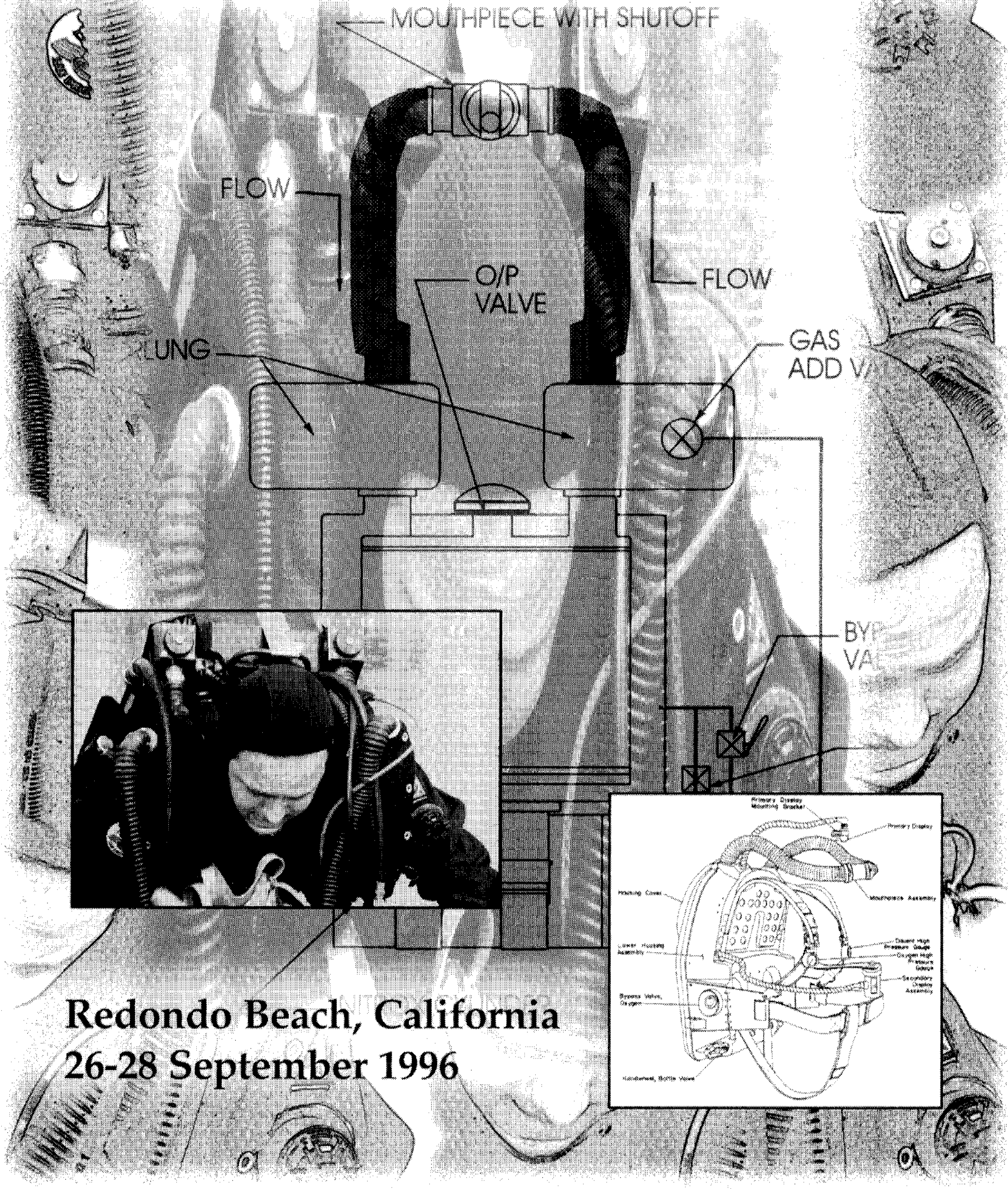
# Proceedings of Rebreather Forum 2.0




Redondo Beach, California
26-28 September 1996

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## ⚠ Warning:

The Rebreather Forum 2.0 was an open information exchange in which individuals were encouraged to express opinions and concerns. Therefore, the opinions, information and statements made in the transcripts of the Forum, and in the included papers, are the views of the speakers/authors at that time, and not necessarily those of DSAT, PADI, the editors, or any other Forum participant or sponsor.

The Forum sponsors and the publisher of these proceedings make no claims or warranties regarding the validity or accuracy of opinions or information presented in the Forum and reproduced here. The reader uses any information presented herein entirely at the reader's own risk.

## ⚠ Warning:

Scuba diving is a potentially hazardous activity. Do not attempt to learn to scuba dive without supervision and training by a certified scuba instructor. Do not attempt to learn to dive with closed or semiclosed circuit scuba without supervision and training by an instructor certified to teach diving with the unit. Otherwise, you may expose yourself to hazards including injury or death. This publication contains information of interest to those using closed and semiclosed circuit scuba, but it is not a training manual nor a substitute for training.

# Table of Contents

# Preface

These are the proceedings of a workshop convened 26-28 September 1996 in Redondo Beach, California to address the major issues surrounding rebreather technology and its application to sport diving. Named after a first such meeting held in Key West, Florida in 1994, Rebreather Forum 2.0 brought together a highly qualified group of over a hundred specialists, experts, vendors and experienced practitioners, representing a variety of communities, to discuss this re-emerging technology and to share information.

Today, there are nearly a dozen manufacturers that have announced their intention to offer rebreathers to the sport diving public, some of whom have already entered the market. In 1996, German manufacturer, Dräger, who supplies rebreathers to the US Military and other navies of the world, introduced the Atlantis 1, a semiclosed system designed specifically for recreational divers. Nissan-affiliate, Grand Bleu introduced a similarly-targeted rebreather, the Fieno, to Japan consumers the year earlier.

Rebreather Forum 2.0 was organized to address the major issues involved in bringing this equipment to the consumer marketplace. The program was divided into sessions which covered the different aspects of rebreathers. The objective was to provide a common base of knowledge on rebreather technology, to identify the key safety, training, technology and risk management issues, and to begin to develop a set of community guidelines to ensure diver safety.

In order to best convey the information that was presented at the Forum, the proceedings are organized into four major sections. These are the findings & recommendations, transcripts, supporting papers and articles, and an appendix.

The findings and recommendations were prepared with the help of a senior group of advisors who served as the steering committee (see chapter 14), and are meant to convey the sentiment and significant conclusions of the Forum. The findings and recommendations attempt to reflect the general opinions of the forum as it addressed the major issues.

The actual transcripts of individual sessions, which represent the "meat" of the Forum, are presented in their entirety (except portions lost during tape changes) with limited edited for readability. A number of formal papers were also prepared for the Forum. These have been reproduced in the Papers section, along with several reprinted articles that should provide readers with useful background information. In addition, a glossary of rebreather terminology, list of attendees, manufacturer contacts and other reference material are included as appendices.

Rebreather Forum 2.0 was organized by *aquaCORPS* founder Michael Menduno, and sponsored by Diving Sciences and Technology (DSAT), Hruska and Lesser, OC Lugo, Orcatron Communications, and "tec.asia" magazine. We would also like to thank Christine Grange and the PADI Travel Network for managing registration.

The Editors
December 17, 1996

# Braving The Loop

## Opening Session

*"A scuba regulator is the steam engine of diving gear. It's been around for a long time. They've been honed to a fine art and they're incredibly reliable. By comparison, a rebreather is like a space shuttle."*

--Ed Thalmann/Duke University

### 26 SEP 1996 THU 8:00-8:45 am

**Michael Menduno:** Good morning. My name is Michael Menduno. I'm the organizer of the Rebreather Forum 2.0.

Before we begin, I would like to thank our sponsors for making this workshop possible. They are; Diving Sciences and Technology (DSAT), the law firm, Hruska and Lesser, OC Lugo, makers of Sofnolime, Orcatron, makers of wireless communications gear, and tec.asia, a new technical diving magazine by Asian Diver. I would also like to thank Christine Grange and the PADI Travel Network for managing registration for the Forum. Please join me in a big round of applause for these far sighted companies.

Over the last seven years I've built a magazine and a conference [*aquaCORPS Journal* and the tek.Conference—ed.], on the premise that diving is in the midst of a technological revolution that is changing the way we think about the underwater world. When I say revolution, I mean that technologies once limited to government and commercial use are being scaled for volume use by consumers—end users. And I think this is a basic paradigm of technology. A good analogy is the personal computer revolution of 10—20 years ago, and how this really changed our whole view of the world and ability to communicate with one another. I think that a similar revolution has been happening in the diving world over the last five to six years.

The first wave of this revolution was the application of mix technology to the sport diving world. Five years ago, nitrox was a dirty word. The fact was that most people couldn't even spell nitrox, let alone understand its use. Yet, here we are today, and enriched air nitrox, in fact the whole concept of optimizing one's breathing gas is an accepted technology in the sport and professional diving markets. I believe that rebreathers represent the next wave in this revolution. Deja Vu.

Offering rebreathers to the diving public isn't a new idea. In 1960's, a man named Walter Stark developed- the first commercially available electronic rebreather-, the Electrolung, which was launched with great fanfare and garnered the cover of *Skin Diver Magazine*: "Computerized Scuba to 300 Feet.". Soon after launch, Beckman Instruments picked up the Electrolung and started distributing it. And then there was a string of fatalities as a result of using these rebreathers. A number of lawsuits followed. The result was that Beckman pulled the system from the market, Walter Stark fled the country, and the door slammed on consumer rebreathers, which have been stigmatized for the last twenty years. Until today. What happened then, is one of the reasons that we are here today.

I think that it's a measure of the growing sophistication of the sport market, that unlike enriched air, nitrox, unlike dive computers before it, there really is no opposition to rebreather technology. There are no "Nitrox Wars," for those of you who were around and can remember that period. No stinging DAN & SDM (Divers Alert Network/*Skin Diver Magazine*) editorials. I would say that almost everybody is interested and ready to go forward. That's a major change from five years ago. In fact, just having a group like this representing recreational, military and commercial diving, assembled in one room, to discuss a technology that effects everyone never happened before. I think that this represents a real opportunity for us.

Even though there's no opposition to rebreather technology, there's some very significant challenges ahead. To quote my colleague, Capt. Billy Deans, "the real challenge is going to be to bring the technology to market without killing too many divers in the process."

I believe that that's easier said than done for a number of reasons.

First of all, the interest in rebreathers really isn't limited to just professionals or the technical community. Everybody seems interested in rebreathers. When I was with *aquaCORPS* earlier this year, we would get calls from brand new divers, or about to become divers, who wanted information on rebreathers. Rather than learn to dive on the old stuff, they wanted to learn to dive on the new technology.

In fact, there's enormous interest in the technology among the recreational community today. You can see it in the press. Both *Skin Diver Magazine* and *Rodale's* have had rebreathers on the cover. They're the big hype. That means whatever comes out of this workshop as far as recommendations on training and equipment, it has to take into account that this technology is going into a very broad market representing a wide range of experience and background.

Second, as we will learn over the next few days, rebreathers are much more complex than open circuit scuba. In fact, unlike scuba equipment, you don't even know if a piece of equipment is working just by breathing on it, like we do with scuba. Rebreathers are a lot more complex than open circuit scuba, and have significant maintenance and operational requirements.

Third, and I think very importantly, there really isn't any appreciable experience in the sport diving market. That makes this transition, very different than the early days of tech diving when you had people with a lot of deep diving experience and operations experience and all they had to do was incorporate mix into their diving operations. It was easier leap. We don't really have more than a handful of people outside of the military who have been regularly diving a rebreather, so that's going to make that leap a little trickier.

Finally, as I'm sure many of you are aware, there's tremendous pressure right now on vendors and training agencies, to get this technology to market. These organizations have spent a lot of hard work, time and money developing this equipment, and want to get a payback. There's is a lot of posturing in terms of manufacturer and training agency claims, delivery dates and the number of so-called experts that exist in the field. In fact, there are a lot more experts than there are rebreathers, that's for sure, and considerable misinformation.

I'd like to propose however, that in addition to the economic pressures of bringing this equipment to market quickly, that there's equal or greater pressure to do it right. If this technology gets out there and a lot of divers get killed, it's going to put a kibosh on the whole thing and no one will benefit.

**I'd like to propose however, that in addition to the economic pressures of bringing this equipment to market quickly, that there's equal or greater pressure to do it right.**

So I think the success of the technology is largely going to depend on our willingness and ability to work together as a diving community, as an industry, to address the issues and problems of bringing this technology to market by putting safety first. If there are too many deaths, it's not going to work. Fini. Over.

I'd like to propose that we work together to grow a rebreather pie— because there is no consumer market for rebreathers right now— and once we have a pie, then all the prospective parties can compete for a piece of it. Without a pie, there's nothing to compete over.

That brings us to the forum today.

The Forum is workshop, a vehicle for two-way communication and information flow, and I'd like to propose several goals. The first goal is to provide a common knowledge base on rebreather technology. Again, as most of you are aware, there's a lot of misinformation out there and information that is lacking. So, one focus will be to provide a common base of good solid information that we all can work from. Second, I'd like to propose that we identify the challenges we face collectively, as an industry, to get this equipment in the hands of nonprofessional end users. And third, that we use this forum as a vehicle to raise and discuss the issues involved in bringing this to market: to develop a guideline if you will, or some kind of framework.

We have a really interesting group of people here, a very diverse group representing the military, commercial, tech divers, recreational divers, photographers, the scientific community. I'm personally very pleased that we have so many representatives from military here, and I should say that their presence is somewhat controversial. I have had a number of people say to me, "We don't know if we want the military at this meeting. Is their experience really relevant to sport diving." The fact is that the only user group out there right now with rebreather experience is the military. So, I for one, am really grateful that they're here. I think that they have a lot of experience and information that other user groups really can benefit from. We're going to be hearing from them over the next few days and hopefully they won't have to kill us. A joke.

We've designed this Forum for you to participate. We want to spend about a third of time for each session with question and answers. It's very important that we create a good record of this event. If you have a question or comment, please come up to one of the microphones around the room, say your name, and speak clearly into the microphone.

It is our protocol here, that there are no stupid questions. Over the last few days, I've had three or four people pull me aside and say, "you know, it's probably a stupid question but..." and then they'd ask away. Stupid question is an oxymoron—there are no stupid questions. I'd really like to open it up so that you feel free to talk.

This forum belongs to everybody and the output of it, the proceedings and recommendations that we come up with, is really a product of all of our work, experience and information. My job, and the job of the other chairs, is going to be to keep the thing on track, and to make sure that we get the information out. There's a tremendous amount of information and experience in everybody's head, and over the next three days we want to dump it out so that everybody can share it.

We have a pretty rigorous schedule; we're starting early every day, and we're running late. We have a lot of ground to cover and a lot of discussion. It's a working forum.

I'd like to start by getting some perspectives from some of the people involved in organizing this forum and then open it up to the rest of you in the audience. First, I'd like to introduce Tracy Robinette, who's the co-chair of this workshop and ask him to say a few words.

**Tracy Robinette:** Good morning. My name is Tracy Robinette. My company is called Divematics, USA. We make full faced masks, closed circuit accessories, and a lot of OEM products. I also am the first person to build a microprocessor controlled closed circuit rebreather. I did this over twenty years ago. It was called the Shadowpack. I've got a lot of history with closed circuit rebreathers and have been around the commercial, sport, and military diving equipment business for a long time.

Two years ago, Michael and I organized a rebreather forum in Key West, Florida. That's the reason that this workshop is called the Rebreather Forum 2.0. It was a very good forum from the standpoint of raising out a lot of interesting issues and it got people fired up about where the market place was going. At that time, two years ago, there were no consumer rebreathers on the market but everybody was interested in getting product on market place. Dräger hadn't brought their unit out yet. Grand Bleu's Fieno had not come out. None of the manufacturers that are currently targeting the sport market had products, so, there's been a lot of progress from the manufacturing viewpoint since that time. There's also been a lot of questions that have been raised, and that's one of the reasons for this forum today. We want to try and answer some of these questions and to give you an opportunity to see, hear and experience where rebreathers are going. Almost all of the rebreathers that I can think of, that are currently being targeted to the sport market are here. So, you'll get to actually see some of these rebreathers.

And one thing Michael said is that we want input. This forum is a dynamic device. If you want a question answered, there's plenty of people here to either answer it, research it, or point you in the right direction to get an answer. So, don't be afraid to ask questions. There's no smoke. There's no mirrors. I hope you enjoy this forum.

**Menduno:** Thank you, Tracy.

I'd like to call on another colleague of mine, Capt. Billy Deans. Billy, what would you like to see happen here? What are the issues that you would like to see this forum address?

**Billy Deans:** Good morning. My name is Billy Deans. I'm from Key West. I represent an interesting market—the technical diving market. We want to have units for the end user that are safe, and that we can go out and dive on a day-to-day basis. The investment required for this equipment is a substantial amount of money, and to get a return we want to be able to use it on a day-to-day basis. There are people out there with the money who have a right to have access to these units, but at the same time, we have a responsibility to make sure it gets out there in the right way.

One of the reasons I'm here is that I'm selfish, like most of the people in this room. I don't want to have a problem [with this equipment]. I don't want somebody coming along and saying, "We've had some problems. You guys can't dive it anymore." Mike Harwood [HSE representative] has a lot of good things to say on the subject. If we can come out of this workshop with a few basic guidelines that we can all adhere to, a set of basic minimum guidelines to get us started, I'd be real happy.

**Menduno:** Thank you. We have a number of manufacturers here. I'd like to get some of their perspectives. Anyone? Okay. Peter Readey.

**Peter Readey:** Hi, my name is Peter Readey. I started out as Prism Life Support Systems and teamed up with Cochran Undersea Technology about 16 months ago. We began almost six years ago, trying to find out if recreational divers wanted to dive rebreathers and have put about 1600 recreational divers in the water on one of our units trying to find out.

We'd like to put out a rebreather that's at the right price, that's safe, that can be maintained very easily. We're here looking for feedback from the people that are in this room, of exactly what you are looking for. Hopefully we can provide it. Thank you.

**Menduno:** Thanks, Peter. Later today we're going to have all of the manufacturers up here and you'll all have the opportunity to question them at length, and they'll have an opportunity to question all of us about what we think of the market. I'd like to move on . We have John Heine here with the AAUS [American Academy of Underwater Scientists]. John would you give us a perspective on rebreather technology from the scientific community's viewpoint?

**John Heine:** Sure. The scientific community is certainly interested in using this kind of technology. We're probably a little bit more limited in some ways [compared to the sport diving community] because of the constraints we have on us with respect to training and our diving standards.

I think if the forum can provide some clear recommendations on training and maintaining this type of equipment, then there will certainly be a market there in the scientific world for using these types of machines. Thanks.

**Menduno:** Thank you. Next is Dr. John Clark with the Naval Experimental Diving Unit.

**John Clarke:** EDU is in the business of exploring and evaluating all sorts of new diving equipment, whether it be open circuit, semi-closed, fully closed. The one thing that we've seen is that diving with any of these pieces of equipment can be a rewarding and thrilling experience—something you treasure for the rest of your life—or it can be the worst experience of your entire life; one that you want to forget as soon as possible. These outcomes can be the result of the training that you have had, or have not had, the maintenance on the equipment, or perhaps even it's design. As the diving industry moves to the ever more complex world of closed circuit and semi closed circuit diving, we would like all of a diver's experiences to be good ones. Therefore, we're doing our best.

We evaluate equipment being used for military purposes, and hopefully what we learn and have learned can of benefit to all of you in this transition. Hopefully you can learn from both our bad and good experiences. We'll be discussing exactly what our experiences have been over the next three days. Hopefully there'll be some take-home messages for you. Thanks.

**Menduno:** Thank you. I'd like to hear from some of the recreational training agencies. Jeff Bozanic, NAUI Board member.

**The one thing that we've seen is that diving with any of these pieces of equipment can be a rewarding and thrilling experience—something you treasure for the rest of your life—or it can be the worst experience of your entire life; one that you want to forget as soon as possible.**

**Jeff Bozanic:** Actually, I'm not here representing NAUI. I'm here on my own and with the American Academy of Underwater Sciences [AAUS]. As a past board member, I can say that NAUI is very interested in all types of diving that would be applicable to recreational dive training. NAUI has actually implemented a policy statement for the use of rebreathers, and rebreathers training in recreational diving- which is very similar to what they did with nitrox diving about five years ago. [See appendix—ed.] What they're looking at is that

As this technology comes on line, and as people gain more experience, NAUI is trying to keep this open for all of the recreational diving community and make sure that the lines of communication stay open. They're interested in how the technology develops and how it will be applied to the recreational diving community.

**Menduno:** Thanks, Jeff. Next, Drew Richardson from PADI. Drew, would you offer a perspectives on this workshop?

**Drew Richardson:** My name's Drew Richardson. I'm president of Diving Science and Technology Corporation (DSAT), and also Vice President of PADI, in the training, education, and memberships group. DSAT is an R&D and engineering group, if you will, that designs training programs and does some research.

The reason we're here?

I think the forum design is comprehensive if you look at the topical headings. If in addition, we could come out with some consensus guidelines, and/or recommendations, even if further study is needed in some areas, I think that would be a giant leap forward.

There's a lot of buzz these days about rebreathers in the recreational community. There's also a lot of misinformation and there's a thirst for knowledge. One thing that this forum can do is to provide objectively-based information to this community, and not just marketing information. Consensus recommendations would be ideal. Some guidelines would be fantastic.

**Menduno:** Thank you. I'd like to do is open this up for questions. What questions would all of you like to see addressed over the next three days? Chris Parrett, Abysmal Software.

**Chris Parrett:** I do decompression tables for a living. And my concern is that a properly functioning rebreather gives the diver the potential of having profound decompression obligations. On open circuit, our limiting factor has been gas volume. Now we are looking to open up diving durations that haven't been seen before. For all intents and purposes, you can have all the bottom time you want with closed circuit equipment, though realistically, you're going to get cold before anything else kicks in.

I'm here to find out what the various manufacturers, and what end users will want to do in terms of controlling their decompression obligation so that we don't end up with divers who stay down too long and have decompression obligations that just can't be met. Thank you.

**Menduno:** Next we'll hear from a tekkie who has built his own O2 rebreather.

**Robert Ianello:** Hello, my name is Bob Ianello. I'm a dentist, and I'm probably one of the prime potential consumers of consumer rebreathers, having a little time, interest and money to buy these things. I'm quite interested to see that the development of this new technology is safe, efficient, and actually occurs. That's my personal interest in this and I wish all of us luck in producing everything that it will takes to support a market so that this technology doesn't disappear. Thank you.

**Menduno:** We have a guest from Germany in the back of the room, Christian Schult from Dräger. As most of you know, Dräger introduced its semi-closed rebreather, the Atlantis, to the market last year. The system is distributed by Uwatec.

**Christian Schult:** Dräger has been in the rebreather business since the beginning of the century. Our main business is in military and commercial diving. The Atlantis is our first step into the recreational market.

Before we did this, we collected a lot of information. In fact, we attended the first rebreather forum that was held in Key West two years ago, and we came back very confused, "Where is the market for recreational rebreathers?

We saw that if we wanted to play in this game, we must make this technology available to the broad recreational market. That's the target of the Atlantis One—to have a unit with proven technology, based on our experience in the military field, and to develop training and so-on together with the market.

Now we have been on the market for about ten months and are more than happy about the results. But it's too early to say that we went the right way, or if we should go this way or that way. I would like to get more input coming out of this workshop, go back out on the market again, and come together for Rebreather Forum 3.0 and say, "What happened?"

**Menduno:** Thank you, Christian. This is a diving business forum, so that all of the people in this room are in the diving business to varying degrees. I find it kind of interesting that, and I know this is true in tech diving, that a good part of the market is the industry itself. Typically the first people to get the toys are the people in the business. I think that's certainly true with rebreathers. The people in this room represent a good chunk of the market right now.

I want to hear from some other non-US people. I see Dave Crockford from the BSAC [British Sub Aqua Club] in the back of the room. Dave, what do you want to walk away from this forum with?

**Dave Crockford:** My name's Dave Crockford. I'm one of the Directors of the BSAC. What I'd like to see from this forum is that really safe progressive teaching goes forward. At the moment, we are hearing about a lot of issues from the US, and there is a lot of what we in England call "crap." We would like to see the crap cut away and the issues laid bare. BSAC would like to take on rebreathers, but we don't want to take on the crap. Billy Deans put it quite rightly; the issue of deaths. We do not want to lose one member. Thank you.

**Menduno:** Thank you Dave. Important sentiments. Other questions, comments, things you'd like to do—see out of this forum?

I see Sgt. Jim Brown here. Jim is a rebreather instructor at the Special Forces Combat Swimmer School in Key West, in addition to being a tech diver. What are you hoping to get out of this, Jim?

**Jim Brown:** I'm a member of the short man's club, so I'm going to take the mike off this stick. Military diving is organized very differently than then civilian sport diving— recreational diving, and this organization probably precludes a straight adaptation of our techniques and principles to the recreational diving market. On the other hand, I think that the civilian market can gain is to learn from our mistakes.

As you may know, the US military has been involved with rebreathers starting with the OSS about fifty years ago, and we've made just about every mistake that's possible with a rebreather. So being creative divers, and driven to avoid the pain of mistakes, it's very possible that the civilian market can learn from our mistakes and adopt some of the guiding principles that we use to make rebreather operations and training successful. Put into the proper context, it wouldn't be too hard to do. It'll take a little bit of organization and effort, maybe a little bit more monetary expenditures, but it's definitely something that could enhance the safety or the effectiveness of civilian diving operations.

**Menduno:** Thank you. Next up.

**Mike Wehrs:** Thanks Michael. My name is Mike Wehrs with Orcatron Communications. We manufacture wireless underwater communication products. Up until about a year ago, most of what we were doing was for the military and commercial sectors. These markets have a couple of things that make our life reasonably easy, for example, the use of full face masks. Well, when you start talking about rebreathers and the recreational market, it gets a little bit more complicated.

We think that you add a lot of value by putting communications on a recreational diver. They get to enjoy it more, you get a little bit more control over what's going on from an instructor or dive master standpoint, but you can't assume that they'll be diving a full face mask. They probably won't be. So how do people talk with a bit in their mouth? That's something that we are concerned about. So as we start seeing low priced underwater communication gear becoming available to the market, especially in the time frames that we think the rebreather market is going to coming up to speed, we want to make sure that issues like, how are we going to connect a microphone into mask, and how important are full face masks going to be in rebreather diving. Those are all types of topics that we want to make sure are covered in the forum.

**Menduno:** There's another manufacturer here. An individual who was at our first rebreather forum two years ago in Key West, and has some pretty unique face mask technology to show us on Friday. Bev Morgan, would you stand up and say a few words?

**Bev Morgan:** Yeah, Michael got me going at the last rebreather conference. My name is Bev Morgan. My company builds the Kirby-Morgan line of equipment for commercial divers. Although I've been a scuba diver, as well as hard hat diver, most of my adult life, we haven't built and marketed any scuba equipment.

We're about to introduce a new mask product, that's not ready for sale yet. I will show you how it works later. In addition to use with open circuit scuba, it has rebreather coupling possibilities as well, though there's a lot of work to do. I got started on the thing as a result of the first rebreather forum. I find that just getting together with all of these people who are experienced in the field is great incentive for me to come. Hopefully, the exchange of ideas will really be fruitful for everyone, not only in rebreathers, but in many other fields. Thank you.

**Menduno:** Thank you Bev. An exchange of ideas—that's what this is all about. And you know the stuff's getting serious when the lawyers show up. We have some lawyers here. In particular, Rick Lesser, one of our sponsors. Rick would you share your perspective with us?

**Rick Lesser:** Well, there goes the positive note for the day. Unfortunately, wherever diving goes, problems go, and the plaintiff's lawyers are sure to follow. Bill Turbeville and I are here to learn. We're basically here to absorb everything we can to be in a better position to deal with any claims that come up. As they will. So, I think we're going to be quiet and listen for a change.

**Menduno:** That is a change. Ha. Are there any other questions, comments or something that anyone would like to say. Please. You need to step up to the mike though and identify yourself.

**Wayne Miller:** My name's Wayne Miller. I own Scuba Schools of America, and as a retailer, I'm concerned with the liability and training issues, so that we minimize liability, to make it easier to market these products.

**Menduno:** Do you sell rebreathers now in your store?

**Miller:** Yeah, we have the Uwatec/Dräger units, and we're looking at Undersea Technology.

**Menduno:** Have you started training people, selling them?

**Miller:** Yeah, we do the semi-closed systems and we're going to begin teaching the UT systems with Charlie Johnson of Adventures in Diving.

**Menduno:** Good. Thank you. Would you like to say something? Mark Leonard from Dive Rite, which is building components for some of these rebreathers.

**Mark Leonard:** Mark Leonard, Dive Rite Manufacturing. I'm the janitor on Tuesdays. I'm here to learn. I've got concerns about education, and the amount of time that people are going to dive the units before they're turned loose, and where they're going to take them. That's what I'm curious about.

**Menduno:** Great. We have time for one last question or comment and then we're going to move onto our next session. Would you like to say something? Grant Graves is a is a film producer and tech instructor.

**Grant Graves:** As far as knowledge goes, I consider myself to have enough knowledge to be dangerous to myself and others at this point. Hopefully this forum will help.

As an end user and probably a trainer for this type of technology, I would like to see an infrastructure in place, spare parts from the manufacturer, things like that, but also measurable universal standards that I can teach by, that we can hopefully all agree on. I'm really tired of dealing with a lot of the hyperbole and crap coming through the line. I tell my guys to read as much as you can, believe about a third of it, and more or less come to their own conclusions because it's really hard to get past the politics. What I'd like to see is a more unified front. Because if we're not unified, OSHA's going to come in and stop us. I'm really worried about that in the film industry, particularly if I spend 3- to 40 grand on these things. That's why I'm here.

**Menduno:** Grant mentioned OSHA. We'll have a session that discusses regulation and liability on Saturday. We do have Mike Harwood here from the HSE, the Health and Safety Executive office in the UK. Mike is also a former Royal Navy diver. Okay, Mike's going to talk.

**Mike Harwood:** I suppose we've got quite a few issues that we're going to be looking at, but the big issue I want to focus on is equipment standards. There is sufficient knowledge in the public sector for people to be able to produce good, unmanned and manned testing on their rebreather equipment, and having done so, the consumer should be able to decide what he wants to buy. He can go to the shop and say, "This is what I want. Show me that your kit can do it. Show me that you have tested it. I want to take it into cold water. Show me that it's been tested in coldwater, and what the parameters are going to be.

I get a lot of people that call me up and say, "where is this information?" I've got a lot of it with me, but there are plenty of other people who are here—Ed Thalmann, for instance who I worked down at NEDU. Look at some of his reports, and you'll see all the test standards are there. So if you're an equipment manufacturer, you can't say you don't know where to find the information. From a liability perspective, it's going to be dead easy to get you around the neck. You can't walk away from the fact, if you're going to put high tech equipment on the market, it must be properly tested, properly documented and the results made available to the public. That's the issue.

I'd like to see us move to an international set of standards, rather than get stuck in American or European standards or whatever. We'll hop right over that, because diving is international. Let's just pass straight through and start at the international level. It's going to be difficult, but I really think we can get there. That's the area I really want to focus on.

**Menduno:** Thank you, Mike. We'll take a short break and then begin the next session.

# Rebreather Primer

*"Each type of rebreather has got a particular area of application, where it is entirely suitable. And there are other areas of application and other operations for which they are entirely unsuitable. The trick is to pick the right device for what you intend to do."*

--Stuart Clough

## Session Summary

The session began with a review of basic rebreather terminology and a discussion of the basic types of rebreathers and their function. Next the panel of rebreather designers presented their own history and experience, explaining what led them to their involvement in the technology. It was clear from their comments and observations that rebreathers are a lot more complex than open circuit scuba and designing a specific piece of kit is more of an art than a science.

Following the initial presentations, the session turned to the issues of rebreather design. The differences between axial and radial scrubber canisters, and scrubber chemistry were explained in some detail. It was pointed out that canister duration can vary significantly even under identical conditions and that the only way to determine a particular design's performance was through performance testing.

Next the discussion turned to counterlung design. Most models that are going to be offered to consumers use a split counterlung design (two separate breathing bags; one for inhalation, one for exhalation) to smooth out gas flows. The engineers pointed out that placement is a matter of overall design constraints. The advantages and disadvantages of both were discussed. Then the panel tackled the issue of PO2 control. In particular it was noted that both very low PO2s and very high PO2s (above the units set points) could occur during ascent and descent. The session ended with each designer stating preferences with regard to closed and semiclosed systems.

The session was chaired by Tracy Robinette/Divematics, and consisted of Peter Readey/Cochran , Stuart Clough/Undersea Technologies and Derek Clarke/Divex.

26SEP THURS 9:00-10:30 am:

# Transcript

**Tracy Robinette:** We're going to get started with this session right away. Joining me will be three engineers who are intimately familiar with rebreather technology; Stuart Clough, Undersea Technologies, Peter Readey, Cochran Computing, and Derek Clarke of Divex. One thing about the three gentlemen up here, and also myself, is that combined we have a lot experience as far as mechanics and what these devices do, and some of the pains in the butt involved with dealing with them.

In your packages you should have a glossary of terminology. Does everybody have a copy of the glossary? It's just a list of terms. Some of them are comical, others are pretty straightforward, and some you may not have ever heard of before.

I'm going to leaf through them real quickly so that we all become comfortable with the terminology. There aren't a lot of neophytes in here, as far as rebreathers go, but some of the terms are a little different than a few of you might be familiar with, so we're going to read through this real quick. And if you have questions, go ahead and ask the questions at this time so we can clarify this and get a definitive answer.

[See Appendix: Rebreather Terminology & Common Units]

**Robinette:** OK. Everyone seems to be up to speed on terminology. Michael?

**Michael Menduno:** Just for posterity's sake, that was an excellent presentation but you went through a lot of terms quickly, and I think that there's probably a variation between people who really understand this stuff pretty well and what's being talked about, and those who don't. I was hoping that you would go through a few basic rebreather schematics and explain how these systems work, so that we're all on the same playing field.

**Robinette:** Christian, you have a set of excellent diagrams, would you come up here and go through them briefly with us? Christian Schult, of Dräger.

[ Schult talks through several overheads illustrating a pure oxygen, semiclosed and closed circuit system. See the Papers and Articles section for descriptions and diagrams of rebreather types.]

**Robinette:** I'd like to thank Christian for a very nice presentation [applause]. What Christian's overheads showed was the way in which these systems are put together from components. By adding components or subtracting components, you come up with each one of types of units. That's what's interesting about what Peter was saying a little earlier about integrating a fully closed and semiclosed circuit system in one unit. The way you do that is by modifying the components; either closing them up, or opening up or adding a component, or whatever, to get a system that is multi-mode.

As you could see there are basically two main types of systems and some sub-categories. The first are fully closed circuit systems which fall into two categories; pure oxygen rebreathers, and electronic self-mixing systems, like the US Navy's Mark XVI. Then there are semiclosed systems which are divided into constant mass flow systems, like the Atlantis 1, and self-mixing or metered-dose systems like the AGA DCSC. There are also surface supplied based systems and reclaim systems but these are not of interest to this workshop.

Hopefully we've defined where we're at. We need to move on to the presentations by these gentlemen, and then we're going to open it to the floor for questions and further input into these type of devices. Stuart Clough.

## A brief historical background

**Stuart Clough:** Mr. Chairman, ladies and gentlemen, good morning to you. I have worked with closed circuit rebreathers going back to about the late nineteen seventies—'78 or '79—specifically from an operational point of view. We had no intention whatsoever at that time of ever doing anything other than buying these things. We needed to carry out a certain type of diving operation which required freedom of movement and mobility. Open circuit was clearly not the solution and there were several devices on the market and they seemed to offer an interesting and possibly better solution to what we were trying to do. Those were the CCR 1000, and the Shadow Pak and a few others. As you know, closed circuit systems are some oldest form of diving equipment around. We also looked initially at the O2 systems as a means of providing us with some expeditious decompression improvement as opposed to carrying open circuit oxygen, so they were a consideration in what we were doing as well. We also took a bit of a look at semiclosed devices, but they got us back into having to mix, blend, and transport gases all over the place, which was one thing we were trying to desperately avoid.

## Self-mixing systems

So we focused our attention on what were the self-mixing systems, of which there were only two choices of any note at the time and that was the CCR-1000 and Tracy's Shadow Pak, both of which were quite difficult to get hold of, particularly for foreigners. So we got started with a self-mixing device, the CCR 1000, and it became fairly clear that these things were quite good. They'd give you the right sort of gas mix. It was constant PP02, which was an advantage from a decompression viewpoint, and they had none of the depth limitations associated with the semiclosed or open circuit devices that were floating around.

However, there were some fairly serious shortcomings. There were certain design features of those devices, that left me with a few surprises. Maintenance of the equipment was a major problem, the stability of the O2 sensors, etc. All of these sorts of things caused us a fair amount of operational grief in the first couple of years of working with them.

## Gas control systems

Since we had been working in the computer business, we made the fateful mistake of thinking, "Well, that's relatively easy to fix," and started putting a gas controller on these devices that would more effectively and that would more appropriately manage the whole diving process. There were dive computers around which would help you with your decompression, assuming you had them programmed properly. The electronic self-mixing devices would take care of mixing the ppO2 to a level that was pretty awful from the diving standpoint. You got a device that was maintained a 0.8 or 0.9 bar [For physiological purposes 1 bar =1 atm—ed.] set point which was satisfactory from a life support point of view, but you couldn't go down very long, particularly on heliox before you were accumulating a fairly horrendous decompression obligation.

**Since we had been working in the computer business, we made the fateful mistake of thinking, "Well, that's relatively easy to fix" . . .**

So our first attempt to deal with that problem was to modify the devices to stablely and consistently allow us to operate in the 1.4, 1.5 bar ppO2 range, which consisted of simple electronic modifications to the then existing gas controllers fitted to these devices. Having gotten that thing proved, or reasonably well proven, the next big problem of course was the decompression tables for which you can use with these things. We took on Ed Thalmann's work, and used the USN standard decompression tables to start off with. They proved reliable, reasonably effective, needlessly to say, the wrong ppO2 for what we were actually working with [The USN Tables are designed for a constant PO2 of 0.7 bar—ed.].

So the next deal was to then start work on developing decompression tables appropriate to the type of diving profiles and the depths that we were particularly interested in. And we had to get in commissioned experts in that area to write specific programs for us in order to do what we actually wanted to do. Of course, then it's a case of testing them, a thing which has been addressed here briefly today in the opening remarks. It's fairly easy to do some numerology these days with your computers and come up with a table. Is it a sane decompression table? And therein lies the question. So we took our problem down to DDRC in England, and we started testing these things to develop a reasonably reliable procedure for getting down to where we needed to go and back up again.

But we'd still only partially organized and integrated what we were trying to do. We had ppO2 control, decompression control, a telemetry system and topside computers. The next step was to try to amalgamate all of this type of processing into a complete onboard process controller that would manage the entire diving process and would particularly give us the record keeping so we could find out what happened down there.

Because we were a relatively small company, we couldn't really embark on a test program that was exhaustive or complete. It was necessary to try and come up with a system that made every dive a test dive, that would recover everything that happened from prior to the start of the dive when the system was calibrated and set up, to when the unit was shut down at the end of the dive. So we've always had a fairly serious interest in accurate, high resolution data logging and had quite a lot of sensors fitted to these devices. We wanted to know what our ppO2 was. We wanted to know the gas pressures, flow rates—all of those things that are fairly easy to do with microprocessors.

So, in around 1985-86, we had moved from an independent isolated analog gas controller to an integrated process control system that could be retrofitted to then existing rebreathers. At that time the CCR155, which was essentially an improved CCR1000, could be purchased relatively easily. We started using the CCR 155 by tearing out the existing electronics and putting in gas controllers that were appropriate to what we were doing. And these proved to be reasonable effective, and at this point we'd really spent a fair amount of money and we decided that it might be possible to find a home for these devices as a commercial product.

## Developing a commercial product

Interest in mixed gas diving was spreading. The technical diving market was beginning to emerge, and there was a serious interest in the beyond-the-air range diving operation. So we started looking around for partners to try and develop the technology and provide the commercial and financial backing necessary to put these things on the proper track.

Many people have got home built rebreathers. Many people tried to develop these things. And those of you who've done it probably realize that getting one going in your back yard, is really not that difficult. It's relatively straightforward. There have been a few suggestions that you could fill your Fenzi BCD with Sofnolime and breathe in and out of that. But with a few additions to it, you're not really that far off. However, turning it into a commercial product is quite a different story. And there are millions of dollars at stake in getting those things round to a state and a standard where you could reasonably let somebody other than a test diver go out and use them.

So we've been working really in that area for the last few years. We've been associated with a number of companies, and currently our technology is licensed to Undersea Technologies out of Tulsa, OK with the object of putting a fully integrated gas control processor into a rebreather that is going to come down in price to a level that is actually acceptable to the general consumer.

The devices that we currently have out are the UT 240's which are certainly not in the general consumer bracket. These things are quite expensive, fairly complicated, and are designed to do quite a wide range activities in wide range of diving environments. Our main work is directed towards a more user friendly, smaller, cheaper device for general use, and that's where we fit into the picture.

**Robinette:** Next will be Peter Readey.

**Peter Readey:** Good morning. I'd like to put a couple of slides up, and give you a little background what we've doing the last six or seven years. I mentioned earlier that initially, the systems I worked on with Stuart on the fully closed Mark 155 and others. But we wanted a more flexible system. We needed a unit that we can take anywhere in the world and that could use any cylinders that were available to us. So, if we turned up some in Canada, we could use a 50 cu tank, or we could use a steel tank—anything that was available.

We initially we thought we'd probably go with semi-closed circuit, and the systems that we used were in fact, a standard mass flow controller, in just the same way as Dräger uses theirs. The only difference is, we wanted to be able to use it with mixtures other than nitrox. We wanted to use trimix and heliox to give us an extension of depth. So to have that, we needed some form of constant ppO2 which we did using galvanic sensors. We could control the flow by using this needle valve assembly. It was a mass flow controller that we could adjust, and we could see partial pressure that we flying at the time. The maximum depth: we took that unit to about 420 feet. The problem is, you could be pretty be task loaded when flying the rebreather, which meant that trying do some productive work at those depths was difficult and also trying to track your own ppO2 on the computer was really very difficult to do on a dive.

This is that particular system. It has a front mounted counterlung, that we chose for hydrostatic pressure reasons. It was easier to put a system on front. We used a standard type mouth piece, bite on mouth piece, and didn't use a full face mask at that time. You can see that this particular unit has a axial canister mounted vertically on the back, and cylinders on either side. Typically we'd use a high percentage oxygen mixture on the left and , and a low percentage on the right with the helium or trimix mixture.

We used that product [Prism I] successfully for about two years, and we decided to go out and cruise the world and find out just what the recreational diver wanted. We modified the system a little bit further on from that adding an analog closed circuit system in much the same way as the Biomarine units do. As you can see, that's a very very early model that was probably one of the first closed circuit systems we built. It was put together in our engineering company. The unit is very simple, with very simple resources. It uses a back-mounted counterlung, but it did the job. But the difficulty we found was trying to impart the knowledge to divers to fly this safely and successfully; it was too difficult. So we had to go down the same route as you heard from Stuart with regard to using an electronic control system.

