An Introduction to

Semi-Closed Circuit Rebreathers

The Dräger Series of Recreational Rebreathers

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About the Author

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Joe Odom is the International Training Director for Technical Diving International (TDI). Although specializing in Cave and Mixed Gas Diving applications, he has also conducted over half of all the rebreather training for the Drager SCR systems throughout the world in a variety of locations. Currently active as a Cave Instructor for the Cave Diving Section of the NSS as well as a SDI instructor, he has been teaching scuba since 1980. Joe has served two terms as Chairman of the Board of Directors of the **Cave Diving Section of the National Speleological Society.**

Joe first used scuba in the mid-1960’s while a member of a competition swim team – to clean the pool! It was much better than holding your breath and scrubbing. He prefers not to choose between salt water or fresh, cave or ocean, deep or shallow – keeping the principle that diving is better than not diving. It is untrue the rumors of him being seen in mud puddles however.

In addition to this manual, he is the author of TDI’s A Guide to Mixed Gas Diving and Technician’s Handbook Gas Blending and Equipment Servicing as well as several magazine articles and sidebars.

Joe spent two tours in the U.S. Air Force, then 8 years at a leading independent testing laboratory, serving as the Department Head of Physical Analysis and then as the Manager of Engineering, particularly interested in microelectronic analysis with Scanning Electron Microscopy and Energy Dispersive Xray (SEM/EDX).

He divides his time between diving and flying and holds an Airline Transport Pilot (ATP) certificate, a Certified Flight Instructor (Gold Seal) for both Single and Multiengine as well as Instrument Airplane. Additionally, he holds an Airframe and Powerplant Mechanic certificate with Inspection Authorization. The FAA has designated him as an Accident Prevention Counselor for both flight and mechanic areas. Joe was first licensed by the Federal Communications Commission in 1966 and now holds a General Radiotelephone Certificate with Ships Radar Endorsement as well as an Advanced Class license KD4MJ.

He is a Life Member of the National Speleological Society, the Cave Diving Section and the American Radio Relay League (ARRL).

The ***Real*** Beginning of Recreational Rebreathers

In July 1995, a group of over twenty (lucky) Technical Instructors met in the Bahamas at Stuart Cove's to participate in the first seminar sponsored by Uwatec, Dräger and TDI for rebreather systems that had a real potential of finally getting to the recreational market. Many previous designs had either fallen by the wayside or befell financial woes. In any case, the participants were greeted with over 15 rebreather systems – the **Dräger Atlantis I**. Never before had so many WORKING systems been available. After an intense week of learning, analyzing and yes, literally taking them apart, the group made a series of recommendations to the manufacturer. A sense of achievement and involvement complimented the excitement that the recreational users were *finally* going to get a diving system that could meet their desires.

This was followed by a second instructor training seminar at the TDI conference at Ft. Lauderdale in September 1995, where the participants critically reviewed the course material and assisted in making charts and modifications to the manual.

There are a number of people who have military or scientific rebreather training. A fortunate few also have some civilian involvement. One of the most difficult tasks is to take a technology that has been entrenched for such a long period of time and move it into a new arena. There are already cries of “rec users will never understand it” or "they just aren't ready – it will take weeks or months of class". It seems those were the same cries about that gas "NITROX"! In fact, the particular systems for the recreational users are quite friendly and easily understood.

There is a certain amount of new material to learn, however. And there are new skills to learn. It was interesting to watch highly skilled divers relearn simple skills, such as how to descend! Many scuba skills will undergo a change in operation as well as a new attitude towards the equipment and responsibility.

Russ Orlowsky of Dräger USA said it best – “EARP. Education, Attention, Responsibility and Practice.” Over and over again.

Notes on the Second Revised Edition

Wow! I don't guess we actually realized just how much interest there was going to be in this recreational rebreather program. From the time the word got out about our seminar in the Bahamas followed by the Ft. Lauderdale get-together… the phones have been going crazy! Bret Gilliam, President of TDI, had warned us though.

Rob Palmer and I went to tek96… with the idea that a few people would sign up for the 1 day seminar… wrong again… we were innundated! 2 days and over 50 people later… well, we were off to more seminars. Plus some 60 to 80 divers that participated in the seminars at the Silver Banks on the live-aboards.

This course has evolved rapidly with the large number of people that have been involved. They have been from all walks of life and levels of diving experience. Thanks to everyone who has offered their constructive comments and helped us by realizing that in many cases we were dealing with the first large-scale education of the rebreather technology for recreational users! As such, we can continue to modify the program and react to the input from our users and instructors… thanks to the handy dandy laptop computer… which my wife believes is surgically attached to my hip!

Some people have learned more about what a rebreather isn't instead of what it is. There are still quite a few misconceptions. The diver simply isn't going to zip on down to 300 feet, cruise the area for 'bout 30 minutes then scream up to the surface to catch the cab to go dancing that night…. Darn. On the other hand, there is always the one atmosphere suits!

You still have to be a diver. You still have to watch yourself. You still have to abide by rules that are tried and true for open circuit scuba.

The Semi-closed Circuit Rebreather requires the diver to determine the dive based on not just one factor, but three. The duration of the rebreather, the amount of oxygen exposure time and finally the nitrogen exposure time. If anything, the duration of the system may actually be working against the diver… no more waiting until it gets hard to breathe to determine the maximum bottom time!

Anyway, sit back and relax. Try to recognize the principles of rebreather diving the instructor is bringing to you and we welcome your input in future sections of this manual. TDI staff and members such as Chester Morrison, Sandy Morrison, Mitch Skaggs, Catherine Castle, Rick Thomas as well as the ubiquitous Stuart and Michelle Cove have all had a hand in the reviews as well as a new instructor outline. A big round of applause to them.

Joe Odom, March 1996

Notes on the First Edition

This *Introduction to Semi-closed Circuit Rebreathers* is a compilation of quite a few articles and data. There have been lots of conversations, lots of reading and lots of trying to determine just how much needed to be put into the book and how much needs to be presented to the Recreational Rebreather Diver.

It would be difficult to specifically footnote each source for many are well publicized and frequently used. The following resources were extensively referred to and were invaluable in explanation and assistance:

The U.S. Navy Diving Manual, Volume I & II
The NOAA Diving Manual, 2nd and 3rd Editions

Published articles and works, specifically of:

John Zumrick, MD, USN (Ret)
Ed Thalman, MD, USN (Ret)
Richard Vann, MD
R.W. “Bill” Hamilton, Ph.D.
Larry “Harris” Taylor, Ph.D.
Ian McKernan, B.Sc.

Of particular value was the first SCR Manual by Rob Palmer, used by the participants of the first TDI Rebreather Instructor Seminar.

A Personal Note

For all of the good things that come from my work at research and education, credit belongs to the one person who is responsible for molding and shaping any ability I have in analysis or communication. He taught me everything I know about electronics as well as how to troubleshoot any problem. The man who took and raised me as his own son, to whom I have always regarded as my real father,

Theodore W. Whalen

who passed away before he could read any of my books but always had complete faith in my abilities.

Joe Odom, October 1995

History of Rebreathers (Part 1)

So what is a rebreather? Is it new or old stuff? Let’s take a brief historical look at the development of this remarkable device.

The year is 1680. Giovanni Borelli is walking in his garden when an apple narrowly misses his head. As he continues, his thoughts revolve around how to take the impurities out of air that has been breathed. He believes that if the exhaled air were pushed through a copper tube that was cooled by the cold sea water, the impurities would condense and leave “fresh air”.

Scene II, 1726: Stephen Hale becomes involved in making devices to help people survive in mine disasters. A helmet that contains a flannel liner soaked in seawater and tartar represents the first attempt at “scrubbing” a supply of contaminated air.

1776: While the fledgling United States is struggling to be born, Freminet designs a diving dress with a copper kettle based on Borelli’s theory. He concludes that condensation does not remove impurities and secretly wishes the apple had hit Borelli. He goes on to install a surface supply line to the diver powered by a mechanical bellows.

Dramatic Scene, 1878: Henry A. Fleuss of Siebe Gorman receives a patent on a pure oxygen-recirculating device. One year later the device is used for the first Enriched Air Nitrox dive. In 1880 an English diver, Alexander Lambert, walks 1000’ along a flooded tunnel under the Severn River in total darkness to close several crucial valves using the Fleuss rebreather. (Send me in Coach!)

1881 finds Achilles Khotinsky and Simon Lake pounding on the Patent Office doors for their apparatus that uses barium hydroxide as a chemical scrubber that successfully removes carbon dioxide.

1905: A Fleuss apparatus is patented for submarine escape.

1907: Dräger is involved in diving activities with J. Haldane.

1912 brings Drägerwerk out with their submarine sled that is equipped with a 2-hour closed circuit supply of oxygen. SCIENTIFIC AMERICAN predicts that this development could be "the advent of a new sport.”

1915: The Silver Screen! Oxylite rebreathers are used in the underwater scenes of the movie *20, 000 Leagues Under the Sea.*

1936: Italian divers use a modified version of the Fleuss apparatus, the Davis Lung, to ride underwater chariots with the intention of harassing enemy shipping

World War II: All navies utilize some form of rebreather system in clandestine reconnaissance, mine clearing, shipping interdiction, etc… Many divers are lost to oxygen toxicity problems.

Late 1940s-1950s: Early British cave divers used oxygen rebreathers for some of the first recorded scuba cave dives in England

Remembering that it wasn't until the 1940's that the standard demand valve regulator was improved by Gagnan-Cousteau, you can see that the rebreather technology has been with us for quite awhile longer. The open-circuit scuba did however allow for a relatively simple system of breathing underwater but everyone knew that with each breath, we were wasting alot of oxygen - and scaring the fish in the process!

Throughout the 1950s to 1995 various rebreathers attempted to make their way to market. Some were specifically designed to be custom units and not mass-produced; others fell by the wayside for a wide variety of reasons, from financial to operational, bureaucracy to management. For the most part, recreational users were just teased about getting to own and operate their own system. All three technical training agencies have started RB instructor programs, but there are no mass units available.

1995: Dräger and Uwatec join to bring the **Atlantis I** Semiclosed Circuit Rebreather system to the U.S. marketplace with 250 units available the first year. Training takes off rapidly!

1998-1999: Dräger continues to lead the recreational rebreather market, bringing out the improved version of the **Atlantis I**, known as the **Dolphin** as well as a smaller system specifically designed for the casual recreational diver, the **DrägerRay**.

Chapter 1 What is a Rebreather?

Almost everyone who has taken a CPR course knows that when a human breathes, only about 20% of the inspired oxygen is actually used, so that when they exhale the amount of oxygen must be enough to support life - otherwise CPR wouldn't work! This exhaled breath contains a fair amount of carbon dioxide and some water vapor plus about 16% oxygen. All that we have to do is to eliminate the carbon dioxide and add a bit of oxygen to the mixture and voila! We have a rebreather. Sounds simple? It is, but like most simple ideas, there is always some catch that must be overcome with technology to make it appeal to the majority of divers.

SCUBA comes in three flavors, open-circuit, semi-closed and closed circuit. The open circuit is the familiar cylinder and demand valve regulator, which wastes all that precious gas on each breath. The traditional fix was to just take more tanks! Oops… cylinders. Cave divers, using the rule of thirds, would commonly carry and stage numerous cylinders just to make an exploration dive. Semi-closed circuit implies that most of the gas is reused and only a small portion exhausted to the surroundings. This allows the use of Nitrox mixtures for the system. Closed-circuit systems are typically of two varieties, pure oxygen for shallow depths or more complex mixed gas systems requiring gas monitors and computers for decompression tracking.

The Semi-Closed Circuit Rebreather (SCR) can be manufactured without the use of batteries or electronic components in a very reliable system. It's only moving parts are basically the check valves in the mouthpiece or the demand valve override for deep inhalations. It can be simple, useful and provide many of the benefits divers seek in rebreathers. With the use of nitrox mixtures, the benefits of EAN use are retained with the added benefits of a properly designed SCR that includes:

(5 Quiet, reduced bubble operation
(6 Extended bottom time (efficient use of gas)
(7 Lighter, more comfortable diving systems
(8 All the physiological benefits of EAN (Nitrox)

Other advantages of the semi-closed circuit rebreather become obvious with use in each diver’s chosen environment. For example, the inspired air is moist, not dry, helping to eliminate "cotton-mouth.”

Also the gas is warmer, reducing heat loss in colder water diving. Buoyancy needs only be set once at depth – as the diver breathes, the system acts opposite to the lungs – producing no change in buoyancy. This does take some getting used to for experienced divers!

No single system is a panacea. There are advantages and disadvantages with all diving systems and the SCR is no different. Some SCR systems are available with elaborate construction and operational difficulties, others are not well documented resulting in operator problems.

Divers seeking to use the SCR should be already trained for EAN use or have the material included concurrent with the rebreather course. All of the oxygen considerations for nitrox continue with the SCR as well as planning for nitrogen no-decompression conditions.

All rebreather systems have differences. Some are subtle; others are completely different and require special training. This manual centers on the Dräger series of recreational rebreathers. This includes the **Atlantis I**, the first successful system available, the **Dolphin**, the follow-on to the Atlantis I and the **DrägerRay**, the smaller version specifically for the recreational diver. Many of the principles are directly applicable to other systems.

Each system is accompanied by a manufacturer's manual, which is the primary reference to the operation of the system. Always completely understand the manufacturer's manual, required testing procedures and gain experience with an instructor that is certified and familiar with the system.

Next let's take a look at a Semi-Closed Circuit Rebreather and what makes it work.

Notes

Surface Interval 1

1. What are four advantages of a rebreather system?

    a.
    b.
    c.
    d.

