.

        B) Proper cylinder marking and labeling.

C) Procedures for refilling cylinders.

D) Proper gas analysis and record keeping.

2) Student conduct.

Take notes and ask questions at any time.

Presentation:

A) PROPERTIES OF OXYGEN AND CYLINDER SUITABILITY

1. Pure oxygen is a colorless, odorless and tasteless gas.
2. It is the most abundant element and comprises 21% of the air we breathe and 55% of the earth's crust.
3. Oxygen supports plant and animal life.
4. It also supports combustion and corrodes most metals.
5. Oxygen is hazardous

   a) It is all around us, we breathe it, it is used to save lives, it is not even flammable. If properly managed oxygen is a safe and valuable commodity.

   b) However, oxygen makes everything burn faster and easier and can under certain conditions cause explosions.

   c) The handling of pure oxygen should be done by professionals trained to handle oxygen using only oxygen service equipment.

   d) Attempting to transfer pure oxygen into a scuba cylinder can cause on explosion at the time of transfer or when "topping" with air that contains any hydrocarbon contaminates.

   e) In January of 1990, the largest manufacturer (Luxfer USA Limited) of aluminum cylinders in North America issued a warning bulletin to all of its distributors. The bulletin (SEE APPENDIX EXHIBIT 1) stated:

> 1- "Luxfer has been made aware that some scuba divers are having scuba cylinders partially filled with pure oxygen, then having them topped off with air", and
>
> 2- "Scuba cylinders, valves and other components are not specifically cleaned for oxygen use. Also, the lubricants typically used in the industry are generally not compatible with pure oxygen, which could result in ignition, fire, and/or rupture."

This applies to medical uses as well. Many misinterpret this bulletin and believe it means that oxygen enriched mixtures cannot be used in aluminum cylinders.

B) SELECTION OF MATERIALS FOR OXYGEN SERVICE

Materials that burn in air will burn violently in pure oxygen and explosively in pressurized systems. Also many materials that do not burn in air will do so in pressurized systems.

In oxygen systems, the selection of materials is of paramount importance. Some common materials used in scuba equipment that are not compatible with pure oxygen are among others:

1. Teflon seats,
2. Buna-N O-rings,
3. Neoprene diaphragms and seats, and
4. Plastics in the gas stream under pressure.

Compatibility means that all of the materials that are in contact with the gas are compatible with the gas at the working pressures of the system.

C. OXYGEN SERVICE

This refers to the suitability of a product or a component for use with pure oxygen. Oxygen service requires BOTH oxygen clean AND oxygen compatible components.

1. A component may be oxygen compatible but contaminated (not oxygen clean).
2. Likewise an oxygen clean component may not be oxygen compatible.

When utilizing oxygen enriched mixtures it is recommended by A.N.D.I. that all components are first oxygen cleaned before entering into service.

As long as the percentage of oxygen does not exceed 50% most conventional scuba equipment is considered compatible. Recommended service intervals must be strictly adhered to when using SafeAir mixtures. In 1991 Dacor stated that there should be no service beyond 21% on their regulators.

Cylinders suspected of contamination should be chemically cleaned and warm air dried.

Valves both new and used should be ultrasonically cleaned with the appropriate detergent. Only after the cylinder and valve have been cleaned and inspected may the cylinder be entered into service. Once a cylinder has been prepared for SafeAir© refills and labeled with a SafeAir VIP decal (SEE APPENDIX EXHIBIT 2), it may not be refilled with air from an oil-lubricated source. It is to be considered a dedicated cylinder.

The cylinder can be returned to "air only" service, provided the color-coding and markings are removed.

If at any time contamination is suspected the cylinder should be again inspected and cleaned by the A.N.D.I.certified refill station.

INSTRUCTORS NOTE: As a rule, SafeAir© affords much more bottom time and generally affords a slightly lower than usual air consumption rate.

Because of the above divers should consider selecting larger capacity diving cylinders. The new technology affords the diver the opportunity to plan dives that previously required twin cylinders by utilizing cylinders that are only slightly larger than an aluminum 80. (Sherwood genesis 100 and 120 cubic foot steel cylinders).

The cylinders available at your store/school should be discussed along with the pros and cons of converting used air cylinders or purchasing new dedicated cylinders.

D) CYLINDER MARKING AND LABELING

Why is there a need for color coding cylinders?

1. What could the result be if a cylinder marked for CO_2 was refilled with oxygen?

   Possible Explosion or other problems

2. What could the result be if a cylinder marked for oxygen was refilled with argon?

   Possible death - By asphyxiation

As can be seen from the above, there must be a standard coding for all gas cylinders. The Compressed Gas Association (CGA) requires all cylinders to be labeled and tagged. It also has color-coding for medical gas cylinders to help identify the gas. For example:

1. Oxygen is green
2. Argon is brown
3. Breathing air is yellow
4. Helium is blue

Once a cylinder is color-coded it should be obvious that it would be improper to refill with any gas other than the gas designated by the color-code.

There are other safeguards within the gas industry, such as the use of different valves for each different gas. Argon, oxygen, air, propane and carbon dioxide cylinders all have different valves.

We want to be sure that mistakes will not happen. It is logical to have a color-code for oxygen enriched air mixtures.

The color selection is green top, yellow bottom. (SEE APPENDIX EXHIBIT 3)

NOAA has used:

a) A green top (25%), or

b) A 4" green band

At this time both are considered correct.

ANDI has cylinder wrap decals available that wrap completely around the cylinder and eliminate the need for repainting. (SEE APPENDIX EXHIBIT 4)

There should be additional alphabetical markings to indicate gas content to alert those who have not had the benefit of this training.

Cylinder contents tag should be affixed to the neck of the cylinder.

Two plastic wire ties or ti-wraps to affix the contents tag. Make a small loop through the tag, then after passing the other tie through the small loop fasten the tie around the neck of the cylinder at the base of the valve. Cut the ties clean to remove any sharp edges.

The contents tag enables the user to select the cylinder from a group of others and select the cylinder that he/she analyzed.

Also if you are diving two or more dives but have cylinders that have slightly different fO2, select the one that enables you to complete the deepest dive first.

For an example of the cylinder contents tag. (SEE APPENDIX EXHIBIT 5)

Instructors note: You should state which coding your facility uses and indicate that under no circumstance will cylinders be refilled without the correct color-coding and markings. This protects the entire training program as well as the individual facility. ANDI suggests the serial number be written with permanent marker on the reverse side of the contents tag.

E) CYLINDER REFILLING PROCEDURES

A properly cleaned, marked and inspected cylinder with a cleaned valve may enter SafeAir© service.

The refill process is conducted in the same manner as a standard air refill.

However, special emphasis must be placed on protecting the cylinder from moisture and hydrocarbon contamination. As the cylinder will contain more oxygen than an air filled cylinder, corrosion would accelerate in a contaminated cylinder.

We also know that hydrocarbon contamination can potentially result in disaster for the person performing the refill.

To err on the side of safety a slower speed of pressurization is recommended. Pressurizing at a rate of approximately 400 psi per minute would be a good suggestion as this would reduce the heat buildup associated with the compression process.

Upon reaching full service pressure the end user must perform a gas analysis to measure the fO_2 content.

Cylinders refilled with pre-blended SafeAir© may be analyzed and used immediately. No additional standing time is required for thorough gas mixing.

D) PROPER GAS ANALYSIS AND RECORD KEEPING

Oxygen is the easiest gas to analyze because of its unique properties.

Oxygen analyzers are the least expensive of all gas analyzers and in addition are very easy to calibrate.

The small hand-held type should be calibrated prior to each use. These portable analyzers usually have a calibration dial on the outside of the housing.

> Turn on the meter an expose the sensor to atmospheric air. If the analyzer does not read 21% after stabilizing its display, It must be adjusted by turning the calibration dial.
>
> If the analyzer reads in full units, 18% - 19% - 25%- etc., it should be adjusted to read 20% and then increase slowly stopping just as the display shifts to 21%.
>
> This will maximize the accuracy of the actual gas reading.