This is another version or variation on the theme. We actually spent a while talking to companies and we hooked up with Cochran Undersea Technology (different from Stuart's Undersea Technologies), because they had an electronics capability to actually develop a lot of the lessons we've learned for sensor technology. We've done some work with CO2 sensors. We've worked with a C02 monitoring package to tell you when your canister broke through, or if we had a malfunction—any one of those problems. And initially we looking at using a solenoid injection system. It's the same as, I think, that many closed circuit systems—computer-controlled closed circuit systems— use; an analog control system. We felt that having a pulsed injection system on here was probably not the most effective way of going to battle. So we spent a long time, and we're still developing it right now, perfecting a sequential control system which in fact will exactly meet your metabolic oxygen consumption rate. The advantage of that system is, if it were to fail, it would actually fail in a position where you would last metabolizing that particular amount of O2. Plus the fact, if you ever had full line pressure going into this control system of 3000 PSI of oxygen, it would control that level.

Tracy had very eloquently put some techniques together on closed circuit/semiclosed sets. The thing we wanted was full flexibility in this unit, so it would run closed circuit constant ppO2, it would run semiclosed circuit. If the user put something other than oxygen on the O2 side, say 50/50 nitrox, this control system would be able to control the flow into the rebreather, within a tolerance of the same ppO2 range of O2, except you'd need to be a little bit deeper for it to start picking up higher pressures of oxygen beyond that 0.8 ppO2.

If the control system was to fail on you, there was a backup system onboard where we could reroute the gas and manually inject it. At the moment, we're using three galvanic sensors just like everybody else using the voting principle. There's also a full logging system on this unit. Another nice bit about this system is that you can configure it if you wish to, to use multiple cylinder sizes. So initially you would dive on nitrox, and then later on you could use trimix etc. etc. Onboard decompression, is available to you and the breathing bags on this particular unit are twin counterlungs. We went away from having a single. counterlung on the front, because in some body positions, it was difficult to get the gas, actually to breathe the lung on the side, so we got this split counterlung configuration.

In regard to the canister, we've got two options on that. We're still working on a system that is a different type of material, that in fact is able to trap any water getting into the system. It's one of the biggest problems we've found with divers. They had real difficulties remembering to turn the mouthpiece off when they jumped off the boat. And we used to see an expression we called, the dying fly impression, in which people jumped in and started sputtering. Mixing water and electronics is generally not a good idea.

We have a radial flow canister in there and we've got actual flow depending depths again, too, so a pretty flexible system. If you want more detail, I'd be happy to discuss it with you. But if it's somewhat different from the units you've seen different in terms of the gas control system, I think the computer data logging is probably very similar, the interfaces are a little different and you have a secondary display, which has an interface to work on the computer. The products is a sophisticated system.

There's one of the early ones. We have wireless transmission capability on the system, so we're hanging lots of danglies on the system to give us information. That's it, thank you.

**Robinette:** Thank you, Peter. Next up is going to be Derek Clarke who may be a new face to some of you here.

**Derek Clarke:** Good morning. Yes, that's quite right. I wasn't at the first rebreather forum, frankly because I didn't know about it. Had I known about it, I would almost certainly have gone. But I was at the Eurotek conference in the UK, and it's really as a result of that that I'm here today, because what it demonstrated to me was the amount of energy that was being expended in sport or recreational rebreathers. My perspective is from the military market, and it's quite obvious that the two are going to be inseparable in the years to come, in terms of the technology and the approaches to perhaps training.

What I'm here to talk about this morning, very briefly, is the history of the equipment that I have brought as it's relevant to me and to my company, Divex. Later on this afternoon, I'll be talking specifically about our rebreather which you'll be able to dive on Friday.

My involvement in rebreathers started in 1976 when I dove the PP1. Now for those that don't know, PP1 stands for Porpoise Pack One. It was a commercial adaptation of what was the CCR1000 at the time by a company called Inner Space. At that time, I was working for Strongworks Diving in the UK having just left the aircraft industry. One of the things that was quite hip at that point was submersible diver lockout. This was the mid-seventies, and conventional saturation diving approaches to exploration and exploitation of the North Sea was very much in the advance. Saturation diving techniques were being transferred from the military into the commercial, and huge advances were being made in how to support a diver safely down to 600 feet plus.

One of the techniques using a lockout submersible seemed to have various advantages. Of course one of the issues of being autonomous were the significant constraints of gas, and power, and so the only feasible way to do this was to utilize rebreather technology. Looking around at that time, and I was a relatively young diving engineer then, I did not have a hand in the decision of getting this equipment, but I did have a hand in implementing it into service. And frankly, over a period of about a year, it scared the living daylights out of everybody. The combination of difficulties related to training and to maintenance—keeping the kit working in the North Sea environment, where it's round the clock diving—and constraints related to the submersible made it a very short-lived fact. Serious interest in the use of rebreathers for oil field exploration only lasted about two to two and a half years. You just couldn't support the diver adequately. So that was my introduction to rebreathers. I was a pretty avid recreational diver at the time.

## Divex history

Now a little history on the company side. Divex, is a member of the Pressure Products Group and its history is in commercial diving and commercial diving apparatus. We've worked for many years with Bev Morgan in adapting equipment to suit deep commercial helium reclaim applications and as part of that, developed a semiclosed bailout rebreather in the mid-eighties called the SLS, "Secondary Life Support System." We recognized the problems that would obviously occur if a diver's primary system failed in the target range of 360 meter/1175 feet range be it reclaim or not. He's got very little time on conventional open circuit bail out. Thus the objective was to develop a piece of equipment which would give him a decent bail out. In this case we were looking for about 15 minutes at 450 meters/1465 feet. We in fact developed that piece of equipment. It went into service. The Royal Navy bought a number of sets to use for the HMS Challenger. The guys had various problems, even as a semiclosed set, related to the interfacing it the reclaim rig and Kirby Morgan 17B helmet that the diver would be wearing. And so a lot of the problems related there to ergonomics and packaging. And a lot of those lessons we've carried forward with us.

Later history, going through the late eighties, the group actually went through a period where we owned Biomarine, and Dick King, who's here today was running the operation under our custodianship for about two and a half years. Dick will have to put me right here, we sold something on the order of a hundred Mark XVIs to the US Navy. So you see what goes around, comes around when you are talking about rebreathers.

Bringing you somewhat up to date, what we are dealing with today, in the commercial diving world, is a decline of off-shore commercial diving. It may be going through one of its periodic cyclic glitches, but I suspect not. We think that the use of diverse techniques—robotics technology—is reducing the workload on the diver—there's no doubt about it. There has been a strong emphasis on ethical grounds to only utilize a diver when there is really no other alternative on ethical grounds. I think that potentially navies are looking at a similar approaches as well, as ROVs and robotics technologies advance.

## Improving military technology

Today, we're certainly looking and focusing quite closely on the military market and recognize that military rebreathers—breathing technology— are something that we believe we can help advance. We looked around at what was in service, and frankly, and I don't think anybody would take me to task on this—much of it was really pretty old technology. A lot had been learned about breathing technology and physiology through the period of the North Sea development that can be applied.

Our intent was to really evolve the technology to a point that took advantage of the current knowledge, and so we wanted to get a set that had improved breathing characteristics. It had to have better swimming characteristics. It had to deal with bailout as an integrated item, as opposed to something else you think about later. At that time there was a particular Royal Navy requirement. And we privately developed a piece of equipment essentially to match itself to that requirement. It's interesting to see how sets have evolved. Ours is a microprocessor system, but it has a hardware electronic controller. We recognized that it's probably pretty hard for the military to make a quantum leap in technology; to go straight from a 20 year old technology up to what might be called state-of-the-art that led down the path of a total microprocessor controlled system. We didn't do that. We have a combined control system, combining a hardware controller using good old logic, and a surface- mounted chip. It's state of the art electronics, but it's still using hardware that's paralleled out with a microprocessor which has the same functions but it doesn't actually take control.

**We recognized that it's probably pretty hard for the military to make a quantum leap in technology; to go straight from a 20 year old technology up to what might be called state-of-the-art that led down the path of a total microprocessor controlled system.**

And what it does do is audit the process that the hardware is doing. The main advantage that a microprocessor offers is it has a huge potential to provide information, to monitor what's going on, to easily display things to the diver. And most importantly, to recall what's going on and make that available to those that would like to know post-dive, whatever.

## The Stealth

What I'm going to do quickly now, is to show you some slides about our most recent developments, and then later on this afternoon, I think I'll have an opportunity to tell you a little bit more about the actual equipment that's evolved from this bit of history.

Like all good products that actually start with bits of string, duct tape and chewing gum and whatever. This was actually the first prototype for what's become our Stealth rebreather. It's made up of sheet PVC. What this particular rig was to try to do is to look at the mixing characteristics of the basic breathing loop, and also identify any potential problems of breathing characteristics—local breathing issues. You'll recognize the layout when you see the set later on. It is a split counterlung system. We identified the basic packaging that we wanted right from the outset and that was done from a process of analyzing our experience and what had gone before.

There's no earth shattering developments in this thing. On the diver's left side is his exhale lung, and that comes over to a plenum which has a water trap system in it and that's where the gas is injected. OK, that's the exhale plenum coming over on his left side. The gas passes through into this box which is the scrubber. The discharge from that comes over his right shoulder and into this inhale counterlung and then into the right hand side of his mask. You notice that we are using a full face mask. And gas is injected here, gas is monitored here. Three oxygen sensors in this plenum, monitor what's going on. The logic is the same as everybody else's in principle, I would think, in terms of a voting system, etc.

We were committed day one to have a full face mask, because of we had already acknowledged that we were going to have a changeover capability from a fully closed primary set to either an open circuit or semiclosed bail-out.

Here's another one of the same. This actually is the second prototype. And here's the final evolution of the system with its semiclosed bailout on the front. What we did is to combine some of the developments on the SLS to come up with a way to have systems in one; an integrated bailout. The process of changing from the primary to the bailout is this valve here. It changes you from inhaling over this shoulder and out over here, to pendulum breathing, up and down through this single hose, with the front mounted canister. So essentially what's on your front is your bail-out, what's on your back's your primary. To go to your bailout, you pull a rip cord and that does several things. It deploys both of these lungs. You can now see them—they're the prominent orange bags which come out, and it also switches on the gas dosing system. It's very simple in its concept because it's a constant mass flow over pressure relief system. The difficult part for the bailout was how to package it in and around the diver who is already wearing another rebreather and trying to make it small, compact, etc. And that's about my lot. Thank you very much

**Robinette:** OK, we're going to kind of go through this and open it up to the floor for questions

## Radial versus axial canisters

**Jeff Bozanic:** Axial vs. radial designs was mentioned briefly on the scrubbing systems. I was wondering if you could give us a little information on the advantages and disadvantages of each of those.

**Robinette:** The two basic kinds of canister designs are axial and radial canisters. In an axial canister, [Think of a cylinder] the gas comes in from one direction and goes through the bed and comes out the other end. Radial canisters [Think of a cylindrical cross section] have a little shorter flow path and the gas comes in from the side, goes out to the side. The AGA ACSC has a radial canister, and so does my Shadow Pak.

I'd like to have the panel talk about canisters because I know that each and every one of these people up here has a different style of canister in their rig. First we'll start with Derek.

**Clarke:** I'm glad someone else raised this one, because I was going to. There's two areas, I think, about rebreathers that are worth discussing at this forum. One is canister. The other is counterlung—where they are positioned and whether they're split or not. Those are two major design elements of a rebreather, which, clearly, there is no consensus view on yet, otherwise we'd all have the same thing. And I'll give you my views.

Speaking of canisters, if there's probably one area that's most difficult to understand and predict, it's the scrubber canister's performance. I've given up using my judgment about predicting endurance. I can probably credit myself with having played with a good few scrubber canisters. If there's any way to know how a scrubber canister's going to work one has to test it, and until then, you really don't know. And it's all down to temperatures and humidity and gas flows, gas distribution within the bed, etc.

Probably the biggest constraint from the designer's point of view is the package. The Stealth has an axial flow canister and so did the SLS. My own feeling is that if you have no other constraints upon you, radial flow canister is the one I'd probably go with. That doesn't mean that the axial canister isn't as good. We've gone the axial route for a combination of reasons being performance and packaging, ease of filling, etc. The scrubber system is designed to absorb carbon dioxide. It has to function under certain conditions of temperature, humidity and gas flow which is why the same canister can perform differently on any two days. It can also perform differently depending on how you fill it. So the scrubber canister is one of the biggest variable elements in any rebreather.

**What you have to do with an absorbent bed is to get the reaction working ,and the quicker you get it working, and the more effective it works, the more effective your canister will be.**

That's why from my point of view, is why we are interested in the military market and not so interested in sport rebreathers—it's the discipline related to the military ethos. And frankly, it's that area is of great concern. Anyway, that's moving off the point.

What you have to do with an absorbent bed is to get the reaction working ,and the quicker you get it working, and the more effective it works, the more effective your canister will be. Keeping the canister warm is important. So if you have a very extended surface area that cools the canister in cool water conditions, it will affect how the bed performs and so there's a big variability there. And the moisture that's actually produced through the scrubbing process itself in a long axial bed can become a problem to you, because it starts to contaminate the rear half of the bed during the early phase of the scrubbing process. All scrubbers work the same way, that is, as the CO2 passes in, it is absorbed chemically into the material and it's actually chemically changed. And so there is a "front," a progression—from where the CO2 laden gas enters the bed to the exit point. There is a progression of where the CO2 is being absorbed, and as the bed slowly becomes expended the reaction front has moved far enough down the bed so that there's insufficient bed length to remove the residual amount of CO2.

Now a long bed has a benefit because it takes the reaction front into account and there's always a percentage of absorbent material that doesn't react—you can't react it. The object is to react the highest volume percentage that is contained within the scrubber. That has to do with its efficiency. As I said already, the long bed axial approach has one potential problem and that is that moisture produced as a process of removing CO2 in the early part of the bed, can itself condense on the cooler element of the bed that's further downstream, if you like. And that can start to over saturate it before it's time to remove CO2 later in the dive. Having a much shorter bed, the radial design obviates some of that problem. On the other hand, it's got to deal with this wasted reaction zone through a relatively short bed.

To sum it up, there is no right answer. If any body's got the right answer, I'll probably pay them some money to tell me what it is. Because I don't have it yet, and all you can do is work with the constraints that you have as a designer, and then optimize the performance to give you what you need. That's my reality.

**Robinette:** Thank you, Derek.

**Readey:** It's hard to follow that, really, he's covered most of the points already. One of the main reasons that we opted to go for one of two types of canisters was performance. Our initial axial flow canister was certainly the hotter running canister. But we found for deeper diving and a high work rates, the actual work of breathing—the breathing resistance on the unit—was a little high. So we produced a radial design in the same package which gave us a larger cross sectional area, so therefore the breathing resistance through the canister was lower. That was the main reason why we went for that. That's about all I can say, really.

**Robinette:** Thank you, Peter. Stuart would you like to add to that?

**Clough:** Primarily, I think we all take bids on the idea of a canister design. We use an axial flow canister. Over the years we've always stuck with a jacketed design to keep the things warm, and we found they are really the most tolerant of abusive filling. With the radial flow canister you've got to be far more careful, and fewer of our users have had fewer problems with a properly designed axial flow canister, in terms of the amount of gross misfilling you can apply to them before getting into catastrophic failure. So that's why we've gone down the axial route.

**Robinette:** Thanks Stuart. We've done some interesting things, and I certainly believe that canister design is one of the biggest, blackest arts in rebreather design. There are a number of different canister designs, even in this room, and one of the most unique is probably the Mark 15 or 16 canister in that it's kind of a cross between both, though I would categorize it more as a radial canister than axial canister, just from the short flow paths. Basically, it's a flattened out radial canister, because the flow paths in a 16 are very short, and it has a very lot of surface area. It's like an axial canister that's it's sliced up and done in a large ring.

One of the things about this device is that it's an exothermal device. It throws out heat. Typically, a scrubber does not work properly until you get it up to temperature, and once you have a decent bed temperature, the device will continue to work even though it gets into cold water. We'll touch on it shortly. But typically in all of the canisters now there is a flow path around the canister, both on the axial canister and the radial canister.. This flow path itself insulates the canister and basically keeps it at a reasonable temperature and the canister exothermic reaction preheats the gas that's coming through and kind of evens the temperatures out.

Anyway, Gavin has a question.

## Scrubber chemistry

**Gavin Anthony:** Well, it's a point on canister design. Gavin Anthony, Defense Research Agency in the UK. One of the fundamental things about CO2 absorbent is that it's a chemical reaction. And if you actually apply fundamental principles of chemical reactions, you can start to predict what type of canisters will perform better than others. The first thing that everyone has mentioned is about the exotherm. Nearly everyone knows that chemical reactions will improve at greater temperatures and will go better.

So, the first simple step is to keep it warm and keep it going. So insulate it, as mentioned. But there are other aspects. And one has to do with the probability of a chemical reaction occurring. What you have typically, is a granular material which you're forcing a gas over and that gas contains carbon dioxide. What you have to do is to give the carbon dioxide a chance to collide with the granules in the right place and react. So if you've planned your gas path through the canister such that the gases going slowly past through the canister, you've got a greater probability of the chemical reaction occurring, and the canister will absorb more CO2.

The second point is to do with concentration. If you hit an absorbent canister with a lot of carbon dioxide molecules at one time, then it's got a lot to cope with. If you can design it so that you can keep the CO2 concentration down, you will have an improved canister design. So, if you slow the gas path down and design it so that you can keep the CO2 concentration down, you will have an improved canister. Now I'll leave it up to you, looking at the axial and the radial which you think is the best, but if you look at cross-sectional areas, one has a phenomenal cross-sectional area to the other. And with a large cross-sectional area, the gases are going to travel a lot slower, increasing the aspect of CO2 absorption.

One final point on that is the effect of pressure on CO2 absorption. I mentioned it's a chemical reaction and it depends on the probability of a CO2 molecule colliding with absorbent molecules. As you go to pressure, you get a lot more diluent molecules in the way, so that the CO2 molecule has to work its way past all those diluent molecules to collide with the absorbent. So it gets hard for the canister to work at pressure, as opposed to at one bar.

Robinette: Thank you, Gavin, that brings up another point...

**Readey:** Tracy, can I just make one very small point? One of the modifications that we did to the axial flow canister was that we used a stainless steel, polished stainless steel outer liner, which actually reflected the heat back inside the canister and that made it extremely effective. In fact, we got some temperature increase inside the canister of nearly 15, 16 degrees centigrade, and it also serves to warm the breathing gas.

**Clarke:** That brings up some interesting thoughts. One thing about closed circuit rebreathers and keeping the bed temperature up high which improves the efficiency of the scrubber. What if you're diving in the Bahamas and you've got the bed temperature that so hot—we're talking about bed temperature now—that it's going to be very uncomfortable for the diver because he has very high inspired gas temperatures. The same rig is going to be very comfortable to dive in North Sea applications where the diver needs to be warmed. So the designer and the manufacturer need to balance out this type of device if it's going to be used across the board for sport diving. They're going to be using it in cold water, and they're going to be using it in warm water.

**Robinette:** I need to make one quick point here. Typically, what I've found and Gavin and a few other of my colleagues that one of the reasons for the radial canister is this breathing resistance. Breathing resistance on a radial canister is much better sometimes if you're looking at some very deep depths, like for a 300 meter bail out. However, manufacturers haven't typically had to go to a radial style canister to have the breathing resistance at acceptable levels. Yes.

## Sequential injection system

**Scott Cerf:** Yeah, I'm Scott Cerf. Peter, you mentioned a sequential injection system. I was wondering if you could elaborate on that.

**Readey:** Yeah, I'll give you the plans for $10?

**Cerf:** Sounds good to me.

**Readey:** Yeah, basically what it is—how can I explain this? It's an assembly that is a true mass flow controller which will give you a fixed flow pretty much irrespective of depth to a point, which will—let's say we set it at a half a liter or one liter of gas flow per minute. It will quite happily give you that down to 500-600 feet. But the special thing about it is that if the metabolic consumption rate changes, you can actually rotate this so that the flow will increase or decrease.

Now, there are several advantages of having this. Once you've actually powered the thing up, and it's moved to that particular position, it then shuts off so it uses no power whatsoever while it's actually supplying that flow rate to you. If you then decide to work harder, it will go to the next sequence and will change the flow through the valve. Or let's say, God forbid, you no longer had a mass flow condition, your first stage regulator was to fail, and the interstage pressure goes extremely high taking the full line pressure from your cylinder, then the valve will actually start closing down. It will still control—it's not as accurate as controlling it at the correct interstage pressure, but it will still control the gas flow even on full line pressure from a cylinder.

The other thing is going back to recreational divers—as I mentioned before, we spent a long time diving with a lot of recreational divers, and we found they did things that really blew our minds. Even though you said, look, if you do this you'll die, or don't touch this knob, that's the knob they twiddled. So, we found that it was easier for us to try and design out some of these problems. For example, if they did put a gas in there other than oxygen, say they put a 50/50 mix, it would be very difficult to get the sort of flows that you would need to sustain the diver and avoid hypoxia. Where as with this sequential control system will in fact open up and will flow in excess of 150 liters a minute. Now, it'll be quite obvious if you're supposed to be diving closed circuit, you get in the water and there's gas pouring out of your over pressurization valve, something's gone wrong. So we had to give the diver really positive indications that they've made a mistake and hopefully keep them alive as well.

So it's a different approach to the same sort of control problem as you come against with a solenoid valve system. And the other positive thing we found is when you're using a pulsed injection system like a solenoid valve, it takes usually two or three or full breaths for the gas to actually settle down to give you a nice flat control or a nice flat curve on the graph. We get very, very smooth changes It also stops a lot of overshooting or undershooting as well, because you can actually specifically tailor it to the needs of the diver. So, we think it's a pretty clever system, but hey, I'm biased. [Laughter]

## Designing the counterlung

**Robinette:** Thank you very much. Derek is it something quick?

**Clarke:** I just wanted to bring up another issue which from a design point of view is clearly a variable. A lot of you out there don't understand why some rebreathers have two counterlungs. Some have one counterlung. Do you want to do it later?

**Robinette:** That is our next subject. Right now we're trying to define the basics and get everybody up to speed, and so were going to get into counterlung.

Derek brought this up earlier when he was talking about scrubbers. And, as far as I know, every type of counterlung that you can imagine has been tried. I mean, you name it, it's been done. I've seen a counterlung designed a hat, and don't laugh. Stuart's got it on his Web sites. I stole it off. It's a priceless photograph. I've seen counterlungs over the shoulder, double counterlungs, single front counterlungs. The 16 has a diaphragm in it. I've seen single bags in the back.

I'm going to open the back of this Fieno unit. You can see the two bags which are just two very small urethane bags which sit in the back. These bags are two and a quarter liters— Pepsi bottle standards. One thing about counterlungs is that you need enough tidal volume for them to work correctly. This particular rig was designed for very small Japanese people and my girlfriend uses it.

Unfortunately, she has lungs larger than these bags. It's very uncomfortable when you dive a rig that has very small lungs and it gets a little scary too, because what happens is that it leads to an over pressure situation or an under pressure situation, so it's very uncomfortable. It's very important to have a bag with a sufficient volume.

**So the main benefit really, is one of smoothing the flow out in the breathing loop, and certainly you'll find you'll get better breathing performance out of the split rig.**

One thing about a breathing bag, typically, everybody is using the over-the-shoulder split style bags, because the inhalation and exhalation and the tradeoffs of hydrostatic pressure are the best when you use this type of bag. The Mark 16, which has a single bag positioned on the back, has somewhat of a hydrostatic problem also. One of the reasons that a Mark 16 and some of these other rigs have bags in the back or over the shoulders or whatever, is that they're built directly into the rig. I'd like to hear some comments from Derek first and then go through the panel again about counterlung placement.

**Clarke:** OK. You understand why counterlungs on the chest, from a hydrostatic point of view, are probably the right way to go. We can't change the human physiology, so we really have to adapt the equipment to that. To do that we want to have a setup to match the lungs with both swimming or being in a vertical attitude, or any attitude, for that matter, that's pretty much as good as it gets. And that's been known for decades. There's been plenty of closed circuit rebreathers around over the years and that phenomena was identified then.

But what I really wanted to address was why some of them are split and some of them are single, and what's the advantages and disadvantages. We had to go to a split counterlung because of the actual canister, for breathing resistance reasons. If you've got a single counterlung, either on the inhale side or the exhale side, and we could debate that next, but whichever side it's on, let's say it's on your inhale side, as you exhale, the gas that you exhale comes out at respiratory exhalation volumes, and the first thing that it hits is the scrubber bed. In this case, the gas velocity through the scrubber bed will mirror your breathing pattern entirely. The significance there is that the peak velocities in a typical breathing pattern can be typically three times greater than your mean velocity, so that if you're breathing at 40 liters a minute, your scrubber bed's got to suddenly deal with a hit somewhere in the cycle of 120 liters a minute. And that's going to just become a brick wall to a big axial canister like ours. So, we wanted to use the benefit of smoothing that flow out by having a counterlung on both the inhale and the exhale side, and rely on the water pressure to help distribute the gas for you. Obviously, when you exhale into the bag, you brought up a certain breathing exhalation resistance largely dictated by, let's say, the scrubber entry point. That then inflates the exhale bag because that's what's going to happen next. Hydrostatics are acting upon it, and if this bag volume is greater than the inhale bag volume, hydrostatics will shift it across for you. It'll push it there. So the main benefit really, is one of smoothing the flow out in the breathing loop, and certainly you'll find you'll get better breathing performance out of the split rig.

One of the disadvantages is that in splitting them is that the gas wants to get in one bag rather than the other, because that's what hydrostatics dictate. And that can certainly be a problem, particularly when you have two relatively small bags. Then you've got the hydrostatic problem related to the difference in height between the two bags. So that's what dictated to us, the size of our bags which are about 3.5 liters a piece. So they're about another liter, a liter and a bit bigger than these little jokers in here. Again, it's a compromise. You can have them bigger, but then they take up more space and they create more buoyancy difference as they go from full inflation to fully deflated, etc. That's about all the points I can quickly think of but these guys might...

**Robinette:** We need to keep this as short as possible so we can wrap this up.

**Readey:** We want to keep this going because Derek really says all the same things that we can say, because even in England, physics is still the same. Was it two countries separated by a common language? In fact, notice that everyone up here is English. Yes, so you people out there, don't try building any rebreathers, right?

All the things that Derek said I agree with. One of the biggest problems we had was with gas pocketing with a single bag, so we went to a split bag. It meant for better maneuverability. it meant we could work in different positions. Although, we did quite a lot of work on the single breathing bag, it wasn't nearly as good. It also makes it easier doffing and donning and undoing systems that are swinging around a single bag. I think we have a question coming up here from Mike Cochran? Yes, doffing and donning? I'm sorry—taking off and putting on

**Mike Cochran:** Yes, Peter.

**Readey:** Yes, I'm sorry Michael, you can come up and kick me out?

**Cochran:** Yeah, my name's Mike Cochran, and I would like to talk to Peter very briefly about his green card that he just got

[Laughter].

**Readey:** I think the phrase there is "Oh, shit."

[Laughter]

**Cochran:** The rationale for these bag designs, in addition to what's already been said, we use a dual front bag system on our rigs for the additional reasons of water trapping, which I think have been reasonably clearly addressed. It provides the users with an indicator of what the hell is happening to their system. People get rather confused when they first get into rebreathers, when you've got bags expanding, contracting, inflating and deflating. At least we found that if they're on the front, they do tend to notice what the hell is happening with their equipment.

The other point about it, you can get external gas: reserve gas, emergency gas. With a front mounted bag you provide buddy breathing facilities without having people actually having to take the mouthpiece out. If you tap in your reserve gases to the bags, then you can get additional gas into the system either from the diver or the buddy, without the complications that would go with things like the Mark 16. And that was essentially the additional reason why we similarly, right now use the twin bag system.

**Robinette:** I'm going to take control back for a moment because we're running a little behind. Gavin Anthony.

## PO2 control

**Gavin Anthony:** One thing that needs to be raised and that is on the electronic control systems they can control the PO2 well at a set depth. But the one thing they're not all that good at is controlling the PO2 when you're changing depth, particularly when that change is rapid. What I'd like to do is just show two quick examples of what could happen with changes in depth.

[Slide of a dive profile] This is a 40 meter dive, so your depth profile is down to 40 meters, up to a 9, 6, and 3 meter decompression stop, then back out. Now, the setting is nominally 1.5 by this particular control system. It doesn't really matter in this example which sets they are. As you can see the PO2 is held quite well at depth while everything is steady state. These are work periods—increasing work loads for the diver, so the PO2 is held pretty well during the work period, but when you get this rough a ascent, look what happens to the PO2. It drops rapidly and then the system is trying as hard as it can to make up the gap during that decompression stop. You change stop again, it drops, you change stop, and then once you get down to a depth of three meters, which is 1.35, you can't maintain a 1.5 bar so shifts to a different level and you get a different level. So that's one aspect, is the fact that the PO2 does drop on ascents.

The converse of that is—and this is a similar type of dive profile—when you start at the surface and you go rapidly down to the maximum depth, then your PO2 can accelerate way beyond your set point. And in fact, in this case, you can see the PO2 started to rise such that the diver had to override it and flush the counterlung through. We he went down a bit further, he actually hit a PO2 of two bar in counterlung, and had to take rapid action, flushing through to get it back down to the control system.

The other thing to note between these two examples is the quality of the control systems. Look how this one is yo-yo-ing up and down with much more coarse control system compared to the other. We did also get the rapid descent in PO2 when you're ascending, but that was overcome by having extra gas in the system. I think that the point had to be made at this stage.

**Robinette:** Thank you John. I'm going to make a quick comment here. Ed [Thalmann's] Physiological Primer is coming up next and Gavin can probably bring this out a little bit more in that session. It's good that he brings it up now so that nobody thinks that the closed circuit rebreathers hold a the partial pressure at a very tight level all the time, because they don't. That's the thing about ascent and descents; there is a change and there is a lag time in that also. Michael [Menduno] apparently wants to take over the session so—

**Menduno:** I do. We're running behind time here, which we're going to have to make up during the lunch break. It seems clear to me though in sitting through this session, there's a lot of complexity about these systems, that we've only touched on. ,We've kind of jumped around and touched on a lot of things, but they may take some a while to absorb. So I think what's going to have to happen is, over the course of the next day, is that we're going to need to keep talking about these things, so that these concepts can really sink in.

**Robinette:** One thing about these sessions, we cannot clearly define what rebreathers are or aren't, or how they function in anyone session, because there's an awful lot of information that needs to come out. I have twenty years of rebreather information in my brain and cumulatively, among the presenters here we probably have hundreds of years of experience. So just one little primer isn't going to make you a rebreather expert. It's going to take a lot of cumulative information and experience and personal experience to be able to come up to speed on these things.

## Semiclosed versus fully closed

**Menduno:** Hmm. I want to ask one last question and I'm going to ask for a really short answer from all these guys and then we're going to take a 20 minute break and come back with the physiology session. The question I'd like to ask the panel is this. We've talked about semiclosed systems and we've talked about fully closed systems. As a user, why would I want to have one or the other? I know you've Peter's built both kinds of units. I think you have too

**Robinette:** Before we do that, I'd like to balance this panel out a little because unfortunately everybody sitting up here now is building a fully closed circuit electronic controller. I'd like to have Christian Schult join us up here.

**Menduno:** The man from Lubeck with the slides. Great. if you'd each take 60 seconds to answer the question, and then we'll wrap this session

**Derek Clarke:** OK. Money no object? It's fully closed for me every time. It's the only way you can really manage your decompression, or your nitrogen uptake and it's the only way you can then deal with your perfect decompression. But there's a place for semiclosed. There's a price requirement or constraint, and provided you accept the operational constraints that the semiclosed will give you, then there's nothing wrong with the semiclosed. And we've built those as well, but certainly, if I was going diving, fully closed is what I would use.

**Schult:** I want to think a little bit. How we came to the solution that semiclosed is the right one for the recreational market was that we observed the recreational market and its requirements for a long time.. What is the right technology for this market? One source of information comes surely from the last Rebreather Forum, Forum One in Key West, but we had also other information. We have invited people from the diving scene for round tables—people out of the sports diving community, the science community and we invited Navy trainers and so on and so on. And the result was if you want to be in the recreational market—and I'm not talking now about deep diving, pushing your own limits—I'm talking more about having a new way of diving, a new experience, to come closer to the marine wildlife, to protect the wildlife, then we felt that semi-closed was the way to go. Our slogan is "Enjoy nature," not "enjoy your own limits." Therefore it was very clear for us to have first a nitrox premix unit. Our belief is that the technology must be very simple. "Simple" means simple to prepare, simple to handle and use, and simple to maintain. And we had with our FGT for example, in the Navy, we have more than 30 years experience with this technology. Sure, you can't compare navy divers with recreational divers, because navy divers are doing this every day and five days a week. So, we added some function on for example, the automatic bypass, and we have plug in connectors. I'll talk more about this afternoon. We said, OK, let us go step by step into the recreational market. Let us start first with a semiclosed system. Then later we can think about a self-mixing system. But first we want to go in this normal recreational areas and that is between 15 and 25 meters—80% of the world is diving to these depths and we want to be more closer to the marine life, right? And not pushing these limits. Therefore we think semi-closed is still the right way to start in this market.

**"Simple" means simple to prepare, simple to handle and use, and simple to maintain.**

**Robinette:** Thank you. Peter?

**Readey:** Ah, it's a difficult one for me to answer, because there is no boundary with our particular unit, because of our sequential valve. It will run in the same way any of the units that are presently here. It will run constant percentage, constant ppO2 semi-closed, and constant ppO2 closed circuit. So, depending on how you want to dive, it's all in one system. So, what can I say?

**Menduno:** But in general, is ...

**Readey:** The only reason I would want to change from running closed circuit constant ppO2 is availability of gas. If I didn't have a Haskel pump, if I'm going to get 50/50 mix, you know, that why we went from the Prism 1 to the Prism 2. It keeps it the most flexible system that we could build and hopefully, you know, intrinsically safe as well, so that's really why—that's the whole mind set behind that, is to make it as flexible as we possibly could.

**Robinette:** Thank you, Peter. Stuart?

**Clough:** Obviously, we're in the closed circuit business, in electronically controlled closed circuit systems but I think it's a mistake to try and focus on what is right or wrong. There is no perfect system. You've not got only one item in your dive locker. Each of these things you've got has an appropriate application. You wouldn't take a thousand watt movie light if you were going to grope around the reef and see if there were any lobsters under the rock. You'd take a smaller, more appropriate device with you. And the same applies to all these rebreathers. Each type of rebreather has got a particular area of application, where it is entirely suitable. And there are other areas of application and other operations for which they are entirely unsuitable. The trick is to pick the right device for what you intend to do.

[Applause]

**Robinette:** We're going to take a 20 minute break here and we're going to come back with Physiology.

**. . . but I think it's a mistake to try and focus on what is right or wrong. There is no perfect system. . . . Each of these things you've got has an appropriate application. . . Each type of rebreather has got a particular area of application, where it is entirely suitable. And there are other areas of application and other operations for which they are entirely unsuitable. The trick is to pick the right device for what you intend to do.**

# Physiological Primer

*"Way back when, the physiologists convinced everybody that they knew what they were talking about; the fact of the matter is, we really don't know what causes bends. We think it's caused by bubbles, but we really are not sure."*

--Ed Thalmann

## Session Summary

In this session, some leading doctors in diving physiology presented an overview of physiological issues involved in rebreather diving, tempered by a significant amount of experience.

First, EDU's John Clarke reviewed the concepts behind "work of breathing," offered some new terminology, "resistance effort, " and proceeded to review the problems of CO2 build-up, which can result from either a poorly-designed rebreather, or when the duration of the canister is reached. Several key points were made; first, that there are no reliable CO2 monitors on the market yet, and second; that canister duration is a probabilistic phenomenon, like decompression. Actual duration on a specific canister—the time before the CO2 starts leaking through in significant amounts—can vary significantly from dive to dive, and therefore represents another accumulated risk factor in rebreather diving. The military deals with this problem by statistically testing a large number of canisters and using an average value for duration.

Next, Russell Peterson, reviewed the basic oxygen tolerance with an emphasis on CNS oxygen toxicity. It was noted that the US and Royal Navy have now set their upper limit for oxygen, at a PO2 of 1.3 atm for rebreather diving.

David Elliott then discussed some of the problems of mass flow semi-closed systems from a physiological perspective. This effects both decompression calculations, as well as creating potential hypoxia problems [See Semi-closed Systems: Problems & Solutions—ed.].

Finally, Ed Thalmann provided some perspectives on rebreather decompression, by reminding participants that we don't really know what causes DCS. Thalmann then described the efforts to create the first constant PO2 decompression tables (0.70 atm tables) by simply re-programming the basic USN air table algorithms that didn't work; this is the approach that the majority of deco-engineers use to compute tables for the new wave of closed circuit rebreathers. Thalmann then explained how they finally derived the tables after multiple dive series.

It was pointed out that, the military has an advantage, in that all of their units have been tested by an independent agency (in this case the EDU), and have met established physiological goals before release to the divers. It was suggested that civilian divers will be able to enjoy these same benefits as well. In fact, it was suggested that it may be a manufacturers legal responsibility to do so, or at the minimum, a mistake if they do not. [See the Testing & Equipment Performance session for a detailed discussion—ed.]

The panel, chaired by Ed Thalmann of Duke University, consisted of Drs. John Clarke, David Elliott, and Russell Peterson.

26SEP THURS 11:00-12:30 pm

# Transcript

**Ed Thalmann:** Good morning. In this session, John Clark is going to talk about the work of breathing and CO2 build-up, Russ Peterson will give us some information on oxygen toxicity, and then David Elliott and I will talk a little more about oxygen and then decompression.

First of all, a little background about myself. I joined the Navy in 1971 and spent most of my career at the Experimental Diving Unit during a time when diving in the Navy was going a lot of different places. One of the tasks I was given when I first joined the Navy, was to begin to look at the physiology of rebreathers. At the time, the main rebreather that was used was called the Mark 11, and it had a lot of problems with it. I went on to set up a set of physiological standards or goals for Navy rebreathers, which were then applied to most of the rebreathers that the Navy evaluated, including the Mark 15 and 16, the Dräger LAR V, and some other non-rebreather systems that were used in saturation diving had similar problems.

During the time I spent at EDU, we tested rigs as shallow as 10 feet, as deep as 1800 feet, so we covered a lot of territory. We developed a set of unmanned testing goals that were based on physiology. We also developed the concept of physiological testing, i.e. using the diver to tell us how the rig worked rather than using a bunch of readouts. This formed the basis for the manned testing which EDU does currently on their UBAs [underwater breathing apparatus].

There were some statements made here about military vs. civilian divers, and I began to make a list of similarities and differences. The similarities are that they both breathe air and neither of them can breathe water. Given that regard, they both need underwater breathing apparatus. The main difference I can see is occasionally, somebody might be shooting at a military diver, and it's unlikely they'd be shooting at a civilian diver unless they're some place where they shouldn't be.

**There were some statements made here about military vs. civilian divers . . . The similarities are that they both breathe air and neither of them can breathe water. . . .The main difference I can see is occasionally, somebody might be shooting at a military diver. . .**

When we hear the euphemism, "is the military relevant to sports diving," all I can tell you if you go back and look at data. Being a scientist, I like data; I don't like sea stories—they're fun at the bar, but when you're trying to make a decision, you want data. And if you want data, the only place you're going to get it is in the military.

If anybody here is interested in a primer on rebreathers, you should send off to the Experimental Diving Unit for an EDU Index, and read through the list of EDU reports. You will see in-depth testing of all the UBAs that the Navy has evaluated. These reports are available through NTIS (National technical Information Service), so the data is out there; there's no reason for anybody to stand up here and say, "Well, I think canisters do this or canisters do that." You can get EDU reports that show you how canisters perform, under what conditions. You can get EDU reports that show how the Mark 16 performs under certain conditions. So there's a lot of background material. I'll second Mike Harwood's observation that if you're a manufacturer, and you put a rebreather on the market and somebody gets hurt, they're going to ask you about your design standards. All their lawyer's got to do is spend about $100 to get the EDU reports and you're mincemeat unless you can show that your rig has been designed to a set of standards, and you know how it performed, and you can defend it. The data's there for people to use if they want to.

John Clark should be really interesting, because while he was out there I reprogrammed his computer, so we're going to see how flexible he is. John was shanghaied from the Naval Medical Research Institute by EDU and they plied him with a house and pool and all kinds of fancy gear, and he is now happily settled in Panama City, and he's going to tell us about some of the EDU work on breathing and CO2 absorbers.

**John Clark:** He really did mess up my computer. I used to work for Ed; therefore, he's in a good position to brag on me or kick me in the butt. He did tell me I have to finish this up in 25 minutes so I'll rush through and try to do that. Keep in mind, this is a physiology primer only; you're not going to get in-depth knowledge by any means.

You've already heard the term, "work of breathing" used during this conference. You've also heard the term breathing resistance. I actually like the term breathing resistance, and you'll find out why in just a moment.[See Work of Breathing & CO2 Build-up by John Clarke, in the Papers section—ed.]

## Work of breathing

The intuitive definition of work of breathing, I use a mathematical symbol or physical symbol meaning W for work, it is a measure of how easy it is to breathe on a UBA (Underwater breathing apparatus). Everybody here understands and comprehends that. That's probably the most important point that you need to understand. However, when you do read EDU reports, especially some of the newer reports, you'll see different terms coming up and need to explain briefly where work of breathing came from, how it's measured and what some of the new terminology means.

The non-intuitive definition of work of breathing is the physicist's definition, when forcing gas through a UBA with a breathing machine, W for work, is the product of pressure and volume integrated over one breathing cycle.

## $W = \int PdV$ or $W = \int Pexp\ dV - \int Pins\ dV$

Please don't bother to memorize that. If you're a mathematician, you can memorize this to your heart's delight. However, in simple terms, when we are testing a piece of breathing apparatus, we push gas through it in assigned sinusoidal up and down breathing wave pattern. If we look at volume over time, with time on this horizontal axis and volume on this axis, you get a sinusoidal motion of the volume up and down. Now if we look at pressure, for example, going through a modified Mark 16 UBA, pressure drops to negative values during inspiration or inhalation when the diver or breathing machine is sucking gas out of the rig. Then when the diver starts exhaling, pressure goes up, becomes quite positive over time.

**Everything we do is based on price benefit, cost benefit ratios. By using a smaller grain absorbent you can get a longer dive. If dive duration is important to you, that's the thing to do, put in a smaller grain absorbent. But you're passing gas through a much finer well-packed particles and therefore work of breathing goes up.**

Now if we take the volume tracing against time, and combine it with the pressure tracing against time and then plot volume and pressure against each other, you get a breathing loop. When we talk about a breathing loop or a PV loop, this is exactly what we mean. We don't mean breathing loop on the UBA where the gas flows; we mean a PV loop, a pressure-volume diagram. As it turns out, the work of breathing or the work involved in breathing this UBA is none other than the area inside this particular loop [See Clarke's paper—ed].

Now let's talk about how we find the area inside the loop. We have a computer which will measure the area from some baseline pressure measurement all the way up to the top and find this area here. Then we subtract from that the area underneath the loop during inspiration and what we're left with is this gray area. This is a very simple computer algorithm. We're integrating the area under one portion of this PV loop, subtracting another and this is what we talk about, this is work. This is not "work of breathing" as you've heard it used but it is a measure of PV work.

## Sources of resistance

Work of breathing, the resistance to breathing, the impediment to breathing that you experience when you go underwater, comes from two places. One is from an external source, the underwater breathing apparatus itself; the other is from internal sources, the diver's airways. Designers can alter this to their heart's delight. They can decrease external work of breathing by opening up the sizes of breathing hoses, by opening up mouthpieces, or by using canister designs and even different breathing bag designs.

And them there's the internal sources. The UBA designer/manufacturer can do nothing about this; God handled this all on her own. That has to do with the size of your airways, the length of your airways, and work involved with both of these vary in proportion to a number of things which we encounter in diving. First of all, increases in gas density. The deeper you go, the more dense the gas becomes. If you go very deep, then you want to use a very low density gas, such as helium. At any time that gas density is increasing, then the work, the effort required to breathe, will increase. The harder you work or the harder you breathe, the more the work of breathing is going to increase.