2. Does a diver need to be Nitrox certified to use a rebreather?

3. Will rebreathers replace all open circuit scuba systems?

4. Is a rebreather system considered "SCUBA"?

5. In addition to this manual, what other manual is required for proper rebreather training and use?

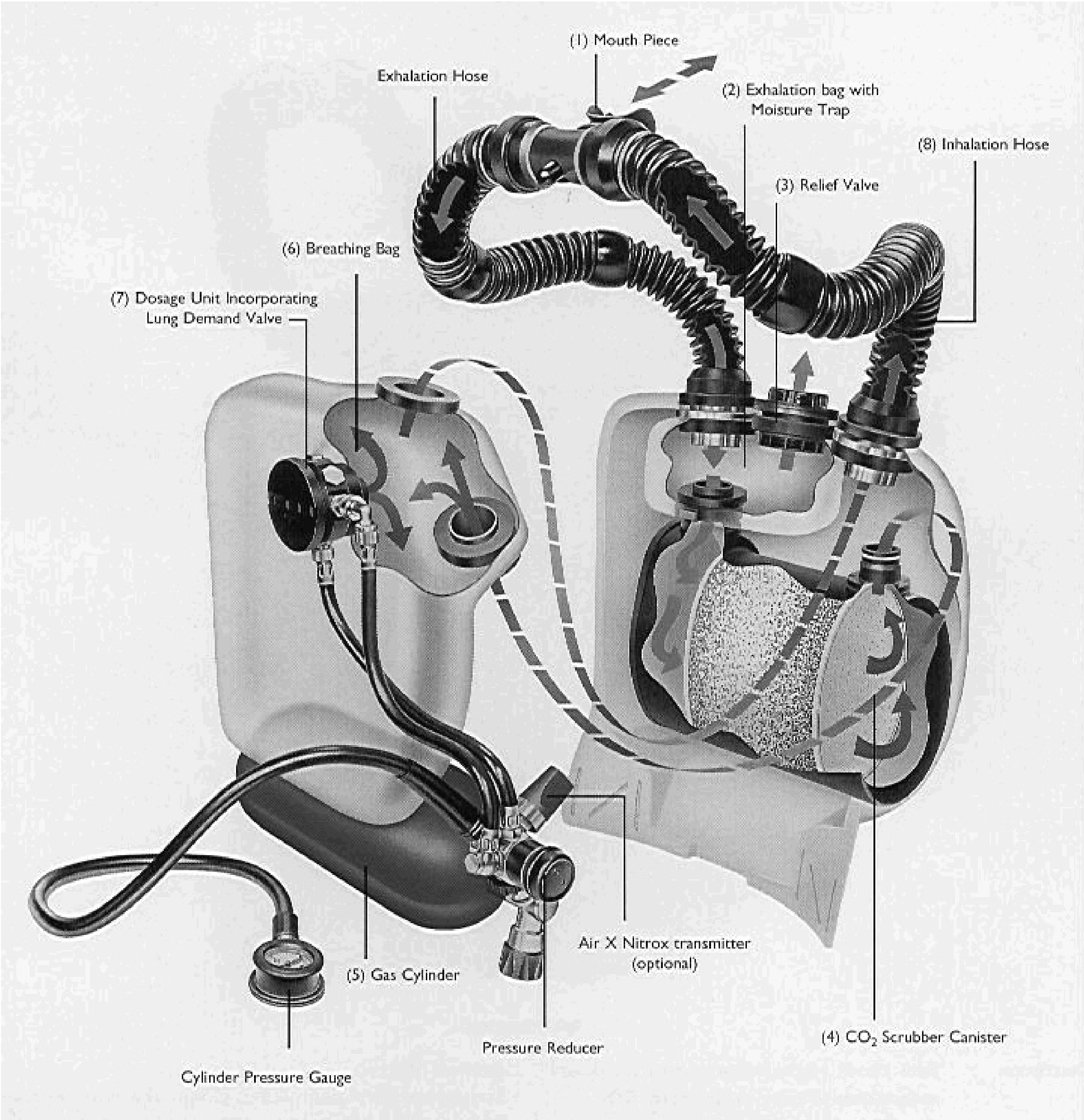
Chapter 2 The Semiclosed Circuit Rebreather

Semi-closed Circuit Rebreathers have a long history and safety record. While some have said the SCR is a "little brother" of the real rebreather - the closed circuit units, it will soon become obvious how simple (read: SAFE[ER]) the system can be as well as significantly less expensive to produce and service.

The truth is that there is very little difference between SCR and closed circuit systems, with the method of gas delivery and mixing being the primary change.

Figure 1 on the next page shows a basic double bag Semi-closed Circuit Rebreather. It consists of an exhalation bag with exhaust valve, carbon dioxide removal canister, gas cylinder, flow valve, demand valve, inhalation bag and mouthpiece assembly. Options that are now commonly available include an oxygen analyzer or monitor. *Any diver should seriously consider this option*.

The SCR system begins at the **inhalation bag**. This breathing bag (also known as a counter-lung) is a flexible container that has a constant mass of gas entering the bag from an orifice or **flow valve**. Dräger typically uses the term **"dosage device"** for this orifice. The flow valve is connected to the first stage of the regulator attached to a Nitrox cylinder. The depth of operation and planned exertion determines this flow rate. Some manufacturers require the diver to preset the system while others use a simple hose connection technique. *In any case, each particular rebreather system requires specific training to understand the peculiar characteristics for safe operation.* The flow rate is defined by a standard formula common to virtually all rebreather systems.



The Sonic Orifice

All of the principles of flow depend on the fact that gas can only travel at the speed of sound through an opening… as long as the pressure on one side is at least twice the pressure on the other side. While the mathematics is not quite as easy as multiplying the area of the opening by the speed of sound, it does follow a physical principle. It will remain constant as long as a constant inlet pressure is at least twice the outlet pressure. The tendency is to think of this in terms of volume, however it really is a mass equation, which means that the number of gas molecules will remain constant. As divers descend, the volume will actually be variable in accordance with Boyle's Law.

The key to the breathing bag is its position on the diver. Each manufacturer has taken steps to assure proper breathing characteristics in the placement of the bags. Basically, it is important to keep the bags as close to the divers lungs as possible to help eliminate some of the breathing resistance associated with the minor differences in depth of the lungs and the breathing bag.

The position of the bag can affect the breathing resistance. Some argue the merits of back or front mounted breathing bags, but a properly designed system results in a negligible difference in position. Traditionally it is thought that a back mounted system requires greater inhalation resistance since the diver has to suck down the gas to the lungs, while the front mounted requires greater exhalation effort due to having to push the gas down to the bag. However, a properly designed SCR operates at a slight positive pressure so inhalation resistance is actually quite good. The exhalation resistance is determined by a number of factors including the exhaust valve setting, flow rate and depth changes. This tends to eliminate some of the objections associated with other types of rebreather where the diver’s lungs do all the work, both inhalation and exhalation.

The diver inhales the nitrox mixture passing through the inhalation hose and check valve. In the event the diver inhales to the point of depleting the breathing bag, the manufacturers provide various methods of assuring additional gas. In the case of the Dräger recreational rebreather systems, this is as simple as a regulator second stage demand valve. Older styles or "homebuilt" rebreathers commonly use a manual by-pass technique. Still other designs may employ a passive addition technique, relying on a second stage demand valve to supply make up gas during each breath based on a system design constant.

The mouthpiece may be separate or included in a full-face mask. The mouthpiece normally has a shut-off valve to prevent water from entering. Most are adjustable for comfort to suit the diver’s particular needs.

When the diver exhales, the used gas passes through another check valve and the exhaust hose into the **exhaust bag**. The Exhaust Bag serves two functions, first to trap moisture that may have entered the hose to prevent contamination of the scrubber canister, and second to hold the pressure relief valve. The pressure relief operates to eliminate a small amount of the exhaled gas to prevent build up of the "inert" nitrogen as well as some of the carbon dioxide.

In general, there may be bubbles on each breath or a continuous stream of bubbles, however greatly reduced in volume that appears at the exhaust valve or even just an occasional “burp.” In some systems the valve is covered with a diffuser material to make the bubbles dissipate in a fine mist. The amount of bubbling is directly related to the flow rate into the system, the setting of the exhaust valve relief pressure as well as the diving depth and profile.

The exhaust bubbling will be greater for example, if the diver is ascending. In this case the effect of Boyle’s Law requires that the bags get larger… therefore more bubbles. On the other hand, descending may result in few if any bubbles… again because Boyle’s Law describes the bags as being compressed. Shallow depths make this effect more pronounced, small changes in depth make great changes in pressure resulting in seemingly more bubbling. If the exhaust valve is set too low, then the gas in the system will essentially flow freely from the bags resulting in bubbling as well as rapid depletion of the system gas supply.

Some Semi-Closed (as well as closed circuit) systems do not incorporate a separate exhaust bag; instead the expired gas goes directly to the scrubber canister. This is a matter for the rebreather designer and each has particular goals and design objectives in mind.

From the exhaust bag, the exhaled gas is directed into the **scrubber** canister where the carbon dioxide is removed from the gas. The chemical material in the canister causes the carbon dioxide to combine with water vapor to create a weak carbonic acid. This acid is then neutralized by the base material in the scrubber, which creates more water vapor and a simple "chalk type" material. The amount of carbon dioxide removed depends on the amount of time the gas spends in the canister (dwell time), the temperature of the canister, and how effectively the canister was packed. If the granular material is too loose, “channels” may form allowing the exhaled gas to “sneak" around the absorbent without removing the carbon dioxide.

Manufacturers spend considerable time evaluating various canister designs. It is vitally important that the user make sure to gain a thorough understanding of how to set up and use the system. For example, the **Atlantis I** and the **Dolphin** have a simple rubber dam that is sometimes overlooked in assembling the SCR, only to find out it is an important part of the system and serves to prevent "channeling" of the absorbent material. Regardless of whether the manufacturer chooses to build a canister with an axial or radial flow, cylindrical or oval or square, it is the diver's responsibility to ensure proper set-up.

In the event the canister becomes flooded, the diver may get some of the caustic material in the mouth. This is known as the "caustic cocktail" and is primarily prevented by proper set-up of the SCR system.

A variety of materials may be used for carbon dioxide absorbents, most are composed primarily of soda lime. Each rebreather manufacturer has specific recommendations or requirements for the CO_2 scrubber and they should be followed for proper operation. Various materials are known by the tradenames Sofnolime, Sodasorb, Drägersorb, Divesorb, or Baralyme. Some of the materials contain additives that change color to indicate the degree of use of the material and help determine when the scrubber contents need to be changed.

Carbon Dioxide Absorbent Action

Sodalime tends to be the safest and most cost effective when developed specifically for diving applications. It is made up of:

Calcium Hydroxide	$Ca(OH)_2$
Potassium Hydroxide	KOH
Sodium Hydroxide	NaOH

(Either or both of these may be present)

The carbon dioxide reacts with water and water vapor to produce a weak carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Then the carbonic acid reacts with the bases (hydroxides) to produce a salt (chalk) plus water:

$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O + \text{Heat}$$

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O + \text{Heat}$$

Generally, 100 grams/3.52 ounces of absorbent can neutralize about 25 liters of carbon dioxide.

Each rebreather manufacturer makes significant studies of their scrubber canister design, material usage, and form. The diver must ensure that they adhere to the specific recommendations otherwise proper operation of the rebreather system will not be assured.

The scrubbed gas is returned to the inhalation bag and mixed with the make-up gas from the flow valve to start the cycle over again. In the event the inhalation bag has too little volume (rapid descent, exhaust valve too far open, etc.) the demand valve or bypass will make up the additional required for proper breathing volume.

The basic SCR is simple in design and safe when used in accordance with the manufacturers specific recommendations. Anyone deviating from the instructions may find the unit to be quite unfriendly! But then consider the original Fleuss device:

> The Fleuss device used a watertight rubber facemask, which was connected by tubes to a copper tank charged with 30 bars of oxygen. The exhaled breath would pass through a breathing bag and be drawn through rope yarn soaked with caustic potash to eliminate the carbon dioxide. The user would control the make-up oxygen with a hand valve.

With the Fleuss device, the diver better not forget to add the oxygen or otherwise the unit would go hypoxic! At the same time, there were problems associated with operating too deep and adding too much oxygen, resulting in CNS oxygen toxicity problems. The French physiologist Paul Bert studied many of these events and brought us some of the early work on oxygen toxicity, both in the diving context as well as mines and caissons.

Notes

Surface Interval 2

1. What is the primary difference between the Atlantis I/Dolphin system and the DrägerRay system?

2. What is the difference between a semiclosed circuit rebreather and a closed circuit rebreather?

3. What is the purpose of the scrubber canister?

4. What is the primary ingredient of the scrubber material?

5. What is channeling?

6. Draw a simple diagram of a semiclosed circuit rebreather:

7. Explain the importance of the "check valves" located in the mouthpiece assembly.

Chapter 3 Rebreather Physiology

As previously described, the same techniques of Enriched Air Nitrox diving apply for the Semi-closed Circuit Rebreather. A brief review of nitrox techniques shows how they relate to the SCR.

Maximum Operating Depth (MOD)

The gas in the cylinder determines the MOD of a SCR. If the SCR uses a variety of gases, then the diver is responsible for determining the proper mix for the intended dive. In any case, this relates back to the application of PO_2 rules. Most divers choose to limit the PO_2 to approximately 1.4 bars for a comfortable safety margin. Exceeding the oxygen toxicity limit may result in the diver experiencing significant problems. This *hyperoxia* is a condition that can cause convulsions, visual disturbances, etc… From the previous nitrox courses the diver should be well aware of the various signs of oxygen toxicity. Some use the acronym "ConVENTID" as a memory aid.

