NAUI NITROX: A Guide to Diving with Oxygen Enriched Air

By R.W. Bill Hamilton, Ph.D., and Joel D. Silverstein

Where

serious

divers

belong

NAUI WORLDWIDE

DIVE SAFETY THROUGH EDUCATION

SA

1/99

NAUI Nitrox: A Guide to Diving with Oxygen Enriched Air

By R.W. Bill Hamilton, Ph.D., and Joel D. Silverstein

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

National Association of Underwater Instructors

1st Edition

Printed in the United States of America

Composition by: Advance Business Graphics
Printing / binding by: Advance Business Graphics

National Association of Underwater Instructors
9942 Currie Davis Drive
Tampa, FL 33619
www.naui.org

Table of Contents

NAUI Nitrox: A Guide to Diving with Oxygen Enriched Air is a comprehensive text that focuses on the practical information a diver needs to know to use oxygen enriched air. The text is presented in 14 chapters. It reviews gases, explains the all-important concept of partial pressure, covers oxygen physiology as well as oxygen limits and tolerance techniques, tells how to select the right mix and to have the right amount of gas, includes both procedures and tables to manage no-stop dives, incorporates dive computers and dive planning software, reviews mixing and how to obtain a tank of enriched air, and provides an introduction to technical diving, as well as contingency procedures. An appendix includes several useful tables supporting the topics just mentioned, a glossary of terms, and a bibliography that also includes cited references. Specific learning goals are stated at the beginning of each chapter. Review these carefully before and after studying each chapter to make sure the educational goals are met.

When this text is used as part of a course of instruction your instructor may schedule the course in a sequence different from that presented here, for logistical purposes. However, the chapters are to be studied in the order presented since each new chapter builds on the previous one. In any event, we encourage you to use this text as your guide to diving with oxygen enriched air and to reference it often. The authors also encourage you to seek out the information that is available from the many fine texts in the reference section, and encourage you to learn all that you can about this subject. If you have a specific question, you are welcome to contact the authors by electronic mail.

This book is not intended to teach all the techniques and knowledge necessary for diving with oxygen enriched air without the guidance and supervision of a qualified NAUI instructor. Local knowledge, techniques, and regulations for all areas cannot possibly be incorporated into this one text. This publication provides only part of your education for diving with gas mixtures other than air. Much of what you will learn about oxygen enriched air will come from this text. However, your instructor will provide valuable demonstrations, present diving techniques, and share personal experiences that are not possible to present in a text.

Thus far in your diving education you have learned the fundamentals of diving. You know what should and should not be done and you understand some basic diving theory. You are qualified to dive in conditions similar or more favorable to those in which you have received training. The purpose of this book, when used as part of a course of instruction, is to increase your understanding of why certain things are or are not done in diving and to expand your skills and qualifications. Upon successful completion of this course you will be qualified to conduct dives using oxygen enriched air and engage in additional diving activities and programs.

About the NAUI Enriched Air Nitrox Diver Course

The NAUI Enriched Air Nitrox Diver course is an intensive program consisting of approximately eight hours of academic sessions plus the application of the knowledge acquired through up to three open water dives. The knowledge you acquire will help make those experiences safer and more enjoyable. One dive is to be a repetitive dive. NAUI strongly recommends that the partial pressure of the oxygen enriched air used during training dives not exceed 1.4 atm.

Responsibilities

Both you and your instructor have certain responsibilities during the NAUI Nitrox Diver course. Your instructor must determine that you have the necessary background and experience to safely participate in the activities of this course, provide an academic session plus an on-site briefing for each activity, ensure that you are properly equipped for the training dive, and oversee your diving activities.

In a specialty diver course it is understood that you are already certified to dive with a buddy, and you will be responsible for your own safety. It is not the responsibility of your NAUI instructor to accompany you during all of the dives, although he or she must be present at the dive site, in control of the activities, and ready to lend assistance if needed. You will be instructed what to do, how to do it, and how to avoid potential hazards. It will then be your responsibility to follow the instructions given. You will learn by doing activities at dive sites selected by your instructor.

Getting the Most From the Course

1. Read and study the assigned section prior to the academic session on the subject matter.
2. Keep the leaning objectives in mind as you study, then review them after completing the chapter to be sure you have acquired the knowledge.
3. As you study, keep notes on areas that are unclear to you, so you can obtain clarification from the instructor during the academic sessions.
4. Become familiar with the "New Terms" identified at the beginning of each chapter. When a term is presented a second time in normal text, refresh your memory of its meaning if it is unclear to you. The terms are defined in the glossary if you are unable to locate them quickly in one of the sections.
5. Obtain a notebook and take it with you to every session, including the open water dives. Note pages that fit into your NAUI Deluxe Log Book are an excellent choice. Save your notes for future reference. These notes will be especially useful should you decide to pursue leadership training, and in additional training programs you may participate in.

6. Log your dives in detail. Your instructor will provide you with underwater activities and skills that you will perform during your training dives. Keep a detailed record of those activities as proof of your successful completion of that training.

We commend you on your decision to become a NAUI Enriched Air Nitrox Diver. You must do more and learn more to acquire this rating of an Enriched Air Nitrox Diver than you would with other training organizations, but we feel you will agree that it is worth it! A NAUI Enriched Air Nitrox Diver is knowledgeable, skilled, and respected. You will know more, be able to do more, and feel more comfortable and confident as a diver when you have successfully completed this program; you will have met one of the highest standards of diver education.

WARNING

Scuba diving is an adventure activity with inherent risks of serious personal injury or death. Good training and good equipment can help to minimize those risks, but there is no guarantee that these risks can be completely eliminated. The code of the responsible NAUI Enriched Air Nitrox diver states that:

You must accept responsibility for your own actions and safety during every dive.

You must dive within the limits of your ability and training.

Evaluate the conditions before every dive; assure that they fit your personal capabilities.

Be familiar with and check all equipment before and during every dive.

Personally analyze or directly observe the analysis of the breathing gas you will be using.

Always dive with an alternate air source.

Know your dive buddy's as well as your own ability level.

A note about Units

In most cases involving units we attempt to include both Imperial and S.I. (metric) units. The conversion between fsw and msw is for the pressure units, not the units of length, so is 3.2568 fsw/msw. Where ranges of depth, etc., are included the conversion is rounded and may not be exact. Gas partial pressures are given in atmospheres; the metric near-equivalent of an atmosphere, the bar, is not exactly one atmosphere, it is not a valid S.I. unit, nor is it equal to sea level pressure, therefore we use atmospheres.

Foreword

You are about to embark on one of the most exciting and challenging areas in scuba diving–oxygen-enriched air. And I can't think of any experts better to guide you than my close friends Dr. Bill Hamilton and Joel Silverstein. I can honestly say that if not for Dr. Hamilton, the world of technical and mixed gas recreational diving wouldn't have proceeded as quickly and as safely as it has. You're learning from "the man." I've put my life in Dr. Bill's hands, in the form of his expertise and table creation, many times. He's the guy NOAA, the military, and the huge international diving concerns trust with the lives of their people. Follow his advice, and learn his lessons, and you'll be diving mixed gas with the best of them.

Joel Silverstein and I have been diving together for years. His experience in exploration, dive publishing, diver safety, operations, and training is an unbeatable combination. During the growth phases of technical diving, his Sub Aqua magazine was one of the best places to learn about key issues. This book is the result of years of communicating clearly to divers. Joel's work in hyperbarics and emergency diver treatment gives him an extra perspective on safety. As an instructor who's been teaching oxygen enriched air almost since its first recreational application, Joel has heard all the questions, and developed reliable and useful answers.

This is a book we've all been waiting for. I almost wish I had written it, but knowing how much work Dr. Bill and Joel have put in, I'm glad I can read my copy along with you, and get more diving time in. You are holding the book we would have paid many thousands of dollars for not too long ago.

Use it well.

Safe diving,

Captain Billy Deans

Credits

Authors

R.W. Bill Hamilton, PhD
Joel D. Silverstein

Contributors

Glenn Butler
Scott Monnier

Principal Photography

Kathy Weydig
Photographic Communications

Additional Photography

Glenn Butler
figure 9-7

Robert D. Decker
figure 9-8

G. Jona Poe
figure 14-2

Joel Silverstein
figure 14-1

Deep Sea Technologies Inc.
figure 9-6

Diving Unlimited International
figure 12-7

U.S. Deep Cave Diving Team
figure 14-4

NAUI Reviewers

Jed Livingstone
Timothy O'Leary
Mike Williams

Copy Editors

Eileen Whitney
Jeffrey Silverstein

Special thanks to:

Abysmal Diving
Amron International
Cochran Undersea Technology
Dacor Corporation
Dive Rite Mfg.
Diving Unlimited International
Key West Divers Inc.
Life Support Technologies Inc.
Luxfer, USA
Mares America Corp.
Ocean Management Systems
R/V Wahoo
Scuba Depot
Scuba Pro / JWA
Scuba Training + Travel Company Inc.
U.S. Navy, Groton, CT
Uwatec, USA
Watersport Publishing Inc.

1 INTRODUCTION

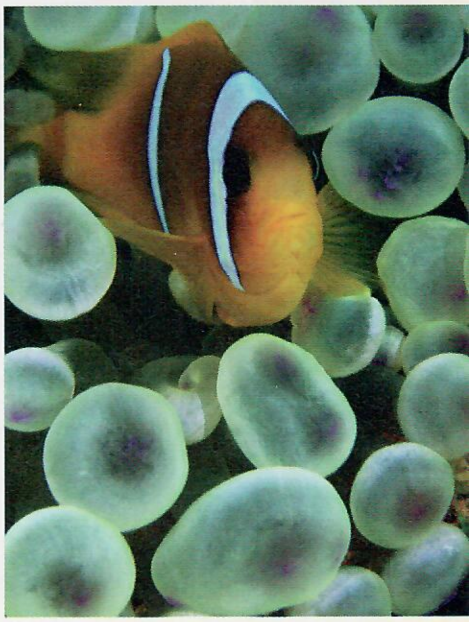
Chapter 1

INTRODUCTION

LEARNING GOALS

In this chapter you will:

- Be introduced to enriched air mixtures for recreational diving.
- Learn how enriched air nitrox can benefit you for no-stop diving.
- Learn about some of the myths that cause confusion in enriched air nitrox diving.
- Compare no-stop air dives to enriched air dive profiles.
- Learn about the history and development of enriched air nitrox.



New Terms in This Chapter

EAN

EANx

Nitrox

Oxygen enriched air, OEA

Enriched air nitrox

Enriched air breathing mixtures in recreational diving

As you begin this book you may ask yourself, "What's wrong with diving on air?" Simply, air contains two major components, oxygen (21%) and nitrogen (79%). As you learned in your scuba diving class, it is the nitrogen that limits no-stop diving times. The nitrogen in normal air limits your bottom time, or the number of dives you can do in a day, or requires a longer surface interval between dives. Nitrogen is also the cause of decompression sickness.

Enter **Enriched Air Nitrox,** also called **Oxygen Enriched Air,** or just **nitrox.** Enriched air nitrox is air that has more oxygen in it. Consequently it has less nitrogen. Since nitrogen is the controlling factor for decompression from no-stop diving, with less nitrogen in the breathing mixture your body will absorb less nitrogen and you will have less of a decompression obligation. This book illustrates why this works, and shows you how to take advantage of this principle.

The two most commonly used nitrox mixtures are 32% and 36% oxygen, called also EAN 32 and EAN 36 (sometimes these are written EAN_{32} and EAN_{36}). In all cases the remainder, the other gas in the mix, is nitrogen. These mixes were first introduced by the National Oceanographic and Atmospheric Administration (NOAA) for use in their scientific and shallow water research dives. Using these gas mixtures can also significantly increase the amount of time a diver can spend at depth without requiring decompression.

Today's diver is seeking more adventure and exploration, which almost always leads to the desire for more bottom time. Many times the only way to get that longer bottom time is to plan dives that require lengthy and sometimes complicated decompression stops. Using enriched air nitrox makes getting that longer bottom time not only easier by eliminating decompression stops required with air, but this also allows the diver to have shorter surface intervals while still maintaining a minimal level of risk.

When you look at Figure 1-1, which is a comparison of no-stop dive times, you see why enriched air nitrox is in such great demand.

A diver making a 90 fsw dive using one of these mixtures can increase the air no-stop dive time from 25 minutes to as much as 50 minutes. This is a significant increase in no-stop bottom time.

But increased bottom time does not come without its price tag. As you have learned in your other scuba courses, enjoying the underwater world comes with limits and safety procedures. In this book and the training you will receive from your NAUI instructor you will learn about the benefits and precautions necessary to conduct enriched air nitrox dives in a low-risk and efficient manner.

No-Stop Dive Times

Depth fsw	21% Air	32% EAN 32	36% EAN 36
60	55	100	100
70	45	60	60
80	35	50	60
90	25	40	50
100	22	30	[40]
110	15	25	[30]
120	12	[25]	
130	8	[20]	

Figure 1-1. No-stop dive times in minutes using NAUI's air, EAN 32, and EAN 36 diving tables. The times at 60 and 70 fsw are the same for 32% and 36% oxygen because of the "EAD" procedures. Brackets indicate high oxygen levels.

Myths of enriched air nitrox

With all technology come facts and perceived facts. In this book and your training program you will learn the relevant facts and procedures for using enriched air nitrox for recreational diving. There are, however, some myths that we need to dispel.

Myth # 1: "Nitrox is safer than air."

"Safe" to most people means without risk, and all diving contains a level of risk. The techniques and procedures you will learn will help you maximize the benefits and minimize the risks. Enriched air nitrox has significant decompression advantages over air, but to take advantage of those benefits other risks must be weighed. The risks include oxygen toxicity and the required depth and time limits, need for special equipment maintenance, and a requirement for gas analysis. When all are managed properly, the risks are minimal, just as for air diving in the same depth ranges.

Myth # 2: "Nitrox is for deep diving."

Enriched air nitrox has very stringent depth limits due to the higher concentration of oxygen in the mixture. The greatest advantages for no-stop diving are in the 50 to 110 fsw diving range. The two standard mixtures of EAN 32 and EAN 36 have maximum operational depths of 110 fsw and 90 fsw respectively, with 130 and 110 fsw available for contingencies. There are other applications for using enriched air nitrox to accelerate decompression from deep dives, but these are outside the scope of this training program and are covered in other courses.

Myth # 3: "You can't get decompression sickness."

No gas nor diving table can absolutely ensure that a diver will not get decompression sickness. Using enriched air nitrox provides significant decompression advantages over air, but with all diving there is a risk of decompression sickness. The procedures and techniques in this book will help minimize those risks while maximizing diving enjoyment. In the unlikely event, however, that a diver who was breathing enriched air nitrox has a decompression incident, the treatment is conducted in the same manner as an air diving incident. There are well proven recompression protocols for treating decompression illness, and they work as well for enriched air as for air.

Myth # 4: "Narcosis is eliminated."

It might seem logical that with reduced nitrogen in the breathing mix there would be reduced nitrogen narcosis at depth. The fact is, oxygen can also be a narcotic gas when under pressure. The result is that there is no significant change in narcosis when diving enriched air nitrox as compared to air.

Myth #5: "Using enriched air nitrox is difficult."

Throughout this book you will learn the proper and simple procedures for conducting dives with enriched air nitrox. Some of the procedures in the planning and preparation process are a bit more involved than for air diving, but they are designed to help you have a relatively low-risk and enjoyable dive. You will apply many of these techniques to your air diving as well.

Terminology

A number of new terms are introduced and used in this course. A box at the beginning of each chapter contains some of the new terms used in that chapter. Some terms used throughout the book and course follow in this chapter. These mainly address correct names for the gas mixtures and types of diving. A glossary at the back collects these terms with their definitions.

The early terms for nitrogen-oxygen mixtures were just that, nitrogen-oxygen mixtures. More recently it has become customary to state the oxygen first, and this is the practice in offshore oil rig diving in the North Sea; U.S. usage has been to state the inert gas first. Because of this it is important always to specify the component gases as well as the percentages.

Sea floor habitats from which divers emerge to do their work were popular in the 1960s and 1970s. These often use an oxygen-nitrogen mixture with less oxygen than air, reduced to avoid oxygen toxicity from long-term exposure. The term given to such a mix was "nitrox." Later this same term became used for oxygen-enriched mixtures, those having more oxygen than air, creating an ambiguity. Since virtually all oxygen-nitrogen mixtures with more oxygen than air are made by adding oxygen to air or removing nitrogen from air, the terms "oxygen enriched air" or just "enriched air" are proper for the mixtures popularly called "nitrox" today. The compromise term "enriched air nitrox" is the primary one used in this book.

From these have evolved the terms "EAN" or "EANx." The "x" was originally the "x" in nitrox, but in some usage has become a subscript of the oxygen percentage, as in EAN_{32} for 32% oxygen. Sometimes this same 32% mix is called "EAN 32." This is not as specific as it might be, but is acceptable. For the record, in the NOAA manual the 32% and 36% mixtures are called "NOAA Nitrox I (NNI)" and "NOAA Nitrox II (NNII)," respectively; these terms are not specific.

A word of caution. It is not good practice to state a mix only as "60-40" or "80-20"; the components should be specified. Terms like this can be interpreted two ways, and getting it wrong can easily cause a fatal accident. This problem does not apply to a 50-50 mix. Because of this mixed terminology this book takes the approach that the student should know all the terms used to describe gas mixtures, and uses them interchangeably. Likewise, gas percentages are frequently stated as percentages, a preferred method, rather than as abbreviations.

Justification for enriched air nitrox

It should seem obvious that using enriched air nitrox provides significant benefits of extending bottom times, but not so obvious is its benefit in helping prevent decompression sickness. By using a gas with less nitrogen in it we effectively lower this risk. This does not mean that a diver will never get decompression sickness, just that with proper management the already small risk of DCS is even smaller when diving with enriched air.

Enriched air nitrox is of special value in the multi-day repetitive dive series. Recreational diving incident statistics show that almost 80 percent of all cases of decompression illness are a result of repetitive dives. If a diver were to dive the same profiles on an enriched air mixture instead of air, not only would the decompression be less but there would also be an overall reduction of nitrogen in the body. As a result of this, many divers report that they are not as physically tired after a series of dives using enriched air nitrox as they have been in the past using air.

Repetitive dive example

Looking at a typical recreational dive profile we compare two dives, one using enriched air nitrox 36% and the other using air (Fig 1-2).

Example #1, diver breathing air does a first dive to 90 fsw for 20 minutes, waits one hour between dives, and then is allowed a repetitive dive to 80 fsw for 12 minutes.

Example #2, diver breathing 36% oxygen does the same first dive to 90 fsw for 20 minutes, waits one hour between dives and then can do a repetitive dive to 80 fsw for 36 minutes. This is 3 times the time allowed with air.

The diver using enriched air nitrox in the above example has a 24 min no-stop time advantage over the diver doing a similar profile with air. The air diver would have to take a 10-min decompression stop to do 36 min on the second dive. If you can imagine a typical dive vacation where you may be diving two or three times a day for five or six days, you can see that the advantages for using enriched air nitrox become quite significant in either extending bottom time or by reducing required decompression.

Comparison of Typical Dive Plans, Air and EAN	
Example #1, Air **First Dive** 90 fsw/20 minutes no-stop One hour surface interval, Group F-->E **Second dive** 80 fsw/12 minutes no-stop	**Example #2, 36% O_2** **First Dive** 90 fsw/20 minutes no-stop One hour surface interval, Group E-->D **Second Dive** 80 fsw/36 minutes no-stop

Figure 1-2. Comparison of typical dive plans. In this example the 36% oxygen provides three times as much bottom time on the second dive as an air dive, 36 min instead of 12 min.

History of enriched air breathing mixtures in recreational diving

Credit for introducing the modern practice of oxygen-nitrogen diving properly belongs to Dr. J. Morgan Wells, who was Diving Officer of the National Oceanic and Atmospheric Administration. The method using 32% oxygen was documented in the Second Edition of the NOAA Diving Manual (1979), which also included derived decompression tables and methods for preparing the gas mixtures; this was later extended in the Third Edition (1991) to include 36% oxygen mixes and more details on mixing.

Oxygen-nitrogen diving gas mixtures other than air were not new with NOAA. This diving concept had been studied intensively by the U.S. Navy in the 1950's, particularly by Dr. Ed Lanphier, who was also chief architect of the 1959 edition of the U.S. Navy Diving Manual. References to oxygen-enriched mixes go back to the 19th century. Although the benefits to decompression were known, the main reason for USN's interest in O_2-N_2 mixes was for rebreathers.

Commercial application of oxygen-enriched air mixtures was practiced from the 1960's, particularly by Andre Galerne's International Underwater Contractors, but at the time this was kept as a proprietary technique. Galerne's secret was that he knew that a proper decompression table could be prepared by considering only the nitrogen component of the mix. Galerne's goal was to keep his divers in the water working while also minimizing the risks of decompression illness. Others suspected this would be advantageous but it was not widely used, partly because it was not well understood by clients, but mainly because the cost and complexity of making, analyzing, and handling the mixtures and training for their use more than offset the benefits. When equipment for on-line mixing of oxygen and air was developed, enriched air techniques were used extensively by a few commercial diving operators. One project using a commercial mixer made by Dräger involved over 5000 working dives (Hartung et al, 1982).

While Morgan Wells gets credit for introducing these techniques for diving with oxygen enriched air mixes, the credit for introducing this concept to recreational diving belongs clearly with Dick Rutkowski, a close friend of Wells and colleague in the initial development within NOAA. Rutkowski began in about 1988 (after he retired from NOAA) to apply and teach the NOAA techniques to ordinary scuba divers. His course was adequate and fairly well designed. Divers from all over the world would travel to Dick's facility in Key Largo to learn about the "new way" to extend bottom time while not increasing decompression obligations. Enriched air nitrox became the "in thing" to breathe among a group of divers known for exploration in caves and wrecks. Divers who had been experimenting on their own with alternative breathing gases were now able to talk about nitrox and not get strange looks. It was emerging technology in a sport that had seen few technological advances since the development of the multilevel dive computer in the early 1980's.

Although NOAA was comfortable in using enriched air in their diving operations, there were still questions. These had to do with the validity of the concept, mixing methods, applications, etc. To address this, in early 1988 NOAA's Office of Undersea Research sponsored a workshop on the subject. Leading experts were assembled at Harbor Branch Oceanographic Institution to study the concept. They concluded that the approaches were sound, and basically endorsed the use of oxygen enriched air. The report of that workshop is a good review of the state of the art at the time (Hamilton et al, 1989). This Workshop settled on the term "enriched air nitrox," abbreviated "EANx," in order to recognize the nature of the gases as oxygen-enriched air but to preserve the vernacular "nitrox."

Despite this, by late 1991 there was enough controversy within the industry to provoke a workshop on the question of oxygen enriched air in recreational diving. Conceived by *aquaCorps* publisher Michael Menduno and jointly sponsored with the Scuba Diving Resource Group in January 1992, the pre-DEMA workshop presented accumulated experience, reviewed mixing problems and myths, defined problems, and set out to define mixing and handling rules. The results of this workshop (Hamilton, 1992), were instrumental in NAUI's entering the world of enriched air nitrox diving. With two specialty agencies already providing nitrox training to instructors, it was only appropriate that NAUI add the specialty to its list of courses; this was done.

Some of the early promoters of enriched air nitrox kept the training highly technical to keep it "special." Others took a very simple approach of "it's just like air–breathe in, breathe out." These two very different approaches created controversy and misunderstandings of what enriched air nitrox was and what it was not. Either way, the development and spread of "nitrox" diving had all the aspects of a fad. However, over time enriched air nitrox has become a viable part of recreational diving. ■

Chapter 1. Knowledge Review—Introduction

Before moving on to the next chapter, **Gases and Gas Properties,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. The ____________ in air limits your bottom time.

2. What are two other terms used to describe enriched air nitrox?
 ____________ and ______________

3. The two most commonly used nitrox mixtures are ____________ and ____________ percent oxygen.

4. The greatest advantages for no-stop diving using nitrox occur in what depth range?
 ____

5. Narcosis is reduced significantly when diving with enriched air nitrox. True or False

6. What does the "x" stand for in the term EANx? __________

7. Who is credited for introducing oxygen enriched air mixes to recreational diving?
 ____

8. NAUI introduced their own enriched air training programs in what year? __________

9. State two benefits of using enriched air nitrox? ____________ and ____________

10. For what category of diving is enriched air most beneficial? ____________

Answers for Chapter 1

1. Nitrogen
2. Nitrox and oxygen enriched air
3. 32% and 36% oxygen
4. 50 to 110 fsw
5. False
6. The oxygen percentage
7. Dick Rutkowski
8. 1992
9. Longer no-stop times and shorter surface intervals
10. Multi-day repetitive dives

2 GASES AND GAS PROPERTIES

Chapter 2

GASES AND GAS PROPERTIES

LEARNING GOALS

In this chapter you will:

- Understand the nature of gases in an intuitive way.
- Learn about air and the common atmospheric gases.
- Become acquainted with quantitative aspects of gas behavior, i.e., the "gas laws."
- Understand the very real hazard of nitrogen narcosis.
- Be introduced to partial pressure and its meaning.

New Terms in This Chapter

"Air"

Gas and gas mixture

"Martini's Law"

Ideal gas laws

Absolute temperature

Boyle's Law and others

Chemical potential or potency

Partial pressure

P = Symbol for partial pressure

Solubility

This chapter presents the general characteristics of gases. It offers a basic introduction to gases for those who have forgotten or never taken chemistry, and provides some reference material potentially of use to recreational nitrox divers.

How gases behave

Matter takes three forms or "states," solid, liquid, and gas. Several properties of gases are important to divers. Probably the most important is that gases are **compressible,** whereas solids and liquids essentially aren't. This is because a gas is made up of lots of individual molecules that can be visualized as being loose and bouncing around, bouncing off each other and off the walls of the container if the gas is confined. A gas will fill a container evenly. This compressibility is affected by temperature, since the molecules become more active at higher temperatures. In fact, for a constant volume the pressure is proportional to the temperature (in absolute units), and at a constant temperature the pressure is inversely proportional to the volume (that is, if the volume is made smaller, the pressure goes up).

Most gases, including all those involved in diving, are invisible, but the interface between gases of different density may refract light in such a way that it can be seen, although with difficulty.

A "gas" can be a mixture of several component gases, in which case it is a gas "mixture." In a mixture, once it is completely mixed, the components are evenly distributed according to their proportions. The gases in a gas mixture are not affected by gravity. In fact, once gas components are mixed it is quite difficult to separate them, and they will not separate by themselves under normal conditions.

The components in a mixture may be either individual atoms or may be molecules, depending on the nature of the gas. The individual components in a mixture exert their chemical or physical effects according to the proportion that each component is of the whole mixture.

Another important property of gases is that they can dissolve in liquids (and also solids). The amount of a gas that can dissolve in a specific substance is a measure of or characteristic of its **solubility** and that of the solute. The amount of gas that can be dissolved in a liquid is also directly proportional to the pressure of the gas at the interface with the liquid, and solubility is greater at lower temperature.

This overview summarizes the "gas laws" as they apply to a diver. In a non-quantitative way, this is a large part of what a diver needs to know about gases. Later in this chapter we go into more detail about some of these in a more practical way, so these principles can be applied.

Composition of air

Compressed atmospheric air is the main gas used in diving. Dry air has the following composition, expressed as fractions:

Oxygen	0.2095
Nitrogen	0.7808
Argon	0.00934
Carbon Dioxide	0.0003
Others	0.0004

Thus for practical purposes oxygen is about 0.21 or 21% and the remaining 79% is "inert" gases (mainly argon and nitrogen; see Fig 2-1). The small amount of carbon dioxide (CO_2) in the atmosphere (atm) is gradually increasing but it is still inconsequential in respiration. The "others" category includes neon, helium, methane, krypton, xenon, and nitrous oxide, all of which are physiologically inert at these low levels.

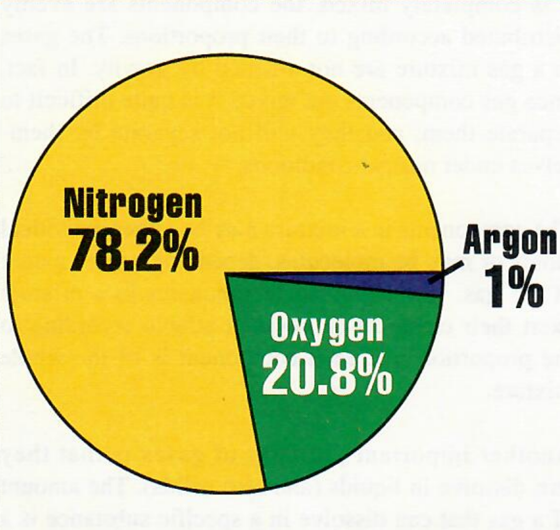


Figure 2-1. Composition of air. Air is mostly nitrogen and oxygen, with about 1% argon and other gases.

In industry, "air" is considered to have between 19.5% and 23.5% oxygen, balance nitrogen. Oxygen, nitrogen, and argon, among others, are obtained from air by distillation. "Air" obtained in cylinders may be prepared by mixing oxygen and nitrogen back together after they have been separated. This is not important in recreational diving because virtually all diving air is compressed from the atmosphere.

Some properties of the individual gases:

Oxygen, O_2

Oxygen is the essential component of all breathing gas mixtures. It is necessary for body metabolism, but in excess it can be toxic. Oxygen's properties would indicate that it should be slightly more narcotic than nitrogen, but because it is consumed in body tissue the amount present at a given moment cannot be known precisely. Likewise, oxygen in excess may act as an "inert" gas for decompression purposes, to a limited extent. Chapter 4 discusses oxygen in more detail.

Nitrogen, N_2

Nitrogen is the inert gas in air and in nitrox mixtures. The narcotic properties of nitrogen are its main disadvantage in diving, but it is also quite soluble and therefore difficult to unload during decompression.

Argon, Ar

Argon makes up about 1% of air; it is usually considered with the nitrogen component. Argon is about twice as narcotic as nitrogen, and it is more soluble and also denser. It has a lower heat conductivity than air and much less than helium, so is used in dry suits to improve their insulating properties.

Helium, He, and neon, Ne

Both helium and neon are less dense and less soluble than nitrogen, and they do not cause narcosis. Helium is the gas of choice for diving deeper than the air range. Neon is too expensive to be of much benefit as a diving gas, but it has been used experimentally.

Nitrogen and narcosis

As mentioned, air as a diving gas creates two main problems for the recreational diver, narcosis and the need for decompression. Decompression is covered in Chapters 6, 7 and 8; narcosis is covered here.

"Narcosis" means "numbing" or a state of stupor, with the apparent implication that it is caused by a narcotic drug, but this is not always the case. Nitrogen is indeed a similar "drug," but in a context different from habit-forming or addictive narcotics. Instead, nitrogen belongs in the class of gaseous anesthetics. Surgical anesthesia can be induced by small amounts of specific gaseous agents, some requiring only a few percent of the breathing mixture at one atmosphere (a partial pressure of 0.01 to 0.15 atm). Nitrogen behaves in the same manner as a gaseous anesthetic, but requires much higher partial pressures to have its effects.

Nitrogen becomes noticeably narcotic at around 3 or 4 atm PN_2 (air at 100-130 fsw or 30-40 msw) for most people, and when 7 atm (200 fsw or 60 msw) is reached almost everyone is seriously affected. A facetious rule of thumb (that actually works) known as "Martini's Law" states that for every 50 fsw (15 msw) of depth breathing air a person is narcotized to the extent of drinking a dry gin martini. Thus the diver on air at 150 fsw has a degree of narcosis equivalent to 3 quick martinis. This diver can be seriously impaired, and probably will not recognize it.

Narcosis is sneaky, because for most people it is a pleasant, euphoric, feeling, yet the diver can be profoundly affected. Although the biochemical mechanism is different, the effects are like alcohol, even to slurred speech, numb lips, inability to concentrate, short attention span, easy distraction, and, amusingly, a tendency to giggle or break out in raucous laughter when stimulated. Sensitivity to narcosis is an individual matter; different people are affected in different ways, but the effects are generally consistent for an individual.

Narcosis has been found by psychologists to work by slowing down processing of information by the brain; it is not a matter of nerve conduction velocity. Narcosis is likely to be the same as the phenomenon of general anesthesia, and both seem to be related to solubility of the narcotic gas in fat.

In recreational diving narcosis is an insidious and dangerous hazard. It is insidious because it induces a feeling of well-being that tends to disguise the threat. Numerous fatalities have resulted with divers who were apparently comfortable until something went a little wrong. Even a slight degree of narcosis can leave a person unable to deal with a problem. In the depth range where narcosis is substantial, if one adds stress, multiple tasks, and a complicated job, most people become dangerously ineffective.

It is said that divers accommodate or acclimate to narcosis. This seems to be valid, but it is not a pharmacological adaptation as much as an improved ability to cope as a result of recent experience (see Brauer, 1985).

The question of whether one can benefit (have reduced narcosis) by replacing some of the nitrogen in a mix with oxygen (such as diving with enriched air) is uncertain. Anecdotes say both that it is better and worse, and laboratory studies are equivocal (Bennett, 1997; Linnarsson et al, 1990). It is best to plan for a narcotic level based on both nitrogen and oxygen, or to assume that the narcotic effect of an enriched air nitrox mix will be the same as that of air at the same depth.

Quantitative aspects of gases

The specific details about how gases behave have been discovered bit by bit over the last several centuries by a few scientists clever enough to make the observations and disciplined enough to write down what they had learned. Consequently, many of these principles bear the names of the discoverers. Their names are not nearly so important as the principles the individuals discovered; they are included here by name for completeness.

This section provides an introduction to the behavior of gases, in order to show the relations between the various properties and how they can be used in a quantitative way. Although quantitative, these relationships are presented here without the essential units to make them into useful tools. Users who have to use these equations should refer to chemistry or thermodynamics textbooks. Quantitative relationships, i.e. equations, necessary for enriched air diving are covered in subsequent chapters.

Pressure, Volume, and Temperature

Gas behavior is often summarized as "the gas laws," or the Ideal Gas Laws. These are extremely useful for making calculations about gases, and can be summarized in a simple algebraic relationship:

$$PV = nRT$$

Here P = Pressure, V = Volume, and T = Temperature. The n is the number of molecules (far too many to count), and R is the universal gas constant. All the terms must be in consistent units, and temperature has to be on the absolute scale. Celsius (centigrade) temperatures can be converted to the absolute scale (Kelvin) by adding 273 degrees, and are related to Fahrenheit by the relation

$$°F = 9/5 \times °C$$

To convert °F to absolute (called Rankine when using Fahrenheit degrees) add 460 Fahrenheit degrees. No gas is really "ideal" in behavior, but the relation holds well for gases at pressures close to atmospheric or lower. At higher pressures real gas behavior can be predicted more accurately by using some modifiers; these can be both theoretical and empirical.

Temperature is rarely measured and used quantitatively in diving work. The values of gas constants can be found in textbooks (Wienke, 1994; Somers, 1997). The relations of the other terms can be shown as the gas laws named after their discoverers.

Pressure and Volume

Pressure and volume (at constant temperature) are inversely proportional to each other. That is, as pressure on a given mass of gas is increased, the volume decreases, or as volume is reduced the pressure increases (both assume a constant temperature). This is **Boyle's Law.**

$$PV = k_T$$

There are two very important applications of Boyle's law to divers. The first practical aspect is that gas can be compressed into cylinders. If the pressure is doubled, twice as much gas (twice as many molecules) can be in the tank, and so on. Another aspect is that as pressure is reduced on the diver's body during ascent, the physical result is for the volume of any gas space to increase. If this gas is held in the diver's lungs during this pressure reduction (ascent) it can cause the lung to rupture, possibly leading to arterial gas embolism or other trauma. Hence the useful adage, "never hold your breath while ascending after breathing compressed air." Boyle's Law can also be expressed as

$$P_1V_1 = P_2V_2$$

Pressure and Temperature

Another look at the same general relationship shows that at constant volume the pressure is proportional to the absolute temperature. This is the situation encountered when one compresses gas into a tank. As pressure goes up, so does temperature.

$$P/T = k_V \text{ or } P = k_V \times T$$

The "k" is a constant that adjusts the units; the little "v" subscript means "at constant volume," which is the case when gas is compressed into a tank. This is often called **Gay-Lussac's Law.** It can be stated in another useful algebraic form.

$$P_1/T_1 = P_2/T_2$$

Volume and Temperature

Still another corollary of the ideal gas law says that if the pressure is held constant the volume is proportional to the temperature. This situation, which is called **Charles' Law,** is not encountered frequently in diving but is quite important in hot air ballooning (Bookspan, 1995). It is occasionally confused with the previous pressure-temperature relation. Charles' Law states

$$V/T = k_P \quad \text{or} \quad V = k_P \times T$$

This says that as temperature increases, so will the volume, if pressure does not change.

Gas Mixtures: Partial Pressure and Chemical Potential

In a mixture of gases the total pressure is made up of the sum of the pressures of the individual components. Each component exerts its own effects according to its proportion of the total pressure.

$$P_{total} = P_1 + P_2 + P_3 + \ldots + P_n$$

The effects of each individual gas can be thought of as the "chemical potential" of that gas, and is a function of the pressure of that component independent of the other gases (to the extent that they behave as ideal gases). These individual pressures are also referred to as partial pressures, and the concept of partial pressures is known as **Dalton's Law.** An understanding of partial pressures is an essential component of safe diving with gas mixtures other than air, including enriched air nitrox. The next chapter (Chapter 3) further addresses partial pressure manipulations.

Stated another way, the partial pressure of a gas "g" is the product of the fraction of that gas times the total pressure.

$$P_g = F_g \times P_{total}$$

This is the **definition** of a partial pressure, where P_g is the partial pressure of the component gas g, F_g is the fraction of the component, and P_{total} is the total pressure. The pressures may be in any type of pressure unit, but for many diving calculations they are in atmospheres (atm) or bars. The "fraction" component has no units (it is dimensionless). The fraction is the decimal fraction, or 1/100 of the percentage.

A capital P is the convention used by physiologists and medical practitioners to represent partial pressure (and is the style used in this book). For a specific gas, the chemical symbol may be used as the subscript, or, because multiple subscripts are hard to handle it may be written on the line with the P, as in PO_2 or PN_2. Engineers sometimes abbreviate partial pressure as pp, or ppO_2, which is not ambiguous. The use of a single lower case "p" is best avoided because this symbol is also used in other ways, such as to represent acidity, as in pH.

Solubility

It was necessary to define partial pressure before the next gas property could be explained–the solubility of gases in liquids. When equilibration is complete, the amount of a gas dissolved in a liquid is proportional to the pressure of the gas at the interface between the gas and the liquid. In the case of a gas in the lung, equilibration is essentially complete between the alveolar gas and the blood passing through the lung (it then becomes arterial blood). That the amount of gas dissolved is proportional to the equilibration pressure is **Henry's Law.**

Solubility depends on the properties of both the gas and the liquid (the solute and the solvent). Gases such as nitrogen are about 5 times more soluble in fatty tissues than in watery tissues.

Solubility also depends on the temperature. Gases are more soluble in liquids at lower temperature. The temperature of blood does not change much, so this principle has minimal effect on gas uptake and, thus, decompression. Temperature does affect decompression, however, because it causes physiological changes in the circulation.

Inspired gas, the gas that is taken into the lungs, is diluted slightly with metabolic carbon dioxide and water vapor. The resulting partial pressures are an important part of life, especially in diving. The alveolar oxygen partial pressure, P_AO_2, is critical in normal metabolism, and plays a major role in oxygen's toxicity. The nitrogen partial pressure in the lung, P_AN_2, is important in decompression and determines the level of narcosis due to nitrogen. The P_ACO_2 (alveolar carbon dioxide partial pressure) basically determines the metabolic and neurological effect of carbon dioxide in a given situation.

As a reminder, note that the equations given in this section do not include the units. The units in an equation must be compatible for it to produce correct results. Except for partial pressure, which is covered in Chapter 3, quantitative calculations with the equations in this section are beyond the scope of this text. ■

Chapter 2. Knowledge Review—Gases and Gas Properties

Before moving on to the next chapter, **Pressure and Partial Pressure,** please test your understanding of this chapter's information by completing the **Knowledge Review.**

1. Which gas in air is essential to sustain life? ________________
2. A diver breathing air at 100 fsw (30 msw) is not affected by narcosis at all. True or false.
3. The gas law that best describes changes in pressure and volume of gases is ________________.
4. As a gas is warmed in a closed container its pressure will ________________.
5. As the partial pressure of oxygen increases on a dive it becomes more ________________.
6. Is air a gas or a mix? __________
7. The three main components of atmospheric air are nitrogen, oxygen, and __________ .
8. "Martini's law" states that every ______ fsw of air pressure is narcotic to the extent of one dry gin martini.
9. The primary safety hazard of diving deep with air is ______________.
10. The mechanism of narcosis is similar to what common phenomenon encountered in a hospital? __________________ .

Answers for Chapter 2

1. Oxygen
2. False
3. Boyle's Law
4. Increase
5. Toxic
6. Mix
7. Argon
8. 50 fsw
9. Narcosis
10. General anesthesia

3 Pressure and Partial Pressure

Chapter 3

Pressure and Partial Pressure

LEARNING GOALS

In this chapter you will:

- Understand fractions and percentages of gases.
- Understand the concept of partial pressure.
- Be able to convert between depth units and atmospheres.
- Be able to define partial pressure and its purpose.
- Be able to calculate partial pressures of gases in a mix.

New Terms in This Chapter

Fraction, F

Atmosphere, atm

Atmosphere absolute, atm abs

ata or "ATA"

fsw (msw)

gauge pressure

The concept of partial pressure

Enriched air nitrox diving is choosing and using specific gas mixtures other than air. The diver has the opportunity to choose a gas that is most suitable for the dive. As discussed in previous chapters, different gases behave differently and have different chemical potencies at various pressures. It is critically important that you know the meaning of partial pressure and how to apply it to dive planning. This chapter discusses partial pressure and other practical aspects of pressure; it is an expansion of Chapter 2 on gas laws.

The best way to describe the effect of the oxygen in any given nitrox mix or of any other component is to determine the **partial pressure** of the gas at a given depth. However, first we need to understand what partial pressure is. A diagram of partial pressure is shown in Figure 3-1.

Consider first a single gas. The effect of the gas is a function of its pressure. If the gas is oxygen, its pressure determines its physiological effect on metabolism, or the toxicity of the gas, or it could apply to burning rate. If it is an inert gas, the pressure determines how much of the gas will dissolve and perhaps be involved in decompression. Even though we have only one gas, that gas's effectiveness, its physical or chemical potential (or potency) is a function of the pressure of that gas. In this example–a single gas–this is the same as the total pressure. If we want to describe this in quantitative terms, we report the pressure in the appropriate units. The most common unit used for this is atmospheres, or the metric equivalent, bars. Pure oxygen at a total pressure of one atmosphere would have an effective pressure of one atmosphere.

Now consider a mixture of gases, air for instance. Air is 21% oxygen and the rest (79%) is nitrogen. The effectiveness or potency of the oxygen in air would be 21% as much as the effect of 100% oxygen at the same pressure.

We need to take one more step to make this more precise, to convert the relative measure "percentage" (%) to an absolute measure. If we let 100% be 1, the whole number one, then 21% will be a fraction of 1 equal to 0.21. The components add up to 1 (i.e., 100%). This is shown for atmospheric air in Figure 3-2.

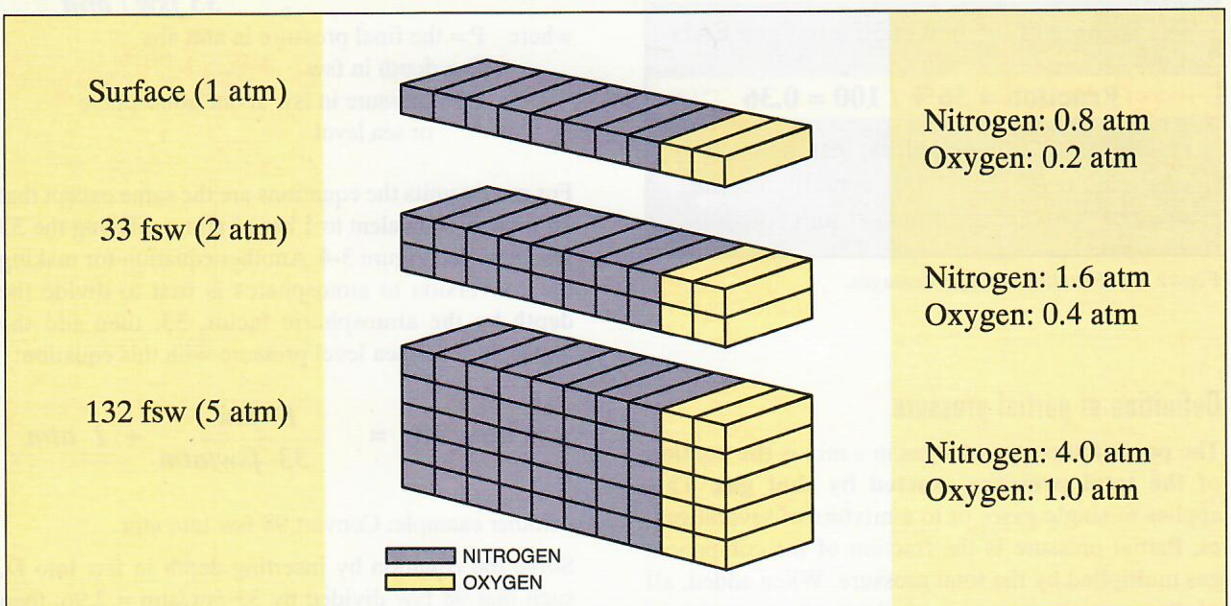


Figure 3-1. Graphical representation of partial pressure, using air as an example. Vertical height is total pressure in atm, while the cells or "bricks" show fractions of nitrogen (shaded) and oxygen.

Air at 1 atm		
Percentage		**Partial Pressure**
79% N_2	=	0.79 atm
21% O_2	=	0.21 atm
100%	=	1.00 atm

Figure 3-2. Air at 1 atm.

Now, the values on the right are partial pressures. If we have air at one atmosphere, the partial pressure of the oxygen in air (21%) is 0.21 atm. If pressures are higher the same relations prevail but are increased as the pressure is increased.

To complete the picture, the oxygen in air is not the only gas. Other inert gases make up 79% of the total pressure (we normally lump all the inert gases into the nitrogen category), and they have a partial pressure of 0.79 atm when the air is at one atmosphere total pressure. As shown in the figure the partial pressures add up to the total pressure.

Fractions and Percentages

Generally the relationship between fraction and percentage is intuitive, but to be specific,

Fraction = Percentage / 100

and the converse

Percentage = Fraction x 100

The fraction of oxygen in 36% oxygen EAN is

Fraction = 36% / 100 = 0.36

Fractions are dimensionless; that means they have no units. The "100" actually has the units of "percentage units per unit fraction."

Figure 3-3. Fractions and percentages.