A sampling device for gauging and sampling the gas from scuba cylinders is required to feed gas from the cylinder to the oxygen analyzer. (SEE APPENDIX EXHIBIT 6)

The procedure for its use is as follows:

1. Connect the sampling device to the cylinder

2. Close the valve on the sampling device

3. Open the cylinder valve and gauge the cylinder pressure.
4. Enter the pressure reading on the cylinder contents tag.

5. Open the sampling valve slowly and slightly, just enough to create a slight gas flow.

6. Connect the sampling hose to the analyzer sensor and read the oxygen analyzer display.

   a) Different gas analyzer models require different amounts of time and gas flow to stabilize the display, usually 10 to 45 seconds.

      Allow sufficient time for the analyzer to stabilize.

   b) An erroneous reading (too high) will result if the sensor chamber of the analyzer is exposed to a pressure higher than one atmosphere. This can occur if the flow rate is excessively high.

7. Turn off the cylinder valve.

8. Enter the fO_2 and fN_2 reading on the cylinder contents tag with the date and tester initials.

9. Purge the sampling device and remove it from the cylinder.

10. Complete the refill record sheet used to record all SafeAir© refills. (SEE APPENDIX EXHIBIT 7)

    Print name, record the cylinder serial number (or facility's rental cylinder number), list the fO_2 and cylinder pressure in the spaces provided,

    Refer to the contents tag (attached to the cylinder)

    Sign name.

Instructors note: A demonstration of the above procedure should be preformed at this time.

The process is only slightly more time consuming than gauging a cylinder for pressure. After a few times, it becomes almost automatic.

Instructor Note: The following information is optional material for SafeAir© users. However, as there are many basement geniuses and short cutters this may prove to be valuable information.

E. NITROX/SAFEAIR PRODUCTION

The ANDI training facilities' refill station should be the central focus of this training program.

1. In general, the higher the pressures and/or temperatures involved, the cleaner the equipment must be to prevent fire, flashing and/or explosion.

    a) NOAA recommends:

        1) If any PO_2 higher than .4 is going to be used, all equipment utilized must be O clean.

            It is required of all ANDI refill stations that only oxygen cleaned cylinders and valves be refilled with enriched air mixtures.

            Diver regulators are considered compatible for fO2 up to .5.

INSTRUCTORS NOTE: The Compressed Gas Association (CGA) and American Society of Testing Materials have published numerous pamphlets establishing guidelines and procedures for oxygen cleaning. Refer to CHART 5 - 5 LIST.

2. Various methods of mixing/blending of oxygen and other gases.

A. Partial Pressure Blending:

This is the least expensive procedure to implement as the equipment necessary is minimal. It is performed by transferring O2 from a storage cylinder into an empty scuba cylinder. After filling the cylinder to 300 or 400 psi the cylinder fill is completed with air. Presto! magic NITROX. It is nitrox, but what fO_2?.

This is the most hazardous and least accurate method currently in use. It is usually used as the short cut - cheap way out.

It is to be strongly discouraged.

The reasons why this method is considered dangerous by NOAA, ANDI, The U.S.N. and all the Compressed Gas Associations are as follows:

1) The equipment is seldom O_2 clean

2) This process requires handling of high pressure O. This is dramatically different than high pressure air.

3) The air used in the top-off fill generally comes from an oil lubricated compressor and has hydrocarbon contaminants.

4) Even if the equipment starts out O_2 cleaned, after several refill cycles from an oil lubricated compressor, the equipment is contaminated with hydrocarbons increasing the risk of explosion.

5) Pure oxygen should not be added to SCUBA cylinders not compatible with 100% oxygen as per LUXFER warning bulletin. (SEE APPENDIX EXHIBIT 1)

INSTRUCTORS NOTE: Please read this bulletin to the class.

6) Gas analysis with accurate O_2 analyzers is seldom done. Remember we said that this was the cheap way out

7) Unless the cylinders are totally empty this procedure yields even more inaccuracy.

8) Gas transferred must stand for considerable time to permit thorough mixing through molecular migration.

9) Gauges used to measure pressure are seldom accurate enough for this purpose. A gauge selected for this purpose should have an accuracy of ± .25%. That's 1/4 of 1%.

10) Gas must be again analyzed prior to use.

11) This process has the highest gas cost.

B. Partial Pressure Blending Via Oxygen Booster Pump

This procedure requires an oxygen booster pump and an oxygen cleaned bank system.

If all the equipment is oxygen clean the fO_2 in the storage bank can be increased by supplying the booster pump with O_2 and filling the bank from the booster pump. Cylinder refills are done by cascading from the bank or utilizing the booster pump.

The problems inherent with this process are:

1) The equipment is seldom O_2 clean

2) This process requires handling of high pressure O_2. This is dramatically different than high pressure air.

3) The air used in the top-off of the bank generally comes from an oil lubricated compressor and has hydrocarbon contaminants.

4) Even if the equipment starts out O_2 cleaned, after several refill cycles from an oil lubricated

compressor, the equipment is contaminated with hydrocarbons increasing the risk of explosion.

5) Usually the oxygen in the O_2 storage cylinders can only be used down to about 500 to 600 psi. The increased cost of O_2 makes this impractical for any serious volume.

6) If the booster pump is being supplied with contaminated air and as booster pumps inherently pump at 200+ degrees F there is increased risk of dieseling within the pump. This would cause carbon monoxide contamination of the entire system.

C. Standard Cascade and Booster Pump

With an O_2 clean system refills may be done in the standard manner. The gas is supplied to the refill center in storage cylinders pre-blended and pre-analyzed. There are no hazards associated with this process as long as the cylinders being refilled are appropriately cleaned.

D. Continuous Blending System

See Chart 5 - 6

This is by far the best method. It required an oil-free (non-oil lubricated) compressor.

The process is simple:

1) Large storage cylinders and scuba cylinders may be refilled with mixtures between 21 & 50% O_2 easily and accurately.

ANDI supports the use of oil-free compressors for production of all breathing air. Therefore once a refill center utilizes the Continuous Blending System all refills, both Air and SafeAir©, would be totally hydrocarbon free. (SEE APPENDIX EXHIBIT 8)

Certified ANDI refill centers produce the cleanest breathing gas for its customers. This process does not require the use of high pressure O_2. Actually if liquid O_2 is available there are even more benefits.

Very cold ultra dry low temperature O_2 is injected into the compressor intake at a controllable variable flow at ambient pressure.

This is the primary difference between this method and all others. It is the most practical and cost effective.

ANDI headquarters has additional information on complete blending systems for sale lease or lease purchase.

American Nitrox Divers Inc.

SafeAir© CLASSROOM MODULE 5
QUIZ

1. What does "oxygen clean" mean?

2. What does oxygen service mean?

3. What is the maximum fO_2 that may be used on oxygen clean equipment?

4. What external markings must be on cylinders entered into SafeAir© service?

5. What information is recorded on the cylinder contents tag?

6. How often should an oxygen analyzer be calibrated?

7. To be used as a primary analyzer how accurate must an oxygen analyzer be?

SafeAir© CLASSROOM MODULE 5
QUIZ ANSWER SHEET

1. What does "oxygen clean" mean?

ALL HYDROCARBONS AND CONTAMINANTS HAVE BEEN REMOVED

2. What does oxygen service mean?

ALL MATERIALS IN CONTACT WITH THE GAS FLOW MUST BE COMPATIBLE

WITH OXYGEN

3. What is the maximum fO_2 that may be used on oxygen clean equipment?

.50 OXYGEN

4. What external markings must be on cylinders entered into SafeAir© service?

A 4 INCH GREEN BAND AROUND THE TOP OF A YELLOW CYLINDER OR A GREEN HAT ON THE TOP 25% OF A YELLOW CYLINDER. BOTH COLOR CODES MUST ALSO INCLUDE AN ALPHABETICAL REPRESENTATION OF THE CYLINDERS CONTENTS (NITROX/SafeAir©) THE ANDI WRAP DOES BOTH