Con	Convulsions
V	Visual Disturbances
E	Ear Disturbances
N	Nausea
T	Twitching
I	Irritability
D	Dizziness

While the above symptoms are classic in lectures and make great test question fodder, the diver needs to understand that they may not occur in any particular order, **may not actually give any warning** and therefore should live by the rule:

"If anything seems wrong - it just might be! Come up - NOW!"

If the cylinder contains EAN_{60}, then the diver should limit depth to 13 m for a PO_2 of 1.4 bars or an absolute maximum of 17 m for a PO_2 of 1.6 bars. EAN_{32} would provide a depth range up to 34 m for 1.4 bars and 40 m for 1.6 bars. The appendix has review material for computing MOD.

In some cases, a look up table or chart is available for a specific rebreather system. This helps eliminate a source of error that the diver may make in using the system. Some educators believe that each diver needs to know how to compute the various numbers, but the fact remains a table or chart ensures repeatable, reliable results without the hazard of a calculator error.

Central Nervous System (CNS) oxygen toxicity time limits need to be observed as with all Nitrox dives. The following chart shows the familiar time limits for oxygen exposure based on the $P0_2$ of the gas being used at the particular depth:

NOAA OXYGEN PARTIAL PRESSURE TIME LIMITS (Minutes)

PO_2 (bars)	Single Dive	%CNS/Min	Daily
1.6	45	2.22	150
1.5	120	0.83	150
1.4	150	0.67	180
1.3	180	0.56	210
1.2	210	0.48	240
1.1	240	0.42	270
1.0	300	0.33	300
0.9	360	0.28	360
0.8	450	0.22	450
0.7	570	0.18	570
0.6	720	0.14	720

Remember that the percent CNS per minute value is used for tracking multilevel dive oxygen exposures.

Hypoxia (Lack of Oxygen)

In the event the diver does not receive adequate oxygen in the breathing mix unconsciousness may eventually follow. In the rebreather system if the flow orifice is clogged, the cylinder is accidentally turned off, or the incorrect mix is in the supply cylinder, the breathing mixture can continue to be recirculated, removing the carbon dioxide - but not replenishing the used oxygen. This results in an increasingly hypoxic mixture. Symptoms of hypoxia include vision disturbances, numbness, tingling and breathlessness, which can occur rapidly and lead to unconsciousness and death. Proper testing of the flow valve is necessary to guard against a condition where the proper amount of gas is not being delivered to the system.

WARNING: Since carbon dioxide is being removed from the recirculated gas, the diver may NEVER recognize that the breathing gas is low on oxygen and simply go to sleep!

Dräger recreational rebreather systems have been designed to provide adequate oxygen when used within the recreational limits. These units were not designed for commercial heavy work situations. For the diver that exerts, the system is designed to provide a minimum of 17% oxygen, by volume, at a maximal metabolisc workload of 2.5 liters of oxygen per minute. In the next section, workload and oxygen will be examined more closely.

There are a variety of tests and checks that can be made to ensure adequate oxygen being delivered to the diver. There are also several oxygen **monitoring** systems available, including the **Dräger Oxygauge**. This unit gives a direct readout of the partial pressure of oxygen in the breathing loop. There are alarms built in to the **Oxygauge** to alert the diver of both high and low oxygen levels. Still other monitoring systems are available that integrate a diving computer to the oxygen monitoring capability, providing a full function diving information system.

Hypercapnia / Hypercarbia (Too much Carbon Dioxide)

Hypercapnia occurs with open-circuit scuba typically by skip breathing, poor equipment maintenance or over exertion as well as not fully exhaling. However with the rebreather system carbon dioxide may accumulate if the scrubber material is used up (exhausted) or inadequately packed. It is also possible that if the canister floods that the carbon dioxide absorbing capacity be reduced or eliminated. In some cases, little change in breathing resistance may be noted. The diver may notice being breathless or having a severe headache. In extreme cases the diver may pass out. In any event the standard rule applies – Switch to Bailout and Surface.

Too little carbon dioxide in the blood system is called *hypocapnia* which results from full deep and rapid breathing which reduces the CO_2 level below that required to trigger spontaneous breathing. The symptoms are similar to those of hypoxia but are rare in divers. Again – *the diver is not very likely to correctly diagnose a gas malady - so at the first sign of any problem*

Simply Switch to Bail Out and Surface.

Notes

Surface Interval 3

1. What is the maximum depth when using EAN_{50} at a PO_2 of 1.6 bars?

2. What is hyperoxia?

3. What is hypoxia?

4. What are the symptoms of hyperoxia?

5. What are the symptoms of hypoxia?

6. What are the real chances a diver will recognize problem symptoms?

7. In the event anything seems wrong during an SCR dive, what is the proper course of action?

Chapter 4 Gas Consumption and Decompression

Gas consumption and duration of the Semi-closed Circuit Rebreather are typically determined by the manufacturer under controlled conditions and specific setups. This is a balancing act that has to take into account the oxygen depth limits of the various nitrox mixtures, the amount of oxygen required by the human body and finally the nitrogen uptake that occurs due to the difference in the supply gas and the inspired gas. These conditions are explained by the standard SCR formula. In the appendix, the math for SCR units is described.

The typical user doesn't need to calculate each dive's mix or flow rates, but rather needs to follow the manufacturers specific guidance. The flow rate required in an SCR is dependent on the oxygen metabolic consumption of the diver and the fraction of oxygen in the gas cylinder.

It is the metabolic consumption rate that is most important to the SCR diver. A diver at rest may only consume between 0.5 and 0.75 liters of oxygen per minute, while with moderate work this may rise to between 1.0 and 1.5 liters per minute and high workloads may require as much as 2.0 liters per minute or more. Highly efficient divers in good shape may even require up to 3.0 liters per minute for short periods of time. Most recreational scuba divers cannot maintain that level of exertion so normal oxygen requirements may be considered in the 1.0 to 1.25 liters per minute range. It is this metabolized oxygen that needs to be replaced by the rebreather. Again, each manufacturer will provide information concerning gas flow rates and proper use of the system.

Oxygen Metabolic Rate

A wide variety of sources each have differing ranges of oxygen metabolic use rates. Thalman describes rates from 0.5 to 3.0 liters per minute (lpm), Bennet, et. al. shows 1.5 lpm as a practical level of sustained exertion (0.6 to 1.1 knots). **Sterba considers 0.5 knots to be the ideal long distance swimming rate with an average VO_2 of 1.25 lpm.** Using a wet suit could require 40% more energy than a dry suit.

Metabolism

Body energy is produced by the conversion of fats and carbohydrates into carbon dioxide and water using oxygen. About 5.1 kilocalories of energy is produced per liter of oxygen, 53% of the energy is used for mechanical energy with 47% being converted to heat. For each liter of oxygen metabolized, about 0.8 to 1.0 liters of carbon dioxide is produced depending on the individual's metabolic efficiency.

Since a portion of the oxygen in the gas being breathed is consumed, there will always be somewhat less oxygen in the breathing bag than what is being delivered by the cylinder since the fresh gas is mixed with the "scrubbed" exhaled gas. The higher the workload, the lower the fraction of oxygen in the breathing bag. Since this value is always lower than what is actually in the cylinder – it doesn't take a brain surgeon to realize that if only air was put in the cylinder then it will actually become HYPOXIC! This is the reason that several instances have occurred where a diver either got dizzy or passed out in a pool while demonstrating or practicing with the rebreather***. This is the worst case environment for the nitrox semiclosed circuit rebreather - shallow and low*** fO_2 ***(such as air) supply gas.*** While the gas may support life at depth, it may only result in unconsciousness when the diver is shallow.

On the following page a chart shows the effect of workload (oxygen metabolism) on the inspired fraction of oxygen for a specific SCR, the **Dräger Atlantis I** and **Dolphin** systems. The chart includes the four EAN mixes approved for these systems and their respective flow rates as determined by the manufacturer. For divers using the **DrägerRay**, there is a separate chart as the EAN_{50} gas is the only choice available and flow rates are different. The MOD is shown for two oxygen values, 1.4 and 1.6 bars. Finally, the actual fraction of oxygen that would be breathed by the diver for several workload conditions are included.

Inspired Oxygen Fraction (fiO_2) ***Dräger Atlantis/Dolphin***				
Workload *(VO_2)*	***EAN_{60}*** *(5.7l/min)* *(.201 ft^3/min)*	***EAN_{50}*** *(7.3 l/min)* *(.258 ft^3/min)*	***EAN_{40}*** *(10.4 l/min)* *(.367 ft^3/min)*	***EAN_{32}*** *(15.5 l/min)* *(.547 ft^3/min)*
High ***2.0 l/m*** *(.071 ft^3/min)*	*.38*	*.31*	*.25*	*.22*
1.75 l/m *(.062 ft^3/min)*	*.42*	*.34*	*.27*	*.23*
Medium ***1.5 l/m*** *(.053 ft^3/min)*	*.45*	*.37*	*.29*	*.24*
1.25 l/m *(.044 ft^3/min)*	*.48*	*.40*	*.31*	*.26*
1.0 l/m *(.035 ft^3/min)*	*.51*	*.42*	*.33*	*.27*
Low ***.75 l/m*** *(.026 ft^3/min)*	*.53*	*.44*	*.35*	*.28*
.5 l/m *(.018 ft3/min)*	*.56*	*.46*	*.37*	*.30*
MOD ***1.4 bars*** ***1.6 bars***	***13 m*** ***17 m***	***18 m*** ***22 m***	***25 m*** ***30 m***	***34 m*** ***40 m***

The chart expresses the breathing bag (inspired) oxygen concentration, also known as the fiO_2, for the Dräger SCR systems.

Dräger information also notes that the **flow rate** values given are nominal and actually may be +/- 11 percent. Considering normal accuracy's of gas analyzers and other items, these nominal figures are adequate.

Dräger has engineered the recreational rebreather systems to provide a minimum of 17% oxygen, by volume, at a maximum workload of 2.5 liters per minute VO_2. This workload is quite high and most recreational divers cannot approach this effort or sustain it continuously.

A full description of how these values are derived is in Appendix A, complete with examples of various gases. While you may want to skip all the technical discussion, for those who are curious, the Appendix describes in a bit more detail the effect of flow rate and the production of bubbles.

Inspired Oxygen Fraction (fiO_2) ***DrägerRay - EAN_{50} Only***			
Workload *(VO_2)*	**6.5 l/min** Low limit	**8.25 l/min** Average Flow	**10.8 l/min** High limit
High			
2.0 l/m	*.27*	*.34*	*.38*
1.75 l/m	*.31*	*.36*	*.40*
Medium			
1.5 l/m	*.35*	*.38*	*.42*
1.25 l/m	*.38*	*.41*	*.43*
1.0 l/m	*.41*	*.43*	*.45*
Low			
0.75 l/m	*.43*	*.45*	*.46*
0.50 l/m	*.45*	*.46*	*.47*
Duration 4-Liter Cylinder	*120 minutes*	*94 minutes*	*72 minutes*
	Time exceeds scrubber canister limit		
Maximum Operating Depth			
1.4 bars	***59 FSW / 18 m***		
1.6 bars	***72 FSW / 22 m***		

The DrägerRay system tolerances are specified as +/- 20 percent.

This system provides a minimum of 19 percent oxygen with oxygen metabolic rates up to 2.5 liters per minute.

Ensure that the system flow rate is tested prior to each dive utilizing the supplied flow meter. In any case, the use of an oxygen monitoring system provides more accurate information about inspired oxygen concentration and is highly recommended.

As shown on the chart, the diver uses the cylinder fO_2 to determine the Maximum Operating Depth. Since the inspired oxygen will be somewhat less, this gives a built-in oxygen toxicity safety margin. The inspired oxygen is determined by *estimating* the workload of the dive, which then allows the diver to set that value into a programmable nitrox computer or to be used with the standard EAD formula or tables.

Example: Jack and Jill are planning a dive to a reef in 17 m using the Dolphin rebreather system. The chart shows that EAN_{50} is the best supply gas with a MOD at 1.4 bars PO_2 of 18 m. This also is an appropriate example for the **DrägerRay** system. While some might pick EAN_{60} with it's MOD at 1.6 bars of 17 m, our divers don't want to push the limits and desire to remain prudent in the event of unexpected emergencies. Since the dive may involve a bit of exertion, they plan for a medium workload and select 1.25 liters per minute (l/min) for their metabolic consumption rate. The chart then shows the inspired fraction of oxygen to be .40. This means although the cylinder is delivering **EAN_{50}** to the breathing bag, because of the recirculating gas diluting the fresh gas, the actual oxygen content the diver breathes is **EAN_{40}**. This still represents a significant physiological benefit to the diver.

In the appendix there are charts for Equivalent Air Depth for nitrox mixtures ranging from air to EAN_{60} with corresponding PO_2 charts and values. Normally the diver would use a chart or programmable computer, but could always use the Equivalent Air Depth formula and calculate the nitrogen depth.

Using the EAD formula, a dive using EAN_{40} at 17 m gives:

$$EAD = \left[\frac{(1 - fO_2)}{.79} \times (D + 10)\right] - 10$$

$$= \left[\frac{(1 - .40)}{.79} \times (17 + 10)\right] - 10$$

$$= \left[\frac{(.60)}{.79} \times (27)\right] - 10$$

$$= [.76 \times 27] - 10$$

$$= 20.5 - 10$$

$$= \mathbf{10.5\ m}$$

Once the flow rate is found from the manufacturer’s chart or table, the duration of the cylinder can be determined. Assume for example, the system has a 4.0-liter cylinder filled to 3000 PSI (200 bars). This would give about 800 liters of gas for the system. If the flow rate were 7.3 liters per minute (l/m), then the system would operate for approximately 109 minutes, regardless of breathing rate.