Definition of partial pressure

The **partial pressure** of a gas in a mix is **the portion of the total pressure exerted by that gas**. This applies to single gases or to a mixture of several gases. Partial pressure is the fraction of the component gas multiplied by the total pressure. When added, all of the partial pressures of the component gases become the total pressure. By calculating gas partial pressures it is possible to estimate how much inert gas (nitrogen) the body is exposed to and can take up. This calculation also helps determine how much oxygen the body will be exposed to at depth. Examples are shown in Figure 3-3.

Calculating the partial pressures of a gas is easy if the absolute pressure and the fraction that the component gas makes up of the total are known. When planning enriched air nitrox dives, we take into consideration the oxygen partial pressure and the nitrogen partial pressure for determining oxygen exposure time and decompression.

Before we do partial pressure calculations we need to review another maneuver, that of converting between depth and pressure units.

Converting between depth and atmospheric units

Since gas partial pressures are usually encountered as depths and handled as atmospheres, it is necessary to be able to convert between these units.

By convention, depth is a "gauge" pressure referenced to one atmosphere or sea level. Therefore when a depth D, say 66 fsw, is converted to pressure in atmospheres absolute (atm abs, sometimes called "ata" or "ATA"), it is necessary to add the initial atmosphere (equivalent to 33 feet of sea water, fsw) according to the formula

$$P \text{ atm abs} = \frac{D \text{ fsw} + 33 \text{ fsw}}{33 \text{ fsw / atm}}$$

where P = the final pressure in atm abs
D = depth in fsw
33 = pressure in fsw at one atmosphere or sea level.

For metric units the equations are the same except that 10 msw is equivalent to 1 bar or atm, replacing the 33 fsw/atm. See Figure 3-4. Another equation for making the conversion to atmospheres is first to divide the depth by the atmospheric factor, 33, then add the atmosphere for sea level pressure with this equation:

$$P \text{ atm abs} = \frac{D \text{ fsw}}{33 \text{ fsw/atm}} + 1 \text{ atm}$$

Another example: Convert 98 fsw into atm.

Solve the equation by inserting depth in fsw into D, such that 98 fsw divided by 33 fsw/atm = 2.96, then add 1 atm; the total is 3.96 atm abs.

The resulting number is fsw converted to atm. This number (total pressure) can now be multiplied by a gas fraction to find the resulting partial pressure of that gas.

To go the other way, converting from a pressure P in atm abs to fsw, multiply the number of atmospheres by 33 and take away the initial ambient pressure in fsw;

D fsw = (P atm abs x 33 fsw / atm) - 33 fsw

Or the ambient atmosphere can be subtracted first.

D fsw = (P atm abs - 1 atm) x 33 fsw / atm

Example: Convert 3.96 atm to fsw

First 3.96 atm abs is converted to fsw by multiplying by 33 to get 131 fsw, expressed as "absolute fsw." Then subtract 33, the number of fsw in the ambient or atmospheric atmosphere to get 98 fsw.

Convert fsw into atm

$$\frac{D\ fsw + 33\ fsw}{33\ fsw\ /\ atm} = P\ atm\ abs$$

For a depth of 66 fsw:

$$\frac{66\ fsw + 33\ fsw}{33\ fsw\ /\ atm} = 3\ atm\ abs$$

For S.I. units the 33 fsw/atm is replaced by 10 msw/atm.

For 20 msw:

$$\frac{20\ msw + 10\ fsw}{10\ msw\ /\ atm} = 3\ atm\ abs$$

Figure 3-4. Example of conversions from depth units (fsw or msw) to atmospheres (atm).

Calculating partial pressures

To determine the oxygen partial pressure multiply the oxygen percentage in the mixture by the total pressure in atmospheres. The higher the oxygen percentage the higher the ultimate oxygen partial pressure will be at a given depth. This formula is:

Partial pressure = Total pressure x Fraction

By rearranging this formula algebraically it is possible to solve it for each of the terms. To make this easier without getting into the algebra, Figure 3-6 is a mnemonic device to help do these calculations. It is derived from one often used for solving Ohm's Law relationships with electricity. To use the figure, cover the item you want to solve for, and the others will be in the relationship needed. For example, if "Partial pressure" is covered, the other two terms are side by side so are multiplied. If you want to know what fraction to use to get a given partial pressure at a given total pressure, cover "Fraction." The other two terms are in the right relationship, with "Partial pressure" over "Total pressure"; this means divide partial pressure by total pressure to get the fraction. And so on.

As an example, Figure 3-7 shows how to calculate the partial pressure of the oxygen in air at 66 fsw.

Convert atm to fsw

(P atm abs x 33 fsw / atm) -33 fsw = D fsw.

For a pressure of 3 atm abs:

(3 atm abs x 33 fsw / atm) - 33 fsw = 66 fsw.

For S.I. units the 33 fsw/atm is replaced by 10 msw/atm. For 20 msw:

(3 atm abs x 10 msw / atm) - 10 msw = 20 msw

Figure 3-5. Example of conversions from atmospheres (atm) to depth units (fsw).

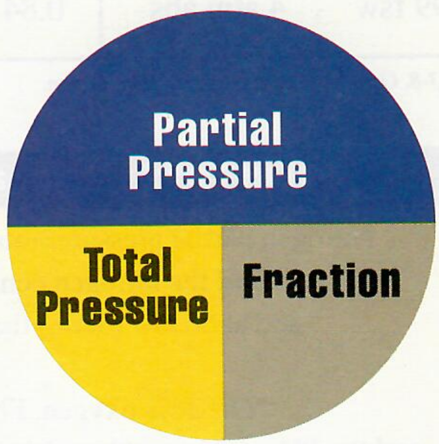


Figure 3-6. Partial pressure mnemonic. Cover the item you want to know and the others will be in the proper relation.

Figure 3-8 shows some partial pressures of oxygen at different pressures, equivalent to different depths.

Let us look next at the nitrogen component in order to compare the partial pressures of nitrogen in air and in 36% oxygen enriched air, EAN 36. The calculations are done the same way as they are with oxygen; the "non-oxygen" fraction of air is the part of interest in this case. An example of this is shown in Figure 3-9, again at 66 fsw to simplify the arithmetic. It can be seen that the partial pressure of the nitrogen is significantly lower (PN_2=1.92 atm) in the 36% oxygen enriched air than in air (PN_2 = 2.37). It is this lower partial pressure of nitrogen in the mix that allows oxygen enriched air to have such a significant decompression advantage.

In Figure 3-10 are several other examples. Look at 32% oxygen at 99 fsw. Air has a PN_2 of 3.16 atm and EAN 32 has a PN_2 of 2.72. This is 14% less inspired nitrogen with EAN 32 than with air. It is this decrease in nitrogen that creates the benefits of enriched air nitrox diving.

Oxygen Partial Pressure in air at 66 fsw

Pressure at 66 fsw =

$$\frac{D\,fsw + 33\,fsw}{33\,fsw\,/\,atm} = ((66 \times 33)/33) = 3 \text{ atm abs}$$

The fraction of oxygen in air is 0.21

Partial pressure, atm = total pressure, atm x fraction = 3 atm x 0.21 = 0.63 atm

Figure 3-7. Calculating an oxygen partial pressure.

Oxygen Partial Pressure at various depths

Depth	Pressure	Air (PO_2)	32% O_2 (PO_2)	36% O_2 (PO_2)	100% O_2 (PO_2)
0	1 atm abs	0.21 atm	0.32 atm	0.36 atm	1.0 atm
33 fsw	2 atm abs	0.42 atm	0.64 atm	0.72 atm	2.0 atm
66 fsw	3 atm abs	0.63 atm	0.96 atm	1.08 atm	3.0 atm
99 fsw	4 atm abs	0.84 atm	1.28 atm	1.44 atm	4.0 atm

Figure 3-8. Oxygen partial pressure comparison.

Nitrogen Partial Pressure at 66 fsw, air and 36% oxygen enriched air

Nitrogen partial pressure=total pressure x fraction of nitrogen component.
The fraction of the nitrogen component in air, FN_2 is $1 - FO_2 = 1 - 0.21 = 0.79$
and at 66 fsw (3atm) the PN_2 of air is 3 atm x 0.79 = 2.37 atm.

For 36% oxygen, $FN_2 = 1 - FO_2 = 1 - 0.36 = 0.64$ FN_2
and the PN_2 at 66 fsw (3 atm) is 3 x 0.64 = 1.92 atm, substantially less than 2.37.

Figure 3-9. Calculating nitrogen partial pressure.

As easy as it is to calculate oxygen partial pressures, there may be times when using a table will be simpler and more accurate. For this reason an Oxygen Partial Pressure chart is included (in Chapter 5, Figure 5-4, and in the Reference Section). To use this chart, find the percentage of oxygen across the top and intersect this column with the corresponding depth. This number is the partial pressure of the oxygen in that particular mix at that specific depth. The table has been created so that it only shows partial pressures of oxygen that are less than or equal to 1.6 atm, which is the maximum allowable partial pressure of oxygen to which scuba divers should be exposed (values 1.4 to 1.6 atm PO_2 are for contingencies). This is a good way to get the PO_2 needed to begin to plan a dive.

Nitrogen Partial Pressure Comparison

Depth	Pressure	PN_2 Air	PN_2 32% O_2	PN_2 36% O_2
0	1 atm abs	0.79 atm	0.68 atm	0.64 atm
33 fsw	2 atm abs	1.58 atm	1.36 atm	1.28 atm
66 fsw	3 atm abs	2.37 atm	2.04 atm	1.92 atm
99 fsw	4 atm abs	3.16 atm	2.72 atm	2.56 atm

Figure 3-10. Nitrogen partial pressure comparison.

As a diver descends the total pressure increases one atmosphere for each 33 fsw (10 msw). Divers are familiar with depth units, fsw and msw, but to calculate partial pressures it is necessary to convert depth to atmospheres before making the partial pressure calculation.

Occasionally the abbreviation "ATA" is used for "atmospheres absolute." It is also frequently misused as the unit of measure for partial pressure. Although it is generally well understood and not the source of dangerous confusion, using ATA is not really proper since a partial pressure is more of a differential than an expression of absolute pressure. An older (and slightly different) European unit no longer in widespread use, the "technical atmosphere," uses the ATA abbreviation as well.

Absolute pressure has its reference at zero pressure; **gauge** pressure or seawater units are referenced to one atmosphere.

Units

This section covers some of the conventions used in non-air diving, describes the units used, and gives examples of some unit conversions.

One **atmosphere** (atm) is the pressure equal to the pressure of the air surrounding us, at sea level. This is the definition of an atmosphere. (Strictly speaking, an atmosphere is defined as 101.325 kPa or 1013.25 millibars, and this equals the pressure of 760.0 millimeters of mercury or 14.696 psi.)

By definition, a **foot of sea water**, fsw, is normally considered to be 1/33.00 atmospheres, and we use that definition here. Sometimes values like 1/33.05 or 1/33.08 are also used, using a definition based on an assumed density of sea water. The difference is not important physiologically (fortunately). A meter of sea water, msw, is **independently** defined as 1/10 bar or 10.00 kPa, and this definition is universally used. This gives a slightly different conversion factor between fsw and msw, which are units of pressure, than the conversion between feet and meters as units of length.

3.2568 fsw = 1 msw (pressure)

3.2808 feet = 1 meter (length)

What if the diving is in **fresh water**? Fresh water is 33/34 as dense as sea water, so it takes 34 feet of fresh water to equal the pressure of 1 atmosphere. The easiest way to deal with this is to dive with sea water gauges, use seawater units, and ignore the fact that the distances are not the same as in sea water; it is the **pressures** that really matter. But what if the gauges are calibrated in fresh water? That, in fact, is the case for most if not all depth gauges made in Switzerland, where there is no sea water. For conversions to atmospheres, to be ultra-precise one can use 34 instead of 33. This problem is mentioned again in the chapters on decompression. The difference is 3%; this is not of major importance physiologically, and we take no further note of it. ■

Chapter 3. Knowledge Review—Pressure and Partial Pressure

Before moving on to the next chapter, **Oxygen Physiology, Toxicity and Tolerance,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. The ______________ of a specific gas in a mix is the portion of the total pressure exerted by that gas.

2. If there is 33% oxygen in a gas mix, what is the fraction of the oxygen in the gas mix? ________

3. During an enriched air nitrox dive using 34% oxygen you reach a depth of 71 fsw (22 msw). What is the partial pressure of the oxygen at that depth? ______________ atm

4. What is the partial pressure of nitrogen from question # 3? ______________ atm

5. The pressure of the air surrounding us at sea level is ________________________.

6. The pressure of the water surrounding us during a dive plus the pressure of the air at sea level is the ________________.

7. The absolute pressure at 102 fsw (31 msw) is ____________ atm.

8. The absolute pressure at 69 feet of fresh water is ______________ atm.

9. The absolute pressure exerted on a diver in the ocean is 4.25 atm. What is the divers depth? ________

10. The partial pressure of nitrogen in air at 130 fsw is ____________

Answers for Chapter 3

1. Partial pressure
2. 0.33
3. 1.07 atm PO_2
4. 2.08 atm PN_2
5. 1 atm or one atmosphere or 14.7 psi
6. Total pressure (or absolute pressure)
7. 4.09 atm
8. 3.03 atm
9. 107.25 fsw
10. 3.90 atm PN_2

4 OXYGEN PHYSIOLOGY, TOXICITY, AND TOLERANCE

Chapter 4

OXYGEN PHYSIOLOGY, TOXICITY, AND TOLERANCE

LEARNING GOALS

In this chapter you will:

- Understand the metabolic role of oxygen in the body.
- Become acquainted with the range of oxygen effects.
- Learn about oxygen's role in decompression.
- Be introduced to oxygen toxicities.
- Learn techniques for managing central nervous system toxicity.
- Become acquainted with procedures for dealing with other oxygen toxicities.

New Terms in This Chapter

Hypoxia

OTU and older terms

CNS oxygen "clock"

O_2 limit fraction

Oxygen the Princess

Hannes Keller, the deep diving pioneer (early 1960s), was aware of oxygen's importance in physiology and its benefit to decompression, and he used the gas effectively in his dives. He dubbed oxygen the **Princess of Gases**, noting her essential nature, the beautiful things she can do, but also the necessity for careful handling and great care in using this wonderful gas. Because oxygen is the only breathing gas we use that has to be kept within physiological limits in both directions and its handling requires special care, we take this somewhat allegorical approach.

Metabolism: Oxygen is essential for life and energy

Oxygen's primary role in the body is to support metabolism. The oxygen used by the body is transferred to the blood in the lungs and to the tissues by the blood. About 80% of the oxygen consumed is converted to carbon dioxide, which is exhaled by the lungs. The amount of oxygen taken up by the body, the **oxygen consumption**, is a means of measuring the body's metabolism and energy production. Usually about 25% of the energy produced by the body is available for muscular activity; the balance produces heat and supports other metabolic functions.

The need for oxygen: Hypoxia

Oxygen is a constant requirement of the brain for energy, and is needed to maintain consciousness and ultimately life. The brain is subject to damage when it goes without oxygen for more than 3 or 4 minutes, as can happen in heart failure when the blood supply to the brain is interrupted, in drowning or asphyxia or if breathing stops and the lungs are getting no oxygen, or if the oxygen partial pressure in the lungs is insufficient. The last case is of concern to anyone breathing mixtures that may be low in oxygen (as in commercial or military diving), or to those who go to high altitude. An overview of the effects of different levels of oxygen is given in Figure 4-1.

An inadequate supply of oxygen is known as **hypoxia**, which means low oxygen. The symptoms of hypoxia are loss of night vision, dimness of vision or "tunnel vision," skin itching or tingling, numb lips, difficult speech, breathlessness, dizziness, and when more severe, collapse and unconsciousness. A common sign is cyanosis, blueness of the lips and fingernail beds. A dangerous aspect is that often the individual feels euphoric (happy). Some hypoxia symptoms are similar to those of nitrogen narcosis.

Uses and Effects of Different Levels of Oxygen

PO_2, atm	
3.0	50/50 enriched air nitrox recompression treatment gas for use in the chamber at 6 atm abs.
2.8	100% O_2 recompression treatment gas at 2.8 atm abs.
2.4	40% O_2-60% N_2 enriched air nitrox recompression treatment gas at 6 atm abs.
2.2	Commercial/military "Sur-D" chamber surface decompression, 100% O_2 at 40 fsw pressure.
1.6	Maximum exposure for working diver, NOAA limits.
1.4	Recommended maximum exposure for recreational diver.
0.50	Threshold for whole-body effects; maximum saturation dive exposure.
0.35-0.40	Normal saturation diver PO_2 level.
0.21	Normal environment oxygen (sea level air).
0.14-0.16	Initial signs/symptoms of hypoxia.
0.09-0.10	Serious signs/symptoms of hypoxia.
<0.08-0.10	Unconsciousness in most people.
<0.08	Coma to ultimate death.

Figure 4-1. Uses and physiological effects of different levels of oxygen.

In terms of inspired oxygen percentage at one atmosphere or at equivalent oxygen partial pressures, down to about 16% oxygen (a PO_2 of 0.16) there are usually no perceptible effects. At 12-14% most people will notice the first symptoms of tingling, numb lips, and tunnel vision. These get more prominent at 9-10%, with onset of dizziness, and collapse is imminent for some. At levels much below this some people can stay conscious with great effort but most will pass out. There is a significant variation between individuals in susceptibility and symptoms. Fitness helps, but individual makeup is a more prominent factor. Typical responses are included in Figure 4-1, which shows both the range of hypoxic effects and the range of applications.

One might wonder, with all this extra oxygen, why we even bother to mention hypoxia. It is always possible to get an incorrect mix, but in enriched air nitrox diving where there are no pure inert gases being used for gas mixing, the chance is slim that a mix will be hypoxic. EAN gas mixes are normally made by adding oxygen to air or by removing some of the nitrogen, so are intended to be richer in oxygen than air. However, other types of diving (as discussed in the chapter on technical diving) may use mixes intentionally lower in oxygen than air. In deeper diving with mixed gases the threat is very real, and many divers have died because of hypoxia. Another possibility of a low oxygen content is from a steel scuba tank that has been stored with a little water in it for some time, months or years. The oxidation reaction (rusting) can, over time, use up some of the oxygen in the tank. It is advisable for all special-mix divers to know about hypoxia.

Oxygen's role in decompression

From another perspective, oxygen can bring about a prominent improvement in decompression. Decompression requirements are dictated by the uptake of inert gases. Since oxygen is metabolized in body tissues it can reduce this uptake by displacing some of the inert gas, thus improving the decompression by making it both quicker and more reliable. The key to doing this effectively is to manage the exposure of the diver to oxygen to avoid the zones where oxygen can be toxic. These techniques require significant training that is outside the scope of this book.

Oxygen as an inert gas: Narcosis and decompression

Interestingly, it appears that too high an oxygen level can leave some oxygen in the tissues unmetabolized, and some experts feel this can take part in **bubble formation**. Also, to the extent that it is present in the tissues, oxygen can act as an inert gas and thus can produce **narcosis**. These levels of oxygen are not attained in NAUI EAN diving.

Toxic effects of oxygen: The need for management

Given oxygen's powerful metabolic effects, it should be no great surprise that in excess it can be toxic. In fact, all living things have enzymes and other mechanisms that protect against oxygen's toxicities. For divers two types of oxygen poisoning are of concern, those affecting the **central nervous system** (CNS), and those affecting many other parts of the body more generally, particularly the **lungs**. These are covered in a later section in this chapter.

Oxygen is a powerful oxidizing agent

Oxygen is the agent responsible for most oxidation that takes place on this planet. The gas itself does not burn, nor does it explode. Virtually everything that is not already fully oxidized can burn in oxygen. When oxygen (or even air) is mixed with a fuel gas, however, the combination can be explosive. In order for combustion to take place there has to be an **oxidizer** (usually oxygen), **fuel**, and a source of **ignition**.

Most people know that things burn in air. They burn more vigorously in oxygen-enriched air, and a great deal faster and more intensely in pure oxygen. With several of the methods for manufacturing enriched air it is necessary to handle pure oxygen. The enriched air diver most likely does not need to know how to make the mixes, but definitely must have some knowledge of the hazards and their countermeasures. More details on this are given in the chapter on gas mixing.

Oxygen toxicity

CNS: Effects on the central nervous system

CNS toxicity (Fig 4-2) acts at the higher end of breathable PO_2 levels, after short exposures. It typically can develop within a few to many minutes on exposure to partial pressures of oxygen above about 1.8 atm (roughly 5 to 50 min, but this is **highly** variable). The end result may be an epileptic-like **convulsion** that is not dangerous in itself but that can result in drowning or physical injury. It is for this reason that the maximum PO_2 for mixed gas diving has been set at 1.6 atm by NOAA. A recommended maximum for recreational diving is 1.4 atm. The mnemonic for remembering the symptoms is shown in Fig 4-2 as "VENTID."

There are other signs and symptoms of CNS toxicity. These are not onerous in themselves, but are justification to stop a dive. They include twitching of lips and facial muscles, visual or hearing disturbances, nausea, dizziness, difficulty in breathing (dyspnea), anxiety, confusion, poor coordination, and unusual fatigue. These may warn of an impending convulsion, but a convulsion may also come **without any warning**. Divers have been known to **"black out"** or go unconscious without a convulsion; this may be a manifestation of oxygen toxicity.

Whole body toxicity, including the lung

Slower developing oxygen toxicities may follow exposure to lower levels of oxygen for longer times. The lung is the principal organ affected, but many other parts of the body can be affected as well. Therefore we use the term **"whole body"** toxicity to include the affected parts of the body other than the CNS.

A classical symptom of oxygen poisoning is **"pulmonary,"** the result of oxygen's effect on the lung. This takes hours or longer to develop from exposure levels that may be lower than those that cause CNS symptoms. It is of no concern to scuba divers doing no-stop dives, but it may be seen during extensive commercial and military diving operations or during long oxygen treatments for decompression sickness in a hyperbaric chamber. Symptoms are chest pain or discomfort, coughing, inability to take a deep breath without pain or coughing, development of fluid in the lungs, and a reduction in vital capacity.

CNS Oxygen Toxicity Signs and Symptoms
[Convulsion]
Visual disturbances, including tunnel vision
Ear ringing
Nausea
Tingling, Twitching or muscle spasms, especially of the face and lips
Irritability, restlessness, euphoria, anxiety
Dizziness, dyspnea

Figure 4-2. CNS oxygen toxicity signs and symptoms. Effects may come on in any order or even start with a convulsion. If symptoms begin, ascend to a shallower depth immediately, reduce work level if possible, and ventilate lungs well with deep breaths. Maintaining PO_2 levels of 1.4 atm or less is strongly recommended.

Non-pulmonary symptoms of "whole-body" oxygen toxicity include skin numbness and itching, headache, dizziness, nausea, effects on the eyes, and a dramatic reduction of aerobic capacity during exercise.

Variations in tolerance

There is wide variation in susceptibility to oxygen poisoning among individuals, and a significant variation in a single individual at different times. Part of this latter variation is due to unknown causes, but a large part can be attributed to known environmental and physiological circumstances. Susceptibility to CNS toxicity is increased by certain factors, particularly those that cause an increase in internal PCO_2 such as exercise, breathing dense gas, or breathing against a resistance. Immersion increases sensitivity, as do extremes of temperature. These differences make it difficult to predict the occurrence of CNS oxygen toxicity.

Benefits of intermittent exposure

Oxygen poisoning can be reduced or postponed by interrupting the exposure. If **"breaks"** of a period of low oxygen are taken during oxygen breathing the tolerance is greatly improved. In the USN tables for treatment of decompression sickness using oxygen, breaks of 5 minutes of air breathing are taken every 20 or 30 minutes of oxygen breathing. This avoids oxygen convulsions in all but very rare cases, and also postpones pulmonary toxicity.

Managing oxygen exposure and prevention of toxicity

Despite the uncertainties, the accepted method for avoiding oxygen toxicity is to have the diver stay within established exposure limits.

Concepts of exposure management

First a comment on the concept of **limits**. Just as with decompression, a limit is implemented as if it were a solid line dividing "no problems" from "guaranteed problems." Actually a limit is a solid line drawn through a wide gray area of gradually increasing risk. The limits given here and in other limit-based algorithms (such as a decompression table) are recommended guidelines for use under normal conditions. They have been proven in practice. They work for most people most of the time, but they are not guaranteed to work all of the time for all people under all circumstances. They may need to be more conservative when conditions are more stressful.

Let us likewise emphasize that diving with the NAUI EAN procedures imposes an extremely **low risk** of oxygen toxicity. The exposures are short and well outside limits expected to cause problems.

Prevention of CNS poisoning

The method used for prevention of CNS oxygen toxicity is to stay within exposure durations that are based on the oxygen level, the partial pressure or PO_2, to which the diver is exposed. These limits allow a certain time at each PO_2 range. Such an approach had been practiced by the U.S. Navy for many years, in their procedures for mixed gas and oxygen diving. The former U.S. Navy procedures (pre-1991) were not physiologically realistic, but were widely applied. In 1991 the Navy set an upper PO_2 limit of **1.3 atm**, with no limit on the duration of exposure. They also have a PO_2 vs. duration chart in the familiar format for cases where the 1.3 atm limit cannot be followed; the latter requires high level Navy permission for its use.

NOAA, mentioned earlier as an originator of enriched air nitrox diving, needed a more reasonable set of oxygen limits than the then-current Navy limits. These were needed for excursions from undersea habitats as well. With the help of experts, NOAA developed new limits that were published in the 1991 version of the NOAA Diving Manual. These limits are shown in Figure 4-3. They are intended for an unstressed diver doing only light work.

NOAA Oxygen Exposure Limits

PO_2 atm	Maximum Single Dive Limit, min	Maximum 24-Hour Limit, min
1.6	45	150
1.5	120	180
1.4	150	180
1.3	180	210
1.2	210	240
1.1	240	2 170
1.0	300	300
.9	360	360
.8	450	450
.7	570	570
.6	720	720

Figure 4-3. NOAA oxygen exposure limits. Table gives limits in min for a single PO_2 exposure level, and for each day (24 hr). (NOAA diving manual, 3rd ed., 1991).

For each level of oxygen the chart shows an allowable time for a single exposure, and also an accumulated time at that level over a full day. The NOAA manual does not specify a recovery time between dives if more than one dive is made (3 dives of 45 min each would theoretically be possible within the 150 min daily total allowed at 1.6 atm PO_2), but a surface interval of at least 90 min should be used if dives are made to the 1.6 PO_2 level. This only applies to the exposure at 1.6 atm, because only one maximal dive can be done in a day with the others.

The NAUI EAN tables use the NOAA limits, but consider that dives at a PO_2 higher than 1.4 atm are for contingencies; exposures at levels above 1.4 atm should not be planned for recreational dives.

The "oxygen clock" or "O_2 limit fraction"

These exposure limits are sometimes referred to as the "oxygen clock" in percentage of the allowable limit, or the "O_2 limit fraction" as a decimal fraction of the limit. For single dives to a single depth (square profile) calculating the percentage of oxygen exposure is as simple as dividing the minutes of the exposure into the maximum allowable exposure time at a given PO_2. However it is rare that a recreational diver is ever at one depth for the entire dive. It is important to know the percentage of exposure for different parts of the dive, so one can calculate total oxygen exposure in a given dive. Enriched air dive computers, discussed in Chapter 7, manage these calculations quite well.

It is not necessary to have a dive computer if the dive can be separated into segments that each have a predominant or average level. The times spent at each depth or exposure level can be assigned a fraction or percentage of the "allowable" limit, and these can simply be added up. Figure 4-4 allows these segments to be determined from a chart.

For multilevel dives or more than one dive of less than maximum allowed duration, it is possible to **interpolate** the limit values (Fig 4-5). That is to say, at any level the full limit on the oxygen clock is 100% of the limit, or an O_2 limit fraction of 1.0. Exposures at all levels are totaled. For example, at 1.4 atm the allowable exposure time is 150 min. If a diver has an exposure to that level for 75 min, half the allowable time, this would run the oxygen clock to 50% of the limit or the limit fraction to 0.5. If there is additional exposure on the same dive, say 60 min at 1.3 PO_2, an additional one-third, 33% or 0.33 is added, giving an oxygen clock now of 83% or a limit fraction of 0.83. When the total reaches 100% or 1.0, the diver is considered to have reached the allowable limit, and further exposure to elevated oxygen is at increased risk. Diving beyond the limit is not recommended.

Although there has been no laboratory validation of this technique of interpolating the exposure times, it makes sense and has been shown to work in practice with many thousands of actual dives. The NOAA oxygen exposure limits themselves are also generalizations, but have been proven to be reasonable limits through extensive practice.

The NAUI Enriched Air Nitrox diving tables fall well within the NOAA oxygen exposure limits. However, dives that involve exposures greater than 1.4 atm PO_2 are considered to be for contingency use only. Thus, normal exposures to 110 fsw (33 msw) can be done with 32% oxygen, and to 95 fsw (29 msw) with 36%. The allowed times are sufficiently generous that the oxygen exposure time limits are not at all likely to be encountered in normal no-stop scuba diving.

One may ask why NAUI imposes more conservative oxygen exposure limits than NOAA. There are several reasons. First, the NAUI procedures are intended to be appropriate for divers with limited training and experience. There may be discrepancies not only in the conduct of the dive but also in gas mixing and analysis, making the actual oxygen exposure greater than expected. The range of activities of a NAUI diver may exceed those used for the planning of the NOAA limits. And there have been convulsions in divers with a calculated oxygen exposure well below the limit. Also, the rescue system for most recreational divers may not be as effective if a convulsion does occur.

If a convulsion does occur

A convulsion in itself rarely causes injury, but the secondary consequences for a diver can be disastrous. First, the intense muscle contraction of the neck and jaw cause the diver to spit out the mouthpiece. It is usually impossible to put it back in. Consequently, the diver is likely to drown unless rescued. There is a risk of pulmonary barotrauma leading to arterial gas embolism if a diver ascends too rapidly or out of control, but this is not nearly so serious a threat as drowning.

Single Dive Oxygen Exposure as a Percentage of NOAA Limits

Oxygen PO_2, atm	NOAA Single Dive Limit, min.	Bottom Time, Minutes: 5	10	15	20	25	30	35	40	45	50	55	60
1.20	210	2%	5%	7%	10%	12%	14%	17%	19%	21%	24%	26%	29%
1.25	195	3%	5%	8%	10%	13%	15%	18%	21%	23%	26%	28%	31%
1.30	180	3%	6%	8%	11%	14%	17%	19%	22%	25%	28%	31%	33%
1.35	165	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	33%	36%
1.40	150	3%	7%	10%	13%	17%	20%	23%	27%	30%	33%	37%	40%
1.45	135	4%	7%	11%	15%	19%	22%	26%	30%	33%	37%	41%	44%
1.50	120	4%	8%	13%	17%	21%	25%	29%	33%	38%	42%	46%	50%
1.55	82	6%	12%	18%	24%	30%	36%	42$	48%	55%	61%	67%	73%
1.60	45	11%	22%	33%	44%	56%	67%	78%	89%	100%			

Figure 4-4. CNS Oxygen Exposure Table; percentage of NOAA "allowable" limits for a single dive. Note the 1.6 atm PO_2 level; the "oxygen clock" runs almost 4 times as fast at 1.6 atm as at a PO_2 level of 1.4 atm. PO_2 levels higher than 1.4 atm are shown for contingency purposes only. Values for intermediate 0.05 atm PO_2 values are linearly interpolated. Values in main table are rounded normally.

Multilevel Dive Oxygen Exposure

PO_2, atm	Single Dive Limit, Min	Time Used, Min	% Limit
1.30	180	60	33%
1.40	150	75	50%

Total dive time = 135 minutes

Total exposure = 83% of the limit

Figure 4-5. Multilevel dive oxygen exposure. By adding the oxygen exposure for each level the total oxygen exposure can be estimated.

If a full-face mask is available the rescuer might make it possible for the affected diver to breathe. If one is not available, it is usually not worthwhile to spend a lot of time trying to reinsert the diver's mouthpiece. As soon as the initial phase of the convulsion is over, the diver should be taken to the surface using a slow ascent rate, but without unnecessary delay. The trade-offs here are a risk of embolism from too fast an ascent, or certain drowning if ascent is delayed. The risk of embolism is the better option; take the diver to the surface. The ascent should take no longer than necessary. At the surface treat for near drowning according to signs and symptoms. This type of rescue has been done successfully a number of times. Use oxygen if available; a diver who has a significant decompression obligation or symptoms of DCS should be taken to a hyperbaric chamber and treated in the usual way.

A diver who blacks out without a convulsion and without losing the mouthpiece and who is breathing may be taken slowly to the surface. An ascent rate for this might be 20 fsw/min deeper than 30 fsw, and 10 fsw/min thereafter. Divers usually awaken from these blackouts.

Prevention of lung or whole-body oxygen poisoning

Other parts of the body are sensitive to excess oxygen, especially the **lungs**. Pulmonary oxygen toxicity, and in due course other whole-body aspects, can become a problem in extended or repeated oxygen-based decompressions and treatments in a pressure chamber. These conditions are most unlikely to be encountered in NAUI nitrox diving, and in fact are not significantly more likely than in ordinary scuba diving with air. However, procedures have been developed for managing this toxicity, and it is helpful for the EAN student at least to be acquainted with the general methods and terminology.

On continued exposure to PO_2, generally at levels below those causing CNS toxicity but above a PO_2 of 0.5 atm, the lungs may show symptoms, and as the toxic effects develop there is a reduction in vital capacity. **Vital capacity** is the maximum amount of gas that a person can exhale after taking a full inspiration. Although it takes training to get reproducible data, vital capacity is relatively easy to measure and it has been used as the indicator for pulmonary toxicity. At the laboratory of Dr. C.J. Lambertsen at the University of Pennsylvania empirical methods were worked out in the early 1970s to use vital capacity as a monitor for pulmonary effects of oxygen exposure (Clark and Lambertsen, 1971; Wright, 1972). Among the developments was a "unit" for measuring and tracking oxygen exposure, the UPTD or Unit Pulmonary Toxicity Dose, as a function of PO_2 and time.

The dose measure was built around a basic unit of exposure of one minute of inspiring 100% oxygen at a pressure of 1 atm. At PO_2 levels above this the dose increases more rapidly as the PO_2 increases. This toxicity seems to have a threshold at 0.5 atm PO_2, below which toxicity development is insignificant. The unit dose for different exposure levels was determined by mathematically fitting a dose curve to empirical data, then deriving an equation to describe the curve. This equation is available in many places, for example Shilling et al, 1976, p. 158, which includes "look-up" tables for deriving doses from exposure data. The method also used an additional dose term, CPTD, a measure of the Cumulative Pulmonary Toxicity Dose. A more recent approach designated the Repex method (Hamilton, 1989), allows doses to be calculated or looked up the same way but uses a single dose unit, **OTU or Oxygen Tolerance Unit**. The Repex method is a little less intimidating than the UPTD/CPTD method of counting, but more importantly, it takes recovery into account and provides procedures for avoiding toxic effects during extended operational exposures. ■

Chapter 4. Knowledge Review—Oxygen Physiology, Toxicity, and Tolerance

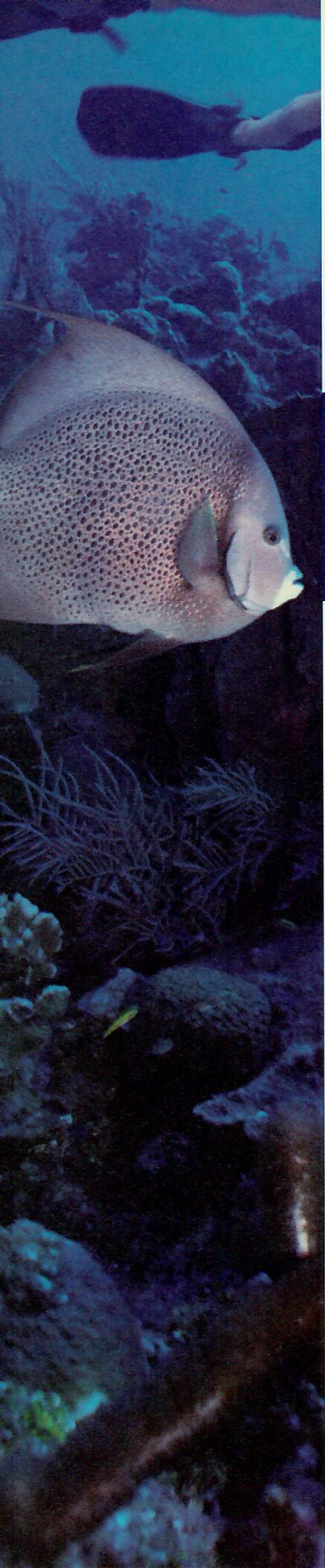
Before moving on to the next chapter, **How to pick a Nitrox Mix**, please test your understanding of this chapter's information by completing the **Knowledge Review.**

1. Oxygen is used in the body to support __________ .
2. The main waste product of oxygen's use in the body is __________ .
3. The best term used to describe a condition of low oxygen is __________ .
4. A high partial pressure of oxygen can cause what at depth? __________ .
5. List six possible warning signs and symptoms of CNS oxygen toxicity other than a convulsion. ______________________________ .
6. According to the NOAA limits, the maximum time a diver on a single dive can be exposed to oxygen partial pressures of 1.6 atm is __________ min.
7. NAUI recommends that the maximum PO_2 for enriched air recreational diving be kept below __________ atm.
8. A diver conducts a 60 minute dive to 80 fsw (25 msw) using a 36% enriched air mixture. What percentage of the NOAA oxygen exposure limit has been used?
9. If signs of oxygen toxicity are observed, a diver is to assist his buddy how?
10. How many minutes of dive time can a diver have in a 24 hour period if breathing an oxygen mix that produces a PO_2 1.3 atm?

Answers for Chapter 4

1. Metabolism
2. Carbon dioxide
3. Hypoxia
4. Convulsion
5. Visual disturbances, Euphoria, Nausea, Tingles and Twitching, Irritability, Dizziness
6. 45 minutes
7. 1.4 atm
8. 33 %
9. Help in going to the surface.
10. 210 minutes

5 HOW TO PICK A NITROX MIX



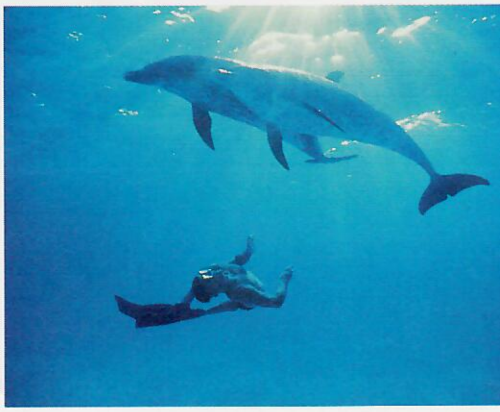
Chapter 5

HOW TO PICK A NITROX MIX

PGOALS

In this chapter you will:

- Gain an understanding of the different standardized nitrox mixes.
- Learn how to calculate maximum and contingency operating depths.
- Apply oxygen exposure limits to dive planning.
- Learn how to choose the optimal mix for any given dive.



New Terms in This Chapter

Maximum operating depth, MOD

Contingency maximum operating depth

Optimal mix

First steps in planning an enriched air dive

In the previous four chapters we discuss the history of enriched air nitrox, gases and their properties, and in extensive detail, oxygen and partial pressures of gases. Each of those chapters contain important considerations necessary for planning an enriched air nitrox dive. There are many steps that a diver needs to take before jumping in the water with an enriched air tank. They include choosing an appropriate enriched air mix, analyzing the gas, planning operating depths, managing oxygen exposure, and choosing the appropriate diving table. Think of this chapter as the beginning of your "planning guide." As with all types of diving, there is a planning process. In the beginning it may take some time to gather all the pieces. Take the time to examine each component carefully, as each will affect the others. With time and practice most divers become familiar with the planning process and it becomes automatic. Examining each component of the EAN dive plan before the dive is critical to the overall safety and effectiveness of the dive.

The steps addressed in this chapter are only the beginnings of the planning process. In later chapters we address diving tables, computers, gas analysis, tank selection, gas logistics, and thermal protection. Here we deal with selecting the most appropriate mix based on the partial pressure of the gas for the depth of the dive. It is important to remember that all of the time spent on a dive may not be at one constant depth, but may be at many different depths throughout the dive. For purposes of oxygen management for dive planning, NAUI nitrox divers use a partial pressure of 1.4 atm as the routine oxygen exposure limit, and up to 1.6 atm for contingency planning. The NAUI diving tables take this into consideration.

The nitrox mixes

Divers use two standard enriched air nitrox mixes, with 32% and 36% oxygen. Figure 5-1 shows graphically that the nitrogen decreases with the increasing percentage of oxygen. These two mixes, first used by NOAA, have been determined to provide effective no-stop diving times in the 40 to 120 fsw (12-36 msw) range.

Chapter 4 discusses that oxygen in high doses becomes toxic and can cause central nervous system problems if the dose is too high for too long. The **partial pressure of oxygen** or the **PO_2** is the depth limiting factor to any enriched air mixture. A key facet in enriched air dive planning is to optimize the oxygen level.

Concerns of the mix

One concern to divers is the final gas mix they will breathe. Qualified technicians are trained to blend enriched air nitrox mixes to certain specifications. In this chapter we assume that the mix delivered to the diver in the cylinder is to the exact proportions requested and has been analyzed. In the chapter on gas mixing we describe the mixing processes, handling concerns, mix tolerance limits, and user analysis. However, the most important concern, the one addressed here, is that the mix chosen is the most

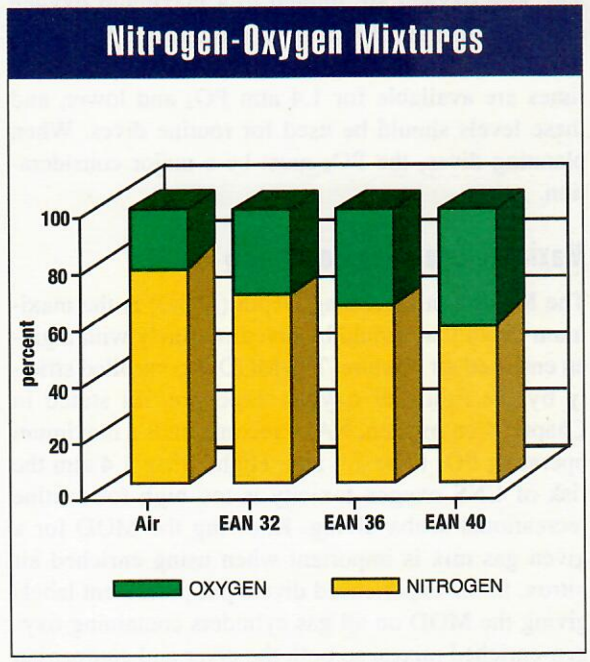


Figure 5-1. Graphic representation of nitrogen and oxygen in various mixes by gas percentage.

appropriate for the dive planned. Too much oxygen in the mix increases risk of oxygen toxicity, too much nitrogen and no-stop time is shortened. Using the wrong mix with the wrong table could lead to decompression sickness or oxygen toxicity. It is important that only the appropriate mix be used with the correct table.

Oxygen exposure time

In choosing the appropriate mix the diver should refer to the Oxygen Exposure Limits (Fig 5-2); this figure is the same as in Chapter 4, but it has the PO_2 limits interpolated. The lower the PO_2, the longer the dive can be from an oxygen tolerance perspective. The higher the PO_2, the shorter the dive has to be.

Enriched air nitrox dives are planned with PO_2 levels not exceeding 1.4 atm. This level provides significant bottom time with minimal risk of oxygen toxicity.

For example, a dive planned for a PO_2 of 1.4 atm will allow up to 150 minutes of dive time according to the oxygen exposure limits. This does not, however, take decompression into consideration; this is discussed in Chapters 6, 7, and 8.

Maximum operating depth

The NAUI EAN_{32} and EAN_{36} diving tables for 32% and 36% oxygen are limited to a maximum oxygen exposure time at 1.6 atm of no more than 30 minutes, but this is for contingency purposes only. Longer times are available for 1.4 atm PO_2 and lower, and these levels should be used for routine dives. When planning dives, the PO_2 must be a major consideration.

Maximum Operating Depth, PO_2 1.4 atm

The Maximum Operating Depth (MOD) is the maximum depth that should be dived routinely with a given enriched air mixture. The MOD is controlled strictly by the limits of oxygen exposure. As stated in Chapter 4 on oxygen, NAUI recommends a maximum operating PO_2 to be 1.4 atm. Higher than 1.4 atm the risk of CNS oxygen toxicity is too high for routine recreational scuba diving. Knowing the MOD for a given gas mix is important when using enriched air nitrox. Some experienced divers put prominent labels giving the MOD on all gas cylinders containing oxygen-enriched mixes, so both the diver and companion divers can check to ensure that the depth is not exceeded. MODs for the two NAUI enriched air mixes are shown in Figure 5-3.

NOAA Oxygen Exposure Limits

PO_2 atm	Maximum Single Dive Limit, min	Maximum 24-Hour Limit, min
1.60	45	150
1.55	83	165
1.50	120	180
1.45	135	1.80
1.40	150	180
1.35	165	195
1.30	180	210
1.25	195	225
1.20	210	240

Figure 5-2. NOAA oxygen exposure time limits. Table gives limits in minutes for a single PO_2 exposure level, and for each 24 hour day. This table has been interpolated for 0.05 atm PO_2 limit increments. Levels of 1.45 to 1.60 PO_2 atm are for contingency purposes only. (NOAA diving manual, 3rd ed., 1991)

An advantageous level for most dives is a PO_2 up to 1.4 atm. This oxygen limit has a low risk of CNS oxygen toxicity; it will allow for up to 150 minutes in a single exposure (dive) and up to 180 minutes of dive time in any 24-hour period. This PO_2 level can be considered the routine limit for most dives.

Typically when a diver knows the dive site ahead of time, an optimal gas mix can be chosen. If possible choose a gas mix that can be used to the maximum depth of the site. If the site does not have a hard bottom (like a wall) choose a mix based on the maximum depth that the diver will not exceed. Under these "no-bottom" conditions, monitoring the depth gauge or computer is critical so that the MOD is *never* exceeded. Exceeding the MOD can increase the chance of a diver suffering from oxygen toxicity, and this can have fatal consequences.

Example: Using A 32% nitrox mix the maximum operating depth is 110 fsw (33 msw). The contingency depth for 36% oxygen is also 110 fsw.

Maximum and Contingency Operating Depths

	EAN32	EAN36
Maximum depth	110 fsw	90 fsw
PO_2	1.39	1.34
Contingency depth	130 fsw	110 fsw
PO_2	1.58	1.56

Figure 5-3. NAUI maximum operating depths and maximum contingency operating depths for standard mixes, based on a normal maximum PO_2 of 1.4 atm, and a contingency limit PO_2 of 1.6 atm. Limit depths are rounded to the nearest table depth.