If you mess with your UBA and put in different size $CO_2$ absorbents, for instance fine grain Sofnolime compared to large grain Sofnolime, you will pay a price. You'll have an increase in the work of breathing. Everything we do is based on price benefit, cost benefit ratios. By using a smaller grain absorbent you can get a longer dive. If dive duration is important to you, that's the thing to do, put in a smaller grain absorbent. But you're passing gas through a much finer well-packed particles and therefore work of breathing goes up. It also goes up as a function of diver ventilation, the higher the ventilation rate the more that is required.

## Getting the terms straight

Just so you understand what's happening with some of the current or new EDU reports, what the Navy has long called the work of breathing really isn't the work of breathing. It's very close to it, though. Work of breathing I define as W, the area inside of the loop. We've found that it's beneficial to normalize or divide that number by the tidal volume, how deep a breath you take. When you do that you end up with a form of pressure, the so-called volume-averaged pressure. The University of New York at Buffalo uses a different phrase: volume-weighted average pressure—that's even more difficult to say. We've become fond of using the term, "resistance effort. "It avoids using the word work at all and now we're talking about something that we can comprehend. Effort.

Resistive effort is a pressure, due to the breathing resistance. If we wanted to get very scientific about that, we can take that measurement that was called work of breathing in the past and make a resistance out of it, an average resistance. That's why I said, when somebody was using the term breathing resistance, that really is a good term to hold onto, something that everybody remembers very well.

If you pick up a new NEDU report, you'll probably see plots of resistance, as well as work, or you may also see plots of resistive effort. Differences in terminology, but if you pick up a report then look back at the notes from this meeting and hopefully you'll understand what we're talking about. In every case we're talking about how easy or how difficult is it to breathe that particular UBA.

## When the work is too much

What happens when the work of breathing is too much or too high? As most of you know, there's a tendency to slow your breathing down, because it takes a lot of effort to breathe against something with a high resistive effort. Unless you take much deeper breaths at the same time you're slowing your breathing down, you're going to start hypoventilating or under-breathing. I think most of you have had enough experience to know that when you start skip-breathing or conserving your breath, bad things tend to happen. Carbon dioxide levels within your bloodstream begin to increase due to hypoventilation; you're breathing too low to get rid of the CO2 building up. Furthermore, the longer that your work rate, the amount of CO2 that you're producing, is outstripping the amount of ventilation or gas that you're taking in, the greater the likelihood of your passing out. I think we can all appreciate passing out underwater is frequently a bad event. Furthermore, high carbon dioxide levels tend to make a diver more susceptible to oxygen toxicity.

Even in a closed circuit rig, if you're diving rapidly to deep depths, oxygen levels can get very high. If you have high CO2 levels at the same time, that considerably increases your chances of getting an oxygen convulsion or seizure very much like an epileptic seizure.

You can get elevated CO2 in your blood, not just from under-breathing but also because of the particular UBA. You can have inadequate mixing between fresh and exhaled gas in a diving helmet or if you have a mask with a oral-nasal mask, CO2 levels can begin to build up. If you inhale the CO2 in and you're not able to blow the CO2 out because of breathing resistance, then guess what, your arterial CO2 will begin to rise.

## Canister "break-through"

You also have a CO2 absorbent which has a finite lifetime, and if you're working hard and working long, sooner or later that CO2 absorbent is going to poop out on you. That means it will start leaking CO2, and will leak in an almost exponential manner. After awhile that CO2 will get higher and higher and higher. Unfortunately we don't have good CO2 monitors yet. A few people are trying to fix that problem, but as it stands now, you have to assume when you're diving you're not getting a lot of CO2 in. If you are, then you may or may not notice it. Expired levels of CO2 equivalent to 0.5%, half a percent of surface value CO2 is all that the US Navy will allow in closed- and semi-closed UBA. We use the term "break-through," or "broken-through," to describe this. What that means is that CO2 canister is beginning to quit, poop out, has now started leaking CO2 and the CO2 in the breathing loop is now reaching 0.5%. At that point, we decide that this particular canister has broken through and we measure canister duration limits for this particular UBA on that basis. We'll run a lot of canisters, on a new UBA, a bunch of them, and come up with some average for "break-through time."

Any increase in expired CO2 is bad. It either causes an increase in ventilation, which increases breathing resistance, which divers don't like and find uncomfortable; or if the diver compensates to that high CO2 by under-breathing, that just makes things worse. The diver can end up in a vicious cycle and lose consciousness, as we said before, due to the hypoventilation. Letting CO2 increase in your breathing loop is never a good thing.

## Canister duration

The last point you need to remember is that canister durations are right now determined statistically. Some day the diver will have a little monitor that tells him not only how much oxygen he has in his breathing loop but how much CO2 he has. When it reaches a certain point, an alarm will go off, he says, "Time to bail out of here." Right now you don't. The best thing you have is somebody like NEDU who will run hundreds, and I do mean hundreds, of hours of tests to determine, get a large quantity assemblage of canister durations and from that try to come up with a safe canister duration. A large number of canister duration measurements, even made under identical conditions of temperature, dive depth, absorbent, and so forth, will vary and the variation can be pretty extreme sometimes [Also see Clarke's comments in the Maintenance & Logistics session. That's why canisters are tested statistically—ed.].

The important thing for you, as an individual diver, to remember is that a dive duration yielding a 0.5% inspired CO2 in the average canister can easily reach 1% or more in any particular canister. If you're diving that particular canister and you stop right at the published canister duration limits, keep in mind, you may be breathing twice what the so-called allowed limit in closed-circuit UBA. Right now, on the average, you'll be safe if you follow published limits. That does not mean, just as in decompression, that you're always going to be safe; there is a risk. In closed- and semi-closed circuit UBA, we have an accumulation of risk. You as a diver are accumulating risk for decompression sickness, you're accumulating risk for oxygen toxicity, and if you dive long and hard, you can accumulate a risk for developing CO2 narcosis.

**In closed- and semi-closed circuit UBA, we have an accumulation of risk. You as a diver are accumulating risk for decompression sickness, you're accumulating risk for oxygen toxicity, and if you dive long and hard, you can accumulate a risk for developing CO2 narcosis.**

## Resistance effort

Work or resistance effort is important to the Navy because high breathing resistance causes divers either to quit working, because of breathing discomfort (the term dyspnea mentioned earlier) or lose consciousness due to CO2 narcosis. One thing we've observed when I was conducting tests up at NAMRI and continuing at EDU is that the magnitude of respiratory pressure is related to the probability that dive will end eventfully. If you're working hard, breathing hard, and you have a high resistance UBA or a high resistance canister, the greater the chances are that something's going to happen. Either you're going to become dyspniac, out of breath and say, "I'm out of here," or you're going to remain quite comfortable and then pass out for one reason or another. Designing a UBA properly is important because if it's designed poorly, you can get either one of these two results.

**Thalmann:** John pointed out that resistance in work of breathing is pretty easily measurable unmanned, but the breathing machine never passes out. It's the relationship between what you measure on a breathing machine and what a diver does that is not well connected yet. If you're breathing through a high resistance rig and you retain a lot of CO2, that's one mechanism for passing out. But when we get to the session on UBA testing, I'll show you where divers have passed out when their CO2 was quite low from other factors of UBA design. A UBA is a pretty complicated piece of respiratory loading that your lungs and chest were never really designed to cope with, and it's pretty easy to get them out of sync so that your respiratory system can't really compensate for it.

## Oxygen convulsions

One of the things mentioned in passing earlier was the fact that if you have a oxygen rebreather, your depth is limited and it occurred to me that everybody here may or may not know why that is. Oxygen is a toxic gas in high concentrations, and certainly if you get much above two atmospheres and begin to exercise, most people will have an oxygen convulsion in a really short period of time. As you get lower and lower back towards what we breathe at room atmosphere, 0.21 atmospheres, the probability of convulsion decreases. Exactly what level you can breathe safely without convulsing is still a matter of great debate, although we will say that below one atmosphere absolute, which is basically breathing the equivalent of 100% O2 is probably safe. We also know that if you breathe much above two atmospheres and exercise for any length of time, there's lots and lots of data to show that you'll convulse. If any body's interested in reading some interesting anecdotes on that, you should get Dr. Donald's book, Oxygen and Diver which you can get through Best Books.

The book covers the largest series of oxygen dives conducted, and which will ever be conducted because it was during World War II when there was a big push on to get divers to breathe underwater.

Russ Peterson is going to tell us about O2 toxicity. Remember no question is a stupid question; write them down. Some of these concepts we're familiar with, and you guys may not be.

**Russell Peterson:** I'm going to talk about oxygen toxicity with specific reference to surface-to-surface bounce diving as opposed to saturation excursion diving. There are a few additional factors involved in the later. Just to give you an idea of the scope of the things I'm going to try and cover briefly; toxicity and tolerance, which are complementary factors here; the biochemical basis—I'll say very, very little about that given limited time; sensitive organ systems, tracking or predicting the effects of oxygen; extension of tolerance; something about the velocity of use of oxygen which I think we all here agree on and understand; something about the philosophy of limits for oxygen and a few comments about establishing limits.

## Toxicity vs. tolerance

Oxygen toxicity relates to the harm that can occur. As Dr. Thalmann said, oxygen is a toxic gas. It's considered a drug by the FDA; there are requirements for the use of pure oxygen in any circumstance. As with any drug, if you have an overdose, some decremental, undesirable things can occur. Oxygen tolerance, on the other hand, relates to the exposure that can be tolerated without harm. When we're talking about diving operations, that's really what we're interested in. What can we do that isn't going to produce a problem?

A dose of oxygen is a function of the oxygen partial pressure that you're breathing and the exposure time. Under normal circumstances, it's been determined that the toxic effects of oxygen are due to oxygen free radicals. These are normally produced, by white cells, in an inflammatory response to things that normally occur in your body. While breathing normal levels of oxygen found in air (0.21 bar), the defense system keeps these radicals in check. If we increase the PO2 and breathe the oxygen for a long enough period of time, the defense system can be overwhelmed. That's really what oxygen toxicity is: the overwhelming of the defense system of oxygen radicals that are being produced in your body.

If the PO2 increase is not very great, it can take a very long period of time. However, if the PO2 is increased very substantially, for example in excess of 2.0 bar, then the oxygen defense system can be overwhelmed very, very quickly. So you get relationships that look something like this: at a very high PO2, the central nervous system is affected very quickly. As the PO2 falls, it takes longer and longer and eventually you reach a point where it takes an extremely long period of time for changes to occur and in certain conditions where no change will occur. If the dose is great enough, all organ systems, all tissues in the body will eventually be affected by oxygen. However, the nature and degree of sensitivity for organ systems vary quite a bit, and in practice the central nervous system, the lungs, the eyes are the most sensitive; and from the standpoint of practical diving, it's really the central nervous system and lungs that are of interest.

## Symptoms and pre-warning

There is a list of symptoms for central nervous system of toxicity that was produced by Donald from the series of experiments that Dr. Thalmann mentioned. These might be called non-serious symptoms and he found generally a progression from facial pallor and sweating through to sensory disturbances and breathing difficulties. All of these symptoms wouldn't occur in any one diver at one time; there might one or several. Or none. The progression goes on to loss of consciousness or convulsion.

In Donald's studies and studies conducted by the U.S. Navy in and around the same time, they found that convulsions or loss of consciousness could occur without any of these other symptoms being present beforehand.These symptoms could occur and even though the exposure was continued, a convulsion wouldn't occur and sometimes you would have symptoms and convulsions following. In a series of dives that Dr. Thalmann was involved in the mid-1980's, they found that convulsions were always preceded by some symptom. I think tintinitus in three cases, three to five convulsions; and the symptoms that did precede the convulsion were always within six minutes. It didn't mean if someone had tintinitus, they were going to convulse, but there was always some warning.

One question I have for Dr. Thalmann is whether he believes this might be due simply to the fact that his divers or subjects were more observant than those earlier, and also whether or not someone who is diving with a high PO2 and focused on some activity, some work that he's doing, would likely be made aware of an impending convulsion?

**Thalmann:** You read a different set of reports than I wrote. Our divers convulsed very few times and there were very few times when they had warning symptoms. Most of the time, if they did have warning, it occurred in such a short period of time before the symptoms that they were not really able to take any action to prevent the convulsion.

## Factors that affect oxygen tolerance

**Peterson:** CNS toxicity is reversible. Recoveries are relatively rapid and is similar to an epileptic seizure, so in itself, it's not harmful. Someone can suffer traumatic injury during it however, or drown if it occurs underwater.

Factors which affect CNS oxygen tolerance include carbon dioxide and, as Dr. Clark said, if you have an increase in breathing resistance, or if you have someone who hypoventilates relative to his activity; these things can increase CO2 which in turn increases brain blood flow posing a greater cerebral mass of the oxygen and you have convulsions at a lower PO2 and less exposure time. Exercise, perhaps through effects on metabolism, decreases tolerance. Immersion has been found to decrease tolerance. That is full immersion. Head-only immersion doesn't seem to do so.

Inert gases? The research there is very conflicting. It's accepted that if you have inert gases that increase density and through that mechanism increase CO2, you can affect oxygen tolerance but probably not through other factors. Temperature, both increases and decreases, increase metabolism and lower oxygen tolerance. Factors such as rapid compression, which tend to promote convulsions themselves, can be interact with other factors such as high oxygen and promote seizure.

## Pulmonary toxicity

Early pulmonary symptoms are often felt in the large airways. You have a mild tickling sensation in the substernal area and these are generally most noticeable during inspiration. They gradually become more intense and widespread, and dyspnea can occur during rest. In extreme cases, you can have a constant burning sensation in the airways and if this is allowed to go on, can lead to severe pulmonary damage, and death. Obviously the likelihood of this happening is almost nonexistent in the diving situation when you're well aware of the very early symptoms.

Functional changes of the lungs include decreases in vital capacity, CO diffusing capacity, lung compliance, and maximal mid-expiratory flow, and increases in breathing frequency. All symptoms of pulmonary oxygen toxicity are in functional changes are reversible until you reach an extreme state. Mild symptoms resolve in about one to three days, and the severe cases may take weeks to several months to recover.

Factors which affect pulmonary oxygen toxicity include neurogenic potentiation—this is when oxygen affects the nervous system, it seems to have a concomitant effect on the lungs; it can come on very quickly and disappear very quickly. There is no system binding either benefit or negative effects of combining inert gas with oxygen, as far as pulmonary effects are concerned. Some studies show a benefit, others undesirable results, and some show no change. At least in a resting situation, the consensus is not to worry about it and there haven't been good studies done in exercise situations.

## Individual variability

With respect to oxygen toxicity in general, and the effects of oxygen in general, there's a very great variability between individuals and even in one individual from one time to another. So this confounds trying to predict what's going to happen. In order to make a good effort requires some parameters or monitors that will allow you to establish relationships between dose and the onset of effects, progression of effects.

## Vital capacity & pulmonary toxicity

Vital capacity has been used effectively for tracking pulmonary oxygen toxicity, and there's been no parameters identified at this point that's useful for CNS oxygen toxicity. There are a series of curves showing decrement and vital capacity in subjects studied at the U of Pennsylvania. These show a 2% decrement in vital capacity, 4% and on out to 20%, and the scheme for working with this can produce a number which predicts the effect in the average individual. This is done using a unit dose concept. We're dealing with everything in terms of the effect of one atmosphere of oxygen breathed for one minute, and CPT stands for cumulative pulmonary toxic dose, and that's equal to the time, times the PO2 minus some asymptote code divided by one minus that asymptote, all of that raises the one over the one-two power. The asymptote that was selected was 0.5 bar on the basis that it doesn't produce any significant effects in two weeks. Not that it will never produce any significant effect, but in a period of time that's long, relative to diving, it has not

There are a number of deficiencies recognized in this scheme [See RW Hamilton's paper, "Tolerating Exposure to High Oxygen Levels: Repex and other Methods," *MTS Journal*, Vol. 23, No. 4, pg. 19—ed.]. . Again, the tremendous individual variation means that you're going to expect quite a few people not to follow this relationship very closely. Recovery isn't accounted for in it. A very basic assumption in it is if you breathe oxygen at three atmospheres and then at two atmospheres, you get the same result as if you reverse and read it at two atmospheres first and then three atmospheres. That's very likely not the case. But you have to take your shot at something to try and produce a useful tool, and in practice this has had a useful impact for expert planning and decision-making. Particularly if you have some prior experience with the particular situations that you're dealing with. A maximum recommended dose, using this scheme, is 425 UPTD (Unit of pulmonary toxic dose) which is equal to a 10% decrement in vital capacity in 50% of the subjects that were studied at the University of Pennsylvania. A 10% decrement is one that can be tolerated by most individuals without serious consequences.

## Predicting CNS toxicity

Predicting CNS oxygen toxicity is a bigger problem because we don't have parameters we can monitor and establish relationships with. So methods had to be derived from practical limits. One approach suggested by Burgage uses a time-weighted average. They simply took the sum of the time any particular PO2 was breathed times that PO2 divided by the total time and came up with an average PO2 for the whole exposure, and then compared that to a particular limit. Burgage did this with 200 reps, used varying types of exposures, and with this formula computed a predicted effect, compared it to reality, and the predictions were pretty good.

Another approach uses a fraction of limits. That's been tried independently by a number of people or groups, including Hamilton and Kenyon. What you do is to simply take the time that someone is exposed to a particular PO2, divide it by the NOAA time limit for that PO2 and that gives you a fraction and then you sum these fractions; and when you get to one, you have a full dose. Bill Hamilton says this works in practice [In fact it's used in several dive computers to track oxygen exposure, and part of most technical diving curriculums—ed.]. I'm unfamiliar with the data.

## Tolerance enhancement

Enhancement of tolerance: quite a few drugs or pharmaceuticals have been looked at. None of them produce any sort of solution that's practical for use. The only approach that has real practicality at this point in time for extending oxygen tolerance is intermittent exposures, that is, breaking the high oxygen exposure with a period of time at a lower PO2 [Also called, taking "airbreaks," the practice of breathing air for 5 minutes after every twenty minutes of breathing pure oxygen—ed.].

**Rod Farb:** Not even enhanced Vitamin E?

**Peterson:** That has been shown to work when a person is vitamin E deficient, but if you have normal vitamin E levels, taking more doesn't improve your tolerance. Recent studies have shown that if you take supplemental or excess vitamin E and are having hyperbaric oxygen therapy, healing can be improved. But as far as tolerance is concerned, the high levels of oxygen supplemental vitamin E isn't the solution.

Obviously oxygen is desirable in diving to minimize the decompression obligations, and perhaps some other risks as well. To minimize these risks, people desire to use maximum oxygen levels, obviously consistent with dive depths and duration, repetitive considerations with respect to the oxygen exposure, the ability to treat decompression sickness, and rescue the divers if they have an oxygen hit. All of these things are involved in decisions related to high oxygen exposures.

## Setting the limits

With respect to limits, a normal assumption for any limit is that below it there's no chance that anything can happen, and above something is bound to happen. That's clearly not the case here. There is tremendous variability, and the best you can hope for is a big gray line. What you're dealing with is a risk. Below some limit, you're saying that under your particular set of circumstances, the risk is acceptable and above that line it's not acceptable. Obviously or right away as soon as you start talking about acceptable and unacceptable, that's a decision that has to be made based on any number of factors. What is the mission that's being done? If it's a military mission in time of warfare and this has to be done or thousands of people are going to lose those lives, you could accept a fairly high risk. For someone doing something for pleasure, they may not want to accept any risk, so you can't say that there is limit that is suitable for all circumstances; there's not. Remember that limits are based on a dose that refers to both the PO2 that's being breathed and the time relationship.

**For pulmonary limits, pulmonary oxygen toxicity isn't a serious problem. It's not a great practical hazard.**

For pulmonary limits, pulmonary oxygen toxicity isn't a serious problem. It's not a great practical hazard. If problems occur, you simply stop diving or stop the exposures and you'll get well in a fairly short period of time and go back to whatever. In the course of a lot of commercial diving operations with high PO2s, it's been determined that a cumulative pulmonary toxic dose of about 300 units for a 24-hour period practically avoids the accumulation of effects over days and days of diving, weeks and weeks of diving, so that's not an unreasonable limit. If you're looking at a one-off diving situation, a dose of 589 UPTDs allows for a fully extended USN Table 6A without exceeding the 10% vital capacity reduction, so that wouldn't be an unreasonable approach for a one-off dive. You can take higher levels and then say, "Well, I'm not going to get decompression sickness or I'm not going to need a fully extended 6A if I do." Those are the sorts of considerations that would be involved.

With respect to CNS oxygen toxicity, obviously loss of consciousness or convulsion underwater represents a very serious hazard. You can drown, you can have injury due to unplanned or uncontrolled descent/ascent, so the consequences of having a CNS hit are very great. The experience that is available that might give some insight into picking an upper PO2 level. A number of serious operational incidents have been recorded at a PO2 of 1.7 atmospheres. These have involved hard work but nothing unusual. Several serious incidents have also been reported at 1.6 atmospheres and there were some non-mitigating circumstances, for instance abnormally high breathing resistance in the breathing apparatus, but it still occurred. At 1.5 atmospheres, I'm not aware of any reports of seizures. There have been some fairly substantial exposures done at 300 to 500 meters with divers working from fairly modest levels to extreme levels over the course of periods like three hours. There have been no problems there. At 1.4 atmospheres, there was one case where two divers were inadvertently given 1.4 atmospheres of oxygen to breathe in a saturation excursion situation and they breathed 1.4 atmospheres for 55 hours over a 3-day period. When they weren't on the diving mix, they were a 0.6 atmospheres, so this was just a tremendous dose of oxygen at 5400 UPTDs and 3 days. The two divers suffered extreme pulmonary effects, took quite a long period of time to recover but there was never any hint of a CNS problem. That's just two divers. We know that there's extreme individual variations.

The current upper limit for routine mixed gas operations in the U.S. Navy is 1.3 atmospheres. But before we really get very complacent about all of this, a study was done awhile ago looking at the results of some 9,000 oxygen training dives in the Royal Navy between 1964 and 1985. There were ten cases of disturbances of consciousness, including loss of consciousness, at 1.3 atmospheres. As the saying goes, "You pays your money and you takes your chances." With respect to oxygen toxicity, there are really no guarantees, thus prudence seems to be warranted particularly if the population at risk is likely to be one that will push the envelope.

**At 1.4 atmospheres, there was one case where two divers were inadvertently given 1.4 atmospheres of oxygen to breathe in a saturation excursion situation and they breathed 1.4 atmospheres for 55 hours over a 3-day period. . . so this was just a tremendous dose of oxygen at 5400 UPTDs and 3 days. The two divers suffered extreme pulmonary effects. . . but there was never any hint of a CNS problem.**

## Take home messages

**Thalmann:** The take-home message here is that pulmonary O2 toxicity is not a problem, but there's a caveat to that. In studies done at the Experimental Diving Unit, we had some divers breathe oxygen day after day, and after about a week, they began to get some mild symptoms of substernal burning. It could become a theoretical problem, but these are very unusual circumstances. It's the CNS problems that we really need to worry about.

The other thing is don't look to your buddy who says, "Hey I breathe this high PO2 and I don't have a problem." Because, from what we know about O2 toxicity, you could breathe that and have a major problem. There's a lot of individual variations, so these limits really do have a lot of statistical uncertainty in them. But 1.3 atmospheres is probably a relatively safe dose to breathe and would keep you out of harm's way.

**Menduno:** The technical community has discussed oxygen limits over the years and has come up with 1.4 atmospheres, 1.45 for the working portion of your dive and then boosting it to 1.6 for decompression with open-circuit scuba. Do we need to rethink these limits for rebreathers running at a constant PO2? Can you run at 1.4 or do you think those need to be backed down more in closed-circuit mode?

**Thalmann:** Dr. Elliott is going to talk on that later on. I think 1.6 is too high to breathe.

**David Elliott:** I'll make comments on that relative to a litigation situation which I think might be relevant.

**Thalmann:** We're going to talk about decompression items. Thermal issues and other issues not going to be covered. If anybody has questions about theses or other physiological issues that we haven't covered, be sure to bring those up during the question period and we'll try to answer as best we can.

## A matter of attitude

**Elliott:** I have had very little to do with recreational, let alone technical diving. About two weeks ago I was invited to speak to the Divers Alert Network in Milan on the hazards of advanced recreational diving. I want to open, with my last slide that I gave at that particular talk, because I think it says something about attitude. What it says is," To claim a depth record, the first thing to do is to come back to the surface."

I think that's an important statement for all of us. I'm sure you all agree, that everybody has the personal freedom to do what the hell they like, but at the same time, if we as a community are going to support this, we must be sure that the individual is fully informed. He needs to be fully informed of two things and only two things in the context of the meeting that we're having here.

The first is physiological limits, and that's what we're trying to address in this session. And that is the responsibility of the trainer as advised by the medical and physiological community. The second are the limits of the equipment and that again is the responsibility of the trainer as an advisor, to a certain degree, by the manufacturer. But I think the message already coming through loud and clear is that he needs information from those who have evaluated that particular type of breathing apparatus. That expresses my attitude.

For those who've not met me before, let me just give you a couple of seconds on my credentials. I started 30 years ago as a mine clearance diver. Mike Harwood, whose in the audience here, did the same thing.

After I trained as a clearance diver and spent a lot of time at it, I actually had to do a conversion course into scuba diving; I didn't understand that stuff at all.

We dove a semi-closed system, with two bottles of premix and a constant mass reducer. The important thing about that was that every time the set was used, one had to re-calibrate the flow. Among the list of take-home messages, I would like you to write down the word, calibration. Recently, I asked somebody who has been regularly diving a semi-closed system, how they calibrated their particular unit, and they wanted to know why they should bother—it was all set by the factory.

The gas went through at a constant mass to the counter lung, which is was on the front, and the bad feature on these units was the pendulum breathing arrangements [It was an old-style single hose system—ed.], so there's a large dead space which promoted CO2 build-up. The other important feature, was a come-home bottle, and the come-home bottle in these sets is pure oxygen and would go straight into the counter lung. This was of course for actually flushing your bag on the bottom before ascending to the surface. This is very good practice for preventing hypoxia on ascent. If you needed to use the gas for bailout, the exposure to pure oxygen would be so brief, that you wouldn't have to worry too much about oxygen toxicity. So there are many features of that which are quite good. One of the things that has now been introduced to that set is a contents gauge, so that as the gas begins to run out, so the individual will not pass into dilution hypoxia.

**. . . Alexander Lambert, made a 90 foot exposure on pure oxygen and he dived for about two to three hours. . . I think it does give us a lesson: just because one person can do it doesn't mean that everybody can.**

## Oxygen anecdote

I want to make a couple of comments on oxygen toxicity before I move on to my main topic. I love history and I am glad to see that the Historical Diving Society is represented here. [Elliott puts up an overhead slide] This is a dive that was made over 100 years ago, and all I'll tell you is that Alexander Lambert, made a 90 foot exposure on pure oxygen and he dived for about two to three hours. But they hadn't found out about oxygen toxicity, so it was all right. I think it does give us a lesson: just because one person can do it doesn't mean that everybody can.

There was a dive in the North Sea a little while ago, which in fact rather is quite an important one. It was an open circuit hose dive on a 32.5% mix [EAN 32.5—ed.]. This is a standard procedure. There was an on-line depth time recording, available to the supervisor at the surface. He could therefore watch. The diver was working on a platform and as the time went by, the supervisor called the guy in, to come back to the surface. The diver began to ascend at a reasonable rate and then he heard what sounded like an engine noise in his ear (he was an ex-clearance diver). He thought, ah, oh, problems, wedged himself into the structure and at that particular moment lost consciousness. I've been through the videos taken in the helmet camera that he was carrying, and you can see the background platform going up and down which means he had a genuine fit. Of course a 32.5 mix at 120 feet is a 1.5 bar oxygen exposure. So Roy Giles, who at that time was the Inspector of Diving in the HSE, and myself and a couple of others really sort of brain-stormed about that. Yes. You can have an O2 hit at 1.5 bar. It's going to happen. Of course, oxygen toxicity, like decompression illness, is a probabilistic phenomenon. Unfortunately, we don't have enough data to be able to put numbers to this probability. What is the risk you're prepared to accept?

## Oxygen rebreathers

Let's put 100% oxygen closed circuit rebreathers to one side, because providing you're doing it right (all of our training was done in a lake where we could not dive deeper than 25 feet), it's pretty damn safe. Again, a contents gauge is useful because with a sonic reducer, you don't always hear it begin to fade out. I have had to do a fatal death investigation on somebody who died in eight feet of water because their oxygen bottle had been leaking and they started to rebreathe all the nitrogen washout that was in their counter lung, and went hypoxic. Oxygen closed-circuit is pretty damn safe and I don't think we need waste any time on it.

I don't know much about, fully closed circuit self-mixing systems, so I'm not going to take part in the debate. Return-line systems, were also mentioned. These are systems that reclaim the gas back at the surface vessel, where it's scrubbed and sent back down to the diver. That's not the kind of diving that you're interested in, so forget that bit.

## Oxygen levels in semi-closed

Let us look at self-contained semi-closed systems. Dräger produced a thing called the FGT 3 about 20 or 30 years ago, and it had the same kind of potential hypoxia problems that we're going to discuss this afternoon, though it's actually still in operational use in some navies in the world. We're going to focus on self-contained systems that use pre-mixed gas [As opposed to self-mixing semi-closed systems like the Fullerton Sherwood CUMA—ed.] The real problem is the basic theory. The important thing I want to stress now, and for later, is that when you calculate oxygen levels in a semi-closed rebreather counter lung, the percentage does not depend on what depth you are. The theory is completely independent of depth, and more important, it's completely independent of the manufacturer, so I can be as rude as I like about all the manufacturers and I don't have to identify any particular one. There are three or maybe four manufacturers in this particular field, so just because I'm being critical, doesn't mean I'm being critical about them all.

The oxygen level in the counter lung depends on the pre-mix oxygen fraction, the flow rate, and the oxygen consumption. That means that in any semi-closed rebreather, the varying oxygen and therefore nitrogen level will affect decompression predictions. That is really all that can be said.

## Equivalent air depth may not be

I'm very happy with open-circuit nitrox where the equivalent air depth is concerned. Very briefly (and all of you should be familiar with this), by increasing the oxygen, and therefore decreasing the nitrogen content of a mix, you can calculate your decompression at a particular depth, by only considering the relative amount of nitrogen in the mix. That's equivalent air depth theory. It sounds great. The only trouble is that one tends to forget that it is not as simple as that. One can very simplistically and, no doubt a good physiologist like our chairman will criticize me for putting it too simply, but in fact, oxygen has got an effect on the circulation, therefore you would not expect equivalent air depth diving to be totally the same as that using air at that equivalent air depth. For what it's worth, and unfortunately this is one of the few years in the North Sea where the total number of dives was not collected, but in 1995 we had two cases of neurological DCI on an EAN 40 mix(40% oxygen, balance N2) and each of them were at 50 feet for 80 minutes, and those are no-stop dives. Basically, without even considering any of the other factors, it does say that EAD doesn't always provide you with a safer dive. I'd like that to be another take-home message.

One or two statements that have been put out in are garbage. One of these is printed in *The Introduction to Technical Diving* [ by Rob Palmer]. I've spoken to the author about it, and he's promised to change it in the next edition. The statement is this, "If the diver has been breathing nitrox during the course of the dive, the chances are the injuries will be comparatively less serious than if they had been diving on air." That's the kind of misinformation that I think a meeting like this has to weed out. We've got enough confusion as it is; let's be careful to stick to the things that we really do know.

I would also be a little bit wary of one recommendation. Bear in mind that I've talked to four manufacturers and the same number of training agencies, about this, and I'm not going to tell you where these particular statements came from (you can do that research for yourselves). The statement is this, "For the calculation of equivalent air depths in a semi-closed breathing apparatus, we suggest using a constant oxygen consumption level of 1.5 liters per minute." Now how on earth do you know when you're going to exceed that? And then, they recommend using air tables when you exceed it! That is totally impractical. We also know that in certain gear, an oxygen consumption of 2.5 liters will give you an equivalent air depth which is actually deeper than the depth you're swimming at. To put it another way, a number of people will say that the minimum oxygen you will get in their counter lung is about 14-17%. That immediately tells you your equivalent air depth is actually deeper than your real depth; and under those circumstances, what on earth are you going to do about the decompression? With ordinary decompression tables, you use the deepest depth of the dive to select the table. What are you going to do if you're using semi-closed circuit and you don't even know what your deepest equivalent air depth is {Because you don't know what your exact oxygen level, and therefore nitrogen level is—ed.]. One is resting upon the use of Jesus factors, and I think with that I will close.

## What causes bends? We don't know.

**Thalmann:** Anybody involved in technical diving knows all about the whiz-bang decompression programs out there. Anybody with a PC on their lap can run a decompression algorithm. High school kids do it. We get messages all the time: "I want to write a decompression program." Way back when, the physiologists convinced everybody that they knew what they were talking about; the fact of the matter is, we really don't know what causes bends. We think it's caused by bubbles, but we're really not sure.

"Well, bubbles cause bends" but the problem is nobody knows where they form, how they form, and we really don't know why they form. We know that the bubbles will form, you can hear bubbles on Doppler after certain dives, but we hear bubbles in people that don't get bent. So just 'cause you're bubbling doesn't mean you will get bent. So we really don't know what's going on.

Now my credentials are that I spent 20 years in the Navy and was personally responsible for the conduct of over 3500 man-dives involving decompression testing. The results of those decompressions were some saturation excursion tables, the constant 0.7 PO2 tables that are in the Navy diving manual, and the constant PO2 helium tables. In every one of these cases, in designing all those tables, and reading all the literature, we really did not have an idea of what causes bends. We can euphemistically say, "Well, bubbles cause bends" but the problem is nobody knows where they form, how they form, and we really don't know why they form. We know that the bubbles will form, you can hear bubbles on Doppler after certain dives, but we hear bubbles in people that don't get bent. So just 'cause you're bubbling doesn't mean you will get bent. So we really don't know what's going on.

## Math of decompression

Second of all is everybody likes to get hung-up in the mathematics of decompression. There's two avenues to take here. In one case, somebody will decide they really know what's going on and they'll say, "Well, it's obvious what we're modeling is a bubble forming somewhere in a critical tissue" and they'll come up with some 10-pages of equations to describe this thing in gruesome detail, which generally don't work or are unsolvable unless you happen to have a super computer. When Haldane approached this problem, he used some fairly simple concepts and that's where our idea of exponential uptake and off-gassing comes from. It's not a bad model of really what happens in the tissue. But the problem is, despite all the mathematics we throw at it, we really don't know whether simply describing gas in this way works or whether we're just lucky. In a sense, all decompression tables are statistical. That means you develop some kind of conceptual model and write down some equations, and then, if you're smart, you go out and test. Then you keep wrenching the constants in these equations around until you can predict a set of decompression tables that don't bend people.

Now what do we mean by don't bend people? We mean the incidence of bends is low. We really don't have a good model of gas exchange kinetics at the tissue level. We could take some areas where there's been a lot of money thrown at this, and it ain't decompression. A lot of money's been thrown at gas exchange, and the modeling of oxygen uptake in the central nervous system. There's reams and reams and reams of papers on the subject, by some very high-powered individuals-, and they can't model it. So after millions and millions and millions of dollars of research, lots and lots of animals who bought the farm supporting this kind of research, they still don't have a good model of how the central nervous system oxygen level changes with time, so what are we supposed to do.

The bottom line is we need to be able to produce safe decompression tables. In that regard, we haven't done a bad job. So in spite of all these shortcomings, we have been able to produce decompression tables. Where you get into trouble is when you begin to believe in your model. The minute you begin to believe it, you're doomed because what you are doing really is making a mathematical, if you will, a curve fit to data hopefully that you have over a certain depth time envelope. But if you begin to extrapolate outside the depth time envelope, you're going to find yourself in trouble very rapidly.

## Decompression is probabilistic

What we'd like to have is a decompression model that accurately predicts when bends will occur based on physiological, physical and chemical considerations only. In other words, we know what's going on and we can write equations to describe it, and we can also construct decompression tables which will keep people out of trouble. One thing we do know, and one thing we can't get around is the fact that decompression is a probabilistic phenomenon. Cancer is a probabilistic phenomenon, getting emphysema is a probabilistic phenomenon, having a heart attack is a probabilistic phenomenon. Given a dozen people with exactly the same status as far as their coronary arteries, some will get heart attacks and some won't. So given a dozen people who are subjected to exactly the same decompression schedule, some will get bent and some won't. That's a fact of life, and there's no decompression model on the face of the earth that can predict the individual variability. It's just not there. Anybody who says they can is probably going to try to sell you a bridge the next time you see him.

What a useful decompression model does is to accurately describes the time of decompression sickness given the dive profile environmental factors. In other words, we have some feel for when decompression sickness will occur, after what type of dives, and we can reasonably steer divers away from areas of very, very high decompression risk. That doesn't mean it will go away. One of the frustrating things, which is natural I guess, is when we get a call at the Divers Alert Network, where somebody comes up with shoulder pain and says, "He exceeded his dive limit by two minutes." That's not the reason he's got the shoulder pain. He's got the shoulder pain because he's got bent. The fact that he exceeded his decompression limit by two minutes is neither here nor there, because he's probably done that many times before and he just hasn't gotten decompression sickness.

## Developing constant PO2 tables

In 1937, the Navy replaced its air tables for the first time. The current air tables, as they appear in the Dive Manual [USN Diving Manual—ed.] were derived between 1955 and 1958. In 1977 we began work on the constant PO2 tables for the Mark 15. This rig was unique at the time, in the sense it controlled the oxygen to a specified set point and there were no decompression tables really available for it. In pursuing that, we ended up coming up with a mathematical model and derived a set of tables. (If any body's really interested in these I can give them a nice reading list to look over.) The Navy is just now getting to the point of programming these things into a decompression computer for fleet use, although 15 years ago we actually had them programmed into two prototype decompression computers. They really never were used in the fleet because some other procedures had been developed which basically allowed the operation to be conducted without

**So given a dozen people who are subjected to exactly the same decompression schedule, some will get bent and some won't. That's a fact of life, and there's no decompression model on the face of the earth that can predict the individual variability. It's just not there. Anybody who says they can is probably going to try to sell you a bridge the next time you see him.**

**The most infamous was diving 60 feet for 180 minutes, which to some of you guys is not a long dive. . . We ended up more than tripling the decompression time before we were able to get a table which was reasonably safe. This was not an unusual phenomenon.**

computers.

As I said, these Constant PO2 tables, are based on a mathematical model. We started out by simply modeling the Navy air tables [which use a constant FO2] and we developed a decompression program which accurately computed the tables. At that time, we believed that these tables were "safe." We soon got a lot smarter than that. Once the mathematical model was developed, and this model was based on the same concepts that were used to compute the original air tables (I'll discuss the mathematical details off line if anyone is interested, so we won't bore those that aren't). In the program, there was simply one Fortran statement that computed the oxygen, and it subtracted from the nitrogen. Well, either you multiply the ambient pressure by 0.21 if you're breathing air or you subtract the PO2 from the nitrogen pressure if you're breathing at 0.7. We made that change and said, OK, we've got it. This program fits the air tables; all we do is change when we compute O2. After about 30 bends later, we decided it didn't work. [Note that some of the rebreather decompression algorithms on the market, have been calculated in this same way, using a standard constant FO2 table, like Buhlmann to begin with. Caveat emptor.—ed.]

## Back to the drawing board

We then went on to develop some more sophisticated models and we began testing them, and eventually, after approximately 800 man-dives, we came up with a decompression model that worked pretty well and we used it to compute the tables in the USN Dive Manual. It turns out, in the interim, we went along and we used this model to dive some air tables out of the Dive Manual and, lo and behold, to our surprise we found that some of them didn't work well. The most infamous was diving 60 feet for 180 minutes, which to some of you guys is not a long dive. The divers were cold, they exercised on the bottom, and we actually used a 200 minute schedule. Out of the first 10 divers we dove, we bent three—obviously a schedule which is unsafe. We ended up more than tripling the decompression time before we were able to get a table which was reasonably safe. This was not an unusual phenomenon.

We found that when we did no decompression limits, that the limits we tested were either the same as in the Diving Manual or slightly longer. We tested 65 minutes at 60 feet, we had no problem. We tested 15 minutes at 190 feet, we had no problem. But the minute we got into decompression, we began to find we had problems. We began to bend people. The problem we have is a lot of the Navy divers say, "We use the air tables all the time and we don't have any problem with them." A lot of the reason is the way the tables are used. There's a lot of slack built into that. But if you dive in real time, the data is pretty clear.

## Military approach to tables

The 0.7 tables are now accumulating their own data and the tables work pretty well. The way the military works is that there is a mechanism for assuming liability. That means if the tables don't work, there's a system to pick up the pieces. The system involves a) reporting and b) treatment. In the reporting mode, every dive is logged in the Navy, so if there's a problem with decompression tables, somebody is supposed to find out about it, and if it looks like an enduring problem, then the system can be changed. There's a constant monitoring of technique. The other thing is that there's a full service medical support system at work. If there is a problem, the individuals who are affected can get treated rapidly. One of the things that impressed me the most was the type and variety of symptoms we would get; we'd have 10 divers who were perfectly OK and could go home, and one diver who was paralyzed from the waist down and needed to be treated. This is the difference between developing decompression tables for an individual, and developing tables for a large group of individuals. You have to keep that in mind. Probably no one sitting in this room today knows which one of those divers that they would be. If you've got a very long track record of decompression you can be confident that , "I don't think so." There are individuals who have a very high tolerance for decompression sickness.

## Rebreather deco algorithms

A lot of the decompression algorithms that are going to be developed for these rebreathers are probably going to be extrapolations of ones that have worked well on air diving, but be mindful that every time you dive one of these, you become a data point. And the real bad news is nobody's collecting the data, so we have to keep that in mind.

One of the things about the technical diving community that is a little bit of unsettling is they are actually repeating a lot of the mistakes that were made by the Navy and commercial companies 10 or 20 years ago. But the bad news is that there's no one central organization that's accumulated this data and put it together to provide the kind of feedback you need in order to make progress. You're also beginning to get into areas where the commercial and military have no experience. If they don't have the ability to do this, then it's not going to be unusual to find the odd dead diver. Unfortunately he won't be able to come back and tell you why.

## Controlling O2 Tolerance

**Unidentified:** Could you please discuss what an individual can do to control or improve their tolerances for CNS oxygen toxicity?

**Thalmann:** As far as we know, stay shallow and at rest. Actually, it's been shown if you don't get in the water, you're better off, too.

Right now, there is no practical evidence that anything you can do can prevent O2 toxicity. There is some very theoretical technological edge stuff that would suggest if you decrease the amount of aspartamine that that's implicated in O2 toxicity. But so far only a few laboratory rats have proved that. The bottom line is that you have to stay shallow (don't exceed the limit)-, and you're better off if you don't exercise; that's absolutely known; and oddly enough, what Dr. Donald showed [See *Oxygen and the Diver*, by Kenneth Donald—ed.] that not only does O2 tolerance goes down when you're cold, but he's got some evidence to say, it goes down when you're hot as well.

The take home message is to keep your PO2 low, 1.3 is probably where it's at. [Note that technical divers are reccomended to keep their PO2s below 1.45 atm during the working phase of their dive, however these guidelines were created for open circuit scuba not for a constant PO2 exposure—ed.]