Note: If the diver turns on the system and lets it sit unattended, that will also deplete the gas in the cylinder!

For this next chart, the maximum system duration in minutes for a variety of cylinders and flow rates are shown:

Cylinder Size	***2.5-liter*** *17.6 ft³*	***3-liter*** *21.2 ft³*	***4-liter*** *28.3 ft³*	***5.0-liter*** *35.3 ft³*	***10-liter*** *70.6 ft³*
Total Capacity @ 3000 psi 200 bars	500 liters –20 liters = 480 liters	600 liters – 20 liters = 580 liters	800 Liters – 20 liters = 780 liters	1000 Liters – 20 liters = 980 liters	2000 Liters – 20 l = 1980 liters
EAN_{60} 5.7 l/m	84	101	136	171	347
EAN_{50} 7.3 l/m	65	79	106	134	271
EAN_{40} 10.4 l/m	46	55	75	94	190
EAN_{32} 15.5 l/m	31	37	50	63	127

The values given in this chart are only for gas flow only and do not include any allowance for system testing, incorrect breathing, sawtooth profiles, leaks or any other situation which takes gas from the primary breathing loop. Dräger rebreathers are specified for cylinder pressures from 3000 psi to 300 psi (200 to 20 bars), and *the diver needs to be aware of the lower pressure limitation.*

From our previous example, assume that Jack and Jill are using a 4 liter cylinder of EAN_{50} at 3000 PSI/200 Bar. The flow rate shown in the chart is 7.3 liters per minute. In our cylinder chart, for a 7.3-liter per minute flow, they would have a total duration of 106 minutes.

So our two happy SCR divers could go to 17 m for:

106 minutes (Cylinder Duration)

120 minutes scrubber canister duration (early canister)

180 minutes scrubber canister duration (new series)

150 minutes (1.4 bars CNS Oxygen Limit)

A long time (No decompression limit for 17 m)

For the **DrägerRay** *divers, the scrubber canister duration Is limited to a maximum of 70 minutes, therefore, that is the limiting factor*

Since the 106 minutes is the shortest time of the three considerations (except for **DrägerRay** divers), that is the value that limits the dive time. Of course, no assumption was made for returning with some safety margin of gas, say 300 - 400 PSI (25 bars). The actual governing factor here may be how tired or chilled they get because 100 minutes is a loooong time to spend at 17 m in a single exposure.

To review, the MOD of a SCR mix is based on the actual cylinder contents. This is because as diver could inhale through the mouth and exhale through the nose, making the inhalation bag gas equal to the cylinder gas. In addition, the diver may not work quite as hard as predicted, and again, the gas would have a higher concentration of oxygen than planned. The no-decompression status or tables to be used or programmed into a nitrox computer is based on the inspired $\mathbf{fO_2}$ from a manufacturer's chart or graph. This technique allows for two levels of safety in both the oxygen exposure and the nitrogen loading. If there is any doubt, then estimate a workload higher than planned, this way there will be extra oxygen and help reduce the chances of decompression related problems.

In any case, the use of an oxygen monitoring system is highly recommended. This will also allow the diver to see how hard they work during specific dives and enable them to predict with greater accuracy the dive planning for future dives.

Some of the more complex SCR and Closed-circuit systems incorporate sensors in the breathing loop to monitor the oxygen content of the inspired gas. They may then "talk" with a specially designed computer to continuously compute decompression status "on the fly" and have valves that control the addition of various gases. While these systems represent a high level of technology, their relative safety depends on many system components - as well as batteries. Typical recreational users will find the basic SCR system well suited to their requirements and ability to monitor the dive parameters, as well as the cost of operation.

With the nitrox Semi-closed Circuit Rebreather, dive planning continues to include all the aspects of standard open circuit EAN diving such as maximum oxygen exposure, Equivalent Air Depth, etc. The rebreather does not eliminate the effects of nitrogen and oxygen "on-gassing" as it relates to the natural human physiology - it just lets the diver get more of it!

Notes

Surface Interval 4

1. What is the maximum depth limit of the DrägerRay SCR system?

2. What is the maximum depth limit of the Atlantis I/Dolphin SCR systems?

3. Using EAN_{50}, what is the depth limit for a dive not to exceed a PO_2 of 1.4 bars?

4. Using the Inspired Oxygen chart, what will the inhalation gas mix be using the EAN_{50} gas and orifice at a workload (VO_2) of 1.25 l/m?

5. Will the breathing bag gas be higher or lower than the source (cylinder) gas?

6. Using the Dräger series of rebreathers, at the maximum design workload of 2.5 lmm, what is the delivered oxygen concentration?

7. Using the DrägerRay system, can a diver make a 17 m dive for 1 hour and 20 minutes using EAN_{50}?

8. With the Atlantis I/Dolphin system, can a diver put EAN_{40} in the cylinder and use the EAN_{50} orifice to make the system last longer?

Chapter 5 Dive Planning Considerations

Preparing for a rebreather dive revolves around **three factors** after a site is chosen and the maximum depth determined:

(5 What depth is planned for the dive?
This will determine the mix to be used for the dive as well as the flow rate/orifice that then determines the maximum operating depth (MOD) and the oxygen exposure time based on PO_2.

The diver can use the Inspired Oxygen chart to quickly determine the best mix, based on the desired oxygen exposure as the MOD for both 1.4 and 1.6 bars are given. In addition, it can be seen at a glance the effect of changing the mix on the inspired oxygen.

Divers using the **DrägerRay** system have a fixed orifice and cannot select additional gases. Their dive planning centers around a maximum depth of 72 FSW (22 m) using the EAN_{50} gas.

(6 What is the planned exertion?
This gives the diver the inspired oxygen of the gas in the breathing bag, based on the inspired oxygen chart from the previous chapter. From that value, the nitrogen exposure time is determined.

(7 What cylinder size and pressure?
Knowing the mix as well as the flow rate, a chart or calculation can be made to determine the actual system duration.

Divers using the **DrägerRay** system are limited to a maximum dive duration of 70 minutes, regardless of the amount of gas available in the cylinder. The system scrubber canister is smaller than the **Atlantis I** and **Dolphin** units and can only be used for the 70 minutes.

Regardless, the diver cannot conserve gas by breath control or skip breathing. The system orifice flows gas regardless of any other factors and as a result the only thing that may happen is shortening the time instead of increasing the duration.

The cylinder contents gauge in the system may be considered a direct time gauge. For example, if the system is flowing 7.3 liters per minute with 800 liters of gas available, then the total duration is 106 minutes… call it 100 minutes. That means when the contents gauge reads 3000 PSI/200 bars, then there is 100 minutes… 1500 PSI/100 bars = 50 minutes… 750 PSI/50 bars = 25 minutes… and so on. It's independent of depth so the diver can breathe all he/she wants, just watch leaks and dive profile, avoiding excessive sawtooth or ups and downs that waste gas.

In many cases at moderate depths, the cylinder duration still becomes the limiting factor of the dive as we saw in the previous chapter. However, as the depths increase then the no-decompression limit becomes the major factor. It is important to remember that since the bag gas (the inspired oxygen) is less than the source gas, when using the EAN_{32} gas and orifice combination, that the no decompression time will be **less** than what normal EAN_{32} tables allow.

In any case, if the diver chooses to use an oxygen exposure of 1.6 bars, then the time limit automatically becomes 45 minutes, due to CNS oxygen toxicity considerations. Significant advantage can be gained by backing off the depth or gas mixture to a value of either 1.5 or even better 1.4 bars. The oxygen exposure time becomes 120 or 150 minutes as well as lessening the chances of hyperoxia. The only steps left are to then consider the equivalent air depth (EAD) as well as the nitrogen exposure.

Surface Interval 5

1. What are the three items that are used to plan a SCR dive?

2. What is the depth limit for using the Atlantis I/Dolphin system and the EAN_{40} mix at a PO_2 of 1.4 bars?

3. What is the no-decompression limit (NDL) using any of the systems with the EAN_{50} gas at 21 m?

4. What is the maximum duration of a dive to 15 m using the DrägerRay system?

Each manufacturer will have a technique for preparing their style of rebreather for diving. This pre-dive preparation is important and represents the primary concern that many have towards the proliferation of SCR technology to the recreational market, believing that the divers simply will not take care of the units or provide for the necessary maintenance. In order to take advantage of all the SCR benefits, the system must be in proper working order and properly setup for diving. Be sure to follow all manufacturers' requirements for setup and testing of the rebreather system.

Ensure that the manufacturer's specific manual is available during any courses of instruction and that for specific system questions, the manufacturer's manual takes precedence. The diver should also check to see if manuals have been updated and incorporate additional information.

Prior to entering the water, the diver ensures that all assembly and pre-dive checkouts have been completed. It is interesting to note that the SCR can in some cases, actually be assembled backwards and will continue to work, however at a much-reduced efficiency. Check it out carefully. Make sure the inhalation hose is really the inhalation hose and that check valves are working in the proper direction of gas flow. Know which side the inhalation bag is on and make sure the inhalation hose comes from that port.

Four critical tests of the rebreather system, which do NOT include all of the manufacturer's recommendations, that help to ensure proper setup and readiness includes a check of the flow rate, canister integrity and two types of checks for leaks for the system.

Flow Rate

The importance of flow rate testing cannot be overemphasized. Always verify the proper flow rate for the desired orifice using the manufacturers supplied device or a flow meter that gives a direct indication. An additional possibility to check the flow while diving is to turn the gas cylinder off, note that the cylinder pressure smoothly decreases, then turn it back on. While this is not a precision test, it is quick and can identify a potential problem with an obstruction that has occurred after the system was tested with a flow meter.

Canister Check

The user of the rebreather should always check to make sure the canister is fully packed with the proper absorbent material and not just take someone's word that it is packed! After that, the seal of the canister can be verified by covering one of the ports and then blowing in on the other port, listening carefully for leaks and verifying the presence of a positive pressure release when finished.

Negative Pressure Test

After the unit is completely assembled, the first check of leak integrity is with a negative pressure test. In this, the diver opens the mouthpiece valve and then inhales through the mouth, exhaling through the nose, essentially "sucking the bags down". Close the switch before removing the mouth. Then examine the bags to ensure they stay collapsed. This test checks the inward integrity of seals.

Positive Pressure Test

Following the negative pressure test, the bags are inflated, normally by turning on the system. This helps verify proper operation of the flow orifice and the regulator system as well as giving the diver a first check of the gas available in the system. After the bag is approximately half-full, turn off the cylinder and then gently press down on the bag(s), verifying that the only place gas escapes is from the exhaust valve. If there is any doubt, immerse the unit in water to check more closely for leaks and bubbles. Dräger recommends placing a weight on the bags and watching for a period of time.

Since the system operates at a slight positive pressure, a small leak will generally not affect the operation of the rebreather. However, any leak could become larger and therefore must be corrected before actually diving the unit.

These three simple tests should also be performed between dives as well as a quick visual inspection of excess water in the breathing bag. Any quantity of a milky looking liquid in the inhalation bag is a sign for further investigation. With the newer breathing bags on the **Dolphin** and the **DrägerRay**, this is difficult to perform, but the diver needs to be aware of any water in the system.

The diver must always ensure that the mouthpiece is in the closed position whenever it's not in the mouth. Do not allow water to enter the breathing loop - extra water is bad for the unit! This must be habit:

- Mouthpiece out of mouth:
  Check to make sure it is closed
- Getting ready to take it out of the mouth:
  Turn it off before removing
- Getting ready to dive:
  Put the mouthpiece in place - then turn on

These skills will become habit, typically by standing in the pool or shallow water and continuously repeating the above steps.

If you must remove the mouthpiece underwater, the mouthpiece is to be closed otherwise the system may flood and buoyancy will be lost rapidly. Typically there is no reason to remove the mouthpiece during the dive and if an emergency does occur, the diver should switch to open-circuit bailout remembering to close the mouthpiece to prevent the loss of buoyancy.

Initial Entry

With the equipment in place according to the manufacturer's recommendations, turn on the SCR cylinder and check the content's pressure. At the same time, the breathing bag will start to fill at the flow rate of the selected orifice or flow setting dial.

Notice: Do not turn on the cylinder and leave it on for an extended period of time if the dive is not about to take place - the SCR will continue to bleed gas into the system for the typical cylinder duration. This could be most upsetting if the rebreather were turned on at the dock, followed by a long boat ride to the dive site - the diver may find the system quite empty of gas! There are some passive addition systems in which this may not actually happen, but check it out first!

After checking the cylinder contents, put the mouthpiece in the mouth and open the valve. Some systems want the diver to exhale from the nose fully prior to breathing from the SCR system. This is to help eliminate some of the nitrogen from the exhaled breath. Begin breathing making sure that there are not any perceived obstructions in the system and that the bags are providing the necessary gas. In some systems with demand valve second, stages, the diver can exhale through the nose and then take in a full breath to hear if the demand valve is working.

Reach up and hold the exhaust hose. Clamp it down with your hand and try to exhale. Listen for leaks around the mouthpiece. Repeat with the inhalation hose. Make sure the hoses are on correctly. Clamping these hoses may require 2 hands and a bit of effort, but does provide a good check of the valves and other leaks.

The SCR has a different breathing characteristic than open circuit SCUBA. To try and compare them is like comparing apples to oranges. The SCR relies on the divers lungs to help power the breathing loop. Some claim the SCR is akin to breathing from a snorkel, others simply say it breathes just fine. It's really just a little different, so relax and enjoy the quiet.