5. What information is recorded on the cylinder contents tag?

fO_2 - PSI - DATE - TESTER

6. How often should an oxygen analyzer be calibrated?

PRIOR TO EACH USE

7. To be used as a primary analyzer how accurate must an oxygen analyzer be?

PLUS OR MINUS 1 PERCENT

Luxfer USA Limited

Aluminum Compressed Gas Cylinders

TECHNICAL BULLETIN

SUBJECT:	OXYGEN IN SCUBA CYLINDERS	DATE:	Rev. Jan. 1993 Orig. Mar. 1989

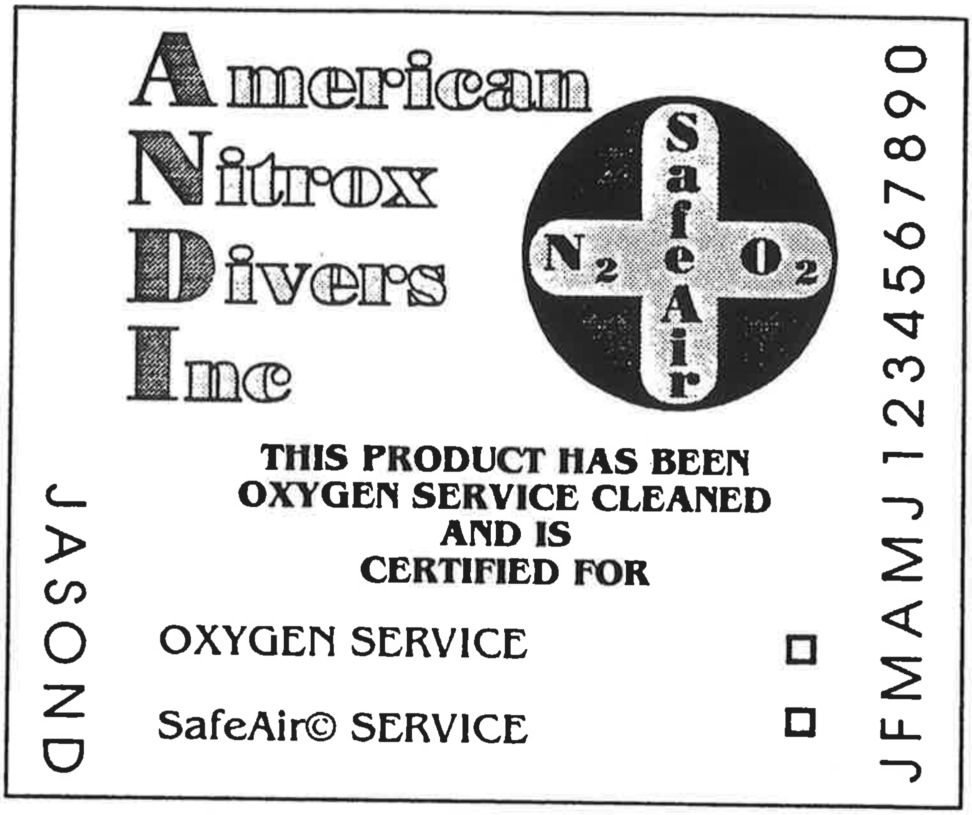
WARNING

Luxfer has been made aware that some scuba divers are having scuba cylinders partially filled with pure oxygen, then having them topped off with air.

THIS PRACTICE SHOULD BE CEASED IMMEDIATELY SINCE CATASTROPHIC FAILURE AND LOSS OF LIFE OR SERIOUS INJURY CAN RESULT. Scuba cylinders, valves and other components are not specifically cleaned for oxygen use. Also, the lubricants typically used in the industry are generally not compatible with pure oxygen, which could result in ignition, fire, and/or rupture.

Oxygen enriched air may be introduced into Luxfer cylinders **only if the cylinder is properly cleaned and maintained for oxygen service.** Cylinders and components must be maintained as **hydrocarbon free** with only oxygen and aluminum compatible lubricants utilized.