**Derek Clarke:** We had a CNS hit in the North Sea at 1.2 bar, and it was so way out we decided to ignore it.

**Thalmann:** With probabilistic phenomenon, the probability of one event is always non-zero.

**With probabilistic phenomenon, the probability of one event is always non-zero.**

The other thing I want to point out is that there is misinformation out there. The Royal Marines came to Panama City when we were doing our oxygen studies, and they didn't like what they saw. The reason they didn't like what they saw is that the O2 limits that we were coming up with were shorter than what they were allowed to dive. When they got back to England, they began basically saying, "Well, the guys who got oxygen toxicity were really the out-of-shape divers that really weren't experienced oxygen divers, dah, dah, dah," which is absolute bullshit. It turned out that the guys that were getting the oxygen convulsions were the guys that leap tall buildings in a single bound, they were young and physically fit. We don't know, it could be that the physical conditioning, in fact, makes you more sensitive to oxygen toxicity, rather than the other way around. So right now, stay shallow and stay at rest.

**Peter Haseltine:** If you believe that the tables can be made better, both for decompression and indeed to estimate O2 toxicity, why is it that the tables basically only take into account the gas pressure and time exposure and don't in fact take into account physiological consumption? You pointed out a moment ago that clearly the toxicity must be related to how you metabolized oxygen, or at least the metabolism of oxygen is what results in the toxicity, so why don't we use even indirect measures such as breathing rates and so forth, integrate those into the tables to, in fact, come up with a more precise estimate of what the exposure is.

**Thalmann:** What tables are you talking about? Oxygen exposure limits or decompression tables?

**Haseltine:** I'm talking about both because the principle really applies to both. If we just consider the nitrogen exposure in a decompression table, why don't we take into consideration how fast somebody's breathing, how much they're consuming, and therefore what the actual exposure is to that nitrogen, if you calculated each breath as a dose? You can do that with a computer fairly easily.

**Thalmann:** You can do lots of things with a computer fairly easily.

**Haseltine:** My question is do you think that there's no...

**Thalmann:** The average cost of one man-dive to test a decompression table is a thousand dollars.

**Haseltine:** My question is has this been done, and discarded because it wasn't helpful? If so, can you tell us that? Or in fact is it an area which would further investigation, leaving aside the cost?

**Thalmann:** Leaving aside the cost, all things are possible. Let Dr. Elliott answer with regard to O2 toxicity first.

**Elliott:** I was going to stick with the decompression in fact, and say the trouble is there are so many other factors that you'd have to plug into your computer; acclimatization, the adaptation of the individual to decompression, is a very good example. And Ed and I could produce a list of about 10 or 12 other physiological factors which would also have to be included. If you happen to be one of that one-third of people in this room with a PFO, you'd have to have a different computer program. There's no end to what could be plugged into a computer. We've got to keep it simple.

**You don't die from the convulsion. You die from drowning; that's the reason you wear a full face mask.**

**Thalmann:** We tested the simple premise, as to whether your risk of decompression is less if you exercise in the dry or if you exercise in the wet. That study took three weeks and probably cost $15 to $20,000 on the low side, not including the salaries of the people involved. So for every variable that you want to test, the problem you run into is the time and effort involved in testing it. That's why when we test decompression schedules, we test them with the diver exercising at depth, at a work rate that we think is high or harder than he would normally do on the average; he's generally in cold water because we think that during decompression cold water impedes decompression, and we also have him at rest. In that regard, we spent about $4 million coming up with two sets of tables. In order to go back and reproduce that, and decide if the variable of exercise plays a role would involve approximately the same amount of money. So that's the reason the military hasn't done it, and that's probably the reason why the military schedules tend to be conservative because they were really designed under the worst-case decompression scenario that we could think of. But if you look at the physiological models, they have all the parameters that you spoke of: blood flow, arterial oxygen, arterial CO2—every one of these parameters is in the equations. The problem is if you begin testing each one individually, you run out of time and money pretty fast.

## Identifying CO2 retainers

**Drew Richardson:** I have a question on medical screening. Is there any call to look at individuals who have a propensity for CO2 retention? We're talking about exposing the general public to semi-closed and closed circuit units. Is there another level of screening that needs to be considered here, from a medical viewpoint on CO2 retainers?

**Elliott:** This was looked at in conjunction with a deep-water blackout by Royal Navy. In the tests, a number of those individuals lost consciousness at depth on the video screen and afterwards of course completely denied they'd had a wonderful dive. Now those individuals were investigated by RNPL as potentially CO2 retainers. The ultimate conclusion was that the Reed Test that was used to detect these people was insufficiently sensitive to screen out those at risk.

**Gavin Anthony:** Gavin Anthony, DRA. If I can come in on that, as a standard procedure for all our manned trials, all our subjects go through the Reed as a CO2 sensitivity test; it's a one-bar test. The relevance to it at pressure just simply has not been shown. Although CO2 retention is certainly linked to decompression effects and oxygen toxicity effects, it's finding an adequate screening that's the problem. I know the Israelis at Haifa are doing some work on a pressurized system, but until we've actually tied that down, you're not going to get much.

**Thalmann:** For such a test to be useful, it would have to be done at depth. First of all, you get into an expense issue. Second, even though we assume that individuals who are more sensitive to oxygen tend to retain CO2, there's no way right now to predict who these individuals are and whether or not they will get O2 toxicity under the specific conditions.

## The importance of full face masks

**Clarke (Derek)**: Someone asked a few moments ago what could the diver do to mitigate the effects of CNS toxicity? I offer one suggestion: spend more money by simply putting a full face mask on your rebreather. One of the things that's certainly going to kill you with CNS is drowning. If you have a full face mask, the chances are the O2 level will reduce even though you may be unconscious and you'll likely regain consciousness and survive. Chances are otherwise, you'll die. So if I was with a rebreather, I would have a full face mask.

**Thalmann:** You don't die from the convulsion. You die from drowning; that's the reason you wear a full face mask.

**Elliott:** I want to reemphasize what Derek just said. This is a particular hobby horse of mine. One of the general things that's come out of this physiology session, is that there are lots of things that can send you unconscious with rebreathers. If you want to reduce the risk, two aspects of breathing equipment that you can do. One as John Clarke rightly pointed out, a high work of breathing leads to increased CO2 and CO2 retention, so you must get the work of breathing down on the equipment. And two, if there is a single way ahead to improve safety, it's a full face mask.

## An automated bailout system

**Bev Morgan:** I'm working on one, but what I wanted to throw in for consideration. Wouldn't it be nice if there was a method to automatically provide the diver with an air window or lower PO2 if he went unconscious. With the full face mask, you have the ability to design something like that. Streetcar conductors used to have a thing called dead-man's switch; if they pass out or anything happens, the streetcar stops. It would really be nice to get a consensus going on what a person should switch to as a safety backup. If they're O2 diving, the apparatus should be adjusted for an air window. Granted, you're supposed to have a backup and people helping you, but it would really be nice to have a machine watching you all the time, and I think that's possible.

## The importance of the buddy

**Thalmann:** Practically, the machine that watches you all the time is your buddy. Right now there is no way to predict when an O2 convulsion will happen, and simply having something which would provide you with a reduced oxygen after the convulsion may or may not be helpful, since we know the convulsion will stop even if you don't come off oxygen. The problem is that you're underwater and unconscious, and I don't think there's any machine other than another diver which is going to be able to get you to the surface. Usually the post phases of these O2 convulsions are four to five minutes, so if the diver is incredibly lucky and his rig is still functioning, it's possible for him to regain consciousness and get back to the surface. But if he's unlucky, he's just simply going to drown.

## Full face mask experience

**Rod Farb:** I actually use a rebreather and I've got three full face masks. I'll tell you that the ones that do not have a mouthpiece to go into your mouth are extremely difficult to breathe with a rebreather. So if you're thinking about a full face mask for a rebreather, try the Cressi Sub. There are a few other manufacturers that manufacture a full face mask where you insert a mouthpiece in your mouth. It's really the only effective and easy way to do it. You can put a full face mask on it; if you need communications gear, you obviously can't have something stuck in your mouth, but a full face mask is extremely difficult to use with a rebreather. I speak only from my experience with the CCR 155. I'd like to know from Richard Pyle has used a full face mask on the Cis-Lunar unit.

**Richard Pyle:** I've been using the Cis-Lunar rebreather. I have used a ScubaPro full face mask on it, which is similar to the Cressi Sub in that the nasal-eye portion is isolated from the mouth portion, which means if you exhale through your nose, bubbles come out of your mask rather than in the loop.

I'm really torn on this issue of the advantages vs. the disadvantages of full face masks and rebreathers. I haven't noticed an increase work of breathing with a full face mask on that particular model, but there are other considerations that concern me, in terms of having to go blind to get something else in your mouth, issues like that. I'm really looking forward to looking at Bev's new mask [The S-1. See The Rebreather Market session—ed.] and see what advantages it might have. Maybe he'll consider giving me one as a prototype test unit. In general, I'm on the fence with regard to the advantages vs. disadvantages of full face masks.

## Treating a CNS hit

**Thalmann:** We'll take one more question.

**Unidentified:** You made a comment that the Navy has all the support structure in case an event does happen under the water. From a practical standpoint, we don't necessarily have all those resources at our immediate disposal, but from your experience, what should the short-term and long-term treatment be, from a self-medicated standpoint if CNS hit should occur? The diver gets a CNS hit. You get him out of the water? How should you treat them?

**Thalmann:** I don't think it makes a lot of difference what you do immediately. In the military the idea is to get the diver out of the water, to stabilize him, make sure he's breathing OK, and then to evacuate him to a medical facility. The point I'm making is that the Navy facilities are usually pretty close at hand when they do these kind of diving operations. They usually don't get into issues of.. Of course special warfare is the exception, where divers may be in areas where, for one reason or another, they don't have immediate access to this stuff, and when these things happen and they pretty much have to take their lumps. The point is whether or not the technical diving community is special in the sense that they either don't have to worry about this stuff, or take these precautions, and they can kind of assume that it's not going to happen and things will be okay. I don't know that tech divers are that much different than military divers, that they don't need to take those kind of precautions. We have consulted on several cases on the *Andrea Doria*, where there's no recompression chamber nearby and the divers have to be evacuated. It's insane; there's just no other way to put it.

## The importance of rebreather testing

You need to know something about physiology to dive rebreathers. There's a lot of stuff that goes on in a rebreather that doesn't happen with scuba regulator. A scuba regulator is kind of the steam engine of diving gear; it's been around for a long time, honed to a fine art, and they're incredibly reliable. There's a lot of redundancy built into this system. By comparison, rebreathers are kind of the space shuttles. They work, if you give them a lot of care and feeding, and if you're willing to provide them with that care and feeding, you can probably use them.

We know, that in the military, which has the capacity to give these things as much care and feeding as they want, that they are suffering from the maintenance costs and problems in reliability and therefore are always on the lookout for new and better ways to do it. By the same token, before any individual in the military slaps a rebreather on his back, John Clarke and Dave Sutherland and the crew at EDU put it through the wringer. These are individuals with no vested interest in whether the thing works or not, and this is important, really important.

As much as the manufacturer thinks he's totally objective, he's not. He's got a lot of money riding on this thing. If it's a failure, if the rebreather performs in a way that it can't be easily fixed and he's looking at his whole investment going out the door, it's likely that he's going to try to fix it as best he can and hope for the best. The military has been very meticulous about making sure that the people that test the rigs have no vested interest in whether they work or not, then they can provide coldly objective data as to whether the things are safe to breathe. This is why there's so much data available, and as far as I know of, this is really the only data available. It would be nice if we could begin getting data on some of the rebreathers that are on display here and have them tested under the same conditions. Of course, if the military becomes interested in some of these, eventually data will become available as they are tested. But my guess is with the number of rebreathers on the market, the likelihood is that most of them are going to be not subject to that testing. This is an issue we're probably going to get into tomorrow during the Testing and Performance session; manned vs. unmanned testing. It's not as simple as it used to be. If you think it's going to be as simple, then you're probably deluding yourself.

**You need to know something about physiology to dive rebreathers. There's a lot of stuff that goes on in a rebreather that doesn't happen with scuba regulator.**

# Rebreather Maintenance & Logistics

*"... it's almost going to have to become a religion to you, if you're going to do it right. If you don't ... the thing's going to jump up and bite you in the butt big time, and we're going to read about it as a statistic somewhere."*

--JR Hott

## Session Summary

Unlike open circuit scuba equipment, rebreathers require significant ongoing maintenance to function properly. This can amount to one to two hours or more per dive. In addition, there is a considerable amount of support equipment, including booster pumps, extensive spares, and tools that are required to operate and maintain these systems in the field.

In this session, panelists experienced with using rebreathers operationally discussed maintenance, logistical and cleaning requirements, including pre- and post-dive checks, and disinfecting the unit. The panel discussed the importance of properly disinfecting between uses and the consequences of not doing.

Other interesting points came out in the discussion. One was that canister duration is a statistical phenomenon, so that an individual can pack the same scrubber on the same day with the same material, dive it in the same environment as on another day, and yet have significantly different canister durations (the time until CO2 starts leaking through in large amounts).

The panel consensus was that the use of pre and post-dive checklists, and formalized maintenance procedures are critical, and that it is the responsibility of the manufacturers to provide these to both training organizations and the consumers. Unlike the military, which has organizations and procedures in place to certify the operational readiness of their equipment, rebreather consumers are largely going to have to accept this responsibility for themselves.

Panelists, and audience discussants, felt that it takes a very high degree of commitment and time on the part of dive store owners to incorporate rebreather technology into their business. The panel was chaired by Tracy Robinette, Divematics, and consisted of; Jim Brown/Spec Forces U/W Operations, Rod Farb/Photographer, JR Hott/US Navy, and Richard Pyle/Bishop Museum.

26SEP THURS 2:00-3:00 pm

# Transcript

**Menduno:** Before we get started with our next session, we're going to hear briefly from Leslie Leaney of the Historical Diving Society, and then I'm going to turn it over to Tracy to begin the session. Leslie?

**Leslie Leaney:** Good afternoon. I'm Leslie Leaney, from the Historical Diving Society. I'd like to take a minute to explain what the Society's about and why we're hear today. First, Nick Eichorn, one of our directors, sends his apologies. He's wife's very ill so he was unable to make it to the Forum. .All the historical rebreathers at the back of the room belong to Nick.

The Historical Diving Society was formed in US four years ago. The original Society is based in England. We're a 501c-3 nonprofit organization, and an historical affiliate for the Association of Diving Contractors (ADC) and groups in England, South Africa and Italy.

Our primary focus is the preservation of equipment and the dissemination of the history of diving. We achieve this principally through publishing Historical Diver. Looking around the room, I'd guess 20% of the attendees here are members of the Historical Diving Society. I'd like to see the other 80% of you come to the booth and see if we can get you to sign up also. We have a strong Board of Directors and a large Advisory Board, some of whom are here. Bev Morgan, also Phil Nuytten, and Andre Galerne. We now have about 700 members, primarily based in America. There are a lot of overseas members: some in Japan, Singapore, dual members in UK also.

We worked with Michael on the last two tek.Conferences, and we were responsible bringing over the original 1879 Fluess rebreather mask, one of the first in the world. The company that built those original rebreathers is Siebe Gorman, the world's oldest diving company, established in 1819. If you're interested in seeing more, come to the booth and take a look.

**Tracy Robinette:** This afternoon we'll be discussing rebreather maintenance and the cleaning procedures you normally don't have to worry about with open-circuit equipment. We're also going to talk about field logistics and how closed-circuit rebreathers differ from other types of gear.

Our panel consists of J. R. Hott with the Navy Undersea Warfare Center in Keyport, Washington; Jim Brown, Special Forces Underwater Operations School in Key West, Florida, film-maker, Rod Farb, from North Carolina, who's informally associated with Biomarine, and Richard Pyle, from Bishop Museum who's a Ph.D. student at Univ. of Hawaii. JR and Jim represent the military, who's got more experience than anyone else. Rod and Richard offer an end-users perspective. Rod dives a Biomarine 15.5 that he's completely redone himself and Richard is diving a Cis-Lunar Mark 4. I'd like everyone to say a bit about their background and then we will move into the discussion.

**J.R. Hott:** I'm JR Hott with the Navy Undersea Warfare Center Division in Keyport, Washington: We're not using any rebreathers at the facility I'm working at right now. I was formerly with the Naval Medical Research Institute, and we had used LAR V's. We'd also done some work with the Canadians using the CUMA rig—Fullerton Sherwood's Canadian Underwater Mine Countermeasures Apparatus. You saw a photo earlier with me with my Dräger Lt. Lund rig.

Some of the aspects of maintenance I want to talk about include rigs but also a lot of the ancillary items that are involved if you're going to do a load-out on a trip; everything from Sofnolime to your tool kit, which is necessary for the replacement of soft goods and things like that. I am ANSI certified O2 Clean Room Technician, which is a three weeks school [Compare this to the half or whole day course offered in the sport market—ed.]. I've done a lot of oxygen cleaning of all types of systems, but mainly with the diver's life support systems at the Naval Medical Research Institute.

**Jim Brown:** I'm with the US Army. I work in Key West at our Combat Dive School. We train Army Rangers, Special Forces, Air Force Para-Rescue, and Combat Controllers. Until last year, we taught closed circuit diving on the LAR V in our basic course. Currently, we teach closed circuit diving in our Dive Supervisor course. We've got about 20 rigs on line right now. We have a total of 80 and 60 of those are currently boxed up in cold storage until we bring closed-circuit diving back on-line in our basic course.

I've traveled with the LAR V overseas with the teams. It's a pretty simple unit. We don't have the electronic problems that you might encounter with more complex rebreathers, but we do carry soft goods, a small tool set, and are prepared to do oxygen cleaning, things of that nature. All of the service is done on the LAR V at our school. We have a pretty good workshop, and our technicians are trained directly from National Draeger. Our program is controlled by the Navy. They have a very extensive maintenance program that has very specific written, step-by-step procedures that are supervised in all aspects of handling the rebreathers during maintenance.

**Rod Farb:** I'm a guy that goes out and does a lot of technical diving on shipwrecks. For the past two years, I've used a Biomarine Mark 15.5. It's kind of a hybrid between the Mark 15 and the 16 military rebreathers. They were never military rebreathers, which is why it was pretty easy to get a hold of these. I travel with it out of the country, across the country. I've been on airliners. I probably look at things that many of the sport diving people in this room who want to buy a rebreather, and I am happy to talk to you about the problems I've had, and the solutions I've come up with.

Simply buying the rebreather is the first step in an arduous process of getting your whole act together to use that rebreather. It's just not a matter of purchasing a rebreather. You have to purchase spare parts, spare sensors, spare batteries, a spare scrubber, Haskel pumps and a whole milieu of ancillary support equipment in order to use it effectively. That makes it much more difficult when you travel out of the country. It makes very difficult when you're getting gases delivered to you on a liveaboard or some foreign shore, and the fittings are different from the fittings you're used to getting, so you have to get adapters for those fittings.

You've got to do a lot more planning for a rebreather dive in the country or out of the country than you would with open-circuit scuba. However, once you have the rebreather, you don't have to worry about constraints of gas consumption any longer.

Furthermore, one of the problems in rebreather industry until now—the lack of a real-time decompression computer—has now been solved, so you can now use your rebreather effectively. You don't have to use air tables and figure your equivalent air depths, or trimix tables cut to your max depth, in which case you're really not using it efficiency. Desert Star Systems has built a wonderful computer that will interface with most rebreathers. I use it on the Mark 155; it's oxygen sensing, or you can run it as a stand-alone computer that's not connected to the unit. You can use it at a fixed PO2, it'll do your decompression profiles, you can do gas switches with it, you can program in 10 different gas mixes in there, and you can interface with a PC and change the diving algorithm. This is something that has not been available before. is not available, and I believe that the rebreather industry needs it to move forward.

**If you suspect that it's contaminated, it's contaminated. Forget about using it again until it's properly cleaned.**

**Richard Pyle:** I was asked minutes ago to be on this panel which is why my hair isn't combed and my shoes aren't tied.

**Robinette:** Richard's hair is never combed.

**Pyle:** This is true. I've been diving with a Cis-Lunar Mark 4 rebreather for the last couple of years. It's a rebreather that people often conveniently refer to as a prototype—it's not actually a prototype because it wasn't designed with the intent of being a prototype. It was designed to get Bill Stone past a certain sump in Mexico. It has become the prototype for the next generation Cis-Lunar Mark V rebreather, which they're working on right now.

I've use the Mark 4 to catch fish. I'm a fish nerd, a marine biologist, I study new species of fish. We have two Mark 4s, myself and my diving partner, John Earl. We've dragged them to Papua, New Guinea, and I've dragged them across the country also. I'll let the questions dictate the discussion from here out.

## Getting back to basics

**Robinette:** I think we need to return to the basics. How are rebreathers going to change how we operate? What requirements are there going to be to take a rebreather out into the field. or work with it at the dive shop or whatever we're going to go. How is it different than open-circuit? I'd like to know more about travel logistics; including gas requirements—how to get gas—problems that you have in the field, also what types of checklists are needed when you're traveling, what kinds of spare parts you need, and, above all, cleanliness requirements.

One of the most important things about a closed-circuit rebreather is are the cleanliness requirements if you plan to use it on an every day basis, especially if you're traveling into different areas. I'd like to hear what our panelists feel is a reasonable cleanliness situation with a closed circuit rebreather.

## Cleanliness is next to Godliness

**Hott:** With closed-circuit systems, you've got your diluent side, and your oxygen side. For the most part, cleanliness standards are the same for both. All of it has to be oxygen clean. As far as transporting equipment, if you've got bottles that are empty or full they should be either capped off or the valve should be bagged. Cleanliness of the hoses: if you've got open hoses, the hoses should be double-bagged. As far as maintaining the cleanliness: any time you feel the unit was contaminated, the unit should be set aside until proper cleaning procedures can be performed. That's not an Well, I think it might be dirty, it might be clean. If you suspect that it's contaminated, it's contaminated. Forget about using it again until it's properly cleaned.

**Brown:** As far as hyperbarics go, the pneumatic systems, J.R.'s right on the money. As far as breathing loops, rebreathers get dirty from a biological view. You've got gas breathed directly from your lungs into a counterlung, so this thing has the same kind of microbes that your lungs have, and the capacity for these things to grow and create an infection is definitely present.

At the school, we assign one unit to one diver, who will dive it several times a day for weeks; at the end of that period, it will receive a cleaning of diluted Betadyne, an iodine type of disinfectant. In the interim, while it's being used, it's rinsed with fresh water in between dives. But the drying part of it is also important. We dry the rigs out and try to keep the folds and creases, where liquid can stay and thus bacteria can grow, down to a minimum. Mouthpieces, dive surface valves are left open.

Obviously, with oxygen involved, the pneumatics have to be very clean and meticulously handled; then the breathing loop components are kept sanitary. Even the floor in our storage room is mopped and swept after every dive, all surfaces are cleaned. Just like in your kitchen, provided you have a clean kitchen!

## Disinfecting with Quatsyl

**Farb:** My rebreather's not kept on a clean floor, but what Jim touched on about decontaminating the unit with a bactericidal agent is very important because stuff will grow. It's warm, it's moist, and that's a perfect environment. After every dive day, I rinse the unit with a product called Quatsyl which is used by hospitals to disinfect. It has bactericidal, viracidal properties. It also has surfactants that are like soap, detergents that will remove particulates and so forth. Betadyne is great. Iodine is certainly a tremendous oxidizing agent and would be certainly bactericidal, viracidal and so forth. It ties up proteins and it's perfect. The problem I have with Betadyne is the taste. It's hard to get rid of. If you've ever had iodine in your mouth, you know what this is about. Quatsyl, on the other hand, can be rinsed out fairly effectively. It has a surfactive agent in it that breaks surface tension. You can rinse it out if you rinse it thoroughly. You run a hose in there and scrub everything out. I do that after every day of diving. I never just shut the unit down and then come back and use it.

One of the things about a rebreather is that while the other guys who are using open circuit (and there's a problem diving with a rebreather with open-circuit divers because they're going to be out of the water way before you ever want to get out of the water) get back to the dock, and are quaffing down beers, you're cleaning your unit. The scrubber is hot, it's moist, you've got absorbent pads on the top and bottom that are soaked with vapor from your lungs. You've got to clean that, soak that, and you've got to prep it up for the next day of diving. Overall, you're going to spend a good part of an hour after you're finished diving getting it all squared away. I take the sensors out immediately; I don't want them sitting in this moist environment. I store 'em away and put them back in the next day for diving.

There are a lot of things to consider with a rebreather that you don't have to consider with open-circuit. Certainly oxygen cleaning everything is important. I use Viton O-rings on the O2 side. Other than just common sense cleaning procedures, there's not a whole lot to it. I'm real sensitive about my unit because I keep a set of spare parts for just about everything but I only have a limited amount of spare parts, so I really want to take care of everything.

If you're not a person who's mechanically inclined, if you're not real good keeping your open-circuit stuff clean, if you're the kind of the guy that throws your equipment in a bag, and washes it a week later before going diving then consider staying with open-circuit. Just have somebody bring tanks down to you if you want to stay longer. Because your rebreather's never going to last if that's the way you take care of it. You have to be meticulous in taking care of this thing. Imagine sewing your lips onto the mouthpiece; you've got a mechanical lung that you're dealing with, and it's life support, it gives you a long time underwater, and that means a much longer time period for screw-ups to happen. You're going to be in the water for a long time and you want the unit to run properly for that four or five hour duration run.

I tend to do long dives underwater. If you're very haphazard in taking care of your unit, you're going to be down there with maybe an hour and a half decompression obligation and your unit's going to crap-out. Then you need a chamber in addition to everything else hat you bought for the unit.

**Pyle:** I'm the guy who, as an open-circuit diver, used to throw all my gear in the closet and let it rot. Rod is absolutely right. In fact, I can't really add much to what these people have said. You have to give a rebreather more attention than you do open-circuit gear. I've learned if you're too lazy after a dive and throw it in the corner and deal with it the next day, you end up putting a lot more hours into bringing it back up to speed than you would have it you did the routine post-dive maintenance on a fairly regular schedule.

## Disinfecting the loop: Betadyne vs. Quatsyl

Our particular schedule for disinfecting the loop depends on our diving regime. If we're diving two or three dives a day for four, five, six hours a day, we use slightly more aggressive routine that if we're only doing a couple of dives a day, a couple of days a week. We use Betadyne, but I have already asked Rod about the stuff that he mentioned for the reason he mentioned. Betadyne has a lingering flavor that takes a long time to rinse out and extends the time of actually cleaning process. If this other stuff is really good as a bio-side, I think it's worth looking into.

**Brown:** I agree with what Richard was saying about Betadyne. If there is another antibacterial or whatever to clean out a breathing loop, as Rod was saying, it would probably be a real good thing for all of us to check out. If you have used a closed-circuit rebreather right after a Betadyne cleaning, you know it's not a pleasant experience.

**Farb:** Dick King has Quatsyl in the back of the room. Many hospitals use it in place of Betadyne.

**Unidentified:** Has there been any kind of testing done to its cleaning out the loop? We know Betadyne works because it's pretty strong as far as being able to kill bacteria.

**Peter Haseltine:** I can give you insight into that. There are half a dozen systems that are used to disinfect breathing loops in hospitals, admittedly they're not rebreathers per se, but the principle's the same. People are using them for long hours. For the most part we use systems which are either disposable or use heat disinfectant. But cold disinfectant, chemical disinfectant is very commonly used. I don't know anybody who uses Betadyne anymore for this purpose because Betadyne absorbs to rubber, absorbs to the surface, and it changes the properties of the surface. It's a very effective agent. The quarternary-ammonium compounds, of which this is one, number at least a dozen that are EPA registered as cold sterilizing disinfecting agents. You want a disinfecting agent. You have to understand that when you do that, you're not sterilizing it. You're going to be disinfecting it. But that's just fine because the air we breathe isn't sterile either.

On a practical basis, it doesn't matter what part of this country you're in or even what part of the world that you're in; go to your local hospital, find what type of quarternary-ammonium compound they're using, and make sure that you're using one that can be used on things that you're going to put in your mouth and not ones that are used on the floor because there are obviously considerable differences in the strength involved. Like every chemical, they are toxic in concentration. Most of these are relatively non-toxic because of the dilution they're in. But that has a disadvantage; there are certain things they won't work on.

I think it's important to have a double system. By all means, use your disinfectant but also remember that drying is, in and of itself, a very important part of the disinfecting process so don't rely just on whatever the chemical agent that you use is. Consider drying as a second level method.

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## Drying the system

**Hott:** I'd like to back that up on the drying thing. We learned pretty early on there's a significant difference, whether or not you dry the unit after every dive. Not only in the amount of sludge that occurs inside a breathing loop but also things like sensor life , scrubber material. It's much better if you take the time to open up the canister and air it out between each dive, even if it's a surface interval between dives. If we're not on a wet splashy boat, we usually open it up, towel off whatever we can reach with a towel, just to try to keep it as dry as possible.

**Brown:** If I could add something on drying and also on cleaning. I like to thumb through the dive supply catalogs. You might have noticed towards the end of Marvel or Amron catalogues, that they offer cleaning and drying cabinets for commercially-used rebreathers. No doubt these things are very expensive but you could fabricate something on your own.

Not only the soap and the presence of water on an object, but also the friction, perhaps the hydraulic effect of water flowing across an object could enhance the cleaning process, particularly in corrugated hoses, the exhalation hose, likes to catch a lot of saliva and things like that. You could probably put together a drying cabinet whereby gentle warm air is forced across the components for a period of time after cleaning.

**Robinette:** Good point, Jim. One of the things Jim brings up is drying cabinets. That would probably be very applicable if you have a number of rebreathers, a store environment or if there's a group of individuals that have their own rebreathers. But I think the key here is taking the time required to dry these systems out. Also, you have to watch out when you open a system up. The absorbent shouldn't be exposed to air. Let's say you haven't gone through all your absorbent and you haven't repacked the canister. Make sure that you either repack that canister, or seal it up when you're trying to dry out that rig.

**. . . Spec War Com paid me and my laboratory to explore the possibility of whether a SEAL could detect elevated CO2 levels, whether he was resting or whether he was exercising. . . by the time, you begin to observe something is wrong, you're probably on the verge of passing out.**

**Farb:** That's absolutely right about drying, and easy to do at the end of a dive day, you take the hoses off the unit and stretch them after you've rinsed them with the quarternary-ammonium called Quatsyl. Then after you've rinsed it out and pull the corrugation so that the liquid will run out, hang them upside down with the mouthpiece open so they dry out. Turn the unit upside down, pour all of the liquid that you can out of the rebreather, but save taking the breathing bag off. There's no way you're going to dry it out for the next day of diving, so it's very important that you just disinfect it.

What I do is pull out the water-absorbing pads, I pull the scrubber section out, I wipe it off, and if I'm going to be overnight I take the sensors out and leave it airing out that way. But there is no way in the world, save putting in a really warm room and hearing it up, that you're going to dry that breathing bag out unless you take the breathing bag off, which is really too big of a pain. And it's probably not necessary. The important thing is if it's going to sit around for awhile, you definitely want to break it apart and let it dry out. The hoses I think, especially the exhalation hose, as Jim hit on, are critical.

## Scrubber protocol

**Steve Barsky:** Say you go out for a day of diving, and it ends up that you don't do as much diving as you thought you would so your scrubber canister has not been completely used. Do you normally empty the absorbent out, clean out the canister and then reuse it? Do you let the canister sit with the absorbent in it? How do you handle that?

**Brown:** For the LAR V and for the other rebreathers that the military uses, there are limits to the time that you can leave a canister loaded, either before you use it or after you use it. You can pack a canister on a LAR V, pre-dive it, assemble it, put it in a box for two weeks before you dive it. Once you've dove it, you have 24 hours to use the absorbent before you throw it out. You can do multiple dives on it up to 200 minutes on the canister, but that gets into canister duration. Twenty-four hours, then we throw it away.

**Farb:** One of the most useful things that you're going to keep with your rebreather is a log. Not only a log on your time that you use it, but you're going to keep a rebreather log on the time that's on the scrubber. My unit has an eight pound scrubber canister. I keep a log of the hours on it and I usually do it away somewhere around eight or nine hours of use. That may occur over a period of days or it may occur over a period of weeks, depending on how I'm using the unit. I'm not sure what kind of scrubber material these fellows are talking about, but I've left scrubber packed (and if I'm leaving it for a couple of weeks, I'll put it in a big garbage and seal it up) but once I've got say three hours on the scrubber, I'll store it and use it again three weeks later and use it quite successfully.

## Sensing CO2 build-up

The best CO2 sensor that's on the market is your own body, and when the scrubber starts going out and you're building up CO2, you just get really tired and it's really obvious. It's really obvious, way before any sort scrubber material changes color, by the time it changes color, you're way past the life of the scrubber [There is evidence to suggest that Farb's statement are unfounded. See John Clarke/EDU comments below—ed.]. As a habit, I don't throw the scrubber out if I use it for an hour and it's brand new scrubber material. It costs about $57 per bucket and you get about five fills out of it. If I'm not going to use it for a year, which certainly hasn't been the case, I would dump it out and repack it at a later date, but if it's just going to be a few days or a week, I'll use it until I get about 8, 9, or 10 hours on it.

**Brown:** Rod mentioned cost. Obviously he's working with a monetary consideration. In the military, we get this stuff by the pallet load and we don't have pay for it.

**Unidentified:** No, The tax payers do.

**Brown:** I should say that the end-user doesn't pay for it. I pay taxes just like all of you do. In any case, our guidelines are more conservative than his. It might be interesting to ask some of the people who have done canister testing, and maybe Dan Miccio from OC Lugo if he knows anything about that, if it's of value.

## Detecting CO2 & scrubber duration

**John Clark:** John Clark, EDU. There was a comment made about the ability as a diver to detect CO2. I need to clarify that. I don't mean to speak against the speaker here, but unfortunately Spec War Com paid me and my laboratory to explore the possibility of whether a SEAL could detect elevated CO2 levels, whether he was resting or whether he was exercising. I can tell you for a fact that if you're exercising, by the time, you begin to observe something is wrong, you're probably on the verge of passing out.

I've ridden a bicycle at very high CO2 rates and finally, at some point, I decided," Well, this is probably about enough , " and then I tried to move, tried to dismount the bicycle and was completely incapacitated. After that experience, research continued for probably three years with Spec War money continuing to come in. The final consensus was that your average person has not a chance in hell of knowing if he's getting too much CO2, especially if he's exercising.

So please remember, as I said before, the scrubber duration that you're going to get is like rolling the dice. You may have a good day, may have a good scrubber, may have a good pack, you may have just the right amount of moisture in the bed—not too much, not too little—it's a risky business to begin with. But then to push your canister on the assumption that you can detect it, maybe some people can but in general that is not case. And it's a very dangerous thing to do.[Note that Clarke is saying that the duration of a specific individual canister may vary widely over time either though it would appear all variables; the unit, the packer, the environment, etc. is the same. That's why predicting canister duration is a bit of a black art. Thalmann made this comment as well in the Physiology Primer session, and it appeared to be missed by many in attendance—ed.]

**. . .the scrubber duration that you're going to get is like rolling the dice. You may have a good day, may have a good scrubber, may have a good pack, you may have just the right amount of moisture in the bed . . .it's a risky business to begin with.**

**Farb:** I don't mean to suggest that in any way, form or fashion, you should use the scrubber all the way until you feel tired and then dispose of it. I simply meant to say that there are no effective CO2 sensors on the market, that the best sensor on the market is actually your body, and your body would be better than any detector that you could attach to a rebreather. There may be ionization detectors in the laboratory setting to detect CO2, but not on a rebreather.

Having said that, it's important that you keep a log of the rebreather time of use and it's important, too, that you use your rebreather enough that you understand with your packing techniques, the type of scrubber you use, how long you get off the scrubber. I never take the scrubber out to the point where I'm tired using it. I'll take it out to eight hours. If I'm going to make a five hour dive the next day, I just repack the scrubber. It is cheap enough to do that.

## Scrubber protocol

**Hott:** Generally when I have used my Lt. Lund, granted I haven't used it as much as Rob's used his, I take it out, pack it, and use for a weekend. At the end of the weekend, when I tore the unit apart I would clean it. A lot of times with my particular unit, if I don't dump the scrubber out, it starts to cake in there and it makes it that much harder to clean. It only takes about 5 to 5.5 pounds of material. So it's not really that big of a deal.

**Robinette:** The canister assembly on J.R.'s Lt. Lund, is made out of aluminum. If you leave wet scrubber material, it goes into it real quick.

**Brown:** You heard him say "my particular unit." We're talking about three different rebreathers here, three different canisters, three different temperatures of water, three different work rates. So this is another example of the kind of complexity that we're talking about with rebreather technology. What's appropriate for one may not be appropriate for another.

**Pyle:** Our protocol's pretty much in sync with Rod's . The only thing I would add is that whether or not we change the scrubber often depends on what our next dive profile intention is going to be. If we're getting into hard-core decompression, we don't want to take any chances. If our next dive is going to be 30 feet where we can abort at any time when we start feeling hypercapnia, we have a little more flexibility..

**Robinette:** Good point.

**Dietmar Luchtenberg:** I am glad that we are discussing the issue of scrubber material. We've talked about microbes that grow in the rebreather, and in the recreational market, where there may be more than one diver using a unit, the issue of cleaning is even more important. I think that a key point for training agencies is to drill their students to change the scrubber if they're in doubt that the scrubber is fresh or not. That's the main point, not only the microbes or the drying unit but to change the scrubber.

## Shared units in training

Robinette: I think everyone on this panel would agree if you're changing divers, everything should be disinfected and the scrubber material should be changed. [all second this opinion]

**Farb:** But that ain't going to happen in the pool session.

**Robinette:** You might have four or five people on a rig in a short period of time. That's a questionable thing, especially if they don't go to the trouble of cleaning out mouthpiece and hoses. That is the absolute minimal requirement as far as I am concerned if more than one person is going to use the system. I know for a fact from three weeks of fighting a upper respiratory infection after being the tenth man on a rebreather experience dive; they didn't clean anything.

**Wayne Miller:** From a retail standpoint, doesn't it make sense, on a retail standpoint, to have the consumers buy their own hoses, if you're going to have multiple people in the pool on the same unit doing training? Then it's just a matter of cleaning out the bags?

**Robinette:** That's an interesting thought. If it's appropriate to do that, that would be good. I think you might find the hoses to be more expensive than you think. A mouthpiece is approximately US $400.

**Miller:** The cost of training has got to be that.

**Robinette:** Hoses are probably another US$ 100.

**Miller:** This is a major concern in a retail environment. You've got a number of people in the pool and you only have so many units. Maybe it would be worthwhile for the store to buy several of these components that could be switched around.

**Farb:** You could have two sets of hoses, one sitting in Quatsyl, one on the unit. Rinse out the Quatsyl one, stick it back on the unit for the next person. You don't have to have a set of hoses for everybody. It doesn't take very long to disinfect.

**Menduno:** At one point I heard these guys say if it's out and you don't use it right away, you should dump, and Rod and Richard saying, "Well, we don't really do that." Is there a definitive answer?

**Robinette:** One of the points made is that whether or not you change out the scrubber right away is somewhat rig-specific, like everything else in rebreathers. JR's Lund has to be unpacked once it's used. It will contaminate the system, it will ruin the scrubber. In a plastic cartridge type device, it's not as necessary especially if the interior scrubber, the basket can be removed and bagged. It's rig-specific and it's also cumulative.

## Danger of infection

**Dave Southerland:** I'm Dave Southerland, a small town doctor from EDU. Someone made a point about replacing the scrubber after every use. I'm not a microbiologist but Sodasorb, Sofnolime, most of that stuff is pretty caustic. Pseudomonas will grow in the Povidone-iodine solutions that we use a lot, so there may be something that'll grow in Drano but I think those things are going to be few and far between and not worth really considering unless someone's got some information otherwise.

**Robinette:** I think that we're operating under "It's better safe than sorry" kind of mind set.

**Bill Delp:** Bill Delp, Undersea Breathing Systems. I've had the opportunity to meet with several divers that have had rebreather experiences in the Bahamas that have gotten unidentifiable lung infections that have taken months to cure. I think in terms of standards and training, this can't be overlooked in any regard. It's more important than the CO2 issues as far as I'm concerned.

**Robinette:** It can't be overlooked or tolerated, either. I know from personal experience.

**Unidentified:** A lot of the liveaboards are looking at adding rebreathers to their arsenal. If you look at their operations and the way they're working, there's very little room for maintaining the open circuit equipment they have let alone rebreathers. That's how this issue came to light. Just look at the issue of how you keep something dry in a liveaboard environment.

## Decontaminating a unit

**Haseltine:** A couple of issues about decontamination. There are two problems of decontamination. One has to do with decontaminating it after use; the other is decontaminating it between people, two somewhat separate issues. In hospital settings, circuits are changed every 48 hours. There are quite substantial studies showing that you can breathe a circuit for 48 hours before the number of organisms build up to a level where they're going to add risk, even if its somebody who's immune-compromised in an Intensive Care Unit.

**The whole circuit has to be changed or disinfected, not parts of it.**

The whole circuit has to be changed or disinfected, not parts of it. You can't change a part, like the hoses for example of the mouthpiece, and assume that you're not going to develop risk. The bit that you didn't change will harbor a significant number of organisms, which will very rapidly contaminate the part that you did change.

Now changing between people is an aesthetic and somewhat separate issue. Whether you got your infection from the rebreather or whether you in fact got it from breathing everybody's air in the airplane on the way back, which is I think far more likely, I'm not sure. When you think about rebreathing, you're rebreathing people's air in the airplane and their moisture, so I think that as a reasonable aesthetic standard, it's going to start to be practiced to decontaminate it between each person that uses it. Now does that have to be terrifically complicated? No. Realistically, although we've mentioned quarternary-ammonium compounds and Betadyne, there are two or three other chemical disinfectant systems out there that sterilize things in 15 to 20 minutes for practical purposes. Even as cheap as hydrogen peroxide, for example. There are ways of quickly disinfecting materials between each person. Just as you wouldn't use part of somebody's toothbrush that wasn't your own, you shouldn't use part of the circuit that somebody else has used.

## Post-diving the unit

**Brown:** I'm not only a military diver, I'm also a technical diver, so I've been able to see the good and the bad of both worlds. We've the tools at our disposal to do proper cleaning, we're able to develop the protocols, but you know what's going to be a problem? And I've seen this already. People are not going to post-dive their equipment. Not post-diving your rebreather after a dive is like leaving a toilet unflushed after you use it. Have you ever walked in a bathroom and seen that? It's kind of nasty, right? That's the kind of offense that I feel when someone doesn't properly post-dive a rebreather. The discipline to do that is probably going to be the problem. Once you start cleaning it, chances are you'll do a good job given the proper tools and protocols.

**Hott:** I think it all comes back to unit-specific instructions. With units coming out on the market now, one of the things that will be needed is a set of procedures that will be specific to that unit, like our OP's: post-dive, pre-dive, and supervisor checklists. It actually spells out exactly what you have to do: take the unit, remove these particular hoses, remove the scrubber, empty the scrubber, remove the bag or whatever type unit that you have. Manufacturers will have to provide a set of checklists. You do a set procedure before you dive the unit, checking everything out. You do a set procedure after you dive the unit to get it ready for the next day of diving or to put it into storage or whatever. That should come with the manual that comes with the rebreather, and should be hashed over and rehashed over when you go through the training course for the particular unit. The manufacturers of the unit have to concentrate more on the paperwork ,and the manuals and the training that goes along with the particular unit that they're going to be manufacturing and selling.

There's a guy I know in Washington who has a rebreather, His shop is near where I work. He had his scrubber in a cardboard box along with some scrubber material. It didn't have any label on it, or a date. He didn't know how old it was. I looked at it and asked, "What are you using that for?" He says, "It's scrubber material" and it's sitting in an open plastic bag with a coffee cup in it. I'm asked, "You took the course, right?" He said, "Yeah." I said, "Didn't you get any training on handling the soda-lime?" "No," I said, "You gotta be kidding me."