Just prior to entering the water, a quick check list for proper operation includes:

1. Gas On
2. Pressure Check
3. Mouthpiece In
4. Mouthpiece On
5. Inhale, Exhale

Another quick check used by rebreather divers to verify gas flowing into the system is to shut off the nitrox cylinder while looking at the pressure gauge. The pressure should smoothly fall, indicating that the system is flowing the gas into the breathing bag. While not a precision test, it is a good check to verify that the flow valve or orifice are not clogged or contaminated. If the needle does not fall smoothly, then retest the flow rate using the meter prior to diving.

Dräger recommends "purging" the system prior to entering the water. This is to eliminate all the low oxygen air from the bags and your lungs. Simply close the nitrox cylinder valve, inhale through the mouth and exhale thru the nose until you can no longer inhale. Open the nitrox cylinder valve, inhale thru the mouth and exhale thru the nose three more breaths. This purging procedure is also recommended any time the diver surfaces and breathes air before descending.

Descend a foot or so and have a buddy check for unusual bubbles or leaks. During this time listen for proper breathing sounds and that there is no "gurgling" or water intrusion into the system. Verify the mouthpiece is comfortable and the hoses in proper position for diving. If necessary, rotate the hoses on the mouthpiece as well as the main housing for comfort and position. Check buoyancy and trim. Reposition weights as required.

If this is the first time with a rebreather, spend a few minutes getting used to the breathing characteristics before moving around much. Close your eyes and concentrate on the sounds of the check valves operating and the demand valve operation (if equipped) when the bag is overbreathed. Next, roll onto each side, left and right and notice any change in breathing characteristics. Hold the mouthpiece in place (for the first time at least) and roll over and look at the surface. For those with back mounted breathing bags, it will immediately be apparent that the gas feels like it is trying to blow the mouthpiece out of the diver's mouth. Front mounted breathing bags act this way in normal swimming position - for example the **Dräger Lar V** has the nickname *'"Lungbuster".* Fortunately, modern recreational units have undergone the necessary human engineering to be fairly comfortable in breathing. The large bore hoses, scrubber canister design and smooth bag connections assist in reducing breathing resistance.

All diving equipment should fit properly and be comfortable - specifically the mask. Divers who continue the open-circuit habit of inhaling through the mouth and then exhaling through the nose to keep the mask clear, will shortly find that the SCR isn't giving them ANY advantage! They may as well be on open-circuit in that case. A poor fitting mask does not contribute to a happy rebreather experience.

Descent

After satisfying that the system is operating properly, the diver can descend while continuing to monitor the system performance. The initial open-circuit habit of exhaling to descend is not effective in this situation - it just fills the breathing bag! Monitor buoyancy control and adjust as required. If the diver is only wearing "skins" then there will be little difference in buoyancy from the surface to the desired depth. Wet suit users on the other hand will still undergo a change in buoyancy associated with wet suit compression and will have to compensate accordingly. Make sure that the buoyancy compensator is fed from another gas source rather than the rebreather supply in order to ensure proper duration. This cylinder may also have a nitrox mixture, but due regard to the maximum depth and PO_2 limits should be observed. With the **DrägerRay**, the system is completely combined, with all gas being supplied by the nitrox cylinder.

Avoid rapid descents. The natural laws of scuba diving continue with the SCR as well as open-circuit diving. Boyle's Law may come into effect if the diver descends too rapidly, by not allowing the breathing bag to be of sufficient size to provide full inflation of the lungs. While the by-pass or demand valve could make up for the shortfall, it is unnecessary and may result in too much gas being used.

Each manufacturer will have some specific recommendations concerning the descent, some require flushing the breathing bag while others require the addition of gas from a manual by-pass or even purging. **Be sure to receive proper training in each specific system you intend to operate.**

Dive Profile

During the dive, each diver should attempt to maintain a constant depth (within reason) to prevent unnecessary dumping of gas. The saw-tooth dive profile will exhaust gas faster than almost any other diving condition (short of a leak). Each time the diver ascends, the breathing bags begin to increase in size, again due to our old friend Boyle's Law, which in turn causes the exhaust valve to react by dumping gas. It is quite simple to see that if the diver goes up and down and up and down, etc., it will only waste gas and reduce the benefit of SCR technology.

The diver should continue to breathe normally - as much as desired. *It does no good to "skip breathe" or hold your breath*, as the gas will continue to be depleted at the same rate due to the fixed orifice. This is a benefit for those who seem to breathe too much, they can now just breathe as much as they want - just don't hyperventilate and pass out!

Buoyancy will continue to be a little strange during the training and first few dives. Practice weight distribution for proper trim and take advantage of streamlining the dive profile. Relax and enjoy the SCR while making mental notes to improve the buoyancy. While many new rebreather divers start out a bit heavy, they become more comfortable as neutral conditions are achieved.

After a while the diver may begin to notice that when exhaling, the bags seem to push the rebreather tighter. Some respond by flexing the shoulders which them compresses the bags and cause them to dump gas. This should also be avoided for obvious reasons as it shortens the gas duration. The system should be somewhat snug, but not too tight so as to cause this continuous depletion of gas by compression.

During the dive the SCR will either have a fine continuous stream of bubbles or an occasional "burp" when the exhaust valve releases the excess gas. *If the diver maintains a constant depth and is breathing uniformly, there should be just a bit of bubble at the end of each exhalation, equivalent to the amount of gas that entered the system during the breathing cycle.* Some systems have a foam diffuser to make the bubbles show as a fine mist to further reduce the intrusive nature of exhaust to the surrounding fish life. It also makes sneaking up on a major naval warship easier!

Ascending

Prior to ascent, the diver should again follow the manufacturers' recommendations. Some require that the counter-lung (breathing bag) be "flushed" or purged prior to ascent. This is accomplished by either activating a manual valve or by simply inhaling through the mouth and exhaling through the nose several times. This ensures that the bag is filled with fresh gas and that if the diver has been exerting (metabolically consuming oxygen at a rate greater than predicted), that the mix will not become hypoxic upon surfacing. Some believe this to be a good standard practice regardless of the manufacturer.

Ascending will cause the bags to expand and may result in the exhaust valve continuously expelling gas. This is normal and should not be cause for alarm. This is also why the diver should avoid **sawtooth** dive profiles - it dumps gas! A careful check of buoyancy during ascent should be made, as both the buoyancy compensator as well as the breathing bags will be getting larger. Don't let it get out of control!

If extra gas needs to be dumped, blow through the nose to help reduce the volume of the breathing bag. Make sure to stop at the desired depth for a normal safety stop and as a final buoyancy control check point.

After completing the safety stop, slowly surface. If the diver must remove the mouthpiece, be sure to close the mouthpiece valve, again to prevent water from entering the system. Closing the cylinder valve will also save the remaining gas in the cylinder.

So at the surface, the standard check items should be:

1. Mouthpiece switched off
2. Mouthpiece out
3. Gas off (cylinder valve closed)
4. Check pressure gauge to ensure completely off

For those who are boat diving or having a long surface swim, remember that *the worst case environment for the SCR is a low* fO_2 *gas in the cylinder and heavy exertion at the surface.* This may result in hypoxia and at all times only the specified gases be used in accordance with proper guidance. **Air is <u>not</u> an approved gas for SCR systems.**

Upon returning to the boat or shore, double check that the cylinder valve is closed and stow the equipment to prevent damage. Remember - if the cylinder valve is left on - the gas continues to bleed into the SCR breathing bags - even if it's not being used.

Post Dive Procedures

After the dive, each rebreather system should be given the maintenance specified by the manufacturer. Prior to disassembly and washing, visually inspect the system to note if any water intruded or connections leaked unexpectedly. More than once, a system has appeared to work, only to be found completely flooded after the dive.

Following the dive, the unit should be washed in clean water, preferably being soaked in lukewarm water, especially if used in salt or contaminated water environments. The rebreather may then be disassembled and inspected as required, including replacing scrubber material and refilling the cylinder. Do not allow the scrubber material to be exposed to the atmosphere to prevent drying out or water contamination. The sodalime scrubber material should be removed from the canister if another dive is not going to be made within 24 hours. In no case should the diving duration of the scrubber material be exceeded. The **DrägerRay** has a 70 minute scrubber duration.

All fittings, clamps, o-rings, and seals need to be checked, cleaned and lubricated as necessary. Special attention should be paid to the mouthpiece valve, keeping it clean and lubricated makes it a bit easier to operate. Be sure to use oxygen compatible lubricants with the system, as many SCRs have very high oxygen contents.

Clean and disinfect the breathing bag(s) and hoses as well as the mouthpiece. They should be cleaned with a bactericide such as Betadine (1:10) or others such as Control III™ which is then rinsed to prevent deterioration of the rubber hoses. Afterwards hang the bags and hoses to allow them to air-dry completely. The DrägerRay system bags cannot be removed, and the entire unit is rinsed, disinfected then hung up to dry.

Avoid crimping bags and hoses. Make sure that no heavy objects are placed on the bags and hoses. Dropping items on the bags can easily puncture them, so ensure that they are protected while drying. In general, do not store the bags loose, but rather assembled into the unit. Never travel or ship bags or hoses unless completely secured and there is no possibility of impact damage.

During reassembly, make sure no grit or debris has collected on surfaces that are supposed to be water or air (gas) tight. Avoid the excessive use of lubricants - a little goes a long way.

Follow all manufacturer recommendations for servicing and periodic inspections. Some require the return of the unit to the manufacturer for routine or annual inspection and repair. Contact the manufacturer or representative for proper procedures of long-term storage and also what to do when returning a unit to service following a period of disuse.

Check to make sure an appropriate number of consumable, user replaceable parts are available if going on a long trip or live-aboard dive trip. Items such as o-rings are obvious, but check valves and hoses as well as any special items might need to be considered.

Aquaseal is an important "first aid" item for the expedition rebreather diver. This allows minor repairs to be made to the breathing bags. Unless you are completely familiar and trained in the proper repair techniques do not attempt these procedures. Be very careful of any solvent cleaning material coming in contact with the rebreather parts, many may dissolve or significantly damage the materials.

Remember to store the pieces properly - many bugs (cockroaches especially) have been known to feast on certain silicone rubber parts and may find the rebreather to be a veritable gourmet smorgasbord! It is also a good idea to shake out bags and hoses prior to assembly for the same reason. More than one rebreather diver has had a "friendly visitor" go along on the dive!

Notes

Surface Interval 6

1. What position should the mouthpiece switch be in whenever it is not in the diver's mouth?

2. What will happen if the diver drops the mouthpiece while in the water without closing the switch?

3. Will sawtooth profiles improve the system time duration?

4. Prior to descending or ascending, is it a good idea to "flush" the breathing bag?

5. What is the memory checklist that should be used prior to any descent?

6. What is the minimum pressure that should be in the cylinder following a SCR dive?

7. Why should you close the valve to the cylinder as soon as possible after surfacing?

8. Why does a rebreather breathe "harder" when a diver in on their back?

9. Explain the importance of verifying the flow rate before every dive.

Chapter 7 Emergency Procedures & Problem Solving

The use of the Semi-Closed Circuit Rebreather is basically simple and requires a little getting used to compared to open circuit scuba. In any system there is bound to be a few difficulties and the SCR is no different. All of the difficulties are easily taken care of with almost always the same response, ***Switch to Open Circuit Bailout and Surface.*** If at all possible, try to remember to close the mouthpiece to prevent additional buoyancy loss.

Mouthpiece Loss

The SCR mouthpiece is always kept in the mouth. The actual techniques of "buddy breathing", while may be an interesting skill to practice, have little practical application in proper SCR diving. Any time the mouthpiece is out of the divers mouth, the shut-off valve is to be fully closed. For those systems with oxygen sensors incorporated, they may become damaged by contact with water.

Obviously, if the diver feels a bit queasy prior to the dive, remember that "regurgitating" into the rebreather will not just blow out and be all right. The exhalation hose would certainly become clogged or if the mouthpiece were to be removed, the very real danger of aspirating the surrounding water makes diving while nauseated a significant risk. Aspiration (inhaling) of water may lead to the deadly problem of laryngospasm - a most unpleasant experience. This is not open circuit scuba!

If the mouthpiece is completely lost or flooded, simply switch to open-circuit and abort the dive. Normally however, the mouthpiece will simply float above the diver’s head. If it is lost, simply lean backwards, looking towards the surface. Reach up and retrieve the mouthpiece. If not too much time is taken, there probably wont be any water in the system. If there seems to be a bit, a roll to the exhaust hose side may help to move the liquid around into the exhaust bag or water trap, depending on the manufacturer’s design. For the “old timers”, this is the same technique used on the old double hose regulator!

Scrubber Depletion

In the event the carbon dioxide absorbent is not replaced as it is depleted it gradually loses its ability to convert the CO_2 to the harmless chalk. If the absorbent material becomes too moist due to the accumulation of diver water vapor and the water from the chemical reaction, the breathing resistance may rise. Many times this is not the case and the diver's first sign of problem is breathlessness and severe headaches due to hypercapnia. In the event this serious condition is observed, the standard response is to switch to open-circuit and abort the dive.

Under no circumstances should a diver try to extend the life of the scrubber material beyond that recommended by the manufacturer. For those materials that have depletion indicators, it should be noted that they are not always 100% accurate and may actually give false readings. A simple log of scrubber replacement will help in ensuring proper removal of the carbon dioxide in a SCR.

Divers should know the system limits of their respective rebreathers, the **DrägerRay** is design limited to a 70 minute use, while the **Atlantis I** and **Dolphin** units have a 120 minute scrubber duration with the early canister, 180 minutes with the improved canister.