IGURE 5 - 4-1 REGULATOR COMPATIBILITY SLEEVE

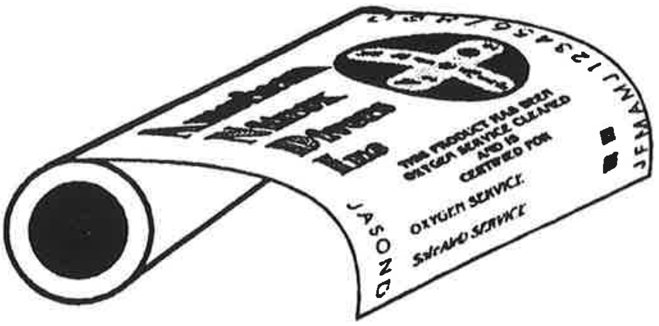


THIS PRODUCT HAS BEEN
OXYGEN SERVICE CLEANED
AND IS
CERTIFIED FOR

OXYGEN SERVICE ☐

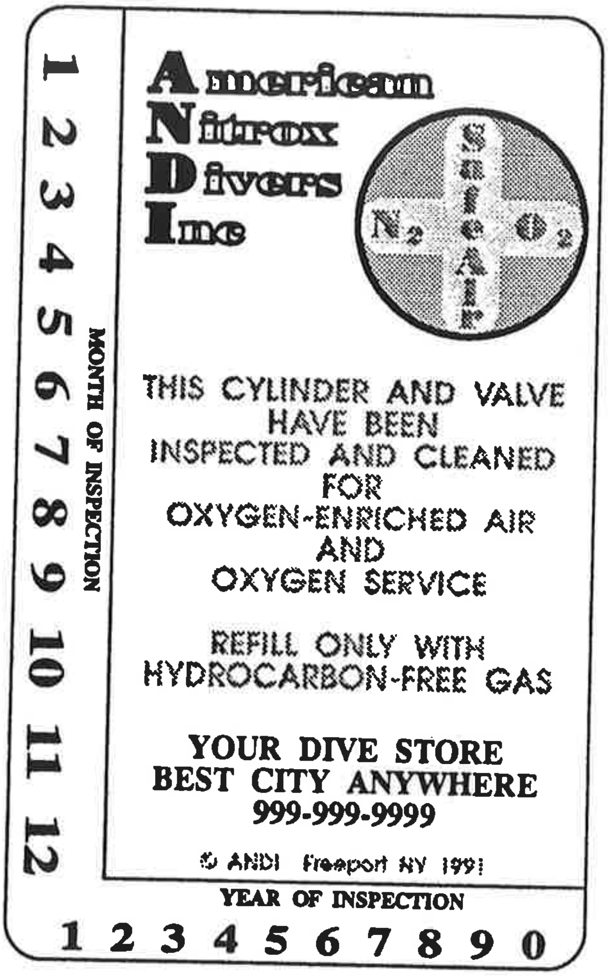
SafeAir© SERVICE ☐

2 X Actual Size



Actual size 2½ Inch Plastic Hose Sleeve

ANDI
VISUAL INSPECTION
DECAL



1 2 3 4 5 6 7 8 9 10 11 12

MONTH OF INSPECTION

American
Nitrox
Divers
Inc

Safe Air

N_2 O_2

THIS CYLINDER AND VALVE
HAVE BEEN
INSPECTED AND CLEANED
FOR
OXYGEN-ENRICHED AIR
AND
OXYGEN SERVICE

REFILL ONLY WITH
HYDROCARBON-FREE GAS

YOUR DIVE STORE
BEST CITY ANYWHERE
999-999-9999

© ANDI Freeport NY 1991

YEAR OF INSPECTION

1 2 3 4 5 6 7 8 9 0

ANDI SafeAir©
CYLINDER DESIGNATION

4 INCH GREEN BAND, OR
GREEN CAP, OR
SafeAir© VINYL MYLAR
COATED CYLINDER BAND

GREEN LETTERING

YELLOW CYLINDER
BODY

BACK VIEW OF
SafeAir© CYLINDER

FIGURE 5 - 2 CYLINDER WRAP STICKER

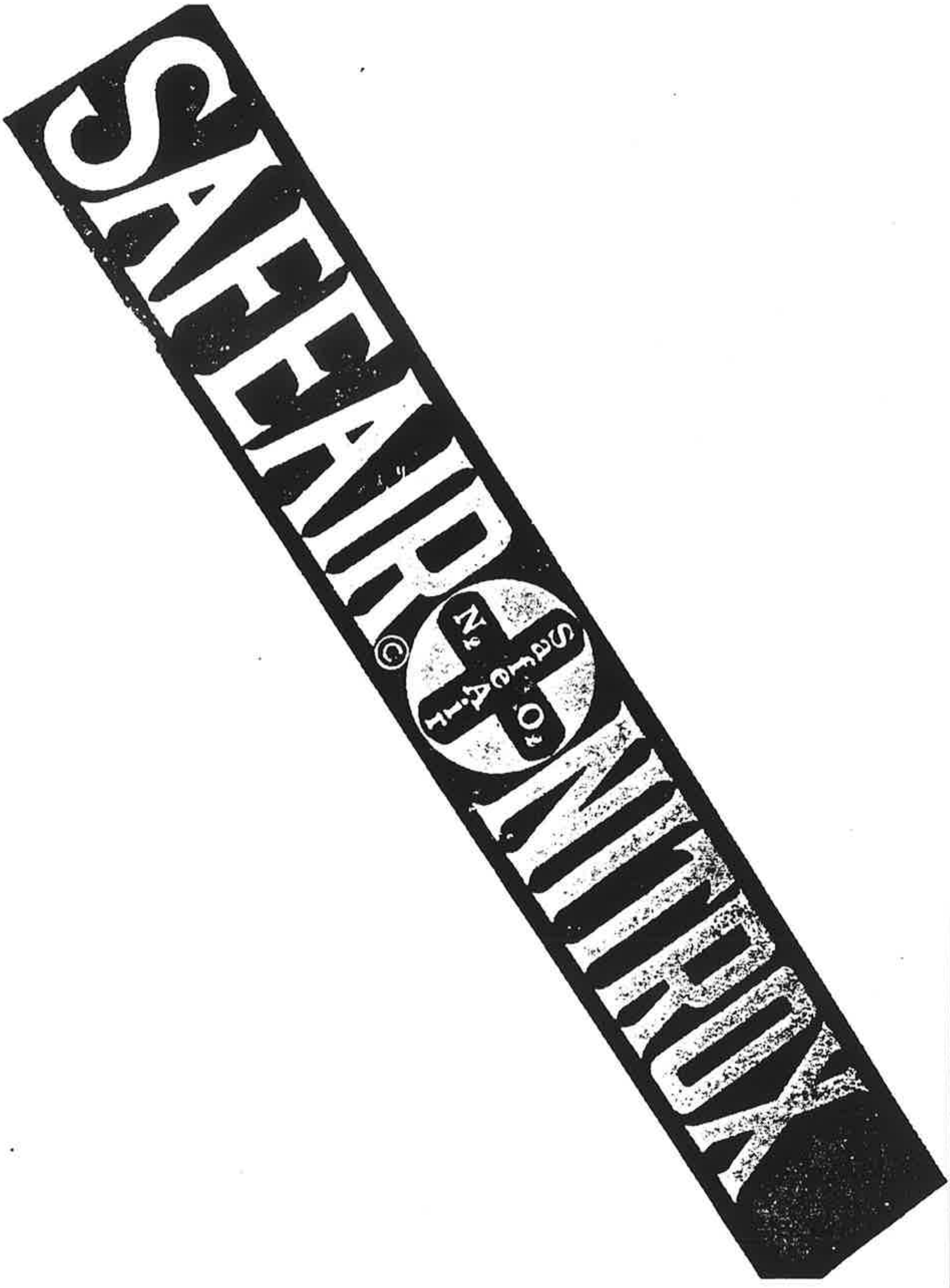
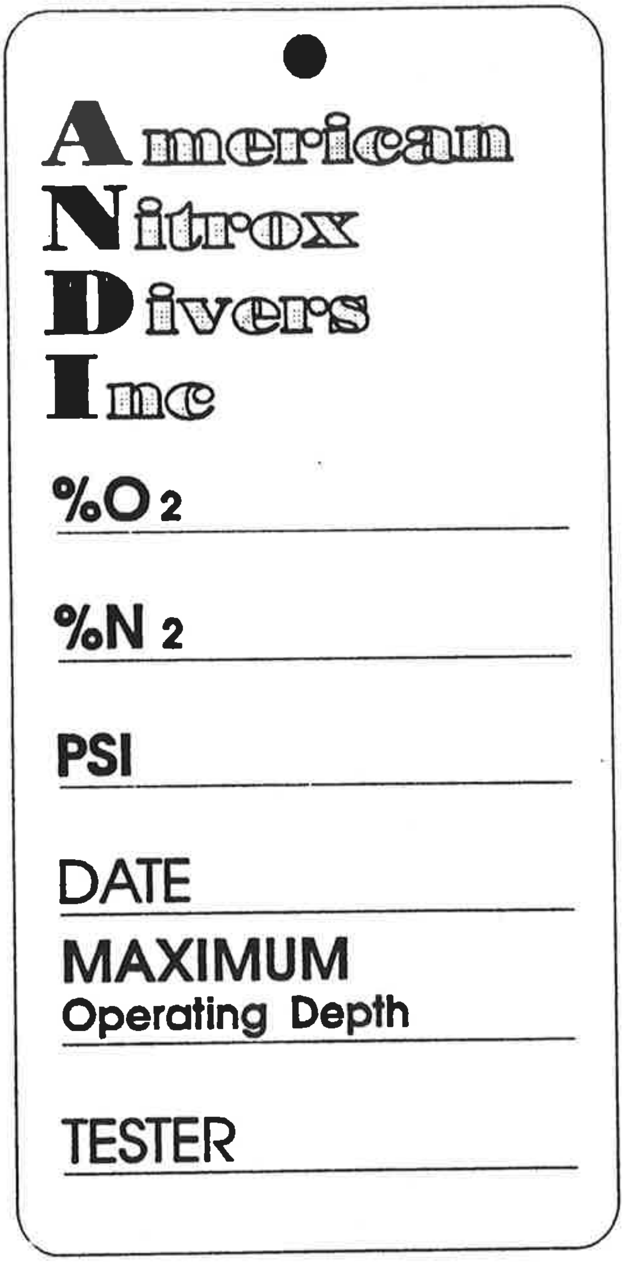