Whenever you open up a bag, it's dated. Actually a lot of the stuff we're getting comes in little foil bags. You rip that open, dump that in, when you're done packing your canister. Whatever you have left over you ball it up and you pitch it. You don't save it." We can do that from a military point of view because we have it. But from my personal standpoint, I reseal everything in a double bag and I've got a date on it. When I open a can, I write the date on the can when I opened it and then I try not to use it if it's past a certain date.

**. . .the manufacturer should provide you with checklists. It's the only practical way to keep track of all the things you need to do with a rebreather.**

**Brown:** Checklists. You've got to have pre-dive and post-dive checklists, and you also need maintenance checklists. Whether these are laminated devices you check off each time, or the kind that you make a copy of and throw away after completing the checklist, the manufacturer should provide you with checklists. It's the only practical way to keep track of all the things you need to do with a rebreather.

## Disposing of spent material

**Scott Church:** You only touched on what you do with all this caustic material when you're done with it. Do you have special disposal procedures? Do you worry about it or dump it over the dock when you're done?

**Mike Vogel:** Mike Vogel, Naval Special Warfare Center. The soda-lime we use is HAZMAT and we have to follow all the applicable HAZMAT procedures developed by the Navy, which are extremely strict. it has to be bagged. It can't be on hand for more than 7 days and it has to go to the HAZMAT center for disposal. Is that the same with you guys [in the Army]?

**Brown:** Yes.

## Violating oxygen cleanliness

**Vogel:** You haven't talked about violating O2 boundaries. As far as Mark 16s, we have things we call FAR (Failure Analysis Report) and a REC (Reentry Control) so every time we touch this rig; even if we just disconnect anything, every time it's pre-dived and post-dived, that's a FAR and a REC. These get sent to the OED mobile unit at Indian Head.

If you get into these rigs, do you do a failure analysis reports or a reentry control? What is the standard for O2 boundaries?

## Civvies will have to certify their rigs

**Hott:** With the military rigs we were using at NAMRI; the LAR V, and the CUMA, there's an ANSI certified system. It you violate a reg or pressure boundary or O2 cleaning system, you're violating the certification of that rig, and that is governed by NAVSEA as you know. The agency who certifies my personal rig, the Lt Lund, goes to bed with me every night, and lays his head on the same pillow. It's me. When civilians buy their rigs, they are going to be their own certifying agency. They're going to have to know that the integrity of their unit has not been compromised, to their satisfaction, so that they have a high degree of confidence. If they do violate or have some suspicions that there are contaminants in the system, the system should be cleaned. That goes without saying: if you suspect hydrocarbon contamination of your O2 side, if they aren't capable of properly cleaning it, take it somewhere and have it properly cleaned by a technician who's been trained in it. As far as violating a certified system, there is no certifying agency that's going to govern it for these people.

## Getting real

**Farb:** First, I really appreciate the military a lot, not only in the development of rebreathers and other systems. I've worked with the military, and have dived their regs, and know and have dived the OSHA regs, and all that. All I've got to say to the rest of us who are sport divers working professionally or for pleasure is, "get real."

There is as much relationship between how you're going to deal with your rebreather compared to how the military does it, as there is with how you deal with your open-circuit scuba and how the military deals with that. This gentleman hit the nail on the head: you're going to do it to your own satisfaction. If you're a slob, that's the way you're going to do it. And your unit is going to function accordingly. If you're anal retentive, then you're going to keep the unit up, it's going to work for you, it's going to be there when you want it, and that's the important thing. If you're a dive professional, using it professionally but not in the military, you cannot afford to be working under contract and have your unit crap-out in the first 15 minutes and not be able to fulfill that contract. You're going to keep it up, it's your livelihood, your living. If you're doing it as a recreational person and you're on a live-aboard, then how you take care of the unit after the dive is really going to depend on how you would take care of an open-circuit system after a dive. If you want somebody else to do it, then they're going to have to do it for you. There are no regulating bodies for rebreathers right now; it's up to the manufacturers to set the standards for keeping these units operational, and for instructors that are going to be teaching on them. In my opinion, the instructors are going to have to own a unit for a long time, before should ever be permitted to teach.

**If you're a slob... your unit is going to function accordingly. If you're anal retentive, then you're going to keep the unit up, it's going to work.. . it's going to be there when you want it and that's the important thing.**

## Legal responsibilities

**Mike Harwood:** Can I just give the legal perspective on that. The legal perspective is quite clear; the responsibility rests with the manufacturer. The manufacturer has to supply all the documentation and training packages required. It may be slightly different the way it's worded in the U.S., but certainly consumer law requires you to do that. It's just like buying a car; you expect to get certain servicing advice. If it is done very badly right across the recreational market and equipment there are going to be problems. My colleague Graeme Laurie and myself have been talking to the industry groups in the UK to tell them if they don't get their act together, one of them is going to be taking a lot of my time whilst I prosecute him. It's as simple as that. It's a manufacturer's problem. When a customer buys the kit, they ask for the documentation and servicing requirements, the procedures about CO2, etc. All of those things should be in the package that you get. After that, I agree, how you look after your rig is up to you, and if you change anything, you violate your contract, but the starting point rests firmly with the manufacturer.

**Brown:** The intent here, at least my intent, is not to impose anything but there are things that people could learn and apply to their diving operations. Certainly the civilian dive community practices are woefully inadequate with respect to handling oxygen and hyperoxic mixtures. If you look at some of the CGA standards (Compressed Gas Association) and other standards, the procedures are not being adhered to at dive shops. How many people take a look at their dive shop's O2 safe cleaning procedures. How many know whether the stores use anything to inspect their work, for example a long-wave ultraviolet light for example. The civilian dive community has a ways to go in this regard in my opinion. It wouldn't be very painful. There's no reason to reject what the military or other sorts of agencies have developed to improve safety, whether its the Compressed Gas Association, or OSHA which governs oxygen handling in the work place. These things should be addressed.

**Hott:** To reiterate on that, I recently walked into a shop that advertises oxygen cleaning. I looked around and there was a workbench. I asked the guy if this was where he did his oxygen cleaning, and he says, "Yeah." I looked on the bench and there was a can of bearing grease sitting on it—not exactly the way to maintain a contaminant-free environment for your oxygen cleaning. Compare this to the 100,000 class clean room we had at NAMRI for oxygen cleaning, that was actually rated out at about 10,000 .

It was a real eye-opener when I went out and started looking at shops that were doing oxygen cleaning. That is something lacking in the education when you talk about mixing systems and in cleanliness standards as far as O2 is concerned. It's something that needs to be looked at because oxygen fires are not pretty; they really are not.

**Brown:** If you look at an occupational user, the very high end-user civilian users, how they're going to get their equipment cleaned and handled in the work shop. Right now it's deficient.

## Are retailers ready for rebreathers?

**Mike Steidley:** This morning we listened to Dr. Clark and Dr. Thalmann explain the physiological problems or potential problems that end users are likely to face with rebreathers in comparison to open circuit scuba. We haven't even really touched on the cost of these units. Now we're talking about all the maintenance procedures.

The gentlemen on stage all have very specific applications for their rebreathers, even the people that would like to call themselves recreational divers. You're doing things like collecting fish in weird places in the world and taking pictures; you're not really using recreational way; it's more of a specific application.

I know that some of the training agencies are here, looking at how to bring this technology into the recreational market. After hearing about problems with the scrubbers, and considerations for recreational proprietors (dive stores and instructors) passing around units, infections and the like, and all of these very strict maintenance requirements, I'd like to know if the panel actually thinks that rebreathers are a practical thing for the average dive store to jump into? The picture that's getting painted sure seems to suggest that it's not. Do you really think this has a practical, realistic application in our industry.

**Hott:** As far as the dive shop getting into it on a rental basis or something like that, I think it's going to require an extreme commitment one that most dive shops aren't going to be able to realize. From my standpoint, looking at an individual business, again it is something that requires commitment, not only taking a course if you decide to buy one but to set aside time and space for that particular rig. It is a completely different facet of diving from open-circuit scuba; it's almost going to have to become a religion to you, if you're going to do it right. Because if you're not going to do it right, you shouldn't do it at all, don't even think about. If you're planning on taking the rig and not doing the proper pre-dives, not doing your proper post-dives, don't even plan on doing it. If you don't do it right, the thing's going to jump up and bite you in the butt big time and we're going to read about it as a statistic somewhere. Then it's going to make it harder for everyone else that wants to get into it as far as liability and everything's concerned. All it takes is a few people that don't do it right and it's going to give the industry a real bad name.

**Brown:** The answer is yes for the high-end range industry and maybe even the mid-range. There's a little bit of work to do getting organized and what-not, but it certainly is not impossible. I tend to be slightly less extreme than JR , its probably similar to other intensive industries that require specialized maintenance, like the small plane market.. It's certainly within the means of the recreational diving community. It wouldn't be hard to do.

## Large commitment for retailers

**Farb:** I agree with bits and pieces of what I've just heard. Right now a dive store really needs to have its owner and operator who's going to make this investment in 10 or 15 units [$100,00 investment?—ed.], own and dive a unit for 100 hours, and understand what's required to maintain that one unit. If you go out and say, "I want 10 units; I'm going to be a rebreather instructor. I'm going to sell these things," you don't have a clue what you're getting into.

I think it's possible that the recreational diving industry could deal with it. Look at the Fieno [a very simple semi-closed system developed by Grand Bleu, Japan—ed.], there's a reason why that unit came out the way it did. It's going to take a very special dive store to do it right, and I think the cost of the units and the liability that they're going to incur is going to really require that people think hard about that commitment.

The best way to deal with rebreathers at this point is to buy one as an individual, learn how to use it and maintain it properly. I've used a unit and I know what's required, and there are a lot of dive stores out there—the majority of them—that are just not prepared. That's not to

**. . . there are a lot of dive stores out there—the majority of them—that are just not prepared. That's not to say they can't get prepared, but it'll mean that they'll have to work a lot harder than they're already working.**

say they can't get prepared, but it'll mean that they'll have to work a lot harder than they're already working. Look at how many hours you have to spend in a dive store now to make a living. You're adding three times—it's an exponential increase in activity; it's not just proportional to the number of units you get in. It's really tremendous when you consider maintenance, cleanliness, and training. You can't certify a brain-dead individual that you could certify on open-circuit, you know that. That's going to kill your market. If I was a dive store owner, the last thing I'd be thinking about was buying 15 units, so I could be the rebreather king of the hill, because you're going to go under from the lawsuits.

**Pyle:** I'm not familiar with the recreational market, so I'm not sure I can answer the question directly. The active word is discipline, and the question is how much discipline is out there among the potential end-users? How much discipline is out there among the manufacturers and instructors? The main bottleneck is going to be the instruction agencies. Certification cards cannot be passed out the way they are for open-circuit. They have to take that issue very, very seriously.

I'm not in the dive business, but it seems to me it might be very difficult to give a student his or her money back and not accept them as a student, but I think that's the responsibility that instructors are going to have to take and not accept students who don't have the level of discipline. I think it can be done, but I think it requires more discipline than most people realize.

**The active word is discipline, and the question is how much discipline is out there among the potential end-users? How much discipline is out there among the manufacturers and instructors?**

# Semiclosed Systems: Problems and Solutions

*"I don't think we should lose sight of the fact that the majority of experience with rebreather technology over the last 45 or 50 years, has been essentially with semiclosed systems. And what's happened is that electronics are now coming on the market."*

--John Sherwood

## Session Summary

With all the interest in fully closed circuit rebreathers, it's important to remember that the majority of rebreather experience over the last 45-50 years has been with semiclosed systems. Of interest in this session were constant mass flow systems, which are the simplest and now offered to sport divers.

The session began with David Elliott, who presented the major concern with these systems, which is that they are designed to provide a fixed oxygen level based upon an assumed consumption rate. Given a preset flow and gas mix, the actual oxygen levels depend only on the divers actual oxygen consumption. Without oxygen sensors, the diver doesn't know exactly what he is breathing. As Elliott explained, if oxygen consumption exceeds the level preset by the manufacturer, hypoxia condition can occur. In this case, the diver is most at risk at or near the surface or during ascent, where there is insufficient pressure to maintain the PO2 at a physiological safe level. Complicating the issue is that the actual oxygen level in the breathing loop is very sensitive to small changes in flow rates and oxygen consumption. Examples were given of sets on the market, whose flow rates could easily create hypoxia in a hard working diver. Oxygen levels also affect equivalent air depth (EAD) decompression calculations. For example if the oxygen fraction falls lower than 21%, the divers equivalent air depth is actually deeper than the diving depth.

The panel discussed how high of an oxygen consumption a semiclosed unit should be able to handle with data that showed that oxygen consumptions as high as 3.0 liters per minute could be reached in extreme situations such as swimming hard against a current or struggling to free ones self from a net.

John Clarke discussed the EDU's work modeling transient oxygen levels in semiclosed UBA, pointing out that not much was known. The two manufacturers on the panel; Christian Schult/Dräger, and John Sherwood, Fullerton Sherwood, then discussed how each of the firms deals with these problems and their extensive product testing prior to releasing their systems to the market.

Panelists offered several solutions for hypoxia problems of semiclosed systems: adequate flow rates, thorough testing of the rig under extreme conditions, and eventually the use of oxygen sensors. The panel was chaired by Mike Harwood, HSE; and consisted of Dr. John Clarke, EDU; Dr. David Elliott, consultant; Christian Schult, Dräger; and John Sherwood, Fullerton Sherwood.

26 SEP THURS 3:30-5:00 pm

# Transcript

**Mike Harwood:** Ladies and gentlemen, if I can have your attention, we'll get started in this next session.

Some of you may not be familiar with my particular background. I've had four years and a half at the Health & Safety Executive office which is somewhat similar to OSHA in the States, except that you have a slightly different challenge. Prior to joining the HSE, I spent thirty-four years in the military, twenty-seven of which I worked in diving including training and research.

I started diving in '62, on a pure oxygen set where if you let down the rope and your tender didn't pull hard, you found out what it was like to go past 33 feet. So, we did experiment with taking oxygen deep in those days, sometimes quite by accident. And one of the sets which my colleague [David Elliott] who is still alive to tell this story, looked very much like a standard set today. It was for taking mines apart. We used to walk around the bottom with just a little life-line to the surface on a float. So nothing really has changed. I see that some of the slides we are using have pictures of this stone age technology. And in this session, we'll be unraveling some of the myths of this type of equipment—semiclosed rebreathers—some of their inherent problems and some of the solutions.

As part of the ground rules for this session, we're not going to get involved in specific manufacturers' equipment. We're talking principles, and the fact that we have two manufacturers up here is not so that we can talk about specific equipment. They're here because they have experience in the principles and design of semiclosed rebreathers. We'll leave all the chit-chat about different equipment until later presentations. Now, I'd like to ask David Elliot if he would kick this session off.

**David Elliott::** Ladies and gentlemen, the topic which I was elected to speak on is: "Safe Oxygen; How low can you go?" which is a very good question. I don't know whether or not there is an answer to it, but it's the opposite of one of the issues this morning which was really "Safe Nitrogen; How high can you get?" in these things. I believe that some of the comments which I'm about to make, are well substantiated, but bear in mind that we are talking generically about semiclosed rebreathers as a whole, and not specific manufacturers equipment.

I think the importance of the history of diving is very evident in this field, because most of these lessons have been learned at least once before, and it's pointless for us not remembering them. But, at the same time, some of the historical examples I've chosen to talk about today are all ones where people have actually managed to get away with it. God knows how.

## The first heliox dive

This is Max Nohl [slide] who, as you know, did a 400 foot plus dive in 1937—the first heliox dive that was done. The Historical Diving Society has an article about him in a past issue. He carried two cylinders. One was bottom mix which he opened during descent. I don't know what the oxygen percentage that he and Edgar End, a charming doctor who in charge of the medical aspects of the dive had calculated. The second cylinder was oxygen. Now, he'd got a breathing apparatus, inside the suit, which has got a bag of soda lime in it, and that was about all, and in fact, the upper part of the suit and the inside of the helmet acted as the counterlung. And what is a mystery—I did manage to get the actual 1938 reference to this from the Historical Diving Society and I will check it when I get back to London), is the wording, that Max Nohl topped up his mixture inside his suit by opening a bypass valve to the oxygen set, "when he needed it." He survived. I think that you know that hearing stories like that is very reassuring for those of us who feel that some of the things being done today are a bit crazy. Well, I hope all you crazy guys survive. You deserve to, and I admire you; but by god, I wouldn't do it myself.

What I'm going to be talking about today are semiclosed constant mass flow rebreathers, and the important thing, is they're the ones without any sensors, the "cheap" ones. The fact that these systems are very attractive is obvious, and as I said this morning, having trained on these things, is that they're beautiful to dive. Please note that there are several varieties of semiclosed breathing apparatus, and I've chosen to talk about the constant mass flow sets.

## Metered dose systems

There's also the type of set, as we heard this morning, that runs on a constant ratio [a metered dose system], where every time you exhale, a fixed percentage of your expiratory volume gets discharged into the sea, and the difference is made up. Now, the mathematics of that type of system are different, and its behavior is different. In fact, as I was remarking to somebody yesterday, the only readily available text, that I could find [on metered dose systems] is a 1969 paper by Sir Williams who was the engineer at the experimental diving unit in Portsmouth 20 or 30 years ago. I don't know how much the science of these things has advanced; I'm sure that is someone here who knows a damn sight more about constant ratio breathing apparatus than I do. So I'm going to talk about only constant mass flow systems, and although the mathematics will be different, I think that the lessons which we need to take home, are going to be identical.

In Europe, which is where it all started, there is another branch of the Historical Diving Society, that also produces a diving history magazine. As you can see from this front cover [slide] that I have chosen, as far as recreational diving is concerned, semiclosed circuit and closed circuit breathing apparatus has been in use for some time. This issue is called "Fifty Years of the Cave Diving Group." The particular joy of this photograph is that the diver on the right, John Buxton, who some of you may be familiar with, is still diving the Blue Holes. He was doing this kind of diving in 1956, and he was at the meeting of The British Subaqua Club last weekend in Oxford where I was a member of the audience. So there's a lot of living history out there as well, and these kind of people have got a hell of a lot of experience that we can learn from.

**I think that one of the most important things about semiclosed constant mass apparatus is that the theory is universal, and does not depend on specific manufacturer, which is in accordance with the ground rules set by our chairman here. And so I can be as rude as I like, and nobody need feel offended.**

## Constant mass flow theory

I think that one of the most important things about semiclosed constant mass apparatus is that the theory is universal, and does not depend on specific manufacturer, which is in accordance with the ground rules set by our chairman here. And so I can be as rude as I like, and nobody need feel offended. I would just like to acknowledge, that over the last year or so, I've had a lot of help from Christian Schult and the Dräger group in providing information. We have one or two minor differences, but that is part of evolution, and they have been very helpful.

What I am going to say does not depend on the name of the manufacturer, or the trainer. Calculating the oxygen percentage of such a system is quite independent of the depth at which the gear is being used. Of course, that means that the lower the oxygen percentage, then the lower the partial pressure would be for any depth, and the shallower you are, the smaller the PO2 be. So I'm absolutely delighted for the sake of your experience, that tomorrow morning's practice dives are going to be conducted in a very shallow lagoon, because if you want to experience hypoxia, it's really quite easy, you just fin like hell.

However, the important thing is that we stick to the rules. We are not singling out any particular manufacturer. Everybody in this game at the moment is on the learning curve, and it won't do us any good if we start slanging off because some body's tripped up on a particular point. The really important thing is that we as a diving community have to come together and raise objectives to target for the future.

I don't like it when people just talk about rebreathers, because when some people say rebreathers, they mean those clever electronic things that I don't understand. When I say rebreathers, I'm talking about semiclosed and will say so. We're talking about self contained sets obviously, not the hose variety, and we're confining it to the premix variety that is regulated by constant mass flow; systems that have no sensors.

Some people might suggest that if you have sensors, you're just a show-off or that you've got a lot of money and you're cheating. Actually, I think the people who do incorporate sensors into these sets are quite wise. I think that I'd rather have one of the more expensive systems—an iron age model rather than one of the more traditional stone age models that Mike referred to earlier.

This circuit [slide of a semiclosed system] has only got one counterlung, but otherwise, its' exactly the same as the one that we saw this morning, the premixed gas goes through a constant mass reducer and then there is a bypass here that please note, is pressure activated, not volume actuated. I think that could be quite significant. Currently, there are three or four different manufacturers of this kind of gear.

## A semiclosed rebreather problem

So what are the problems? There's hyperoxia. Hyperoxia is hazardous. There's no doubt about it. There's a significant risk, particularly, obviously, for those who do not wear a full face mask. But at the same time, I think we are overprotective. In fact, we're so protective about hyperoxia, if anybody gets it really is going to be tough luck.

Conversely, I don't think that enough attention has been given to the risk of hypoxia. And I'm also very pleased that we've been talking quite a lot about $CO_2$ today, and $CO_2$ retention. I am not aware of any data on $CO_2$ levels in this kind of breathing apparatus, and I hope maybe later that I may be proved wrong, but so far I am not aware of any.

## Steady state formula

Let me just remind you of the very basic steady state formula for semiclosed rebreathers. It is:

$O_2\% = [(O_2 \text{ flow} - O_2 \text{ consumed})/(\text{Mixture flow} - O_2 \text{ consumed})] * 100$

The oxygen percentage in the counterlung is a simple function of the mixture flow [Note that $O_2$ flow is the product of the mixture flow times the oxygen percentage in the mix—ed.] and the oxygen consumed. There are two constants, the mixture flow rate which is preset, and the oxygen percentage in the mix which is also preset from which you get the oxygen flow. The only variable in the equation is the oxygen consumption, which is independent of the depth and of the manufacturer and the trainer. So in very general terms, this piece of breathing apparatus is really quite simple if you stick to the simple formula.

Tomorrow, Hans Ornhagen —it's a pity he's not here today—will, I'm sure, show you a far more complex formula which covers the transient state as you change from one workload to another. But my mission today is simply to paint the worst possible picture of this type of breathing apparatus so that you are stimulated to look at it critically and say "what can we do to make sure that this beautiful-to-swim apparatus will be really safe for some of the turkeys who come and buy it?"

## Dilution hypoxia

"Beating the flow" is the name of the problem and it is all too easily done in a semiclosed circuit system. The problem is then one of dilution hypoxia. This morning, I think I mentioned that chap who died in eight feet of water on a closed circuit oxygen set [see Physiological Primer]. The same sort of factors come into play in dilution hypoxia in a semiclosed underwater breathing apparatus. There's a diminishing amount of oxygen, either because the bottle has been used up, or maybe it's leaked, or maybe the diver's working harder than the oxygen flow that's being supplied, and because there's a $CO_2$ scrubber in the circuit [And therefore presumably a low level of $CO_2$, which triggers breathing—ed.] there's no warning to him that the $PO_2$ is going down. The chap who uses this set can't afford a sensor. Although, unconsciousness is the likely outcome, because there is a constant mass flow into the set, it hopefully will be transient, until such time as enough flow has come through and the diver may gently come round and function fairly normally again [Provided he doesn't drown in the process—ed.].

I don't know how many of you have been hypoxic as part of a training program. The best example of hypoxia is actually in a high altitude chamber. Somebody takes away your oxygen mask in a high altitude chamber, they'll then strip you and put the oxygen mask back on your face and you'll wonder where the hell have all your clothes gone. And it's rather like deep water blackout, particularly on air at round about 250 feet; you've got no recollection whatsoever. So the fact that you think things are going well doesn't mean you haven't just missed a major problem. That is what we're concerned about with constant mass flow semiclosed rebreathers.

## What should oxygen flow be?

I am rigorously adopting the principles set forth by both the British and Royal Australian Navies who specify a maximum of three liters of oxygen consumption per minute. Note that the Australian Navy actually works on a minimum $O_2$ consumption of zero, because they want to account for the fact that when you flush the lung through before you make the ascent, you are actually breathing pure gas. In fact, I think that's purely an academic point. I don't think it's particularly important, but I wanted to emphasize there was one small difference between the two Navies.

Three liters per minute is in excess of the oxygen consumption recommended by, I think I can say, most of the manufacturers and training agencies in the recreational industry. Is it justified to use?

This next slide is a graph created by a man named, Mike Harries, who's a doctor to some of the Olympic teams. The graph plots maximum respiratory minute volume against maximum $O_2$ consumption. As you can see, it's pretty much of a straight-line relationship, which is fine. But what I want you to look along the bottom of the graph at the maximum oxygen consumption used; 1, 2, 3, 4, 5 liters a minute. The data points above five liters, were derived from elite athletes doing track and rowing events—male only. But notice, even here, in rowing and track that

**"Beating the flow" is the name of the problem and it is all too easily done in a semiclosed circuit system.**

includes women athletes. They are still way above three liters oxygen consumption per minute.

Has anyone suggested to those of you who might take out divers in a semiclosed rig, that in your pre-dive briefing you should say, "Excuse me, are you a good athlete, because if you are you might actually exceed the limits of this bit of gear?" No they have not. Bear in mind that there will occasionally, very rarely, be extremely fit people who can certainly exceed the 2.5 liters per minute oxygen consumption which an awful lot of these sets are being calculated on. Also note that the most dangerous place is just below the surface, because you don't have any benefit of increased PO2, and of course, that is the depth at which the maximum ventilatory volume will not be inhibited by pressure effects.

What I'm really getting across is that there is actually more to it than the salesman may try and tell you, and there are papers here which support that. One is by Lenneart Fagraeus who showed that an individual could have a oxygen consumption of 3.6 liters a minute for more than three minutes at depths to three atmospheres. Now, the odds are that both this result and Harries's results were derived from individuals that were not using breathing apparatus and therefore had a very, very low breathing resistance. So, although I have prefaced my arguments with a lot of caveats and reservations, I think that a three liter per minute oxygen consumption should be used in these systems for the sake of safety.

## Examples of systems on the market

Take that unit we saw earlier. I am not going to mention the specific manufacturers name here. Who on earth is going to be able to wear that unit and walk down the corridor without collapsing, I don't know. Using a 3 liter per minute oxygen consumption, we can apply the formula above to a mixture of 60% oxygen, and the flow rate of 5.0 liters per minute specified by the manufacturer. I'm very pleased that, in fact, some other manufacturers are now using higher rates than that. But in this case, applying the formula will give you an oxygen content of 3% in the breathing bag. All right, that's OK if you're really deep, I suppose. If the flow rate is increased, to 5.5 liters, as recommended by one of the training agencies, and there is no bypassing, the counterlung will have 12% oxygen. If you compare this to a British Navy set with a mixture flow of 6 liters per minute, you would have a bag content of 20% oxygen, which is fine.

I want to make two more points here, and that is that the bypass [A valve that admits additional gas directly into the system—ed.] on some of these units is a pressure activated device and is therefore dependent on, for instance, the resistance within the CO2 scrubber, to cut in at the right relative pressure. So, there are an awful lot of particularly worrying variables here, if one is going to depend upon these units. Maybe some other people can speak to that later.

The second point that I wanted to make, which is really quite an important one, is well illustrated by this: if you look at this rather appalling range of oxygen percentages in the example we just went over, you will notice that increasing the mixture flow rate from 5.0 to 6.0 liters per minute makes one hell of a difference. So, as I said this morning, making sure that the flow that comes out is what it is supposed to be, i.e. calibrating the damn thing [Making sure that it is working properly—ed.], is extremely important because if you just get slightly the wrong mix, you may well find yourself not having the PO2 or the PN2 that you were expecting, with possible eventful results.

There is another system which is available on the market. I will make no comment about it except to say that it only supplies you with five liters with a 40% EAN mix, i.e. two liters of oxygen is all you're getting. Well, if you were breathing at even 1.75 liters oxygen consumption per minute, although you'd have a PO2 of 3 atm at 100 foot, there'd only be 8% in the bag, so whatever you do, don't come back to the surface. So on theoretical grounds at least, there is a valid reason for saying these pieces of equipment must be tested and validated. The oxygen and CO2 contents of the counterlungs must be measured when men and women are using these sets really hard, and you can do it as shallow a depth as you like.

Now, I'm used to a manual bypass. One of the sets on the market does not use a manual bypass. Of course exhaling through the nose will actually trigger the counterlung to be filled up automatically. Another set is extremely clever, it doesn't have a bypass at all. Think of that.

What I'm really saying is that there is a very strong argument for the proper validation of the gas levels. Now, I'm also fairly convinced that when you do that, they're going to be proved to be all right in most cases. What I have purposely done today is to take the extreme example in the interest of safety, we must look at the worst possible case. When you're actually doing the risk assessment, you can come up with a picture that's not quite as bleak as the one I have just painted.

## Equivalent air depth

I'm also somewhat concerned with open circuit nitrox and some of the misinformation that is out there. Some people say that you can have both a prolonged no-stop time using equivalent air depth, and at the same time you are actually safer. Well, you are no more safe than you are from an air dive from that equivalent air depth. You cannot have both advantages at the same time; you must go for one or the other. And exactly the same is true of the semi-closed set. I can assure you that a number of the authorities that I am quoting admit that they have planned that the counterlung can go down to 15% oxygen. I personally think it could go lower, but even those authorities have said it can go down to 15% oxygen in the extreme condition. The question is, how are you going to work out your decompression where your equivalent air depth is actually deeper than the depth at which you are swimming?

## Hypoxia on ascent

So, there are a lot of things that I am concerned about, though a low oxygen content is of most concern. The set flow may be too low or the person may be working too bloody hard. If in fact you are trapped in a nylon fishing net, I don't think you're going to be hanging back just because the set wasn't designed to cope with the amount of energy that you're now having to expend.

Depending on depth, the low oxygen can lead to impaired consciousness underwater, and though as I've already suggested, this could be a reversible phenomenon, the real problem is the hypoxia of ascent, because although the PO2 may be good on the bottom, it drops off as you come up. In that case, you will arrive at the surface unconscious and then you might find yourself unconsciously going down, down, down again. Hypoxia on ascent is a real hazard.

## Flushing the counterlung on ascent

The answer is that you must flush your counterlung through before ascent. Now that assumes you have got enough of the mixture to do that with; the alternative is to breathe from an independent source, and I'm going to be a little radical here. I don't like being conservator all the time. I don't care what that source is. It can be air, it can be nitrox, it can even be pure oxygen, because if you're making your ascent, you're not going to be at depth long enough for it to be a worry.

## Back to the beginning

I would then go back to where I began, and just remind you that some of the stone age divers actually had apparatus which was, barring one or two errors, really quite effective. There was a large volume of gas, they had a high flow rate, that could be set without limiting endurance. The constant mass sonic reducer was calibrated each time you changed the mixture, so you know you're getting the right mix. The mix went into a counterlung, to a full face mask with a mouth piece, and there was a come-home bottle—the ascent mixture—so if you actually had to use the bottle to come home, you didn't have to change your mask. It gets fed straight into the counterlung. There was not a problem.

So, there's a lot to be said for historical diving. I know that I represent a slightly older generation than most of you. But what I do hope that you'll take away from this session is that the answers to an awful lot of the questions that we are now asking are there in the Experimental Diving Unit (NEDU) records. You don't have to go scratching around too far to make sure that the mistakes of the past are not being made again.

## Potential solutions

I will conclude by reviewing some potential solutions. One of them is oxygen monitoring sensors. The sooner that these systems have the capability of monitoring oxygen content, the better, if Joe Public is going to use these things safely.

But the most important thing I think, is the need for unmanned and manned testing, to look not only at oxygen, but also the CO2 levels in the bag when divers are working physically very hard. As Ed said this morning, laboratory testing is very good up to a point, but one must get testing done by an independent group of divers working hard in an independent physiological laboratory. Only then can one say that the equipment is going to be safe, or to use the words of the PPE directive in Europe "fit for purpose." Thank you Mr. Chairman.

**Harwood:** Thank you, David. This morning I wrote down some observations regarding the difference between the recreational use of these type of equipment and military usage. I suppose this is being a bit flippant, but like it or not, wars often produce crude answers to a problem, as the risk to the life of the diver becomes a lower priority. You have to remember that a lot of the rebreather technology that I was brought up with stems from World War II technology.

Interestingly, as a result of a minor confrontation with people in the southern hemisphere, the British Navy had to look at low signature equipment in a hurry, and that rather crude set that you saw this morning has a very low magnetic signature. When you start to look at risk, end user risk, in the case a military end user, it was much better for our divers to have low magnetic signature equipment rather than worry about whether the set was going to crack up. And that is a slight difference. A recreational diver really shouldn't have to worry about the risk of something going wrong, while swimming around looking at whatever he wants to look at.

I'd like to keep this moving and go straight on with the next presentation. Dr. John Clarke, from the Navy Experimental Diving Unit.

[Dr. Clarke struggles to power up the computer projector]

**John Clarke:** There is a lesson in this, and that is when your batteries goes down, your computer, or worse, your electronically controlled closed circuit rebreather is going to lose power, and your a dead duck.

**Harwood:** While's John's saving his duck, I have a quick announcement. If anybody wants their cylinders filled, or as they new in the new European-Speak as of the first of September, your "transportable pressure receptacles," please bring them to the back of the room.

## Oxygen control

**Clarke:** I am sorry about delay, but like I said, there is a lesson to be learned. The more complex the equipment, the more likely a failure. I plan to talk about oxygen control primarily in semiclosed UBA, but to round things out, I want to talk a little bit about what can go wrong in terms of oxygen control in closed circuit UBA.

First I'd like to talk about the semiclosed UBA. The US Navy has not used semiclosed devices for about 20 years. The last time we did, they were high flow units which meant six liters or more of gas were being injected into the UBA every minute. Now, because of portability or logistics— I'm not sure what reasons are—most of the semiclosed devices on the market are relatively low flow. The Mark 6 and Mark 11, which was used a lot in both deep and fairly shallow diving all were very good rigs, but they were big, and bulky. Certainly a petite diver is not going to be comfortable wearing the old Navy equipment. However, when you're dealing with a small, portable, low flow, semiclosed UBA, you do have to at least be concerned about a couple of points.

When working hard, a diver can quickly get into trouble with hypoxia, as Dr. Elliott pointed out, and we'll spend a lot of time talking about that. As divers, we have to have a very good understanding of a UBA's performance not only under average conditions, but also under worst case conditions. And a worst case condition that Dr. Elliott brought up to me at lunch, is a diver, who has a low flow UBA and gets caught on a net and is struggling to free himself before he runs out of gas, and suddenly has a very high oxygen consumption, because he's working very hard to free himself, and the rig is not cooperating at all, as you'll see in just a moment.

## Transient oxygen in semiclosed

We also have to understand the details of human and UBA oxygen interactions, including kinetics of diver oxygen demand, and the kinetics, meaning the time course, of semiclosed UBA oxygen levels. Now when we began a series of tests, I didn't realize that Hans Ornhagen had defined the mathematics behind the transient oxygen levels in semiclosed UBA, so we did it ourselves. As it turns out, a number of years ago, Hans and I had very similar interests in high pressure physiology of hearts. Now, apparently, we have both defined the kinetic transient phenomenon in semiclosed UBA. My only request is that next time, Hans pick some more exciting and easily solved problem than this one.

This graph [See O2 Control in Closed and semiclosed Circuit UBA by John Clarke—ed.] is a plot of the fraction of oxygen in a semiclosed rig over for various levels of oxygen consumption. This is time course at a consumption of 1.5 liters per minute, which is often times assumed as sort of an average-, perhaps even a little bit conservative value for oxygen consumption. If you take a higher oxygen consumption rate, then over this time course, the oxygen fraction in the rig will drop to a much lower value. You can see that at an oxygen consumption rate of 2.3 liters per minute over a period of maybe 10 or 12 minutes, we're reaching almost a negligible amount of oxygen in the semiclosed UBA. So this makes the point:

#1) If your rig is set up as this one was to have an initial 0.7 oxygen fraction in the rig (and not all semiclosed UBA start off with 0.7 oxygen in the gas supply), but if you do, and if you're working fairly hard, as this example shows, then you have maybe 10 minutes or so of very hard work that you can accomplish before passing out completely from hypoxia. So for the first time at least, as far as the US Navy is concerned, you can actually see how rapidly things can decay in these systems.

My next slide is a screen shot of a program that allows us to take a starting value of oxygen and then find out exactly how long it takes before we reach a critical level of oxygen at various consumption rates. In this case, the screen is showing the oxygen partial pressure in the rig over time. This red line is the partial pressure, which represents a value that we don't like to see oxygen fall below, and that is 0.21 atm. In this case, with a fairly heavy work rate, 2.0 liters a minute, we have about 8.5 minutes before we drop from a nice, healthy oxygen partial pressure down to one which is marginal.

## What's reasonable consumption?

Now, we've had a lot of discussion and inquiries about what is a reasonable oxygen consumption. We've heard before that one and a half liters per minute is sort of an average, and that three liters per minute is not at all unattainable, and in severe cases, you could go even higher. Well, thanks to a prototype oxygen monitor, that we installed in an experimental semiclosed UBA, we decided to find out what very fit divers, combat swimmers, could accomplish.

This testing was done at our place [NEDU in Panama City—ed.], and we borrowed some folks from the West Coast. I think that most of the divers would say that they were in reasonable shape—very good shape, certainly by my standards. These combat swimmers swim day in and day out on very long swims, up to 2,000 yard, at least that was what I was told. If they were exaggerating, I wouldn't be too surprised. The plan was to throw these guys in the water and have them do a swim from the beach from shallow water out to approximately 25 feet while they were being monitored.

Now this next graph is a little bit complex. It shows, time going out to 30 minutes and PO2 along this axis; this was what was actually being measured from the oxygen monitor, and this is depth, in feet of sea water which went to a maximum of thirty feet. So here we have one of the combat swimmers take off from the beach, he's about five feet under water when he started to swim, and as he swam down the slope of the beach, his depth slowly increased to about 27 feet. He sat there for a couple of moments, and then he started heading back in again. So, as you see as time progresses, the depth got shallower.

Well, what we saw on the oxygen monitor was that he started off with a PO2 of about 0.6 atm at the surface, it was an 0.7 atm, but he's breathing the oxygen down a little bit when he first started. As you can see, the PO2 quickly rose to about oh, 0.8 atm. Then when he stopped, he stopped working, so the PO2 begins to rise again to about 0.9 atm. And then he headed back towards shore and the depth started decreasing. That's the primary reason that the PO2 began to decrease again. So we had a maximum PO2 of about almost .9, if you consider this little spike right here. Now that data in itself isn't terribly helpful. It's nice to have, but then you have to do a little bit of mathematical gyrations, and make at least one simple assumption to predict that actual oxygen consumption from that. Here we're not so much concerned about transience as we are sort of the steady state.

So what we've plotted here is the divers oxygen consumption. When the fellow first started out his oxygen consumption was already above one liter per minute. At this point, when he reached his maximum depth of about 27 feet, oxygen consumption was up to about two liters per minute. He rested and his oxygen consumption rapidly dropped and then as he started to swim back in, it began to rise again.

The maximum oxygen consumption, was occurring at the same time that he was at the minimum depth. He was beginning to feel fatigued, but he was still swimming like a bat out of hell, burning up oxygen like crazy. Now he was in the unfortunate position where he was shallow, and his oxygen consumption was still above two liters, about 2.2, 2.3 liters per minute. This was obviously not what we expected when we assumed that his average oxygen consumption was 1.5 liters per minute. If you look at the beginning of the dive, 1.5 was obtained within about two minutes and beyond that, it steadily increased.

**The maximum oxygen consumption, was occurring at the same time that he was at the minimum depth. He was beginning to feel fatigued, but he was still swimming like a bat out of hell, burning up oxygen like crazy.**

## NEDU's simulation software

So that is a concern for us. Because of our own ignorance about oxygen consumption rates, our own ignorance about how the partial pressure of oxygen in a semiclosed UBA is effected by various gyrations of the diver, we developed our own simulation software, which we are willing to make available to the attendees of this conference You will have to write to us to get a copy for legal reasons but I want to give you some examples of what that software tells us.

This is a the opening screen of our semiclosed UBA simulation software, which allows you to do many different things. You can simulate all sorts of manufacturers' UBAs, such that the injection or mixture flow rate can vary from 3 liters per minute up to 6 liters per minute, oxygen consumption can be varied, and you can select whatever particular oxygen fraction or gas mix that you're interested in looking at, and the amount of gas carried in the cylinders simply by pressing this little button here.

Then over on this screen we have a number of other factors that you can play with; the total gas volume in the rig; the total in the breathing bag; how much gas you have in the breathing bag at the beginning of the dive; and so forth, and once you're fairly happy with that, then you can progress to the part of the program where you outline your dive.

Now, in this dive profile we have selected three different depths. These are fairly square dives; we have a programmed 60 foot per minute descent rate, and a very conservative 30 foot per minute ascent rate, but these are the bottoms. Now, for this particular example, we put in very short values so that you can see the detail of what's going on. When we're talking about transient changes of oxygen in semiclosed UBA, things happen fairly quickly over a period of three to 10 minutes or so. If you wish to simulate a four hour dive, you can do that just fine too. It simply takes a lot longer to simulate.

Having done that, if we move to the real meat of the program, it shows a screen like this. And this is where you get to have fun. You get to change the exhaust valve setting. That is, basically, what pressure at which your exhaust valve is going to burp off. We found that is a critical setting, not only the oxygen consumption which can be varied here. The default is set at 1.5 liters per minute, measured under standard conditions—but you can take it up to 5 liters per minute, and watch how quickly the diver passes out. Or you can change this exhaust valve setting, and you can find out that some very strange things can happen. This is really the reason why we began simulating, because we found such strange behavior in our test pool at 15 feet. You can manually activate a bypass valve which adds fresh gas. Normally the program will automatically add gas as bags collapse and pressure in the breathing bag becomes negative. That is what we would hope to see from a UBA, but if you're not happy with the way things are going, you can manually pump it up and watch what happens.

You can set tidal volume and breathes per minute, or you can tie these respiratory parameters to your oxygen consumption. So, the higher your oxygen consumption is, the more these vary. You can change a lot of things in here, and then you sit back and tell it to go, and see what happens.

## Loss of consciousness

This is a case where a diver lost consciousness, and what's fun about it, interesting about it, is that the diver survives. Why? Because he's wearing a full face mask. If he had been wearing a T-bit or mouth-bit, he probably would have drowned. In this particular case, one way to lose consciousness (and there are many, many others), is a low injection rate. In this case the UBA gas injection rate was only 3 liters per minute. The oxygen fraction was 0.5, which means that the gas supply had 50% oxygen. This was on a 15 foot dive for 15 minutes. The diver lost consciousness 10 minutes into the dive. You see the PO2 heading down towards these yellow and red lines. At this point, the guy is unconscious, he's still alive, but he's now definitely resting. At that point, the PO2 and the bag begin to rise, and at some point, the diver regains consciousness, decides he's not going to work any longer or harder and after a while, he decides to come up.

## Running out of gas

The next example shows what happens if you run out of gas (hopefully this will never happen to you). In this case it was on a fairly long dive. The gas injection rate was 6 liters per minute, O2 fraction 0.5 again, bottle size is 1.5 liters, which is not all that uncommon to find. The depth was 90 feet. Unfortunately, 49 minutes into the dive he ran out of gas. Did he make it to the surface? Well, look at the oxygen consumption here: 0. Respiratory rate: 0. Tidal volume: 0. He probably didn't make it to the surface alive. But you can kill this diver as much as you want; he never complains. But it is a good way to learn that how improperly setting up or diving a rig can wreak havoc.