Scrubber Canister Flood - System Flood

There are a few conditions that will result in canister or system flooding, most notably when the mouthpiece is not properly closed when not being used. Occasionally a hose will leak or an O-ring in the system will become pinched allowing water to intrude into the canister. This should not be confused with the normal amount of water (and spittle) that collects in the breathing hoses during use.

If the flood is large, then a couple of conditions may occur. The first is that the breathing resistance will probably rise and certainly the ability of the scrubber to remove the carbon dioxide will be compromised. If the canister has quite a bit of water in it, then buoyancy is also affected as the gas is displaced by the water.

In some SCR systems, excessive water or flooding results in some of the scrubber chemical combining and migrating through the inhalation hose. This is the infamous "caustic cocktail" and the diver must immediately discard the mouthpiece and switch to open circuit and abort the dive. While modern scrubber materials have inhibitors and buffers to help prevent fast foaming, the liquid is still highly caustic. When the caustic water enters the mouth, it may be described as an instant burning sensation or even an electric shock in the mouth.

If "gurgling" is heard in the inhalation hose, switch to bail-out and surface. Do not continue the dive, otherwise you may inhale caustic liquid. Determine the cause of the leak at the surface.

All SCR dives should include sufficient fresh water on the boat or at the dive site to rinse the mouth for first aid following getting some of the caustic soda lime in the diver's mouth. The diver should rinse the mouth several times with fresh water. If some of the material was swallowed, then the diver should also swallow several mouthfuls of water. *In no case should the diver try to neutralize the caustic material with lemon juice or vinegar solutions.* If there is no fresh water available, then the diver can rinse the mouth with seawater, but should not swallow. Do not induce vomiting. Seek medical attention as soon as possible. Remember that a characteristic of caustic materials is that they feel "slippery or soapy" to the touch on skin tissue. Whenever possible, rinsing should continue until all sensation of the material is gone. This may take quite a few rinsings.

Most who have experienced the "caustic cocktail" have been uncomfortable eating or drinking for a period afterwards. After 24 hours, discomfort may still be present. At 48 hours it could feel much like eating hot pizza! Generally by 72 hours most sensations of the event are gone. If there is any doubt, seek proper medical attention.

Again, switch to open-circuit and abort the dive - NOW.

Breathing Bag Rupture

If a breathing bag fails during a dive, the buoyancy will be lost as well as an inevitable flooding of the scrubber canister. Quite simply, the standard "switch to open-circuit and abort" is the proper response. Use the buoyancy compensator to offset any loss in lift. Since the bag has ruptured or has a severe leak, there is really nothing that can be done under the surface.

Running out of gas

If the diver allows the rebreather to run out of gas, it will most certainly become hypoxic. Unlike open circuit, the rebreather may continue to breathe with no apparent change in breathing resistance. The diver must always monitor the pressure gauge during the dive and surface with a minimum of 300 PSI or 20 bars. In addition, the diver should expect the pressure to fall according to the flow rate, for example, when using the EAN_{50} gas, every 25 minutes, the pressure gauge should fall at least 750 PSI or 50 bars. If the gauge appears "stuck" it may well not be flowing any gas into the rebreather. In any case, if the pressure gauge reads very low the diver must switch to bailout, even if the rebreather "appears" to be breathing satisfactorily. While at depth there may be a marginally adequate pressure of oxygen, surfacing would cause this to become dangerously low and may result in unconsciousness. If the system is equipped with an **Oxygauge** and alarms for low oxygen, do not surface using the rebreather. Switch to bailout and surface.

Sensor or Battery Failure

Some of the SCR systems on the market or in the future incorporate an electronic monitoring system. Typically these do not actually control the system, rather only providing dive and system information to the user. The course for the specific rebreather system should describe the proper action to be taken by the diver. In some cases, the dive can continue manually but others may require surfacing. Much of this will depend on the diver's experience with the system. It is imperative that a user become as totally familiar as possible so that all procedures are second nature to the diver.

Semiclosed circuit rebreather systems require more maintenance than standard open circuit units. They demand attention to the assembly details and each use requires some degree of disassembly. Careful attention is necessary during the reassembly to ensure proper operation so that there will be no system problems.

In choosing a rebreather, consider the ease of setup, the complications of assembly as well as the overall maintenance required between each dive.

REMEMBER AT ALL TIMES: If there is any doubt about the proper operation of the system or problem, switch to open-circuit bailout and surface.

If water enters any rebreather system, the unit must be disassembled in accordance with the manufacturer's recommendations. The unit must be cleaned, sensors (if any) checked and scrubber material replaced. Particular attention should be paid to all hose connections and o-ring fittings.

In any case, be sure and perform all the manufacturer's recommended tests prior to use ***and welcome to the world of quiet scuba…***

Notes

Surface Interval 7

1. What is the primary emergency procedure?

2. Will a diver recognize the impending symptoms of hypoxia?

3. Will a diver recognize the impending symptoms of hyperoxia?

4. If there is an increase in breathing resistance during a dive or the demand valve activates on every breath, what does this indicate?

5. If the rebreather cylinder runs out of nitrox, will the breathing resistance change?

6. When diving the SCR and something doesn't seem right, what should the diver do?

7. Should the breathing bags be perfectly dry after a dive?

8. Is it recommended to use an oxygen monitor?

9. What is the first aid for a "caustic cocktail"?

Appendix A

The Semiclosed Circuit Rebreather Equation

Most, if not all, SCR systems rely on the following equation for the validity of inlet gas and oxygen value in the breathing bag. It is based on the following factors:

Source Gas Oxygen	**fsO_2**
Gas Flow Rate	**Qs**
Oxygen metabolized	**VO_2**

With these quantities defined, the Inspired Oxygen Percentage, fiO_2, can be calculated. This is based on the principle of mass balance, i.e. there is a flow of oxygen rich gas into the breathing bag, a certain amount will be metabolized (used) by the body and then the exhaled gas dilutes the fresh input gas. The equation is written and then simplified as follows:

$$fiO_2 = \frac{(fsO_2 \times Qs) - VO_2}{Qs - VO_2}$$

From this equation, each manufacturer recommends the gas to be used, the recommended flow rate or a combination of each. In any event, the equation relies on an accurate determination of the oxygen metabolized by the diver for a more exact value of the oxygen that is inspired by the diver. A common technique is to use the source value of oxygen to determine the MOD, and then assume a worst case scenario for the oxygen metabolized in order to determine the nitrogen loading for those systems without some form of monitoring and computing updates in real-time.

Examples:

Assume the diver uses a **Dräger Atlantis I** or **Dolphin** SCR, with the 50% oxygen orifice. From our previous chart we find that the flow rate defined by Dräger for EAN50 is 7.3 liters per minute. The diver is expecting to do a simple drift dive and chooses an oxygen metabolic rate of about one liter per minute. Using the equation above, the inspired oxygen, the bag gas, can be determined as follows:

$$fiO_2 = \frac{(0.50 \times 7.3) - 1.0}{7.3 - 1.0}$$

$$= \frac{3.65 - 1.0}{6.3}$$

$$= \frac{2.65}{6.3}$$

$$= 0.42 \text{ or } 42\% \text{ oxygen… } EAN_{42}$$

If the diver mistakenly (or stupidly!) uses air instead of EAN_{50}, then notice the effect on the inspired oxygen fraction:

$$= \frac{(0.21 \times 7.3) - 1.0}{7.3 - 1.0}$$

$$= \frac{1.533 - 1.0}{6.3}$$

$$= \frac{0.533}{6.3}$$

$$= 0.085 \text{ or } 8.5\% \text{ or in other words -}$$

Hypoxic!

It can readily be seen that if AIR is used as a source gas, then depending on the workload, the breathing bag gas might be quite hypoxic. This is of particular importance at shallow depths, since the PO_2 will approximate the fO_2. Don't play with SCR systems in a pool when air is involved!

Another consideration of the Semiclosed Circuit Rebreather formula is the flow rate. The flow rate as defined in the equation is actually the flow rate at the surface. This is termed Standard, so if the unit utilizes a liter flow rate, such as the **Dräger Atlantis I**, then the flow is in SLPM, Standard Liters per Minute. Imperial systems described in cubic feet per minute, would be SCFM. What this means is that the flow **volume** is related to pressure when diving. If the Sonic orifice is allowing 7.3 l/m of gas to flow at the surface, then at 10 m, at 2 bars of pressure, the actual volume flowing into the breathing bag will be 3.65 l/m. The same number of **molecules** will enter the bag regardless of depth, it's just the volume that will change.

Good ole' Boyle's Law…

This has significant advantage when the diver understands the system and chooses the lowest flow available for the maximum depth of the dive. This would result in the minimum amount of exhaust bubbles to be released, the desire of most photographers and marine wildlife observers.

Appendix B

Nitrox Review Formulas

Convert Pressure (bars) to Depth

$$\text{Depth (FSW)} = (\text{bars} - 1) \times 33$$
$$\text{Depth (m)} = (\text{bars} - 1) \times 10$$

Convert Depth to Pressure (bars)

$$\text{bars} = (\text{Depth}/33) + 1 \quad \text{(Feet)}$$
$$\text{bars} = (\text{Depth}/10) + 1 \quad \text{(Meters)}$$

Best Mix Nitrox

$$\text{Best Mix} = fO_2 = \frac{PO_2}{P_{total\ (bars)}}$$

Maximum Operating Depth (MOD)

$$\text{MOD} = P_{total} = \frac{PO_2}{fO_2}$$

Just remember to convert the total pressure to a depth!

Oxygen Dose PO_2

$$PO_2 = fO_2 \times P_{total\ (bars)}$$

Equivalent Air Depth Formula

$$\text{EAD (FSW)} = \left[\frac{(1 - fO_2)}{.79} \times (\text{Depth} + 33)\right] - 33$$

$$\text{EAD (m)} = \left[\frac{(1 - fO_2)}{.79} \times (\text{Depth} + 10)\right] - 10$$

Appendix C

Glossary

(not in alphabetical order!)

PO_2 Pressure of the oxygen, sometimes called the partial pressure when in combination with other gases. It is the actual "dose" of the oxygen "drug".

FSW Feet of Sea Water…. The ocean…

FFW Feet of Fresh Water…. If you can find fresh…

SCR Semiclosed Circuit Rebreather

CCR Closed Circuit Rebreather, also known as C^2R

SCUBA Self Contained Underwater Breathing Apparatus… includes rebreathers! Traditional SCUBA is termed "Open Circuit"

MOD Maximum Operating Depth… associated with the amount of oxygen in a diver's breathing gas

Best Mix The fraction of oxygen that gives the least amount of nitrogen in a diver's breathing gas for a selected oxygen exposure

bars Atmospheres Absolute, includes the pressure of the air above the surface of the water

EAD Equivalent Air Depth, the depth used to calculate nitrogen loading based on the amount of oxygen in the diver's breathing gas

fO_2 The fraction of oxygen in a diver's breathing gas

fN_2 The fraction of nitrogen in a diver's breathing gas

Inspired Oxygen Fraction (fiO_2) ***Dräger Atlantis/Dolphin***				
Workload (VO_2)	**EAN_{60}** (5.7 l/min) (.201 ft^3/min)	**EAN_{50}** (7.3 l/min) (.258 ft^3/min)	**EAN_{40}** (10.4 l/min) (.367 ft^3/min)	**EAN_{32}** (15.5 l/min) (.547 ft^3/min)
High				
2.0 l/m (.071 ft^3/min)	.38	.31	.25	.22
1.75 l/m (.062 ft^3/min)	.42	.34	.27	.23
Medium				
1.50 l/m (.053 ft^3/min)	.45	.37	.29	.24
1.25 l/m (.044 ft^3/min)	.48	.40	.31	.26
1.0 LPM (.035 ft^3/min)	.51	.42	.33	.27
Low				
0.75 l/m (.026 ft^3/min)	.53	.44	.35	.28
0.50 l/m (.018 ft^3/min)	.56	.46	.37	.30
MOD				
1.4 bars	**13 m**	**18 m**	**25 m**	**34 m**
1.6 bars	**17 m**	**22 m**	**30 m**	**40 m**

Cylinder Size	***2.5-liter*** *17.6 ft³*	***3.0-liter*** *21.2 ft³*	***4.0-liter*** *28.3 ft³*	***5.0-liter*** *35.3 ft³*	***10-liter*** *70.6 ft³*
Total Capacity @ 3000 psi 200 Bars	500 Liters	600 Liters	800 Liters	1000 Liters	2000 Liters
EAN_{60} 5.7 l/m	84 Min	101	136	171	347
EAN_{50} 7.3 l/m	65 Min	79	106	134	271
EAN_{40} 10.4 l/m	46 Min	55	75	94	190
EAN_{32} 15.5 l/m	31 Min	37	50	63	127

Inspired Oxygen Fraction (fiO2

DrägerRay EAN_{50} Only

Workload (VO_2)	**6.5 l/min** Low limit	**8.25 l/min** Average Flow	**10.8 l/min** High limit
High			
2.0 l/m	**.27**	**.34**	**.38**
1.75 l/m	**.31**	**.36**	**.40**
Medium			
1.5 l/m	**.35**	**.38**	**.42**
1.25 l/m	**.38**	**.41**	**.43**
1.0 l/m	**.41**	**.43**	**.45**
Low			
0.75 l/m	**.43**	**.45**	**.46**
0.50 l/m	**.45**	**.46**	**.47**
Duration 4 Liter Cylinder	**107 minutes**	**85 minutes**	**65 minutes**
	Time exceeds scrubber canister limit		