Calculating the MOD

To calculate the maximum depth to give a PO_2 of 1.4 atm with a given mix, we need to find out how many atmospheres of that mix it takes to produce a PO_2 of 1.4 atm, then convert that back to fsw. First, determine the fraction of an atmosphere of oxygen in each atmosphere of the mix (here 0.32 atm), then divide the limit PO_2 (here 1.4 atm) by this value, then convert this from absolute units back to depth units by subtracting 1 atmosphere and multiplying the number of atmospheres remaining by 33, the number of fsw per atm.

$$MOD, fsw = \left(\frac{(PO_2 \text{ limit, atm})}{(FO_2 \text{ mix})} - 1 \text{ atm}\right) x\ 33 \text{ fsw/atm}$$

Or, the conversion back to fsw can be done by multiplying by 33 first, then subtracting the number of fsw in one atmosphere.

$$MOD, fsw = \left(\frac{(PO_2 \text{ limit, atm})}{(FO_2 \text{ mix})} x\ 33 \text{ fsw/atm}\right) - 33 \text{ fsw}$$

To calculate the MOD for 32% oxygen, which has an FO_2 of 0.32, at a limit of 1.4 atm:

$$MOD, fsw = \left(\frac{(1.4 \text{ atm})}{(0.32)} - 1 \text{ atm}\right) x\ 33 \text{ fsw/atm} = 111 \text{ fsw}$$

Contingency maximum operating depth, PO_2 1.6 atm.

The contingency maximum operating depth is the depth to which the diver can descend for a limited time under special circumstances. This is the depth where the mix has a PO_2 of 1.6 atm. Dives should not be planned so as to exceed this depth; the risk of CNS toxicity increases sharply above this limit, and is higher than acceptable for routine recreational diving in the range 1.4 to 1.6 atm PO_2. Although routine dives should not be planned to exceed 1.4 atm, it is a good idea to have an idea where the contingency limit for a given mix will be reached.

Calculating the contingency MOD

Another way to determine the maximum operating depth of an enriched air nitrox mixture is to back into the formula. Let's say we have a nitrox cylinder that has been analyzed at 32% oxygen. How deep can that gas be used in a contingency situation? Since we know that the maximum PO_2 allowed for contingency oxygen exposure is 1.6 atm abs, and that each atmosphere of 32% oxygen has a partial pressure of 0.32 atm, just divide 1.6 by 0.32; the result is 5 atm abs. Remember that oxygen exposure limits are measured in absolute pressure, so convert 5 atm abs into depth units by subtracting 1 atm and multiplying by 33; the result is 132 fsw (40 msw).

$$1.6 \text{ atm} / 0.32 = 5 \text{ atm abs}$$

$$\text{Contingency MOD, fsw} = (5 \text{ atm} - 1) \times 33 \text{ fsw} = 4 \times 33 = 132 \text{ fsw}$$

This can be done with any mix. Here a 37% mix is used that has an oxygen fraction of 0.37.

$$(1.6 / 0.37) = 4.32$$

$$(4.32 \text{ atm} - 1) \times 33 \text{ fsw/atm} = 3.32 \times 33 = 109.7 \text{ fsw}$$

Partial pressure of oxygen chart

To make these calculations easy, use the **Partial Pressure of Oxygen** chart, Figure 5-4. To use the chart to find the depth for a given PO_2 with a specific mix, enter from the top under the percentage % of oxygen in the mix, then slide down that column to the number that is closest to but does not exceed the desired PO_2, then move to the left to the fsw/msw column to read the depth. To find the depth for maximum PO_2 with a given mix, select the mix at the top, move down to the maximum PO_2–in this case 1.4 atm, the maximum PO_2 allowable for that mix–then move to the fsw/msw column; this number is the maximum operating depth for that gas.

PARTIAL PRESSURE OF OXYGEN, PO_2, atm
BASED ON DEPTH AND PERCENTAGE OF OXYGEN (FO_2)

Depth fsw	Depth msw	atm abs	21%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%
0	**0**	1.00	0.21	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40
35	**10**	2.05	0.43	0.57	0.59	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82
40	**12**	2.21	0.46	0.62	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88
50	**15**	2.52	0.53	0.70	0.73	0.75	0.78	0.80	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.01
60	**18**	2.82	0.59	0.79	0.82	0.85	0.87	0.90	0.93	0.96	0.99	1.01	1.04	1.07	1.10	1.13
70	**21**	3.12	0.66	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.19	1.22	1.25
80	**24**	3.42	0.72	0.96	0.99	1.03	1.06	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.37
90	**27**	3.73	0.78	1.04	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.42	1.45	1.49
100	**30**	4.03	0.85	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.45	1.49	1.53	1.57	1.61
110	**33**	4.33	0.91	1.21	1.26	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60			
120	**36**	4.64	0.97	1.30	1.34	1.39	1.44	1.48	1.53	1.58						
130	**39**	4.94	1.04	1.38	1.43	1.48	1.53	1.58								

Figure 5-4. Partial pressure of oxygen chart. Body of chart has PO_2 values for various mixes at a range of depths. Standard 32 and 36% mixes are in light grey. PO_2 levels higher than 1.4 atm should be avoided and are shown for contingency purposes only, darkened.

Fraction of Oxygen for the Mix

Once the diver has determined the PO_2 level for the dive the next step is to find the correct faction of oxygen needed to make the mix. This is all based on the ultimate partial pressure of the oxygen. This is covered next, using Figure 5-5.

Choosing the best mix for a given dive

For most recreational enriched air diving the standard 32% and 36% oxygen mixes are quite sufficient. As Chapter 8 on diving table techniques mentions, the NAUI EAN_{32} and EAN_{36} diving tables cover these gas mixes, ±1%. This tolerance range makes the standard NAUI nitrox tables useful for dives using gases from 31 to 33% and 35 to 37% oxygen content.

There may be times however when a diver would like obtain the most no-stop dive time for a specific depth. This would be achieved by determining the fraction or percentage of oxygen needed for that depth and having a specific mix blended for that dive. This mix is sometimes called the "best mix."

Figure 5-5 provides oxygen percentages for PO_2 levels from 1.3 to 1.6 atm and depths to 130 fsw (41 msw). When planning dives use the 1.5 and 1.6 atm levels for contingency purposes only.

One can also make these calculations by formula. Select the desired PO_2 and divide by the depth of the dive converted to atmospheres absolute. This will result in the fraction of the gas needed to be mixed.

$$PO_2\ Fraction = \frac{PO_2\ limit}{Depth\ in\ atm}$$

This is another application of the basic formula for partial pressure covered in Chapter 3. Remember to convert fsw to atm abs. As an example, if the PO_2 is to be 1.4 atm, the "best mix" for a dive at 85 fsw (3.58 atm) is 1.4/3.58, or 39% oxygen, 61% nitrogen.

The planning process can also be done in reverse, as we did with the maximum operating depth of a given mix (Fig 5-6). If you have a nitrox cylinder that has been analyzed at 32% oxygen, how deep can that gas be used and still maintain an operating PO_2 of 1.4 atm? Divide 1.4 atm by 0.32, the result is 4.4 (4.375) atm. Next, convert 4.4 atm into depth units (fsw/msw) and the result is 111 fsw (33 msw).

From the steps just applied, the diver can take the desired mix and go on to choose the appropriate diving table. ■

Maximum Depth for a Mix:

PO_2 limit, atm/ FO_2 = atm

1.4 / 0.32 = 4.4 atm

(4.4 atm x 33 fsw/atm) - 33 =111 fsw

Figure 5-6. Maximum depth for a mix.

Percentage of Oxygen at Various PO_2 Levels

fsw	msw	atm	1.3	1.4	1.5	1.6
40	12	2.21	59%	63%	68%	72%
45	14	2.36	55%	595	63%	68%
50	15	2.52	52%	56%	60%	64%
55	17	2.67	49%	53%	56%	60%
60	18	2.82	46%	50%	53%	57%
65	20	2.97	44%	47%	51%	54%
70	21	3.12	42%	45%	48%	51%
75	23	3.27	40%	43%	46%	49%
80	24	3.42	38%	41%	44%	47%
85	26	3.58	36%	39%	42%	45%
90	27	3.73	35%	38%	40%	43%
95	29	3.88	34%	36%	39%	41%
100	30	4.03	32%	35%	37%	40%
105	32	4.18	31%	33%	36%	38%
110	33	4.33	30%	32%	35%	37%
115	35	4.48	29%	31%	33%	36%
120	36	4.64	28%	30%	32%	35%
125	38	4.79	27%	29%	31%	33%
130	39	4.94	26%	28%	30%	32%
135	41	5.09	26%	28%	29%	31%

Figure 5-5. Selecting a mix by PO_2. Choose the desired upper PO_2 limit, then intersect with the row having the target dive depth. This percentage is the oxygen in the mix to get the chosen PO_2. Avoid using 1.5 and 1.6 levels.

Chapter 5. Knowledge Review—How to pick a Nitrox Mix

Before moving on to the next chapter, **Decompression Principles,** please test your understanding of this chapter's information by completing the **Knowledge Review.**

1. What are the two standard enriched air mixes recreational divers use? ____________
2. What is the primary concern divers have about the gas mix? ____________
3. The Maximum Operating Depth (MOD) of a gas mix is controlled by its __________ and a limit chart.
4. Calculate the maximum and contingency depth limits for a 34% oxygen enriched air mix. _______ fsw and _______ fsw
5. Calculate the oxygen partial pressure of a 38% enriched air mix at the following depths.
   A. 55 fsw ______ C. 105 fsw ______
   B. 66 fsw ______ D. 87 fsw ______
6. Calculate the best mix to use at a partial pressure limit of 1.4 atm for a dive to the following depths.
   A. 81 fsw _____ C. 105 fsw _____
   B. 93 fsw _____ D. 110 fsw _____
7. What would be the best enriched air mix to use for dives in the following depth ranges that would not exceed 40% or a 1.6 atm PO_2 contingency depth?
   A. 40 to 60 fsw ______ C. 100 to 130 fsw ______
   B. 60 to 90 fsw ______
8. What is the contingency depth limit for a 32% enriched air mixture? __________
9. At 98 fsw what is the percentage of oxygen in the mix if the PO_2 is 1.4 atm? __________
10. At 132 fsw what is the fraction of oxygen in the mix if the PO_2 is 1.6 atm? __________

Answers for Chapter 5

1. 32% and 36% oxygen
2. That it is appropriate for the dive; the correct mix with the correct tables.
3. PO_2 at depth
4. 103 fsw and 122 fsw
5. a: 1.01 atm b. 1.14 c. 1.59 d. 1.38
6. a. 40% b. 36% c. 33 % d. 32 % [round down]
7. a. 40% b. 40% c. 32%
8. 132 fsw
9. 35%
10. 0.32

6 DECOMPRESSION PRINCIPLES

Chapter 6

DECOMPRESSION PRINCIPLES

LEARNING GOALS

In this chapter you will:

- Learn the meaning of decompression.
- Learn why decompression is important to the diver.
- Appreciate why decompression is not to be feared, but to be respected.
- Get an overview of decompression physiology.
- Be introduced to table development.
- Gain an understanding of table reliability.

New Terms in This Chapter

Decompression
Profile
Table
Schedule
M-value
Gas loading
Doppler
Haldane
Empirical

Meaning of "decompression"

In this chapter we confront "the D word," and try to show that while it deserves respect, the diver should not be intimidated by decompression. The word **"decompression"** has two different meanings in diving. The first is the dictionary definition, the second is the act of doing it in a controlled way.

The dictionary definition of decompression is the **reduction of pressure** or **release from compression**. In the context of a pressure vessel, this meaning is more or less obvious, reducing the pressure is decompressing the vessel (Fig 6-1). It might as well be called depressurizing. In the context of a diver ascending, the ascent takes the diver to a place where the pressure is lower, and this too is decompressing. Decompression is nothing to fear, you do it every time you dive.

However, although divers occasionally use the word as defined, they also use the word **"decompression"** to mean the release or reduction of pressure **in a controlled or planned way** to avoid bubble formation and decompression sickness (DCS). The latter is an outcome of decompression when the pressure release is not done properly. So it is in the best interest of the submerged diver to "decompress" in order to reach surface pressure. "Decompression" in this sense means the diver is required to follow a specific time, depth, and breathing gas profile. This profile, which may be called a **decompression table** or **decompression schedule**, is designed to allow a diver to ascend to the surface without incident or symptoms. It may involve stops, or only require a specific ascent rate without stops.

Figure 6-1. Dissolved gas forms bubbles on reduction of pressure.

The process of ascending to the surface is decompression in both senses. Ascending without stops is still decompressing. The important point is that every ascent is a decompression; you actually "decompress" from every dive. Further, every dive of any consequence involves a certain decompression obligation. More about this later.

The NAUI diving tables are for no-stop diving. They have provisions for decompression with stops, but these are not considered routine application of the normal tables. "Decompression diving", diving with planned or "required" stops, is not normally practiced for most recreational diving in the U.S. There is a provision for this in some European diving organizations. Decompression diving, however, is done for some advanced types of dives that require additional training and equipment. This is discussed in greater detail in the NAUI Technical Nitrox and Decompression Techniques Diver courses.

Decompression physiology

Divers in training are exposed to various descriptions of decompression and the need for it. Because the benefits of diving with enriched air relate solely to decompression, it is worthwhile to know a little about it. This section reviews the basics.

Gas uptake

When a person's body is exposed to increased pressure, greater than the familiar one atmosphere at sea level, additional inert gas dissolves in body tissues. Inert gas is gas that is neither metabolized by nor is a product of body metabolism; inert gases are not

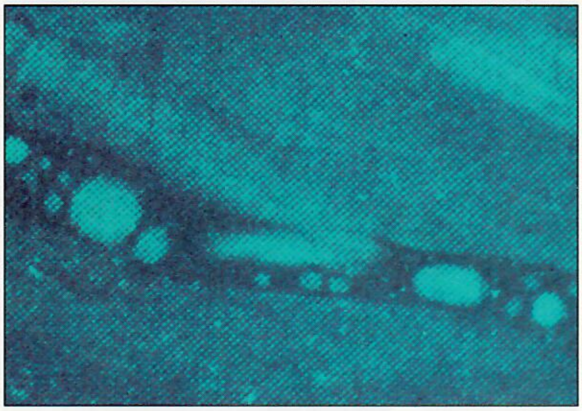


Figure 6-2. Bubbles in blood stream of experimental animal. These are much larger than those detected by Doppler.

changed in the body. When a gas is dissolved it is not in gaseous form. The inert gas of interest in air and enriched air diving is nitrogen (N_2).

During an exposure to increased pressure inert gas is picked up by the blood in the lungs and distributed to all parts of the body, at different rates and not necessarily evenly. When pressure is reduced the opposite takes place. Gas is picked up from the tissues–still dissolved–and moves into the lungs where it resumes the gaseous state and is exhaled uneventfully. However, if the pressure reduction takes place too fast the gas does not stay dissolved but is released into the tissue or blood as bubbles. Bubble formation inhibits the transport of gas out of the body in several ways.

Bubble detection

It is not easy to detect bubbles in tissue, but they can be detected in circulating blood because they are moving. This is done with a device called a Doppler ultrasonic bubble detector. Ultrasonics, sound waves at too high a frequency to be heard, are used in medical diagnosis. Using Doppler electronics, ultrasound reflected from moving objects is detected. Bubbles can be "heard" moving through the circulation on the way to the lungs (Fig 6-2). Doppler bubble detectors have shown that normal and otherwise benign dives may create a few circulating bubbles in some divers. These are called "silent bubbles" because they do not cause symptoms. In fact, the bubbles detected in the venous blood are "on their way out" and are not likely to be involved in decompression sickness. Doppler bubble detection in venous blood has not proven to be useful for predicting DCS in a given diver, but dive profiles that cause a lot of bubbles also tend to cause a lot of DCS cases.

Prediction: Table computation

The most common method used for predicting if a profile (of pressure and gas as functions of time) will cause DCS dates back to around the turn of the 20th century, when physiologist J.S. Haldane developed a method for keeping track of gas in the body and showed how to prepare decompression profiles or "tables." At the outset it is important to make clear that this "model" proposed by Haldane and later modified by others is hypothetical. It is not what really happens in the body, nor was it intended to be, but it does afford a method of moving from yesterday's dive experience to tomorrow's new tables. This was the first such model; many others have followed, and many are offshoots of the Haldane method. A well developed computational method similar to Haldane's was published by the late Swiss cardiologist, Prof. A. A. Bühlmann, and it has been widely used by others.

At today's state of knowledge (this is not likely to change much in the near future) the only criterion for the preparation of useful decompression tables is empirical experience. As models improve, prediction capability will continue to get better, but the judgment as to whether a model is right is how well it actually works, not how sophisticated the math is.

Review of Haldane

Because it is the oldest and most used of the computational methods, it might be worthwhile to review the Haldane method. The model considers that the body is made up of a number of independent **compartments**, each of which takes up and releases inert gas at different rates; the computations keep track of where the gases are expected to be. Although compartments are sometimes called "tissues" they are not anatomical entities; each consists of whatever parts of the body handle gas at a specific rate.

The rate of uptake and elimination of a gas is proportional to the difference between the amount in the compartment and the inspired gas in the lung, and it is normally considered to work the same way in both directions (it is "symmetrical"). The greater the difference between the gas in the lung and in a given compartment, the faster gas moves into or out of that compartment. Quantitatively this process is called "exponential" after the mathematical method used to calculate the rates.

The rates associated with the individual compartments are described in terms of "half times," which is the time it takes the gas in a given compartment to proceed halfway toward being equal to the source. From six to as many as 32 compartments have been used, with half times ranging from two to over 1200 min. A short half time results in a faster rate of gas transport. Gas "quantities" in this context are handled as partial pressures. One may speak of the "gas loading" in the 60-minute compartment as the **partial pressure** of that gas in that compartment. Remember that these are hypothetical values.

After gas uptake, when an ascent is begun and pressure is reduced, some of the compartments may not release gas fast enough to match the ascent rate, and, as a result, bubbles can form.

Computing decompression tables

Experience has shown that certain profiles–and presumably the hypothetical gas loadings produced by such profiles–have or have not produced DCS. With enough experience–data–it is possible to assign limits to ascent. With these tools, table developers calculate suitably slow ascent rates for a variety of exposure profiles; the results of these calculations are **decompression tables**.

The **limits** just mentioned are in terms of the gas loading that can be tolerated in each compartment at each depth during ascent. Ascent limits are normally considered in 10 fsw or 3 msw increments, and are known as **"M-values"** (where M stands for "maximum"), the maximum permitted gas loading at that depth in that compartment. To calculate a decompression table, the developer needs a set of M-values, usually determined from experience. The calculated gas loadings in each compartment are compared with the M-values, and ascent is adjusted to keep the loadings below the limits. The diver's ascent is halted with "stops" at specified depths to wait until the hypothetical gas loadings have "decayed" to below the limits for that depth; the diver then ascends to the next stop and the process is repeated.

Haldane's method goes back nearly a century, but by using it with continuously updated experience, it can be used to produce **reliable** decompression tables. It is not quite correct to consider this a "theory" of how the human body works. Rather, it is a computational tool that allows prediction of tomorrow's dive from yesterday's experience. Bühlmann's method uses the same gas uptake but calculates the ascent limits in a different way; it, too, incorporates experience.

Reliability of tables

Virtually any exposure to pressure imposes an obligation for decompression, and even when decompression is done correctly it may create some probability of symptoms of a decompression disorder. For this reason we do not use the word "safe" to describe a decompression procedure. In the sense that **"safe"** means "an acceptable level of risk" the word may be applicable, but too many people perceive that as meaning no risk at all, and that is not the case. We refer to a satisfactory decompression table as being **"reliable."** The tables in this manual are considered reliable.

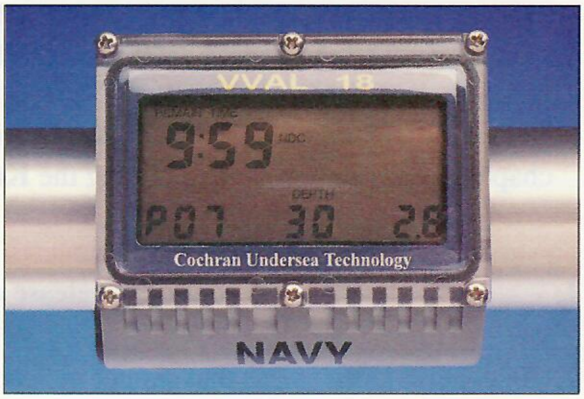


Figure 6-3. Cochran Navy VVAL-18 dive computer which uses the exponential-linear program for determining decompression.

The limits of a decompression procedure do not represent a hard line between developing or not developing decompression sickness symptoms, but rather a fuzzy boundary of "acceptable risk." Accordingly, one should always consider DCS as a possibility. Plan for it, be prepared for it psychologically, and have a plan for dealing with it.

There is a wide variation in the physical makeup of divers, and part of this variation is in susceptibility to decompression disorders. There are differences among individuals, and in each individual at different times.

There are also environmental effects. Immersion, exercise, and warmth increase gas uptake and elimination; cold and dehydration reduce them. Depending on where in the dive these conditions occur, they may be either beneficial or detrimental to the decompression. Because of the variations, a given schedule is not "safe" or "unsafe," but rather DCS has a certain probability of occurring. Therefore, decompression data is sometimes analyzed statistically. The U.S. Navy and other decompression researchers have developed a means of analyzing past dives using a type of statistics called "maximum likelihood." With it, the probability of DCS can be predicted from a given profile when compared with a collection of past dives of the same general type. ■

Chapter 6. Knowledge Review–Decompression Principles

Before moving on to the next chapter, **Diving Tables,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. ____________ is the controlled release of pressure during a scuba dive.

2. In general terms, a gas that cannot be metabolized by the body is called ________________.

3. Name an electronic device used to detect silent bubbles in the venous circulation. ________________________

4. The first person to calculate decompression in quantitative terms was __________.

5. The rate at which a ______________ absorbs gases is expressed as its ______________.

6. The maximum gas loading that a compartment can tolerate at a given depth, hypothetically, is called its ______________.

7. The numbers on a decompression table are rigorous, and if they are not exceeded it is certain that bends will not occur. True or False.

8. A satisfactory decompression table is best referred to as __________.

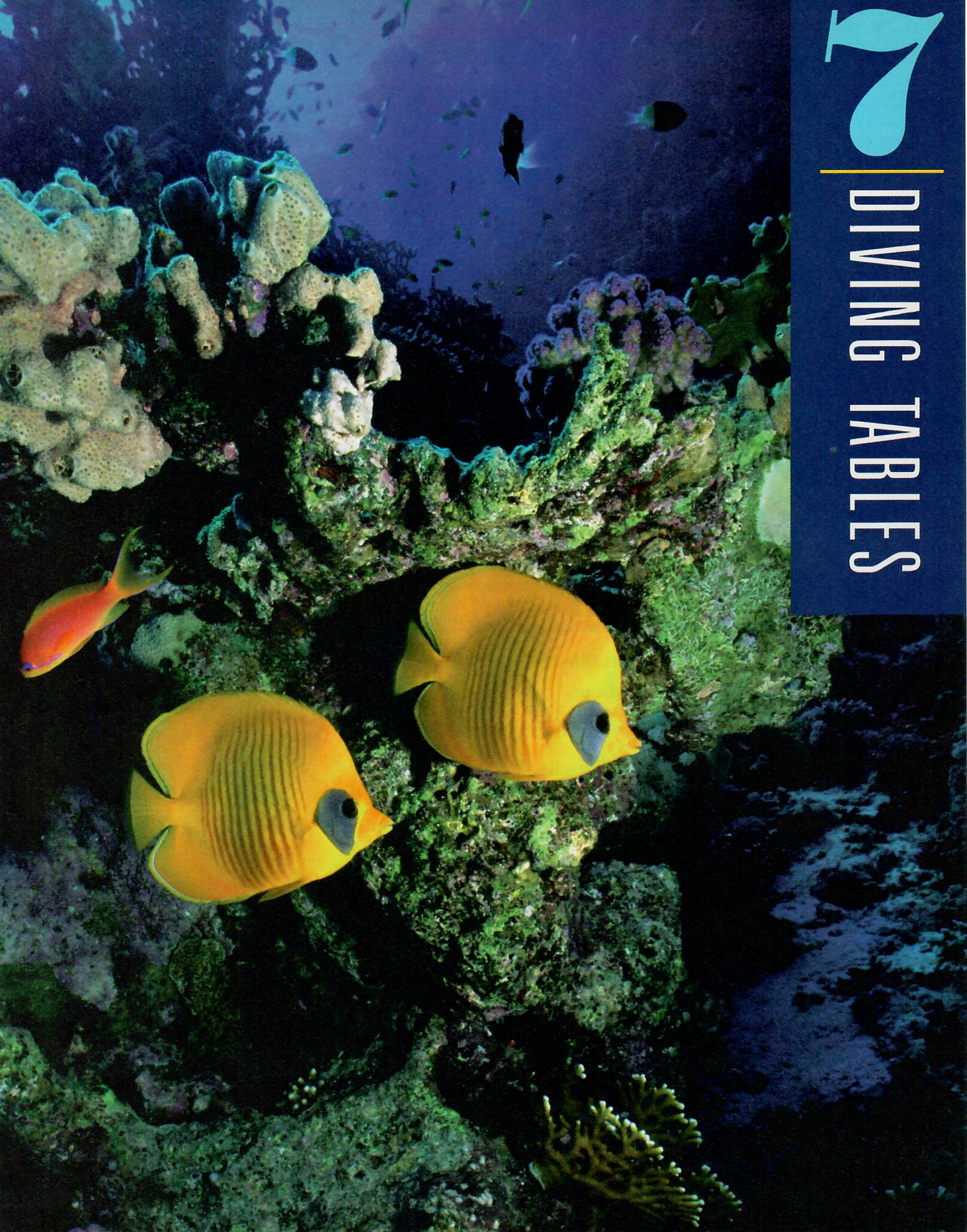
9. All decompression models are _____________ and are not an exact representation of what happens in the body.

10. No matter how sophisticated the mathematics, reliable decompression tables still have an ___________ basis.

Answers for Chapter 6

1. Decompression
2. Inert gas
3. Doppler ultrasonic bubble detector
4. J. S. Haldane
5. Compartment; half time
6. M-value
7. False
8. Reliable
9. Hypothetical
10. Empirical

7 DIVING TABLES



Chapter 7

DIVING TABLES

LEARNING GOALS

In this chapter you will learn about:

- Air diving tables.
- Enriched air nitrox diving tables.
- The equivalent air depth principle.
- The NAUI EAN tables.
- Alternative methods of dive planning.
- No-stop diving.
- Repetitive diving.
- Altitude diving.

New Terms in This Chapter

Equivalent air depth, EAD

No-stop

No-decompression

Safety stop

Repetitive diving

Surface interval

Custom tables

Dive computer

Dive planning software

Air tables

This section discusses some examples of standard decompression tables and moves on to the special tables and techniques needed for diving with enriched air.

The US Navy tables

Beginning with Haldane's work early in the 20th century, the U.S. Navy has developed over the years a set of air decompression schedules that have become something of a standard. These make up the *U.S. Navy Standard Air Decompression Tables*. Although the Navy did not have recreational diving in mind when the tables were developed, they have become the basis for many recreational tables. The present set of tables were first issued in the 1959 version of the U.S. Navy Diving Manual. They were not changed appreciably until 1993.

A **table** is a set of schedules; a **schedule** is for one depth-time combination. It is customary in the U.S. also to refer to a single schedule as just defined as a "table," and we occasionally do that in this book.

The Navy's *No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives* has been adopted by most recreational diving agencies (sometimes with modification). This table is used for air dives that do not require decompression stops, and it provides for repetitive diving. The no-stop table covers the depth range 10 to 190 fsw (3-60 msw), with bottom times as short as 5 minutes at 190 fsw to as long as 310 minutes at 35 fsw (11 msw).

The main table, the *US Navy Standard Air Decompression Table*, covers air dives that require decompression stops over the range 40 to 300 fsw (12-92 msw). Dives to depths 200 fsw (60 msw) and deeper and some longer exposure times in the shallower range are considered "exceptional exposures," are printed in red in the manual, and may be used by Navy divers only with high level military approval.

In the 1993 revision of the U.S. Navy Diving Manual, some modifications were made in the USN tables. The main one is a change of the 60 fsw/min ascent rate in the original tables to a slower 30 fsw/min rate.

Two other USN air decompression tables are for "surface decompression." These are used with a deck decompression chamber, where some of the decompression is performed in the water and the rest in a chamber using either air or oxygen. This procedure is useful in that it gets the diver out of the water as soon as possible during decompression from long dives, and can allow oxygen breathing for improved decompression. Since decompression for some dives can take up to four hours, the advantages of a warm, dry chamber are significant. These tables are used for military and commercial diving operations and have no application in recreational diving.

The fact that USN tables exist for depths deeper than 130 fsw (40 msw) should not be interpreted as meaning that it is safe to make recreational dives to such depths. Navy and commercial divers have an entirely different support structure that includes an air hose to the surface, communications, a tender, a stand-by diver, and a decompression chamber.

Other air tables

The Defense and Civil Institute of Environmental Medicine in Canada, as its name implies, serves both the civilian and the military sectors. Primarily for the Canadian Forces, DCIEM in 1983 released a set of decompression tables for air diving. These tables were designed to be slightly more conservative for air diving than tables available at the time. They have a good track record and have been widely used by recreational divers as well as commercial diving companies. The Finnish Navy has air tables that work well but are not widely distributed, and there are Dutch and French commercial air tables in the public domain. The British Royal Navy has its own set of tables covering many different diving styles. Many other navies and commercial ventures use tables derived from those of USN.

An excellent set of air tables was also prepared by

Prof. A.A. Bühlmann. These are conservative in the no-stop range, but are efficient yet reliable in ranges requiring stops. The published tables also provide for diving at altitude. Unfortunately the older English version of Prof. Bühlmann's book (1984) is out of print, and the latest versions (1993; 1995) are only available in German at this time. Bühlmann's tables deserve special mention because the algorithm has been published and serves as the basis for many dive computers and PC decompression programs.

In 1983 Dr. Ray Rogers set out to create a set of recreational no-stop diving tables that took into consideration the general diving public as opposed to military divers, using the 60 minute half time for controlling repetitive diving (USN uses 120 min). In 1987 the Diving Science and Technology Corporation (DSAT) commissioned the development and testing of his new computational method. The development involved comprehensive laboratory studies conducted by Dr. Michael Powell using Doppler bubble detection, hyperbaric chamber exposures, and over 900 dives in Puget Sound. The result was new diving tables that provided slightly shorter no-stop dive times than the U.S. Navy tables but with shorter surface intervals.

The NAUI air diving tables

The NAUI air diving tables are based on the U.S. Navy Standard Air Decompression Table, with modifications for recreational diving use. These changes make the NAUI tables more conservative in nature than the standard US Navy tables (Fig 7-1).

The NAUI modifications to the tables are a reduction in allowable no-stop dive times, the addition of a 3 to 5 minute safety stop, and changing the surface interval to 24 hours instead of 12 hours for repetitive diving. Another change is the depth at which the decompression and safety stops are made; this has been set at 15 fsw (5 msw), instead of 10 fsw. All of these modifications have worked well.

A comparison of US Navy and NAUI no-stop dive times shows that NAUI decreased the no-stop time significantly at 30 and 40 fsw, and made modifications for depths of 50 fsw and deeper (Fig 7-2).

The NAUI table allows a diver to start fresh at a certain dive depth with a choice of several no-stop dive times, follow with a repetitive dive adjustment based on the actual depth and time of the first exposure, then re-enter the table for a subsequent "repetitive" dive.

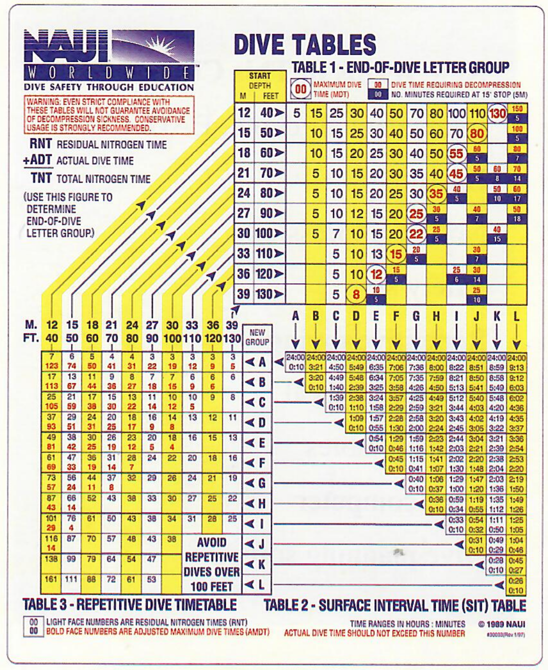


Figure 7-1. NAUI air diving table.

Divers are not encouraged to plan dives with decompression stops, but stop times for several bottom times are included on the NAUI table for contingency purposes.

No-Stop Time Comparisons for a Single Air Dive

Depth fsw	US Navy min	NAUI min
30	310	130
40	200	130
50	100	80
60	60	55
70	50	45
80	40	35
90	30	25
100	25	22
110	20	15
120	15	12
130	10	8

Figure 7-2. No-stop time comparison between US Navy and NAUI air diving tables, minutes.

Tables for enriched air diving

NOAA enriched air nitrox tables

In 1979 the diving program of the National Oceanic and Atmospheric Administration, NOAA, introduced diving procedures and decompression tables for a standard oxygen-enriched mixture of 32% oxygen, 68% nitrogen. At that time NOAA felt the 32% mixture was the best all-around gas for diving in the 50 to 130 fsw (15-39 msw) depth range. The decompression tables were calculated using what has become known as the **"equivalent air depth"** concept, which is simply to decompress from an enriched air dive using the air table that has the same nitrogen partial pressure (PN_2). For the air tables, NOAA chose the U.S. Navy standard air tables. Later they expanded the program to include a 36% oxygen mixture, which was even more beneficial for the 50 to 90 fsw (15-35 msw) range, and almost doubles no-stop time compared to air diving. The display of the tables is in the same format as the USN tables. The NOAA diving tables for 32 and 36% oxygen, which NOAA named NOAA Nitrox I and NOAA Nitrox II, are the most widely used enriched air tables.

NAUI EAN Tables

NAUI has chosen to use the NOAA nitrox tables as the basis for the NAUI tables. The NAUI EAN tables use the same 32 and 36% oxygen mixes, and provide the same no-stop times as those developed by NOAA (Fig 7-3, Fig 7-4). Because of the efficiency of these tables and the reliability of this type of decompression, the NOAA no-stop times are taken at face value, without conservative modifications like those felt by NAUI to be necessary for air diving. Two minor but familiar changes have been made. The first is in decompression stop depths; in the event a decompression stop is needed the "10 fsw stop" is taken at 15 fsw, as are any safety stops. The second modification is in the repetitive procedures. The surface interval necessary for a dive not to be repetitive is increased from 12 to 24 hr. This causes the repetitive group letter "A" to remain in effect for up to 24 hours following a dive, instead of the 12 hours used by NOAA.

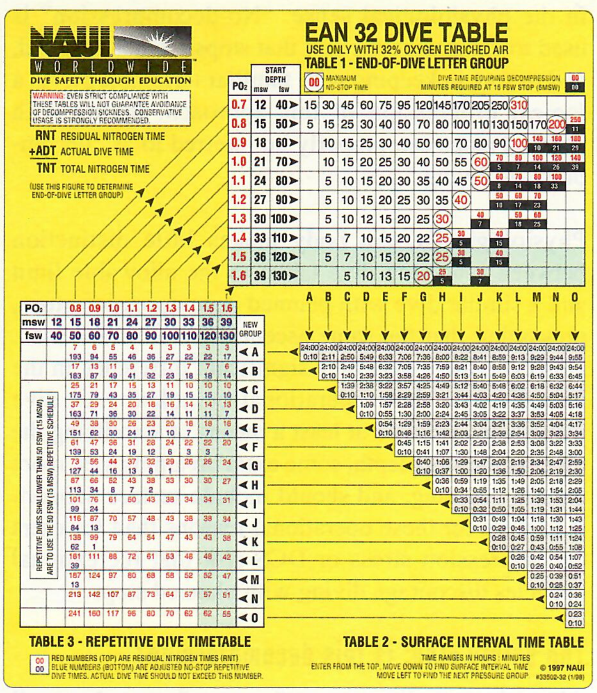


Figure 7-3. NAUI table for EAN_{32}, 32% oxygen enriched air.

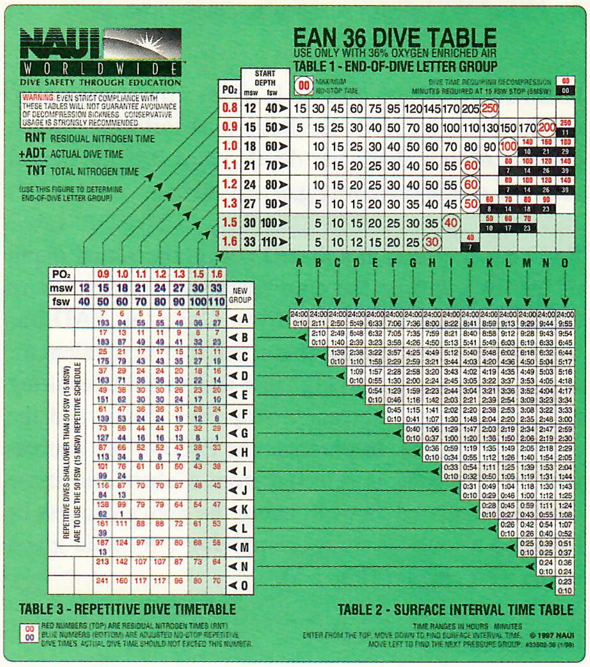


Figure 7-4. NAUI table for EAN_{36}, 36% oxygen enriched air.

Additional methods for EAN diving

Equivalent Air Depth principle

The **equivalent air depth** (EAD) is the depth defined by the partial pressure of nitrogen that will be breathed, rather than the actual depth of the dive. For a nitrox mixture with less nitrogen than air, the equivalent depth is **shallower** than if air were being

Equivalent Air Depth Comparison

Actual fsw	Air	EAD 32%	36%
60	60	47	42
80	80	64	59
90	90	73	67
110	110	90	83
130	130	107	

Figure 7-5. Equivalent Air Depth Comparison. Shows equivalent shallower depth for determining no-stop times for 32 and 36% oxygen mixtures compared with air.

breathed. Although a diver is physically at a specific depth, physiologically the body is absorbing nitrogen equivalent to a shallower depth, since it is the partial pressure of the breathing gas that matters.

EAD decompression is based not on the actual depth of the dive, but on the equivalent inert gas exposure depth experienced by the diver. Once the EAD has been determined, the diver can use the "equivalent air depth" with any air diving table and find the resulting no-stop and decompression stop dive times, and the repetitive criteria. In practice, the EAD or the equivalent no-stop time is selected from a chart, but these can be calculated as well, using the above process or by using a look-up chart or applying a formula given in the next chapter (Fig 7-5).

Custom tables

NOAA and NAUI as well as other recreational scuba training agencies have produced diving tables for 32% and 36% oxygen enriched air mixtures. Tables for other mixes are not generally available. Some of these are calculated with the EAD method from existing air tables, others are calculated directly. The tables computed directly are likely to appear more efficient (more available no-stop bottom time) but they do this at the expense of conservatism. There may be situations where a table for a specific mix and depth are needed for a special diving project. In these cases, the diver has a few choices. The first and most effective option is to use a dive computer equipped for enriched air calculations. Another option is to select a table using EAD techniques. Here the diver determines the equivalent air depths for the specific depths and mixes, either selected from a chart or calculated using the formulas, then selects the desired air diving tables based on the equivalent depths. This is time-consuming and presents opportunities for error. Another approach is for the diver to seek out a professional "table maker," a person well-versed in decompression computation who is able to prepare custom tables. Or the diver can generate ("cut") tables specific to the actual dive project using one of the many personal computer programs designed to produce custom decompression tables.

No-stop dives

Definition of no-stop diving

Traditionally, "no-stop" or "no-decompression" diving is **staying within time-depth exposure limits that allow the diver to ascend at a specified rate to the surface without the need for a stop**. That is, the diver's exposure time, depth, breathing gas, and ascent rate are specified, and when the profile stays within these specifications the diver can ascend without stopping.

Accordingly, we use the terms "no-stop" and "no-decompression" interchangeably. "No-stop" is used to remind divers that every dive is a decompression dive in the physiological sense. "No-decompression" is used to emphasize the fact that stops are not required, and to stay in keeping with familiar terminology. As a logical progression of this approach, diving with planned stops can properly be referred to as "decompression diving."

Physiologically, the body makes little distinction between a no-stop dive taken to the allowable limit and a similar dive with planned decompression stops, presuming that the same ascent constraints are used. However, there may be a significant difference in the two dives in their operational complexity. A dive using stops requires at least a means of stabilizing the diver at the stop depth, some extra breathing gas, more careful planning, and should include surface support. It is more for these operational reasons than for extra decompression stress or DCS risk that recreational agencies discourage diving with planned stops.

The safety stop: Is this decompression?

Along the same lines, some "no-stop" procedures call for the diver to make a **safety stop** of 3 to 5 min in the range of 10 to 20 fsw, nominally 15 fsw. This has been shown experimentally to reduce the level of ultrasonically detected bubbles, and should therefore reduce the likelihood of decompression sickness.

The safety stop has been criticized as being "decompression diving." This is a moot argument. If the stop is required as part of the decompression, it is a decompression stop. If the profile is one calculated or developed to allow decompression without stops but the safety stop is inserted to give the dive profile a lower risk of DCS, then it is a no-stop dive with a safety stop. The distinction does not matter; the important thing is to carry out the dives as planned.

One benefit of the safety stop and a good reason for doing it is that it more or less obligates the diver to have good buoyancy control, and this is an all-around safety factor.

Repetitive dives

Repetitive diving is not widely practiced in either the commercial or military diving communities, but is quite common in recreational diving.

Physiology of a repetitive dive

In the physiological sense, a repetitive dive is one carried out soon enough after a previous dive that its decompression is influenced by the previous dive or dives; effects may accumulate over several dives.

Unless the first dive was relatively short and the interval between them (called the "surface interval") is relatively long, there is likely to be a "gas loading" remaining from the earlier dive. This means that some inert gas is still dissolved in the diver's tissues.

Another thing that may result from an earlier dive is bubble formation. Bubbles may form and may be eliminated during a decompression, but some may remain; these can grow if subjected to an additional compression and decompression. On the other hand, preexisting micronuclei (necessary to form bubbles) can be destroyed by the first dive, leaving fewer available for the second dive. This can be beneficial.

Research indicates a higher incidence of DCS from repetitive dives than from single non-repetitive dives. This depends, in part, on how a repetitive dive is defined.

Definitions of a repetitive dive

Although uncertainties remain about the physiology of repetitive diving, to some extent it has been defined explicitly. The U.S. Navy defines a repetitive dive as one that begins within 12 hours of a previous dive. This means that the tables assume that a diver is clear of inert gas (for practical purposes) after 12 hr. If the second dive starts within 10 minutes of the first it is considered an extension of the previous dive.

NAUI and most other authorities consider that there may be residual effects lasting beyond a 12-hr surface interval, and extend the influence of the first dive to 24 hr. Thus the NAUI definition of a repetitive dive is one that begins more than 10 min and less than 24 hr after the end of a previous dive.

How developers produce repetitive tables

The developers of the USN tables devised a somewhat arbitrary but quite effective method of managing repetitive dives. USN developers assumed that the effect of a previous dive on a following dive can be expressed in terms of gas loading, and calculated this for each schedule using the 120-min compartment as the reference. They then evenly divided the allowable inert gas overpressure in that compartment into 16 "groups," and assigned a letter to each group. The later letters are associated with larger overpressures in the "repetitive group" chart. This group designation then leads the diver to the "residual nitrogen timetable" chart, which shows how a diver's gas loading and hence group designation changes as the gas in the compartment decreases during the time at the surface. The effect of this loading depends in part on the depth of the next dive, so the final chart in the sequence, the "new group designation" chart, shows how much residual nitrogen time should be used, as a function of the depth of the next dive.

The surface interval does not begin until 10 min after the end of the first dive. This somewhat arbitrary value is intended to recognize that during the transition period the outgassing process of the surface interval may not be fully functional.

Using repetitive procedures

The procedure for using USN-type repetitive adjustments is straightforward and reasonably simple for users who have a good idea what they are trying to accomplish. Basically you want to determine from the first (or previous) dive its "residual" effect, then apply that to the next dive. For a first dive read the repetitive

Figure 7-6. Diving at altitude requires special diving tables.

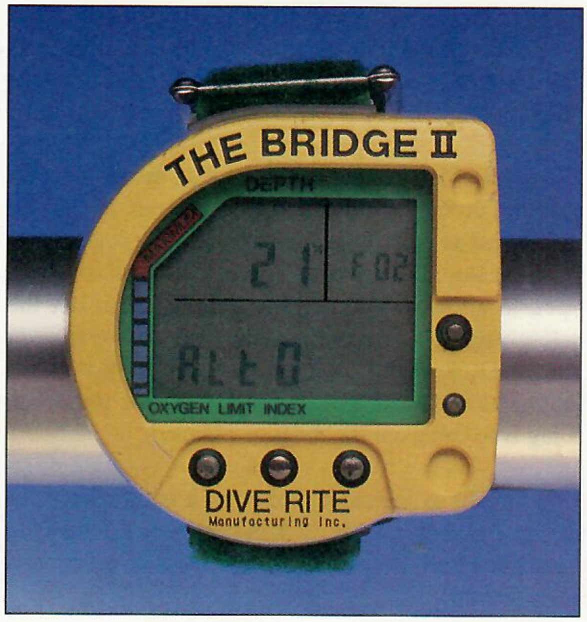


Figure 7-7. Dive-Rite Bridge II allows the manual setting of altitude.

group directly off the chart. This letter group depends on the actual bottom time of the dive, for both no-stop and decompression dives. Then the time spent at the surface between this dive and the next one is used to determine the "repetitive group." The selection here depends on the duration of the surface interval. Once this is determined, select the new group designation to be in effect after the surface interval. Follow that to the depth of the next dive and read the "penalty" for the second dive, in minutes to be added to the actual bottom time to use in selecting the right table for the second dive. This method works the same for both USN and NAUI tables, although the charts are configured differently.

Once the second dive is complete, re-enter the chart with a new repetitive group designation and repeat the process. For surface intervals of less than 10 minutes, add the entire time of the first (or previous) dive to the actual time for the second (or following) dive to get the corrected repetitive dive time, and use this for selecting the table to use.

Diving at altitude

When a dive is performed in a lake at an altitude well above sea level, several things are different, and some of these must be considered in planning the decompression (Fig 7-6). First, the barometric or ambient pressure at the surface of the lake is less than normal. The surface acts as the reference point for tables, and since that is different, some compensation is needed in standard tables. The relative change in pressure on descent in the water will be greater than at sea level; this requires that the tables be adjusted for altitude. Details on diving at altitude are beyond the scope of this text.

Altitude tables may be prepared by performing altitude "corrections" to standard tables. Methods used for calculating altitude tables have been reviewed by Egi and Brubakk (1995) and the principles by Wienke (1993). Probably the best known method is the "Cross Corrections," examined in detail and reported in table form by Bell and Borgwardt (1976).