## Oxygen seizure

Here we have a fellow who had an oxygen seizure. We've tried to make this as physiologically relevant as possible. This particular dive was with an injection rate of 4.5 liters per minute, O2 fraction of 0.7, this exists in actual UBA. The diver was a little bit foolish and dove to 110 feet for 30 minutes. Now what is interesting about an oxygen seizure is that it's not likely to occur instantaneously. The diver reached a high PO2 and then he began to sort of stabilize the oxygen in the breathing bag. A few minutes later, the lights went out on him. During the first two phases of the seizure, he's not breathing here. He's contracting first and then convulsing; during that period of time, he's not breathing. The CO2 is still accumulating; he finally reaches a point where he starts breathing again—a big gasp here—and then he's very rapidly trying to blow off that extra CO2, and then things calm down. During this period where things are calming down, the diver is not himself, however. This period can continue for anywhere from three to five minutes, up to as much as 30 minutes. So, the diver is definitely at risk at this point. If he is not weighted correctly, he will come to the surface, or descend to the bottom.

## Closed circuit: What can go wrong?

Now, quickly—I don't want to keep you longer—but I do want to say something about closed circuit UBA. We talked about closed circuit being the ideal rig, the ideal way to solve the problems of the semiclosed UBA, which we've just seen. I'd like to point out, if you can put an oxygen sensor, oxygen monitor, on your semiclosed UBA, you've just solved a lot of the uncertainty about what you're breathing. Well, closed circuit UBA has, of course, an oxygen monitor, and it has alarms and bells and whistles. The US Navy's uses the Mark 16 which has alarms and triple redundancy in that they have three oxygen sensors. They have back-up, manual override, so if everything really goes bad, you can manually pump oxygen in, and then monitor what goes on, so it sounds like the perfect rig. So what can go wrong?

**The take home message: Even the best UBA is not failure proof. So if we think closed circuit UBA are inherently better than semiclosed, well, you have to look at on a statistical basis. If diving with semiclosed UBA, please understand the dynamics of PO2 variation and the interaction with dive profiles and the diver's physiological state. It's not necessarily simple.**

In the business we're in, we see plenty of things that can go wrong. Not necessarily with the Mark 16, but with any closed circuit system, problems can happen in experimental rigs or in operational rigs. At EDU, we have seen flooded cables and bad connectors. Manufacturers have decided to make an engineering change that was poorly documented. It turned out to be a poor choice because we started getting electrical failures, which creates a problem with oxygen control. The software logic to correct for sensor failure does not always work. The alarms do not always work. We've ended up having to perform CPR on a diver in our test pool. Sensor failure logic can be designed so that you don't have triple redundancy. So if anybody's designing or manufacturing a rig, you as a diver need to be concerned about "can this happen to me?" We've also seen canister flooding without the cognizance of the diver. This happened on a semiclosed rig, but it could also have happened in a closed rig as well. In certain rig designs you can get water in the canister and not know it. If you go too long without knowing it, you can end up dangerously hurt. And we had one unfortunate soul who covered up his alarms in an operation, probably a training scenario, that turned out to be a big mistake, a fatal mistake for him. So, most problems with closed circuit rigs are equipment-related in origin, but there can also be human error equipment failures that cause fatalities.

The take home message: Even the best UBA is not failure proof. So if we think closed circuit UBA are inherently better than semiclosed, well, you have to look at on a statistical basis. If diving with semiclosed UBA, please understand the dynamics of PO2 variation and the interaction with dive profiles and the diver's physiological state. It's not necessarily simple.

That's all I have. Thank you very much.

**Mike Harwood:** Thanks for that. It would be interesting to see, looking at some of the old profiles that some of us elderly gentlemen have dived with some of the old equipment, how we would have survived on the simulator. I'm now going to ask our two manufacturers to comment on how their companies have looked at some of these problems and the sort of solutions that they would suggest. Shall we toss a coin?

**Unidentified:** Much too high tech, Mike.

**Harwood:** Okay Christian Schult, Dräger.

**Christian Schult:** Yes. The question is oxygen consumption and hypoxia in semiclosed rebreathers. As a manufacturer, we have had a lot of experience with semiclosed rebreathers and have been testing these units for a very long time. This here is a picture made in the year of 1914 where we tested a rebreather for the first time, and it was a milestone also for decompression procedures as well. We supply other rebreathers to Navies worldwide and they are tested under different requirements.

For the recreational market, we have developed a semiclosed system and we have done a lot of tests. Also, it is one of our requirements, that a buyer has to be trained by an accepted training organization. And at this moment, there are a number of training organization with programs that we have accepted. These are; TDI, RAB, ANDI Australia, Uwatec Australia, the Swiss Underwater

Federation, and IANTD.

## Opinions on oxygen consumption

In preparation for this session, I was running through the different rebreather manuals which are available at the present time available, and I was looking at the O2 consumption that has been specified. What is the right workload? Here are some examples; ANDI specifies from 0.0 to 3.0 liters per minute for heavy work, the RAB has set a high of 2.5 liters, TDI: 1.0 liters for light work to 2.5 liters for heavy work, and IANTD from 0.0 to 3.0 liters per minute.

What's happened? What's the right value and how shall we, as manufacturers, deal with these different estimates?

We have calculated our constant flows so that we can assure that the minimum oxygen in the breathing loop is 17% at an oxygen consumption of 2.5 liters per minute. But the question is, what is happening if the diver has oxygen consumption of more than 2.5 liters? We heard that a three liter consumption is possible, so what will happen in the unit?

## Testing the Atlantis

What we have done is to conduct different test procedures. Starting with laboratory tests, we have done chamber tests, and manned and unmanned tests, where we tested the work of breathing, the breathing resistance, inhalation, exhalation, tested the breakthrough of the soda lime, the effects of temperature. We have done all of these things. We have done pool tests, manned tests, we have done field tests. Before we delivered the first unit to the public we had done more than 1000 tests on the unit, mostly in combination with training courses, so that we have gotten a lot of experience. Also for those of you who may not be aware of it, in the European market we have also had to do CEN testing in order to meet the requirements, otherwise we could not sell to that market.

But, before I present the test results, I'd like to show you some slides of the test pool, and the test divers so you can see what we have done there. What you can see here is our test pool that's at our development laboratory. It's 12 meter in length and 4.5 meter deep. This is where we do all of our in-house tests of the apparatus. Outside, we do a lot of tests with the German institute, GKSS which has a lot of experience also with saturation diving systems. Here we have an Atlantis unit with a test diver, I think at that time, we had around 20 to 25 test divers in the pool. Here's ear the unit, you see lots of cables and tubes to the surface. We have instruments here to measure the content of the oxygen concentration in the inhalation breathing hose, and the breathing hose pressure and the cylinder pressure, and everything else.

Here is the test machine, where first we started the test warm up phase about ten minutes. Then the diver increased the work load until the bypass worked every time, and then when the diver holds his work load on a level that is stable, and we measured the oxygen concentration in the inhalation hose. Then we changed to open circuit by opening the over pressure relief valve, and measured then the amount of breathing strokes and the pressure difference in the gas cylinder. With these figures we can calculate the respiratory minute volume.

The results of our tests? The bypass worked very well. We were on the safe side every time, and there was a sufficient oxygen concentration in the system. We have done these tests with different types of divers, different fitness levels, and made a lot more measurements here. And remember also, users are trained to flush the system before ascent and descent.

## Incorporating oxygen sensors

Sure, the dream is still to have an oxygen measurement system on board. Dräger is also the manufacturers of oxygen sensors; the problem is that they must be reliable. Here you can see different oxygen sensors that we produce at this moment. Dräger produces these for the medical market, not only diving. We produce about 100,000 per year.

We have done these. Under pressure, underwater tests. The results have been sometimes very negative; because all these electrochemical sensors depend on a variety of parameters, like , change for temperature, and humidity. We have tested them with different gases, different measurement points, and for problems with humidity, and water is humidity. We have problems with the useful lifetime of these sensors. No one can say what the usable lifetime really is; is it 18 months or 20 months.

And as John Clarke said, you need three sensors for calibration, and this brings up costs. So let me say at this moment, sensors should be the future; it is our dream. We are close to being there; but we need time. In the mean time we have made our system very easy and simple, and hopefully I have shown our efforts to test these units and show that it runs on the safe side. The increase in respiratory volume kicks in the bypass and rushes the gas into system under hard workloads. Thank you.

**Mike Harwood:** John, would you like to make some comments on your experience, the work that you've done, and how you view some of these problems that have raised. I understand why people would want to stick sensors on their set, but you know, As far as the problem of not having sensors on these units, I really don't want to have a sensor that tells me I'm just going to kiss my ass goodbye. I actually want a sensor that tells me, that something is wrong and that I should switch to my back-up to get me back to a safe place. The systems we're talking about are in the lower cost market, and if you're going to be working in that area, they're going to be pretty crude. As soon as you start putting the sensors in, they introduce other things. And I'd like John Sherwood to say a few words about how he addresses the problem.

**John Sherwood:** I'm from Fullerton Sherwood. We manufacture semi-closed rebreathers for the military market. We have been manufacturing since 1987 and currently have product in service with the Navy's of seven different countries on three different continents. And I'm here to have a look at this market [sport market], and to educate myself as to what the requirements of that market are.

As far as the problem of semiclosed sets, I think that we can take a page out of the military book. Inherent in the design of any underwater rebreather should be the minimum standards that have been set forth by the military. The PO2s; the minimum they accept is 0.2, and the maximum is 2.0. They want your set to be capable of handling O2 uptakes which vary from 0.25 to 3 liters per minute. Regardless of what any training agency will tell you, most of the specifications that Christian and I and others have had for military contracts over the last five years have had those two things in common. Your set must be capable of doing—dealing with that.

## Maintaining sufficient oxygen

Our sets have adjustable flow controls, which means that we can really have people screw our sets up. The sets solve the equation that has been presented here for the two worst cases. We start off with your worst case of an oxygen consumption of 3.0 liters. You're at one atmosphere, and your PO2 must not go below 0.2 atm. The other worst case is having a diver on the bottom that's comatose, at a consumption of 0.25, and your PO2 is not allowed to go above 2,0. In order to help our customers use our semiclosed underwater rebreather, we provide them with roughly a 150 page document which outlines the operation and maintenance of the equipment pre and post dive routines, maintenance drills, calibration, and in-water emergency procedure drills.

One of the drills that is done on most semiclosed underwater rebreathers is conducted at depth. You flush the counterlung before you begin ascent, and that way you've topped up your counterlung, you don't run as great a risk of hypoxia going back towards the surface. And that is as pointed out by Dr. Elliott. The greatest chance of hypoxia is going to occur at or near the surface when you're working extremely hard.

The other thing that can be done to desensitize the unit to changes in PO2, or changes in O2 consumption, is to produce a large breathing volume loop. The breathing volume includes the canister, the counterlung, and the diver himself. By adding to that volume, you're actually adding to the capacity and increasing the time that John showed us—the amount of time you can allow a person to undergo heavy physical exertion at or near the surface, in excess of three liters a minute consumption, before they actually encounter PO2s which are dangerously low.

The other thing you can do, which most of the manufacturers will do, is offer sets with low work of breathing, or, sorry, low breathing resistance. In the military, they set the limits. And with those settings, comes an acceptance of risk. The consumer does not set limits and the consumer does not accept risks. If we are going to offer a semiclosed set to a consumer group, then we must look at what can go wrong with the set. Obviously one of the things that can go wrong with the set is that you can start having too little O2 in your bag. And you know, I'm not going to be able to stand on the witness stand and have somebody come up and say, why isn't it there, and the only answer would be, "it's too expensive." Those answers simply aren't good enough.

## CO2 build-up & cold water

The other thing we can do in terms of semiclosed systems, is to control the CO2. There have been tests done on CO2. Those tests have been conducted on our sets, by the NEDU, the Canadian Experimental Diving Unit, in the UK, in Norway, and in Sweden. All of these tests are there, they are available. The data is available as well for a prospective customer, so that they can understand exactly what our system is capable of doing, and what it's not capable of doing. We do our tests for carbon dioxide scrubber efficiency at 0 degrees sea water, because we're Canadians, and we have cold water. As well, the placement of the canister inside the loop can have an effect on the way in which the equipment is used, in cold water and warm water. We're a cold water nation, so we designed our system so that when you exhale, you exhale to the bag, it knocks out the condensation, when you inhale, the gas comes from the bag through the canister, warming the gas up, so that the diver can then breathe a nice warm mixture. However, in tropical areas, this is exactly the opposite. The solution was very simple. You just changed the mouthpiece around reversing the pattern, and in tests this has changed the inspired temperature by about five degrees Celsius. And again, this is arrived at with tests. We also sell our set with a full face mask. It comes standard with a Cressi, which is a bite type mouthpiece.

## The importance of testing

We support our customers with documentation, operation and maintenance manuals, calibration, which is yet to be addressed, and testing. These sets are made up of a bunch of stable components. Unfortunately, not everyone wants to buy exactly the same thing each time. So they always make a request: Can you do this? Yes we can do this. We can do this by taking this component from this set and putting it in this set. Now, everyone knows, you can take a bunch of stable components and put them all together and create a hugely unstable system. And so, in order to sell a system into any market with any assurance that you've done the right thing, you must test it. That testing must be objective and it must be quantifiable. Simply jumping in a pool, swimming around and saying, well, it worked OK this time isn't good enough.

So those are ways in which we can address the semiclosed market. I don't want you to get the feeling that semiclosed is not a safe way of diving. It's a highly reliable way of diving. It has reliability which is, I believe, far greater than that presently demonstrated by electronic sets. I think electronic sets do have their place. That's why there's chocolate and vanilla. But there is an opportunity here to look at a semiclosed system which is reliable, which is rugged, which is good for intermediate depths up to 50 odd meters, and which will satisfy the majority of the people who are interested in that kind of market. Thanks.

**Harwood:** Well, that's the sort of formal part. Now I'd like to hear from my learned colleague, and neutral party, Gavin Anthony from the DRA [Defense Research Agency—ed.] who has just finished a series of tests. In fact, Gavin and myself had a bit of a shock. We unfortunately had one of our young trainee officers get into a bit of a mess on the set that David showed you earlier on, and then we had a guy that got tied to the bottom which unfortunately resulted in a fatality. And then we went back and did an historical review of the development of the set, and where we went wrong, and applied the new breathing standards to a very old piece of equipment. It amazed me that we hadn't actually killed a heck of a lot more people. It was a hard thing to try and get across to people, that the standards were suddenly going to change it from a 90 minute set to a 45 minute set, and this to was a group of guys who didn't think that they had a problem.

People had survived, because it was the military and they had two things that were mentioned earlier. The first was discipline. The military has a certain way of dealing with discipline: You do it my way or you end up getting fined or whatever. It's a very strong disciplined environment. The second thing is that we have actually over-trained our people including dealing with unplanned events. So we've been probably fooling ourselves for some time on these pieces of equipment.

And with that, I'll ask Gavin what his views are.

**People have been talking about CO2 canisters, gas endurance, and how long will the canister go. . . Design your set such that it runs out of gas before the CO2 absorbent will run out.**

## Why take the risk?

**Gavin Anthony:** Throughout the day, we've heard about a lot of the problems with rebreathers: hyperoxia, hypoxia, hypercapnia (high $CO_2$), and a high work of breathing. We know about all of these. We know the problems. They've been put to you today. What you've also been able to see today is that we have solutions to a lot of these. Now, much of the discussion on semiclosed circuit sets this afternoon has been what flow rate should I use? What mix should I use? Can I bare it down to the minimum? What I would say is, that if you want to go ahead in rebreathers and get it right, and not start to damage people-, and if you know how to do it with very little risk, why not do it? Go into that. If you know you can set a flow rate that will cope with 3 liters a minute $CO_2$, why not use it? Why take the risk of being drowned.

There are other aspects. Mike mentioned that we certainly had work of breathing problems with a semiclosed circuit set that has been used for a long time. We know how to solve work of breathing problems. You increase portage, sizes of hoses. If you know how to do it, then solve it. Don't take the risk of coming down with that.

One other aspect: People have been talking about $CO_2$ canisters, gas endurance, and how long will the canister go. Well, there's an easy way of solving it with something you can measure. Design your set such that it runs out of gas before the CO2 absorbent will run out. I think if I can get that one message over, it is that you can design out the risk. We want to make it as safe as possible. Design it out. And don't put the risk on the guy who's got to think under water when he wants to be doing other things. I think that's my view.

**Harwood:** Thank you Gavin. Now I'll throw it open to the floor. We've got to watch the time because the good professor has to fly around the world and give the message to the Australians again. But step up to the microphone, guys, let's hear what you have to say.

**Michael Menduno:** I would like to hear some commentary on decompression issues. With a varying oxygen levels in the breathing bag, hypoxia is obviously of more concern then decompression. But I would like to hear about people's experience with decompression on semiclosed sets, if you don't have a good handle on PO2s.

## Semiclosed decompression

**Sherwood:** Most of the navies that are using semiclosed use a EAD conversion. And that's the extent of it.

**My own personal view on semiclosed is that it's a good starting point. It's a good way to do "try dives," to get people to understand the different buoyancy controls and some of the procedures. . .**

**Schult::** When we are talking about recreational diving, then we are looking to the standards set by the training agencies. I think that most training agencies are talking about using an 80% factor in calculating decompression. I don't know, perhaps Dietmar Luchtenberg from the Rebreather Advisory Board can tell us something about decompression in these systems. Dieter?

**Luchtenberg:** Christian, I think we have an expert in this are. Max Hahn is the expert in decompression for the RAB, so I give him the floor.

**Max Hahn:** I'm Max Hahn from Germany. If you use an ordinary dive computer, that allows you to set a mix, then if you set it to about 80% of the mix that you have in your tank you're not very far from reality [i.e. setting the computer at a 40% mix, if your diving EAN 50—ed.]. That is for a medium work load. If you set it to about 80% of the mix in your tank, then probably OK. Everybody has to keep in mind that dive computers have a very large error margin anyway. So it is absolutely ridiculous to talk about, say, single percents of nitrogen in your breathing gas. Because the error margin in your personal susceptibility for DCS is much larger than a single percent of nitrogen in your breathing gas. Thank you.

**Harwood:** Anyone else? Karl, do you want to lead off, and then we'll ask the legal eagles to close us all down?

## Differences: semi and fully closed

**Karl Shreeves:** Karl Shreeves, DSAT. I'd like to get the panel's agreement as to what I see as sort of synopsis of your last presentations. Would it be a reasonable general conclusion to say that in their present form that semiclosed circuit is more technologically reliable, but more prone to problems due to exceeding the limits, either due to logistics or user error, whereas fully closed electronic is going to be the opposite? It has a wider ability to accept logistical changes, but is going to be more prone to mechanical, and electronic problems. Was that as clear as mud?

**Clarke:** No, I think that point is very well taken, and all is not hopeless in terms of even semiclosed UBA, which, again, provide more mysteries, if you will. I think a lot of those mysteries can be solved with education. I think anybody using a semiclosed UBA, unless they have a lot of experience, really needs to make themselves very aware of how they can get themselves into trouble. Of course, that applies to any aspect of diving.

## Semiclosed as a starting point

**Harwood:** My own personal view on semiclosed is that it's a good starting point. It's a good way to do "try dives," to get people to understand the different buoyancy controls and some of the procedures like when you take your mouthpiece out, switch it before you take it out for Christ's sake, and doing some of those basic touch procedures. But I think that it's definitely got a depth restriction. I want to be confident, really. The more I've found out about how I've managed to survive, the more worried I am, really. To me, it [semiclosed] is a good starting point to make your mind up if you want to go down into the more expensive equipment. In the UK, our legal position is quite simple. We are quite happy for people to use rebreathers, as long as the manufacturer is taking the weight of responsibility. And we want them to come out with the right training courses.

The one thing I'm a bit wary of here; I don't think we should keep looking at training agencies to provide solutions. Training agencies are there to provide good quality training based on what the manufacturer has given them. They can give generic training, but they shouldn't be the people to solve the problems and that's one of the points I wanted to make. But I believe the semiclosed has its place as a starting point.

## What has the experience been?

**Rick Lesser:** Rick Lesser, Hruska & Lesser. This was the session I was probably the most concerned about, because we wind up involved when what can happen, does happen. My question is this. In the real world, how much experience do we have with semiclosed? What kind of a history do we have? How many users? What kind of a fatality rate or problem rate do we have?

I was sort of getting a feeling that we were talking about the bumblebee; that measures out, and his wings aren't big enough for him to fly, and he doesn't know it, and he keeps doing it. Here we have heard about all the bad things that happen with a semiclosed set, but is it happening? Has it been happening? And is there anything more concrete, or more definitive than saying, just set your nitrox computer at about 80% of your mix?

**Sherwood:** I don't think we should lose sight of the fact that the majority of experience with rebreather technology over the last 45 or 50 years, has been essentially with semiclosed systems. And what's happened is that electronics are now coming on the market. The one big drawback with semiclosed is endurance. You can't carry enough gas. But I don't think that it's responsible to say that one set is more problematic than another; or say that semiclosed is better than closed circuit. Each of them has their place.

**Schult:** I think the issue is that if we want to bring this into the recreational market that the user understands the basic function. And if I look to the normal recreational divers, without putting any blame on them, they don't understand what's going on with compressed air in the human body. Therefore, in my opinion, the technology we give them must be very simple. It must be very easy to understand the basic function and we shouldn't give them too much to play with it. Okay, Give him regulations, give him depth limits and so on, and it should not just be the responsibilities of the training agencies. The, training agencies and manufacturers, and all experts, must work together so that the first accident will not happen. So, regulations, specifications, all of these things must be in place before recreational diver use the unit.

## Data on semiclosed incidents?

**Lesser:** A nice answer, but I don't think it was responsive to my question. I mean, do we have any real numbers as far as what kind of problems we've had and how many users. That was what we wanted to get at.

**Harwood:** In the recreational market, or in the military market?

**Lesser:** Both. Or either. Take your pick.

**Harwood:** Ed, I can't remember what the UK fatality rate is—one during my lifetime.

**Ed Thalmann:** The answer is yes. People do pass out. People don't set-up their rigs right and do have problems. The Navy went to a multi-million dollar program to fix the canister on the Mark 11, which has thousands and thousands of man dives on it. It's a semiclosed rig. There were some problems and some people almost died. So these problems are not academic, and if you don't know what you're doing you can kill yourself on a closed circuit rebreather pretty fast. As John mentioned, the EDU had a problem in the test pool. I personally resuscitated somebody from passing out and convulsing in 15 feet of water because an O2 sensor failed. So these are not academic problems, and if you don't have people around you that know what the hell they're doing, then you'll end up dead.

**Harwood:** What can I say, that just about sums it up, doesn't it?

[Laughter]

**Menduno:** Is there a report? Does the Navy keep track of incidents, statistics on rebreathers, and are those public documents, or available to the public?

**Clarke**: The Navy has a safety center, of course, and the data is available to the Navy. I don't really know if it's available to civilians or not. Dan keeps I think pretty good track. Ed, are they directly tied in to the safety center?

**Thalmann:** The Navy data's for the Navy. I don't know if it makes a lot of difference. I mean, why do you care if 10 people died or if 100 people have died? The fact is, it happens, and the fact is, the way to prevent it is by training, and by knowing how to maintain the rebreather. But the Navy data is not available to anybody outside the Navy. Certainly, Dan is starting to keep track of mixed gas divers as a separate entity from air divers, but I don't think that data's going to mean much for the next couple three years. But the point is, what difference does it make? It happens. I think that you can talk to anybody that's been in a semiclosed business, and they'll tell you it happens. And the reason that people don't always die is, like I say, you have people around you that know what you're doing.

## A heck of a lot of near misses

**Harwood:** I wrote down something this morning at the start when Michael was doing a couple of things. I'm a great believer that death is not the only measure of failure. There's a heck of a lot of near misses, and it's when we're trying to get stats from the commercial market, the law says one thing, but we believe, in Health and Safety that the only time they tell you that something's gone wrong, is when they want to put the marker down for litigation later. If they've got away with it, they don't usually tell you. And so it's very hard to track that. My experience in the Navy was probably the same. When I became Deputy Superintendent of Diving, I went through a bad patch and I was looking at one incident report a week, I'm not joking when I say that it was one a week for over a year. And then it just went away; it just disappeared again. I don't think that's because it really went away, its' just that we just had a group of people who went out there, and decided to fill out the report forms, and then the got bored with it because they didn't see the kit being changed or anything else. And they didn't bother to send any more in. Trying to chase these numbers is a very difficult business.

If you dive for a long time and you've survived, when somebody comes along and says that you've got to change the rules, you react to that by not telling them anything; you just shut up completely. That's been our experience in Health and Safety. Yes, I'm sure there are people getting in trouble using scuba sets in commercial diving. You never hear of it. It's very hard to chase the sort of numbers game. And at the end of the day, does it mean that it's foreseeability. Start where you are today, look at what you're trying to do. See if it's foreseeable. As Gavin says, you reduce the risk.

The only thing I would slightly disagree on is that engineers will always tell you they can engineer everything out. That's when the trainer comes in. He just fills the gap between where the engineer thinks he got it to and where it did get to. And that's where you need the combination of good training to just fill those gaps in where the engineering is not going to do it for you.

**Elliott:** I just wanted to close out. I've been really hammering the business of hypoxia and the dangers of that. But let us not lose sight of the fact, when it comes to numbers, that these semiclosed sets have been used for hundreds of thousands of dives, the majority of which have been absolutely fine, because they've been dived in accordance with, in our particular circumstances, Navy procedures. What we're looking at, and what we're concerned about is the exceptional dive, which may not happen to any one of us here, but it's a question. Therefore, in a risk assessment, it's a question of looking at the worst possible scenario and deciding to what extent do we have to go and perfect it? So, the person who's diving outside our recommendations will nevertheless be safe. What bothers me is the fact that if a manufacturer—and Christian is representing them all here—is dependent upon a training agency to solve these particular problems, then we have a problem. We've already seen from Christian, the range of standards for oxygen consumption that the training agencies are using. How can that vary from one human being to another, just because one goes to one agency or another. Somebody has got to sort that out. That is the danger area. But the semiclosed rebreather as a whole, when used gently, is a beautiful piece of equipment to use. I mean we can't lose sight of that either.

**Harwood:** Well, I think, unless any body's got a really strong question they want to ask, I'd like to wrap this up because we've drifted away into drinking time, and our manufacturers probably won't be able to sell us anything except a few drinks. I'd like to thank my colleagues here on the panel, and particularly say thank you to David, as he disappears. It's a pity you're not staying with us David, but we thank you for the attendance.

**Harwood:** Thank you. Glad to be here.

**Menduno:** We're going to have one more session tonight with the manufacturers, and then they can buy us drinks. Why don't we say that we'll come back at six o'clock, which is about 21 or 22 minutes from now, and that'll be our last session for the evening. Thank you.

# The Rebreather Market

*"The meeting so far, in the last couple of days has not changed my view that we're fairly well away from having a mature enough market in terms of the infrastructure, training, and knowledge of the products to really take the risk of entering into it."*

--Derek Clarke/Divex

*"It's a unit that allows you to pack hours of weekend diving in your car, or your boot, without having to wonder where the next gas filling is coming from. For us, it's, a revolution in nitrox diving."*

--Christian Schult/Dräger

## Session Summary

It was clear from manufacturer presentations that they view the sport diving market as different from the military market. The main differences are the absence of an extensive infrastructure to support the technology, training, discipline and user sophistication. All of these issues represent a challenge for manufacturers. As a result, some of the existing suppliers of military rebreathers were skeptical about sport diving market prospects.

The session began with manufacturer presentations reviewing their planned product offerings and discussing their view of the sport diving market. This included rebreather manufacturers as well as supporting technology vendors including full face masks, computers and communications. Planned pricing on consumer rebreathers ranged from $5,000 to $15,000 U.S.

Following the presentations, panelists answered questions from the floor including issues of disposing of used CO2 absorbent, back versus front mounted breathing bags, calculating constant PO2 decompressions, and oxygen control and fittings.

The session was chaired by Michael Menduno, and consisted of Derek Clarke/Divex, Mike Cochran/Cochran , Marco Flagg/Desert Star Systems, John Fullerton/Fullerton Sherwood, Dick King/Biomarine, Bev Morgan/DSI, Christian Schult/Dräger and Mike Wehrs/Orcatron.

# Rebreather Market

26 SEP THURS 5:30-7:00 pm

## Transcript

**Michael Menduno:** Bev, are you in the audience? Mr. Face Plate, himself. No. When Bev Morgan walks in, why don't you send him up here. Could we close the door back there?

This is our last session today. And in preparation for tomorrow when we get some "hands-on" over at the lagoon with some of these systems, I'd like to have all of the rebreather manufacturers up here and also several manufacturers who make supporting equipment to be integrated in with the rebreathers. What I'd like to do is to give everyone five minutes to present what they do, and we'll hold pretty much to schedule. After that, we'll open it up for questions from the audience. It's your opportunity to drill these guys and ask all the questions that you've wanted to, and maybe then we'll turn it around and let them ask questions of all of you, since most of the people here represent at least a portion of the market that these manufacturers are hoping to reach.

There's Bev. Bev, would you come up here? This is last in, first out. Are you ready to talk?

## The S-1 full face mask

**Bev Morgan:** I didn't bring any slides or anything, we've been working our fanny off trying to get the product out [The S-1]. And actually, I'm not here to sell anything. It's going to be a year or so before we come out with this product, but this is the first product that we've decided to show prior to having it for sale, with the hope that we can do some interchange with the community to improve it before we go to hard tooling and manufacturing. I've got some flyers and I sent one of the crew off to get some more so I could pass them around, but I guess all I got to show you is the stuff.

So far we've made two basic versions of this unit, and this is the military version. It's a more rugged and heavy duty. That's an exo-spider, and you know we take what we already have tooled and make use of it. The idea here is to make a modular unit so that you can change certain components without having to build a whole new mask or a helmet. This the mask version. There will also be in the helmet version. But basically, you've got a seal and a hard mount for the seal, and then a spider harness module which carries the buckles and that sort of thing and then the top part of the front and the bottom part of the front.

As you can see, for those that like mouthpieces, it's got a mouthpiece in it and you can shove the mouthpiece in or out of your mouth any time you want, so you can swim around with the thing in your mouth all the time. We've found that most of the guys who have tested it so far don't want the mouthpiece in their mouth, once they get used to it. The mouth module has got a couple of locks and it opens very easily. A very simple deal. It's a full face mask when you want it. It's a scuba diving mask when you want it. As you can see, the upper part of the mask seals just like a scuba mask. So it seals across under your nose, and you can put this on and go diving with any mouthpiece or any regulator that you have.

In other words, you can take your right out of the box and hook it up to your rebreather. And with the mouthpiece in your mouth of course, it swims just like any other rebreather with any standard scuba mask. So you put it on and as you can see, I can have a ham sandwich and talk to you, do anything I want, wait for my buddies to get their dive gear ready. You can see that the front top seals just like a scuba mask, and I could stick any regulator in my mouth, or any rebreather, right now and go diving with it. [applause]

The mask, of course can come in oxygen clean green with an oxygen clean system, and this can be hanging from a hose on the surface, or for a standby rig, and there's no worry about O2 cleaning, because it's all O2 cleaned. And oh, by the way, you can buddy breathe with this. I'll show you: I'll put the mouthpiece in my mouth and it'll go in anyone else's mouth with scuba mask.

So, you don't have to put it on to use that mouthpiece bit, because it's very flexible. But then, if you want to put it in place-, of course you can. I could talk to you without taking it off, just by loosening the latches here. But you're saying, " Hey, Charlie, go ahead and get your gear on for crying out loud, I'm tired of waiting for you." When you're ready to go in the water, you just snap these. But of course, if you forget to close it or you forget to put it on, you hit the water and you go gulp, and bite the mouthpiece. So, it's kind of mistake proof and of course it comes off just like a scuba mask.

There are a lot of different things, different designs that you can utilize with this to make it really neat. On one of the designs we have a full face deal which is really interesting because you can talk to each other at close range without any communications device. Of course, for the communications guys, all this does is get you customers, because you swim over and you look at each other just like we are right now and you talk to each other and you'd be amazed at how much communication goes on seeing just the face without any verbal talk.

The first thing you see is that the diver's OK. You can tell if the diver's in trouble; you can tell if he's relaxed. There's a whole bunch of information that comes from just seeing the diver's face. And of course, the face plate itself acts as a speaking diaphragm. So, you come over and you talk just like I'm talking to you right now, and even with bubbles from open circuit and everything, you talk 100%. You can hear everything. But of course, with communicator you can get away from each other and still hear.

So actually, there it is. I'll be dragging them around. The other ones work the same. [applause]

**Menduno:** Mike Wehrs, Orcatron Communications

## Underwater communications

**Mike Wehrs:** Well, good evening everybody. In talking with Michael about this conference during the last month or so, we got into discussions about what's going on in the industry and it was interesting to talk about some of the parallels between what's going on in underwater communications and what's happening or about to happen within the rebreather market. So I thought from a contrast perspective, I'd present a couple of slides on who Orcatron is and how we have evolved as a company, and will relate that technologically, to what I think is happening within the rebreather market. And then I'd like to talk about some of the reasons why we are so excited about it, and why Orcatron, an underwater communications company, became a sponsor of a rebreather forum.

First a little bit about Orcatron: We've been in business since 1983. Our primary business has been selling wireless underwater communication products to military and commercial divers. In addition to the stand-alone products, we also provide systems integration into larger systems like Atlantis submarines and things like that.

Like Bev, we did a little bit of pre-announcement about what we're going to be shipping very soon, and we are going to demonstrate the product; everybody can dive it tomorrow. We're entering the recreational market where things are very different, and the things that we could assume, about types of equipment, level of expertise, as I indicated in my opening comments this morning, are totally different. How we have to address this market, and the things that we've had to do as a company to prepare ourselves have been very, very different.

As an example, here's a sample of what our commercial product looks like. Now, if your normal recreational diver showed up on a dive charter boat with one of these things, he'd scare everybody to death. From a military perspective, though, this is a great product. Gives you about a kilometer of range underwater, push-to-talk system. You can disconnect the microphone while you're in the water without flooding your mask, and it works with a whole variety of full face masks. It's got all the right features for that kind of application.

One nice thing, that Tom and I were taking notes about, is that everybody's making comments about how great full face masks are. We think that's just terrific. It's much easier to talk with a full face mask on, and a mouth bit out of your mouth. So we think they should keep coming. Bev, get that out now.

In addition we have other products, like this, which is a sub phone; it's our highest end product. The range is ten kilometers underwater, wireless, boat to diver, sub to diver, you know, all different combinations. It takes a typical military/commercial type sales efforts though. Get it spec-ed in, make sure it meets the individual requirements, mission requirements, make it all one-off special frequencies-, everything that a normal sale would have to take into account.

As we started to expand the company and say, well, what are we going to do next, the whole concept of this sport unit came out. Well, not only on the marketing side which was really significant, but also, features and functions had to be significantly different. It had to be really inexpensive to start with. It had to use components that anybody could buy anywhere. It couldn't be something that had to have a recharger that was plugged into ship power, that required all these other types of things. It couldn't rely on things like push-to-talk systems. It was a real ergonomic interface issue that we had to go through for the design elements here. Couldn't we make so that as the diver swims along he just talks. That was one of the things we looked at hard: the whole concept of push the button and then talk, and then remember to let go of the button—that's screwed everybody up.

It was really a matter of getting things down to absolute basics here for the recreational diver who just got certified. I could now let them talk underwater for an inexpensive price, but what features does he want? What is he going to expect from the unit? How are we going to position and package it? And how much is he willing to pay for it? That's kind of the driving factors of what went into our sport model.

In parallel, there were very similar things happening in the rebreather market. And the situation is that there have been some competitors that have tried to take their military commercial products, sell them into the recreational world with at best questionable results from doing that. They just didn't have the right features, the right functions. You have to adjust six or seven different electronic parameters to get the things to work with you, and you give it to someone else to try and it doesn't work with them. It's too much money, and it's unreliable, and you can't get the batteries and things like that. We had to go through all of these things ourselves over a period of five or six years of development in order to introduce the product and have it ready for the market.

Wrapping up here, our view is that there's two distinct markets; there's a commercial market effort that we're involved in. Everything about how we sell into it, how we position the company, how we address it, what the product looked like, the features—everything—goes out through one particular channel. The other channel is for the recreational product. And everything about how that product is packaged, functions and performs is targeted at the recreational diver's education and experience set. So, we invite you to come over and dive the equipment tomorrow. We'll have it down at the lagoon, and I'll be happy to answer any questions when we get to the question period. Thank you.

**Mike Innis:** Michael? Okay? I'm Mike Innis. I have a couple of AGA face masks with one of your competitors' comm devices installed. My son owns a scuba store and he has experiment in using them, particularly with his customers who tend to flounder a little bit, to be very uncomfortable initially in the water. He finds that after the first couple of PADI modules—once they have done some of their basic skills, and are honing and fine tuning them that he notices a remarkable reduction in their anxiety level. And I think that working with PADI, NAUI, some of the other certifying agencies to make sure that your device is approved by them for use in their various basic training, I think, that would be just excellent.

A secondary use that I've found valuable is in a cave diving situation. We find that it's extremely interesting how far they will communicate around corners. Supposedly it's a line of sight, and yet we have found through experience in wrecks and in caves, that it really communicates quite nicely. I guess it bounces, and don't know enough about the acoustics to understand how it does it. All I know is that we're surprised. I think that your price-point appears to be correctly set and that you need to go after primarily the instruction group to get the devices out there. I think you're going to have yourself a winner, Mike.

Wehrs: I appreciate the comment. We did do a little bit of checking with some of the training organizations, and nothing about our device violates any basic open water training standards and so it can be used for all the modules. So yeah, we did look at that. The instructor community is definitely one of the primary targets and some of the initial work that we've done with some of the schools—when the students first are going through the pool sessions that we notice there's a remarkable reduction in the number of dropouts and anxiety as well. Thanks.

**Menduno:** Mr. Readey

## Cochran Undersea Technology

**Peter Readey:** Hi. First of all I'm going to show you some goodies, and then we'll talk about the Prism II. We heard earlier from Ed Thalmann—about the Navy's constant ppO2 algorithm that they're putting in a dive computer. We're the ones doing that, and this is the dive computer. I think that we're going to change the color to battleship gray, but in deference to the Navy, that's that.

We also have another constant ppO2 device that goes inside a rebreather. Now this can be used in the water, or in a breathing bag. There's a ppO2 sensor that goes on the end of it, so if you want to, you can mount this outside the breathing bag with just this connector and the ppO2 monitor inside the breathing bag, or you can chuck this whole thing, in a breathing bag like the Prism II has in it. It has data logging. It's completely independent, autonomous, has tremendous data logging capability, graphics, and that sort of thing. It's a completely independent and autonomous sensor and computer.

I also heard a few other things throughout the day today that I'd like to talk about briefly here, and it kind of smacks right on the Prism II. One of the things I heard was the statement about CO2 sensors; that there wasn't any CO2 sensors around that were low cost and worked. But the Prism II has one on it. It's a proprietary design. It's very effective. It's water proof. It's low cost. And it works fine. It also provides CO2 logging capability as well as graphics in that product. [Note that EDU director, John Clarke, stated that there were no CO2 monitors that they were aware of that had been tested and had worked—ed.]

The Prism II is a fully closed circuit system that also functions in the semi closed mode on the basis of its unique control system . It has a wide dynamic range. So the clear distinction that I keep hearing about between closed and semiclosed systems really doesn't exist in the Prism II . You can take the exact same product, chuck a 50/50 mix on it and it'll run semiclosed. It may yell at you a little, because you told it the wrong mix or something, but it'll regulate and do everything it's supposed to do as if it were a semiclosed system. In fact, it's working as a semiclosed system. Or if you chuck 100% O2 on it, of course, it works as a fully closed system.

I also heard something earlier about canister flooding being a problem with some of these products. While we've done everything that we can to prevent that sort of thing. I guess, if you try hard enough, you can always flood a canister. But our canister has a flood alarm in it. It lets you know that there's water accumulating in the canister before there's enough water to really cause any damage, and there are pull dumps on both breathing bags so you can evacuate the water before it becomes a problem

I heard another comment about batteries. Of course, batteries are always an issue in an electronically controlled closed circuit system. The Prism II uses four D cells; off the shelf alkaline batteries that last for about 40 hours. It has four AA backup batteries. They're completely independent backup batteries. So if your main goes down for some reason, your double A's will kick in and allow you to fly the system.

Speaking of flying the system you can also fly the Prism II manually. If the electronics crap completely, just blows up, floods, whatever happen to it, you have a wired ppO2 monitor that actually looks at all three cells, gives you little bar graphs, and allows you to fly the system manually. There is a manual control valve that allows you to inject gas manually and so you can fly the entire thing manually. And of course, you can always put one of these independent ppO2 monitors in there as well if you really want to go all the way on the backup and redundancy.

That's about all the notes I have. We're in testing right now with the unit. It's going to be just under $8,000 and will be available to the public in first quarter of next year. And like I said, we're in testing. There are a lot of people here, who have dived its predecessor, the Prism I, and some other people in here as well who dived the Prism II. So we're having a lot of fun. Thanks.

## Fullerton Sherwood Engineering

**John Sherwood:** I'm John Sherwood from Fullerton Sherwood Engineering. We're a Canadian company nestled between the two runways of Toronto National Airport. It hardly is what you would think of as a hot bed of diving, but there are a couple of unique advantages to being located there. Number one is access to precision machine shops which service the aircraft industry. The second is it's a nice staging point for our marketing guys who accumulate mega air miles. And the third thing is that it's about twenty minutes away from Canadian Forces Experimental Diving Unit at DCIEM.

We're a small company. We started off in 1979, with a background in engineering from working at EDU. My partner, Dave Fullerton, was a test and evaluation engineer with EDU during the mid 70's when they bought and evaluated virtually every available rebreather on the market. We began in 1979 offering hyperbaric engineering services to any and all. In 1994, we began an R&D program for the development of an underwater rebreather. It was a two stage process, the first stage was to develop a breathing loop with a constant mass flow, semiclosed system. The second part of that was to develop a deeper 90 meter version of a semiclosed set which would mix diluent and oxygen on the fly.

Today, we've got four different products in two basic product lines. We sell our equipment to the military. We're in service in seven countries and on three continents. This is the basic SIVA 55. In Canada it's known as the CCDA. The deeper version of it is known as the "CUMA." It's a chest mounted counterlung with a backpack to a breathing hose. And an integral weight pack so that it can be dumped and jettisoned. This is what we see the fashionably attired combat swimmer wearing in the next year or two. This is the S-10, S-24 variant. It's a chest-mounted underwater breathing apparatus which is used closed circuit for 0 to 9 meters, and it can be fitted out for semiclosed circuit for shallow water swimming. Its magnetically and acoustically safe to 24 meters.

So that's who we are and what products we have. One of the reasons we're here is to try and look at who the market is. And the number two thing is how do we safely enter into this market? We have equipment which is built to military standards to be operated by the military. It seems that this group is completely different from the military, and with that will come new kinds of equipment that we need to add to our equipment to make it compatible with that market. For example, simple things like packing a scrubber is going to take time, energy and effort, we're wondering whether or not that should be pre-packaged.

**It seems that this group is completely different from the military, and with that will come new kinds of equipment that we need to add to our equipment to make it compatible with that market.**

There are all kinds of issues that need to be addressed. Calibration and maintenance. All sets needs to be calibrated. It requires calibration instruments. Those instruments in turn need to be calibrated against some sort of standard. So that eventually you don't wind up calibrating to something which is un-calibrated itself.

There's training standards which need to be addressed. Our belief is that the training standards need to be set by the company that manufactures the equipment. We have to tell a training agency what a diver must know in order to operate our equipment properly and then they can tell us how best to train them, but we have to set some minimum standards.

And the last thing is support. We have to be able to provide support to our end user. We're used to dealing with end user groups that have an infrastructure to support their divers. Now we're basically looking at going past them as a company going directly to the end user and trying to support them, and that's a very different task than what we're used to doing. Thanks very much.

## Dräger

**Christian Schult:** My name is Christian Schult of Dräger, a manufacturer of rebreathers. I'd like to start by talking about rebreathers for the military market and not for the recreational market, so that you get a feeling what we are doing on this field. The recreational market is a new field for us.