Maximum Operating Depth
1.4 bars 59 FSW / 18 m
1.6 bars 72 FSW / 22 m

NOAA OXYGEN PARTIAL PRESSURE TIME LIMITS (Minutes)

PO_2 (bars)	Single Dive	%CNS/Min	Daily
1.6	45	2.22	150
1.5	120	0.83	150
1.4	150	0.67	180
1.3	180	0.56	210
1.2	210	0.48	240
1.1	240	0.42	270
1.0	300	0.33	300
0.9	360	0.28	360
0.8	450	0.22	450
0.7	570	0.18	570
0.6	720	0.14	720

Equivalent Air Depth (EAD) Table Air thru EAN_{40} Feet of Sea Water (FSW)

Air Table	*.21*	*.22*	*.23*	*.24*	*.25*	*.26*	*.27*	*.28*	*.29*	*.30*	*.31*	*.32*	*.33*	*.34*	*.35*	*.36*	*.37*	*.38*	*.39*	*.40*
30	30	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	46	47	48	49
40	40	40	41	42	43	44	46	47	48	49	50	51	53	54	55	57	58	60	61	63
50	50	51	52	53	54	55	56	58	59	60	62	63	64	66	67	69	71	72	74	76
60	60	61	62	63	64	66	67	69	70	71	73	75	76	78	80	81	83	85	87	89
70	70	71	72	74	75	76	78	80	81	83	84	86	88	90	92	94	96	98	100	102
80	80	81	82	84	86	87	89	90	92	94	96	98	100	102	104	106	108	110	113	
90	90	91	93	94	96	98	100	101	103	105	107	109	112	114	116	118	121			
100	100	101	103	105	107	108	110	112	114	117	119	121	123	126	128					
110	110	111	113	115	117	119	121	123	126	128	130	133	135							
120	120	121	123	126	128	130	132	134	137	139	142									
130	130	132	134	136	138	141	143	145	148	150										
140	140	142	144	146	149	151	154	156	159											
MOD																				
1.4	187	177	167	159	151	144	138	132	126	121	116	111	107	102	99	95	91	88	85	82
1.6	218	207	196	187	178	170	162	155	149	143	137	132	127	122	117	113	109	105	102	99

Depth, Mix and PO_2 Chart

PO_2	*O_2 Time*	*.21*	*.22*	*.23*	*.24*	*.25*	*.26*	*.27*	*.28*	*.29*	*.30*	*.31*	*.32*	*.33*	*.34*	*.35*	*.36*	*.37*	*.38*	*.39*	*.40*
1.0	300	124	117	110	104	99	93	89	84	80	77	73	70	67	64	61	58	56	53	51	49
1.1	240	139	132	124	118	112	106	101	96	92	88	84	80	77	73	70	67	65	62	60	57
1.2	210	155	147	139	132	125	119	113	108	103	99	94	90	87	83	80	77	74	71	68	66
1.3	180	171	162	153	145	138	132	125	120	114	110	105	101	97	93	89	86	82	79	77	74
1.4	150	187	177	167	159	151	144	138	132	126	121	116	111	107	102	99	95	91	88	85	82
1.5	120	202	192	182	173	165	157	150	143	137	132	126	121	117	112	108	104	100	97	93	90
1.6	45	218	207	196	187	178	170	162	155	149	143	137	132	127	122	117	113	109	105	102	99

Equivalent Air Depth (EAD) Table EAN_{40} thru EAN_{60} Feet of Sea Water (FSW)

Air Table	*.40*	*.41*	*.42*	*.43*	*.44*	*.45*	*.46*	*.47*	*.48*	*.49*	*.50*	*.51*	*.52*	*.53*	*.54*	*.55*	*.56*	*.57*	*.57*	*.58*	*.59*	*.60*
20	36	37	39	40	41	43	44	46	47	49	50	52	54	56	58	60	62	-	-	-	-	-
30	49	51	52	54	55	57	59	60	62	64	66	68	70	72	75	77						
40	63	64	66	68	69	71	73	75	77	80	82	84										
50	76	78	80	82	84	86	88	90														
60	89	91	93	95																		
70	102	104																				
MOD																						
1.4	82	79	77	74	72	69	67	65	63	61	59	57	55	54	52	51	49	48	48	46	45	44
1.6	99	95	92	89	87	84	81	79	77	74	72	70	68	66	64	63	61	59	59	58	56	55

Depth, Mix and PO_2 Chart

PO_2	*O_2 Time*	*.40*	*.41*	*.42*	*.43*	*.44*	*.45*	*.46*	*.47*	*.48*	*.49*	*.50*	*.51*	*.52*	*.53*	*.54*	*.55*	*.56*	*.57*	*.58*	*.59*	*.60*
1.0	300	49	47	45	43	42	40	38	37	35	34	33	31	30	29	28	27	25	24	23	22	22
1.1	240	57	55	53	51	49	47	45	44	42	41	39	38	36	35	34	33	31	30	29	28	27
1.2	210	66	63	61	59	57	55	53	51	49	47	46	44	43	41	40	39	37	36	35	34	33
1.3	180	74	71	69	66	64	62	60	58	56	54	52	51	49	47	46	45	43	42	40	39	38
1.4	150	82	79	77	74	72	69	67	65	63	61	59	57	55	54	52	51	49	48	46	45	44
1.5	120	90	87	84	82	79	77	74	72	70	68	66	64	62	60	58	57	55	53	52	50	49
1.6	45	99	95	92	89	87	84	81	79	77	74	72	70	68	66	64	63	61	59	58	56	55

10	15	20	25	30	35	40	50	60	70	80	90	100	110	120	130	140	DEPTH					
					310	200	100	60	50	40	30	25	20	15	10	10	← No Deco LIMITS					
60	35	25	20	15	5	5															A	:10 12:00
120	70	50	35	30	15	15	10	10	5	5	5	5								B	:10 2:10	2:11 12:00
210	110	75	55	45	25	25	15	15	10	10	10	7	5	5	5	5			C	:10 1:39	1:40 2:49	2:50 12:00
300	160	100	75	60	40	30	25	20	15	15	12	10	10	10	8	7		D	:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00
	225	135	100	75	50	40	30	25	20	20	15	15	13	12	10	10	E	:10 :54	:55 1:57	1:58 3:22	3:23 6:32	6:33 12:00
	350	180	125	95	60	50	40	30	30	25	20	20	15	15		F	:10 :45	:46 1:29	1:30 2:28	2:29 3:57	3:58 7:05	7:06 12:00
		240	160	120	80	70	50	40	35	30	25	22	20		G	:10 :40	:41 1:15	1:16 1:59	2:00 2:58	2:59 4:25	4:26 7:35	7:36 12:00
		325	195	145	100	80	60	50	40	35	30	25		H	:10 :36	:37 1:06	1:07 1:41	1:42 2:23	2:24 3:20	3:21 4:49	4:50 7:59	8:00 12:00
			245	170	120	100	70	55	45	40			I	:10 :33	:34 :59	1:00 1:29	1:30 2:02	2:03 2:44	2:45 3:43	3:44 5:12	5:13 8:21	8:22 12:00
			315	205	140	110	80	60	50			J	:10 :31	:32 :54	:55 1:19	1:20 1:47	1:48 2:20	2:21 3:04	3:05 4:02	4:03 5:40	5:41 8:40	8:41 12:00
				250	160	130	90				K	:10 :28	:29 :49	:50 1:11	1:12 1:35	1:36 2:03	2:04 2:38	2:39 3:21	3:22 4:19	4:20 5:48	5:49 8:58	8:59 12:00
				310	190	150	100			L	:10 :26	:27 :45	:46 1:04	1:05 1:25	1:26 1:49	1:50 2:19	2:20 2:53	2:54 3:36	3:37 4:35	4:36 6:02	6:03 9:12	9:13 12:00
					220	170			M	:10 :25	:26 :42	:43 :59	1:00 1:18	1:19 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00
					270	200		N	:10 :24	:25 :39	:40 :54	:55 1:11	1:12 1:30	1:31 1:53	1:54 2:18	2:19 2:47	2:48 3:22	3:23 4:04	4:05 5:03	5:04 6:32	6:33 9:43	9:44 12:00
					310		O	:10 :23	:24 :36	:37 :51	:52 1:07	1:08 1:24	1:25 1:43	1:44 2:04	2:05 2:29	2:30 2:59	3:00 3:33	3:34 4:17	4:18 5:16	5:17 6:44	6:45 9:54	9:55 12:00

Residual Nitrogen Time (Minutes)

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

U.S. NAVY AIR NO-DECOMPRESSION TABLE (21% OXYGEN 79% NITROGEN) DEPTHS ARE IN FEET OF SEA WATER (FSW)

Checklist & Operating Considerations

The **Dräger/Uwatec Atlantis I,** which was superceded by the **Dräger Dolphin** Semi-closed Circuit Rebreather system requires a level of maintenance that is more involved than standard open circuit diving systems. The following details the general considerations for this as well as some instructor hints for watching other divers in an effort to analyze the diver's status. As always, if there are other items you find, be sure and communicate them to TDI so they may be incorporated. Think of this as the "Care and Feeding" of a SCR system. In any case, be sure to follow the manufacturer's recommendations.

Maintenance

Mouthpiece

Atlantis I units are delivered with a heavy amount of Molycote III lubricant in the mouthpiece housing. This lubricant is stiff at best and the primary reason for the difficulty in moving the mouthpiece switch on and off. Some have disassembled the mouthpiece and cleaned the Molycote from the cylinder. Relubricate with the oxygen compatible TechLube, Krytox, Christolube, etc. This lighter weight lubricant is much easier to move. It will require more frequent applications to ensure the sealing ring is not excessively worn, however the trade-off for ease of movement is significant. Since common causes of water entering the system is a mouthpiece that is not fully opened, making it easier to operate should reduce this problem. The Dolphin system has an improved barrel design for the mouthpiece and may not require this treatment.

The mouthpiece switch handle has a small flat sealing ring. During disassembly, make sure that this disk is not torn or damaged. It is possible to forget this ring when reassembling or stress it during reassembly.

The check valves are an item that needs to be checked frequently. The Dolphin is delivered with new semi-clear silicone valves and these are also available for the Atlantis I. The old valves are black and can curl and shrink. This is particularly true if the unit is stored damp, in excessive heat, etc. There have also been cases where some foreign "pest" ate the sides of the soft valve material. In any location pay particular attention to making sure the hoses and mouthpiece assembly are DRY and that no roaches/mice/aliens get into that area.

When assembling the check valve holders into the mouthpiece, there is an o-ring that provides the sealing surface. This o-ring can be damaged if the holder is not rotated as it is put into position. The o-ring tends to extrude a bit while being mated and then is subsequently pinched and cut or damaged. By turning/twisting the holder as it is put in place, this is unlikely to happen.

Make sure that when the clip-ring is installed it is with the holder fully seated. It is possible for the clip-ring to be pushed on and fall into the o-ring groove. This is prevented by making sure that the holder is flush against the mouthpiece housing before attaching the clip-ring.

ALL of the black check valves should be replaced with the silicone valves, which are now readily available.

Breathing Bags

The Atlantis I system was delivered with semi-clear breathing bags that had relatively heavy brass hose connectors on them, while the Dolphin system has a black breathing bag with lightweight plastic connectors. The Dolphin bags also have a water drain hole provided to assist during cleaning, but be careful not to loose the small sealing nut and screw!

Breathing bags with the older style (heavy brass) connectors should be carefully handled, particularly during shipping. The brass connector can cut small crescent shaped holes in the bag if it is allowed to fall or vibrate hitting the bag. Also other heavy items should not be allowed to contact any of the bags, old or new, as holes can be made by impact.

The exhaust valve in the exhalation bag should be checked frequently for accumulation of debris that includes trace amounts of the scrubber material as well as when diving in water that has excessive dirt. Watch out for sand accumulation during beach diving activities.

Check that the poly spiral tubes in the bags are attached with a wire-tie inside the bag and not loose. These spiral tubes ensure that there is a pathway for gas to enter the bag and also ensures that the demand valve always has a pathway to the inhalation hose, allowing it to activate then filling the bags even during rapid descent. Do NOT remove these spiral tubes.

The breathing bags must also be stored dry. If they are allowed to remain damp during storage, molds and a variety of other bacterial problems may grow and cause diver respiratory problems. One method is to hang the bags by passing a broom handle through the openings so that air can circulate freely.

The use of a proper bactericide is a must for health concerns. A variety exists but some may have deleterious effects on the rubber/silicone parts of the rebreather system. Check with Dräger and/or Uwatec for a list of approved cleaners. In general, those cleaners that are in common use by local fire departments for cleaning their own facemasks are adequate for the rebreather. A check with the local medical supply or pharmacy may provide just the right liquid. Use according to the manufacturer’s recommendations.

Both Betadyne and Control III have been used with good results. Betadyne is commonly available at most pharmacies as well as most large supermarkets. Chlorine bleaches generally have a negative effect on the bags and should not be used.

Demand Valve/Orifice Assembly (The Second Stage)

The Atlantis I orifice assemblies (dosage units) have small etched numbers on the hexagonal wrench flats to indicate the proper oxygen concentration, while the Dolphin units have larger numbers and color coded bands. Some of the Atlantis style of orifice assemblies can be quite difficult to read, particularly after a few years of service. Use an identification vibrating etcher to enhance the markings where necessary. When cleaning the second stage assembly careful attention to the orifices is necessary. Do not allow water to collect inside the barrels of the orifice assemblies. When ever possible, leave the hoses attached while immersing and cleaning the second stage assembly. If it is suspected that water has gotten into the orifice, attach a cylinder to the first stage and let it run for at least 15 minutes to blow-dry the orifice. Some of the early orifice(s) have a filter assembly inside the barrel that comes from the factory with a metal circlip holding it in place. This plastic filter will not fall out anyway, and the circlip is prone to quite severe rusting. If present, remove this circlip and discard. Do not discard the filter. If it seems to be loose and may fall out, a simple o-ring will slip inside the barrel into the circlip groove and hold it in place.