The U.S. Navy air tables are authorized for use to altitudes of 2300 feet (700 meters). The NAUI tables are more conservative and are recommended for use to an altitude of 1000 feet.

There are a number of other factors to be considered. The water in a mountain lake will be fresh water, which has a lower density than sea water, and because of the lower reference pressure some pressure gauges will not read correctly in a mountain lake. Buoyancy is affected by altitude. At significant altitudes, say above 10,000 feet (3000 meters) another concern is relative hypoxia, which can lead to mountain sickness.

For diving at elevations above 1000 feet, it is necessary to use tables designed or adapted for altitude, and the diver should be trained for diving at altitude. The Equivalent Air Depth principle will work for altitude diving with enriched air, but should be done with air tables that are already adjusted for altitude, such as those just mentioned. Enriched air nitrox is well suited for diving at altitude for several reasons. One is the benefits to decompression; these become even more valuable at altitude to help offset the reduced dive time due to altitude adjustments. A given table should be more reliable, and there is less chance of hypoxia when the diver is near the surface. As mentioned above, altitude tables are included in those published by Prof. Bühlmann.

The best way to minimize altitude as a decompression problem is to use a dive computer equipped for both altitude corrections and enriched air (Fig 7-7). Dive computers made in Switzerland are calibrated for fresh water, and if they use Prof. Bühlmann's algorithms, they are likely to manage altitude quite well.

Dive computers and enriched air

A dive computer performs the same sort of calculations mentioned above for tables, but does them in real time. Instead of displaying a series of stops at 10 fsw increments as a table does, the computer shows the "ceiling"–the depth to which the diver can ascend without violating the computer's ascent limits. This has been called the "safe ascent depth," but for the same reason we do not speak of a decompression table as "safe," we prefer to use the term "ceiling."

There are two options for using dive computers with enriched air. The best is to use a computer designed for enriched air, and use it with the proper mixes. Early "nitrox" DCs were limited to one or two oxygen percentages, but more recently DCs have become available that allow the percentage of oxygen to be set in one percent increments (Fig 7-8). Some computers even allow for multiple nitrox mixes to be used during advanced types of dive. Enriched air computers monitor the diver's exposure to oxygen, based on the mixture entered, and warn when limits are approached or exceeded. For these computers, we refer the diver to the manufacturer's instructions and to the specific training for the particular DC. A dive computer is not a substitute for proper training.

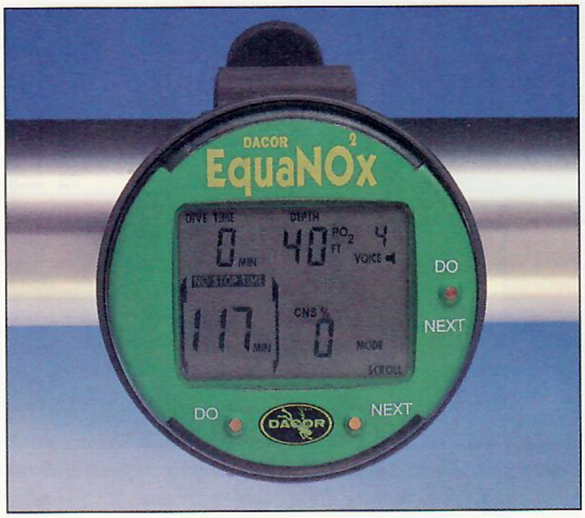


Figure 7-8. Dacor EquaNO²x enriched air dive computer. Monitors decompression status and oxygen exposure for gas mixes in 1% increments. The recorded data can also be downloaded to a PC for logging and analysis.

As a second option, a common application is an enriched air mixture used with a dive computer designed for air. Here the main gain is the same as mentioned above in reference to tables, a reduced risk of DCS. In using an air computer with oxygen enriched air it should be possible to use the computer to its full no-stop limits (but not beyond!) without the need for as much added conservatism as when using air. Even so, ascent rates should be according to recommendations; the benefit of the extra oxygen in enriched air is not enough to compensate for too fast an ascent rate. Be sure to check the oxygen limits of the mixture; since the computer "thinks" the diver is using air it will not warn when oxygen limits have been exceeded. It is most important to observe the maximum operating depth of the gas being used, as the air computer will not be able to issue a warning if the maximum depth is approached or exceeded.

Dive planning software

In recent years there has been a remarkable development in the field of decompression technology–the development and marketing of commercial computer programs for generating decompression tables. For decades it has been felt that only decompression specialists, and in the case of the Navy, diving medical officers, were qualified to produce decompression tables. That consideration has not really changed, especially in the eyes of commercial divers, diving companies, and their lawyers, as well as the Navy, but

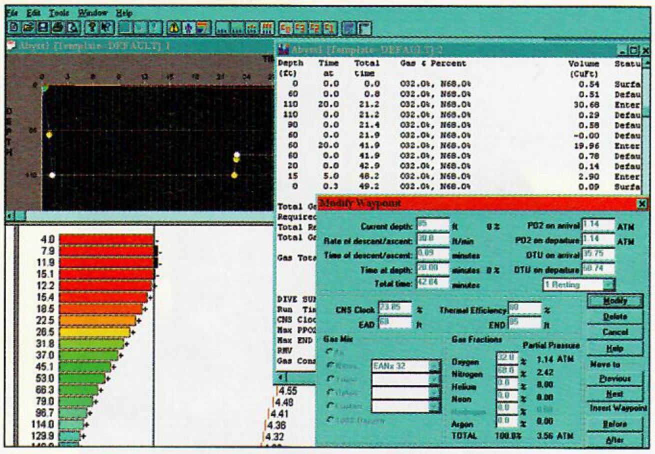


Figure 7-9. Abyss advanced dive planning software. Data input screen for creating diving tables for specific gas mixtures.

the development of technical diving has presented a need for tables that were just not "in the book."

Responding to this need, several entrepreneurs have prepared and distributed computer programs that can be used to generate tables. This has been possible because of publications by Prof. Bühlmann (1984; 1995) that give tested and accepted algorithms for computing tables. All the readily available programs are based at least fundamentally on Prof. Bühlmann's algorithms.

The different programs manage the algorithm in different ways, especially with regard to introducing extra conservatism into the computations. Even so, when used properly they all produce acceptable enriched air tables. As with dive computers, many of these programs allow oxygen exposure to be tracked and warn the user when limits are exceeded. It is up to the user to know the meaning of the oxygen calculations and the limits used.

The caveat remains, however, that producing proper decompression tables in a safe manner requires a substantial knowledge of decompression practice. The user should have a firm idea of what to expect, and should be able to recognize if things are not right. These programs can generate satisfactory tables in the right hands, but we do not advocate their casual use by novice divers or those with limited experience in decompression. ■

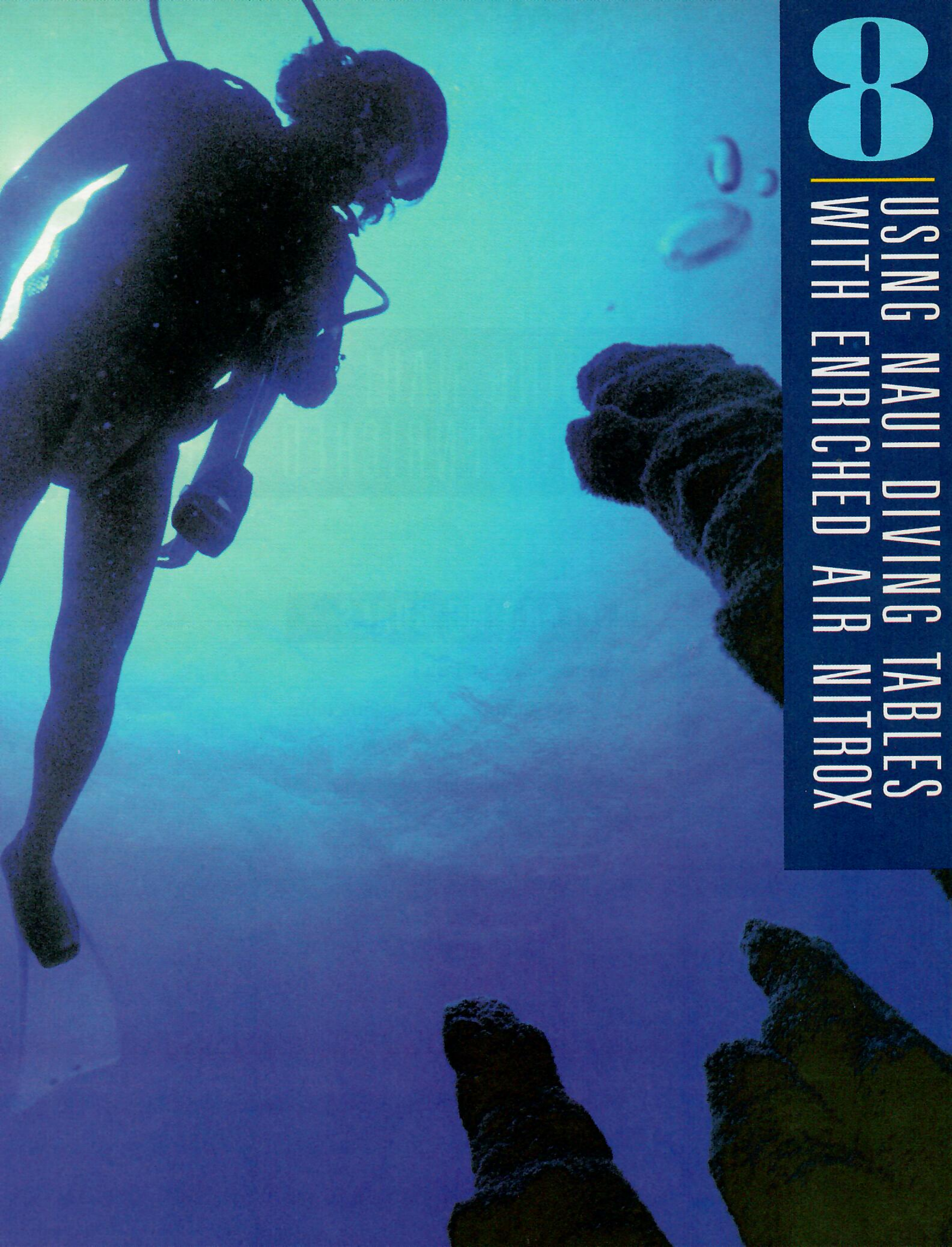
Chapter 7. Knowledge Review—Diving Tables

Before moving on to the next chapter, **Using NAUI Diving Tables with Enriched Air,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. A decompression table may be made up of a set of ________ .
2. In 1993 the ascent rate for the USN air tables was changed from ______________ fsw/min to __________________ fsw/min.
3. NOAA introduced diving tables for use with a 32% oxygen enriched air mixture in 1979 by using the ___________ concept to determine the decompression.
4. For an enriched air mix with less nitrogen than air, the EAD is a ______________ depth.
5. Staying within time-depth exposure limits that allow the diver to ___________ at a specific rate to the ______________ without stopping for decompression is called a ___________ dive.
6. It is a good idea to do a __________________ at the end of a no-stop dive.
7. Gas loading from a earlier dive is important when doing a ________________ dive.
8. NAUI recommends that you do not use their tables at an elevation more than ________ feet above sea level when diving at altitude.
9. The best way to do multilevel dives is with a __________________ .
10. NAUI provides tables as plastic cards for enriched air mixes containing _____% and _____% oxygen.

Answers for Chapter 7

1. Schedules
2. 60 fsw/min to 30 fsw/min
3. Equivalent air depth (EAD)
4. Shallower
5. Ascend; surface; no-stop (or no-decompression)
6. Safety stop
7. Repetitive
8. 1,000 feet
9. Dive computer
10. 32% and 36%



8 USING NAUI DIVING TABLES WITH ENRICHED AIR NITROX

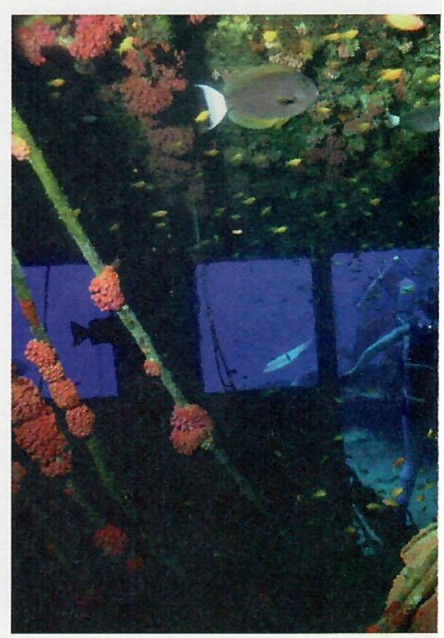
Chapter 8

USING NAUI DIVING TABLES WITH ENRICHED AIR NITROX

LEARNING GOALS

In this chapter you will:

- Select an appropriate diving table.
- Use the NAUI EAN diving tables.
- Use the Equivalent Air Depth Conversion table.
- Use the NAUI air tables with oxygen enriched air.
- Learn about dive computers and their role in enriched air diving.



New Terms in This Chapter

Fixed or flat table

OCEANx calculator

Multi-level diving

Dive computer

Selecting the appropriate diving table

This chapter discusses the procedures for using oxygen enriched air mixtures with NAUI EAN tables, and NAUI and other air tables.

Using fixed tables

Part of the dive planning process is selecting the appropriate diving table and schedule for the dive. The most expedient method is to use a prepared table, such as the NAUI EAN_{32} and EAN_{36} tables. Beyond this, by using the EAD principle any valid enriched air dive can be planned using the EAD formula and an air diving table. However, the length of the dive should be considered from an oxygen exposure perspective in choosing the appropriate diving table. Prepared tables may be called "fixed" or "flat."

NOAA Oxygen Exposure Limits

PO_2 atm	Maximum Single Dive Limit, min	Maximum 24-Hour Limit, min
1.60	45	150
1.55	83	165
1.50	120	180
1.45	135	1.80
1.40	150	180
1.35	165	195
1.30	180	210
1.25	195	225
1.20	210	240

Figure 8-1. NOAA oxygen exposure time limits. Table gives limits in min for a single PO_2 exposure level, and for each 24 hr day. Interpolation used for 0.05 atm increment limits. Levels of 1.5 to 1.6 atm PO_2 are for contingency purposes only. (NOAA diving manual, 3rd ed, 1991)

As discussed in Chapter 4 on oxygen, divers have certain single and repetitive time limits for oxygen exposure, depending on the partial pressure of the oxygen at the maximum depth of the dive. For dives with a maximum operating partial pressure of 1.4 atm, the time limit is 150 minutes (Fig 8-1). No-stop times fall well within this time limit. If a single planned dive is to be longer than 150 minutes the PO_2 level will have to be reduced by choosing an EAN mix with a lower oxygen content.

Other considerations include having enough gas to breathe, repetitive diving procedures, and verifying the actual mix in the tank. For most enriched air nitrox diving the mix you request from your dealer will be delivered to you with an accurate composition. Make sure that the mix falls within the tolerance limits of ±1 percentage unit from the nominal value. When using the EAD principle, always base the calculation on the **exact mix** in the tank.

NAUI enriched air nitrox 32% and 36% tables

The NAUI EAN_{32} and EAN_{36} diving tables make planning dives that use 32% and 36% oxygen relatively simple (Fig 8-2, 8-3, 8-4). The familiar format is one that NAUI divers have been using for years. The full tables are shown in the Reference section in the back of this book and are available on waterproof plastic cards.

These tables are designed for no-stop enriched air nitrox diving in the range 40 to 130 fsw (12-39 msw). Each depth schedule has contingency information for completing required decompression stops if they are needed. The EAN_{32} table has a useable depth range to 130 fsw (39 msw) and the EAN_{36} table has a range to 110 fsw (33 msw). The deeper depths are for contingency use for both of these tables, otherwise these tables fall within the normal range of oxygen exposure limits as described in Chapter 4 on oxygen.

To become familiar with the table and some of the new information, let's look at it section by section. The EAN diving table is divided into three sub-tables that interact with each other.

Figure 8-2 shows Table 1, the **No-stop Time and End-of-Dive Letter Group table**. It shows the no-stop dive times for the various depths with a circle around the maximum no-stop time for each depth. For dives of less than the maximum time, the times are shown in the body of the table and the End-of-Dive letter group is shown at the bottom for each of these times. Dive times that require decompression are shown as a double entry, with the upper figure the time at depth and the lower figure, in a dark box, the stop time. Stop time is to be taken at a depth of 15 fsw (5 msw).

Table 1 also has a PO_2 level indicator for each depth of the table. The dive schedules that are listed for PO2 levels higher than 1.4 atm are for contingency planning only and are not intended for routine dives.

EAN 32 DIVE TABLE

USE ONLY WITH 32% OXYGEN ENRICHED AIR

TABLE 1 - END-OF-DIVE LETTER GROUP

(00) MAXIMUM NO-STOP TIME

DIVE TIME REQUIRING DECOMPRESSION 00 / MINUTES REQUIRED AT 15 FSW STOP (5MSW) 00

PO_2	START DEPTH msw	START DEPTH fsw	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
0.7	12	40➤	15	30	45	60	75	95	120	145	170	205	250	310			
0.8	15	50➤	5	15	25	30	40	50	70	80	100	110	130	150	170	200	250 / 11
0.9	18	60➤		10	15	25	30	40	50	60	70	80	90	100	140 / 10	160 / 21	180 / 29
1.0	21	70➤		10	15	20	25	30	40	50	55	60	70 / 5	80 / 7	100 / 14	120 / 26	140 / 39
1.1	24	80➤		5	10	15	20	30	35	40	45	50	60 / 8	70 / 14	80 / 18	100 / 33	
1.2	27	90➤		5	10	15	20	25	30	35	40		50 / 10	60 / 17	70 / 23		
1.3	30	100➤		5	10	12	15	20	25	30		40 / 7		50 / 18	60 / 25		
1.4	33	110➤		5	7	10	15	20	22	25	30 / 5		40 / 15				
1.5	36	120➤		5	7	10	15	20	22	25	30 / 5		40 / 15				
1.6	39	130➤			5	10	13	15	20	25 / 5		30 / 7					
NEW GROUP			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

Figure 8-2. The Table 1 part of the NAUI EAN_{32} table, the No-stop Time and End-of-Dive Letter Group table.

For example, we do a 40 min dive at 70 fsw (21 msw) using a 32% mix.. This shows an end-of-dive letter group of G, which is at the bottom of the column containing 40 min on the row holding 70 fsw. The PO_2 is shown at the left end of the 70 fsw row as 1.0 atm for this dive.

Table 2, Figure 8-3, is the **Surface Interval Time Table**. This table is for determining a new letter group after a surface interval following a dive. Enter this table from the top, following down from the letter group at the bottom of Table 1 to the appropriate interval time. This time is a range, so select the range that will include the actual interval time from surfacing from the first dive until beginning ascent for the next. For example, for an interval of 2:20, enter the table in the G column, move down to the box containing 2:58/2:00, indicating any time between 2 hours and 2 hours 58 minutes. From here, move to the left to find then next group letter at the end of that interval, which in this example is now D.

Table 3, Figure 8-4, is the **Repetitive Dive Timetable**. The top of the table has a depth (in both fsw and msw)

1.6 / 39 / 130	NEW GROUP	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
3 / 17	◄A	24:00 / 0:10	24:00 / 2:11	24:00 / 2:50	24:00 / 5:49	24:00 / 6:33	24:00 / 7:06	24:00 / 7:36	24:00 / 8:00	24:00 / 8:22	24:00 / 8:41	24:00 / 8:59	24:00 / 9:13	24:00 / 9:29	24:00 / 9:44	24:00 / 9:55
6 / 14	◄B		2:10 / 0:10	2:49 / 1:40	5:48 / 2:39	6:32 / 3:23	7:05 / 3:58	7:35 / 4:26	7:59 / 4:50	8:21 / 5:13	8:40 / 5:41	8:58 / 5:49	9:12 / 6:03	9:28 / 6:19	9:43 / 6:33	9:54 / 6:45
10 / 10	◄C			1:39 / 0:10	2:38 / 1:10	3:22 / 1:58	3:57 / 2:29	4:25 / 2:59	4:49 / 3:21	5:12 / 3:44	5:40 / 4:03	5:48 / 4:20	6:02 / 4:36	6:18 / 4:50	6:32 / 5:04	6:44 / 5:17
13 / 7	◄D				1:09 / 0:10	1:57 / 0:55	2:28 / 1:30	2:58 / 2:00	3:20 / 2:24	3:43 / 2:45	4:02 / 3:05	4:19 / 3:22	4:35 / 3:37	4:49 / 3:53	5:03 / 4:05	5:16 / 4:18
16 / 4	◄E					0:54 / 0:10	1:29 / 0:46	1:59 / 1:16	2:23 / 1:42	2:44 / 2:03	3:04 / 2:21	3:21 / 2:39	3:36 / 2:54	3:52 / 3:09	4:04 / 3:23	4:17 / 3:34
20	◄F						0:45 / 0:10	1:15 / 0:41	1:41 / 1:07	2:02 / 1:30	2:20 / 1:48	2:38 / 2:04	2:53 / 2:20	3:08 / 2:35	3:22 / 2:48	3:33 / 3:00
24	◄G							0:40 / 0:10	1:06 / 0:37	1:29 / 1:00	1:47 / 1:20	2:03 / 1:36	2:19 / 1:50	2:34 / 2:06	2:47 / 2:19	2:59 / 2:30
27	◄H								0:36 / 0:10	0:59 / 0:34	1:19 / 0:55	1:35 / 1:12	1:49 / 1:26	2:05 / 1:40	2:18 / 1:54	2:29 / 2:05
31	◄I									0:33 / 0:10	0:54 / 0:32	1:11 / 0:50	1:25 / 1:05	1:39 / 1:19	1:53 / 1:31	2:04 / 1:44
34	◄J										0:31 / 0:10	0:49 / 0:29	1:04 / 0:46	1:18 / 1:00	1:30 / 1:12	1:43 / 1:25
38	◄K											0:28 / 0:10	0:45 / 0:27	0:59 / 0:43	1:11 / 0:55	1:24 / 1:08
42	◄L												0:26 / 0:10	0:42 / 0:26	0:54 / 0:40	1:07 / 0:52
47	◄M													0:25 / 0:10	0:39 / 0:25	0:51 / 0:37
51	◄N														0:24 / 0:10	0:36 / 0:24
55	◄O															0:23 / 0:10

ABLE

RNT)
PETITIVE
HIS NUMBER.

TABLE 2 - SURFACE INTERVAL TIME TABLE

TIME RANGES IN HOURS : MINUTES
ENTER FROM THE TOP, MOVE DOWN TO FIND SURFACE INTERVAL TIME.
MOVE LEFT TO FIND THE NEXT PRESSURE GROUP.

© 1997 NAUI
#33502-32 (1/98)

Figure 8-3. The Table 2 part of the NAUI EAN_{32} table, Surface Interval Time Table.

REPETITIVE DIVES SHALLOWER THAN 50 FSW (15 MSW) ARE TO USE THE 50 FSW (15 MSW) REPETITIVE SCHEDULE

PO_2		0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	
msw	12	15	18	21	24	27	30	33	36	39	NEW GROUP
fsw	40	50	60	70	80	90	100	110	120	130	
		7 / 193	6 / 94	5 / 55	4 / 46	4 / 36	3 / 27	3 / 22	3 / 22	3 / 17	◄A
		17 / 183	13 / 87	11 / 49	9 / 41	8 / 32	7 / 23	7 / 18	7 / 18	6 / 14	◄B
		25 / 175	21 / 79	17 / 43	15 / 35	13 / 27	11 / 19	10 / 15	10 / 15	10 / 10	◄C
		37 / 163	29 / 71	24 / 36	20 / 30	18 / 22	16 / 14	14 / 11	14 / 11	13 / 7	◄D
		49 / 151	38 / 62	30 / 30	26 / 24	23 / 17	20 / 10	18 / 7	18 / 7	16 / 4	◄E
		61 / 139	47 / 53	36 / 24	31 / 19	28 / 12	24 / 6	22 / 3	22 / 3	20	◄F
		73 / 127	56 / 44	44 / 16	37 / 13	32 / 8	29 / 1	26	26	24	◄G
		87 / 113	66 / 34	52 / 8	43 / 7	38 / 2	33	30	30	27	◄H
		101 / 99	76 / 24	61	50	43	38	34	34	31	◄I
		116 / 84	87 / 13	70	57	48	43	38	38	34	◄J
		138 / 62	99 / 1	79	64	54	47	43	43	38	◄K
		161 / 39	111	88	72	61	53	48	48	42	◄L
		187 / 13	124	97	80	68	58	52	52	47	◄M
		213	142	107	87	73	64	57	57	51	◄N
		241	160	117	96	80	70	62	62	55	◄O

TABLE 3 - REPETITIVE DIVE TIMETABLE

00 RED NUMBERS (TOP) ARE RESIDUAL NITROGEN TIMES (RNT)
00 BLUE NUMBERS (BOTTOM) ARE ADJUSTED NO-STOP REPETITIVE DIVE TIMES. ACTUAL DIVE TIME SHOULD NOT EXCEED THIS NUMBER.

ENTER

Figure 8-4. The Table 3 part of the NAUI EAN_{32} table, Repetitive Dive Time Table.

for each column. In the body of the table, in the column below those depths, the entries each have two numbers. The top (red) number is the *Residual Nitrogen Time* from the previous dive, the number below (blue) is the *Adjusted No-stop Dive Time* that can be done for the repetitive dive to the depth at the top of the column.

To use this table the diver enters on the right with the letter group designation from Table 2 (which is D from the above example) and moves to the left to the column that has the depth of the next dive at the top. Let us continue with a repetitive dive to 60 fsw (18 msw). Intersect row D with the 60 fsw column and the resulting no-stop dive time is 71 minutes and the residual nitrogen time is 29 min.

Let us look at some single dives done with the NAUI EAN diving tables.

Dive Example #1.

In this example (Fig 8-5) the diver uses a 36% mix for a dive to 90 fsw, using the 90 fsw schedule. The PO_2 level is 1.3 atm at 90 fsw so the oxygen exposure limit of 1.3 is applied for calculation of the CNS "clock" using the exposure limits chart in Chapter 4, Fig. 4-4. MOD limits are on the EAD chart, Fig. 8-7.

Single Dive, EAN_{36} Table
Dive Depth = 90 fsw
Mix = 36% oxygen enriched air, EAN_{36}
Maximum No-Stop Time at 90 fsw = 50 min
PO_2 = 1.3 atm
Maximum Operating Depth at 1.4 atm = 95 fsw
Contingency Depth at 1.6 atm = 110 fsw
Repetitive group letter = J
[From O_2 chart] Oxygen exposure "clock" for single dive = 28% or 0.28 limit fraction

Figure 8-5. Dive Example #1. Using 36% O_2 for a 90 fsw dive for 50 min.

Single Dive, EAN_{32} Table
Dive Depth = 110 fsw
Maximum No-Stop Time at 110 fsw = 25 min
PO_2 = 1.4 atm at 110 fsw
Maximum Operating Depth at 1.4 atm = 110 fsw
Contingency Depth at 1.6 atm = 130 fsw
Repetitive group letter = H
Oxygen exposure for single dive = 17% or 0.17

Figure 8-6. Dive Example #2. Using 32% O_2 for a 110 fsw dive for 25 min.

Dive Example # 2

In this example (Fig 8-6) the diver uses a 32% mix for a dive to 110 fsw using the 110 fsw schedule on the NAUI EAN_{32} table. The PO_2 level is 1.4 atm at 110 fsw, so the oxygen exposure limit of 1.4 is applied for calculation of the CNS "clock" using the oxygen limits chart.

Application of Equivalent Air Depth and NAUI air tables

We have discussed the NAUI EAN_{32} and EAN_{36} diving tables and have shown the ways they are mix specific. However, enriched air divers may not always have access to those mix-specific tables or the mix available may not be applicable to those tables. In these cases an effective alternative is to apply the equivalent air depth conversion to the NAUI air tables (or any air diving table). The first principle to remember is that any time the fraction of the oxygen is greater than 0.21 you can use an air diving schedule for a depth shallower than the one you are actually diving.

When using an oxygen enriched mixture, the body is considered to be taking up nitrogen in a way equivalent to diving with air at a shallower depth. A formula is used later in this chapter to convert the actual dive depth into one that can be applied to an air diving table. But first, let us make this conversion with a look-up chart.

EQUIVALENT AIR DEPTH CONVERSION and MOD

PERCENTAGE OF OXYGEN AND ACTUAL DEPTHS (FSW)

EAD fsw	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	EAD fsw
30	36	37	38	39	40	41	42	43	44	46	47	49	49	30
40	47	48	49	50	51	53	54	55	57	58	60	61	63	40
50	58	59	60	62	63	64	66	67	69	71	72	74	76	50
60	69	70	71	73	75	76	78	80	81	83	85	87	89	60
70	80	81	83	84	86	88	90	92	94	96	98	100		70
80	90	92	94	96	98	100	102	104	106	108				80
90	101	103	105	107	109	112	114	116						90
100	112	114	117	119	121	123								100
110	123	126	128	130										110
120	134	137	139											120
130	145	148												130
MOD fsw @ 1.4 atm	132	126	121	116	111	107	102	99	95	91	88	85	82	MOD fsw @ 1.4 atm
MOD fsw @ 1.6 atm	155	149	143	137	132	127	122	117	113	109	105	102	99	MOD fsw @ 1.6 atm

Figure 8-7. Equivalent Air Depth Conversion and MOD chart. Enter the chart at oxygen percentage, move down the column to the depth or next greater depth of the dive. Move across to the left or right to find the Equivalent Air Depth for use with the NAUI air diving table (or another air table). Maximum Operating Depth (MOD) of each oxygen percentage is indicated at the bottom, the standard limit at 1.4 atm PO_2 and the contingency limit at 1.6 atm.

Using the Equivalent Air Depth Conversion Chart

The Equivalent Air Depth Conversion table (Fig 8-7) converts actual dive depth ranges to EADs, Equivalent Air Depths. The steps for using this table follow.

1. Enter the table at the top under the oxygen percentage, move down that column to the depth or next greater depth for the dive.
2. Move to the right or to the left end of that row to find the EAD, equivalent air depth.
3. Use this EAD to find the no-stop time for that depth using the NAUI air diving table (or another air table).

Note that the depths in the body of the table are not even or numbered by tens. This is to take advantage of the entire "group" range that converts to each even table depth. The Maximum Operating Depth (MOD; 1.4 atm PO_2) and the Contingency Operating Depth (shown as MOD for 1.6 atm PO_2) for the various mixes are given at the bottm of the chart.

Example 1: Planned dive to 90 fsw. Mix to be used is 34% oxygen enriched air. Enter the table at top of the 34% column, track down to 90 fsw. Read to either right or left side; the resulting EAD is 70 fsw. This dive is now planned using a 70 fsw air schedule, which has a no-stop time of 45 minutes. Oxygen exposure and gas usage have yet to be determined.

Example 2: Planned dive to 105 fsw. Mix to be used is EAN32. The next deeper depth in the 32% column is 109 fsw, which give a resulting EAD of 90 fsw. This dive is now planned using a 90 fsw air table, with a no-stop dive time of 25 minutes.

OCEANx calculator

In addition to the Equivalent Air Depth Conversion chart shown here there is another tool that also makes the EAD calculations easy. It is the NAUI *Oxygen Calculator Enriched Air Nitrox*, the OCEANx calculator. This is a wheel-type tool that allows the oxygen percentage of the mix to be dialed in, and the equivalent air depth for several actual dive depth ranges and some other oxygen exposure information is shown. This includes oxygen partial pressure (PO_2) at the dive depth, the NOAA time limit, the rate of approach to the CNS limit, and the rate of buildup of oxygen tolerance units.

Calculating the Equivalent Air Depth

There may be times when a diver would like to calculate the EAD manually. This is done by finding the depth at which air has the same nitrogen partial pressure, PN_2, as the enriched air being used at the depth of the dive. This is done by multiplying the absolute pressure (in "absolute" depth units) by the ratio of the FN_2 to that of air, then converting back to depth units.

EAD formula:

$$EAD, fsw = \left(\frac{(D\ fsw + 33\ fsw)\ (1 - FO_2)}{0.79}\right) - 33\ fsw$$

This equation shows the EAD formula, where

- **EAD** is the equivalent air depth.
- **D** is the actual depth of the dive with enriched air, in fsw.
- **FO_2** is the fraction of oxygen in the enriched air mix.
- **($1-FO_2$)** yields the fraction of nitrogen in the mix, FN_2.
- **0.79** is the fraction of nitrogen in air.
- **33** is the number of fsw in one atmosphere.

The formula for the equivalent air depth converts the depth D fsw to an absolute pressure by adding 33 fsw (the number of fsw in one atm), then multiplies this by the fraction of nitrogen in the enriched air mix, the term ($1-FO_2$); this term derives the FN_2 by subtracting the oxygen fraction from one. The product of the two terms in the numerator is the nitrogen partial pressure in "fsw absolute." To relate this to air it is divided by the fraction of nitrogen in air, 0.79, with the result still in "fsw absolute." Then this is converted back to fsw by subtracting 33 fsw. (The unit "fsw absolute" is an oxymoron, since fsw by definition is a gauge pressure, but this unit disappears at the end.)

EAD example:

$$57.91 = 58 = \left(\frac{(81 + 33)\ (1 - 0.37)}{0.79}\right) - 33$$

This is a dive to 81 fsw using 37% oxygen EAN. The EAD computes to 57.91 fsw, which rounds to 58. The appropriate dive schedule would be a 60-fsw air schedule.

Repetitive diving

As noted, in the military and commercial sectors it is rare that divers conduct repetitive dives, but among recreational divers its more the rule than the exception. Repetitive diving is a major part of recreational diving, whether on a local charter or a live-aboard vessel in an exotic place. To review, a repetitive dive by NAUI procedures is any dive that follows a previous dive during a 24-hour period.

Repetitive dive with the same gas

Repetitive diving with the NAUI enriched air diving tables basically is really no different from the procedures used for air diving. Using the repetitive time table is covered earlier in this chapter. A normal "same gas" repetitive dive can be carried out with the NAUI EAN table or with the EAD method. If the first dive is done with an EAN table, then the repetitive dive can be done with the same table. Likewise, if the first dive was done with the EAD conversion and an air table, then subsequent dives should use the same method.

Also, dives should be conducted in a progressively shallower manner. The initial dive should be the deepest, with subsequent dives being the same depth or shallower. For example, consider a first dive to 105 fsw (30 msw) and a second dive to 70 fsw (21 msw). and if a third dive is done it should be shallower than the previous dives (or equal to the last one). The rationale for this is based on empirical data that doing a deep dive after a shallow one increases the risk of decompression sickness. Further, there just may not be enough no-stop time to do another dive to the same or deeper depth. Divers should pay close attention to the repetitive dive table to avoid entering the situation where decompression is required.

Repetitive dive with a different gas

There may be times when a diver will use a different gas for a repetitive dive, by choice or circumstance. By choice, the diver will have already planned to use a higher oxygen mix for the shallower repetitive dive,

Figure 8-8. Dive computers, both air and enriched air types. [From front] Dive Rite Bridge II, Uwatec Aladin Nitrox, Uwatec Aladin, Cochran Nemesis IIa, Cochran Commander, and Dacor EquaNOx.

which will ultimately provide longer no-stop time. By circumstance, the diver's analyzed mix may be different from the standard 32 and 36% mixes for which there are tables. In either case, the diver will resort to calculating the repetitive dive using the equivalent air depth conversion and air tables. **The procedure for doing this is to calculate the ending pressure group from the previous dive based on its EAD, and plan the repetitive dive using the EAD for the new gas.**

Example: Dive # 1 using 32% oxygen mix was to 110 fsw. The EAD is 90 fsw with a no-stop dive time of 25 minutes from the **NAUI air tables.** The pressure group at the end of the first dive is G; after a 1:30 minute surface interval the new Group is E.

Dive # 2 will use 36% oxygen with a planned depth of 60 fsw. The EAD is 50 fsw. Enter Table 3 at Group E (from the first dive, after the interval). Follow to the column under 50 fsw; the adjusted no-stop dive time is 42 minutes (blue, lower number).

A repetitive dive with a lower oxygen content than the previous dive, although it will calculate correctly, will provide shorter no-stop dive time. For that matter it is best to plan repetitive dives with progressively higher oxygen content mixtures.

Multilevel diving

A multilevel dive is one in which the diver moves to a progressively shallower depth during a dive. Due to the lower nitrogen absorption at the shallower depth, the no-stop dive time continues to increase as the levels of the dive get shallower. The NAUI air and EAN diving tables were not designed for efficient multilevel diving calculations. Multilevel diving is best planned and carried out using an electronic dive computer that calculates no-stop dive time throughout the dive.

Dive computers

Dive computers (Fig 8-8) have become extremely popular over the past ten years. In fact, one is hard pressed to find an experienced diver today who does not use one. The dive computer tracks time and depth every second or so (depending on the model), calculates the gas loadings, and presents the diver with the decompression status more or less instantaneously. The remaining no-stop dive time is displayed throughout the dive. If the diver enters into a required decompression mode, the computer will display a "ceiling," which is a depth above which that diver must not ascend until the required decompression has been completed; in effect, this is the first stop depth.

Using a diving table is a slightly more conservative approach, since decompression is based on the deepest part of the dive and does not take into consideration that a diver will work progressively shallower on most dives. The diving table, for all intents and purposes, "averages" the overall decompression into groups. The DC, on the other hand, allows divers to have no-stop diving time calculated based on where they have actually been. When using a dive computer for "square" dive profiles, there is usually not much of a no-stop dive time advantage over conventional tables.

Using an air computer with enriched air

Using a dive computer designed for air while breathing oxygen enriched air allows the diver to conduct multilevel dives in the same manner as done while diving on air, but with the enhancement of less nitrogen being absorbed in the body.

To use an air computer while breathing enriched air the diver needs to add two things to the dive protocol, the monitoring of the maximum operation depth of the oxygen-enriched gas and the maximum exposure time of the deepest part of the dive, both to maintain oxygen limits. Since the air computer does not "know" that the user is breathing anything other than air, it cannot warn when maximum operating depths or oxygen exposure times are being reached. We recommend that the diver using an air computer with enriched air place a piece of tape on the computer or console indicating the maximum operating depth and contingency depths for the gas being used, and keep it in mind throughout the dive (see Fig 8-9).

Enriched air computers

During the past few years, several manufacturers have made dive computers specifically designed to use oxygen enriched air mixtures. The first enriched air computer was introduced by Orca as the Phoenix Nitrox. This was a single gas, 32% oxygen unit with the EAD conversions applied to its algorithm. Its main limitation was that it could not also be used with air. The Dive Rite Bridge was the first programmable unit. The Bridge allows a diver to change the oxygen percentage within the range 21% to 50%. The Bridge also tracks oxygen toxicity limits (Fig 8-10).

Today, almost every manufacturer has programmable enriched air computers. These units allow the diver to program the computer in 1 to 2 percent oxygen increments, usually up to 50% oxygen. These computers also track oxygen tolerance limits and display warnings when a diver approaches a limit. Programmable enriched air computers simplify diving with different mixtures.

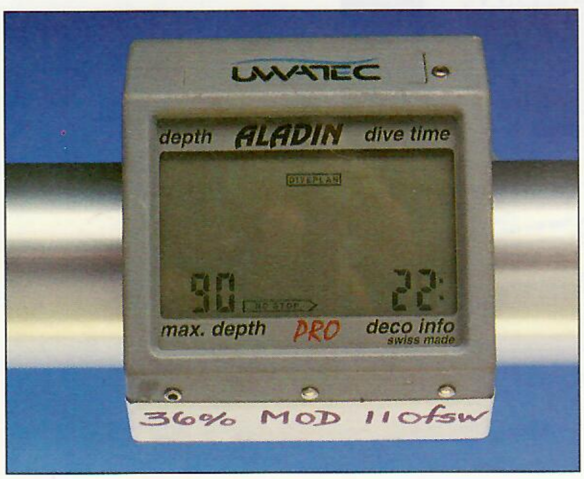


Figure 8-9. Air computer with MOD markings.

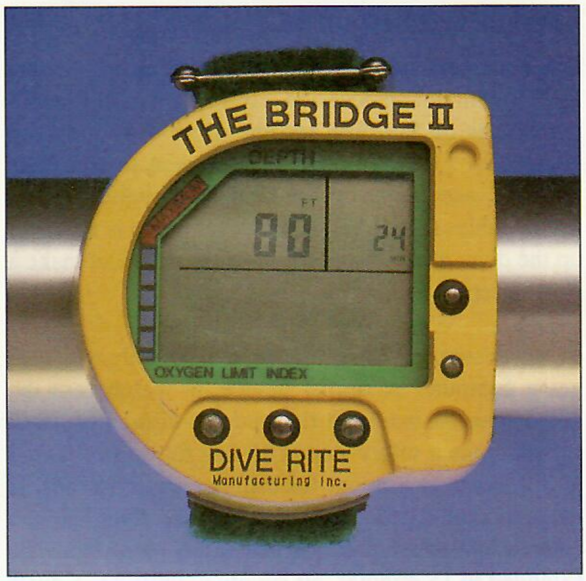


Figure 8-10. Photo of DiveRite Bridge II computer. This was the first enriched air computer that allowed the oxygen percentage to be set.

The diver using a programmable enriched air computer must pay more attention to gas analysis and planning of the dive. The computer must be programmed each time it is used, since gas mixes may be different from dive to dive. It is critical that one does not use a low oxygen content mixture with a computer programmed for a higher fraction of oxygen; the results would be an inaccurate decompression and an increased risk of decompression sickness. Because these units have many variables that require attention, the diver is strongly urged to read the computer's instruction manual and understand how to use the computer before diving with it. A professional dive retailer can assist in determining which computer is most appropriate for a diver's needs.

Repetitive diving with computers

A great advantage of dive computers is that they calculate repetitive dives. Within ten minutes of surfacing from any dive, the computer goes into desaturation or surface mode. During the surface interval, the computer periodically recalculates allowable no-stop dive time for the next dive. A screen will scroll this information. When an appropriate surface interval has passed, diving can resume. On programmable units the diver can reset the oxygen fraction for the gas to be used on the subsequent dive, and the computer will use this when calculating the next dive. Pay attention to surface interval time. Even though the computer calculates no-stop dive time with surface intervals shorter than 60 minutes, it is best to wait a minimum of one hour between dives.

Return to dive from computer failure

When a diver's equipment is well maintained it is rare for it to fail, but on occasion it does happen. If the failure occurs on the dive and the diver has a back-up computer or bottom timer, it is prudent to terminate the dive, ascending on the back-up computer or on diving tables (Fig 8-11). If, however, there is no back-up the diver should just terminate the dive and make a slow ascent.

In most cases, the diver will be with a buddy who also has a computer or timing device, in which case the ascent can be made on the buddy's computer. Both should make a safety stop at 15 fsw for no less than 3 to 5 minutes to account for differences in profiles. If the computer failed at a point where the diver had just entered into decompression, the safety stop should be extended to 15 minutes, air supply permitting. A diver who has become separated from his buddy should make an ascent to 15 fsw (by estimation if necessary) and make a contingency decompression stop for 15 minutes, air supply permitting. The chapter on tank selection covers procedures for determining time elapsed by gas consumed.

Once the diver has surfaced from a no-stop dive, it is recommended that no further diving be conducted for the number of hours required by the computer's manufacturer-or wait 24 hours. Then the diver may return to diving using dive tables. This method allows the diver to go back to diving in the event a computer has failed.

The diver who will have access to another computer and does not wish to resort to table-based diving should follow the above procedure, and start over with the new computer. Divers should never share activated computers for repetitive dives, since they are not likely to have the same gas loadings. ■

Figure 8-11. Mares Divemate air computer with NAUI air diving tables.

Chapter 8. Knowledge Review—Using NAUI Diving Tables With Enriched Air Nitrox

Before moving on to the next chapter, **Overview of Gas Mixing,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. The most efficient decompression table to use with enriched air nitrox is a _______________ nitrox table.

2. _______________ exposure is a major safety consideration when picking a nitrox table.

3. Using the equivalent air depth conversion table, what is the EAD for a 75 fsw dive on 32% oxygen enriched mix? _______ fsw

4. Using the EAD formula, calculate the answer to question #3. _______________.

5. Using 32% oxygen mix and the NAUI EAN 32 diving table a diver does a dive to 112 fsw for 23 min, surfaces, and has a surface interval of 2 hr 33 min. What is the new group after the interval? _______ Then the diver does a second dive on the same gas to a depth of 65 fsw for 35 min. What is the diver's end of dive letter group after the second dive? ________

6. Using 32% oxygen mix, a diver does a dive to 112 fsw for 23 min., surfaces, and has a surface interval of 2 hr 33 min. What is the new group after the interval? _______ Then a second dive on 38% oxygen mix to 65 fsw for 35 min. What is the diver's end of dive letter group after the second dive? ________

7. When using an air computer with oxygen enriched gas, what are two additional protocols the diver must use? ______________________________ ______________________________

8. If your dive computer fails while in decompression dive mode in the range of NAUI EAN tables and you have no backup, you should ___________________.

9. Computers designed for enriched air allow the diver to __________________ and monitor _____________ levels.

10. When planning repetitive dives with different gas mixes it is best to use __________________ or __________________.

Answers for Chapter 8

1. Specific or custom
2. Oxygen
3. 60 fsw
4. 60 fsw
5. D; J
6. D; I
7. MOD of the mix, and maximum time at the depth of maximum PO_2
8. Ascend and make a 15 min stop at 15 fsw
9. Set oxygen percentage; PO_2
10. EAD with air tables; an enriched air dive computer

9 OVERVIEW OF GAS MIXING

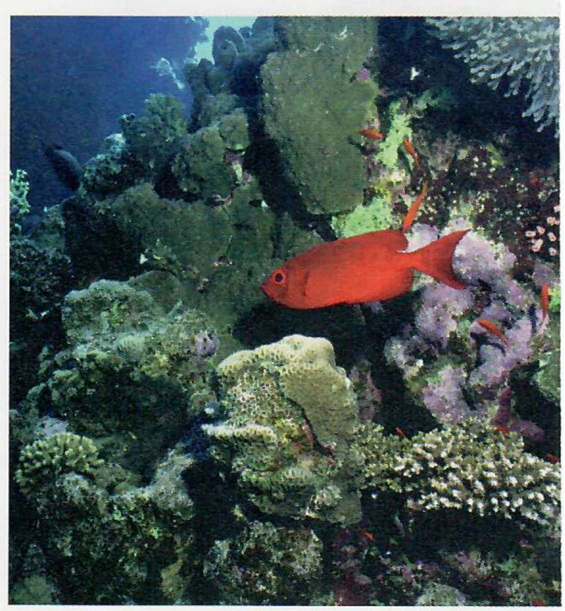
Chapter 9

OVERVIEW OF GAS MIXING

LEARNING GOALS

From this chapter you will learn:

- About fire safety with oxygen.
- About oxygen handling.
- How to apply the "40% rule."
- About the different gas blending systems.