FIGURE 5 - 3 CYLINDER CONTENTS TAG



American
Nitrox
Divers
Inc

%O_2 ____________________

%N_2 ____________________

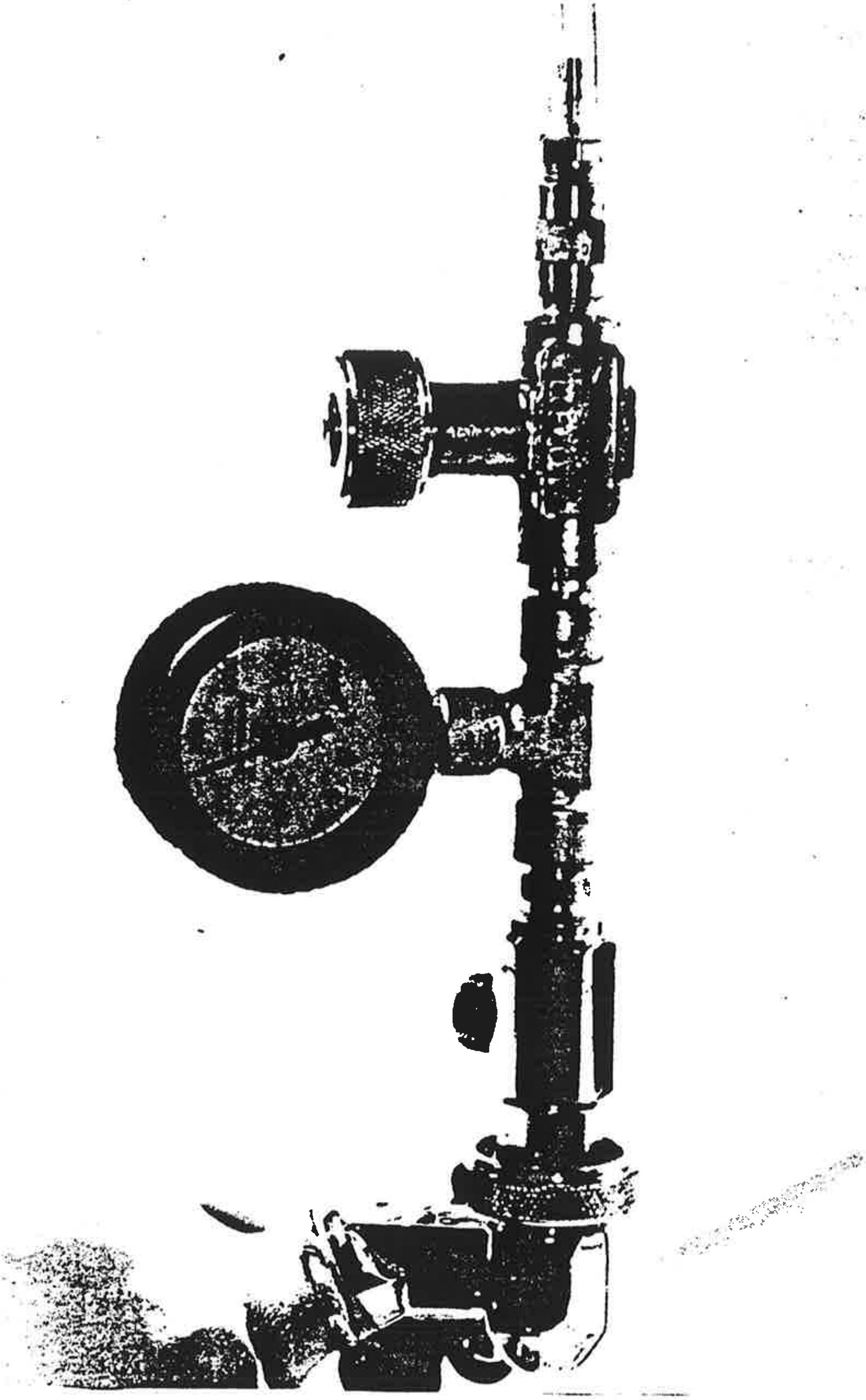
PSI ____________________

DATE ____________________

MAXIMUM
Operating Depth ____________________

TESTER ____________________

FIGURE 5 - 6 MIXTURE SAMPLING DEVICE



PLEASE PRINT

XYZ DIVE STORE - NITROX VALIDATION SIGN-OFF

American
Nitrox
Divers
Inc

[illegible]
[illegible]

NAME	CYLINDER SERIAL NO.	DATE	PSI PRESSURE	% O2	SIGNATURE
JOE DIVER	P39856774	JUNE 8 1999	3050	36	Joe Diver

FIGURE 5 - 8 CONTINUOUS BLENDING SYSTEM

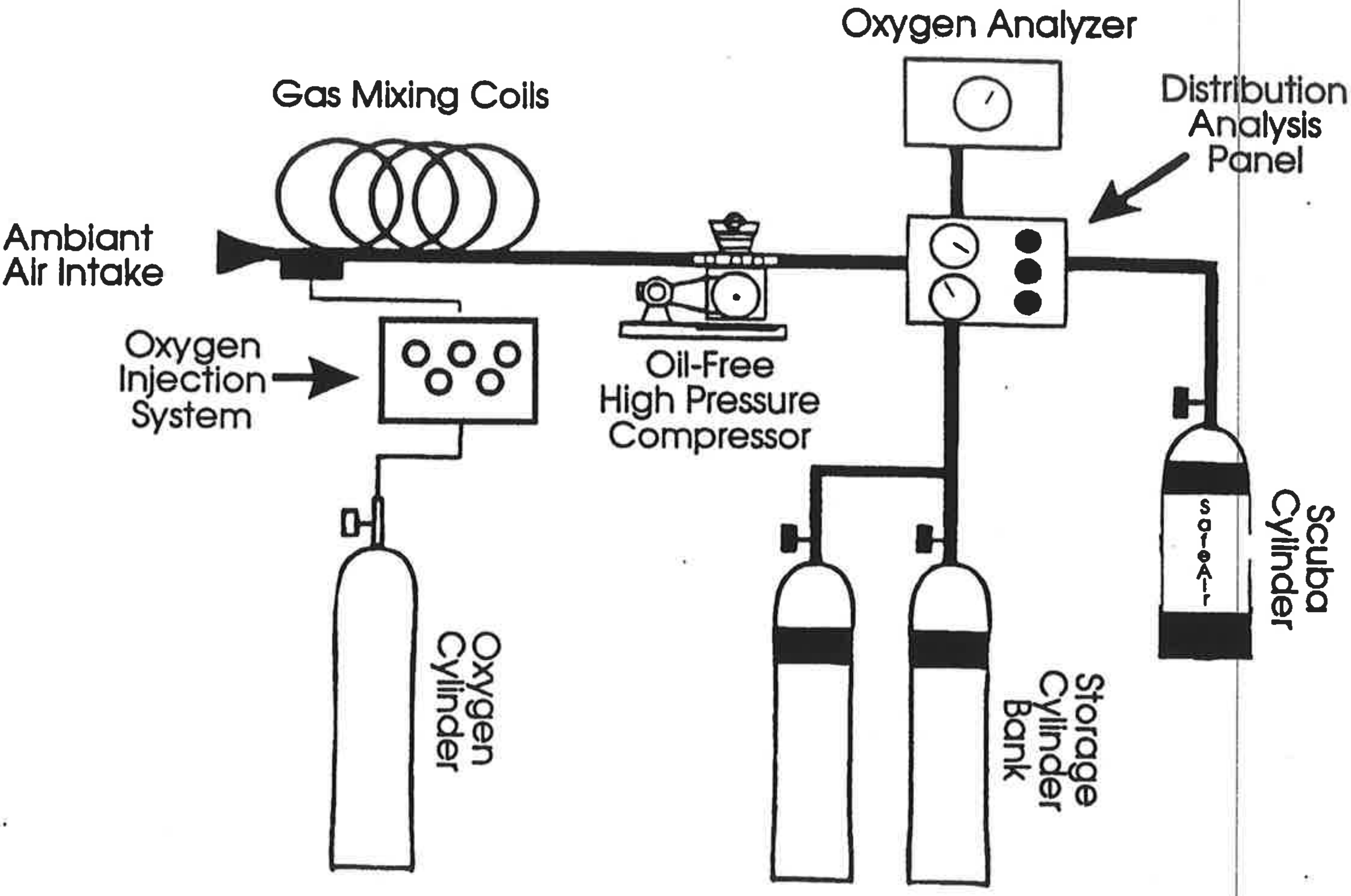


TABLE E-1

NOAA NITROX I (68% N_2, 32% O_2) NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE FOR NO-DECOMPRESSION DIVES

**American
Nitrox
Divers
Inc**

74 Woodcleft Avenue,
Freeport NY 11520

(516)-546-2026
(800)-451-2551

	DEPTH FSW	No-Deco. Limits (min)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	15		60	120	210	300											
	20		35	70	110	160	225	350									
	25		25	50	75	100	135	180	240	325							
	30		20	35	55	75	100	125	160	195	245	315					
	40		15	30	45	60	75	95	120	145	170	205	250	310			
13,6	45	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
15,15	50	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
18,18	60	100		10	15	25	30	40	50	60	70	80	90	100			
21,21	70	60		10	15	20	25	30	40	50	55	60					
24,24	80	50		5	10	15	20	30	35	40	45	50					
27,27	90	40		5	10	15	20	25	30	35	40						
30,3	100	30		5	10	12	15	20	25	30							
33,3	110	25		5	7	10	15	20	22	25							
36,4	120	25		5	7	10	15	20	22	25							
39,4	130	20			5	10	13	15	20								
42,4	140	15			5	10	12	15									
45,4	150	10			5	8	10										

TABLE E-2

NOAA NITROX I (68% N_2, 32% O_2) DECOMPRESSION TABLE

DEPTH (feet)	BOTTOM TIME (min)	TIME FIRST STOP (min:sec)	DECOMPRESSION STOPS (feet) 50	40	30	20	10	TOTAL ASCENT (min:sec)	REPETITIVE GROUP
50	200						0	0:50	•
	210	0:40					2	2:50	N
	230	0:40					7	7:50	N
	250	0:40					11	11:50	O
	270	0:40					15	15:50	O
60	100						0	1:00	•
	110	0:50					3	4:00	L
	120	0:50					5	6:00	M
	140	0:50					10	11:00	M
	160	0:50					21	22:00	N
	180	0:50					29	30:00	O
	200	0:50					35	36:00	O
70	60						0	1:10	•
	70	0:60					2	3:10	K
	80	0:60					7	8:10	L
	100	0:60					14	15:10	M
	120	0:60					26	27:10	N
	140	0:60					39	40:10	O
80	50						0	1:20	•
	60	1:10					8	9:20	K
	70	1:10					14	15:20	L
	80	1:10					18	19:20	M
	90	1:10					23	24:20	N
	100	1:10					33	34:20	N
	110	1:00				2	41	44:20	O
	120	1:00				4	47	52:20	O
	*** 130	1:00				6	52	59:20	O