Here you see different types of rebreathers that Dräger has developed; oxygen rebreathers, nitrox rebreathers. For example here an oxygen closed circuit rebreather with diving depths to 9 meters, diving hours up to three hours. We have the LAR VI unit which works with oxygen but has a longer duration. We have the Lever 24 that's a unit that can work with oxygen or nitrox, and the Lever 45 which is a semiclosed nitrox rebreather, and here's the Reynold FGT which has now been on the market for more than 30 years, and is used by many Navies all over the world, and last but not least, here is a deep diving unit.

All of these units represent a lot of dreams, just as it is our dream to get into the recreational market. People come to us all the time and say we want to have this, we want to have a recreational unit to go to 100 meters, we want to go with your unit to that. And it's our company policy to say, "No," because our company has decided if we are going to go into recreational diving, we have to go step by step in a safe way.

We've had other discussions at the past Rebreather Forums and it came out that we have different requirements for the recreational market. That means the technology—I like to emphasize this—must be simple to understand for the average recreational diver. Sure, we as a manufacturer have to fulfill the requirements to work together with the training agencies and bring in our knowledge of the technology of what we are doing. For example, at this moment if a training agency want to train on the Atlantis, they give us a manual, we participate in the courses and then we decide if we will approve them. So we put our knowledge into it.

The Atlantis is a semiclosed system and works with premix. In order to use the unit you have to be able to get gases. And this is different from country to country. In America we have one situation, and the same is true for the UK or German or Australia. So we must fulfill this requirement that we have or that our users will be able to get gas mixtures.

While using a rebreather like Atlantis; it's one shot. It's a unit which is lightweight and portable, simple to use, offers extended dive times compared to conventional open circuit systems, reduced bubble noises, there are still bubbles but only a few bubbles. These few bubbles are behind the diver, so it allows you to get closer to the marine life. And this is our message. It's not a deep dive unit to push your own limits; it's a unit for the normal recreational diving and most of the advantages of these systems are up to 20, 25 meters. It's a unit that allows you to pack hours of weekend diving in your car, or your boot, without having to wonder where the next gas filling is coming from. It's for us, a revolution in nitrox diving.

**We've had other discussions at the past Rebreather Forums and it came out that we have different requirements for the recreational market. That means the technology—I like to emphasize this—must be simple to understand for the average recreational diver.**

If you look once more, here is a general graphic that illustrates how the system works. I think we have to talk about this. We have no oxygen sensors in it. I'll explain why. We have no CO2 monitors in it. We have no electronics at all, because first, we had a lot of experience with semiclosed systems with mechanical working systems for all of these last years and the units work fine. We're concentrating more on the things that make the unit usable by the recreational diver. For example, the military unit has a manual bypass. The Atlantis works with automatic bypass. So, if this breathing pack collapses, the automatic bypass will work and will add fresh air from the cylinder. Or, another thing to make it easier, we have plug-in connectors to make it easy to assemble and disassemble. We have this exhalation bag here and this works like a water trap, so if there is water in the system, you will hear it. There will be gargling behind you, and if more water comes into the system, and the canister is flooded then you will lose buoyancy, and the breathing resistance will climb so that the automatic bypass will work the whole time. That's also the indication of reduced buoyancy, so you know that something is wrong with my system. And the last thing is when water's in the system, the exhalation breathing resistance will be high so that your overpressure valve—will work the whole time. So we have thought about a lot of problems and have worked to solve them, so that the machine deals with the problem and so that users can concentrate on learning to how to use the unit.

The Atlantis uses nitrox breathing gases, it's a constant flow supplemented by second stage, CO2 scrubber canister and integrated buoyancy compensator—you must have a buoyancy system to feel comfortable, to be in the right place at the right time as far as buoyancy situation. Final, we required that there be a bailout system on the unit; if something went wrong with the machine, you can switch off over to the compressed air bail out system.

So, let me finish with one chart. We have learned this day that rebreathers require a lot of different things, but sometimes it requires also a new way of transportation. [A picture of a pair of cyclists wearing Atlantis units]. Thank you.

## Biomarine

**Dick King:** Hi, I'm Dick King, Biomarine, and as you can see, I'm dressed for the occasion. I really wasn't prepared for this. For those of you who aren't familiar with Biomarine, we've been called a number of things over the years. We were founded in 1969 by a group of GE engineers that were involved in the space program and when that program lost a lot of its funding, several of these gentlemen, primarily an individual by the name of Fred Clarker started our company.

At that time, we took the technology that was meant for the space program and applied it to underwater systems. We developed the unit that was known as the CCR1000, and from that unit came the Porpoise Pack One which was in fact a CCR1000 that was modified by Inner Space for their particular uses. We got involved with the US Army in about 1974. They were looking-, the Special Forces were looking for an underwater rebreather and they adopted the CCR1000 design.

Just after that in about 1975, actually about a year, or a year and a half later, the US Navy became involved through the Special Warfare Group. What we did was to take and militarize the CCR1000 which hence became known as the Mark 15. We designed and built about between six to seven hundred Mark 15s in the span that we built them.

Then EOD came to us, I guess in about 1979, and asked us to design a unit or essentially take the Mark 15 and give it some non-acoustical, non-magnetic characteristics for a particular EOD mission. We did that. A lot of it involved getting rid of some of the mask in it, such as the stainless steel center sections. We had to get rid of the electronic solenoids which violated both the acoustical and the magnetic signature problems and we did that with the Piezo electric valves. We started building and delivered the first Mark 16s in 1985. We actually started building them before that, but their first deliveries were about '84 or '85 [Note that Biomarine Industries built the Mark 16, which is a differennt company than Biomarine Instruments who is buiding the CCR 500—ed.]. We built two contracts, and then in 1989 we were low bid, and hence Carleton Technologies builds the Mark 16 today, because the Mark 16 design became the property of the US Navy. So, that's just to give you a little background on Biomarine.

For a period of time, we were known as Rexnard, from about 1980 to 1988—beginning of '88. Then, my esteemed colleague over there, Derek Clarke, who was with Pressure Products bought us at that point in time, and for about I guess about two and a half years we were associated with them. And then, we went off in separate directions after that.

Over the years we have not just built the diving equipment; we're also in emergency surface breathing equipment. We built what was called the Biopack 45, the Biopack 30, the Biopack 60 and the Biopack 240. I'm giving you a little bit of background on this because I'm trying to explain where the market is today. The military market is very exacting in that a unit has to do certain things at certain times, and the operators have to be trained within specific boundaries and perform within those boundaries, and there's really not a whole lot of discretionary decision making in the way they use those units. Whereas in this type of market [the sport market], there's a lot of other things that enter into it, such as cost, time—getting a mission accomplished on time—because there's money involved for the individuals, and so there's a different discipline involved here.

The Biopack units that we built were—are a controlled unit as well. They're controlled by NIOSH, they are all tested and certified by NIOSH, and so, everything that we have made has been tested, tested, tested and re-tested over the years.

Where we are today is back into the diving business. This is sort of Deja vu. In January of this year, I attended the tek show, primarily to find out if we really wanted to do this. Because there were a few individuals out there, many of you in this room, that have our products, and are using them actively—primarily the 155 and the CCR1000s. So I attended the show and I saw a little of interest, but I still wasn't convinced. And as time went by, I had more people contact me and say, could you build this type of product. So what I did was I went out and offered the 155 style unit for a price in order to find out if there was a market at that level. And I found out very quickly that there wasn't any. I realized at that point in time that if we were going to offer a product to this market place that we had to approach it in a different way than what we had been doing it with the military.

So what we did was to take the Biopack design that we have built for many years—the Biopack 240 design and adapted the scrubber center section design of that unit to fit the diving profile of the 155 unit. And so essentially what you have is a downsized version of the CCR155. The reason we did that, (I'm running over and I have to end; I'm getting a signal here), the reason we did that was that we said, rather than sit here and try to redesign something, why don't we take what we know works, what has literally a decade and a half worth of data on, and offer that to this market place and that's essentially what we've done. And so if you've ever dove a Mark 15 or a Mark 16 to some degree, or a CCR1000, the CCR500 which is the new unit, does in fact operate like those units. Basically it is exactly like those units except in a downsized version and portions of it are different from the Mark 16, because that design is owned by the military; we cannot copy that. In a nutshell that's where we are today. We're offering the CCR 500 product to the market place for $5,000. That's considerably less that the thirty to forty thousand dollars we sold them to the US Navy for. Thank you.

## Desert Star Systems

**Marco Flagg:** I am Marco Flagg, with a company called Desert Star Systems up in the Monterey area in Northern California. We specialize in underwater navigation. We have a variety of underwater navigation systems. However a while ago, a very pesky individual by the name of Rod Farb decided that because of the great computational flexibility of our underwater navigation system, it would also make for a great decompression computer for rebreathers. So we charged him a few hundred dollars and developed the software necessary to make a go out of that. The result you see here is the Dive Tracker computer set up for rebreather diving. Of course the big difference between a rebreather dive computer and a regular dive computer is that the rebreather computer has to know the oxygen level, and therefore the inert gas level in the rebreather. This computer does just that. It interfaces to the port that's named Sonar right here, which is also the Sonar interface of the unit for navigation. It interfaces to the rebreather.

This is some of the data that you get out of that unit. Some of it is fairly standard. This display looks like that of many dive computers. You get your depth and you get your no-stop decompression limit here. You get a graph of your depth profile and a tissue loading display. There's a variety of other graphs. Here is the partial pressure of oxygen in your system. You see the status of the three oxygen sensors. And a lot more.

So this unit essentially provides you with a very large degree of flexibility in decompression computing. The software is based on the ZHL16 algorithm from Buhlmann, but you can modify the coefficients yourself if you want to. You can enter conservative factors to reduce or increase your risk and reduce or increase your decompression obligation, so there's a great amount of flexibility in here. It's a system that's somewhat expensive so it's really meant for a user who does not has a requirement for these specialized capabilities.

The unit that you see here is quite a massive construction. It's good for use at depth to 1000 feet, and it's also shark proof. This unit here has been bitten by a great white shark and if I hadn't worn it at the time, I wouldn't be standing here right now, so it's a good thing to have when you're diving shark infested waters. Plus it really does make you look really cool.

All right, so let's talk about some other aspects of rebreathers and some more of our home territory here which is underwater navigation. Now one of the aspects of rebreathers is that you have a greatly extended bottom time available to you, and if you're swimming at even a reasonable place, you're going to visit parts of the ocean that you've never seen before. The question then becomes, well, how do you return home? And this little system helps you with doing just that. This is called the Dive Tracker Sport and it's a very simple and effective navigation system. It consists of a transmitter here that you may secure to the anchor line or hang over the side of the boat, or attach to your buddy, or to any other point that you'd like to relocate, and you carry a receiver that has an LED display on it. And you just point the receiver around until the greatest number of LEDs lights up. Now you are pointing in the direction of the transmitter. So you can easily return home and it's a very effective little system for this application.

This graph shows the transmitter on the boat and the diver underwater. I want to end with a view of one of our commercial products which is called the Aquanet System. This is an example of how two different technologies can be combined to provide you with some very unique results. This is one of our customer companies called Envirotek Diving Inc., up in Seattle. They contract out with people like fish processing plants for example, to do environmental studies for them which are required under regulations from the Environmental Protection Agency. If a company, like a fish processing plant emits wastes, such as fish waste into the water through a pipeline, then they are required to survey the impact on the ocean environment on a regular basis. Once a year is the typical requirement. The divers have to go down and survey an area which may be, say, a kilometer by a kilometer in size, or a half a kilometer by a half a kilometer or whatever. Within that grid there are thousands of well-defined points each of which has to be visited once a year, and the accumulation of waste and the nature and the type of the waste has to be surveyed at these points.

Traditionally, the job has been done with survey lines that are laid out on the ocean floor. It's a very tedious setup to do that, and there is very poor quality control, because the accuracy of returning to a specific point depends on the qualification of the diver and you have no good control over it. So this company switched to one of our systems which essentially consists of these little base line stations here. These are cylinders that have flotation collars around them. They float in the water column. They are your reference points. Then they go around propelled by their scooters, that has a Dive Tracker attached to it, and the Dive Tracker tells them where to go. It says to go 20 feet, direction 257 degrees. And it tells you how far you are away from it. You arrive at the point. You take your observation. It records where you are. It records the accuracy—the error—of your position measurement and/or the observations as well.

What this technology offers in combination with rebreathers is that the individual diver, who now can have a very extended bottom time, can cover a vast amount of territory and accurately measure a number of positions without much support (no more main lines, and such). So this is an indication of where navigation technology and rebreather technology combined can provide you with a whole new set of capabilities. And that's about it for me.

**Derek Clarke:** .It's Derek Clarke from Divex. And I've put this rig on the deck here. You're not going to see it very well, so I'm going to put it on in a minute. But before I do that, I'm just going to show you some pictures which if I've got it running are going to be coming up next. What I've actually got with me, and what we can dive tomorrow is a rebreather called the Stealth Leader. This unit has a demand bail-out built into the mask, because it's a dual mount mask. As we talked about already today, it has oral nasal and a bite mouthpiece on the inside at the side of the siphon You can go from closed circuit to open circuit with a quarter turn of this valve.

Now you can't really see very much on this picture, so I'm going to quickly go through it quickly to give you a feel for the size of the overall package. It is nominally a four hour duration set in this form here today. This version is not non-magnetic. It has a relatively conventional solenoid valve. There's another version that has a Piezo electric valve. It can be configured as a two or four hour duration, non-magnetic or magnetic with either open circuit or a semiclosed bailout. In both cases, there is a fully closed primary system.

I'd probably better explain it while I'm wearing it, because then you can see the various bits and pieces about. We deliberately wanted to configure it so that we could get as much equipment in as small a space as possible. That was one of the objectives if you recall from this morning that we set out at the outset was to create a swimmable set. Therefore the low profile was essential as far as hydrodynamics were concerned. And it's fully closed, because we wanted to make it as small as possible.

And what I'll do is I'll quickly cheat and take the breathing hoses off. Now I'm a little bit inflated here. Please bear with me a minute, I'll get fully dressed. [Clarke finishes dressing in the Stealth system.]

I'll just go through the essential elements and on this side. This is to do with buoyancy control. In order to make it a good swimming set, we wanted to have excellent trim capability, so we can inflate and deflate the buoyancy jacket. This is a Buddy Commando jacket which some of you will be familiar with. It also has its own gas supply that fills the bag from here. If I press this valve it will be filled from the diluent cylinder as it's currently configured. On this side is the display, and this is where I can switch the thing on or switch it off and it tells me various stories about what's going on. It's currently going through a start-up sequence. And while it's doing that, if I can find it, which I might not, [anyone see a little blue thing around here?] do you see some lights flashing there? That's called a status LED. It'll sit there and blink away; green right now. That normally sits up in a receptacle in the mask which is here, and that's what keeps you informed of what's going on. And ordinarily you want it to be continuously green. If it starts to flash green, it means you've got some sort of alarm condition which may or may not be serious. But if it doesn't goes away, you can interpret it as being serious.

This is the back-lit display which provides all sorts of information. It currently tells me I'm probably going to die. But we won't worry about that at the moment. This is the diluent bypass. If you press this it basically bypasses this contraption in the center which is the diluent demand valve. Ordinarily, it's an automatic addition demand valve, coming off the diluent cylinder which is on my left side.

What else have I got on the front here? A couple of weight pockets with a release. That's the emergency fill for the BCD. There's an over pressure relief valve up here, you vary it from 6 to about 50 centimeters of exhalation pressure on this particular valve. Although you can't see it, there's another valve under this side. These are my breathing bags [He exhales and inhale. This is the diluent side and the oxygen side, an electronics module in the center, and you can see the scrubber at the top here. The electronic sensors are on this right side so you're monitoring the oxygen content of the gas prior to expiration through the inhalation lung.

There are very good water traps in both locations. There's a water expulsion arrangement utilizing either this valve or a hidden valve that's underneath the bag here on the inhale lung. By the way, you can expel water that accumulates in these bags.

What else do I need to tell you? That's about it, I guess. All right. That's it.

**Unidentified:** Where's the O2?

**Clarke:** You did observe there are no cylinders in here. They are being filled for tomorrow. Normally the diluent goes in this space and the oxygen lives in this space, OK? There's a diluent regulator down here, and a oxygen regulator here. So ordinarily, between dives, you exchange these and renew the scrubber at the top. So the breathing loop becomes very open at that point. And it's quite relevant to the cleaning situation we talked about before. Any more questions?

**Unidentified:** Can you operate the O2 or diluent add-values manually?

**Clarke:** There is a manual diluent add valve here. It doesn't have an O2 add valve. It could have an O2 add valve. But it doesn't. It's a philosophical issue. If you had it there it could cost your life, if it failed. But it's a debatable point whether you have one or not. This system doesn't have an O2 bypass. If someone was passionate about having an O2 bypass, they could have one. It comes back to money—we've already heard that today. Engineers could give you everything if you pay them lots of money. Any more question? Thank you.

**Menduno:** I'm going to open it up for questions. Now's a good time to ask questions of any of the gentlemen up here. Dan Miccio, OC LUGO, one of our thoughtful sponsors.

## OC Lugo

**Dan Miccio:** I don't know how many people here in the audience know who our company is. [Miccio points to the mike] Oh, it's not on? It is on. Hello. We represent Molecular Products who manufacture Sofnolime and I hope that everyone here is familiar with the material. Our company has been involved with Molecular Products for some eight years now, and our efforts have been to support this particular group and Mike's efforts. I know you had some questions before regarding shelf life—and what have you. And I'd just like to basically give you an overview of what we do:

We are chemical manufacturers OK. We supply chemical materials to manufacturers of equipment. We do not manufacture equipment. We offer technical assistance to rebreather manufacturers, people who are working in different types of safety devices, whether they be open circuit or closed circuit, mine safety equipment etc. Our testing and the information we provide is based on tests that we've done on our product. So when we supply a keg of Sofnolime to you, that material is supplied with a specific expiration date. I know that was one of the questions that came up earlier. How long does the material last once you open that keg? Can we leave it out? Can we leave it in our canister? Those are not questions that we can answer. What we can say to you is that if you buy a keg of material from us, it'll last three years from the date that we manufacture that. That material, once it's opened, and how it's handled after that needs to be, for lack of a better explanation, considered by yourselves. If you're leaving it open and there's a high CO2 level, or it's not packaged properly, those are things that we can't predict. I'd love to answer any questions that you might have regarding our product.

## Disposing of Sofnolime

**Russ Peterson:** I had one question about the product. When it's expended, what precautions do you need to take to dispose of it? How do you dispose of expended

Sofnolime?

**Miccio:** That's a question that's often asked. It really depends on what your particular state's EPA criteria are. In certain states, if the material is completely exhausted and there is no alkaline material left in it (for this particular application, there will be some residual alkalinity), the law is pretty clear. You need to be able to test the material at some level and dispose of it. In most cases, we've found that material is easily land-filled. i.e., it's disposed of in an appropriate fashion.

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## Is CO2 absorbent caustic?

**Clarke:** I have a question for Christian and yourself. Does Dräger supply material that does not in any way cause a caustic solution when it's wet? I've heard this rumor. Is this so?

**Schult:** This is sheer rumor. What I explained to you before is that there are so many safety functions in the system, like alarm systems that let you know when water is in. OK, we have our DiveSorb material which we use on the unit and which we have tested on the unit. It's in the form of pellets so, there's not much dust and so it's not so dangerous when you mix it with water in the system. But its' not a material that you can say is not caustic.

## Different absorbent with Atlantis?

**Menduno:** Christian, I know that you specify—your marketing agent specifies using DiveSorb with the Atlantis system. In fact, I was talking with Rick Lesser about it; whether using a different absorbent, would somehow create problems—liability problems.

**Schult:** Liability problems?. We have the product liability of the unit, and it must cover everything. And we have a CE mark for the unit and we tested the unit with the our material and so on, and have done a lot of test work. The technical data we have can only say yes, the Atlantis works with our absorbent.. Therefore, we say, use it. It's very good because we are producing a special mixture for rebreather systems. Each production lot that we produce is tested in the unit, underwater, under pressure conditions. So, we use it, it is in the frame of our technical data. I can't speak for other products.

## Suggested retail?

**Jeff Bozanic:** Some of you have mentioned prices of your units and some of you didn't. For those of you that didn't, would you give us what typical prices might be for a configuration that might be appropriate for a recreational/technical diver? Just for comparison purposes?

**Menduno:** Let's go down the line. Do you want everybody, or just rebreathers, or just the whole gamut?

**Bozanic:** The whole gamut.

**Menduno:** Suggested retail.

**Morgan:** [S-1] Under $600 is the price we're shooting for suggested retail on the mask.

**Wehrs:** On the underwater comm systems, it's between $500 and $600 for the sport unit. On the commercial military side, it goes up to about $15,000. It depends how far you want to talk.

**Readey:** The Prism II is just under $8,000.

**Sherwood:** The SIVA 55 in its magnetic version is about $20,000.

**Schult:** I don't want to tell you prices for the US market, but I know that you can buy the Atlantis in the world region for under $4,000.

**King:** The CCR500 is $5,000. We will, in fact we have built a couple of similar to the 155 this past year and delivered them, and we gave those away at $13,000. If we were to build those today for someone, they would be in the range of about $20,000. We also will have and Marco sort of hinted at this. But as of January, we will have a downsized version of the dive computer portion of the Desert Star Dive Tracker that will be available with our unit. We expect to be showing that at the DEMA show in January. Booth #1688. [laughter]

**Menduno:** Will it still be shark proof?

**King:** Yes. Smaller sharks.

**Flagg:** OK, well, our systems, the Dive Tracker Sport that's a navigation system retails for $498. This computer as it stands right now is $3,000. I think Dick King will sell the version we are building for him for substantially less than that. And for those of you who are interested in that precision mapping system, that is right around $10,000.

**Clarke:** Bev said a little under $600, the Stealth is a little over $600. We do not have plans to have a rebreather for sport market available in the near future and it's not because we don't think there is a commercial opportunity. The meeting so far, in the last couple of days has not changed my view that we're fairly well away from having a mature enough market in terms of the infrastructure, training, and knowledge of the products to really take the risk of entering into it. So, I applaud those of you who are bold enough to make an investment. We probably aren't. If you ask the question, really, we would be competitive with John's product [Laughter].

## Testing, one, two, three

**Menduno:** We've heard a lot the last couple of days about testing. Christian talked a lot about testing and verification. We'll have a session about that on Saturday. I'd like to know how many of the rebreather manufacturers plan to have outside some kind of verifiable outside testing to support their specifications for their units? One, Two, Christian, everybody. So that'll be just something that's done. OK.

## Export restrictions

**Rich Neiswonger:** Hi, Rich Neiswonger, potential end user. Are there issues to address with United States export restrictions for closed circuit units?

**The closed circuit unit, under [U.S.] regulation[s] is considered to be a weapon in the Weapons Act.**

**King:** The answer is yes. The closed circuit unit, under that regulation is considered to be a weapon in the Weapons Act. I recently spoke with some individuals at the State Department and they believe that because of the nature of this particular product—and that's not decided yet—but they believe that because of the nature of this individual product [CCR 500] and its non-military construction, that it will not fall under that category in the future. But at the moment, we could not export that without getting an export license to do that and we have to apply through the State Department for that.

**Schult:** This is world wide. There are world wide regulations, all NATO and NATO allied countries have these regulations, so that not only closed circuit, but also semiclosed. All rebreather systems are under this guidance and you must call for export license before you bring it out. So if I want to travel from Germany to here, I must have an export license. The authorities are opening it more and more, and we have been in discussion for a long time on this. In the future, they want to distinguish between military and recreational use. But still, we have to fulfill this regulation.

**King:** I might add one thing. If you are an American citizen and you've taken possession of this unit, and this is your own personal unit, you can travel with this unit as long as your intent is to bring it back with you. You cannot sell it, because then you fall under the same restrictions.

## Back mount versus front mount

**Rob Cornick:** Good afternoon gentlemen. Lieutenant Rob Cornick, Royal Navy, fellow survivor with Mike Harwood of the RN system. He's just proved that again all technology does work. All of the manufacturers we're seen today have been sort of selling us back-mounted rigs. It's a well known fact in combat swimming that a front mounted rig swims a lot better. You pay pains for the endurance, obviously. To get the endurance and the mixture, it's got to get bigger. And are there any considerations from the manufacturers to provide us with a bigger front mounted rig, or are you going to stick with a back mounted rig, purely because it's what the scuba diver is used to?

**Schult:** We have no plans.

[Laughter]

**Sherwood:** Even within the combat swimmers, there's debate on whether or not they want to have a front mounted set. They're still going back and forth, but I mean, in terms of where you want to have the breathing bag, that's up front. If you've got a lot of weight and a lot of packaging to do, if you strap that on front, you know, the guy's going to go out of balance. So throw that stuff on the back.

So, no, we don't have any plans to introduce like a deep diving set based on a chest mounted design.

**Mike Cochran:** Nor do we.

**King:** We don't either, but in addressing the issue of back vs. front, it also depends on the mission. So, if you're in the EOD community normally it's best that it be on your back, rather than on your front, so that you can address the real problem at hand.

## Constant PO2 decompressions

**Menduno:** I was intrigued by something you said today, Dr. Thalmann. I understood you to say which was if you took a decompression table based on just a constant fraction of oxygen, and just substituted in a constant PO2, that table wouldn't necessarily work well. Did I understand you to say that? Okay. So I was curious for the manufacturers who all have integrated dive computers, how you relate to this statement. That is taking a Buhlmann algorithm and just changing the math to make it a constant PO2—doesn't necessarily work well Obviously we don't have a lot of dives on these systems yet, so we don't have a lot of input on how well these tables work, but, anyone want to comment on that?

**King:** I agree with your statement.

**Menduno:** It's a good question. I mean is that kind of approach—take mathematics and tweak them a little—that you're using.

**Flagg:** Personally I think it's a good question. We are really supplying more the electronics of the decompression computer and then relying on published academic data like Buhlmann. That question really needs to be raised. Now what the answer to that is, I do not know, and I would hope that maybe the academic community would shed some light on it and make it public. One thing that has bothered me a bit in the current generation of dive computers, is that none of the manufacturers will tell you exactly now their algorithms work. And I find that slightly disturbing because essentially you're relying on a safety system but you don't know exactly how it works. It would seem better to me if everybody could rely on such safety and decompression systems that are well published, that are public domain, so everybody knows just what you are dealing with.

**Derek Clarke:** For our part, we asked Bill Hamilton and Russ Peterson, who's here today, to produce some tables for us. We have tables; they're not validated and I think that's important to know. They are not validated tables; they are tables. There are some good questions to be asked. But our role has primarily been to develop the set. It's probably going to be the case of the military will have their tables and they'll be known within the military community. And then sort of providing the equipment to be demonstrate to stay within the constraints of that table, there's your match. Because certainly to produce military acceptable tables as a private manufacturer is totally out of the question.

**King:** I just want to add one other item.

**Peterson:** Could I just add something first.

**King:** Yeah, go right ahead Russ.

**Peterson:** Thank you. Those procedures were interpolated from some established approaches and done on a worst case basis, given the information that Derek had generated about the kit, so we would expect them to work well. We would still think that some sort of validation program would be appropriate for them.

## The cost of liability insurance

**Unidentified:** As a percentage of cost, how much is the liability insurance?

**King:** Well, that's all related to the amount of units that you sell, of course. Initially, we're taking a very large hit per unit. The idea is that if we make a unit available and make it affordable, that the market size will grow, thereby spreading the cost over a larger area of the market. At the moment, we couple this in with everything else that we do so it's not just that product supporting the cost of it, but it approximately doubles our insurance rates by coming out with this product.

## The precision in oxygen control

I just wanted to answer one thing relative to the control. One of the things I think that we've not touched on is these units are not that precise. None of them are, as far as control points—controlling ppO2. So there's inherent errors, particularly in using sensors. There's built in errors in the sensors. There's built in errors in the electronics, because you have an accumulation of error in components. So you can have as much as a 10% error in these units, and so based on high set points, you're talking about a tenth of an atmosphere, roughly in that area, so that you do have that kind of error. So when you consider that, you should calibrate your unit accordingly.

**Cochran:** Well, I think I would disagree with the 10% perhaps, at least in our unit. When you calibrate the ppO2 sensors, the entire system is calibrated to within 1%. The ppO2 control, due to our unique control system, is extremely precise and very, very responsive. And we manage to keep very, very tight control on ppO2.

## Varying PO2s in constant PO2 tables

**Bozanic:** I have another question dealing with the decompression aspects. And that's that several of the systems appear to have no sensors in them, and yet the decompression tables that are being used are based on a constant set point. I think David Elliott and others have mentioned the fact that that set point actually varies to a significant degree. The question I have is how valid are the tables at that point in time, and do we have any operational history that's indicated that perhaps the tables are problematic with respect to incidents of any kind of decompression illness.

**Sherwood:** Were you referring to semi closed systems?

**Bozanic:** I'm referring specifically to the semiclosed constant mass closed systems.

**Sherwood:** Yeah. We produce such a unit, and the tables have been developed and validated by the Department of National Defense through Ron Nishi at DCIEM. So, we provide the conversion factors that are to be used in calculating your EADs and those have been validated in chamber dives and also are backed up by the operational dives that the Canadian Forces do.

**Schult:** We, as a manufacturer are not producing any decompression tables. We are listening to what the experts out of the decompression world says. As Max Hahn mentioned before, you can calculate your decompression using an 80% factor on your gas mix. So that's yeah, that's the line.

**King:** I don't make semi closed.

**Menduno:** Christian, is your unit specified for decompression diving or just no-stop diving?

**Schult:** You can do decompression diving, but the most benefits you have are with non-decompression diving. And it's good that you say this. The main advantage of this unit is in diving depths from around 20 meters, to have long no decompression times and be on the safe side every time. To go deep with the unit, and to be in the decompression phase, you will lose a lot of benefits of the unit.

**Menduno:** Other questions? You guys can ask questions, too.

**Mike Harwood:** It's Mike Harwood. Since we're coming to the end I'd just like to say thanks to Bev for doing something which we in the UK are now saying to commercial divers, you will use communications and if you're on scuba. You will use full face mask if you're going to have to do that. I think this is one of the most exciting developments we've seen in safety over the last five years. And I'm not taking away from the other guys who are going into the sort of long term future of rebreathers, but there are two developments there. There's the dual mode system which is on the Divex unit, and if you fitted that into Bev's mask, I think really we'd get all the problems solved. Wouldn't we? Should there be a full face mask or not?

**Morgan:** Thank you, Mike. I might say that that guy right there [Michael Menduno] is probably the one that is most responsible for that mask because he got me out to one of these meetings so I could find out what was needed. And my daughter, actually, did the last design configuration on the unit. I ran across something that I couldn't beat. My design had like a duck bill that opened and closed, but I couldn't get the separation that I wanted so you could put it on like your standard gear, and she developed the module that comes off.

## Oxygen fittings

**Unidentified:** I just have one logistics question for the semiclosed manufacturers. What types of valves do you plan on putting on the oxygen cylinders? Are you planning on standardizing on yoke, or DIN fittings or will you be using something a little less standard?

**Sherwood:** For oxygen at 3500 PSI we use DIN fittings. Yoke fittings are restricted to 3000 PSI.

**Schult:** And in connection to the amount of oxygen we use in our systems—up to 60%, we have these this new requirement of the EN 144 so that you can't change compressed air with nitrox.

**Harwood:** don't want to get into an argument here, but it's a European standard. It is still a proposal. That's all it is. And it's been pushed. PPE is causing us a lot of problems in Europe because diving just seems to have to ride on the back of surface equipment. And as I suppose I'm going to get into trouble again, there are some pretty dumb things being done at the moment, The diving standards group that I work with, doesn't want to start using these proposals until they are finalized. I guess there's going to be a lot of European blood floating around again. All I'm saying is it's a proposal. It has not yet got a yes vote. And I'll say it up front now. Ours is a NO vote. [Audience claps]

**.. give [divers] a fitting and say this is the one you're going to use, and they get somewhere and they find it doesn't fit, they are very quick at making adapters. . . . Let's go with what we've got, go with what we're familiar with, and make sure that if we use it where there's oxygen present, we keep it clean. There's no need to mess around.**

**Schult:** But Mike, it's very important to know and we notice this in the past—all over the world, in each country you have other regulations or you have no regulations. It's difficult sometimes to go with the system into the country to get nitrox or to get oxygen. Sometimes a regulation must be made. So at this moment, this is one of these regulations. We think it's necessary that there are regulations to use oxygen in a safe way, and not mix this with compressed air.

**Clarke:** I know the regulation that Mike's talking about it and he's quite right and there are some real engineering civvies in it. I'm not actually sure what's stimulating the need for change. In that rig, there is a DIN oxygen fitting on one side and a DIN air fitting on the other side and they're not interchangeable. The DIN air fittings are the same that everybody else is using are DIN air, and have been for some time. You wouldn't be using DIN oxygen, because you haven't been using oxygen, typically. But they are two perfectly good fitting standards and I don't quite know the logic as to why Europe's changing again. Why are you changing it Mike?

**Harwood:** It's being driven by the surface group. There are some countries in Europe that use nitrox and oxygen for surface rebreathers and for surface systems in respiratory protective equipment. And there are two arguments which we're putting up, and one is that in diving you tend to take your cylinders or "transportable pressure receptacles" away from the equipment when you're carrying them around, whereas when you're looking at surface emergency equipment you tend to keep the two together. So you don't mind too much. These new fittings that are coming out have got a male thread on the cylinder valve; you could put protectors on them. Everybody knows that. People have put thread protectors [on valves and] the first time use it they've gone out the dive bag and you don't use them again. That's the first thing I think is wrong. The second thing is, when you look at the drawings—I'm no engineer, I trained as an engineer, but that was ages ago—but I can read the drawing and I can assure you, that if you look at what they've done to adapt what was a sensible piece of equipment to meet the standard, and you look at the thicknesses of some of the material, in machining it you can make a mistake and whittle it right off the end. If that's going to be a high pressure fitting? Jeez. Not on any set that's going to be used around me! And it sticks out from the shrouding. I mean, there are just some real dumb engineering things there that have nothing to do with whether it's safe, or should the diving market go that way. We've looked at it from an engineering point of view, and in fact, Gavin sits on the same committee. He's like me officially we're not supposed to have a vote, so it's the manufacturers. But we open our mouths and tell people what we think and they can take it where they like it. As far as I'm concerned, it's in the letter that's with my recommendation through the Health and Safety Executive that hasn't been signed out yet. But quite clearly as far as I was concerned when I drafted it, it says "No." Don't do it. There's one interesting thing with divers: you give them a fitting and say this is the one you're going to use, and they get somewhere and they find it doesn't fit, they are very quick at making adapters. We don't want a proliferation of adapters. Let's go with what we've got, go with what we're familiar with, and make sure that if we use it where there's oxygen present, we keep it clean. There's no need to mess around. But it's driven by this surface group. They just forget us all the time.

**Menduno:** If there are no more comments, we are going to wrap up for the evening. Tomorrow, we're going to be right in front of the Hotel across the street from the lagoon with the little slide on it. You can't miss it. The ocean I think is 65.

# Military Operations

*"Why should civilian recreational diving agencies look to the military for advise on rebreather diving? The military has been using rebreathers for about 50 years, starting with the OSF back in World War II; and has probably made just about every mistake that it's possible to make with these things."*

--Sgt. Jim Brown

## Session Summary

The US military and others have been diving rebreathers for more than 50 years and as one panelist pointed out, "... have made just about every mistake in the book ." This is one reason that makes their experience so valuable.

In this session, military representatives discussed their experience with rebreathers from an operational perspective, including diving protocols, organization, and the need to maintain proficiency. The panelists emphasized repeatedly that rebreathers have insidious problems rarely encountered in open circuit scuba, such as hypoxia, hyperoxia and hypercapnia, which can quickly turn a pleasurable dive into an accident. It was pointed out that sport divers need to realize this fact.

One of the problems identified from an operational point of view was the capacity of human error. Panelists discussed how the military tries to offset human error through the use of checklists, supervision and dive teams.

The unanimous panel consensus was that rebreather diving should always conducted with a buddy. It was also emphasized that full face masks could be an extremely useful safety device for rebreather diving. The panel was chaired by Michael Menduno, and consisted of; Jim Brown/Special Forces Underwater Ops, Lt. Jason Gilbert/USN and Randy Poladian/EDU.

27SEP FRI 3:00-4:00 pm:

# Transcript

**Menduno:** Before we get started this afternoon, I'd like to thank our luncheon sponsor, Orcatron Communications, for the great lunch over at the lagoon today. That was fun, wasn't it? I hope that you all had the chance to dive the systems that you were interested in.

I was going to introduce the members of the next panel, but I was informed that if I told you what these guys actually do, they'd have to kill me, so I'm going to let them introduce themselves.

**Randy Poladian:** My name is Randy Poladian. I'm Chief Warrant Officer at the Navy Experimental Diving Unit, in addition to being the Naval Warfare Projects Officer. What does that mean? I handle the paperwork, and make sure things go smooth when it comes to Spec War life support systems. I'm not here to tell anybody how to conduct their business. I'm not here to advise you about Navy policy or anything like that. I'm just going to give you a brief insight on how we conduct business.

I was introduced to rebreathers 20 years ago when I went through SEAL training. That's when they had the Emerson and then the Mark 6. I started diving the Mark 15; and eventually, when I got to EDU, the Mark 16. One of the most important things that needs to be done if this type of diving is going to be introduced to the sport divers is to get their attention right off the bat, and explain to them that this is quite a different ball game than scuba diving.

How do you do that effectively? You need to put together a comprehensive package with standards and present it to the community so they can understand it and have the necessary respect for rebreathers.

Yesterday, I was trying to figure what I could compare this to. Do you remember when you were getting ready to drive a car, how excited you were, and what you had to go through before you could drive that car. You probably were shown those gruesome Drivers Ed movies that showed how serious it was. Of course, we don't want to go to that extreme—we'd never get the guys in the water.

When I was in training, we started diving the Emerson, and I remember on one of the dives we went through these 6-foot boomers in San Diego during a surf entry onto the beach and one of the guys never made it. That got my attention right away—this is pretty serious stuff. I think we need to address it in an appropriate fashion. That's probably half the battle right there.

I want to take you through a typical fleet diving training scenario. In order to teach a course, it first has to be approved by the Commander of Naval Sea Systems Command and the Commander of Naval Education and Training. That's where they scrutinize the instructor and student guides and approve it before it gets taught. There's an involved selection process for the students that are going to be going through the training. They go through medically screening, to make sure they're physically qualified; and then a physical screening test to make sure they have the endurance to go through the training program. Of course, they have to have a certain amount of academics so they can make it through the diving physiology.

## LAR V course

Courses of instruction include Open Circuit, Closed Circuit, Mixed Gas, O2, and Semi-closed. The course I'm going to talk about is the Dräger LAR V course taught to me at Special Warfare. That course is 93 hours, just to give you an idea of the length. It includes theory, lab and open water. The course covers O2 exposure limits, including single-depth dives with transits and excursions and then it goes into the physical and functional description of the rig itself, and of course the life jacket that it's going to be used with it. Next they talk about the pre-dive procedures of the life jacket and of the rig; donning procedures, purge requirements, and dive rescue procedure. We talk about post-dive operations, the maintenance involved and a little bit about operational planning: how to maximize the time on the rig—they don't get too involved in that during the training course. You get most of your operational planning after the course when you are assigned to a unit. Next are emergency procedures and safety: safety is of course one of the main focuses in the military diving because we don't want to have casualties. Because of the high-risk nature of the course, there is what's called a DOR—any time you want out of the course, all you got to do is drop. And there are "training time-outs." This allows participants to stop the evolution if they see something that's not safe. The open-water portion of the course consists of 19 dives, 6 of them at night and covers donning, doffing, purge requirements and dive resource procedures. You can go through this course and get your diver status, but that's really not the end—it's a continuing educational process.

## Military diving protocol

When we conduct a military dive, we always do a brief and there's a diving supervisor involved; he runs the show and is on top of who, what, when, where and why.

What the team is going to do, what kind of equipment is going to be used, who's doing what, the limits and the times of the evolution. And we always cover safety: emergency procedures, and lost diver, because if you don't and something happens, the first thing they are going to ask if these were covered.

**The one thing that's drilled into you from day one is not to break that Golden Rule, stay with your buddy.**

The one thing that's drilled into you from day one is not to break that Golden Rule, stay with your buddy. I'm sure everybody's probably done it one time or another-diving open circuit, but I'll you what: you start diving by yourself with a rebreather (and this is just Randy Poladian talking), I think you're just asking for it. Another rule is: Take care of your gear and your gear will take care of you.

**Lt. Jason Gilbert:** I'm Lt. Jason Gilbert. I'm available to discuss Navy applications of the Mark 16 rig. A little bit of background on myself. I was commissioned in the Navy about eight years ago and started out as a Fleet Diver qualified on all the surface supply diving rigs, save saturation rigs. Three years later I was put through the EOD School and learned to dive the Mark 16 rig. I've been an officer in charge of Mine Counter Measures Detachment since then. My unit is comprised of eight personnel. We've got four rigs in our inventory, that we maintain and operate. We've deployed to foreign countries with these rigs and taken care of these rigs autonomously, so if there's any logistical questions that you'd like to ask—how do you get around with the Mark 16, and field requirements-, I'm available to discuss some of that.

**Jim Brown:** I'm Sgt. Brown from Key West Special Forces Underwater Dive School. We teach Army, and Air Force combat divers. I'm also an IANTD trimix dive supervisor. And I'd like to see rebreathers come to market probably as much as most of you.

I'm trying to address my thoughts to technical divers, because they are the primary individuals interested in closed-circuit, mixed-gas rebreathers and the most challenged to come up with an operation that's safe and effective.

**The bottom line in military operations is to eliminate the human capacity for error.**

All levels of the market can probably benefit from some of the information on rebreathers that the military has to offer. At some point there are bound to be some failures out in the field, and with any luck it's not going to shut all of this down. If we can get together and come up with some kind of standards, maybe a committee could be formed that will help guide our efforts and the evolution of this technology, we will all be better off.

Why should civilian recreational diving agencies look to the military for advise on rebreather diving? The military has been using rebreathers for about 50 years, starting with the OSF back in World War II; and has probably made just about every mistake that it's possible to make with these things. As a result, this has stimulated a good deal of creativity within the military organization, in the form of procedures and organization. If some of these ideas are placed in the context of civilian operations, they might be able to enhance your operations substantially.

What aspects of the military diving operations are applicable to civilians? It's hard to take a look at military operations and find readily apparent, easy-to-use information. After all, the military has developed its way of diving with rebreathers to suit its way of doing business, which is a whole lot different than recreational diving. Some people have even suggested that since military rebreathers are different than the units that sport divers are going to be using, there can't possibly be anything to learn.

When I looked at the whole subject, including my training experience in the Army, I had to back away from all the details because they can actually overload you. It occurred to me that the military has stored its collective rebreather experience—what has been learned through its failures—in the principals and concepts that guide military diving. You have to step back from all the details and take a look at, for example, the operations chapter of the navy dive manual. I started there, with Volume 2: Mix-gas Diving. That's where it discusses rebreather diving, and I ended up being referred back to Volume 1, which covers air diving. What does air diving have to do with rebreathers? It's the fundamental foundation that applies across all military diving operations. I'm going to run through some of the key points.

The bottom line in military operations is to eliminate the human capacity for error. That's what you should be striving to do in your operations, if you want to be more than a relative amateur. In the military we try to eliminate human error by using checklists and supervision. These are very useful tools that you can put in your program. Supervision—not a dictatorship.

I'm not talking about a big hairy dive supervisor that stands up in front of you with his arms crossed, telling poor little old you, an independent tech diver, how to use your rig. The dive supervisor is there as a back-up, because putting two heads in the process can go a long way to eliminate the possibilities for error.