New Terms in This Chapter

- Fire triangle
- Oxygen-compatible lubricant
- Adiabatic heating or dieseling
- Oxygen cleaning
- 40% rule
- Partial pressure blending
- Continuous flow mixing
- Pressure swing absorption
- Membrane separation

As a diver using enriched air nitrox, you need to obtain gas mixes other than air. You do not need to know how to mix nitrox, but you should know about how it is prepared and the requirement for cleaning your equipment that using an oxygen enriched mix creates. Several of the commonly used methods for creating oxygen enriched air are discussed in this chapter, each with its own advantages and disadvantages. The gas you ultimately breathe has to have the proper oxygen content.

Oxygen handling

Oxygen is the wonder gas that can be friend or foe. In the process of gas mixing for scuba use, the object is to get the right percentage of oxygen in the high pressure mix. This can be done by mixing pure oxygen with nitrogen or air, or by removing nitrogen from air. The main problem with mixing high pressure oxygen is the risk of fire. Everything that is not already completely oxidized–which means virtually everything–will burn in high pressure oxygen when there is a source of ignition. There is a certain risk with oxygen-enriched mixtures once they are mixed, but by far the biggest hazard is high pressure oxygen. The enriched air nitrox diver has no need to handle pure oxygen, but some understanding of its hazards is essential; oxygen does come into the operation as diving range and complexity increase.

Figure 9-1. Oxygen cylinders in oxygen room at US Navy Submarine Escape Training School, Groton, CT.

The fire triangle

To prevent a fire its important to know what ingredients are needed to start a fire and keep it burning. These are summarized in a mnemonic called "the fire triangle" (Fig 9-2). Fire is a rapid chemical reaction between a **fuel** and **oxygen** (an oxidizer), and it can only take place if there is a source of **ignition** (heat) to start it. Oxidation can occur without fire, as in rusting, but fire requires heat to initiate burning. After ignition the chemical reaction releases energy as heat, and this heat sustains the reaction. If we remove any one of the ingredients (fuel, oxygen, or ignition) there cannot be a fire. If all three are not present at the same time, fire is prevented. If a fire does exist, removing any one of the ingredients can make the fire go out. This is the basic theory of firefighting. Another essential element is that a fire has to propagate, to spread, if it is to carry on. There is a trend toward adding propagation as another limb of the fire "triangle."

Oxygen

In the systems under discussion, oxygen is present by intent at levels greater than in air; the oxidizing agent in the fire triangle is there by default and cannot be

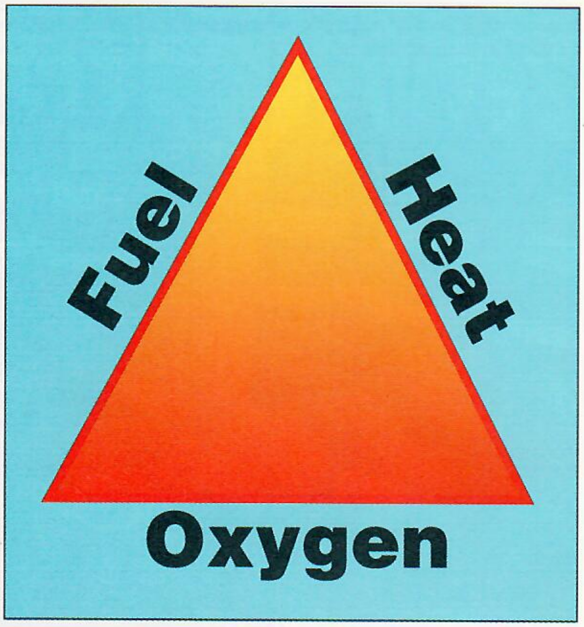


Figure 9-2. Fire triangle.

removed from the equation. The oxygen in air, as everyone knows, can participate in combustion vigorously under the right circumstances, so increased levels of oxygen can only increase the hazard. Further, recalling the main theme of this enriched air text, as oxygen is increased in a mix the inert nitrogen background gas is reduced; for this and other reasons combustion does not follow oxygen fraction in a linear way. The rate of combustion increases as both the **fraction** and the **partial pressure** of oxygen increase.

Fuel

We are concerned here about the fuel in a breathing gas system. At high pressures of oxygen, once a fire is started the system itself can become the fuel, but it takes something more finely divided and more flammable to start a fire in a piping system. This can be any sort of particulate matter, lubricants, solvents, and "soft goods" like rubber and plastic that may be part of the system.

Some types of fuels found in scuba systems that normally are of little fire concern in air become quite flammable in an oxygen enriched environment. These include silicone grease, silicone rubber, neoprene, compressor lubricants, plastic shavings, metal shavings, organic material, dust from a variety of sources, and even finger oils. Lubricants are probably the worst offender in practice. Since "silicone" sounds exotic there is a misconception that it is safe with oxygen, and this is not so. There are oxygen-compatible lubricants such as Christo-Lube, Krytox, and Halocarbon and these should be used.

Ignition

Some ignition sources are obvious, but most of these are outside the breathing gas system and are not of consequence. Two main sources of ignition inside a gas handling system are **friction** and **compression** of gas flowing through the system, and these are interrelated. Friction is used in a general sense here to mean particles moving in a gas stream or the gas itself moving around corners or through constrictions. Another phenomenon, the one that causes a tank to heat up when compressed, may cause enough heat to initiate combustion; this is the same effect that causes fuel to ignite in the pistons of a diesel engine without a spark plug, and in fact a gas heating up in this manner is called adiabatic heating or "dieseling."

The compression in a gas line when a valve is opened or closed abruptly can cause ignition temperatures to develop. If there are contaminants in the line a fire can result. For this reason, oxygen systems do not use quick opening valves ("ball valves").

Technique in using oxygen systems

The bottom line is that risk of fire in a system working with high oxygen levels can be minimized by proper design and technique. Design includes avoiding sharp corners and fast-operating valves, and using the right materials. The metals used for ordinary scuba equipment are acceptable for oxygen use. The "soft goods," which includes seals, flexible tubing, diaphragms, etc., should be replaced with "oxygen-compatible" components. In some cases these are less likely to burn in oxygen, but in other cases the materials are chosen because they are more durable when exposed to high pressure oxygen. Kits are available for converting scuba gear.

Techniques include cleaning systems properly and keeping them clean, using proper lubricants, handling gases so as to avoid causing ignition, and opening valves slowly.

Cleaning for oxygen service

Confusion about the need for oxygen cleaning

The matter of "oxygen cleaning" is a source of confusion in recreational diving. The reason for this is that it is not really clear whether oxygen-enriched air with oxygen in the range between air and 40% requires oxygen cleaning. A problem arises here because there are no existing industrial procedures for handling gases with oxygen fractions in the range between air and 100% oxygen, so to comply with industrial practice if a gas has more oxygen than air, it has to be handled as if it were pure oxygen.

The Compressed Gas Association (CGA), National Fire Protection Association (NFPA), NASA, and numerous other organizations consider that gases in this intermediate range should be handled as if they were oxygen. It is not that they have examined this issue, it is just that there are no rules covering this range and they therefore take the conservative position. The U.S. Navy, on the other hand, has issued procedures saying that gas mixes with oxygen up to 40% can be handled as if they were air. No definitive test results have been published to show this is a valid conclusion, but it has been in practice for many years with no reported problems. NOAA has adopted this limit for its enriched air operations. NAUI accepts this, with some stipulations.

Clean compressed air

Another cause of some confusion has to do with the cleanliness of compressed air. The various "grades" of breathing gas purity from organizations like CGA and the U.S. Navy are misleading with respect to being clean enough to use with oxygen. The standards allow a certain amount of "oil mist" in compressed air (usually 5 mg/m3). This may be safe to breathe, but the allowed condensable hydrocarbons are high enough that oil can accumulate in equipment and cause a fire with high pressure oxygen.

There is no recognized purity grade for air that restricts oil enough to make the air safe for mixing with high pressure oxygen. Industry leaders have agreed that a condensable hydrocarbon level of 0.1 mg/m3 is acceptable for "air to be mixed with oxygen," and filtration systems have become available in the last few years that can produce compressed air meeting this requirement (Fig 9-3). Compressors that do not expose the air to lubrication in the first place can produce oil-free air, but these are more expensive.

Formal oxygen cleaning

One reason oxygen cleaning is intimidating is that when it is done in industry it requires rather strict procedures to be followed and detailed documented by trained technicians. CGA and other organizations publish the procedures. Procedures of this type have been found time and time again to be necessary to maintain safety when working with high pressure oxygen.

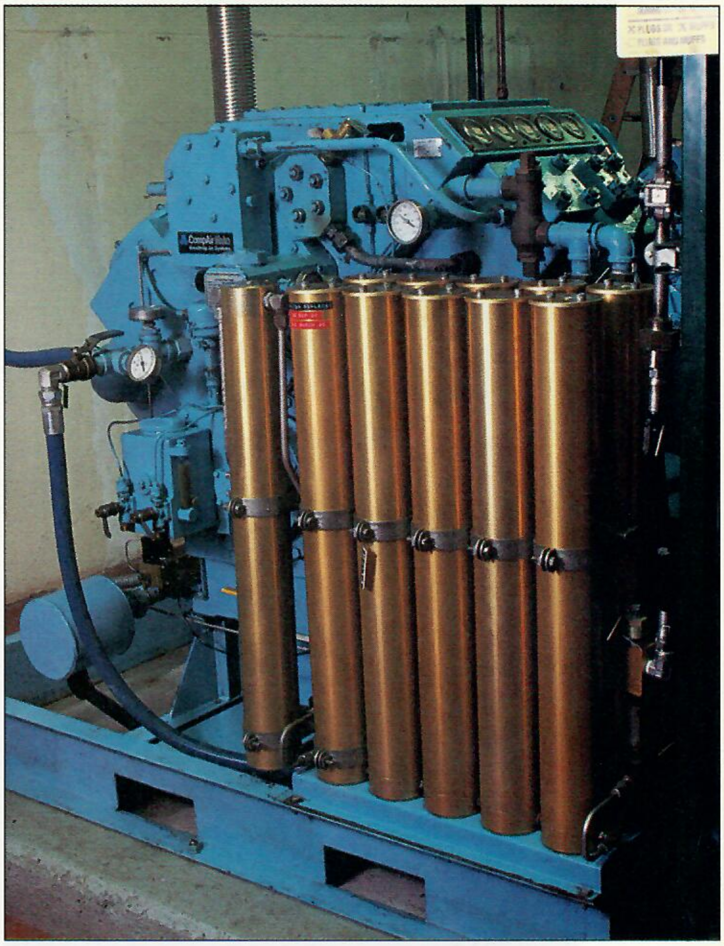


Figure 9-3. Mako compressor with ten-canister filtration package for purifying air.

The NAUI rule is that any equipment used for pure oxygen or an oxygen level above 40% at high pressure (above 200 psi) must be oxygen compatible and cleaned for oxygen service. This includes the tank and first stage regulator, and any high pressure hoses. For some scuba equipment, it is possible to obtain conversion kits.

Informal oxygen cleaning: The "40% rule"

Despite its lack of documented testing, the so-called "40% rule" has merit and has not been found to cause problems in the field . There have been many fires in diving gas systems, but these have all involved higher levels of oxygen.

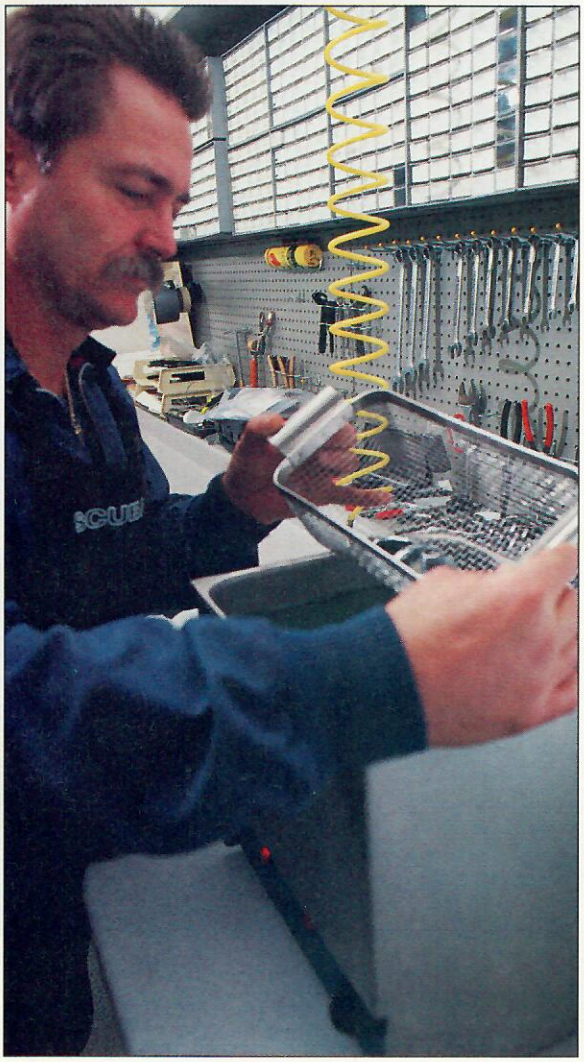


Figure 9-4. Service technician J.D. Selser prepares regulator parts for enriched air service.

NAUI accepts this rule, but requires that the equipment be cleaned, and oxygen-compatible lubricants used. This level of cleaning is less stringent than formal oxygen cleaning, but if done properly will be effective. The cleaning is to be done by trained technicians.

Equipment should be cleaned of any visible debris and lubricants, then scrubbed or cleaned ultrasonically with a strong detergent in hot water, then rinsed several times in clean hot water. Good detergents are liquid household detergents such as Joy®. The cleanliness should be "as clean as one expects dishes and silverware to be." When dry, the soft components are replaced and the equipment is lubricated as necessary with oxygen-compatible lubricant.

Once cleaned, the equipment should be dedicated to enriched air use only and not used for compressed air. If it is, it should be cleaned again.

Preparing enriched air nitrox

Enriched air blending systems have traditionally involved adding oxygen to air in some manner. Recently two new methods have become available that enrich air in a different way, by removing some of the nitrogen. This section reviews three "oxygen addition" methods, commercial mixing by weight, partial pressure, continuous flow, and the two nitrogen removal methods, pressure-swing absorption and membrane separation (Ballantyne and Delp, 1996).

The type of system that a dealer uses is important to the end user with regard to filling procedures and range of mixtures that can be delivered.

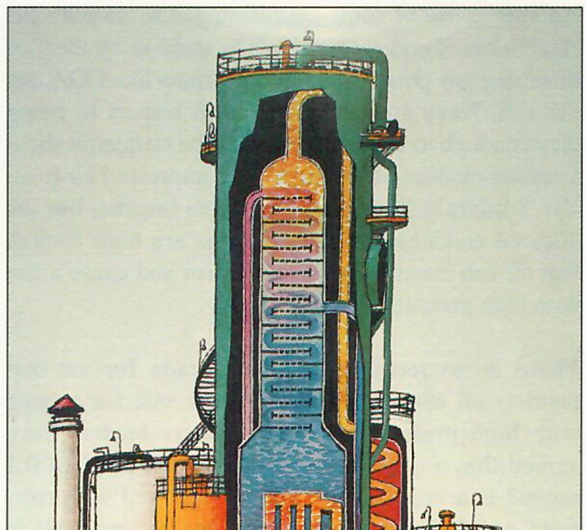


Figure 9-5. Cutaway view of typical air distillation plant.

Commercial pre-mix

The simplest and most straightforward method of obtaining precisely mixed gases is to purchase them from a commercial supplier (Fig 9-5). An industrial gas company will normally mix pure oxygen and nitrogen instead of oxygen and air.

The gases are mixed by weight; this avoids any anomalies due to "non-ideal" behavior of the gases and allows mixes to be quite precise. Mixing can be in cylinders, small banks of cylinders known as "quads," or tank trailers. It is necessary to have appropriate scales, which are somewhat expensive because they measure a small change in a heavy weight. This is by far the most accurate method of obtaining oxygen enriched gas, and mixes come with a reliable analysis. Although premix requires oxygen handling by the commercial gas company, it does not require oxygen handling by the retailer. This is one of the most expensive methods, and additional expense is incurred because the containers belong to the supplier and must be rented.

Partial pressure mixing

As its name implies, partial pressure mixing sets the proportions of the mix by partial pressure (Fig 9-6). The technician puts a measured amount of oxygen (by pressure) into a cylinder and then fills the cylinder to a specific final pressure with ultra-clean air. Oxygen is added first so that it need not be handled at the full cylinder pressure. Because high pressure oxygen is used, the entire system, including the cylinder being filled, must be oxygen compatible and clean. Because pressure is influenced by temperature and the cylinders get hot during compression, it is necessary to let the cylinders cool or adjust for the temperature in making the pressure determinations. Because the proportions often need to be adjusted after cooling, the overall process is fairly time consuming. This process can also be used to "top off" a cylinder for which the oxygen content and pressure are already known, to the same or a different mix.

A compressor is not needed for this method if air can be supplied at a pressure high enough to fill the scuba cylinders completely. To get maximum utilization of pressure from a bank of supply cylinders, they are often used in a "cascade" technique, by which the supply cylinder with the lowest pressure is used first and others follow one at a time in sequence, progressing to the one with the highest remaining pressure. This method is often called the "cascade" method of mixing.

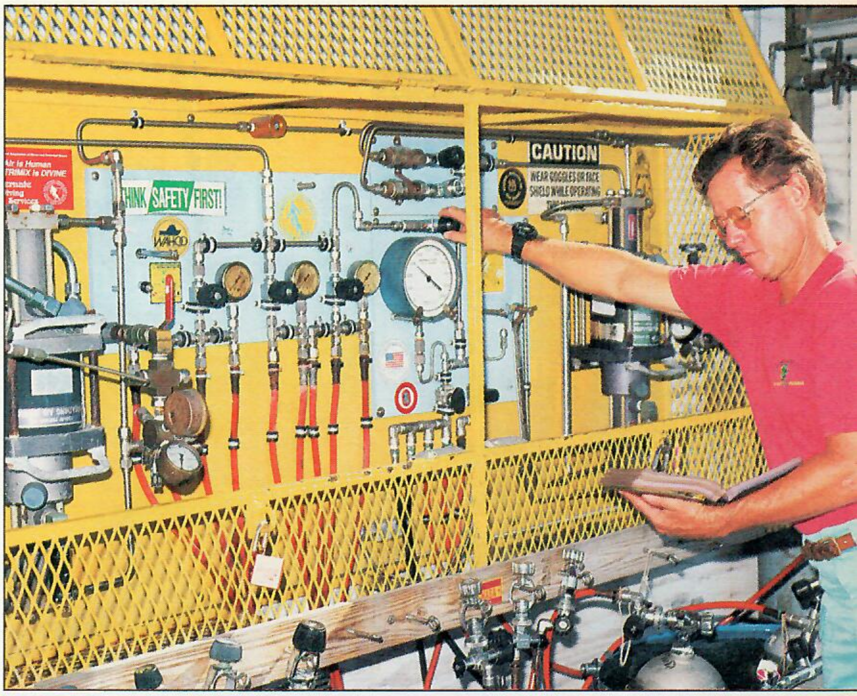


Figure 9-6. Enriched air cylinder being filled by partial pressure blending method at Key West Divers. Note that Capt. Billy Deans is wearing eye protection, an important safety measure when handling pressurized gases.

Compressors are often used with this method. They must be oil free or used with ultra-filtration systems that can supply air suitable for mixing with oxygen. Another way to "boost" gas to scuba cylinder pressure is with an air-driven booster pump. These can easily be designed and cleaned for oxygen service. They use low-pressure air as a power source, and amplify pressure by means of different sized pistons on the same shaft. A popular brand is Haskel®, and these are often called "Haskel boosters."

Partial pressure blending is popular among dive facilities that mix a variety of custom blends in rather low volumes for different recreational and technical diving applications, including enriched air mixtures with oxygen percentages higher than 40%. The main expense is for a precision gauge, but a booster pump is extremely useful with this method. This method is good for mixing in remote locations. Because oxygen is added at relatively low pressures, some technicians do not clean the cylinders for oxygen service. This is not recommended; the cylinders should always be clean before adding oxygen.

Figure 9-7. Rix oil free compressor with oxygen entrainment system installed. This facility is at the University of North Carolina at Wilmington, a NOAA undersea research center.

Continuous flow mixing

This system, also known as the atmospheric entrainment method, was first employed by NOAA (1979; 1991) and is by far the most user-friendly method for mixing oxygen enriched air (Fig 9-8). With this method, oxygen is added at low pressure to the input stream going to an oil-free compressor. The mix coming out of the compressor is analyzed continuously, and this analysis is used to adjust the input oxygen flow; the output flow is allowed to bypass the storage bank until the mix is correct. Once in storage cylinders the mix can be transferred into scuba cylinders using a gas booster pump, or scuba cylinders can be filled directly. A PSA system (Fig 9-8) may also be used as a source of oxygen to be mixed with air in a continuous flow blender.

There is another category of continuous flow mixers used in commercial diving, in which the diver is supplied directly by hose from the mixer or blender. One system uses precision regulators and flowmeters to provide a constant mix. Another commercial system uses a blending tank with a mixing fan inside and continuous on-line analysis. Both these systems do the mixing at the pressure needed to supply the diver, usually under 200 psi.

Pressure swing absorption (PSA)

This system is based on a material called "molecular sieve," a synthetic clay-like mineral that has pores that give it a very high surface area that adsorbs gases ("adsorb" means to absorb on the surface). Nitrogen is adsorbed more readily than oxygen, so air that has passed through the adsorbent bed emerges richer in oxygen. Two beds of adsorbent are used, and the gas stream is selectively alternated between them. While one is adsorbing, the other is being purged. Control of the cycling and pressures enables different levels of oxygen to be produced. The maximum oxygen such a system can deliver is 95%, with the balance argon. Argon behaves much like oxygen in this type of adsorbent bed, so will be present in the product gas in about the same ratio to oxygen as it is in air. This argon is of no consequence to a diver.

This system does not require high pressure oxygen, but is complicated and moderately expensive to

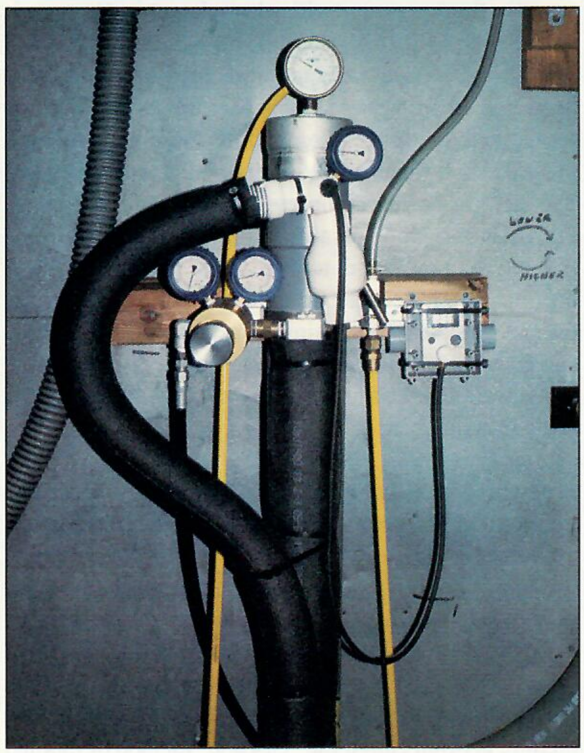


Figure 9-8. Pressure swing absorption (PSA) system.

acquire and maintain, and the output gas has to be boosted to scuba tank pressure with an oxygen-clean, oil-free booster pump or compressor (Fig 9-8).

Membrane separation

This system works by forcing clean air through a membrane that allows oxygen to pass more readily than nitrogen. The "membrane" is in the form of thousands of tiny hair-like hollow tubules. The output gas is richer in oxygen than air, and the level of oxygen can be controlled by means of the flow rate. The maximum effective oxygen level in commercial membrane systems is about 40%. This technique, by the way, is used commercially to separate helium from natural gas and for other processes.

Like the PSA system, no oxygen is needed to prepare enriched air nitrox with the membrane system. The output gas has to be boosted to scuba cylinder pressure with a suitable oxygen-compatible booster pump or compressor. The membrane system is relatively sturdy and needs little maintenance if the input gas is properly filtered.

Divers getting their cylinders filled from this system are warned to be sure that an oil-free compressor is used. Some dive shops believe that because the mixes never contain more than 40% oxygen that it is all right to pump this gas with an oil-lubricated compressor. This is not recommended. They might get away with the pumping, but in the process might also fill divers' cylinders with oil-contaminated mix. ■

Chapter 9. Knowledge Review—Overview of Gas Mixing

Before moving on to the next chapter, **Obtaining and Analyzing Enriched Air Nitrox,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. The main risk when mixing with high pressure oxygen is __________.
2. All components of the ______________ are required for a fire to take place.
3. With regard to oxygen enriched air, as the _________ and _________ of oxygen increase, so does the rate of combustion.
4. Silicone lubricants are safe to use with oxygen. True or False
5. ___________ and ______________ are the two main sources of ignition inside a gas handling ystem.
6. The NAUI rule is that any equipment used for pure oxygen or with an oxygen level above ___________ shall be formally cleaned for oxygen service.
7. NAUI requires that equipment to be used with enriched air be cleaned and _____________ lubricants used.
8. The simplest method of obtaining precisely mixed gas is _______________________ .
9. In _________________ mixing, oxygen is added first so that pure oxygen is not handled at full cylinder pressure.
10. The continuous flow blending system allows oxygen to be added at low pressure to a compressor intake, but it requires an ______________ compressor.

Answers for Chapter 9

1. Fire
2. Fire Triangle
3. Fraction and partial pressure
4. False
5. Friction and compression
6. 40%
7. Oxygen compatible
8. To buy commercial pre-mix
9. Partial pressure
10. Oil free or oil-less

10

OBTAINING AND ANALYZING ENRICHED AIR NITROX

Chapter 10

OBTAINING AND ANALYZING ENRICHED AIR NITROX

LEARNING GOALS

From this chapter you will learn:

- How to get your cylinders filled with enriched air nitrox.
- Why it is important to calibrate an oxygen analyzer.
- How to analyze enriched air mixtures properly.
- How to label and log cylinders.

New Terms in This Chapter

Electrochemical sensor
Fuel cell sensor
Zero
Span
Cylinder label
Fill station log

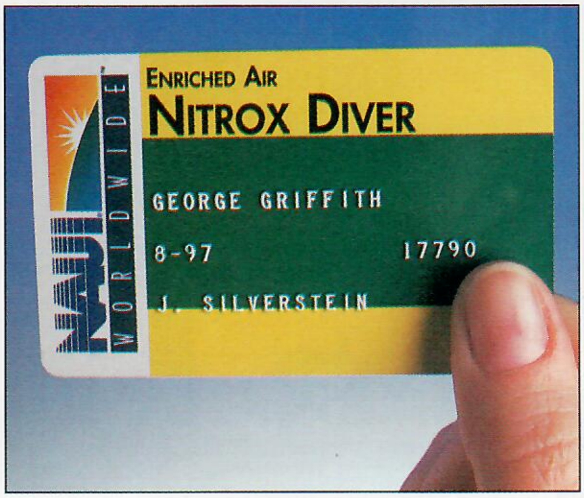


Figure 10-1. NAUI Enriched Air Nitrox Diver Certification Card.

Obtaining nitrox fills

Completing the NAUI enriched air diver course certifies a diver to make enriched air dives and obtain enriched air tank fills. Certain protocols between the diver and the blending station warrant discussion.

Certification required

To obtain an enriched air tank fill, a diver must present a valid Enriched Air Nitrox Diver certification card (Fig 10-1). This card indicates that the diver has been trained for using enriched air. All reputable facilities around the world honor the NAUI certification.

Rental cylinders

If a diver is renting cylinders from a store or a dive vessel, the gas–in most cases–will have already been premixed, and will probably be available in a variety of blends. The diver has only to request what is needed in terms of oxygen percentage and tank size. The facility will have the diver verify the analysis and sign the tank out. Most facilities have restrictions on having rental cylinders refilled by other facilities.

Filling a cylinder

A more common way to get enriched air is to have a cylinder owned by the diver filled at a dive shop, in the same way that this is done with air. When an enriched air cylinder is presented to a blending facility the technician will check the cylinder to make sure it is in current hydrostatic service, and that is has been visually inspected and cleaned for enriched air service within the past 12 months.

Next the technician will examine the cylinder contents tag or label. This label will show the date and oxygen percentage of the last filling of this cylinder. Then the technician will analyze the tank to confirm that the tag and the analysis match. If it does not match, the technician will ask why, and may–depending on the explanation–require that the cylinder be re-cleaned for oxygen or enriched air service.

If all is fine with the labels and initial analysis, the technician will fill the cylinder to the requested oxygen percentage and pressure using one of the methods discussed in the chapter on mixing. Once the cylinder has been filled, it will be analyzed for accuracy; if adjustments are necessary they will be done, either by adjusting the existing mix or dumping it and starting over. Most qualified gas blenders mix accurately the first time. Once the technician is satisfied with the final mix, the cylinder is tagged as full with the technician's analysis and initials.

Performing gas analysis

In the overall picture of oxygen enriched air diving, the gas analysis is one of the critical steps. All enriched air divers need to know how to properly analyze the gas they will be using. Before discussing analysis procedures, we should cover how analyzers work and what they do.

Oxygen analyzers

Oxygen analyzers are available from many manufacturers, in different sizes and types; some have a digital

Figure 10-2. Oxygen analyzers. (From left) Analox Mini-O_2, OMS Professional, Teledyne 320B, Miniox (Catalyst Research).

display and others use an analog (needle) readout (Fig 10-2). Either type can be used successfully for analyzing enriched air mixtures. Ideally, an analyzer must be able to read and show oxygen values down to a fraction of 0.001 or 0.1% (one-tenth of a percent). For example, the digital read out should be able to read 32.4% instead of 32% or 35.8% instead of 36%.

The heart of an oxygen analyzer is its detection method. There are two primary types of oxygen analyzer generally used for breathing gases. The paramagnetic analyzer takes advantage of the fact that oxygen is attracted to a magnetic field; these are primarily used in research laboratories and industry; they are accurate, stable, relatively expensive, and somewhat delicate.

The other main category of oxygen analyzer available in portable units comprises those that are electrochemical in function. These break oxygen into ions and electrons and measure the current generated; this current is proportional to the partial pressure of oxygen to which the sensor is exposed. The electrochemical analyzers are of two types–polarographic and fuel cell. The function of these is the same to the user and the difference is not relevant here. These are also used in hospitals, laboratories, and industrial settings.

Electrochemical oxygen analyzers use two electrodes made of different metals; these are immersed in an electrolyte solution that is contained by a thin, oxygen-permeable membrane (Fig 10-3). Oxygen diffuses through the membrane to the cathode, where it is reduced, generating a very small current. This current is linearly proportional to the PO_2; it is measured by the unit's electronic circuit and the result displayed.

Electrochemical analyzers are relatively inexpensive, can be made portable and rugged, and show little interference from other gases. However, they tend to be unstable and may need frequent calibration, especially as the cell begins to age.

The need for calibration

No matter what the method or mechanism of a gas analyzer, the analysis is no better than the calibration of the analyzer. An electrochemical cell tends to be quite linear (some types are not linear, and these can be a great deal more trouble to use). Being linear, it need be calibrated in only two places to give reliable read-

Figure 10-3. Electrochemical oxygen sensors.

ings. This is called "zeroing" and "spanning." In effect this sets the slope and the intercept of the calibration curve. Usually an oxygen analyzer is "zeroed" with an inert gas such as argon, nitrogen, or helium; the gas type does not matter with this mechanism. Some analyzers rely on an electrical zero, but this may not be quite as reliable, since this method does not account for drift of the sensor cell.

Ideally it is best to calibrate or "span" an analyzer with a "standard" gas that is close in oxygen level to the sample. For analyzing oxygen in the range to 40% oxygen, it is normally satisfactory to calibrate with air, using the value 20.95% oxygen. Since values above 20.9% are "extrapolations," if an analyzer is spanned but not zeroed properly it may be off by a percentage point or two at 40%. The best method is to "bracket" the unknown with calibration gases.

Need for two analyzers

One properly calibrated analyzer, used correctly, is adequate for checking scuba cylinders. The notion that two analyzers are necessary to be "sure" of the reading suggests a lack of confidence in the analysis process. Better than a second analyzer, for the same gas analysis, are competence and confidence in calibrating and using one analyzer well. Repeated analysis with the same unit properly calibrated helps build the confidence in the tool.

However, while one good well calibrated analyzer is sufficient for a given analysis, every gas blending facility dependent on gas analysis needs a **backup** analyzer. This means also that extra sensors and batteries should be on hand. Complete analysis redundancy is a good practice for field and other operations where prompt repetitive analysis is critical.

Acceptable range of mixes

When a diver requests a specific mix from a supplier, it is generally accepted practice that a mix within ±1% of the desired mix is acceptable. If a mix is more than 1% off the desired mix, have the blender make adjustments or re-mix the tank. The NAUI tables and most other EAN tables are tolerant of this range.

Analyzing the gas

When a diver picks up an enriched air cylinder, the vendor will require an analysis of the gas by the diver before signing it out, and the diver will want to analyze the gas again just before diving with it. The procedures for analysis are simple enough to follow but

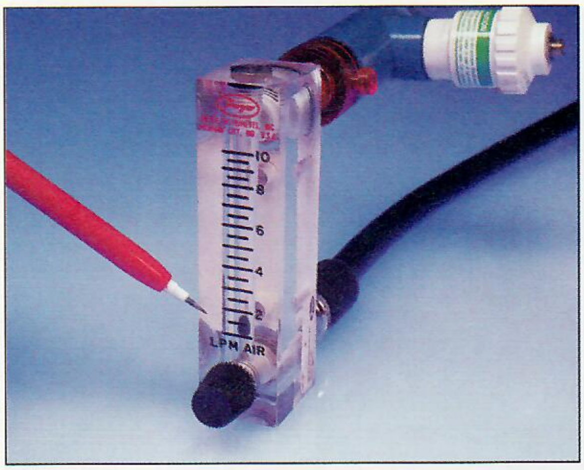


Figure 10-4. Gas sampling flow meter that connects to low pressure inflator hose set up for gas analysis with 0 to 10 lpm range set to 2 lpm.

must be done carefully to maintain the integrity of the resulting analysis. The diver will choose diving tables and oxygen limits based on this analysis. The retailer who supplies enriched air nitrox will have an analyzer for customers to use, but we encourage divers to have their own unit if possible. It is standard protocol and a good idea as well to check the analyzer's calibration with a known gas (such as air) before performing the analysis.

Flow rate

Proper analysis is dependent not only on the analyzer itself but on the flow rate of the gas passing in front of the sensor cell (Fig 10-4). Too much flow and the pressure in the cell may be raised and the partial pressure of the gas will read too high. Too low a flow and the reverse might happen. **The sample should be read at the same flow rate as was used for the calibration.** Different facilities use different equipment to regulate the gas flow for analyzing (Fig 10-5). Some will use a special regulator fitted with a flow valve capable of adjusting the flow rate from perhaps 0 to 10 liters per minute, but the upper end of this one is much higher than needed. Ideally, the flow should be between one-half and 2 liters per minute, nominally 1 lpm. Some analyzer distributors make a special fitting that connects to the low pressure inflation hose of the scuba regulator that acts as a flow meter that is adjustable or preset to 2 lpm. Although it is possible to analyze the gas without a flow meter, readings are often inaccurate and this is not recommended practice.

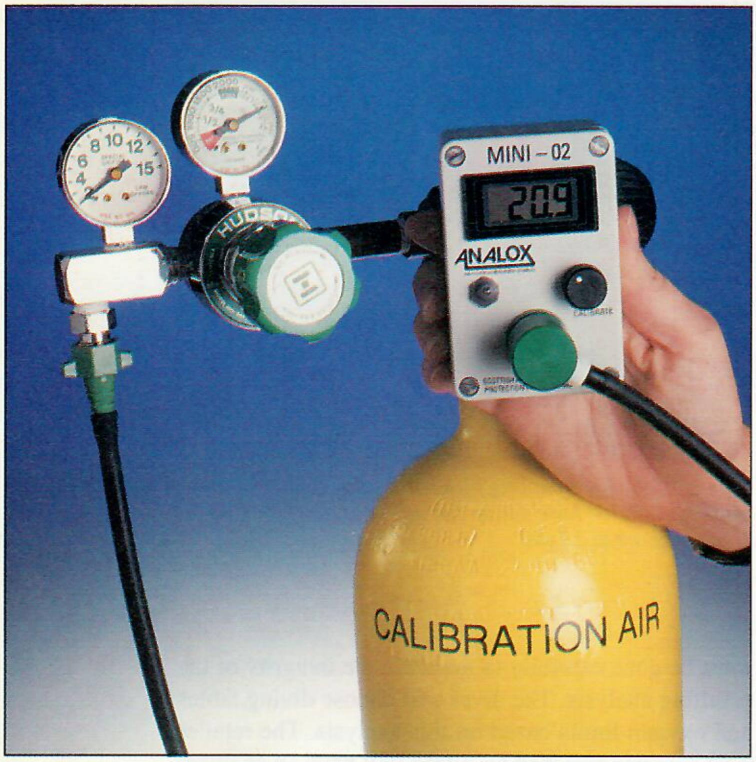


Figure 10-5. Gas sampling system using an oxygen analyzer with flowmeter set to 2 lpm, using air for calibration showing reading of 20.9%.

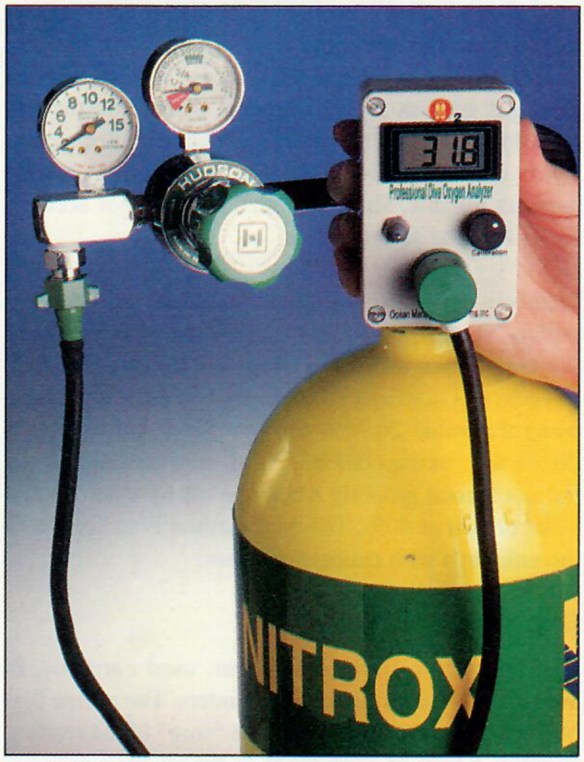


Figure 10-6. Gas sampling system using an oxygen analyzer with flow meter set to 2 1pm, analyzing an enriched air cylinder showing reading of 31.8%; this would be used as EAN_{32}.

Calibration

An oxygen analysis is only as good as its calibration. Before analyzing an enriched air cylinder, the meter should be calibrated to a known gas. For most enriched air applications, calibrating a meter with air is sufficient. The flow rate regulator is to be attached to a scuba cylinder that has air in it. Turn on the oxygen analyzer, set the flow rate between 1 and 2 lpm and let the air flow for approximately one minute until the reading has settled. Once settled, make sure the reading is set to 20.9%; if not, adjust the calibration setting on the unit. Make sure the air is compressed atmospheric air, not industrial "air."

Analyzing the enriched air cylinder

Once the meter has been calibrated, leave it turned on and move the sampling device onto the tank that needs analysis (Fig 10-6). Remember that the flow rate must be the same as that to which the unit was calibrated. Let the meter read the new gas for at least one minute or until stable. The resultant reading is the partial pressure of oxygen in the tank. At sea level this is equal to the oxygen fraction, which can be converted to percentage by multiplying by 100. Transfer this number immediately to the cylinder contents label, fill out the rest of the data, and attach it to the cylinder.

Cylinder Labeling

Every enriched air cylinder must be properly labeled as to its contents and fill data (Fig 10-7). In some cases, once a cylinder has been analyzed at the fill station it is possible it may not be analyzed again. Thus, the cylinder contents label is the *only* way to know what gas is in the tank before diving. The data include fill date, tank pressure, oxygen percentage, maximum operating depth, the name or identification of the person who filled it out, and the users initials verifying that it was analyzed. The contents label or tag should be firmly attached to the tank or tank valve. Plastic re-useable contents tags can be written on in pencil and erased for the next use. Non-reusable labels should be written on with a permanent marker, never with a grease pencil (which may come off), and should only be removed by a gas blending technician before the next fill.

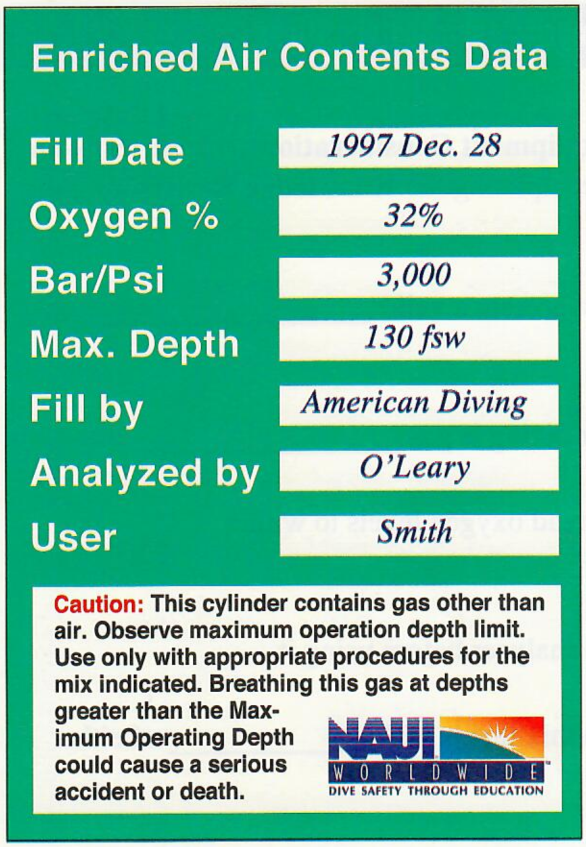


Figure 10-7. NAUI EAN cylinder label for a tank filled to 3000 psi and 31.9%.

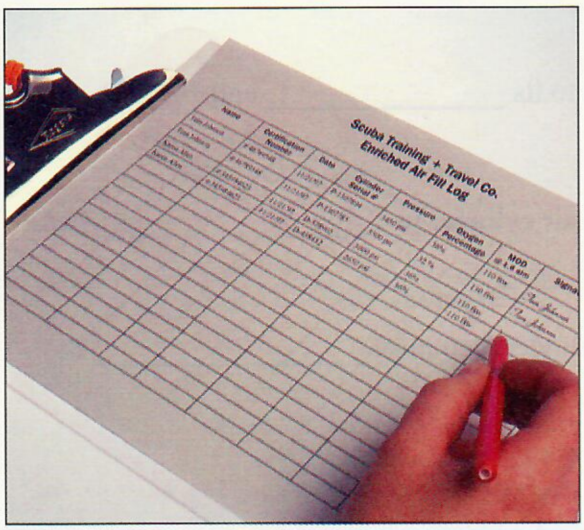


Figure 10-8. The job is not over until the paperwork is done. The diver acknowledges the analysis in the fill log.

Fill Station Log

Once a cylinder has been filled and analyzed a permanent record is kept at the filling center in a *Fill Station Log*. The diver picking up a cylinder is required to "sign it out" from the facility (Fig 10-8). In the log the diver will print her name, the date, certification number, tank serial number, tank pressure, oxygen percentage, and maximum operating depth, and then should sign the log.

The tank log is used to help keep track of cylinders from facility to facility, and helps ensure that a technician can verify the last fill in the tank should a contents tag or label somehow get removed from the tank. The log also verifies, by the diver's signature, that the diver has either personally analyzed or watched a technician analyze the tank being received. ■

Chapter 10. Knowledge Review—Obtaining and Analyzing Enriched Air Nitrox

Before moving on to the next chapter, **Diving Equipment Considerations,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. To obtain an enriched air tank fill, a diver must present a valid ________________ certification card.
2. One of the critical steps in oxygen enriched air diving is gas ________________ .
3. A practical oxygen analyzer should be able to read oxygen levels to within ______________ .
4. You must always ______________ an oxygen analyzer before using it.
5. The NAUI enriched air diving tables tolerate a mix that is within __________ of either side of the specific mix.
6. The proper flow rate for gas analysis is ______________ .
7. When analyzing a gas mix the ______________ must be the same as when the unit was calibrated.
8. Every enriched air cylinder must be labeled as to its ______________ and ______________ .
9. Every diver must _____________ an enriched air cylinder in a ________________ before removing the cylinder from the fill station.
10. If you are not sure of the gas mix in a scuba cylinder, you must ________________ the gas before use.

Answers for Chapter 10

1. Enriched air diver or enriched air nitrox diver
2. Analysis
3. 0.1 %
4. Calibrate or verify the calibration of
5. 1.0 %
6. 1 lpm (0.5 - 2.0) liters per minute
7. Flow rate through the analyzer
8. Contents and fill data
9. Sign out; Fill Station Log
10. Analyze

11

DIVING EQUIPMENT CONSIDERATIONS

Chapter 11

DIVING EQUIPMENT CONSIDERATIONS

LEARNING GOALS

In this chapter you will:

- Learn which scuba equipment can be used with enriched air nitrox.
- Know why it is important to have scuba cylinders dedicated for enriched air use.
- Understand how scuba gear is prepared for enriched air service.
- Review how to maintain your scuba equipment.

New Terms in This Chapter

Equipment conversion
Oxygen service
Enriched air service
Cylinder dedication
DIN

This chapter explores how scuba gear works with enriched air nitrox, how it needs to be maintained, and how it may require modification for safe use.

Cleanliness

As mentioned in Chapter 9 on mixing, industrial standards exist for cleaning equipment for oxygen service. This we are calling "formal" oxygen cleaning. Chapter 9 also mentions that the demands of enriched air in the range to 40% oxygen do not require such rigorous cleaning nor the comprehensive documentation and control that industrial oxygen cleaning requires. Accordingly, the recreational diving community has accepted, in general, that a type of cleaning we are calling here "informal oxygen cleaning" will suffice. But make no mistake, both methods call for careful, detailed cleaning and record keeping.

The cleaning method addressed here and used by the industry for enriched air nitrox is the "informal" cleaning method. This method is the same as that described by Professional Scuba Inspectors and required on the NAUI tank inspection sticker. It is not "cleaning for oxygen service" as practiced in industry.

It has become common practice that scuba gear–with the exception of tanks and tank valves–that will not come in contact with oxygen mixtures above 40% need not be cleaned to be used with enriched air nitrox. Tanks and tank valves should be cleaned for any mixes with oxygen greater than air.

However, it is recommended for ease of management and for overall safety purposes that all equipment that will be used for oxygen enriched air ultimately be cleaned and dedicated for oxygen enriched air service. It just makes good sense. It is a prudent approach to handling gas, as cleaner is always better. In addition, many manufacturers require retrofitting to oxygen enriched air service to maintain warranties.