TABLE E-3 RESIDUAL NITROGEN TIMES FOR NOAA NITROX I (68% N_2, 32% O_2) DIVES

American
Nitrox
Divers
Inc

[illegible]

Repetitive Group Designation

REP. DIVE DEPTH fsw	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
50	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
60	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
70	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
80	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
90	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
100	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
110	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
120	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
130	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
140	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
150	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3

Values are minutes

TABLE E-4 RESIDUAL NITROGEN TIMETABLE FOR REPETITIVE NOAA NITROX I (68% N_2, 32% O_2) DIVES*

Repetitive group at the beginning of the surface interval

A																0:10 12:00*
B															0:10 2:10	2:11 12:00*
C														0:10 1:39	1:40 2:49	2:50 12:00*
D													0:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00*
E												0:10 0:54	0:55 1:57	1:58 3:22	3:23 6:32	6:33 12:00*
F											0:10 0:45	0:46 1:29	1:30 2:28	2:29 3:57	3:58 7:05	7:06 12:00*
G										0:10 0:40	:41 1:15	1:16 1:59	2:00 2:58	2:59 4:25	4:26 7:35	7:36 12:00*
H									0:10 0:36	0:37 1:06	1:07 1:41	1:42 2:23	2:24 3:20	3:21 4:49	4:50 7:59	8:00 12:00*
I								0:10 0:33	0:34 0:59	1:00 1:29	1:30 2:02	2:03 2:44	2:45 3:43	3:44 5:12	5:13 8:21	8:22 12:00*
J							0:10 0:31	0:32 0:54	0:55 1:19	1:20 1:47	1:48 2:20	2:21 3:04	3:05 4:02	4:03 5:40	5:41 8:40	8:41 12:00*
K						0:10 0:28	0:29 0:49	0:50 1:11	1:12 1:35	1:36 2:03	2:04 2:38	2:39 3:21	3:22 4:19	4:20 5:48	5:49 8:58	8:59 12:00*
L					0:10 0:26	0:27 0:45	0:46 1:04	1:05 1:25	1:26 1:49	1:50 2:19	2:20 2:53	2:54 3:36	3:37 4:35	4:36 6:02	6:03 9:12	9:13 12:00*
M				0:10 0:25	0:26 0:42	0:43 0:59	1:00 1:18	1:19 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00*
N			0:10 0:24	0:25 0:39	0:40 0:54	0:55 1:11	1:12 1:30	1:31 1:53	1:54 2:18	2:19 2:47	2:48 3:22	3:23 4:04	4:05 5:03	5:04 6:32	6:33 9:43	9:44 12:00*
O		0:10 0:23	0:24 0:36	0:37 0:51	0:52 1:07	1:08 1:24	1:25 1:43	1:44 2:04	2:05 2:29	2:30 2:59	3:00 3:33	3:34 4:17	4:18 5:16	5:17 6:44	6:45 9:54	9:55 12:00*
	0.10 0.22	0:23 0:34	0:35 0:48	0:49 1:02	1:03 1:18	1:19 1:36	1:37 1:55	1:56 2:17	2:18 2:42	2:43 3:10	3:11 3:45	3:46 4:29	4:30 5:27	5:28 6:56	6:57 10:05	10:06 12:00*
New group-designation	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A

* Dives after surface intervals of more than 12 hours are not repetitive dives. Use actual bottom times in the NOAA NITROX I (68% N_2, 32% O_2) Decompression Table to compute decompression for such dives.

TABLE F-1 NOAA NITROX II (64% N_2, 36% O_2) NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE FOR NO-DECOMPRESSION DIVES

	DEPTH FSW	No-Deco. Limits (min)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	20		60	120	210	300										
	25		35	70	110	160	225	350								
	30		25	50	75	100	135	180	240	325						
	40		15	30	45	60	75	95	120	145	170	205	250	310		
15,2	50	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200
18,2	60	100		10	15	25	30	40	50	60	70	80	90	100		
21,2	70	60		10	15	20	25	30	40	50	55	60				
24,2	80	60		10	15	20	25	30	40	50	55	60				
27,2	90	50		5	10	15	20	30	35	40	45	50				
30,3	100	40		5	10	15	20	25	30	35	40					
33,3	110	30		5	10	12	15	20	25	30						
36,3	120	25		5	7	10	15	20	22	25						

TABLE F-2 NOAA NITROX II (64% N_2, 36% O_2) DECOMPRESSION TABLE

DEPTH (feet)		BOTTOM TIME (min)	TIME FIRST STOP (min:sec)	DECO. STOPS (feet)					TOTAL ASCENT (min:sec)	REPETITIVE GROUP
				50	40	30	20	10		
50		200						0	0:40	*
		210	0:30					2	2:40	N
		230	0:30					7	7:40	N
		250	0:30					11	11:40	O
		270	0:30					15	15:40	O
60		100						0	0:50	*
		110	0:40					3	3:50	L
		120	0:40					5	5:50	M
		140	0:40					10	10:50	M
		160	0:40					21	21:50	N
		180	0:40					29	29:50	O
		200	0:40					35	35:50	O
70		60						0	1:00	*
		70	0:50					2	3:00	K
		80	0:50					7	8:00	L
		100	0:50					14	15:00	M
		120	0:50					26	27:00	N
		140	0:50					39	40:00	O
80		60						0	1:00	*
		70	0:50					2	3:00	K
		80	0:50					7	8:00	L
		100	0:50					14	15:00	M
		120	0:50					26	27:00	N
		140	0:50					39	40:00	O
90		50						0	1:10	*
		60	1:00					8	9:10	K
		70	1:00					14	15:10	L
		80	1:00					18	19:10	M
		90	1:00					23	24:10	N
		100	1:00					33	34:10	N
		110	0:50				2	41	44:10	O
		120	0:50				4	47	52:10	O
100		40						0	1:20	*
		50	1:10					10	11:20	K
		60	1:10					17	18:20	L
		70	1:10					23	24:20	M
		80	1:00				2	31	34:20	N
		90	1:00				7	39	47:20	N
		100	1:00				11	46	58:20	O
		110	1:00				13	53	67:20	O
110		30						0	1:30	*
		40	1:20					7	8:30	J
	**	50	1:20					18	19:30	**
		60	1:20					25	26:30	**
		70	1:10				7	30	38:30	**
		80	1:10				13	40	54:30	**
120	**	25						0	1:40	**
		30	1:30					3	4:40	**
		40	1:30					15	16:40	**
		50	1:20				2	24	27:40	**
		60	1:20				9	28	38:40	**

*** See No Decompression Table for repetitive groups**
****Repetitive dives may not follow exceptional exposure dives**
*****Oxygen partial pressure exceptional exposure**

American
Nitrox
Divers
Inc
[illegible]

TABLE F-3 RESIDUAL NITROGEN TIMES FOR NOAA NITROX II (64% N_2, 36% O_2) DIVES

REP. DIVE DEPTH fsw	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
50	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
60	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
70	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
80	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
90	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
100	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
110	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
120	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3

RESIDUAL NITROGEN TIMES (minutes)