Examine the diaphragm to make sure it is properly seated. Make sure the metal disk is in place on the inside of the diaphragm. Early units also had a thrust washer on the face of the diaphragm that could move off center and then not allow proper sealing. The Dolphin has an improved design. After the second stage assembly is complete, a positive pressure test by simply blowing into the opening on the second stage will check for tightness and leaks.

Orifices that have been clogged result in little or no flow. The majority of these cases are where salt water has gotten blown through to the orifice area. A common way this occurs is when there is a bit of salt water on the rebreather supply cylinder valve. When the valve is turned on, the salt water is blown through the first stage and then into the orifice connector. This salt water then crystallizes at the opening, effectively reducing the flow or stopping it completely. Sometimes the orifices may be cleaned by immersing the entire second stage unit in warm water and soaking, followed by blowing dry with first stage attached to a cylinder of gas. There have also been cases where the cylinder supply high pressure gauge fails to register or registers very slowly. This is typically an artifact of the same salt-water contamination, as there is a very small orifice built into the first stage, which becomes clogged the same way as the low-pressure delivery orifice.

The orifice flow rate needs to be checked before each dive. Atlantis I systems were delivered with a yellow bag supplied by Dräger, and requires a somewhat involved test for flow rate. While this is adequate, it does not provide a quick and easy method of checking and is also subject to user errors. Dolphin systems delivered in the USA have a mini flow meter assembly that is quick and far more accurate. Atlantis I users may contact Uwatec or one of the third party sources for availability of these flow meters. An adapter for a Dwyer flow meter can be easily fabricated using the connector from the yellow bag. Details are available from TDI.

Scrubber Canister

The Atlantis I systems were delivered with a scrubber canister that relied on a flat sealing surface and was prone to difficulty. The most common difficulty with the scrubber canister is storing the unit with the lid tight. This causes the lid to bow and distort, typically leaking at the two end areas. While it may be possible to make it tighter and seal that leak, it is a loosing battle. Allowing the lid to sit unattached will typically allow it to relax and return to a near normal position. This tends to be more troublesome in warm climates, however the canister should never be stored with the lid tight. The Dolphin system has an improved lid design with increased strength in the inside web, however still should not be stored clamped tight. The main advantage of the Dolphin lid is the seal design, a semi-vee that does not allow the sealing ring to extrude out with pressure.

An occasional interior wash with a mild diluted vinegar solution will clean much of the accumulated scrubber material from the canister. Ensure all the vinegar is rinsed away. Some of the materials may be affected by the acetic acid in vinegar, but a quick wash and thorough rinse will not cause a problem.

The canister screw assembly needs to be disassembled occasionally and cleaned, paying particular attention to the buildup of scrubber in the o-ring sealing areas. The main screw in the center of the canister can be removed by pushing it down and out of the main canister housing. Older versions of the canister had a snap clip or circlip holding the rod in place, the newer versions have a simple flexible clamp that holds the rod tight against the bottom screen. Clean all exposed areas after removing both the screw and the lid nut and re-lubricate the o-rings.

Do not lubricate the canister seal! On Atlantis I systems this will typically result in the canister seal extruding outward and a major leak. Even if it appears all right during assembly, frequently when the canister is placed into the housing it is pulled away from the sealed position by rubbing against the side of the rebreather housing.

Check to make sure the screens are clear of any accumulated scrubber material. They can be washed in a warm water solution or also use a toothpick to clean any stubborn holes.

I M P O R T A N T

Remember to make sure the rebreather system is completely dry before storing. In high use environments, allow the hoses, bags and mouthpiece assemblies to dry as much as possible.

I M P O R T A N T N O T I C E

The Dolphin scrubber canister NO LONGER has the pre-dive checklist as did the Atlantis I scrubber canister. Ensure all pre-dive checks as required by the system's manual have been accomplished. This includes, but is not limited to a visual inspection, flow test, canister test, negative and positive pressure

tests. A checklist is included at the end of this document but ensure that any additional manufacturer's tests or recommendations are also performed.

Assembly and Diving Considerations

Assembly

A. Lay out all the components for the rebreather. Make sure all items are clean and lubricated as required. Pack the scrubber canister and test as described below.

B. Assemble the unit, beginning with installing the Exhalation Bag first. The Exhalation Bag is mounted in the location identified by a red dot on the housing. Make sure the hose connector is in place with the guide pin in the hole in the housing. The connector will be tilted considerably if it is not mounted correctly. Snug the mounting ring, but it is not necessary to use extreme pressure. The exhaust valve is mounted by press-fitting the valve into the rubber sleeve. Ensure it is fully seated and the rotating valve is not ajar or impeded.

C. The Inhalation Bag is the second item to be installed. The bag lies on top of the Exhalation Bag. Ensure the guide pin is in the locator hole as with the Exhalation Bag. Snug the mounting ring.

D. Double check the scrubber canister for leaks. Hold the canister out of the housing, and move the connectors together ensuring that they latch and click. Pull on the connectors to ensure that they are intact. Slide the canister into the housing, making sure that the canister seal does not pull away or become dislodged. Secure the canister with the Velcro straps.

E. Guide the two low pressure hoses from the first stage assembly thru the cutout on the side of the housing with the Inhalation Bag/Hose. Check for all unused orifice caps to be snug. Verify the proper orifice to use and attach the low pressure hose with the elbow adapter. The remaining low pressure hose is attached to the demand valve opening. Verify that all connections are snug. Check the **Flow Rate** if it has not already been established. Snap the Second Stage housing onto the Inhalation Bag. Make sure it clicks and is firmly attached.

F. Turn the housing over and attach the gas cylinder. Secure the cylinder with the cam-band. Attach the 1st Stage to the cylinder.

G. Check the breathing hose check valves by blowing against the direction of the intended flow. This can also be done thru the mouthpiece by alternately sucking and blowing while holding the free end closed. Attach the breathing hose assembly to the connectors, making sure that the exhalation hose is on the exhalation bag connector. Snug the connectors. The hoses should rotate on the connector after the being tightened.

H. Dress all pressure gauges, inflator hoses, bailout system as necessary. Perform all pre-dive checks and inspections as described below.

Pre-Dive Checks and Tests

A. Check all hose connections at the demand valve for proper tightness. Frequently these items loosen, leaks have been noted as well as hose connections that were barely attached.

B. Early Atlantis I units had a separate thrust washer with the diaphragm assembly. Visually check the thrust washer holding the diaphragm in place on the demand valve. This can also be checked by blowing into the opening on the demand valve, listening for leaks. If the thrust washer is off center, leaks have been noted.

C. Check all rings and clamps at the mouthpiece. The rings can loosen due to movement of the mouthpiece. It is very difficult for a hose to pop off, but still needs to be checked.

D. Canister test: Most common source of difficulty with leaks in the system. DO NOT LUBRICATE THE SEALING RING! It may extrude (squeeze out) under the pressure of the clamping action, with a significant leak following. Make sure when placing the canister in the unit, that the seal is not pulled loose. This can be somewhat alleviated by placing the seal end first into the backshell, then the other end.

E. Negative Pressure Test: Make sure the mouthpiece is completely closed. A slight amount of relaxing is normal, however it should not continue. This test gives an indication of general integrity.

F. Positive Pressure Test: Turn on the system to ensure flow to the Inhalation bag. This is also a good time to check to ensure the proper gas is sent to the proper Flow Orifice. Ensure that the leak or hiss is only present at the Exhaust Valve. If there is little or no tension on the bag when pressing down, and all the gas seems to be escaping from the exhaust valve, there may be a bit of grit or foreign material contaminating the valve. While the positive pressure test may be performed by blowing into the bag, this does not give the visual indication of the orifice flowing gas into the system. **Make sure that the flow test has been completed to verify the proper flow rate, failure to do this may result in a hypoxic situation if one or both of the holes are clogged in the orifice assembly.** With the flow meter assembly, this test can be done with the rebreather assembled and bags in place.

G. Breathing Hose test: With the unit assembled, squeeze closed the inhalation hose while trying to inhale. Similarly, squeeze closed the exhalation hose while trying to exhale. There should be no leakage in either direction, ensuring that the mouthpiece check valves are operating correctly. If the check valves are not correct, it is possible to have a high carbon dioxide situation, or even a hypoxic condition.

In-water Checks and Tests

The instructor/divemaster/guide needs to be aware of the normal indications as well as the abnormal ones to prevent a possible problem with the unit. Frequently new SCR divers are unaware of these indications or they may think there is a problem when the unit is actually performing correctly.

· NOISES

A) Normal

1 **Surface Exhaust.** When first entering the water, the inhalation bag will be full and water will wash over the backshell. Many times this results in a fairly loud noise that is disconcerting at first.

2 **Demand Valve.** On descent, it is normal for the demand valve to be activated, sometimes on every breath if the diver is descending rapidly. This is not a waste of gas as long as the diver doesn't engage in "sawtooth profiles".

3 **Sonic Orifice.** Some divers hear the "hiss" of the orifice while diving. The EAN60 orifice is the quietest, and if a diver changes over to the EAN40, there is a significant difference in noise. Many divers can hear the EAN50 flow as well.

4 Another noise that may be heard is a high pitched whistle, this is typically due to the small poly sleeve on the orifice output having just a bit of water in it or it is vibrating. Sometimes rotating the sleeve, or removing it and cleaning before replacing should alleviate this noise. In any case, this can be confirmed by turning the cylinder valve on and listening to the second stage, but does not affect the performance of the system.

5 **Air in BC.** As the diver moves, the air shifts in the BC and combined with a bit of water, it may sound like there is water in the breathing bag.

6 **Check valves.** Usually the new divers don't notice that noise, but after a few times using the unit, they become aware of a "thunk-thunk" noise as they breathe. Simply explain that this noise verifies that the check valves are operating normally.

7 **Condensed Water.** As the diver breathes underwater, the humidity from the breath is condensed by the cooler water in contact with the mouthpiece. After 30-60 minutes, enough moisture may accumulate to cause a bubbling sound when they exhale. Rolling to the exhalation side and around will help clear this noise and move the fluid into the exhaust bag. This "gurgling" is a different sound than when inhaling.

See abnormal indicators.

8 **Exhaust Valve on Ascent.** While ascending, the exhaust valve may sound quite loud to the diver due to the excessive pressure in the system. They may also experience some alarm at the fullness of the mouth due to this pressure. Avoid reducing the tension on the exhaust valve too much. Four clicks is about the maximum to prevent water from leaking into the exhaust bag from the exhaust valve, which can then migrate into the exhaust hose or the scrubber canister.

B) Abnormal

1 **Gurgling in the Inhalation Hose.** This is a significant sound which may indicate the impending “caustic cocktail”. Whenever the diver hears any type of gurgling while inhaling Abort the dive. Also, if the diver goes into a head down position and hears a rush of water in the hose next to the ear, this may also indicate a large leak in the system.

2 **Demand Valve Action on Every Breath**

- Exhaust Valve set too loose, which may also result in water entering thru the exhaust valve into the exhaust bag. This usually results in insufficient bag volume.

- Flooded Canister. Doesn’t allow the gas to flow from the exhaust bag thru the system, resulting in demand valve action on every breath

· VISUAL INDICATIONS

A) Normal

1 **Exhaust bubbles on every breath.** This is normal as long as the bubbles are generally smaller that the equivalent open circuit exhaust stream. Ascending there should be A LOT of bubbles, descending there may be few, if any, bubbles. It is not uncommon to see a small group of bubbles from the strap slot on the back shell, but should cease relatively soon in the dive.

B) Abnormal

1 **LEAKS ANYWHERE?!** (except the exhaust valve)

- Mouthpiece. (Bubbles in front of the diver’s face)

  (a) Mouthpiece switch not completely open
  (b) Screw on switch handle loose

- Backshell or Around Breathing Hose Connections

  (a) Loose connections
  (b) Cuts in breathing bags. This occurs most frequently in older systems with the heavy hose connections. When dropped, the metal piece impacts and makes small crescent shaped cuts.
  (c) Demand valve diaphragm
  (d) Scrubber canister seal

2 Mouthpiece Position. If the diver is holding the mouthpiece all the time throughout the dive, it usually means there is some discomfort. Have them let go and look at the mouthpiece.

- Mouthpiece moves high: Pull the mouthpiece into proper position then rotate the two breathing hoses backwards (towards the diver) to provide the tension to maintain the position. Use caution not to pull the mouthpiece from their mouth! Possibly during the pre-dive briefing, explain that you may have to do this for their comfort and not to be alarmed.

- Mouthpiece moves low: Opposite of the above. The discomfort the diver experiences range from pushing on mask, hurting the nose or an irritation of the gums.

3 Hose Dressing. If the breathing hoses are against the diver's head, rotate the hoses at the connection to the backshell, spreading them away from the head. It may not be perfect in all positions, but can provide a bit more comfort.

NOTES:

Test Checklist for Atlantis I/Dolphin

1. Ensure scrubber canister is properly filled
2. Scrubber canister pressure check
3. Inhalation and exhalation check valves tested
4. Verify Nitrox cylinder gas analyzed
5. Verify proper flow orifice selected to match cylinder mix
6. Verify proper flow rate for the selected orifice
7. Verify Nitrox cylinder pressure adequate/filled
8. Negative pressure test performed
9. Positive pressure test performed
10. Ensure Bail-out cylinder properly filled and bail-out regulator tested