The accompanying chart (Fig 11-1) lists equipment that should be cleaned before being used with oxygen enriched air with oxygen percentages of between 21 and 40%. If, however, the equipment will be used with mixtures greater than 40%, items on the first two sections of the list should be formally cleaned for oxygen service. Once clean, this equipment should not be used with air cylinders filled with air from oil lubricated compressors, as this will contaminate them again.

Equipment List

Equipment that must be cleaned for enriched air service

- Cylinder valves
- Scuba cylinder

Recommended to be cleaned

- Regulator first stage
- Regulator second stage
- High pressure hoses
- Submersible pressure gauges

Not necessary to be cleaned

- Buoyancy compensators
- Low pressure inflator
- Dry suit inflator

Figure 11-1. Equipment cleanliness requirements.

What is done during cleaning and conversion to EAN service?

Most products are made using machines that use oil for lubrication. Although great care is taken to clean all equipment before it is sold, an amount of trace oil is usually left behind. For most scuba applications this is not a problem.

In addition, scuba regulators, tank valves, and submersible pressure gauges use O-rings and lubricants for proper sealing and operation. The standard silicone lubricant and the rubber products used in the O-rings are not compatible with high pressure oxygen. High pressure oxygen is pure oxygen at 200 psi or greater.

Figure 11-2. ScubaPro Mk-20 first stage regulator with conversion kit parts.

Essentially, each piece of equipment is completely disassembled and then cleaned in a series of liquid solutions that will remove oil, grease, and non-compatible lubricants. This work is done in a special area of a shop that is also clean, as are the tools used. Once clean, they are reassembled with oxygen compatible soft goods, o-rings, seats, and lubricants. Bear in mind that the cleaning achieved is not "formal" cleaning for oxygen service, but it has been accepted for enriched air use.

Most manufacturers can supply their dealers with enriched air conversion kits that have all appropriate components for converting regulators for enriched air service. Conversion kits (Fig 11-2) usually contain distinctive marking rings or labels to show that the regulator has been prepared for enriched air service. The parts used for conversion are cleaner and more tolerant of both oxygen and oxygen-compatible lubricants but they are not necessarily appreciably less flammable.

Scuba cylinders

Scuba cylinders that will be used for oxygen enriched air are to be properly "dedicated" for enriched air nitrox use so that no one can accidentally confuse an enriched air nitrox cylinder with an air cylinder. Enriched air nitrox cylinders are to be conspicuously marked to identify them as enriched air tanks. In addition they need to be cleaned properly as outlined above so that the cylinder can be filled.

In the commercial gas world different gases (helium, oxygen, argon, air, propane) are placed in cylinders with distinctive valve fittings. Each gas is assigned a unique valve connection to prevent its being connected incorrectly. A cylinder content label is also required.

The scuba industry currently has two valve configurations (Fig 11-3), one the standard "yoke" regulator and the other the DIN-threaded connector with captured O-ring. Unfortunately, at this time neither of these connectors can prevent a scuba regulator not prepared for enriched air use from being placed on a enriched air cylinder. Because any scuba regulator can fit onto any cylinder despite contents, it is most important that identification procedures be strictly followed.

There are three labels placed on an enriched air cylinder to distinguish it from other scuba cylinders. The labels have become an international standard for identifying enriched air nitrox cylinders, their level of cleanliness, and their contents.

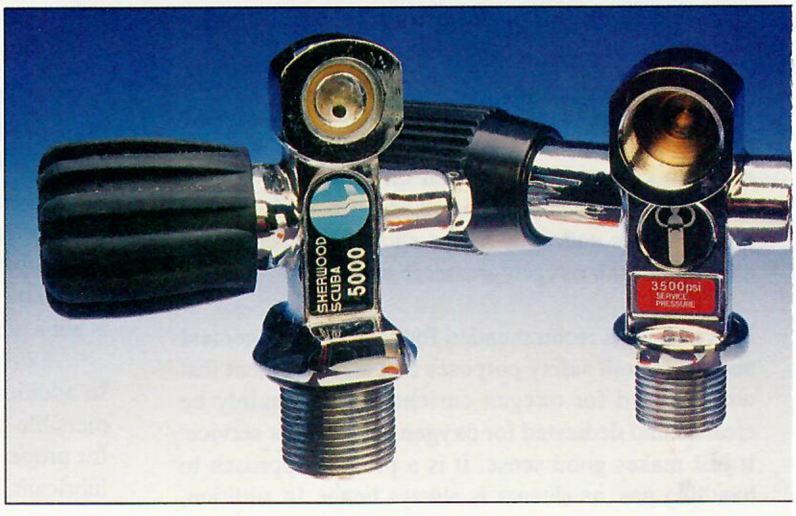


Figure 11-3. Yoke style (at left) and DIN scuba tank valves. Both use an O-ring for sealing, but the DIN O-ring is less likely to extrude under high pressure.

Identification of enriched air cylinders

One method of identification of enriched air cylinders is a yellow painted cylinder with the top painted green down 4 inches from the shoulder of the cylinder. On the body of the cylinder in two-inch high letters the words "Nitrox" or "Enriched Air" are to be stenciled.

Another acceptable method is to use a label that surrounds the top of the tank (Fig 11-4). On yellow tanks a four-inch green band with the words "Enriched Air" or "Nitrox" printed in yellow or white letters is placed just below the shoulder of the tank. For cylinders that are not yellow the same green band will have a one-inch yellow band on both top and bottom. A cylinder that does not have an enriched air cylinder label in the proper position should not be filled with oxygen enriched air.

Oxygen service

This label (Fig 11-5) is applied to the cylinder after it has been cleaned and placed into oxygen service. It shows when the cylinder was cleaned, who did it, and to what level of cleanliness. Some enriched air nitrox filling systems require a tank to be cleaned for oxygen service since high pressure oxygen is in contact with the valve and the tank when it is being filled. Other systems do not use oxygen for filling. The label distinguishes whether the tank has been cleaned for oxygen service or not. A cylinder that does not have an "oxygen service decal" should not be filled by partial pressure methods. The label only certifies that the tank has been cleaned to the PSI (Professional Scuba Inspectors) standards on the date punched out. If the tank has been contaminated anytime after the inspection date, it should be cleaned again and re-labeled. Contamination can occur by having the tank filled with air from an oil-lubricated compressor.

Cylinder contents

Once an enriched air cylinder is filled, a content label or tag is placed on it (Fig 11-6). This label or tag shows the date the cylinder was filled, what mix is in it, who filled and analyzed it, and the maximum operating depth. The content label is the most critical label on the cylinder. The label should be filled out with a permanent marker so there is no possibility the information can change after it has been entered. The content label is the only way of knowing what is in a cylinder once it has left the analysis station.

Some facilities use a plastic tag attached to the neck of the tank that has the cylinder serial number on one side and the content data on the other side; these tags are reusable.

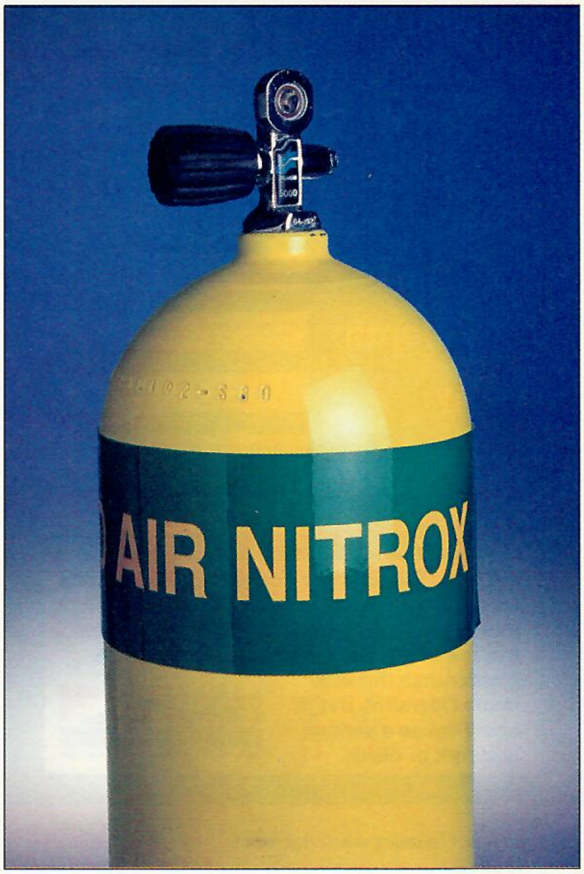


Figure 11-4. Single tank with enriched air nitrox tank wrap.

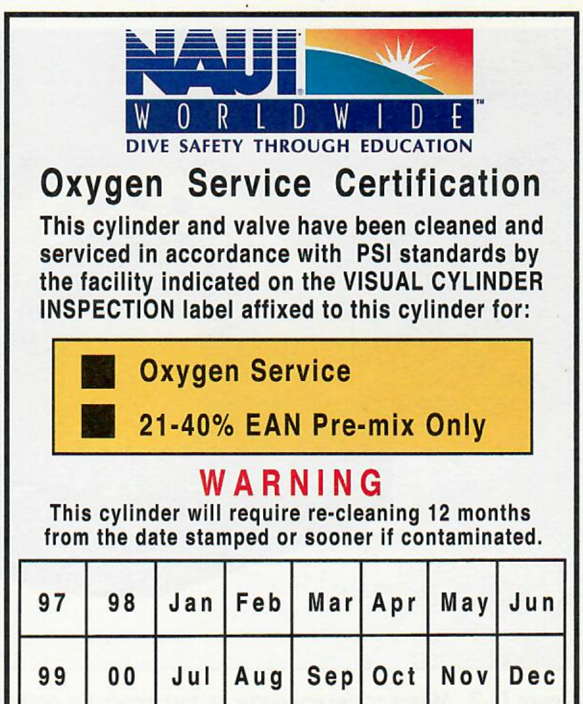


Figure 11-5. NAUI Oxygen Service Certification label.

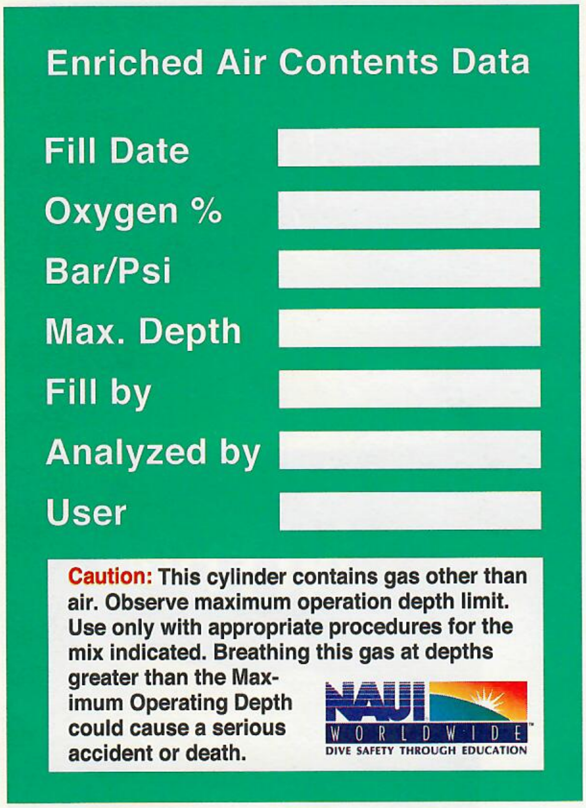


Figure 11-6. Cylinder contents label.

What about new equipment?

Scuba diving is an equipment intensive activity. Typically, scuba divers are always adding, replacing, or changing some gear. This has to do with different types of diving, new equipment styles and developments, or old items just wearing out. Today, many manufacturers can deliver tanks, regulators, valves, manifolds, and pressure gauges that are ready for enriched air nitrox service right out of the box (Fig 11-7). However, if a particular item does not come "factory-ready" it can usually be prepared for enriched air use or oxygen service by an authorized dealer.

Routine care and maintenance

As divers learn in their basic scuba class, scuba gear is life support equipment, and it needs to be maintained on a regular basis for continued good service. Equipment that has been prepared for enriched air use requires similar handling. Cylinders and regulators that have been dedicated to enriched air service should never be filled or used with air from conventional air compressors; doing so contaminates them. Besides

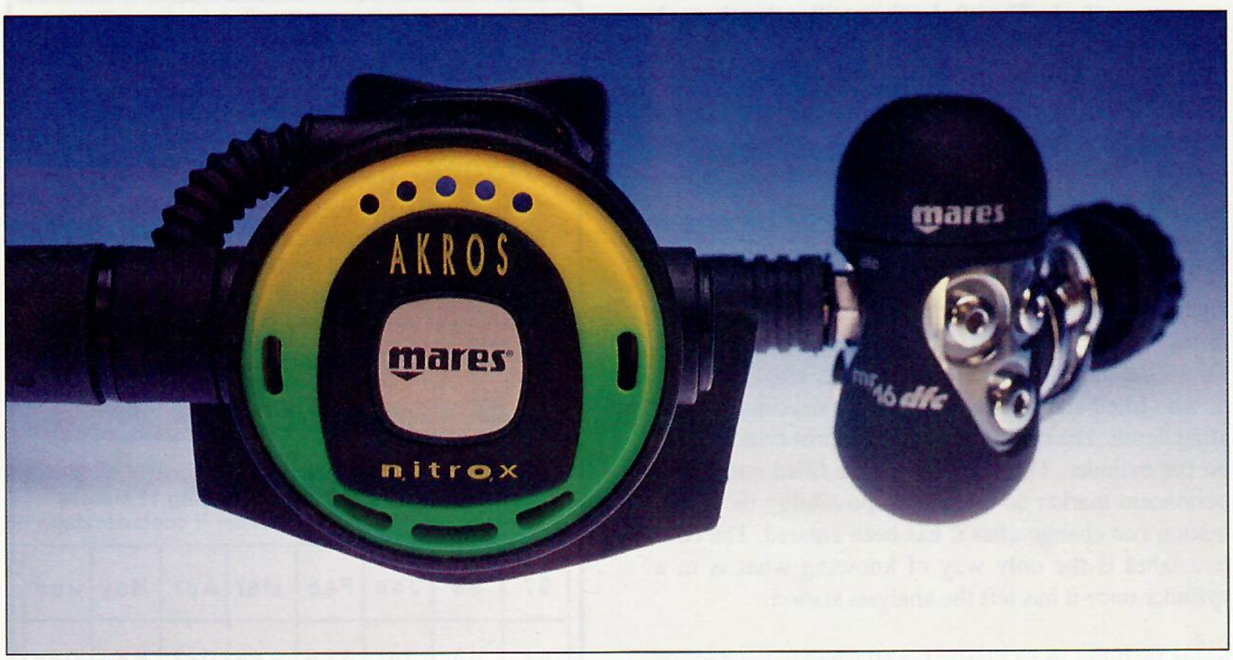


Figure 11-7. Mares scuba regulator factory ready for enriched air nitrox use.

caring for equipment after use, pre-dive handling and inspection is important too. Never let your scuba regulators or tank valves come in contact with oil or grease. Also, do not put tape over tank valves; many of the materials are not compatible with oxygen service.

To keep scuba gear in prime working condition, following any dive rinse the gear with fresh water. This includes regulators, tanks, hoses, gauges, computers, buoyancy compensators, and personal gear. After rinsing tanks and valves open the valve slightly to let any water that got into the valve be blown out. Also make sure that dust caps are securely in place when washing regulators. And never spray lubricants like oil or silicone on regulators or valves; this will contaminate them for enriched air service.

Periodic service

An annual service overhaul by a factory-trained technician is usually all that is needed to keep the scuba equipment in good working order. It is important however that when equipment is taken in for service that the dealer is notified (if it is not marked) that the equipment is for enriched air use and that appropriate cleaning and lubrication procedures are to be followed.

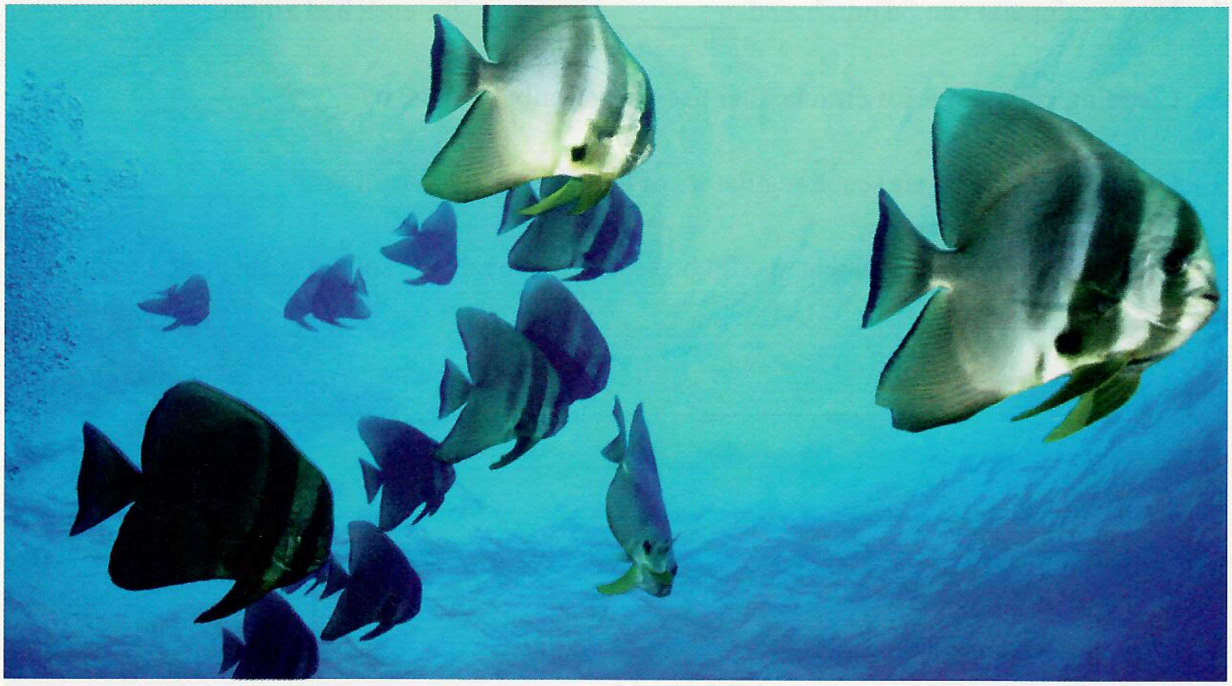
Scuba cylinders require annual visual inspection and a hydrostatic test every five years. It is a very good idea to have the cylinder and valve re-cleaned annually. If it is suspected that the tank had been contaminated the tank should not be refilled with oxygen enriched air, but it should be taken out of service until it has been re-cleaned.

Effects on warranties

Most manufacturers' warranties allow for oxygen enriched air use if the conversion is done by an authorized technician to the company specifications. Consult a professional equipment dealer for details on specific equipment and warranties. Converting scuba equipment to enriched air service by a non-factory authorized technician will probably void any warranty.

Contamination

Even after equipment has been cleaned and placed into oxygen service, it can easily become contaminated. Contamination can occur by placing a regulator on a regular air tank or by filling an enriched air cylinder with air from an oil lubricated compressor. It is strongly recommended that once equipment has been dedicated to oxygen enriched air use that it not be co-mingled with other scuba equipment. Doing so can become and expensive proposition from an equipment maintenance standpoint and from the perspective of safety. ■



Chapter 11. Knowledge Review—Diving Equipment Considerations

Before moving on to the next chapter, **Having Enough to Breathe and Staying Warm,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. __________ and __________ must be cleaned for enriched air service before being used with enriched air.

2. A scuba cylinder that is to contain a gas other than air must be properly cleaned and __________ before use.

3. Most scuba regulators can be converted to enriched air service by cleaning and using __________ .

4. Contamination of cleaned equipment can occur if __________ from an compressor is used.

5. An __________ indicates when a cylinder has been placed into enriched air service.

6. A __________ is a possible means of identifying what is in a cylinder without an analyzer.

7. New equipment can be purchased __________ for enriched air use.

8. Cleaning equipment for enriched air use should only be done by __________ .

9. Do not let enriched air scuba regulators or tanks come in contact with __________ .

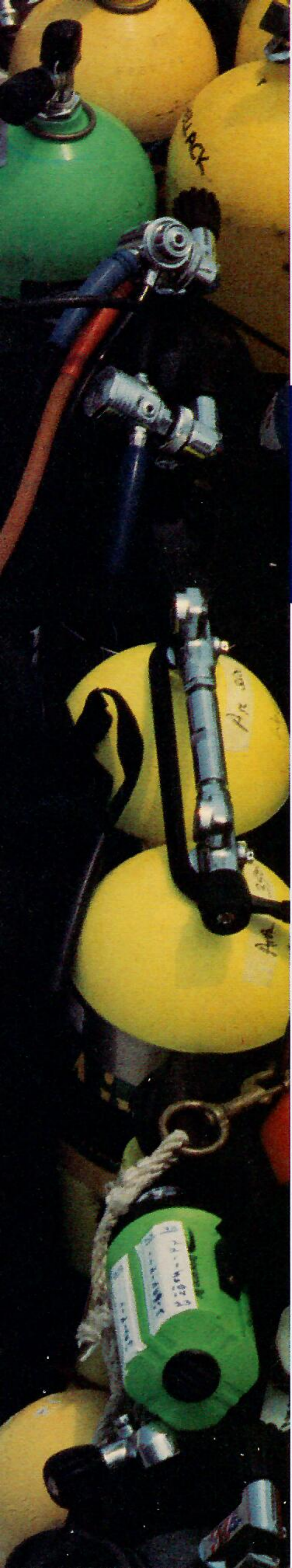
10. Enriched air scuba equipment should be serviced annually or sooner if suspected of being __________ .

Answers for Chapter 11

1. Scuba cylinders and cylinder valves (first stage regulator)
2. Labeled
3. Oxygen compatible lubricants.
4. Air; oil lubricated
5. Oxygen service label
6. Cylinder contents tag or label
7. Factory-ready; oxygen clean, or cleaned for enriched air
8. A qualified service technician
9. Oil or grease
10. Contaminated

12

HAVING ENOUGH TO BREATHE AND STAYING WARM



Chapter 12

HAVING ENOUGH TO BREATHE AND STAYING WARM

LEARNING GOALS

In this chapter you will:

- Understand the need for breathing gas management.
- Learn how to determine how much gas is needed for a dive.
- Learn how to calculate gas supply.
- Learn how to apply workload factors to your gas planning.
- Understand the definition of Respiratory Minute Volume.
- Determine your personal RMV.
- Learn about the importance of staying warm.

New Terms in This Chapter

Respiration

RMV, Respiratory Minute Volume

Dry suit

We have already seen the no-stop and decompression time advantages of using oxygen enriched air. The advantages provide the diver with the opportunity to stay under water longer. Increased dive times raise two important issues, having sufficient gas to conduct the dive, and keeping the body warm. In this chapter we discuss how to provide the proper amount of gas and how to choose the most appropriate thermal protection.

Normal respiration

The lungs fill and empty approximately 12 to 16 breaths per minute while the body is at rest. Any amount of exertion will increase the breathing rate, often by many times, and will increase the depth of breathing or tidal volume as well. A normal resting breath will inhale approximately 1 to 2.5 liters of air into the lungs. At a normal rate during moderate activity we breathe approximately 30 to 40 liters per minute, and 5 to 15 at rest.

The term for the volume of gas moved in and out in a minute is Respiratory Minute Volume (RMV). If we convert liters into cubic feet, the average person will breathe about 1 cubic foot of air per minute at rest at 1 atm. Thus a person has an RMV of about 1 cubic foot (28.32 liters/cu. ft.) per minute at the surface.

Since each person is different and their breathing rates may vary, some breathe more or less than 1 cubic foot per minute. Later in this chapter we show you how to calculate your "personal" RMV. For the examples we assume 1 cubic foot per minute gas consumption as the standard. Since these calculations are based on several rather rough estimates the results are only estimates.

How much gas is needed?

As a diver descends the gas breathed becomes denser, more closely packed. It takes more gas, more molecules of gas, to fill the lungs. We need to determine how much more gas is needed. Converting pressure in feet of sea water at the dive depth into atmospheres absolute provides the appropriate factor for the density conversion. Once we know how much gas per minute is needed at depth, we can multiply that number by the planned bottom time to estimate the amount of gas needed (Fig 12-1).

Effect of Depth on Gas Consumption

Depth fsw(msw)	atm	RMV	Cu. Ft./ Min.
0 (0)	1	1	1
33 (10)	2	1	2
66 (20)	3	1	3
99 (30)	4	1	4
132 (40)	5	1	5
165 (50)	6	1	6

Figure 12-1. Effect of depth on gas consumption. Multiply pressure of the diver in atm by Respiratory Minute Volume (RMV) to get cubic feet per minute at depth.

Gas used for a square dive profile

Example: How much gas is needed for a 65 fsw dive for 60 minutes?

For this example we use a "square" dive to 65 fsw for 60 min; we have to consider only one pressure and time. Using the techniques in Chapter 3 we determine that 65 fsw is equal to 3 atm. The basic or "standard" RMV of 1 cfm (cubic foot per minute per atm) is multiplied by this 3 atm to determine the gas volume at depth necessary to provide a lung ventilation of 1 cfm. The result is 3 cfm. Multiply this by the dive duration, 60 min, to get the resulting 180 cfm. To conduct a 60 minute dive at 65 fsw with an RMV of 1, the diver will consume 180 cubic feet of gas.

The equation for this is:

Volume used, cubic feet =
standard RMV, cu ft/min/atm x P, atm x time, min

In liters this is 30 x 3 x 60 = 5400 liters.

Square Dive: 100 fsw 30 minutes

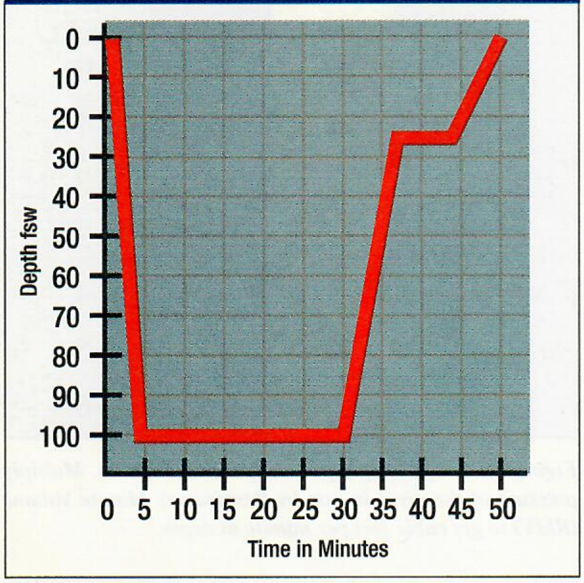


Figure 12-2. Square dive profile, 100 fsw/30 min.

Example: How much gas is needed for a 100 fsw dive for 30 minutes?

Starting again with the standard RMV of 1 cfm/atm, we note that 100 fsw is equal to 4 atm so multiply this 4 atm by the RMV of 1 cfm/atm and the result is 4 cubic feet per minute. Multiply 4 by 30 minutes and the result is 120 cubic feet (Figure 12-2).

For a 30 minute dive at 100 fsw with an RMV of 1 cubic foot per minute, the diver will need 120 cubic feet of gas, plus gas for the ascent.

Working backwards, how long will it last?

Another way to plan a dive is to determine how long a diver can stay at depth with a given tank.

Example: How long will an 80 cubic foot tank last at 65 fsw if the RMV is 1?

Using the equation for " Volume used, cu. ft." we rewrite it to give time:

$$time, min = \frac{Volume\ used,\ cu.\ ft.}{standard\ RMV,\ cu.\ ft./min/atm \times p,\ atm}$$

80 cubic feet divided by 1 cfm/atm x 3 atm = 26 minutes.

It is clear that to take advantage of the extended no-stop dive times of oxygen enriched air a diver needs to carry sufficient gas. In many situations the standard 80 cubic foot tank may not be enough and the diver will need to use one of the larger cylinders, or "doubles."

More often the dives are multileveled. Let's take a look at a typical multilevel dive profile and determine how much gas will be needed for a dive. Many of the gas calculations for this type of profile can be done either by hand or by using one of the dive computational software programs.

Multilevel Dive: 80 fsw 20 minutes

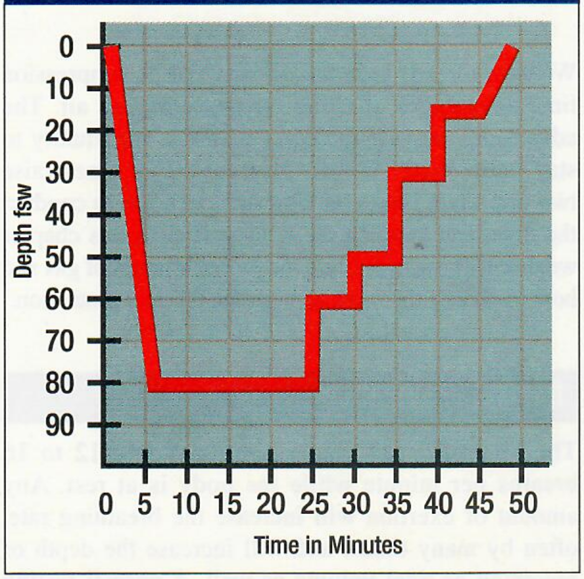


Figure 12-3. Multilevel dive based on 80 fsw/20 min.

Multilevel dive to 80 fsw

Consider a dive to 80 fsw for 20 min followed by 5 min steps at 60, 50, and 30, and a safety stop at 15 fsw. The profile of this dive is shown in Figure 12-3 and the analysis in 12-4. The dive was checked with dive planning software to make sure the stops were proper, and will be executed with a dive computer.

Assumptions:

- Enriched Air 32 % is the mix
- 30 fsw per minute is the ascent and descent rate.
- A 5 minute safety stop at 15 fsw.
- RMV of 1 cubic foot per minute.
- 80 fsw is the maximum depth for the dive.
- Maximum no-stop time on EAN_{32} table at 80 fsw is 50 minutes.
- Cubic feet are rounded up to next full foot.

With this set of assumptions we can now determine how much gas will be needed.

Depth fsw	atm	Time at depth	RMV	Work Mod	Cu. Ft. Breathed
0	1	0	1		
30	1.9	1	1	1	2
60	2.8	1	1	1	3
80	3.4	20	1	1.5	103
60	2.8	5	1	1.5	21
50	2.5	5	1	1.5	19
30	1.9	5	1	1	10
15	1.45	5	1	1	7
0	1	1	1	1	1
Totals		43 min			165 cu ft

Figure 12-4. Profile of multilevel dive with gas consumption calculations, including work modifiers.

Modifying Factors

The RMV of a diver will change depending on the type of dive. If the dive does not require much work or swimming and it will be a relaxing "sightseeing" dive, then the base RMV will probably be sufficient to use. However, if there are currents, long swims, work, or other strenuous activities the RMV should be modified by a workload factor (Fig 12-5).

After determining the planned dive profile and gas requirements, a work load factor should be applied to each portion of the dive. When work factors are applied to the previous dive it becomes clear that more gas is needed to conduct the dive.

This dive requires, with an RMV of 1, a minimum of 119 cubic feet of 32% enriched air without any reserve. Adding in a minimum reserve of 1/6 of required gas, the diver will need to carry 140 cubic feet of gas to make this dive. If, however, the RMV is less the diver will need to carry less gas. A person with an RMV of 0.50 will need to carry 70 cubic feet of gas and a diver with an RMV of 0.75 will need to carry 105 cubic feet of gas (plus reserve). Use the tank volume chart in the Reference Section to assist in planning gas requirements.

At Rest	0.5
Touring	1.0
Mild Work	1.5
Moderate Work	2.0
Heavy Workload	3.0

Figure 12-5. Approximate RMV workload modifiers. Multiply RMV by appropriate factor.

Finding the personal RMV

We have used an RMV of 1 cubic foot per minute for many of the examples. However, many divers have an RMV lower than 1. This has been developed over time as they gain more experience and are more comfortable in the water. It also has a lot to do with physical size. A 200 lb. man will have an RMV higher than one who weighs 110 lb.

Divers can conduct their own exercises to determine their personal RMV. It's easy and it's fun. These exercises can be done in a pool or in the open water. If using open-water its best to do these exercises in 10 to 15 fsw. Here is how it is done.

Gear up in all of your normal equipment. The tank should be filled to its working pressure only. In addition, have a pencil and slate to take notes.

Descend to ten fsw, get comfortable, mark down the pressure (you will learn how to convert this to cubic feet later) and breathe in a resting position for 10 minutes. Use normal inhalations and exhalations; do not try to conserve any air, just breathe. At the end of ten minutes write down the ending pressure.

Next do some swimming. Mark down the pressure and swim at a comfortable touring pace for 10 minutes. Use your normal leg strokes and maintain a constant depth and neutral buoyancy. At the end of ten minutes mark down your psi.

Tank Size	80 Cu Ft
Fill Pressure	3000 psi
Resting Start Pressure	2500 psi
Pressure at 10 min	2000 psi
Resting Depth	10 fsw
Swim Start Pressure	2000 psi
Pressure at 10 min	1200 psi
Swim Depth	10 fsw

Figure 12-6. RMV calculation dive slate.

After you have done these exercises you will be able to calculate the RMV for both resting and swimming. Once you have these numbers you will be able to estimate how much gas you will need for most dives. Remember to convert the depth of exercise back to the surface.

If this exercise is done in open water be sure that you first swim into the current; this will allow you to use the current to help bring you back to your starting point.

Converting pressure to cubic feet

The measurement for monitoring a tank's gas volume is psi (pounds per square inch). We don't breathe psi, we breathe cubic feet of gas, but the psi number is the reference for it. It is important to remember that two different tanks of the same volume can have the same cubic feet but not necessarily the same working pressure. For example, consider two tanks: one made of steel holds a gas volume of 80 cubic feet when filled to 3,500 psi; the other tank is made of aluminum and has a volume of 80 cubic feet when filled to 3,000 psi. Each tank holds the same amount of gas but at different pressures. In the Reference Section there is a listing of the tanks currently available, including their volumes and working pressures. As divers we need to know not only the working pressure and the volume of the tank but how much gas is left as it gets used.

Example: An 80 cubic foot tank rated at 3,000 psi will have 80 cubic feet when filled; at 1500 psi it will be half full or have 40 cubic feet remaining.

Example: A 100 cubic foot tank rated at 3,500 psi will have 100 cubic feet when filled; at 1500 psi it will have about 43 cubic feet remaining.

To arrive at these remaining volumes use a simple formula. Divide the volume of the tank by its working pressure; this results in a "tank factor," the number of cubic feet per psi. Then multiply the factor by the remaining pressure on the gauge and get the remaining volume in cubic feet.

80 cubic feet divided by 3000 psi = 0.027 cu. ft./psi
0.027 multiplied by 1500 psi = 40.5 cubic feet

$$\frac{\textit{No. cu.ft. of gas in the tank, cu.ft.}}{\textit{pressure, psi}} = \textit{tank factor, cu. ft./psi}$$

If the tanks are doubled up add the two tanks' volumes together at the beginning.

160 cubic feet divided by 3000 psi = 0.053 cubic feet/psi
0.053 multiplied by 1500 psi = 80 cubic feet

This is the factor you need to determine the RMV. Once you know the factor, calculating gas volume comes easy. Numbers should be rounded to a realistic value.

If the actual physical volume of the tank ("water volume") is available then the volume calculations are even easier. Simply multiply the physical volume by the pressure in atmospheres to get the gas volume.

Calculating the standard RMV

Once the diver has done the underwater work and has calculated the 'cubic feet per psi' factor for the tank, that data will be used to determine the personal RMV.

From the 10 minute resting exercise the diver used 500 psi. Multiply 500 psi by the factor of 0.026 cu.ft./psi and the result is 13.3 cubic feet. Divide the 13.3 cubic feet by the 10 minutes of breathing and the result is 1.33 cubic feet per minute or an RMV of 1.33.

From the 10 minute swimming exercise the diver used 800 psi. Multiply 800 psi by the factor of 0.026 cu.ft./psi and the result is 21.3 cubic feet. Divide the 21.3 cubic feet by the 10 minutes of swimming and breathing and the result is an RMV while swimming of 2.13 cu.ft./min.

From a practical standpoint knowing the RMV allows you to monitor your gas supply, both as gauge drop in psi but also as a mental note of how long the gas will last based on what you consume. These references make the difference in divers having sufficient gas to do a dive or running out of it, which obviously could lead to injury.

Thermal protection: Staying warm

Three components determine allowable diving time, decompression, gas supply, and heat. Each component works interactively with the other. If a diver plans a 60 minute dive but only has gas for 30 minutes the dive is shortened. If a diver plans a 60 minute dive but gets cold after 30 minutes again the dive must be shortened. Staying warm during a dive is another component of the dive plan that must be considered.

Figure 12-7. Divers in wet and dry suits

Consequences of hypothermia

From an objective point of view, we can say that a diver is beginning to be affected by cold water when she begins to show both physiological and psychological signs and symptoms. Some of the obvious signs are shivering, discomfort, decreased manual dexterity, judgement loss, and memory lapses about the dive. These are all signs of hypothermia. When these signs begin to exhibit themselves and are noticeable to a dive partner, the affected diver is probably long past the time when she should have left the water. For that matter, we need to address thermal protection before the dive begins.

Statistically, cold divers use more air than divers who stay warm. Tests have shown that cold divers can use up to 29% more gas than divers who are warm in the same water temperature. The reasons are simple. The metabolism of a cold diver will increase as the body burns more calories to keep warm. If the body is too cold, normal metabolism cannot take place.

Breathing gas heat loss

Besides cold water drawing heat away from the diver, the act of breathing compressed gas also contributes to heat loss. Each time a diver exhales heat is lost. This happens because the gas in the scuba tank is about the same temperature as the surrounding water. Furthermore, when gas expands from cylinder pressure through the regulator the pressure drop decreases the temperature. The cold air is warmed as it enters the body. A scuba diver can lose up to 20% of her heat just through breathing gas.

Efficiency and Reliablity of Wet Suits vs. Dry Suits						
	WET SUIT			DRY SUIT		
Water Temperature	1st Dive	2nd Dive	3rd Dive	1st Dive	2nd Dive	3rd Dive
70°F	100%	100%	100%	100%	100%	100%
60°F	100%	90%	80%	100%	100%	100%
50°F	80%	70%	50%	100%	100%	100%
40°F	50%	25%	*	100%	85%	75%
32°F	*	*	*	100%	75%	55%

*Figure 12-8. Thermal efficiency table. Table is based upon 30 minute dives at 50 fsw, with one hour surface intervals between dives. The * indicates an exposure not recommended unless involved in a contingency situation (from Barsky, Long, and Stinton, 1995).*

Also, an unprotected head, due to its surface area and blood flow, can lose up to 50% of the body's heat as it shunts blood and warmth away from other extremities (hands and feet) in its attempt to stay warm.

There are other consequences of heat loss, beyond the scope of this book. Suffice it to say that when a diver plans extended dive times as allowed when using oxygen enriched air, thermal protection needs to be addressed.

Types of protection

Divers are familiar with two types of thermal protection, the wet suit and the dry suit (Fig 12-8). The wet suit keeps a diver warm by allowing only a thin layer of water to enter between the skin and the neoprene rubber. The body warms the water and the neoprene insulates it. Wet suits work well for water that is 65° F and warmer. Wet suits are available in a variety of thicknesses to provide the insulation required.

Lycra dive skins have become fairly popular for warm water diving. Although they provide some protection from the sun and abrasion they have no meaningful insulation properties.

Dry suits protect divers by keeping them dry and warm by keeping water out (Barsky et al, 1992). Different suits have different thermal properties, but for the most part they all require the use of undergarments to provide for varying degrees of warmth. Dry suits have been used for diving since the early hard hat days of commercial diving. Many divers today find using dry suits and varying the undergarment allows them to use the dry suit system in water as warm as 80°F (27°C), to as cool as 32°F (0°C), sometimes even cooler.

Wearing hoods and gloves will help a diver retain significant heat. The head, as mentioned earlier can be responsible for up to 50% of the body's heat loss. It is also a good idea to wear a thin hood even in warm water.

Whether a diver uses a wet suit or a dry suit depends on individual diver preference, the temperature, and the degree of exposure. The more dives one does in a day or a week the colder one will ultimately become, sometimes to a dangerous point. It is important to determine thermal protection long before a dive begins. Wearing the right thermal protection will not only protect the diver from heat loss, but will make the dive a great deal more enjoyable. A professional NAUI retailer can help in determining the right suit for the diving you will be doing. ■

Chapter 12. Knowledge Review—Having Enough to Breathe and Staying Warm

Before moving on to the next chapter, **Contingencies: If Things Don't Go as Planned,** please test your understanding of this chapter's information by completing the **Knowledge Review.**

1. A normal resting breath ventilates the lungs with __________ liters of air.

2. At a depth of 66 fsw how many cubic feet of gas will be breathed at a surface RMV of 1 cubic foot per minute for a 75 minute dive? ____________________

3. A diver with an RMV of 0.5 cubic feet/min plans a square profile first dive to 110 fsw for the maximum no stop time using the NAUI EAN 32 diving table. Approximately how much gas will be needed for the complete dive, assuming no reserve? _____________

4. The above diver does another dive at a different dive site, making a 50 minute no-stop dive to 80 fsw using the NAUI EAN 36 table. How much gas will be needed, adding in a 1/3rd reserve? ___________

5. Three divers plan to dive together using a 36% enriched air mix. The dive plan is to spend 30 minutes at 80 fsw then ascend to 50 fsw where they will spend another 20 minutes. The divers have RMV's of 0.5, 0.7 and 1.0 respectively. What is the minimum size tank each will need? (Round up)
   A. ________ B. ________ C. _________

6. An aluminum 80 cubic foot tank (77.4 cubic feet) has a working pressure of 3,300 psi. How many psi equal one cubic foot of gas? _________

7. Two divers have two different tanks, one has a high pressure steel 65 cubic foot tank rated at 3,500 psi, the other has a low pressure steel 66 cubic foot tank rated at 2,400 psi. Which tank has more gas in it when they both reach 750 psi? ________

8. Using the tanks in question # 7, how many cubic feet of gas are left in the high pressure tank at 750 psi? ________

9. A diver who does not wear a hood can lose up to _____% of the body's heat production via the head.

10. Shivering, discomfort, loss of judgement, and decreased manual dexterity are signs of __________ .

Answers for Chapter 12

1. 1 to 2.5 liters
2. 225 cubic feet.
3. 54.2 cubic feet
4. 114 cubic feet
5. a. 80 b. 120 c. 160 cubic feet tank size
6. 43 psi/cu.ft.
7. Low pressure tank has more at 750.
8. 13.89 cubic feet
9. 50%
10. Hypothermia

13 | CONTINGENCIES: IF THINGS DON'T GO AS PLANNED

Chapter 13

CONTINGENCIES: IF THINGS DON'T GO AS PLANNED

LEARNING GOALS

In this chapter you will:

- Learn how to plan for contingencies.
- Begin to develop the right attitude toward incident management.
- Learn the importance of having oxygen at the dive site.
- Know how to avoid and manage out-of-gas emergencies.
- Review what to do if a decompression stop is needed.
- Learn what to do if a decompression stop is omitted.
- Review decompression sickness first aid.
- Review oxygen toxicity.

New Terms in This Chapter

Demand regulator

Oxygen administration training

Convulsion

Omitted decompression

Contingencies

Diving with oxygen enriched air offers certain procedures and techniques to maximize the dive time and reduce the risks. However, even with conscientious planning and prudent adherence to procedures, things can go wrong. This chapter addresses some possible problems and provides some options on how to solve them. The NAUI Scuba Rescue Skills and Techniques text is an excellent resource for detailed emergency procedures. This chapter highlights some of the specific emergency procedures for diving with oxygen enriched air, but it is not intended to replace specialized emergency training.

Most problems encountered in diving do not start as emergencies, and most never become emergencies in the true sense of the word. How the diver responds to the situation is often decisive in determining the problem's importance; many events that do become accidents begin with a phase where something is a bit out of order that can easily be corrected if the right steps are taken. Understanding problems that may arise helps divers be better prepared to handle them when they do occur. The most important thing a diver can do when something goes wrong is to slow down, think about the problem, and respond in a calm and deliberate manner. Practicing certain skills regularly helps develop a good attitude toward problems, so when one does occur the diver is not surprised and is prepared to manage it confidently. The "right" attitude for managing problems takes time to develop, but developing it should be at the top of every diver's goal list.

Oxygen supply

Whenever diving is to be done, be sure a full kit of emergency equipment is on hand. An essential part of this "kit" is a sufficient supply of oxygen, available and ready for use. Administration of oxygen should ideally be done by someone with training, but every diver should know the main situations where oxygen might be beneficial, and should have a positive attitude about using it. NAUI has a specialty course in Oxygen Administration that is strongly recommended for all divers, especially dive leaders and instructors, and there are other suitable courses. It is in each diver's best interest to make sure that appropriate equipment and personnel are available on a dive vessel or at a dive site. Some experts advise having enough oxygen to support two divers breathing 100% oxygen for up to two hours. Effective oxygen administration has to be with a tight fitting mask and a "demand" regulator. A demand regulator supplies gas only when the user inhales.

At today's level of understanding about diving problems and their countermeasures, there is no excuse for a reputable diving operation not to ensure that oxygen is readily available.

Out of gas, out of life

A diver should rarely run out of gas, but it does happen. Chapter 12 discusses how divers plan their gas consumption so as to have enough gas to complete a dive. As mentioned there, diving enriched air allows more bottom time, and thus allows more time for the gas to be used up. Running out of gas generally occurs in one of two ways, diver error or equipment failure, and it can be a combination of both. Whatever the cause, the out-of-gas diver needs to have something to breathe, and needs it promptly. A different gas from the one being breathed is much better than none. Air is always good. Likewise, do not let concerns about decompression cause delays that could lead to drowning. Redundant breathing systems carried by the diver are a first line of defense, allowing for a seamless transition from an empty scuba cylinder to a backup one that will allow the diver to make a deliberate and controlled ascent and end the dive uneventfully.

Out of air procedures

Five of the low-on-air or out-of-air procedures are reviewed here. These should be familiar; details can be found in the NAUI entry-level diver text. In any situation the diver needs to decide quickly the best survival option.

1. Normal ascent. The diver uses the remaining gas in the cylinder or the gas from the diver's own pony cylinder to make a normal ascent to the surface, making a safety or decompression stop as needed.

2. Alternate air source ascent. The diver uses the buddy's alternate air source either the octopus regulator or pony system, for ascent, making the appropriate safety or decompression stops along the way if there is enough gas. Keep in mind that if one diver is low on air or out of air there is a good chance the dive buddy will be close to the same situation.

3. Emergency swimming ascent. In this situation the diver makes a direct and controlled swimming ascent to the surface, exhaling and venting the expanding gas from the lungs and the buoyancy control device. It is necessary to exhale continuously during the ascent, especially when nearing the surface. The diver maintains buoyancy control and the weight systems remain in place. This procedure has been shown to be effective from depths of about 60 fsw (20 msw) or shallower. Training in this procedure before it is needed will help make this a comfortable routine.