TABLE F-4 RESIDUAL NITROGEN TIMETABLE FOR REPETITIVE NOAA NITROX II (64% N_2, 36% O_2) DIVES*

Repetitive group at the beginning of the surface interval

New Group Designation	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
A																0:10 12:00*
B															0:10 2:10	2:11 12:00*
C														0:10 1:39	1:40 2:49	2:50 12:00*
D													0:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00*
E												0:10 0:54	0:55 1:57	1:58 3:22	3:23 6:32	6:33 12:00*
F											0:10 0:45	0:46 1:29	1:30 2:28	2:29 3:57	3:58 7:05	7:06 12:00*
G										0:10 0:40	1:41 1:15	1:16 1:59	2:00 2:58	2:59 4:25	4:26 7:35	7:36 12:00*
H									0:10 0:36	0:37 1:06	1:07 1:41	1:42 2:23	2:24 3:20	3:21 4:49	4:50 7:59	8:00 12:00*
I								0:10 0:33	0:34 0:59	1:00 1:29	1:30 2:02	2:03 2:44	2:45 3:43	3:44 5:12	5:13 8:21	8:22 12:00*
J							0:10 0:31	0:32 0:54	0:55 1:19	1:20 1:47	1:48 2:20	2:21 3:04	3:05 4:02	4:03 5:40	5:41 8:40	8:41 12:00*
K						0:10 0:28	0:29 0:49	0:50 1:11	1:12 1:35	1:36 2:03	2:04 2:38	2:39 3:21	3:22 4:19	4:20 5:48	5:49 8:58	8:59 12:00*
L					0:10 0:26	0:27 0:45	0:46 1:04	1:05 1:25	1:26 1:49	1:50 2:19	2:20 2:53	2:54 3:36	3:37 4:35	4:36 6:02	6:03 9:12	9:13 12:00*
M				0:10 0:25	0:26 0:42	0:43 0:59	1:00 1:18	1:19 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00*
N			0:10 0:24	0:25 0:39	0:40 0:54	0:55 1:11	1:12 1:30	1:31 1:53	1:54 2:18	2:19 2:47	2:48 3:22	3:23 4:04	4:05 5:03	5:04 6:32	6:33 9:43	9:44 12:00*
O		0:10 0:23	0:24 0:36	0:37 0:51	0:52 1:07	1:08 1:24	1:25 1:43	1:44 2:04	2:05 2:29	2:30 2:59	3:00 3:33	3:34 4:17	4:18 5:16	5:17 6:44	6:45 9:54	9:55 12:00*
Z	0.10 0.22	0:23 0:34	0:35 0:48	0:49 1:02	1:03 1:18	1:19 1:36	1:37 1:55	1:56 2:17	2:18 2:42	2:43 3:10	3:11 3:45	3:46 4:29	4:30 5:27	5:28 6:56	6:57 10:05	10:06 12:00*

* Dives after surface intervals of more than 12 hours are not repetitive dives.
Use actual bottom times in the NOAA NITROX II (64% N_2, 36% O_2) Decompression Table
to compute decompression for such dives.

American
Nitrox
Divers
International

74 Woodcleft Avenue
Freeport NY 11520
(516) 546-2026
Fax (516) 546-6010

ANDI STANDARDS AND RECOMMENDATIONS

GAS PRODUCTION

To maintain gas quality and the integrity of the filtration system, appropriate oxygen handling protocol and filtration system maintenance rules must be followed. Because of this educational and procedural requirement, no facility should be producing on site oxygen enriched air mixtures without at least one CERTIFIED Gas Blender on staff. This requirement is the result of much consultation industry wide. ANDI Gas Blender training is available at ANDI Regional Clinics as well as at ANDI Headquarters in Freeport, N.Y.

ANDI recommends that the standard for "Oxygen Compatible Air" be adhered to.

Oxygen Compatible Air is referenced as follows:

Oxygen Compatible Air (expressed as maximums):

CO - 2ppm
CO_2 - 500ppm
gaseous hydrocarbon - 25 ppm (reference Methane)
condensed hydrocarbons - 0.1 mg/M^3
moisture/water vapor - dewpoint -40°F
solid particulate - 2 micron.

"SafeAir© Compatible Air" (22 - 50% oxygen concentration) may contain no more than 0.5 mg/M^3 of condensed hydrocarbon contamination. All other specifications remain as expressed for "Oxygen Compatible Air".

Since condensed hydrocarbon contaminants are cumulative, if ***any*** condensed hydrocarbons are contained within the gas stream, a schedule of periodic maintenance and cleaning should be implemented. Premix may be dispensed as air. Have an ANDI Certified Gas Blender perform all gas production other than plain ***air.***

Quarterly gas analysis is recommended for all gas dispensing facilities and is ***required*** for ANDI licensed dispensing facilities. Ask ANDI Headquarters regarding licensing as an ANDI SafeAir© dispensing facility and about ANDI's "Ultra-pure Breathing Gas" monitoring program.

CYLINDER HANDLING STANDARDS

Cylinders are required to be dedicated to Air, SafeAir© or Oxygen Service. No cross-usage is to be permitted.

Oxygen cylinders must be oxygen service rated, green in color and clearly labeled as cleaned, inspected and rendered suitable for oxygen service "Oxygen" must be clearly labeled and stenciled on the cylinder exteriors.

Cylinders must be oxygen cleaned prior to entry into service and visually inspected annually. The cylinder should be recleaned for oxygen service at any time if suspected of contamination. After hydrostatic test cylinders ***must*** again be recleaned. ANDI Inspection stickers are required as the standard at ANDI training facilities. However, any sticker indicating that the cylinders are inspected, cleaned and rated SafeAir© compatible are to be honored at ANDI facilities, utilizing standard VIP procedures.

Cylinders must be externally marked with either a 4" green band with yellow lettering on a yellow cylinder or a 4" green band with a 1" yellow border on each side of the green for cylinders not yellow in color. No other labeling is acceptable. SafeAir©cylinders are recommended to be yellow in color however after June 1, 1993 any color cylinder is permitted, provided all other standards are in place. This "any color cylider" standard only applies to the U.S.A. the yellow cylinder standard is in force for all non- U.S.A. ANDI facilities.

The lettering should clearly indicate that the contents gas is not Air. ANDI standard for an alphabetical designation is ***SafeAir© - Oxygen Enriched Air.***

All cylinders & valves must be oxygen cleaned prior to conversion to SafeAir© service.

An industry wide announcement dated September 1991 has alerted all to the fact that silicone grease is not compatible with all aspects of enriched air usage. The preferred lubricant is ***CHRISTO-LUBE 111*** by Lubrication Technology, Jackson,Ohio. Specification sheets are available from ANDI Headquarters upon request.

Cylinder gas contents must be clearly & legibly indicated and dated by means of a ***cylinder contents tag.*** The cylinders ***individual*** serial # must be permanently affixed to the reverse of this tag.

ANDI SafeAir© dispensing facilities may honor stickers affixed to the cylinder indicating gas contents. Specifically: fO_2, date of analysis, maximum operating depth and testers initials or name. This is the ***minimum*** information required. The contents tag/label ***absolutely must at all times*** accurately indicate the cylinder's gas content.

BREATHING EQUIPMENT

It is required that ANDI facilities follow the equipment manufactures recommendations as to the products compatibility with oxygen enriched air or oxygen. We, at ANDI Headquarters, are working with manufacturers to clarify their positions. ANDI instructors and Training Facilities will be kept abreast of new developments.

As of February 1, 1992 only Oceanic, San Leandro Ca. and Beauchat, Ft Lauderdale, Fla. had issued a firm policy statement . On March 20, 1992 ANDI received from Poseidon Industri AB Guteborg, Sweden a firm policy statement. Many other statements are on the way. See ANDI Headquarters for more information.

Based upon the fact that silicone grease is not compatible with all aspects of oxygen service or oxygen enriched air service, it is required that ANDI instructors & training facilities properly educate their students/clients as to the need for proper lubricants and hose cleaning where required. Certainly submersible pressure gauges should be properly cleaned and lubricated.

To properly identify compatible equipment ANDI compatibility sleeves (Pat Pending) are to be utilized. Oxygen service equipment may be used with SafeAir but SafeAir service equipment may not be used with oxygen mixtures or oxygen. Refer to the compatibility designation sleeve which should be affixed to the hose in question.

ANDI Service Technician Courses are recommended for all technicians intending to service enriched air equipment. Ask ANDI Headquarters for a schedule of regional training clinics.

ANDI American Nitrox Divers International

The first insurable/insured enriched air training program.

The first enriched air cylinder inspection sticker, color wrap decal and cylinder contents tag.

The first instructor teaching manual.

The only ***compatibility designation sleeves*** (pat pending)

The best student workbook on Enriched Air Applications.

The only program that supports the retailer ***all the way.***

Written by retailers for retailers.

The first Gas Blender program industry wide.

The first Breathing Gas Purity standards other than air.

The first enriched air service tech course.

The first international dealer network of Enriched Air Facilities.

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VIKING DIVING INC.

9043 Dutton Drive
Twinsburg, Ohio 44087
216·963·0310
800·344·4458
FAX 216·963·0316

May 21, 1992

Dear Poseidon dealer:

One of the biggest issues in the sport diving market today is *Nitrox*. It is time for us at Viking Diving to discuss this issue and define our position on it.

"Nitrox," or oxygen enriched air, has many beneficial features for sport divers. Essentially, these stem from reducing the amount of nitrogen absorbed by the diver. There are now legitimate agencies teaching about the procedures and benefits involved. Contact them for detailed information.