4. Buoyant emergency ascent. This is also a free swimming ascent, but in this case the diver removes the weights, becomes immediately buoyant, and makes a direct ascent to the surface, exhaling and venting expanding gas from the lungs. This procedure has been found to be effective from depths as great as 130 fsw (40 msw), but it may be used from any depth if the diver has no other options.

5. Buddy breathing. This is not a common practice now that alternate gas sources are widely available, but there may be times when the only choice is to share the dive buddy's primary regulator. The divers each take two breaths in turn from the donor's regulator, maintaining contact and composure, and together they make a controlled ascent to the surface. Safety stops and necessary decompression stops are to be made as usual, gas supply permitting. Buddy breathing is an effective means of making an ascent, but it requires cooperation of the two divers. Training for this is essential if it is to be a viable alternative.

Different gas, different divers

There may be situations where divers who need to share gas have been breathing different gas mixtures. Since the important thing is to have something to breathe, this is not a matter of great concern, but some procedures should be followed.

Enriched air diver within no-stop limits. For a NAUI enriched air diver who has not yet exceeded the no-stop time, breathing air or any enriched air mix for an immediate ascent is acceptable. This will have trivial decompression consequences. A safety stop should be made at 15 fsw (5 msw) for 3 to 5 minutes. If the situation is reversed and an air diver needs to breathe enriched air, this is fine also.

Enriched air diver in decompression mode. If a NAUI enriched air diver who has a decompression obligation has to switch to air, the procedure is to make the ascent as usual to the stop depth of 15 fsw. Decompression calculations have shown that doubling the required decompression is a good guideline. Remain at 15 fsw for twice the required decompression, air supply permitting. If the modified decompression must be shortened because the air supply is depleted, follow procedures for omitted decompression upon surfacing.

In any event, conducting a safety stop for 3 to 5 minutes at 15 fsw (5 msw) is important to slow the ascent and regain composure. Remember that the distance from 15 fsw to the surface is where the greatest gas expansion occurs. A slow ascent from the safety stop will help avoid lung expansion injuries.

What if a decompression stop is required?

If a diver has overstayed the no-stop time limits, this by itself is not an emergency. The NAUI diving tables provide decompression stop information. Normally if you enter decompression status, you "call" (end) the dive, return to the ascent line, and ascend with the prescribed stops as indicated on the diving table. If you are using a dive computer, you ascend to the first stop shown and follow the computer for the balance of the decompression.

It is a good idea (even when diving with a computer) to have your dive plan on a slate and carry it along on the dive. Also, you should always have a set of NAUI plastic dive tables in your BC pocket. The slate should include a variety of depths and times. An example is shown in Figure 13-1.

It is important in the gas supply part of planning a dive to consider safety stops and decompression contingencies. Should decompression be required there should be enough gas to complete the required stops uneventfully.

Bob's Dive Slate

Location:
Paradise Wall 36% O_2

Depth fsw	No-Stop Time	Contingency Time with Decompression Stop time at 15 fsw		
80	60	80/7	100/14	
90	50	60/8	70/14	80/18
[100]	[40]	50/10	60/17	70/23
[110]	[30]	40/7		

Courtesy of Scuba Training + Travel Co.

Figure 13-1. Dive slate showing no-stop dive times and contingency times that require decompression stops.

Omitted decompression

For the NAUI enriched air diver who surfaces with a decompression obligation, for whatever reason, or upon surfacing discovers that some required decompression has been omitted, the following procedures can be employed.

When oxygen is available: The diver with omitted decompression is to immediately begin breathing 100% oxygen at the surface. Initiate first aid and monitor for signs and symptoms of decompression sickness and initiate evacuation to the nearest hyperbaric medical facility. In all cases of omitted decompression give the diver fluids (juices, sports drink) to maintain hydration.

If oxygen is not available: Although oxygen should always be available, there may come a time when there just isn't any. In this case the diver is to remain on the surface, drink fluids for hydration, monitor for signs and symptoms of DCI, and initiate evacuation to the nearest hyperbaric medical facility. The diver is to remain in a resting position with limited activity.

In either case, the diver is not to be exposed to altitude for 24 hours.

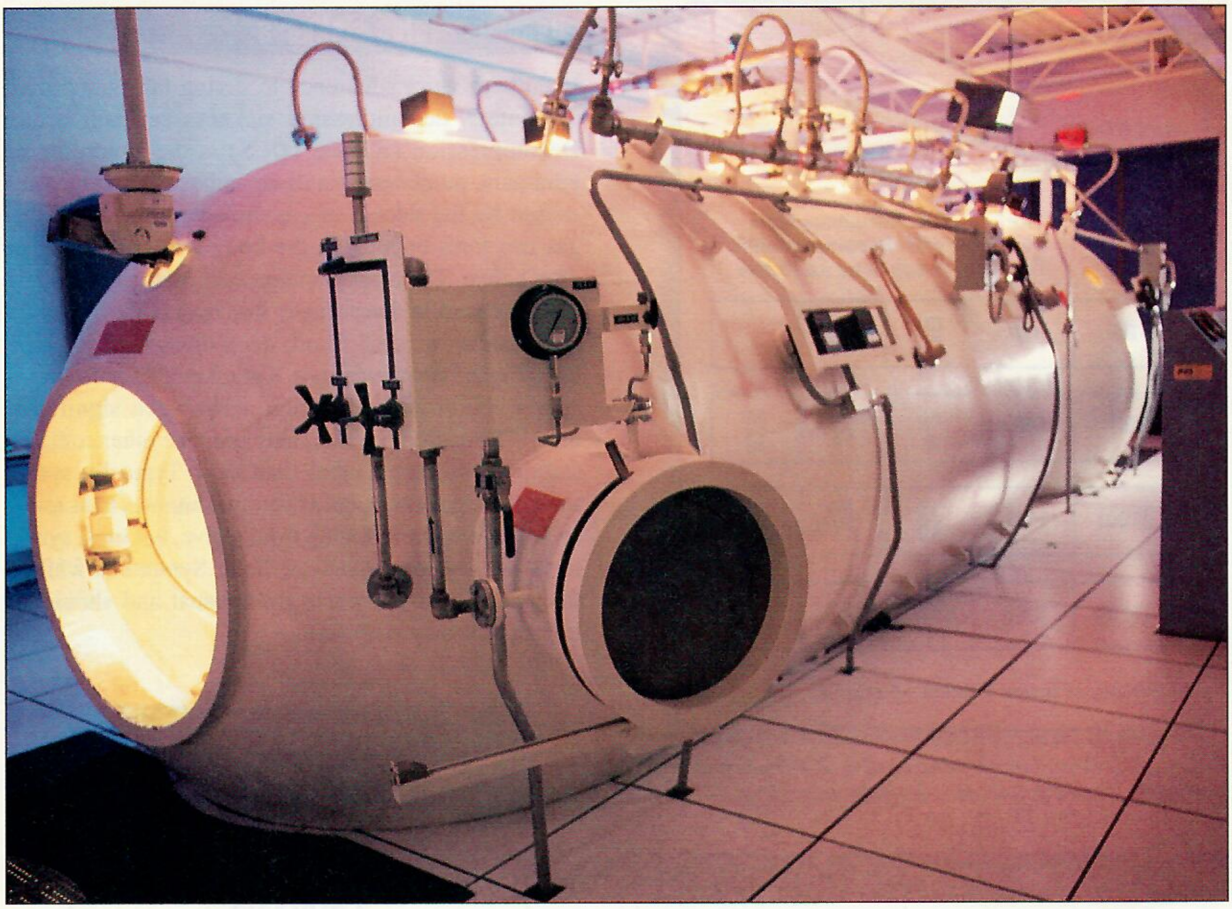
Decompression sickness

Even with strict adherence to diving tables and dive computers, decompression sickness can still occur. Decompression sickness (DCS) is the syndrome of joint pain, numbness, paralysis and/or other symptoms caused by the release of gas dissolved in tissues; this gas can form bubbles in the body while surfacing or after a dive. The most common occurrence for shallow or long duration dives (many minutes) is the joint pain of classical "bends." Short, deep dives tend to cause neurological manifestations, disturbance of both sensory and motor nerve function. Also when significant bubble formation occurs it may provoke other complex reactions, problems other than pain. Typically symptoms and signs can appear from five minutes to as much as 24 hours after surfacing from a dive, but most symptoms are noticed within one hour. Symptoms while a diver is still in the water are unusual and should be treated as if they were serious.

Decompression Sickness Signs and Symptoms

Joint Pain
Paralysis
Muscle Pain
Skin Rash
Disorientation
Slurred Speech
Dizziness
Agitation
Hearing Disturbances
Tingling
Fatigue
Vision problems
Numbness
Weakness

Figure 13-2. Signs and symptoms of decompression sickness. Most symptoms occur within one hour of surfacing, but occasionally may take up to 24 hours or more.



Figurer 13-3. Multiplace hyperbaric treatment chamber at the U.S. Navy Submarine Escape Training School, Groton, CT.

In any event, should divers experience changes in how they feel, or have any signs or symptoms such as those listed in Figure 13-2, they should immediately begin breathing 100% oxygen. Continue to monitor signs and symptoms, and arrange for immediate and prompt evacuation and transportation to the nearest hyperbaric medical facility (Figure 13-3) for evaluation and probable recompression. Even if signs and symptoms dissipate during oxygen breathing, and they often will, the diver is to be transported and evaluated at a hyperbaric medical facility.

The fact that a diver had been breathing oxygen enriched air will have no practical effect on the treatment protocol at the hyperbaric facility. The dose of oxygen a diver receives during oxygen enriched air diving is not sufficient to warrant a change in treatment protocols. Standard recompression treatment options should be used.

There is much more to decompression sickness and its evaluation and treatment than is covered in this overview. The *NAUI Scuba Rescue Skills and Techniques* text and course covers this subject in greater detail, and the U.S. Navy Diving Manual is also an excellent resource.

Evacuation and transportation to hyperbaric medical facilities can be arranged either through local Emergency Medical Services, the United States Coast Guard, or the Divers Alert Network depending on where you are. Divers should have an emergency plan in place before diving begins.

Oxygen toxicity

Although oxygen toxicity problems rarely occur during no-stop enriched air diving, it can happen and divers should be prepared for it. The most likely cause would be exceeding the oxygen exposure limits, but another cause could be an incorrect mix for the depth being dived. This could result from inaccurate gas analysis, but more likely from an incorrect or missing

CNS Oxygen Toxicity Signs and Symptoms

[Convulsion]

Visual disturbances, including tunnel vision

Ear ringing

Nausea

Tingling, twitching or muscle spasms, especially of the face and lips

Irritability, restlessness, euphoria, anxiety

Dizziness, dyspnea

Figure 13-4. Oxygen toxicity signs and symptoms. Effects may come on in any order or may even begin with a convulsion. The mnemonic, VENTID, helps one to remember the signs and symptoms.

cylinder label. There are some signs and symptoms (Figure 13-4) that can warn a diver of oxygen toxicity, but an oxygen convulsion can occur without warning.

The best prevention of oxygen toxicity problems is to ensure a correct analysis and to maintain oxygen exposure levels at 1.4 atm or lower. However if there are any signs of oxygen toxicity the diver is to ascend immediately to a shallower depth and end the dive. The greatest threat from an oxygen convulsion is drowning.

If a convulsion does happen do not spend time trying to reinserting the mouthpiece, it will not usually be possible. Take the diver to the surface as soon as possible to avoid drowning. Once the diver is at the surface, treat for near-drowning according to signs and symptoms, and for DCS and AGE as appropriate. The rescuer should also be monitored for signs and symptoms of DCS or AGE and treated for omitted decompression if it were missed. If a convulsing diver is able to breathe (perhaps through a full-face mask) wait until the "tonic" part of the convulsion (the initial extreme stiffness) is over before heading for the surface. For the scuba diver who has spit out the mouthpiece, embolism is a possibility but drowning is a certainty, so get the diver out of the water as quickly as possible. ■

Chapter 13. Knowledge Review—Contingencies: If Things Don't Go as Planned

Before moving on to the next chapter, **Technical Diving Overview,** please test your understanding of this chapter's information by completing the **Knowledge Review**.

1. The minimum supply of oxygen to have on hand is enough to support ________ divers for up to ______ hours.

2. A ___________ air supply is the best defense for out of air emergencies.

3. If there is no alternate air supply and the divers buddy is not available to help there are two options for ascent to the surface. They are _________________ and ___________.

4. Once a diver has obtained emergency air from either a redundant supply or a buddy the ascent should include _____________________ .

5. An enriched air diver has entered decompression and now must breathe air only from a buddy. The diver is to make the decompression stop and ___________ the stop time.

6. A diver is to always carry ________________ on every dive.

7. A diver surfaces while omitting some decompression. The protocol is to breathe oxygen at the surface for _____ times the missed decompression time, but not less than _____ minutes.

8. A diver suspected of decompression sickness should be __________________ and __________________ .

9. The most likely cause of oxygen toxicity would be an _____________________ for the dive.

10. At first signs of oxygen toxicity the diver should ___________________________ .

Answers for Chapter 13

1. Two; two
2. Redundant
3. Emergency swimming ascent and Buoyant emergency ascent
4. A safety (or decompression) stop
5. Double
6. Diving tables
7. Breathe surface oxygen for three times the missed stop time but not less than 30 minutes.
8. Placed on 100% oxygen and transported to the nearest hyperbaric medical facility.
9. Incorrect mix
10. Terminate the dive and go to the surface.

14 TECHNICAL DIVING OVERVIEW

Chapter 14

TECHNICAL DIVING OVERVIEW

LEARNING GOALS

In this chapter you will:

- Be introduced to technical diving.
- Learn some history of technical diving.
- Be able to define technical diving.
- Learn about the techniques employed by technical divers.
- See what a technical diver looks like.
- Understand the need for additional training.
- Be introduced to the NAUI diving technical programs.
- Begin your own self evaluation to learn if technical diving is for you.

New Terms in This Chapter

Technical diving
Untethered
Bottom mix; back gas
Intermediate mix
Sidemounts; wing tanks
Scooter, DPV
Drift decompression
Decompression station/habitat
Rebreather
Full-face mask
Hookah


Figure 14-1. Technical diver Kathy Weydig dressed in dry suit, twin tanks with back plate and harness, redundant regulators, high powered canister light, decompression gas cylinders, decompression computer, and emergency equipment.

Technical diving

In the middle 1980's a new form of diving began to develop, scuba diving activities that go way beyond the usual no-stop limits. By using special techniques and equipment divers learned to do ocean and cave exploration in the 150 to 350 fsw (50-100 msw) range. This kind of diving had been done for quite some time, but quietly and without notice except for an occasional accident or significant find, and the only communication was one-on-one by word of mouth. Then in 1990 Michael Menduno, a diver from California, started a small magazine that addressed these activities. His *aquaCorps Journal* gave "technical diving" its name (as an analogy to technical mountain climbing) and started the technical revolution in sport diving by talking about it. Divers who were starved for information and techniques finally had a voice; those who were adapting and improving commercial and military techniques found others with similar interests.

Technical diving has evolved into a legitimate part of the recreational diving sector. Training agencies sprouted up, and equipment manufacturers began to develop and market gear specifically for "high tech" diving (Fig. 14-1). However, technical diving is not just about equipment; it requires a high level of training and discipline, and a substantial investment in personal preparation as well as equipment. Technical diving originated with cave divers who needed special decompression and breathing gas management techniques. The development of these techniques allowed technical diving to expand.

Let us make it quite clear that this chapter is not dedicated to convincing divers that they should become technical divers. Quite the contrary, it is to define the scope and highlight the risks of such activities so that anyone interested can approach the challenge with eyes wide open. You should not even dream of doing technical diving unless you are willing to do it right. Nevertheless, one definite benefit is that technical diving techniques offer an alternative to diving deep with air.

Figure 14-2. USS Monitor at a depth of 235 fsw (72 msw).

What is a technical dive?

A technical dive is a self-contained untethered dive in which the diver switches breathing gas during the dive. Diving with a rebreather is also technical diving, and in fact the term "technical diving" has been used in the U.K. for that type of diving for nearly half a century.

Technical diving practice usually involves descent while breathing a "bottom mix," followed by one or two "intermediate" decompression mixes of oxygen-enriched air, and finished by breathing oxygen or a high oxygen mix at the shallow decompression stops. The bottom mix is usually a "trimix" composed of nitrogen, helium, and the appropriate oxygen for the target depth. There are variations on this pattern depending on the mission or other factors. Since there is no hose to supply gas from the surface (hence the "untethered") the method requires the diver to carry a great deal of gas. Effective thermal protection, sophisticated buoyancy control, and many other factors must be considered.

Deep recreational dives

Recreational diving is well recognized as limited to a depth of 130 fsw (40 msw), and it is further limited to no-stop dives with air or oxygen enriched air as the breathing gas. Realistically, these are not the true limits within which all recreational divers operate, but they are the limits to which divers are initially trained by the diving training agencies. "Deep" is a relative term that involves the diver's own skill and preparedness as much as it does the water depth. Within these limits special "deep" training is needed to go even as deep as 130 fsw (40 msw).

For some years now some scuba divers have exceeded the 130 fsw (40 msw) limit, using decompression stops when necessary, and under some conditions have even used oxygen for decompression. These divers customarily went well beyond the depth at which nitrogen narcosis can become seriously debilitating; although the narcotizing effect may feel good, the diver cannot solve problems or deal with emergencies. As depth increases much beyond about 190 fsw (60 msw) the PO_2 in air also begins to become a risk factor due to CNS (central nervous system) toxicity.

Because of the narcotic risk, in the late 1980's deep cave divers began to add some helium to their bottom mixtures to reduce the narcosis. This also allowed the oxygen fraction to be reduced, allowing a lower PO_2 to be used at bottom depth and thus making longer bottom times feasible with less risk of oxygen toxicity. These special mixtures (mainly trimix) made special decompression tables necessary, and these were developed. This technology quickly spread from caves to deep wreck divers, who learned to use the same techniques with diver-carried gas.

Definitions: "Technical diving" and "nitrox"

What is "technical diving?" By one definition the minimal requirement of a technical dive, the characteristic that sets it off from recreational diving, is that on a technical dive the diver uses more than one breathing mixture. Just diving beyond the limits defined for recreational diving is not enough to qualify as technical diving, especially if air is the only breathing gas.

NAUI defines a category of **recreational technical diving** for purposes of diving instruction and insurance as diving that is not commercial and that meets any of the following conditions: Depth beyond 130 fsw (40 msw), oxygen-nitrogen breathing gas of 41% or greater oxygen or any other non-air mix, and/or planned decompression.

The practical depth limits of enriched air are less than the 130 fsw (40 msw) limit for recreational diving. The technical diving community will generally agree that single-mix diving with enriched air or "nitrox" is not technical diving.

Although the contrast with the recreational diving domain is clear enough, since most technical divers are in it for fun it is in fact "recreation." Some are photographers, treasure hunters, and wreck and cave enthusiasts, so there is an extra incentive beyond just "fun," but rarely are these divers "employees" in the traditional sense (therefore they are different from commercial divers). Still, it is well recognized that technical diving practice does not meet most occupational safety standards for diving.

Equivalent Narcotic Depths

Actual Depth fsw	Actual Depth msw	END with 50% He trimix fsw	END with 50% He trimix msw
165	50	66	20
180	55	74	23
200	60	84	26
230	70	99	30
260	80	114	35

Figure 14-3. Equivalent narcotic depth, "END". A very rough estimate of the equivalent narcotic properties of a tri-gas mixture containing 50% helium, expressed as a depth diving with air. The relative proportions of oxygen and nitrogen are not pertinent, only the helium.

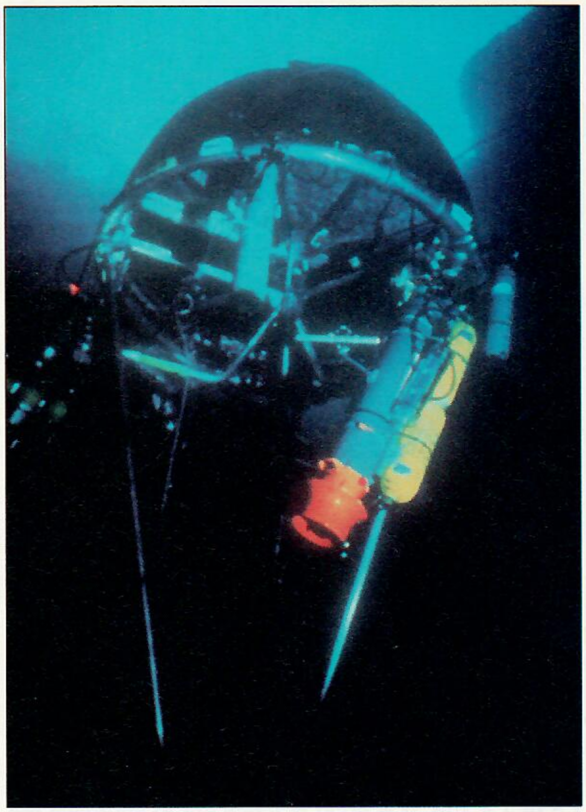


Figure 14-4. Decompression station used at Wakulla Springs.

Technical diving practice

The technical diver tries to be self-sufficient. Technical divers often work in teams of two or more, but the "buddy system" as used by recreational divers is not usually regarded as an effective safety reserve except in special circumstances. Tech divers do, however, use a variety of redundancies, including such things as extra regulators, back-up gas, and survival gear. The surface cannot often be regarded as a safe haven, either because it cannot be reached (from a cave or inside a shipwreck) or because the diver has a significant decompression obligation and cannot surface without stops. Once technical divers enter the water they are, for the most part, on their own.

Special gas mixes

A typical technical dive might be to explore a shipwreck at a depth of 250 fsw (75 msw). The diver might carry four scuba tanks of gas. Two of these might be large tanks joined with an isolation manifold filled with a bottom breathing mixture, enough to allow up to 30 minutes of time at the bottom depth (allowing some as a reserve). These "back" tanks are mounted to a back plate and harness that have a "wing" type buoyancy bladder sandwiched between the plate and the tanks. This system keeps the tanks snug to the body and the overall system simple and streamlined.

The mix would most likely be a "trimix" of oxygen, helium, and nitrogen, with the oxygen level selected to give a favorable decompression but primarily to stay out of the range of CNS oxygen toxicity. The helium component in the trimix could range between 17 and 50%, for example; it is chosen to give an adequate reduction of nitrogen narcosis. Conducting dives to, say, 260 fsw (80 msw) with the 50% helium trimix would yield narcosis levels roughly equivalent to diving to 114 fsw (33 msw) with air (Figure 14-3). The reduction in narcosis allows dives of this type to be done with a much lower risk than if done on air, which makes using trimix a smarter choice for diving to these depths. Gas mixtures are available at some specialized dive shops. Many expedition leaders in remote locations make their own mixes. In any case it is considered essential for the diver to check each mix with an oxygen analyzer before diving.

Besides the "back gas" or "bottom mix" one or two "side mount" or "wing" tanks might contain an intermediate or "decompression" mixture. This would probably be an enriched air mixture, again chosen to optimize decompression, avoid oxygen toxicity, and be of sufficient quantity for the job. Sometimes two different intermediate decompression mixtures are used. Still another tank usually contains pure oxygen or high-oxygen enriched air, to be used for the last part of the decompression. Sometimes oxygen is supplied from the surface on a "hookah" rig. Each tank or tank manifold has its own regulator, of high quality and reliability. Keeping track of all these tanks and mixtures is a formidable task, and failure to do so has resulted in fatalities.

Figure 14-5. AGA full-face mask with communications.

Maintaining the right oxygen level is an ongoing problem in technical diving, mainly to ensure that CNS toxicity is avoided, but also to optimize the decompression. The NOAA oxygen exposure limits (Chapter 4) allow an exposure of 1.6 atm PO_2 for as long as 45 min, but this limit is only appropriate for a diver not working hard and with no buildup of CO_2; most technical divers wisely use a lower limit, such as 1.5 or 1.4 atm. It is good practice not to approach the 1.6 atm limit too closely. Management of the slower acting "whole body" oxygen toxicity is only a consideration in an extreme exposure technical dive, or sequential dives.

Special decompression techniques and equipment

Decompression from these dives can be quite long, up to several hours. Tech divers need to ensure that they have an appropriate means for decompression. In the open ocean an anchor line or other type of float on the surface that allows for an ascent line to be used is essential. In areas where a static decompression line cannot readily be used, "drift decompression" techniques are employed. Here a diver floats with the current on a line attached to a buoy; this reduces diver exertion and can reduce the "wind chill" effect of a current, making the decompression more effective as well as more relaxing. It requires a highly experienced boat captain and dive team, and very careful planning to do it successfully. In a cave, it is a good idea to use a comfortable location away from the main line into the cave so the decompression does not interfere with other divers.

For some dive projects where decompressions take many hours special decompression stations or "habitats" are used. These are placed in the water so the diver can conduct part of the decompression in a semi-dry or dry environment that helps reduce both the risk and the dire consequences of an oxygen convulsion. These stations are often supplied with oxygen by "hookah" hose from tanks at the surface. These are similar in principle to a commercial diver's diving bell.

Staying warm and dry

As noted in Chapter 12, thermal protection for extended dive time is critical. Most divers use dry suits for technical dives, even in warmer waters. Supplementing dry suit underwear for passive thermal protection, some divers inflate their suits with argon gas instead of air or a mix containing helium, because argon has lower thermal conductivity and thus greater insulating power.

It is best not to urinate in the suit's insulation because this reduces its effectiveness (among other things). However, high fluid intake is necessary for proper fluid balance, so diapers and various "relief tube" devices are used on long dives.

Having enough gas

Carrying enough gas is always a challenge for the technical diver, yet it is the critical element to survival. A few years ago many technical divers overpressurized their tanks to cram more gas in. Although no catastrophic events are presently known to have resulted from this practice, it is very risky and not recommended. Tanks with larger capacities without the need for extra pressure are now available. Back mounted tanks can now carry as much as 300 cubic feet of bottom mix and decompression tanks upwards of 100 cubic feet, making the need for over-pressurization unnecessary. Cave divers in particular have worked out sophisticated methods for storing additional gas cylinders in the cave system. These tanks are placed before the actual dive is done. Staging of tanks is also done, but less confidently, by open water deep divers. Open water technical divers usually carry all the gas they need for a given dive.

Regulators and full-face masks

Most technical divers use a standard scuba face mask and breathe from a demand regulator, and also have a redundant regulator on a long hose. The long hose simplifies gas sharing in an emergency, and allows two divers to swim in tandem comfortably while sharing gas. Some are beginning to look at full-face masks and through-water voice communications (Fig 14-4), but these are not universal, and unfortunately, not very practical while using scuba because they cause extra gas consumption. One important benefit of a full-face mask is that it improves the chance of survival after a convulsion. The convulsion itself is not necessarily damaging, but drowning becomes almost inevitable when a diver spits out the mouthpiece; full face masks greatly reduce this aspect of the risk. Full face masks also make it more difficult to share gas; this requires special connectors rather than just changing mouthpieces.

Other equipment

Other necessary equipment adds to the complexity and overall investment of a technical diver. High-powered lights and lines are needed for cave and wreck penetrations. For long swims (as in a cave penetration) or swimming in a current the tech diver might use a battery-powered "scooter," or diver propulsion vehicle. Open-water divers also carry a personal ascent line with a float to help in the decompression should the anchor line not be available, and signaling devices such as flares, dye marker, electronic beacons, and strobe lights.

Decompression tables and software

There are no published decompression tables for trimix diving of the sort that make air and oxygen enriched air diving so accessible. In early technical diving most decompression was done with special "custom" tables prepared for the particular exposure by a few table specialists. In fact, these tables were the breakthroughs that allowed "technical diving" to evolve.

A new decompression option has developed in the last several years in several PC-based computational programs that can be used by the diver to calculate their own decompressions. These programs all use the algorithms of the late Prof. A.A. Bühlmann; these are the only suitable algorithms published in a form that can be readily adapted. The algorithms are effective, and with most of the application programs the user can adjust the degree of conservatism. A diver should have considerable experience with decompression tables and decompression diving and a good understanding of the risks of oxygen toxicity and narcosis before relying on do-it-yourself programs of this sort.

Dive computers

Most technical dives are beyond the capacity of normal dive computers (DCs). Some computers can calculate air decompressions that require stops as deep as 60 fsw (27 msw), but these decompressions become quite lengthy. Some enriched air DCs (Fig 14-6) allow for up to three nitrogen-based intermediate gas mixes to be used. Computers that can calculate helium decompressions are under development. One currently available unit allows for gas switches "on the fly"

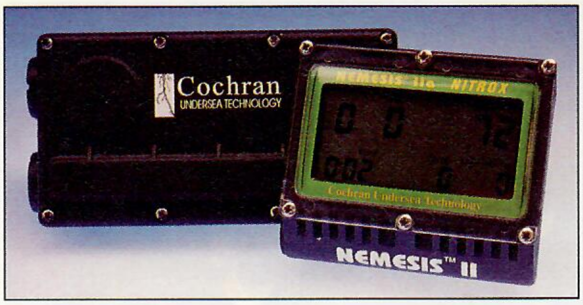


Figure 14-6. Cochran Technology Nemesis Nitrox IIa. This computer uses hoseless technology and allows for the use of three nitrogen based gas mixes for calculating decompression requirements.

on either open or closed circuit equipment. Other available DCs are useful as timing and data recording devices.

Decompression sickness

Responsible divers, especially technical divers, have a definitive plan in place for evacuation and treatment in the event an incident occurs. The distinction here is that technical divers make more stressful exposures and expect DCS to occur occasionally and are prepared for it, whereas the recreational diver generally does not give this much concern until it happens.

The matter of treatment for DCS is not a simple one. There is a high premium for beginning treatment promptly. Ideally a "deck" decompression chamber ("DDC") will be at the dive site. An alternative to a full chamber is a portable recompression chamber. These are primarily hyperbaric stretchers for evacuation, not for treatment on site; they are effective as well as expensive. If a chamber is not on site, the next plan is to evacuate the diver to the most accessible one. Diving operations in remote areas also may plan to use in-water recompression with oxygen, and arrange to have the gas supply, full face mask, procedures, and essential support team on hand as a minimum to carry out this option.

Rebreathers are here

For some conditions the limit to a dive is the diver's endurance or ability to stay warm. For most technical dives, however, the limitation of what an untethered diver can do depends on how much gas can be carried. A rebreather can provide a significant time advantage over open circuit (scuba) systems. A typical rebreather weighs about as much as a standard scuba rig, maybe less, but can provide up to eight hours of breathing time at depth. Thus rebreathers are an attractive tool for exploration divers who need much more bottom

Figure 14-7. Diver with a ***Prism*** *semi-closed circuit rebreather.*

time than conventional scuba can offer. Closed-circuit recirculating breathing apparatuses are not new. They have been used by the military for almost half a century, with some dating back more than a hundred years.

A rebreather consists of a breathing bag or counterlung, a canister for absorbing CO_2, a pressurized gas supply, and the necessary valves and hoses (Fig 14-7). With each breath a diver takes, some oxygen from the mixture is used up by metabolism, and on exhalation some carbon dioxide is given off. A rebreather passes the exhaled gas through a CO_2 chemical absorbent and "scrubs" the CO_2 out of the system. The remaining gas is sent back through the breathing loop where it is replenished with a small amount of gas to make up the oxygen used on the previous breath. Because the diver gets to re-breathe most of the gas, only a small amount is used and it lasts much longer than if it is all exhaled.

The most sophisticated rebreathers are electronically controlled and are designed to maintain a constant oxygen partial pressure throughout the dive, at various depths and under different work loads and conditions. The constant oxygen partial pressure enables decompression to be optimized. Rebreathers with built-in computers perform other functions, such as decompression, system monitoring, and even navigation. Simpler "semi-closed" rebreathers use a constant flow of an oxygen-rich mixture to maintain enough oxygen in the counterlung, with a portion of each breath exhausted overboard. With this type the oxygen level varies inversely with the exercise rate, making it more difficult to plan an efficient decompression. Some units link the oxygen inflow to the divers breathing level (respiratory minute volume) and thus maintain a more nearly constant oxygen level and permit a more efficient decompression.

Rebreathers require a significant investment in time, money, training, and maintenance, but they have their place in recreational diving. Consistent with their inherent problems, rebreathers are useful for long diving exposures and where gas availability is a problem, and in situations where the limited bubble activity makes interaction with aquatic life easier.

Getting into technical diving

The team approach

Although training programs are designed to develop an individual diver's skills and knowledge, the common thread among all technical divers is equipment redundancy, self sufficiency, and the team approach. Although this may sound contradictory, a technical diver cannot do it safely alone, and the good divers know that. It takes commitment from a team of divers to train properly and to dive responsibly.

Throughout the world divers are conducting dive expeditions on shipwrecks and in caves. Shipwrecks like the *Andrea Doria, Lusitania, USS Monitor, Edmund Fitzgerald, USS Wilkes Barre,* the WWII wrecks in Truk Lagoon and on Bikini Island, and recently the *Britannic,* are all being dived. Cave systems in the Yucatan, Central Florida, Europe, and Blue Holes in the Bahamas are being explored with team efforts.

New technical divers are best served when they team up with experienced technical divers and form groups that support each other and train together on a regular basis. There is a growing "community" of diverse individuals with varying levels of training, experience, and sophistication who have a common goal to extend their diving capability beyond the traditional limits and to do this with safety.

For one or two untethered divers to penetrate a wreck or a cave at 250 fsw (70 msw) without a support team is foolhardy. At the very least a backup/standby diver and topside personnel plus a workable emergency plan are minimum requirements. This is part of what is meant by "doing it right."

Standardized training programs

Whereas commercial, military, and scientific dives are nearly all handled as project operations with leadership and administrative structures, the pattern for technical diving may involve a buddy pair or trio, but today it too rarely involves a full team approach. Each diver has her own equipment, tables, and often procedures. This means that there are often limitations in things like organization, communications, and topside support.

NAUI has developed a series of technical training courses that encompass the tools, information and techniques necessary for responsible technical diving. This book, although not intended to be a technical diving program, provides the significant groundwork necessary to the successful progress of a technical diver.

The NAUI Technical Diver Courses address particular areas of technical diving. Accordingly, these technical courses are designed to provide more detailed training than specialty diver courses and result in more extensive qualifications. The programs are designed to give the diver the opportunity to enjoy organized diving that yields experience and documents training in technical diving activities. Presently five courses are available, each building on the previous ones.

Technical Enriched Air Diver–this program provides the enriched air diver with the skills and knowledge needed to reduce the risks of using enriched air breathing mixtures of 25% through 80% oxygen. This course goes into greater detail on all the special aspects of enriched air diving, stressing optimization and safety.

Decompression Techniques Diver–this program gives the diver a working knowledge of the theory, methods and procedures of planned decompression diving.

Extended Range Diver–this program gives the diver the training and experience necessary to understand the hazards of and uses of air or oxygen-enriched air for dives that require staged decompression, using oxygen enriched air mixtures and/or oxygen for decompression.

Figure 14-8. NAUI Technical Diving Centers are specialists in technical diving training.

Technical Wreck Penetration–helps train the diver in the hazards and safety procedures necessary for wreck penetration where decompression may be involved.

Trimix Diver (levels I and II)–these programs introduce a diver to helium-based mixed gas diving for exploring deep water areas while managing oxygen and nitrogen exposure.

Should you dive tech?

While technical diving seems, to some, to be the next level of accomplishment for an enriched air diver, we urge you the diver to take some time to examine and explore the reasons why you want to venture deeper and longer. It is not safer than no-stop enriched air diving, although it has some rewards.

Some questions divers should ask themselves are:

Am I getting into technical diving too soon? People should have a fair amount of practical diving experience and be comfortable in a variety of environments before attempting technical diving. If a diver is not completely comfortable in the water, technical diving is not a practical option.

What is the real motivation? Is it a sincere healthy interest in a particular dive site or challenge?

Are you physically strong enough? Technical diving places significant physical demands on a diver. It requires carrying heavy equipment and being able to swim with it, sometimes in adverse conditions.

Are you disciplined? Technical diving requires a diver to be disciplined in procedures and technology, and to remain up-to-date with training and diving procedures. Technical dive training does not stop with one training program.

Do you understand your emotional limitations? The technical diver may need to function under stress and task loading. A diver should be capable of getting out of trouble on his own and be comfortable doing it.

These are just some questions you should ask yourself before making the move to technical diving. Self evaluation is the key to a responsible technical diver. While procedures for technical diving have been successful in extended range underwater exploration, technical diving remains a high risk activity. These traits help minimize that risk. ■

Chapter 14. Knowledge Review—Technical Diving Overview

1. Technical diving began to take off when ___________ became available.
2. Technical diving was invented to avoid diving deep with __________.
3. In general terminology, not NAUI's, a technical dive is a dive that uses __________ or __________ .
4. Helium mixtures are used to reduce the effects of _____________ and to limit ___________ .
5. Technical divers strive to be _______________ .
6. A regulator fitted with a __________________ hose is standard equipment.
7. To avoid long swims technical divers sometimes use ___________________ .
8. Decompression from a classical technical dive usually requires ________ .
9. To improve the insulation technical divers fill their dry suits with ________ .
10. Optimal technical diving operations require a ____________ approach.

Answers for Chapter 14

1. Appropriate decompression procedures
2. Air
3. More than one breathing gas or a rebreather
4. Nitrogen narcosis; oxygen exposure
5. Self-sufficient
6. 5 to 9 foot long hose
7. Diver propulsion vehicles or scooters
8. Multiple gases
9. Argon
10. Team

This list contains both references cited in the text and additonal reading. Citations in the text are by author and date.

Ballantyne L, Delp B. 1996 (1st quarter). EANx: Enriched vs. enhanced breathing gas. Undersea J :34-35, 38.

Barsky S, Long D, Stinton B. 1992. Drysuit diving. A guide to diving dry. San Diego: Watersport Books, Inc.

Bell RI, Borgwardt RE. 1976 Mar. The theory of high-altitude corrections to the U.S. Navy Standard Decompression Tables. The Cross corrections. Undersea Biomed Res 3(1):1-23.

Bennett PB. 1997. Inert gas narcosis and high pressure nervous syndrome. In: Bove AA, ed. Bove and Davisí diving medicine, 3rd ed. Philadelphia: WB Saunders.

Bookspan J. 1995 Jun. Diving physiology in plain English. Kensington, MD: Undersea Hyperbaric Med Soc.

Brauer RW. 1985. Acclimation to nitrogen narcosis: A review. In: Hamilton RW, Kizer KW, eds. Nitrogen narcosis. UMS 64WS(NN)4-26-85. Bethesda, MD: Undersea Medical Soc.

Bühlmann AA. 1984. Decompression: Decompression sickness. Berlin: Springer-Verlag.

Bühlmann AA. 1993. Tauchmedizin: Barotrauma, Gasembolie, Dekompression, Dekompressionskrankheit. Third ed. Berlin: Springer-Verlag. (In German)

Bühlmann AA. 1995. Tauchmedizin: Barotrauma, Gasembolie, Dekompression, Dekompressionskrank-heit, Dekompressions computer. (Diving medicine. Barotrauma, gas embolism, decompression, decompression sickness, decompression computers.) In German. 4th edition. Berlin: Springer Publishing House.

Clark JM, Lambertsen CJ. 1971. Rate of development of pulmonary oxygen toxicity in man during oxygen breathing at 2 ATA. J Appl Phys 30(5): 739-752.

Egi SM, Brubakk AO. 1995 Sep. Diving at altitude: A review of decompression strategies. Undersea & Hyperbaric Med 22(3):281-300.

Hamilton RW. 1997. Mixed-gas diving. In: Bove AA, ed. Bove and Davisí diving medicine, 3rd ed. Philadelphia: WB Saunders.

Hamilton RW. 1992 Jan. Workshop findings: Evaluating enriched air ("nitrox") diving technology. Boulder, CO: Scuba Diving Resource Group.

Hamilton, RW. 1989 Dec. Tolerating exposure to high oxygen levels: Repex and other methods. Marine Tech Soc J (23(4):19-25.

Hamilton RW, Crosson DJ, Hulbert AW, eds. 1989 Sep. Harbor Branch Workshop on enriched air nitrox diving. Report 89-1. Rockville, MD: NOAA National Undersea Research Program. "Harbor Branch" Workshop.

Hartung KH. 1982. Use of gas mixers in shallow water diving. In: Seemann K, ed. Proceedings VIIIth annual congress of European Undersea Biomedical Society. Luebeck: Draegerwerk AG.

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

NOAA Diving Manual. 1979 Dec. Edited by JW Miller. Second edition. Washington: U.S. Dept of Commerce.

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

Shilling CW, Werts MF, Schandelmeier NR, editors. 1976. The underwater handbook: A guide to physiology and performance for the engineer. New York: Plenum Press.

Somers LH. 1997. Diving physics. In: Bove AA, ed. Bove and Davisí diving medicine, 3rd ed. Philadelphia: WB Saunders.

US Department of the Navy. 1985 Jun. US Navy Diving Manual. NAVSEA 0994-LP-001-9010. Volumes 1 and 2. Revision 1. Washington: Navy Department.

US Department of the Navy. 1993 Feb. US Navy Diving Manual. Volume 1 (Air Diving) Revision 0994-LP-001-9110. Washington: Navy Department.

Wienke BR. 1993. Diving above sea level. Flagstaff, AZ: Best Publ.

Wienke BR. 1994. Basic diving physics and applications. Flagstaff, AZ: Best Pub.

Wright WB. 1972. Use of the University of Pennsylvania, Institute for Environmental Medicine procedure for calculation of cumulative pulmonary oxygen toxicity. Report 2-72. Washington: U.S. Navy Experimental Diving Unit.

GLOSSARY

40% rule: An anecdotal rule that allows scuba regulators and other breathing gas equipment to be used with oxygen enriched mixtures with up to 40% oxygen content without the need for special cleaning.

ADT, actual dive time: The time from the moment of descent until returning to the suface.

AMDT, adjusted maximum dive time: For a repetitive dive, the no-stop time limit minus the residual nitrogen time.

Arterial gas embolism: (AGE, CAGE) Bubbles in the arterial circulation to the brain, usually causing paralysis and other neurological deficits. Caused normally by a lung overexpansion injury that allows air bubbles to escape from the lungs into the arterial circulation. Because of its cause it is sometimes referred to as "pulmonary barotrauma." In severe cases, AGE can be fatal. Treatment is immediate oxygen breathing and transport to a recompression chamber. Also known as air embolism. Symptoms may be similar to neurological (type II) DCS.

Air consumption rate: See SAC, surface air consumption, also see RMV. The amount or volume of air or breathing gas a diver consumes per minute.

Air embolism: See AGE, Arterial Gas Embolism

Air: The ambient atmospheric gas, the gas we breathe at sea level or compressed into scuba tanks. Consists of 21% oxygen, 78% nitrogen, and the balance as trace gases including argon, carbon dioxide, neon, and others. For industrial purposes air is described as containing 19.5 to 23.5% oxygen, balance nitrogen.

Algorithm: A formula or method, used here for the mathematical model or set of equations used to compute decompression tables.

Ambient pressure: The surrounding pressure. Under normal surface condiditons this is one atmosphere.

Analysis, gas: The precise measurement of gas components in a breathing mixture. Most diving operations will analyze for oxygen only.

ATA or ata: Occasionally used for atmospheres absolute, preferrably abbreviated atm or atm abs.

Atmosphere, atm: As used here, the pressure of the earth's atmpsphere at sea level, 101.325 kilopascals (kPa), 760.0 millimeters of mercury (mmHg) or 14.696 pounds per square inch (psi). Used as a unit for expressing gas pressures and partial pressures.

Atmosphere absolute, atm abs: Atmospheric pressure referenced to zero pressure.

Back gas: (also see Bottom Mix) the gas the technical diver carries on his back; the gas breathed on the bottom.

Bends: See DCS.

"Best mix": A gas mix chosen to optimize oxygen for efficient decompression yet minimal toxicity risk.

Bottom mix: Breathing mixture used at the deepest portion of a dive.

Bottom time: Time from the moment of descent to the beginning of ascent.

Boyle's law: The phenomenon of gas volume changing as a result of pressure changes. "For any gas at a constant temperature, the volume will vary inversely with the absolute pressure while the density will vary directly with the absolute pressure."

Buddy breathing: An emergency out-of-air procedure in which two divers share one second stage regulator and gas source while ascending to the surface.

Ceiling: A minimum depth to which a diver may ascend, or the lowest pressure, still staying within the limits of the computer or decompression table.

Charles' Law: The volume of a gas at constant pressure varies directly with the temperature.

Chemical potential: The potency or effectiveness of a chemical system. May be applied to individual gases as to their behavior in a mixture or as a function of pressure or partial pressure.

CNS oxygen toxicity: The toxic effects of breathing high-pressure oxygen on the central nervous system. May manifest as an epileptic-like convulsion that is dangerous to a diver because it may cause drowning.

CNS: Central nervous system

CNS oxygen "clock": (see O_2 limit fraction) the percentage of the maximum allowable exposure limit to oxygen at various partial pressures, according to a prescribed limit. The NOAA limits (NOAA Diving Manual, 1991) are frequently used in enriched air diving.

Contingency maximum operating depth: The depth range for a specific gas that gives an oxygen partial pressure between 1.4 and 1.6 atm.

Continuous flow mixing: A method of blending oxygen enriched gas whereby oxygen is mixed with air in the intake of an oil-free compressor and compressed as a gas mix, using on-line oxygen analysis.

Convulsion: A complex muscle spasm incorporating the whole body. Can be initiated by breathing oxygen at physiolgically high partial pressure. The convulsion in itself is not life threatening, but underwater a convulsion can lead to drowning.

Custom tables: Normally unpublished diving decompression tables that have been formulated for a specific diving operation using specific gas mixes to optimize bottom time and produce an efficient decompression.

Cylinder markings: For oxygen enriched air the standard for scuba tanks is a yellow tank with a green band. Cylinders also have information about the cylinder itself stamped into the metal. The Compressed Gas Association recommends that color alone not be used for identifying a cylinder's contents, only the label, because the color coding practice is not uniform.

Cylinder dedication: Specifying and properly identifying a scuba cylinder for use with a specific gas. A dedicated enriched air cylinder would require that it be properly labelled and cleaned for that use.

Dalton's Law: "The total pressure exerted by a mixture of gases is equal to the sum of the pressures exerted by each of the gases if it alone were present and occupied the volume."

DCAP: (Decompression Computation and Analysis Program) Hamilton Research's proprietary computer program to generate decompression tables. Used for decompression for military, industrial, scientific, technical and recreational diving.

DCIEM: Defense and Civil Institute of Environmental Medicine, Canada. DCIEM has issued a well-respected set of air tables and a protocol for using them with oxygen enriched air.

DCS: Decompression sickness. A condition caused by inert gas (nitrogen) bubbles forming in the body when a diver ascends too quickly. Also known as the bends. The onset of DCS can be within minutes of the ascent, though it usually occurs within 1 to 3 hours and occasionally up to 24 hours or even longer.

Decompression: The reduction of pressure or the release from compression. As used in diving decompression means a controlled recuction of pressure or ascent in the water.

Decompression sickness: (DCS, Bends) A condition caused by gas bubbles (typically nitrogen) forming in various parts of the body when a diver ascends too quickly, thus does not decompress properly.

Decompression station: A dry or partially dry chamber or flexible, air-filled container suspended underwater for decompression. Divers climb fully or partly into the gas space, getting out of the water for decompression. This allows the diver to stay warm and provides a better environment for breathing decompression gases. Sometimes divers call these "habitats" because they resemble underwater living chambers. See habitat.

Demand regulator: A device that delivers compressed gas upon inhalation "on demand."

DIN: (Named for Deutsches Institut fur Normung, or German Institute for Standards) Valve and regulator fittings featuring the "captured o-ring" design whereby the regulator is screwed into the cylinder valve. Adaptable to higher pressure ratings, typically in excess of 3000 psi. In Germany, all scuba fittings meet the DIN 477 valve spec, even the lower pressure scuba fittings. Currently the most reliable type of scuba valves.

Dive computer: An electronic device that monitors time and depth and uses a a mathematical algorithm to display time, depth and decompression information.

Dive planning software: Computer software that allows a diver to plan no-stop and decompression profiles.

Doppler bubble detection: An ultrasonic device that uses ultrasonic sound to monitor gas bubbles moving through the bloodstream. The "Doppler" method only detects moving bubbles. Doppler bubble detection is a useful research tool in studying the bubbles of decompression, some of which may lead to symptoms of decompression sickness.

DPV: A diver propulsion vehicle used to transport an untethered diver under water, usually battery powered.

Drift decompression: An open water procedure whereby a diver conducts decompression while drifting with the current below a surface marker or buoy.

EAD: Equivalent air depth.

EAN: Enriched air nitrox (see oxygen enriched air). An oxygen-nitrogen mixture containing more than 21% oxygen.

EANx: A way to express a specific enriched air mix. A mixture that contained 32% oxygen would be expressed as EAN32.

Electrochemical oxygen sensor: A sensor that uses a voltage and specific electrodes to break up oxygen into components that can be measured electrically.

Empirical: Data, judgements, or information based on experience.

Enriched air nitrox: (see; EAN, oxygen enriched air) Any oxygen nitrogen mixture containing more than 21% oxygen.

Equipment conversion: Method by which equipment is cleaned and prepared for oxygen or enriched air use.

Equivalent air depth (EAD): The depth using air that has the same nitrogen partial pressure as the enriched air being used for the dive. For example, using an enriched air mixture containing 32% oxygen a diver who is at 110 fsw is exposed to an inert gas level equivalent to 90 fsw.

ESA, Emergency Swimming Ascent: An independent, emergency ascent made upon depletion of the diver's air supply. Also referred to as an emergency out of air ascent or a swimming ascent.

Fire triangle: the three ingredients needed to start and keep a fire burning; oxygen, fuel, and a source of ignition.

Fraction: F, the fraction of a gas as used in mathematical equations. Eg: $F = 0.32$ is equivalent to 32%.

fsw (msw): Depth measured in feet of sea water. Defined as 1/33 of a standard atmosphere, or 0.0307 kPa. When used in this text the corresponding metric conversion is also made. The conversion factor between fsw and msw is 3.2568 fsw per msw.

Fuel cell: In this context, one type of electrochemical sensor used to anaylze for oxygen.

Full-face mask: (FFM) A diving system with the regulator built into a diving mask that completely covers the face, nose and mouth. Provides extra safety margin with high oxygen exposures (helps prevent drowning in case of a seizure) and is easily adaptable to communication units.

Gas laws: the physico-chemical laws that predict how a gas will behave with changes in pressure, temperature, and volume.

Gas analysis: A procedure whereby the fractions of gas in a breathing mixture are determined. Generally it is used to determine the percentage of oxygen in a mix. Most diving operations will analyze for oxygen only.

Gay-Lussac's Law: The gas law that the pressure of a gas at a constant volume is directly proportional to the absolute temperature. This is the phenomenon that causes gas to get warm when compressed in a scuba tank.

Habitat: An underwater dwelling for divers in saturation. Divers may be supported for extended periods of time to accomplish work objectives and then be decompressed. See also decompression station.

Haldane: John Scott Haldane, a Scottish physiologist, who in the very early part of the 20th century developed methods of determining gas loading and unloading into tissues for the creation of decompression schedules from compressed gas dives.

Half time: The exponential rate at which various theoretical tissue compartments on-gas and off-gas. The times represent the number of minutes it takes for an individual compartment (or tissue group) to fill to 50% of its capacity to hold a given gas.

Henry's law: "The amount of gas that will dissolve in a liquid at a given temperature is directly proportional to the partial pressure of that gas."

Hookah: A surface-supplied compressed air or gas apparatus which delivers breathing gas to a diver through a hose. Typically used for shallow water, scallop and lobster diving, but is also used in recreational diving for the delivery of gas for safety or decompression stops.

Hypothermia: A condition in which the deep tissue or core temperature of the body falls below the normal physiological range, approximately 94°F (35°C) rectal. Also used to mean any condition where heat has been lost from the body.

Hypoxia: A condition brought on due to an insufficient partial pressure of oxygen (PO_2) in a breathing gas. There are several physiological manifestations of hypoxia leading to a failure of the tissues to receive sufficient oxygen.

Ideal gas laws: The rules that apply to all gases in general, but the behavior of specific gases varies slightly from the general rules. The rules are said to apply to a hypothetical "ideal" gas.

Inert gas narcosis: Loss of judgment and cognitive skills caused by the narcotic effect of the inert gases and probably oxygen components of breathing gas at elevated pressures (i.e. at depth). The condition is generally alleviated upon ascending, or by changing the mixture ratios to reduce the partial pressure of the offending gas or gases. Argon, nitrogen and hydrogen are known to be narcotic, but helium and neon are not.

Intermediate mix: A gas mixture used for decompression between the bottom mix and the final oxygen decompression.

Instantaneous descent: A hypothetical mechanism whereby the bottom time starts the instant descent begins. Used when calculating tables to enable the diver to ascend without regard to rate. Descent time is part of the bottom time.

Letter group: A letter symbol for the residual nitrogen remaining in the body from previous dives.

Martini's Law: A facetious gas "law" described by Capt. Jacques Cousteau that equates the narcotizing effect of nitrogen to one dry martini for every 50 fsw (15 msw).

Maximum dive time; (MDT) The no-stop or no-decompression time or limits (NDL). The length of time that may be spent at a given depth without being required to make a mandatory decompression stop.

Maximum operating depth: (MOD) The maximum depth a particular gas can be used without exceeding an oxygen toxicity limit, based on the partial pressure of the oxygen at depth. In NAUI practice the depth at which the PO_2 of the mix reaches 1.4 atm.

MDT = no-stop limit: Maximum dive time, the time allowed without requiring a decompression stop, from the moment of descent to beginning of ascent.

Membrane separation: Separation of gases by forcing them under pressure through a differentially permeable membrane; the gases pass through at different rates so they can be separated.

MOD: Maximum operating depth, which see. The deepest a mix can be used without exceeding an oxygen exposure limit.

msw: Meters of sea water. A msw is defined as 1/10 bar or 100 kPa. 3.2568 fsw = 1 msw.

Multilevel dive: A type of dive that does not conform to a maximum depth and time square-dive profile. Ideally, such dives are conducted with the deepest sections first and then the diver ascends progressively to various shallower depths.

Narcosis: See nitrogen narcosis and inert gas narcosis.

Nitrogen narcosis: Loss of judgment and cognitive skills caused by the nitrogen and probably oxygen components of breathing gas at elevated pressure (i.e. at depth). The condition is alleviated upon ascending. Also known as "Rapture of the deep." A form of inert gas narcosis. With air, narcosis can be encountered at depths as shallow as 70 fsw (21 msw), and the narcosis becomes seriously debilitating as pressure increases; for most individuals this is below about 150 fsw (45 msw).

Nitrogen: Makes up approximately 78% of the air we breathe; the gas responsible for narcosis and DCS when diving on compressed air.

Nitrox: (also see EAN and Oxygen Enriched Air) A non-specific term often applied to a breathing gas mixture of nitrogen and oxygen. Generally means the oxygen percentage is in the range of 21-50%. In habitat diving nitrox has always meant an oxygen percentage less than 21%.

No-decompression: A dive that does not require a decompression stop. The term "no-stop" is preferred to remind divers that all dives involve decompression, even though stops may not be needed.

No-stop dive: A dive that does not require a decompression stop.

O_2 limit fraction: (see CNS "oxygen clock") The percentage of the maximum allowable exposure limit to oxygen at various partial pressures, using a specific set of limits.

OCEANx calculator: A NAUI product that allows a diver to determine oxygen exposure limits and to perform equivalent air depth conversions for enriched air mixtures; non-electronic.

Omitted decompression: A condition whereby a diver has not performed its required decompression time.

Open circuit: Breathing equipment that allows exhaled gas to be vented out of the system into the atmosphere.

OTU: (Oxygen Tolerance Unit) A unit of measure to describe exposure to oxygen, with concern for whole-body toxicity, usually over an extended period of time. OTU are calculated by the same equation used for the older units CPTD and UPTD.

Oxygen administration training: Training for the practice of administering oxygen by mask as first aid in diving accidents.

Oxygen service: A condition of equipment that is prepared for oxygen use, including the use of oxygen-compatible materials as well as being oxygen clean.

Oxygen clean: Refers to the cleanliness of a system or component, or more specifically, to the absence of contaminants. Contaminants vary but the most serious are those that act as a source of combustion such as oil, grease, paint, fingerprints, soot, lint, dust, metal particles, rust, cleaning solvents, and cleaning detergents. New scuba equipment is generally NOT oxygen clean.

Oxygen cleaning: The process by which equipment is prepared for oxygen service. "Formal oxygen cleaning" follows very strict cleaning, handling, and documentation procedures. "Informal oxygen cleaning" uses the same cleaning techniques but with less rigorous procedures for monitoring and documentation.

Oxygen compatible lubricant: A lubricant designed to be used in oxygen environments that does not burn in high pressure oxygen. Products like Christolube, Krytox, and Halocarbon, are compatible lubricants. Silicone is not a compatible lubricant.

Oxygen Enriched Air: OEA (see EAN and nitrox). Air that has been enriched with oxygen to a percentage above 21%. Typical OEA mixtures for recreational diving are 32% and 36% oxygen.

Oxygen exposure limit: Maximum time on a singe dive that the diver can be exposed to a certain partial pressure of oxygen without exceeding a particular limit or set of limits.

Oxygen toxicity: Short or long term physiological effects of elevated partial pressures of oxygen. Oxygen poisoning. Also referred to as CNS or "whole body" or pulmonary oxygen toxicity. See also OTU.

Partial pressure: The portion of the total gas pressure exerted by a single gas in a breathing mixture. Expressed as Pg for a given gas "g," or PO_2 in the case of oxygen.

Partial pressure mixing: A mixing method by which gases are combined in a pressure vessel using proportions of each gas to determine the composition of the resulting mixture. Each gas is added so that its partial pressure gives it the desired fraction of the resulting mix. A common method for mixing oxygen enriched air.

PO_2: Partial pressure of oxygen. It is recommended that the exposure not be allowed to exceed this level.

Pressure: The force acting on a unit of area.

Pressure, absolute: (see also atm) A pressure measurement referenced to zero pressure. Absolute pressure is the total pressure from all sources; includes water (hydrostatic) and air (atmospheric) pressure.

Pressure, athmospheric: (see also atm) The measure of the weight of the surrounding column of air at sea level. One atmosphere is equal to 101.325 kPa, 14.696 psi, 33.00 fsw, 34 feet of fresh water, 760mm Hg (mercury).

Pressure gradient: The difference in pressure between two separate locations. Used in diving to describe the driving force on a gas that causes it to move in or out of a body compartment.

Pressure swing absorption: A method of separating gases using differential absorption properties on a porous material, usually molecular sieve. The pressure swing involves alternating between pressurizing and evacuating the sieve bed.

Profile: A time, depth, and breathing gas plan or review of a dive.

Rebreather: A device that allows a diver's exhaled gas to be replenished and reused. Typical rebreathers allow a diver to use significantly less gas than is used with open circuit breathing equipment. Rebreathers also result in few bubbles.

Repetitive dive: Any dive following a previous dive within a particular time frame. According to NAUI, any dive within 24 hours of a previous dive is a repetitive dive.

Residual nitrogen: The nitrogen remaining in the body as a result of previous dives.

Residual nitrogen time, RNT: The time to be considered in planning a repetitive dive due to nitrogen remaining in the body from previous dives within the last 24 hours.

RMV, respiratory minute volume: The amount of air that is consumed in one minute, usually referenced to the rate at the surface. This is expressed in volume units such as cubic feet or liters per minute, or as pressue drop in the cylinder.

Rule of thirds: A rule used primarily by cave and wreck divers that states that the dive should be "turned" and exit begun when 1/3 of the gas supply has been used. This leaves enough gas for the diver to reach the exit with an equal reserve for the buddy.

Safety stop: A precautionary delay in ascent from a no-stop dive. The safety stop is usually taken at 15 fsw (5 msw) for 3 to 5 minutes at the end of every dive. Strongly recommended for all no-stop dives.

Saturation: In diving, the exposure condition such that additional time at depth does not increase the decompression time. As applied to an individual compartment, when it has absorbed all of a given gas at a given pressure that it can, it is considered saturated.

Schedule: One depth-time-gas combination for decompressing from a single dive exposure.

Scooter: Diver propulsion vehicle; see DPV.

Side mounts: Scuba cylinders carried on the sides or front of a diver. Side mounts are used in cave diving to ease passage through small openings. They are also used to carry additional gases on technical dives, usually that used for decompression. Also called wing tanks.

SIT, surface interval time: See surface interval.

Solubility: (see Henry's Law) the parameter describing how much of a specific gas will disolve in a specific liquid under specified conditions.

Square profile dive: A type of dive that involves going to one particular depth and staying there for the entire bottom time and then ascending to the surface without time at other depths, with the exception of safety and decompression stops.

Surface air consumption rate, SAC: (see RMV) The rate of underwater gas consumption converted to an equivalent surface rate, roughly equivalent to "standard" conditions. Measured in volume units such as cubic feet or liters per minute, but may also be related to pressure drop in the scuba cylinder.

Surface interval: The time spent on the surface between dives. In practice, this must be at least 10 minutes. A minimum surface interval of one hour is strongly recommended. Also used for the period on the surface in the "surface decompression" technique.

Table: A set of time-depth-gas procedures for decompressing; also called a schedule. A table is a set of individual schedules.

Technical diving: A mode of diving using advanced techniques, equipment, and training, usually used for diving beyond the traditional scuba range. A "technical dive" by definition involves the use of two or more gas mixtures or a rebreather. The term has been applied to rebreather diving for several decades, mainly in Britain.

Thermal protection: Device or clothing worn by a diver to slow down loss of heat from the diver into the water, typically a wet suit or dry suit.

Treatment: Vernacular to describe therapy of decompression illness and other gas lesion diseases with pressure and oxygen.

TNT, total nitrogen time: The sum of residual nitrogen time from previous dives and the planned bottom time for the next dive. Used for obtaining a letter group on NAUI Table 1for a repetitive dive.

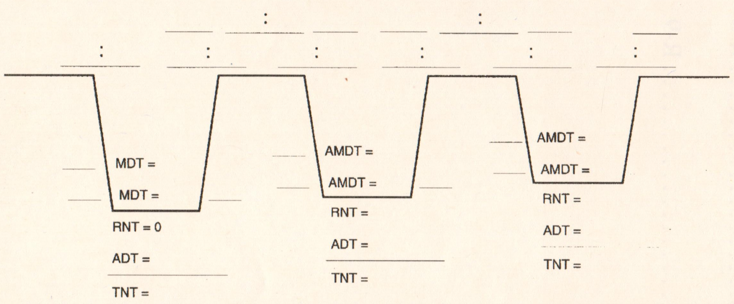
Trimix: A breathing mixture of three gases, usually oxygen, helium and nitrogen.

Untethered: Describes a diver who is not tied to the surface by either a safety line or an umbilical which might include breathing gas and hard-wired communications.

Reference Section

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

DIVE PLANNING WORKSHEET



TERMS AND ABBREVIATIONS USED IN DIVE PLANNING

Repetitive Dive – Any dive made less than 24 hours after a previous dive.
ADT – Actual Dive Time – The time from the moment of descent until returning to the surface.
Letter Group – A letter symbol for the amount of Residual Nitrogen remaining in the body from previous dives.
SIT – Surface Interval Time – The time spent at the surface between dives.
RNT – Residual Nitrogen Time – The nitrogen remaining in the body from a dive or dives made within the past 24 hours.
AMDT – Adjusted Maximum Dive Time – The maximum Dive Time for the depth of a dive minus the RNT.
TNT – Total Nitrogen Time – The sum of RNT and ADT. This figure is used to obtain a letter group after repetitive dives.

REMEMBER

- Consider all dives made shallower than 40'/12m as 40' dives.
- On any dive, ascend no faster than one foot every two seconds (30ft/9m per minute).
- For maximum dive time, make all repetitive dives shallower than your previous dive.

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

WARNING: EVEN STRICT COMPLIANCE WITH THESE TABLES WILL NOT GUARANTEE AVOIDANCE OF DECOMPRESSION SICKNESS. CONSERVATIVE USAGE IS STRONGLY RECOMMENDED.

RNT RESIDUAL NITROGEN TIME
+ADT ACTUAL DIVE TIME
TNT TOTAL NITROGEN TIME

(USE THIS FIGURE TO DETERMINE END-OF-DIVE LETTER GROUP.)

DIVE TABLES

TABLE 1 - END-OF-DIVE LETTER GROUP

00 (circled) MAXIMUM DIVE TIME (MDT)
00 / 00 DIVE TIME REQUIRING DECOMPRESSION / NO. MINUTES REQUIRED AT 15' STOP (5M)

START DEPTH M	FEET	A	B	C	D	E	F	G	H	I	J	K	L
12	40	5	15	25	30	40	50	70	80	100	110	130	150 (5)
15	50		10	15	25	30	40	50	60	70	80		100 (5)
18	60		10	15	20	25	30	40	50	55	60 (5)		80 (7)
21	70		5	10	15	20	30	35	40	45	50 (5)	60 (8)	70 (14)
24	80		5	10	15	20	25	30	35	40 (5)		50 (10)	60 (17)
27	90		5	10	12	15	20	25	30 (5)		40 (7)		50 (18)
30	100		5	7	10	15	20	22	25 (5)			40 (15)	
33	110			5	10	13	15	20 (5)			30 (7)		
36	120			5	10	12	15 (5)			25 (6)	30 (14)		
39	130			5	8	10 (5)					25 (10)		

TABLE 2 - SURFACE INTERVAL TIME (SIT) TABLE

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

TIME RANGES IN HOURS : MINUTES
ACTUAL DIVE TIME SHOULD NOT EXCEED THIS NUMBER

TABLE 3 - REPETITIVE DIVE TIMETABLE

M. / FT.	12 / 40	15 / 50	18 / 60	21 / 70	24 / 80	27 / 90	30 / 100	33 / 110	36 / 120	39 / 130	NEW GROUP
	7 / **123**	6 / **74**	5 / **50**	4 / **41**	4 / **31**	3 / **22**	3 / **19**	3 / **12**	3 / **9**	3 / **5**	A
	17 / **113**	13 / **67**	11 / **44**	9 / **36**	8 / **27**	7 / **18**	7 / **15**	6 / **9**	6 / **6**	6	B
	25 / **105**	21 / **59**	17 / **38**	15 / **30**	13 / **22**	11 / **14**	10 / **12**	10 / **5**	9	8	C
	37 / **93**	29 / **51**	24 / **31**	20 / **25**	18 / **17**	16 / **9**	14 / **8**	13	12	11	D
	49 / **81**	38 / **42**	30 / **25**	26 / **19**	23 / **12**	20 / **5**	18 / **4**	16	15	13	E
	61 / **69**	47 / **33**	36 / **19**	31 / **14**	28 / **7**	24	22	20	18	16	F
	73 / **57**	56 / **24**	44 / **11**	37 / **8**	32	29	26	24	21	19	G
	87 / **43**	66 / **14**	52	43	38	33	30	27	25	22	H
	101 / **29**	76 / **4**	61	50	43	38	34	31	28	25	I
	116 / **14**	87	70	57	48	43	38	AVOID REPETITIVE DIVES OVER 100 FEET			J
	138	99	79	64	54	47					K
	161	111	88	72	61	53					L

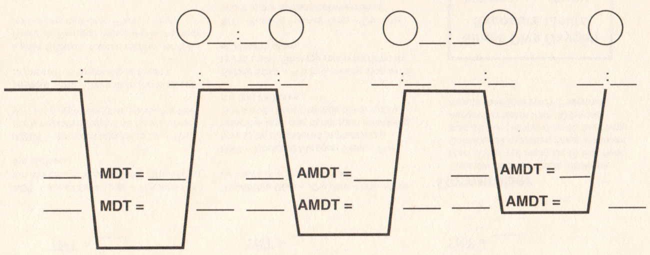
00 LIGHT FACE NUMBERS ARE RESIDUAL NITROGEN TIMES (RNT)
00 BOLD FACE NUMBERS ARE ADJUSTED MAXIMUM DIVE TIMES (AMDT)

#30033(Rev.1/97)

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

EAN$_{32}$ DIVE PLANNING WORKSHEET

use with 32% oxygen enriched air only



RNT = 0 ADT = ____ PO2 ______ TNT = ____ % Limit ___	RNT = 0 ADT = ____ PO2 ______ TNT = ____ % Limit ___	RNT = 0 ADT = ____ PO2 ______ TNT = ____ % Limit ___

ADT – Actual Dive Time – The time from the moment of descent until returning to the surface.

AMDT – Adjusted Maximum Dive Time (for a repetitive dive). The no-stop time limit for a repetitive dive, minus the RNT.

Bottom Time – Time from the moment of descent to beginning of ascent.

Letter Group – A letter symbol for the Residual Nitrogen remaining in the body from a previous dive. Place in circle.

MDT – Maximum dive time allowed without requiring a decompression stop.

Oxygen Exposure Limit – Maximum time on a single dive that the diver can be exposed to a certain partial pressure of oxygen.

PO$_2$ – Partial pressure of oxygen. It is recommended that this be kept below 1.4 atm.

Repetitive Dive – Any dive made within 24 hours of a previous dive.

RNT – Residual Nitrogen Time – The time to be considered in planning a repetitive dive due to nitrogen remaining in the body from previous dives within the last 24 hours.

Safety Stop – A 3 to 5 minute stop at 15 fsw (5 msw). Strongly recommended for all no-stop dives.

SIT – Surface Interval Time – The time spent at the surface between dives.

TNT – Total Nitrogen Time – The sum of the RNT and ADT. This figure is used to obtain a letter group on Table 1 for a repetitive dive.

Remember

- Consider all dives made shallower than 40 fsw (12 msw) as 40 fsw dives.
- Consider all repetitive dives shallower than 50 fsw (15 msw) as 50 fsw dives.
- Ascend no faster than 30 feet per minute (one foot every 2 seconds)

Single Dive Oxygen Exposure Limits

PO$_2$ atm	Minutes
1.60	45
1.55	83
1.50	120
1.45	135
1.40	150
1.35	165
1.30	180
1.25	195
1.20	210

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

EAN 32 DIVE TABLE

USE ONLY WITH 32% OXYGEN ENRICHED AIR

TABLE 1 - END-OF-DIVE LETTER GROUP

WARNING: EVEN STRICT COMPLIANCE WITH THESE TABLES WILL NOT GUARANTEE AVOIDANCE OF DECOMPRESSION SICKNESS. CONSERVATIVE USAGE IS STRONGLY RECOMMENDED.

RNT RESIDUAL NITROGEN TIME
+ADT ACTUAL DIVE TIME
TNT TOTAL NITROGEN TIME
(USE THIS FIGURE TO DETERMINE END-OF-DIVE LETTER GROUP)

(00) MAXIMUM NO-STOP TIME

DIVE TIME REQUIRING DECOMPRESSION 00 / MINUTES REQUIRED AT 15 FSW STOP (5MSW) 00

PO$_2$	START DEPTH msw	fsw	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
0.7	12	40	15	30	45	60	75	95	120	145	170	205	250	(310)			
0.8	15	50	5	15	25	30	40	50	70	80	100	110	130	150	170	(200)	250 / 11
0.9	18	60		10	15	25	30	40	50	60	70	80	90	(100)	140 / 10	160 / 21	180 / 29
1.0	21	70		10	15	20	25	30	40	50	55	(60)	70 / 5	80 / 7	100 / 14	120 / 26	140 / 39
1.1	24	80		5	10	15	20	30	35	40	45	(50)	60 / 8	70 / 14	80 / 18	100 / 33	
1.2	27	90		5	10	15	20	25	30	35	(40)	50 / 10	60 / 17	70 / 23			
1.3	30	100		5	10	12	15	20	25	(30)		40 / 7	50 / 18	60 / 25			
1.4	33	110		5	7	10	15	20	22	(25)	30 / 5		40 / 15				
1.5	36	120		5	7	10	15	20	22	(25)	30 / 5		40 / 15				
1.6	39	130			5	10	13	15	(20)	25 / 5		30 / 7					

TABLE 2 - SURFACE INTERVAL TIME TABLE

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

TIME RANGES IN HOURS : MINUTES
ENTER FROM THE TOP, MOVE DOWN TO FIND SURFACE INTERVAL TIME.
MOVE LEFT TO FIND THE NEXT PRESSURE GROUP.

TABLE 3 - REPETITIVE DIVE TIMETABLE

PO$_2$		0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	
msw	12	15	18	21	24	27	30	33	36	39	NEW
fsw	40	50	60	70	80	90	100	110	120	130	GROUP
		7 / 193	6 / 94	5 / 55	4 / 46	4 / 36	3 / 27	3 / 22	3 / 22	3 / 17	A
		17 / 183	13 / 87	11 / 49	9 / 41	8 / 32	7 / 23	7 / 18	7 / 18	6 / 14	B
REPETITIVE DIVES SHALLOWER THAN 50 FSW (15 MSW) ARE TO USE THE 50 FSW (15 MSW) REPETITIVE SCHEDULE		25 / 175	21 / 79	17 / 43	15 / 35	13 / 27	11 / 19	10 / 15	10 / 15	10 / 10	C
		37 / 163	29 / 71	24 / 36	20 / 30	18 / 22	16 / 14	14 / 11	14 / 11	13 / 7	D
		49 / 151	38 / 62	30 / 30	26 / 24	23 / 17	20 / 10	18 / 7	18 / 7	16 / 4	E
		61 / 139	47 / 53	36 / 24	31 / 19	28 / 12	24 / 6	22 / 3	22 / 3	20	F
		73 / 127	56 / 44	44 / 16	37 / 13	32 / 8	29 / 1	26	26	24	G
		87 / 113	66 / 34	52 / 8	43 / 7	38 / 2	33	30	30	27	H
		101 / 99	76 / 24	61	50	43	38	34	34	31	I
		116 / 84	87 / 13	70	57	48	43	38	38	34	J
		138 / 62	99 / 1	79	64	54	47	43	43	38	K
		161 / 39	111	88	72	61	53	48	48	42	L
		187 / 13	124	97	80	68	58	52	52	47	M
		213	142	107	87	73	64	57	57	51	N
		241	160	117	96	80	70	62	62	55	O

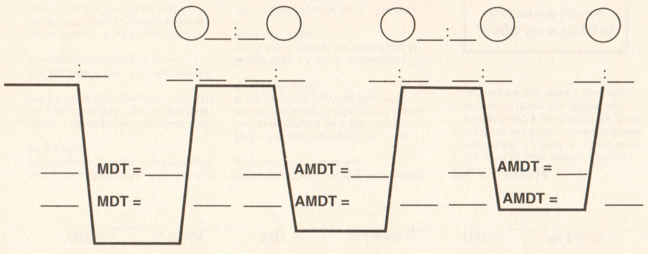
00 RED NUMBERS (TOP) ARE RESIDUAL NITROGEN TIMES (RNT)
00 BLUE NUMBERS (BOTTOM) ARE ADJUSTED NO-STOP REPETITIVE DIVE TIMES. ACTUAL DIVE TIME SHOULD NOT EXCEED THIS NUMBER.

#33502-32 (1/98)

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

EAN$_{36}$ DIVE PLANNING WORKSHEET

use with 36% oxygen enriched air only



RNT = 0 PO$_2$ ____
ADT = ____ % Limit ____
TNT = ____

RNT = 0 PO$_2$ ____
ADT = ____ % Limit ____
TNT = ____

RNT = 0 PO$_2$ ____
ADT = ____ % Limit ____
TNT = ____

ADT – Actual Dive Time – The time from the moment of descent until returning to the surface.

AMDT – Adjusted Maximum Dive Time (for a repetitive dive). The no-stop time limit for a repetitive dive, minus the RNT.

Bottom Time – Time from the moment of descent to beginning of ascent.

Letter Group – A letter symbol for the Residual Nitrogen remaining in the body from a previous dive. Place in circle.

MDT – Maximum dive time allowed without requiring a decompression stop.

Oxygen Exposure Limit – Maximum time on a single dive that the diver can be exposed to a certain partial pressure of oxygen.

PO$_2$ – Partial pressure of oxygen. It is recommended that this be kept below 1.4 atm.

Repetitive Dive – Any dive made within 24 hours of a previous dive.

RNT – Residual Nitrogen Time – The time to be considered in planning a repetitive dive due to nitrogen remaining in the body from previous dives within the last 24 hours.

Safety Stop – A 3 to 5 minute stop at 15 fsw (5 msw). Strongly recommended for all no-stop dives.

SIT – Surface Interval Time – The time spent at the surface between dives.

TNT – Total Nitrogen Time – The sum of the RNT and ADT. This figure is used to obtain a letter group on Table 1 for a repetitive dive.

Remember

- Consider all dives made shallower than 40 fsw (12 msw) as 40 fsw dives
- Consider all repetitive dives shallower than 50 fsw (15 msw) as 50 fsw dives.
- Ascend no faster than 30 fee per minute (one foot every 2 seconds)

Single Dive Oxygen Exposure Limits

PO2 atm	Minutes
1.60	45
1.55	83
1.50	120
1.45	135
1.40	150
1.35	165
1.30	180
1.25	195
1.20	210

NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

WARNING: EVEN STRICT COMPLIANCE WITH THESE TABLES WILL NOT GUARANTEE AVOIDANCE OF DECOMPRESSION SICKNESS. CONSERVATIVE USAGE IS STRONGLY RECOMMENDED.

EAN 36 DIVE TABLE

USE ONLY WITH 36% OXYGEN ENRICHED AIR

TABLE 1 - END-OF-DIVE LETTER GROUP

(00) MAXIMUM NO-STOP TIME

DIVE TIME REQUIRING DECOMPRESSION / MINUTES REQUIRED AT 15 FSW STOP (5MSW): 00 / 00

PO2	msw	fsw	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
0.8	12	40	15	30	45	60	75	95	120	145	170	205	250				
0.9	15	50	5	15	25	30	40	50	70	80	100	110	130	150	170	200	250 11
1.0	18	60		10	15	25	30	40	50	60	70	80	90	100	140 10	160 21	180 29
1.1	21	70		10	15	20	25	30	40	50	55	60		80 7	100 14	120 26	140 39
1.2	24	80		10	15	20	25	30	40	50	55	60		80 7	100 14	120 26	140 39
1.3	27	90		5	10	15	20	30	35	40	45	50	60 8	70 14	80 18	90 23	
1.5	30	100		5	10	15	20	25	30	35	40		50 10	60 17	70 23		
1.6	33	110		5	10	12	15	20	25	30		40 7					

RNT RESIDUAL NITROGEN TIME
+ADT ACTUAL DIVE TIME
TNT TOTAL NITROGEN TIME

(USE THIS FIGURE TO DETERMINE END-OF-DIVE LETTER GROUP.)

TABLE 2 - SURFACE INTERVAL TIME TABLE

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

TIME RANGES IN HOURS : MINUTES
ENTER FROM THE TOP, MOVE DOWN TO FIND SURFACE INTERVAL TIME.
MOVE LEFT TO FIND THE NEXT PRESSURE GROUP.

TABLE 3 - REPETITIVE DIVE TIMETABLE

PO2		0.9	1.0	1.1	1.2	1.3	1.5	1.6	
msw	12	15	18	21	24	27	30	33	NEW GROUP
fsw	40	50	60	70	80	90	100	110	
		7 193	6 94	5 55	5 55	4 46	4 36	3 27	A
		17 183	13 87	11 49	11 49	9 41	8 32	7 23	B
		25 175	21 79	17 43	17 43	15 35	13 27	11 19	C
		37 163	29 71	24 36	24 36	20 30	18 22	16 14	D
		49 151	38 62	30 30	30 30	26 24	23 17	20 10	E
		61 139	47 53	36 24	36 24	31 19	28 12	24 6	F
		73 127	56 44	44 16	44 16	37 13	32 8	29 1	G
		87 113	66 34	52 8	52 8	43 7	38 2	33	H
		101 99	76 24	61	61	50	43	38	I
		116 84	87 13	70	70	57	48	43	J
		138 62	99 1	79	79	64	54	47	K
		161 39	111	88	88	72	61	53	L
		187 13	124	97	97	80	68	58	M
		213	142	107	107	87	73	64	N
		241	160	117	117	96	80	70	O

REPETITIVE DIVES SHALLOWER THAN 50 FSW (15 MSW) ARE TO USE THE 50 FSW (15 MSW) REPETITIVE SCHEDULE

00 / 00 RED NUMBERS (TOP) ARE RESIDUAL NITROGEN TIMES (RNT)
BLUE NUMBERS (BOTTOM) ARE ADJUSTED NO-STOP REPETITIVE DIVE TIMES. ACTUAL DIVE TIME SHOULD NOT EXCEED THIS NUMBER.

#33502-36 (1/98)

Procedures for using NAUI diving tables

The NAUI Air and EAN diving tables specify procedures for maximizing their effectiveness while minimizing risks. These are standard procedures to be used when diving with NAUI diving tables.

Maximum Descent Rate:
75 fsw per minute (23 msw/min)

Maximum Ascent Rate:
30 fsw per minute (9 msw/min)

No-Stop Bottom Time:
Bottom time is considered from the time a diver leaves the surface to the time she leaves the bottom (for a direct ascent to the surface).

ADT:
Actual Dive Time - The time from the moment of descent until returning to the surface.

Safety-Stop:
A safety stop of 3 to 5 minutes is taken at 15 fsw (5 msw) on all dives deeper than 60 fsw (18 msw) and on all repetitive dives deeper than 15 fsw (5 msw) of any depth.

Cold or Strenuous Dives:
If a dive is particularly cold or strenuous use the next greater dive time to determine your repetitive group. For example, if you are cold during a dive to 27 meters (90 ft.) for 20 minutes, consider the dive schedule as 27 meters (90 ft.) for 25 minutes.

Repetitive Dives:
A repetitive dive is any dive that has been made less than 24 hours after a previous dive. Repetitive dives are to be at the same or progressively shallower depths.

Short Surface Interval:
Whenever a surface interval of less than ten minutes occurs the two dives are to be considered as one single dive and the dive schedule for the deepest dive for the total time is to be used.

Flying After Diving:
Wait at least 12 hours after a single no-stop dive within a 24 hour period before flying. Wait at least 24 hours after any dive requiring decompression or any repetitive dive.

Altitude Diving:
The NAUI diving tables may be utilized to 1000 feet (300 meters) elevation. For diving at higher elevations, use EAD with altitude tables or a dive computer that has an altitude adjustment.

Omitted Decompression:
In the unlikely event a required decompression was omitted, there are two possible procedures that can be utilized depending on the circumstances. These are discussed in Chapter 13 in detail.

EQUIVALENT AIR DEPTH CONVERSION and MOD

PERCENTAGE OF OXYGEN AND ACTUAL DEPTHS (FSW)

EAD fsw	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	EAD fsw
30	36	37	38	39	40	41	42	43	44	46	47	49	49	30
40	47	48	49	50	51	53	54	55	57	58	60	61	63	40
50	58	59	60	62	63	64	66	67	69	71	72	74	76	50
60	69	70	71	73	75	76	78	80	81	83	85	87	89	60
70	80	81	83	84	86	88	90	92	94	96	98	100		70
80	90	92	94	96	98	100	102	104	106	108				80
90	101	103	105	107	109	112	114	116						90
100	112	114	117	119	121	123								100
110	123	126	128	130										110
120	134	137	139											120
130	145	148												130
MOD fsw @ 1.4 atm	132	126	121	116	111	107	102	99	95	91	88	85	82	MOD fsw @ 1.4 atm
MOD fsw @ 1.6 atm	155	149	143	137	132	127	122	117	113	109	105	102	99	MOD fsw @ 1.6 atm

Figure 8-7. Equivalent Air Depth Conversion and MOD chart. Enter the chart at oxygen percentage, move down the column to the depth or next greater depth of the dive. Move across to the left or right to find the Equivalent Air Depth for use with the NAUI air diving table (or another air table). Maximum Operating Depth (MOD) of each oxygen percentage is indicated at the bottom, the standard limit at 1.4 atm PO_2 and the contingency limit at 1.6 atm.

PARTIAL PRESSURE OF OXYGEN, PO_2, atm

BASED ON DEPTH AND PERCENTAGE OF OXYGEN (FO_2)

Depth fsw	Depth msw	atm abs	21%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%
0	0	1.00	0.21	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40
35	10	2.05	0.43	0.57	0.59	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82
40	12	2.21	0.46	0.62	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88
50	15	2.52	0.53	0.70	0.73	0.75	0.78	0.80	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.01
60	18	2.82	0.59	0.79	0.82	0.85	0.87	0.90	0.93	0.96	0.99	1.01	1.04	1.07	1.10	1.13
70	21	3.12	0.66	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.19	1.22	1.25
80	24	3.42	0.72	0.96	0.99	1.03	1.06	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.37
90	27	3.73	0.78	1.04	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.42	1.45	1.49
100	30	4.03	0.85	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.45	1.49	1.53	1.57	1.61
110	33	4.33	0.91	1.21	1.26	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60			
120	36	4.64	0.97	1.30	1.34	1.39	1.44	1.48	1.53	1.58						
130	39	4.94	1.04	1.38	1.43	1.48	1.53	1.58								

Figure 5-4. Partial pressure of oxygen chart. Body of chart has PO_2 values for various mixes at a range of depths. Standard 32 and 36% mixes are in light grey. PO_2 levels higher than 1.4 atm should be avoided and are shown fo contingency purposes only, darkened.

Percentage of Oxygen at Various PO_2 Levels						
fsw	**msw**	**atm**	**1.3**	**1.4**	**1.5**	**1.6**
40	12	2.21	59%	63%	68%	72%
45	14	2.36	55%	595	63%	68%
50	15	2.52	52%	56%	60%	64%
55	17	2.67	49%	53%	56%	60%
60	18	2.82	46%	50%	53%	57%
65	20	2.97	44%	47%	51%	54%
70	21	3.12	42%	45%	48%	51%
75	23	3.27	40%	43%	46%	49%
80	24	3.42	38%	41%	44%	47%
85	26	3.58	36%	39%	42%	45%
90	27	3.73	35%	38%	40%	43%
95	29	3.88	34%	36%	39%	41%
100	30	4.03	32%	35%	37%	40%
105	32	4.18	31%	33%	36%	38%
110	33	4.33	30%	32%	35%	37%
115	35	4.48	29%	31%	33%	36%
120	36	4.64	28%	30%	32%	35%
125	38	4.79	27%	29%	31%	33%
130	39	4.94	26%	28%	30%	32%
135	41	5.09	26%	28%	29%	31%

Figure 5-5. Mix selection chart. Choose the desired upper PO_2 limit, then intersect with the row having the target dive depth. This percentage is the oxygen in the mix to get the chosen PO_2. Avoid using 1.5 and 1.6 levels.

NOAA Oxygen Exposure Limits

PO_2 atm	Maximum single exposure, min.	Maximum per 24 hr.
1.60	45	150
1.55	83	165
1.50	120	180
1.45	135	180
1.40	150	180
1.35	165	195
1.30	180	210
1.25	195	225
1.20	210	240
1.10	240	270
1.00	300	300
0.90	360	360
0.80	450	450
0.70	570	570
0.60	720	720

Figure 4-3, 5-2, 8-1. NOAA oxygen exposure limits. Table gives limits in min for a single PO_2 exposure level, and for each day (24 hr). (NOAA diving manual, 3rd ed., 1991).

Single Dive Oxygen Exposure as a Percentage of NOAA Limits

Oxygen PO_2, atm	NOAA Single Dive Limit, min.	Bottom Time, Minutes											
		5	10	15	20	25	30	35	40	45	50	55	60
1.20	210	2%	5%	7%	10%	12%	14%	17%	19%	21%	24%	26%	29%
1.25	195	3%	5%	8%	10%	13%	15%	18%	21%	23%	26%	28%	31%
1.30	180	3%	6%	8%	11%	14%	17%	19%	22%	25%	28%	31%	33%
1.35	165	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	33%	36%
1.40	150	3%	7%	10%	13%	17%	20%	23%	27%	30%	33%	37%	40%
1.45	135	4%	7%	11%	15%	19%	22%	26%	30%	33%	37%	41%	44%
1.50	120	4%	8%	13%	17%	21%	25%	29%	33%	38%	42%	46%	50%
1.55	82	6%	12%	18%	24%	30%	36%	42$	48%	55%	61%	67%	73%
1.60	45	11%	22%	33%	44%	56%	67%	78%	89%	100%			

Figure 4-4. CNS Oxygen Exposure Table; percentage of NOAA "allowable" limits for a single dive. Note the 1.6 atm PO_2 level; the "oxygen clock" runs almost 4 times as fast at 1.6 atm as at a PO_2 level of 1.4 atm. PO_2 levels higher than 1.4 atm are shown for contingency purposes only. Values for intermediate 0.05 atm PO_2 values are linearly interpolated. Values in main table are rounded normally.

Tank Scuba Cylinder Chart

The chart illustrated here lists over 35 scuba cylinders that are currently available in the United States. Care has been taken in its accuracy, though it is possible that some have not been listed and for that we apologize. Specifications have been provided by the manufactures and are believed to be accurate. A professional NAUI retailer will be able to assist in the correct size and type for each diver. This chart gives some useful data about scuba tanks, but it is missing two items about each tank that would be more useful than the information that is there. This would be the actual physical tank volume, sometimes called "water volume," and the manufacturer's part numbers. We hope that future editions will contain this information.

Manufacturer	Material	Cubic Feet	Service Pressure	Psi /Cu. Ft.	Outside Diameter	Length Inches	Weight Lbs.	Buoyance Full/Lbs.	Buoyancy Empty/Lbs.
Catalina	Alum	6	3000	500	3.20	11.0	2.6	-1.3	-0.9
OMS	Steel	13	2400	185	3.90	14.0	5.9	-3.3	-2.25
Catalina	Alum	13	3000	231	4.37	12.3	5.4	-1.4	-.04
Luxfer	Alum	13.2	3000	227	4.38	13.1	5.8	-1.6	-0.6
Catalina	Alum	19	3000	158	4.37	17.1	7.5	-1.2	neutral
Luxfer	Alum	19.9	3000	151	4.38	18.6	8.2	-1.4	0.1
Catalina	Alum	30	3000	100	5.25	20.0	13.7	-2.3	neutral
Luxfer	Alum	30	3000	100	4.88	21.9	11.6	-1.0	1.2
Catalina	Alum	40	3000	75	5.25	24.9	15.7	-1.1	1.9
OMS	Steel	46	2400	52	5.50	23.0	17.6	-4.0	neutral
Luxfer	Alum	48.4	3000	62	6.89	19.0	21.2	-2.4	1.3
Catalina	Alum	53	3000	57	7.25	19.0	25.6	-4.0	neutral
Catalina	Alum	60	3300	55	7.25	19.9	27.3	-4.9	-0.4
Luxfer	Alum	63	3000	48	7.25	21.9	26.9	-2.3	2.5
Pressed Steel	Steel	65	3500	54	7.25	16.8	24.0	-4.5	-1.5
OMS	Steel	66	2400	36	7.00	21.0	25.0	-5.2	-1.67
Catalina	Alum	67	3000	45	7.25	23.7	32.5	-5.0	neutral
Faber/Scubapro	Steel	71.4	3000	42	6.84	20.5	29.0	-11.3	-5.9
Faber/Scubapro	Steel	75.8	2640	35	6.76	26.2	29.5	-6.5	-1.7
Catalina	Alum	77.4	3300	43	7.25	25.1	35.0	-5.8	neutral
Catalina	Alum	77.4	3000	39	7.25	25.8	31.6	-1.7	4.1
Luxfer	Alum	77.4	3000	39	7.25	26.1	31.7	-1.6	4.1
Luxfer	Alum	78.2	3000	38	8.00	22.9	35.2	-3.6	2.2
Pressed Steel	Steel	80	3500	44	7.25	19.8	27.0	-5.5	-1
Taylor-Wharton	Steel	80	2400	30	7.25	24.0	34.0	-7.7	-1.89
OMS	Steel	85	2400	28	7.00	26.0	31.0	-6.7	neutral
Faber/Scubapro	Steel	95.1	2640	28	8.02	23.8	37.6	-8.5	-1.2
OMS	Steel	98	2400	24	8.00	24.0	38.0	-7.7	neutral
Pressed Steel	Steel	100.1	3500	35	7.25	23.9	33.0	-7.5	0
Pressed Steel	Steel	104	2400	23	8.00	26.2	46.0	-5.3	-2.5
OMS	Steel	112	2400	21	8.00	26.0	41.0	-8.0	-1
Pressed Steel	Steel	120	3500	29	7.25	27.9	38.0	-10.0	1
Pressed Steel	Steel	120	2400	20	8.00	29.4	52.0	-7.0	-2
Heiser/Beauchat	Steel	120	3190	27	8.03	25.8	55.0	-26.4	-17.82
OMS	Steel	125	2400	19	8.00	29.0	45.0	-9.5	neutral
Heiser/Beauchat	Steel	140	3190	23	8.03	29.9	63.0	-28.4	-18.04
Heiser/Beauchat	Steel	190	4400	23	8.03	31.3	87.0	-62.3	-46.86

Scuba Cylinder Chart, courtesy of Watersport Publishing.

ABOUT NAUI

NAUI Worldwide is the world's oldest not-for-profit membership training agency organized solely to support and promote dive safety through education. Formed in 1960, the association is controlled by a Board of member Directors elected by the membership. NAUI Worldwide offers a full range of training programs from Skin Diver through Instructor Course Director, with dozens of specialized certification courses including enriched air nitrox and technical diving. Thousands of member Instructors, affiliated stores, resorts and service centers are located in scores of countries throughout the world. Visit the NAUI Worldwide internet web site at http://www.naui.org/, call 813-628-6284, FAX 813-628-8253, or write NAUI Worldwide, 9942 Currie Davis Dr., Suite H, Tamp, FL 33619-2667.

אלב

1994