The use of gases other than air provides us with some special equipment considerations. Poseidon regulators equipped with first stage O-rings made of Viton-Butyl and using a special oxygen safe lubrication are compatible with Nitrox use. Attached is a price list of individual O-rings and overhaul kits featuring these O-rings.

We at Viking Diving feel that Nitrox use by sport divers will continue to grow. To foster this growth, it will need to be legitimately and properly dispensed by dive store owners such as yourself. We urge you to seek out proper training from one of the Nitrox agencies.

The use of other mixed gases for deeper diving should not be confused with Nitrox. Although Poseidon regulators and Viking dry suits represent some of the finest equipment available today, deep mixed gas diving is a highly specialized discipline that requires extensive educational, logistical, and experiential requirements beyond the scope of casual sport diving.

Respectfully,

Joseph J. Schelorke

Joseph J. Schelorke
Manager, Diving Products

JJS/keg

A member of the Trelleborg Group

SCUBAPRO ENGINEERING BULLETIN # 226

1/93 PAGE 1 OF 2

USE OF ENRICHED AIR (NITROX) WITH SCUBAPRO EQUIPMENT

The following is intended to clarify the status of compatability of Scubapro products with Enriched Air (Nitrox). The increased popularity of Nitrox has prompted Scubapro to make a careful safety assessment of our products with regard to breathing mixtures other than standard compressed air.

Scubapro regulators were originally designed for use with compressed breathing air of normal atmospheric oxygen concentration, not mixtures containing elevated oxygen levels. The increased oxygen concentrations of these mixtures at high pressures could result in fire or explosion if used in systems containing incompatible materials, hydrocarbon contaminants, or pneumatic designs that are contrary to safe oxygen handling practice.

There has been considerable confusion in the diving community over the compatiblilty of existing regulator systems with enriched air. There can be no blanket statement that assumes safe use of this equipment with enriched air. There is no threshold level of oxygen concentration at which all equipment can be considered safe. Each component piece of equipment must be reviewed for materials compatiblilty and airflow design at its rated service pressures.

For this reason Scubapro has begun to reevaluate the design and materials used in our breathing systems for enriched air. Whereas Scubapro does not actively support or discourage the use of these other than air mixtures by recreational divers, we will make available compatible systems whenever possible. The following is a status overview of the currently available Scubapro products with respect to enriched air use.

1. Scubapro **SECOND STAGE REGULATORS, INFLATORS, AND AIR 2's** (low pressure 135-150 psi operation) are designed and constructed of materials compatible with Enriched Air Nitrox containing oxygen concentrations up to 40%. These products can be used from the factory without modification.

2. Scubapro **TANKS, VALVES, FIRST STAGE REGULATORS**, and **HIGH PRESSURE HOSES** are <u>not</u> compatible as received from the factory with any enriched air mixtures containing oxygen concentrations in excess of 22%.

3. Scubapro will be making available an Enriched Air Conversion Kit for the **MK 10 FIRST STAGE REGULATOR**. This kit will include all necessary replacement components to make the MK 10 enriched-air compatible (to oxygen concentrations up to 40%) when oxygen cleaned and installed.

4. Scubapro is currently reviewing changes to make compatible **HIGH PRESSURE HOSES** and **TANK VALVES**. These products currently contain components <u>not</u> enriched-air compatible or of design that is not yet approved for Nitrox use.

5. Scubapro **TANKS** are unaffected by enriched air, but must be oxygen cleaned and fitted with a valve approved for enriched air use.

6. Scubapro **DECOMPRESSION METERS** are designed for <u>air decompression only and do not contain oxygen toxicity algorithms</u> that may be needed for certain enriched air exposures.

ntrx.doc

OCEANIC LIFE-SUPPORT EQUIPMENT ENRICHED AIR COMPATIBILITY

This notice is intended to advise Authorized Oceanic Dealers and Oceanic equipment users as to the specific limits of Oceanic life-support equipment compatibility with various oxygen concentrations (enriched air) and the importance of Authorized Service.

Oceanic regulators, dive computers, instruments, and buoyancy control devices (life support equipment) are designed for use with compressed air (21% oxygen content). **Oceanic life-support equipment is never to be used with pure oxygen.** Oxygen enriched air with oxygen concentrations not exceeding 50% may be used without adverse effects with Oceanic life-support equipment **provided that the equipment has been specifically designated as enriched air compatible, or has been rendered compatible.**

FIRST STAGE REGULATOR COMPATIBILITY

Oceanic high-pressure first stages and high-pressure hoses attached to Oceanic SlimLine Pressure Gauges or other Oceanic instruments must be rendered compatible for enriched air by the proper installation of the appropriate o-ring and lubrication kit. O-ring kit installation on Oceanic equipment must be performed by an Authorized Oceanic Dealer technician who has been certified by **Oceanic** in the service of Oceanic products *and also certified* by the **American Nitrox Divers Inc. (ANDI)** in the proper handling of Enriched Air Nitrox Mixture equipment. **Installation procedures must follow ANDI guidelines.** Oceanic assumes no liability for consequences resulting from the improper installation of the o-ring kit.

SECOND STAGE REGULATOR COMPARIBILITY

All Oceanic second stage regulators produced after June 1, 1993 are designated compatible for use with oxygen mixtures not exceeding 50% (enriched air). Oceanic recommended service intervals and procedures must be maintained. The lack of service or improper service to any piece of Oceanic life-support equipment may cause product failure which may result in serious personal injury or death.

All service performed on any Oceanic second stage, first stage, or other life-support equipment must be done only by an Authorized Oceanic Dealer Service Technician according to the procedures detailed in the *Authorized Oceanic Dealer Service & Repair Guide* and the *University of Oceanic Total Service Seminar* procedures. **Oceanic assumes no liability for consequences resulting from improper service performed by unauthorized or untrained service technicians.**

Oceanic life-support equipment which has been or will be used with an enriched air mixture must be serviced and maintained by an Authorized Oceanic technician who has been certified by Oceanic in the service of Oceanic products and also certified by the American Nitrox Divers Inc. (ANDI) in the proper handling of Enriched Air Nitrox Mixture equipment.

IMPORTANT NOTICE:
This notice specifies operations required to refurbish Oceanic scuba regulators for use with Enriched Air/Nitrox Mixture (EANx).

⚠ WARNING

Oceanic regulators may only be used with Enriched Air/Nitrox Mixtures as follows:

- Oxygen concentration in the EANx must be NO MORE THAN 50%. **Only ANDI approved gas mixtures and mixing** techniques may be employed when using Oceanic equipment with Enriched Air/Nitrox mixtures.
- Regulator refurbishment must be performed only by a technician who holds certifications from both Oceanic and the **American Nitrox Divers Inc. (ANDI).**
- Regulator refurbishment must be performed in accordance with Oceanic and ANDI specifications.

⚠ WARNING

Non-compliance with the above conditions when preparing Oceanic regulators for use with Enriched Air/Nitrox Mixtures can result in serious injury or death and voids any warranty either expressed or implied.

Enriched Air/Nitrox Mixture Conversion Procedure:

1. Disassemble regulator first stage entirely. Immediately discard ALL o-rings and seats.
2. Thoroughly clean all parts, removing all silicone grease with an **ANDI approved cleaning solution.**
3. Reassemble regulator, replacing all o-rings and seats with parts included in the *Oceanic Viton O-ring Kit* for the appropriate model.
4. Where lubrication is necessary, dress parts only with *Christo-Lube MCG 111*. DO NOT use silicone grease.
5. Calibrate first stage using hydrocarbon-free gas, such as laboratory-grade dry nitrogen or USP air.

⚠ CAUTION

Pressurization of an EANx refurbished regulator on a compressed air system will contaminate the system requiring a complete repeat of the refurbishment procedure.

⚠ WARNING

It is the user's responsibility to ensure EANx compatibility of any other equipment attached to Oceanic EANx compatible regulators.

American Nitrox Divers Inc

N$_2$ SafeAir O$_2$

Has completed the lecture and theory requirements (Part 1) for ANDI SafeAir© certification

74 Woodcleft Avenue, 1-(516)-546-2026
Freeport NY 11520

DATE ________________ 199_

CERTIFIED BY ________________________________ **No** ____________

American Nitrox Divers International

Educational Flow Chart.