At our school, and at the dive shop that I dock with back home, we are constantly try to improve our program. Some of the civilian dive operations I am familiar with are outstanding. Others are minimal if not nonexistent in their operational development, and don't do much more than provide transportation to the site. That may be all right for certain types of recreational diving, but when you're talking mixed-gas closed circuit rebreathers, you have to cut out that human element 'cause it'll screw you every time.

I don't want to burn any bridges here. It'd be easy to get up here as a military diver telling what you what you can or cannot do, but that's not my intention. What I'd like to do is to stimulate some dialogue and ideas.

## Formally qualified personnel

Within the military, we have formal qualification standards. There's no Good Old Boy network in the schools. If any favors are done, they're done in the soldier's home unit that send him to school in the first place, but once a student comes to my school, if he's not performing to standards, he's going to take a hike. We have no problem doing that. We catch a lot of flak regarding our attrition rate because it obviously costs money.

I'm going to bring up a few negative things and I apologize if I anger anybody. But if the shoe fits, wear it; if you can benefit, take this example in context and make the thing work for you. Recently, a well-known cave diver approached a certifying agency concerning becoming a rebreather instructor. This agency, very appropriately, put together a package of standards and training requirements that he would have to meet, and of course a price.

Apparently, this guy hung up the phone and called another training agency; it appeared he wasn't satisfied. Over the phone, for a fee, this guy got qualified as a rebreather instructor. It would be an understatement to say that this is not an effective way to train people. In any case, this kind of thing impacts negatively on the credibility of our community, that is taking as a civilian technical diver, and it's doesn't set a very good example. This guy is well-known and the individual who gave him the certification is also very well-known. These guys are leaders and act as role models for their followers. That kind of thing has to be fixed; we simply cannot tolerate it.

## Team diving

The military dives in teams. You've seen pictures of the Navy ship with recompression chamber, gear everywhere, people everywhere, a big expensive equipment package and manpower package. We can't do that as civilians. Plus we're doing it for recreation. We don't want to end up paying so much money that it's no longer fun. There's a lot of different ways of doing business.

At a minimum, the military has support personnel, and you can apply the same concept to your operations. We use it in the shop I work at. We have a Dive Supervisor who is a support person; he can dive, but while he's topside he is supporting the divers in the water. Someone else might play Dive Supervisor for his dive; it doesn't mean that this guy is going to stay dry. The Dive Supervisor provides checks and balances to the systems.

On the LAR V, the Dive Supe supervises the negative pressure check, the positive pressure check where the rig is dipped to make sure there's no bubbles/no troubles. He checks the flow rate of the bypass valve, and he checks the one-way valves and the mouthpiece and the hoses. He can also give a really good dive brief. In our civilian activity, other people are in-water safety divers. I'm talking about deco diving. The safety diver meets the dive team at it's first decompression stop, and support them with gas. Everybody has duties and responsibilities. There's cross training involved so in case something unforeseen happens, another team member can jump in and fill someone's shoes without sacrificing the effective support of the divers.

## Comprehensive briefings

The military uses a comprehensive briefing. We talk about protocol, depot schedules, things like that; we talk about operating emergency procedures. We do this at the civilian dive shop and also in the military. It takes about 20 minutes. You don't want to put out too little information; you also don't want to overload it and put everybody to sleep.

## Procedures and standards

We have written procedures and standards. That's not to say that an operator can't interpret these procedures to a certain extent and make them fit his operations. Our written procedures don't say, "Take your right hand and connect the right buckle on your..." whatever; it's not that cumbersome. It's something to get everybody on the same wavelength. Checklists are part of that. The checklists are a real help because they cut to the bottom line, which is the human element, the capacity for error.

Our leadership works. Leaders have comprehensive knowledge of diving operations, whether it's rebreathers, open circuit or whatever. Role models within the operation allow people to grow, and at some point become supervisors themselves.

## Equipment familiarity

Military divers are thoroughly familiar with the equipment being used in the operation. A comment was made yesterday: "When I get cut loose with my unit..." That's going to happen; someone's going to grab the rebreather and be the only knowledgeable person on the boat and go dive it. If he makes a stupid mistake and forgets something, or doesn't notice something, or decides to accept a minor deficiency in his equipment which becomes a major deficiency, and it kills him, then that's a shame. Dive Supervisors are useful.

There are negative points about military diving that I would like to change. Open circuit procedures have been a weakness. Believe it or not, the Navy only requires a single second stage on open-circuit regulators. We don't have an octopus, so we're depending on our buddy for our safety.

By the way, we don't mix open and closed circuit equipment in the same dive plan. Because the open circuit diver can out swim the closed circuit diver. He can do more work without the same kind of detrimental effects; this is with the LAR V. Other rebreathers may very well not have that characteristic. Also, an ignorant open circuit buddy can't necessarily help his closed circuit buddy; what can he possibly do for him if he knows nothing about the apparatus that he's diving. About all he can do is to take his single regulator and stuff it in his mouth.

## The stress test

Now we stress learning confidence-building exercises to select our people. We require our divers be confident under water. They will drown just as fast as anybody else, in a time sense, but they will probably not panic as fast because they're able to think about what they're doing until they pass out. That's been demonstrated in quite a few cases. I've seen it in a controlled pool environment. Combat divers tend to be pretty calm and collected when the fit hits the shan subsurface; that's the kind of guy we're looking for, somebody that can work through the very complex reactions that are going to be required for complex equipment. This, by the way, may be a technique for assessing a students potential and suitability for your course? You can come up with a prerequisite program to allow you to assess candidates before they spend a lot of money, before they start training. It'll be a challenge. I'm not suggesting you adopt this whole-hog, because it's recreational, but it might not hurt to allow a little stress-loading in a controlled environment to sort of inoculate against your students against events that may occur in the open water and hopefully, by that means, avoid panic. Thank you.

**This piece of life support is like a weapon for a soldier during war, and you need to use it until it is nothing more than your hand or your foot or any other part of your body that you're able to manipulate. That's the standard.**

**Unidentified:** We all know that there are rebreather instructors out there that don't own a unit, and probably have minimum time on a rebreather. What do you think about the agency that granted them that certification?

**Brown:** I think an instructor should have, at a minimum, very easy, almost at-will access to a unit so that the instructor can develop the highest degree of proficiency possible. I can't defend or discuss these particular instructors' qualifications. It seems to me that if you're going to be an instructor, you should either own a unit or have a unit available to you at will, and you should use that unit to the extent that it's an extension of your body. This piece of life support is like a weapon for a soldier during war, and you need to use it until it is nothing more than your hand or your foot or any other part of your body that you're able to manipulate. That's the standard. It's subjective, not real concrete; and I would tend to put those ideas to the agencies and see what kind of response they come up with.

## Maintaining currency

**Unidentified:** What would you tell a potential rebreather buyer as far as making sure his or her instructor knows what they are doing? Would you have them ask that instructor: a) Do you own or have access to a rebreather?, and b) how many hours do you have on the unit? In other words, is he getting the best bang for the bucks or is this going to be the blind leading the blind? I think you ask the guy that's going to be the rebreather instructor if he has any experience. And if the answer is no, you walk away and find somebody else. Would you agree with that?

**Brown:** Definitely. If you don't have a unit on-site, as an instructor, you can't maintain currency; and what are you going to do after three months? You're not even a current diver, much less an instructor.

**Doc Brewer:** You don't go to a dentist who has a piece of paper hanging on his bathroom wall that says, "I am a dentist" who hasn't practiced dentistry in years either. Common sense dictates. I know what I would do as an end-user. I would ask to see that rebreather instructor's log book; and if he takes offense, then I won't train with him.

**Brown:** Good point.

**Brewer:** I think it's a moot point about how many rebreather instructors we have because it's going to be the manufacturer that controls that. You can have a generic program for a rebreather instructor, but, for instance, depending on the specific unit, that instructor has to go through that manufacturer's program. That's where the control is going to come in.

I would like to find out the requalification specifications. You can take an individual and make him a superlative diver, razor-sharp, and in two to three weeks, a month, he won't have that edge and could potentially kill himself. That's a problem I foresee in this industry. I'd like answers from the military perspective.

**Brown:** In the military, requal if for pay purposes, tied to dive pay, so there's some different standards. For mixed-gas open circuit decompression diving, I consider two weeks to be the limit before I'd sit down and look at my references and my entire planning and operational sequence for an upcoming dive. If I'm out of the water for two weeks, I'm going to sit down and think hard about the next dive. We had a death in a rock quarry this year where an individual hadn't dove for about five months. He jumped in the water and was training for a big dive. He switched to oxygen at about 130 feet, which was not a good move. This guy wasn't current. If you're feeling rusty, look for an experienced person to help you through a bit of a requal process or at least the pre-dive process for an upcoming dive. But I like to slow down after two weeks, think about what I'm doing; after a month, I'll dry fire my gear extensively before I get in the water just to develop that muscle memory again. That kind of thing could transfer over to rebreathers.

**John Sherwood:** What's the standard for currency? How do you maintain currency?

**Brown:** It depends on what rig. With open circuit, we requal every six months; and within that time frame, you have to conduct so many dives. Six, I believe. If you're requalified on a rebreather, and you're at a command that operationally uses those, then you need to maintain that status [6 dives, 6 months].

And of course, to say that you're going to make those dives, doesn't mean you sit at the bottom of the swimming pool, suck some air, come back up 10 minutes later and chalk that up as a dive. You have to make distance swims, the time and depth is dictated for it to qualify as a requal dive. Taking that one step further, somebody posed a question concerning supervisors. Supervisors have to supervise so many dives within a given period of time to maintain their qualifications to supervise dives. There are checks and balances to make sure everybody on-station is good to go.

## Rebreather instructors for sale

**Tony Zarikos:** I like to bring facts so we don't talk about rumors. Somebody mentioned an ad. If you look in your registration packets, on page 18 of this nice magazine (tec.asia 1.1), you will find an ad in which somebody claims to be a rebreather instructor trainer. Some of the units that are mentioned in the ad, don't even exist yet. That's not a rumor because I was in the same qualification class, standing within one meter of this gentlemen. I'm wondering, how we let individuals swim free and advertise things like this?

**Brown:** This is really good, we have got the dialogue cranked up. I'm going to mention a dirty word, for some people here—the ADC, Association of Diving Contractors. They voluntarily wrote the rules for commercial divers to follow in the US. Well, not really voluntarily; they had the choice of the government writing the rules for them. Maybe that's the kind of thing that higher end of sport diving needs, to help structure the environment, and make it difficult for irresponsible people. I don't mean to limit anybody's creativity.

## Mark 16 diving protocol

**Menduno:** I would like to hear about diving with the Mark 16, the typical kinds of dives you do. Do you conduct decompression diving? What kind of profiles and procedures do you use? Do you dive in pairs?

**Gilbert:** Without going into too much detail, with any training or diving scenario, safety is paramount. As a rule on the Mark 16, we dive in pairs, without fail. In addition to having your dive buddy with you, you're going to have a Dive Supervisor up on the boat, who is the overall person in charge; you're going to have a standby diver who is dressed and qualified and can dive as deep as the dive team in the water. And you're going to have a Tender who is there to assist on the dive station. Those personnel requirements vary from dive rig to dive rig; but it's fairly typical of the Mark 16.

## Emergency Breathing System

In addition to that, there's ancillary pieces of equipment that we use to support our dives. If there's a possibility of a decompression stop or if its a deeper dive—right now Mark 16 is certified to 200 feet/61 meters; they're making certifications to 300 feet/92 meters with some modifications here—we use an EBS, Emergency Breathing System, essentially two sets of tanks—they've upgraded that to four sets—with a super-long octopus that you can dangle over the side. It's a come-home system for the diver in case he does have a rig emergency.

**Menduno:** That's not just for decompression; it's for bail-out? You have the umbilical down to where you're working?

**Gilbert:** Right.

**Menduno:** What's a typical working depth? Anything to 200 feet?

**Gilbert:** Sure.

**Menduno:** You would have an umbilical down to 200 feet?

**Gilbert:** Not attached to the divers, but to the surface.

The Mark 16 was designed specifically for military use—for divers going after underwater munitions. It's magnetically and acoustically clean. You wouldn't want to be dragging an umbilical across the bottom when you're looking for an angry munition and the possibility that this thing could bang up against it and ruin your day.

## Work-up dives, deco and gas mixes

**Barry Burgess:** We teach Mark 16 Supervisor Course at my command. The EBS is only used for decompression; it's not required unless you're decompressing. We'll drop it 10 foot below the first decompression stop. We have to do work-up dives. Anytime you're diving deep, on any diving system, we do work-up dives. We'll start at 60 foot/18 meters and go all the way down to 190 foot. The rig is certified to 200 right now. They're looking at 300 feet/94 meters, but that's a ways down the road.

**Menduno:** Bottom times?

**Burgess:** That's depth-dependent.

**Menduno:** Do you try to stay as a no-stop dive?

**Burgess:** It depends on the mission. We don't do a decompression dive unless we plan a decompression dive. On open circuit, we have to get permission to do decompression dives. Mark 16, it's fairly routine.

**Menduno:** Do you use a hyperoxic mix to decompress on?

**Burgess:** No, it's just air in the EBS for right now.

**Menduno:** Do you run helium in your diluent or air?

**Burgess:** You're required to breathe helium on the Mark 16 depths deeper than 150 feet/46 meters

**Poladian:** We use the LAR V for combat swimmer operations and basically practice doing ship attacks. We'll send a bunch of pairs into a harbor and watch them from a boat or something with a specific mission to hit so many ships and then turn around and get out of there without being detected. They're doing underwater navigation inside a harbor.

## Typical problems

**Menduno:** What problems do you have on rebreather dives? A lot of things could go wrong, but what's your experience, what tends to go wrong, problems with the rigs occasionally?

**Poladian:** I don't know that it's necessarily a problem with the rig. I think they're problems common to most divers: visibility. Ninety percent of all the dives I've done with the Navy has been in zero-viz conditions. Water temperature: you're down there long enough and it gets cold so thermal management becomes a problem. You can wear a drysuit or thicker rubber- wetsuit but then mobility becomes a problem and mobility is a key factor in any kind of job you're doing. Surge, current, turbulence—trying to do your job.

**Menduno:** Do you have occasions to fly manually? For example, we've heard people say electronics in a closed circuit rebreather are temperamental. Do you have problems with electronics on your rigs?

**Gilbert:** Generally no. The maintenance of the rigs is scrutinized fairly heavily; re-entry control and failure analysis reports. I haven't had any electronic failures that were catastrophic or dangerous in any way. During training dives, as a matter of routine, even though there are protocols that allow you to dive your rigs, if there is any failure or any warning, we abort the dive for the sake of the diver's safety.

**I want to qualify the point that a rebreather actually gives you more time to solve some problems which eliminates some of the stress. But the flip side is that the rebreather has problems that scuba doesn't that are insidious; hypoxia, hyperoxia and hypercapnia, and can kill you quickly before you even know anything's going on. The caveat is that you have more time to solve a problem if you know there's a problem in existence.**

**Mark Caney:** Two questions. One refers back to a point Jim Brown raised. You mentioned a diver wearing open-circuit scuba will work better than someone in a particular closed-circuit unit. Could you expound on why that is. The second question—with your experience of open-circuit and closed-circuit operations, would you say that you are more likely to get problems with one of those pieces of equipment than another? If so, what types of problems?

## LAR V Limitations

**Brown:** First question, we use a LAR V made by Dräger. The unit has a certain pace associated to it due to physiological limitations. You can put a diver with twin 80's on his back in a Conshell 14 regulator and he can swim substantially faster without appreciable physiological detriment. The pace recommended for the LAR V is a 3 minutes per 100 meters pace. You can figure out how fast that is, but it's slower than an individual on open circuit gear. Perhaps one of our experts could better describe the limitations, but if you breathe the LAR V very quickly, you're going to smoke the gas across the scrubber bed and it's not going to absorb the CO2. That's one of the problems. That characteristic may not be inherent in other apparatus.

## The problems with rebreathers

As far as open circuit vs. closed circuit decompression diving, I haven't done any closed circuit decompression diving. I've heard Richard Pyle talk about; he's a pretty smart guy to talk with about that kind of thing. It would seem to me that if you go down the fundamentals of things that compose our dives, for example thermal exposure, your thermal exposure is greater due to longer bottom times that are possible on a rebreather. If I have less decompression time, I'm going to spend more time on the bottom.

As far as open circuit goes, if you have a failure, it's immediate. You either have a big Jacuzzi coming up off your back, and/or you can't breathe off your regulator and you switch to your backup or any other number of scenarios. That's not the case with a rebreather. Fortunately, a rebreather actually gives you a couple minutes to play around before the O2 percentage in your bag gets down to a point you are in trouble, provided that you're not changing depth. If I was going to dive a rebreather in a decompression situation, I would tend to take some stage bottles with me for more gas because the bottles on rebreathers are small and are not going to last very long down deep on open circuit bailout mode. I'd carry a stage bottle with a bottom mix, that would support me on the bottom, and another mix that would support me for decompression to the surface or at least establish contact with my support team. But I like to stay independent. I'm not going to rely on the people on the surface if I can help it. Those are some of the things, but you could talk about this for hours.

**Richard Pyle:** I want to qualify the point that a rebreather actually gives you more time to solve some problems which eliminates some of the stress. But the flip side is that the rebreather has problems that scuba doesn't that are insidious; hypoxia, hyperoxia and hypercapnia, and can kill you quickly before you even know anything's going on. The caveat is that you have more time to solve a problem if you know there's a problem in existence. The flip side to the rebreather is that you can have a problem without knowing about it until it's too late. There's trade-offs, pluses and minuses; you have to decide if the pluses outweigh the minuses.

## Mark 16 depths & failures

**Mike Vogel:** Mike Vogel from the Navy Special Warfare Center. Besides EOC and Indian Head we're the only other certified Mark 16 school in the Navy.

This is right out of the technical manual, "The depth limits of the Mark 16 are dives to 150 feet/46 meters of seawater, which can be made with N2O2 as diluent, and 300 feet/94 meters of seawater using HEO2 as a diluent. The current certification limits are 200 feet of seawater." But there has been some changes, and now it's 300 feet/94 meters.

Second, a question was asked about failures in the Mark 16. The Mark 16s we have at our school house are made by Carleton. We have experienced failures with the rigs, mostly involving secondary cable failures. That is a dive ending failure. If you don't know what's happening on your secondary display, you better go open circuit, straight to surface. You ride your diluent and go to the surface, because at that point you have no idea what your mix is inside your rig.

## Requalifying instructors

**Brown:** Mike, while you've got that book out, what are the requalification specifications for your school, for training-instructors and divers themselves?

**Vogel:** We're certified by CNET. CNET is Commander Naval Education and Training. They tell us how to teach. Evolving out of that comes instructor qualifications. Instructors got to Instructor Training School, pass IT school, go to their command, and have to be recommended by the CO.

At Naval Special Warfare, high-risk instructor training is much more involved than any other at our school house because we teach courses that are high risk. High risk instructors need to be certified once a year. We have a program to maintain Instructor Training Records (ITR's) where once a quarter, all the instructors are formally evaluated and have to pass. Plus they have to audit the course. You show up at Naval Special Warfare, you sit through the course (in our case, the Mark 16 course and SDV Operator course) and then go to High Risk Instructor indoc where they discuss the TTO (Training Time-outs) and Drop on Request, and all that has to get signed off, before you go to the CO and are even allowed to teach in Naval Special Warfare. It takes about six months, in our case, to get certified after you show up to the school hall to teach.

**Brown:** Right out of the book, this is AR 61175, an Army regulation. Realize, there's for-pay and for minimum currency. This isn't done in the field. You have to do one 3,000 meter surface swim, one 1,500 meter subsurface swim, apparatus doesn't matter; and you have to do one 130 foot deep dive (no decompression) every six months. If you go over one year without diving, you have to go through requal under supervision and review the material that's recommended in the AR. Dive Supervisors who are not current have to get re-taught by a current Dive Supervisor all the basics. Then they supervise a dive under their supervision. The Dive Supervisors have to supervise a dive about every three months. Pay purposes, it's one dive per month or six in six months.

**Burgess:** For the Navy, there are different classifications for different classes of diver. I don't know what spec war's is but I do know that EOD and a Second Class fleet diver just needs four dives every six months. Supervisors have got to make four dives and supervise two dives. In EOD, they make four dives, using the same tables as a fleet diver. If they're at an Mark 16 detachment, then they have to make two of those dives on Mark 16. Again, if you don't make a dive within six months on a Mark 16, the only thing you need to bring yourself back up according to instruction is make a work-up dive and then he's back up to qual.

**Brown:** Are there any private pilots out there? I think you have to make three day and three night landings every 90 days to stay current with your private pilot's ticket in order to fly passengers. If you only do that, you're not going to stay current. That's what's written in the books. If you only do what I just talked about for Army divers, you're not going to stay current. These are very, very minimum standards.

**Unidentified:** For diver quals in Naval Special Warfare, you have got to do six dives every six months. Four of those dives need to be closed circuit or mixed gas, and three of the dives need to be at night.

**Rob Cornack:** I can add the Royal Navy's perspective. Our qualification periods work two ways. The second way is the way that US Navy's does it; we have to do 120 minutes every four months to maintain our pay. However, as clearance divers on operational ships, we're expected to do 90 minutes per month, 30 minutes per month of that is meant to be in darkness or no visibility. To dive to 30 meters, we have to have dived to 24 meters in the previous month. Likewise, to go to 42, we have to have achieved 30. To get down to our maximum depth, which is currently 54 meters in the RN, we have to dive to 42 meters during the previous month. However, there are drawbacks to that because we use single diver operations, the diver is tendered from the surface. But the safety diver also has to achieve the same standards at the same time, and we maintain a chamber 300 meters away from the dive site.

**Karl Shreeves:** Karl Shreeves from DSAT. To build on the requalification issue, I'm curious how the various military departments accomplish the requalification dives. Is the diver expected to make them happen, are they assigned, how's it scheduled, what's the mechanism for being sure the diver stays qualified?

**Gilbert:** In Special Forces, we have scuba teams and these teams dive as a team, obviously. Requal is primarily left up to the leadership within the team. We've got an O3, a Captain, an E8, and a Team Sergeant who schedule these things. We have a very high Ops tempo, so we're not occupational divers in the sense that we do it every day. This is no more than another infiltration technique for us, just like riding a helicopter or jumping from an airplane, so it's hard for us to do it to the extent we would like. So the answer is that it's maintained at the team level and then it's audited from above during the command inspection program—they come to look at your paperwork. If you're a month or two out of date, you're going to lose a couple months' pay.

**Unidentified:** In the Navy, if you don't qualify, they'll take $200 from you a month, so that's a stimulus to get you to qualify. It's up to the individual to maintain his quals.

## Complacency

**Dave Baiss:** Dave Baiss, Dive Officer at EDU. One thing keeps going through my mind. We're talking about getting to a level of expertise, but I've seen one thing that's counterproductive to all of this and that's complacency. I've seen that in scuba, in a lot of things, where you think you've got your stuff together. The first thing that happens is that the checklist goes out the door and people are jumping in the water, making mistakes. As long as they come back, everything's all right but it's something that you have to watch.

**Brown:** I'd like to add to that. I did a LAR V dive some weeks ago. This LAR V is privately owned (I don't own it) and I used a pre-dive checklist. I have a bunch of dives on the LAR V; I'm a certified LAR 5 repair technician, and I could put it together in the dark. But I used a checklist to put it together. I didn't have a military dive supervisor, but I talked Mike [Menduno] through the Dive Supe checks, and he looked at that stuff. This is the kind of attention to detail you need to incorporate to avoid complacency and falling into that fatal trip of making a mistake.

## Royal Navy protocol

**Cornack:** Again, from the RN perspective, our divers at sea, our main work force divers, tend to stay worked up purely because they're diving every other day, or every couple of days at least, so they are much in date. For the shore-based guys, once every three or four months, we pack up three lorries, a Shaycon (one of the 28 foot Shaycons) full of gear, another one with a recompression chamber in it, and we ship the whole lot to Scotland. We use a 75 foot dive tender and we dive five days a week, doing bounce dives in the morning and endurance swims in the afternoon, to make sure the guys stay current. That's the only way you can do it- and it's expensive.

## A commercial horror story

**Mike Harwood:** I'm ex-military and now let's put the commercial horror story forward, just so you can put the thing in perspective. I look after the standards for commercial diver training in the UK, and we've trained too many divers. They pay their money and there's not much we can do about that. By law, I'm not allowed to look at the finances of companies. If people turn up with their money, they get the training. From a safety point of view this worries me, because the kids leave the schools and some of them don't dive for another nine months, twelve months. The phone rings, the contractor says, (they're all self-employed) "Here's a dive coming up; come out." The chap goes out. He says, "Have you seen this kit?" Of course he's seen the kit 'cause he wants the job. In the water he goes. We've got a big push now, that's why we've just changed our inspection regime, and we're going to take out all the dive contractors that do that sort of employment.

That's on-shore.

Off-shore, you won't get the job unless you're worked up. Scientists, you won't get a job—they have a very strict regime of working up. Police, no problems. Recreational divers, I don't have any problems with the professional side of those. But the on-shore divers-—you can call them cowboys; that's just being polite.

So, just put it in perspective. They're a lot of bad things going on there in the onshore commercial sector, certainly in the UK. We've now got 14 inspectors in our organization. Three of us, unfortunately, ride desks. The rest are out kicking ass, and things are going to change. We're talking about a military regime where you can churn them out, but the downside is in the commercial sector where people think everybody's got it right. Not true.

## Is solo rebreather diving acceptable?

**Menduno:** Several times over the last few days, I've heard buddy diving stressed—not solo diving. I know that its the rule in military diving; but it's not that way in the sport community. In technical diving, a team of one is acceptable, depending on the mission. What I want to know is do you believe that it's operationally essential to dive with more than one person on a rebreather?

**Brown:** It's kind of depends on how anal retentive that diver is. If he is ape-shit for attention to detail, he could probably go out and dive alone because he's going to take care of himself. But that's kind of sticking my neck out a little bit. I feel that dive pairs should have the same apparatus and that's the only way that your buddy can help you. If you're down there all alone and a piece of equipment decides to kick off and you start losing gas... trouble comes in more than one event. You're down there, a hose bursts, there's a heavy current and you get swept off, so suddenly you're out of touch, out of contact, and that's the day that God's going to call you up to watch Sunday Night football with him. A partner in that case could help very much. If you want to cut Murphy out of the program, dive with a buddy. There are applications for diving alone; and I'm sure other people could argue those points very effectively. But I recommend diving with a buddy when you're using rebreathers.

**Gilbert:** We tend to follow the practices of the agency that taught us. I learned to dive with the Navy and the Navy's fairly stringent on diving with a buddy; as a consequence, that's my personal belief. It certainly increases the safety factor when you dive with a buddy, and on the lighter side, it certainly increases the enjoyment factor; you can come out of the water and relate to another person who was down there with you. From both ends, safety and fun, yeah, I would dive with a buddy.

**Unidentified:** I've been diving 20 years and I plan on diving another 20 years, and I don't dive alone.

**Menduno:** What I am asking is if buddy diving is essential to rebreather safety.

**Jim Ruth:** Jim Ruth of Naval Sea Systems Command. We're the fun guys who write the diving manuals that you see. In my particular case, I work in the Special Warfare and EOD side with all of the closed-circuit rebreathers so I'm the guy who overlooks the materials and design. I don't certify; another branch does that. Over the past couple of years, we've been involved in some incident investigations, and I think this brings this to light. The more complex these rigs get, and they're electronically driven, the more there is a tendency for complacency to come in, because the rigs take time to catch up. The light gives me an alarm, I'm going to give it awhile to catch up. Let the O2 level come back up. Let it do whatever it's going to do. In some of those instances, that's cost us some lives. You really have to look at the rig, really be familiar with that rig; but you also got to sit there and say, "You've got to have a buddy." There's no way around that. We've had fatalities even with buddies.

There are two things that I think you've really got to look at real hard: full face masks and a buddy. If you're doing this kind of diving you're talking about doing, deep diving, you're really asking for problems if you don't do those things. Because when you black out, you're not going to know it . You may kid yourselves into thinking that you're going to know when you feel that CO2 hit or O2 hit and black out; but you're not going to know it. I've buried too many friends over the last several years because they've allowed their ego to get in the way of their mental capacity. They've allowed their ego to think that they know better than anybody else, they can feel it, I've done that.

In my case, I have a kind of unique perspective. I started out scuba diving; I've been teaching scuba for 20 years and I've been in this present job for 10. The Navy sent me to all their schools. I'm qualified on the 16 and the Dräger; I'm hard-hat qualified. I do all that stuff. But I gotta really tell you guys, you've got to dive with a buddy. There's no way around it. As soon as you black out, that's it; and the only guy that's going to save you is a buddy. He's the only one.

# End User Diving Operations

*"Almost everybody I know that has a rebreather, has had an incident whereby if they weren't able to think it out or didn't react in the right way, or there wasn't a buddy there to help, they would have been in serious trouble."*

-- Jack McKinney,film-maker

## Session Summary

In spite of the many hazards, and the work involved in operating a closed circuit rebreather, the handful of end-users, who own and regularly dive these units, sounded like it's worth it for them. One panelist said, "I find rebreather diving the most fun I've had in the water. It's a lot of work, but I wouldn't trade it for anything."

However, the five panelists in discussing their rebreather application, diving protocols, and their learning experiences, weren't reserved in discussing the risks involved. Panelists emphasized the importance of bail-out procedures, maintaining proficiency, and proper maintenance. As far as the equipment, the consensus seemed to be that if you are not mechanically inclined, or willing to spend the time it takes to keep a rebreather running, you shouldn't buy one. Rebreathers require significant support.

From the ensuing discussion it was clear that there are currently no standards for rebreathers, a situation one panelist compared to diving open circuit in the early sixties. It was recommended that the risks and hazards involved should be pointed out to potential interested users.

All of the panelists, who are largely self-taught after taking an initial course, seemed to agree that rebreather diving must be learned slowly, and that complacency and over-confidence can lead to accidents. In spite of these hazards, all of these pioneering users remain dedicated to rebreather diving.

The panel, chaired by Tracy Robinette, consisted of Rod Farb/photographer, John McKenney/film-maker, Richard Pyle/icthyologist , Leon Scamahorn/trainer and Mark Thurlow/film-maker.

27 SEP FRI 4:00-5:30 pm

# Transcript

**Tracy Robinette:** After hearing about military operational experience with rebreathers, you are probably going to enjoy this session. The gentlemen up here are the draft choices of civilian endusers who are currently using rebreathers for their specific application. Let me introduce Mark Thurlow, Rod Farb, Leon Scamahorn, John McKinney and Richard Pyle. In rotation, they'll tell you what they do, how they do it, how they use the rebreathers to do it, and then we'll open it up for questions and answers.

**Richard Pyle**: I'm going to talk about why I do what I do, and secondly is how I do what I do.

I'm interested in the biological twilight zone. It's coral reef habitat at depths greater than those accessible by conventional scuba, which is considered to be about 200 feet, (actually 190 feet is generally thought of as the absolute limit of productive scientific research on conventional scuba) and depths shallower than where the majority of submersible research is taking place. I call this range between 200-500 feet, the twilight zone and I'd like to know what lives there.

I started out by going to the Cook Islands years ago with open-circuit tri-mix. We found a bunch of new species in a very short amount of time. which is pretty exciting for us Fish Nerds. Unfortunately, we discovered a couple of limitations very quickly. To be able to practically carry out the decompression, open-circuit trimix gave us very short bottom times. That was one of our fundamental problems. So I turned to my friend Bill Stone, who had developed the Cis-Lunar Mark IV rebreathers for his cave exploration. He sent two of them out to me and my diving companion, John Earl.

The Cook Islands are located in an area of low species diversity. If we found more than a dozen new species of fish in such a short amount of time out there in the Cook Islands, imagine what we might find in an area where the diversity is much greater. So we set our sights on Papua New Guinea, the Maelin Bay area aboard the live-aboard vessel, "Telita," owned by Bob Halstead. It's an excellent dive boat. I can't recommend it enough.

We were doing four to six hour dives to depths in excess of 300 feet, and a t-shirt and bathing suit was all I needed; it's 85° F in decompression depths. It was wonderful. We discovered even more new fish and soft body marine organisms.

I'm going to talk about the practicalities of how we do what we do. I'm not a rebreather expert; I'm a rebreather student, so I'm giving you the perspective of what it is like to be a tech diver getting into these rebreathers.

## The cost of rebreather diving

These are some of our real world expense, the actual prices we've averaged over two years of diving, altogether a few hundred hours of rebreather diving. Sofnolime [CO2 absorbent—ed.], ends up costing us about $2 an hour, oxygen about a quarter an hour, about forty-five cents for helium; that depends on the dive, usually it's much less than that, and batteries which about 80 cents per hour of bottom time. The total is about $3.50 an hour of actual consumable expenses. We end up paying about $175 a year for maintenance; $150 for replacing oxygen sensors, and about $25 for other routine maintenance expenses; Cristo-lube, things like that.

As far as our time investment, we spend about two hours per dive, an hour before and an hour after, prepping the rig and posting the rig. About an hour for scrubber replacement; we end up using about a canister a week or sometimes two canisters a week if we're doing a lot of intense diving. About two hours a month for full breakdown and build back up again. Those are some of our real world numbers.

**Complacency kills. One of the paradoxes is that the more reliable your rebreather is, the more likely you are to get complacent.**

## Fish nerd wisdom

I'd like to offer some words of wisdom from a fish nerd who is a rebreather student.

Number one: Know your PO2. That doesn't mean you just look at your gauges all the time; it means that you know your PO2. You know that your sensors aren't giving you misinformation, it means that you understand various protocols to make sure you know your PO2.

The word complacency came up today. I've been using that word as the ultimate killer in rebreather diving. Complacency kills. One of the paradoxes is that the more reliable your rebreather is, the more likely you are to get complacent. That's why you have to have the discipline to train for life-threatening situations on your own time, and to do the drills so that you stay current with the bailout procedures. And you have to know your PO2.

My opinion is that a good grasp of gas physics and physiology is more important than scuba experience. I think scuba experience can, in an indirect way, be detrimental to becoming a rebreather diver. On the good side, it means you've got a lot of comfort in the water. On the bad side, it gives you confidence that you shouldn't necessarily have.

One of the most dangerous things about rebreather diving is allowing your confidence level to exceed your ability level. Confidence, if you're an experienced open-circuit diver, you become very comfortable on a rebreather very quickly and your confidence level goes through the roof because," Hey, this is easy; I got the buoyancy thing worked out. ."The problem you're not really qualified to dive it yet. It took me about 50 or 60 hours of rebreather diving to realize that, and a few close calls. Complacency kills, and you need to have a really disciplined, humble attitude going into these things.

Training courses: My recommendation for training is that you emphasize bailout procedures, more than operational procedures because rebreather training is learning how to stay alive on a rebreather. If I had my way, I would give the student adequate classroom work and then put them in the water with no batteries in the rebreather at all. No electronics at all. I would teach them how to dive the thing completely manually at first. After they were comfortable with that, I'd give them back their backup PO2 display (this is in a controlled environment obviously) and then have them fly the rig manually with their backup PO2. , At the very end of the course, I'd give them the batteries and show them how easy it is when the computers work. They have to be comfortable however, operating the thing when it doesn't work; that's where the training matters, when the rebreather doesn't work. Not when it does work.

**. . . what Bill Stone told me—the ultimate words of wisdom I've received from him is "always cover your ass." . . . I have taken to mean, always have an alternate pathway to the surface**

The last point, what Bill Stone told me—the ultimate words of wisdom I've received from him is "always cover your ass." By that he meant, and I have taken to mean, always have an alternate pathway to the surface. The point is to be able to get back to the surface even in the event of a catastrophic loop failure. That means the rebreather ain't no good anymore; you can't use the rebreather. You either have to have a second rebreather or enough open-circuit gas to get back to the surface. The problem is, of course, that one of the reasons to get a rebreather is so you don't have to lug huge volumes of gas around, so how do you rectify this? How do you do rebreather dives to 300-400 feet/ 92-123 meters and carry enough gas to get you back to the surface?

## Operational procedures

Let me go over the procedures we've converged on as the optimal way to do these dives. We vary these procedures according to the conditions, of course, but I'm just giving you the general template. With the Cis-Lunar MK VI, we carry 80 cubic feet of diluent on any dive that's deeper than 250 feet/76 meters. We carry two 40 cu feet "portable pressure receptacles" (PPR) [pony bottles]. The pink one has 10% heliox in it. The other one has air in it. We also carry a 13.5 cu ft a backup oxygen supply.

Inside the rebreather are two more 13.5 cu ft tanks; one with air, one with oxygen. So basically we have two air cylinders. That's the volume of gas we carry with us in person during the dive.

Sitting in the boat are a set of double 80's which, depending on the depth of the dive and the decompression program we're going to get into, can take anything from EAN 50 [50% o2, 50% N2] to air, depending on where our initial decompression system is. Also in the boat is a surface supplied oxygen system. We use that for the final stage of our decompression.

Our protocol is as follows. The two rebreather divers each have a tow line to the surface. We operate with a live boat; we have lots of reasons to do that (I'm not going to go into that now). Under normal circumstances, when it is time for the divers to ascend, the boat clips the decompression line to the tow line with a flow that slides down the line. The divers intercept that, unclip it from the tow line, do their decompression. You get the idea here. That's the easy dive; fortunately all of our dives have been easy dives.

The tricky one is when someone has to do a bailout. The easy bailout scenario is when only one of the buddy pair has to bailout. The diver switches to open-circuit and starts heading to the surface; the diver has 80 cu ft of gas to get out of deep water to as close as they can get to the decompression ceiling. During the course of those events, an emergency sausage is sent to the surface. When a better full face mask becomes available (like Bev Morgan's S-1), we'll probably move to that so that we can have communications with the surface. So, the emergency float comes up. The boat clips-off a set of doubles which are sent back down to the diver who now has a large supply of open-circuit gas to begin the open-circuit decompression. The point is that the diver has to carry enough gas to get to the back up doubles that can be sent down from the surface.

A trickier scenario is when the divers get separated and one of them needs to do an open-circuit bailout. Assuming the separated diver is the one that needs to do the bailout, the same protocol is followed except now the boat has to go with the second diver.

A really tricky situation, is two simultaneous open-circuit bailouts from a buddy pair that's been separated. By the laws of probability, this cannot happen, but from our perspective it can. In that scenario, the boat will stick with one of the divers. Both divers have tow lines with the emergency sausages that they send to the surface. So both of one of them can communicate to the surface support team, and create a physical connection to the surface so that the boat can drop cylinders down to each of the divers. Note that we only use those sausages for bailout situations; that way when the boat sees it, they know exactly what to do; there's no if, ands or buts.

**John McKinney:** How can you beat that?

I'm a wildlife film maker that specializes in underwater productions. I've had a rebreather for two years; a Biomarine CCR 155. I've got 101 hours on the unit and I've probably invested $15-20,000. My unit cost somewhere in the neighborhood of $8500, and then I had to buy a Haskel pump and the sundry items that went along with it.

It's been pretty easy traveling with a rebreather. I've taken my unit to the Galapagos, Fiji, and couple other places around the world. I ended up calling ahead, make sure there is oxygen on the boat.

The incidents that I've observed along with others in my group that dive rebreather, make me wonder what's going to happen with the market. Like the Navy guys talked about; it could be as simple as a losing a fin strap in a current, to your battery on your rebreather going out, to maybe two sensors going out. Richard Pyle mentioned close calls. Almost everybody I know that has a rebreather, has had an incident whereby if they weren't able to think it out or didn't react in the right way, or there wasn't a buddy there to help, they would have been in serious trouble.

The people I know with rebreathers are very good divers. But there's a lot of divers out there that have more money than smarts. My question is this: just because you have a lot of money, do you think you need to buy a rebreather? I know a couple of people who haven't been diving at all who have bought rebreathers. That is one of the concerns I had. It comes back to training and the prerequisites of what you have to know.

Bailout. The majority of hours I had on my rebreather, I didn't have a bailout system for a lot of the hours on my rebreather until Rod Farb kindly beat it into me. I have since plumbed in a bailout bottle that I can also use for trimix. If we're doing a trimix dive, I actually carry five bottles on me.

Mechanics. If you don't have a mechanical aptitude, or know someone who does, you shouldn't think about buying a rebreather. One of the things that keeps my hands on my rebreather all the time is the fact that certain things happen; wires corrode, fuses go out; the rebreather is constantly on my workbench. I constantly have my hands in it. You have to be aware of what's going on with it, know how to fix it, and actually be able fix it in the field. Again, if you don't have those capabilities, you should think twice before buying a rebreather.

## Near misses

Complacency—what Richard, and the Navy guys said is absolutely true. On one or two occasions, I got complacent. For example, I had just finished filling an O2 bottle and was going up for a dive the next day. I've got more than one sphere for my unit [The Biomarine has spherical gas bottles—ed.]. I pumped one of the spheres full, set it on the bench, and went to do some work. The next morning, I got packed, grabbed the bottle, got on the boat, and didn't bother looking at my gauge. The sphere was full. Right? Very stupid. I got down to 60 feet. Looked at my gauge and all of a sudden realized that I only had 200 pounds of $O_2$. If I had headed down to 200 or 300 feet, I would have had a serious problem. Checklists? Every single time you dive the unit, get your checklist out and make sure every thing is the way it's supposed to be. That's about it.

**Leon Scamahorn:** Hello. My name is Lt. Leon P. Scamahorn of the National Marine Rescue Academy, St. Helens, Oregon. You might be saying, "What's the fire department doing training people on rebreathers?" Well, it's a small business out there in a pretty small town that's very progressive.

## National Marine Rescue Academy

We established the National Marine Rescue Academy to offer specialized diver training. Our instructors are hand selected from Special Operations. I'm a twelve and a half year veteran of Army Special Forces. I've been through dive supervisor program, and I have run a Special Forces diving scuba locker and controlled group operations.

I left the service on July 4th, 1995 and started a company called Intrepid Research which had to do with specialized types of training. Then I bought a company called Inner Space Systems, a corporation which had done commercial diving using the Inner Space Porpoise Pack I, which is a beefed-up Biomarine CCR 1000 rated at a thousand feet for six hours. A pair of these units sold for $45,000 a piece, and the commercial diving field was looking at rebreathers as a means of minimizing the cost of diving at that time [In the late 60s, early 70s. They eventually opted for surface-supply equipment—ed.]. Surface supplied heliox is expensive. However, at that time, rebreathers didn't go over too well in commercial circles because you couldn't fix them with a hammer. It took a lot of Tender Loving Care (TLC) and you just don't have the time to do that in commercial diving. The result was that Inner Space went out of business, and rebreather technology was essentially put on the shelf.

**. . . proficiency is the big thing; you've got to dive the units all the time to maintain proficiency. I stress in training is muscle memory, by repetition of movement.**

## Rebreather training

Currently I've trained 30 divers in the commercial field, law enforcement, and tactical operations. I try to share what I've learned in the military and commercial diving fields. I realized when I got into technical diving to teach rebreathers, I could take the best of all worlds and combine them to provide the best level of training.

I train people primarily on the Biomarine systems. You see a lot of my students are in this room, and I'm pretty proud of the fact that they're all successful. Most of them are professional divers, and now I'm getting to train technical divers. One of my students is in this room today.

I think proficiency is the big thing; you've got to dive the units all the time to maintain proficiency. I stress in training is muscle memory, by repetition of movement. The only way to attain that is by being a pool monster. It's extreme but true: You've got to lay the law down and say, "Get back in the water" and "Well, I'm bored, I'm cold." No, that's not the way. You got to go on semi-closed, you got to do the oxygen bailout, you've got to go through the bailout scenarios, the entire thing until you know this unit upside down, left and right, and you feel comfortable. If you don't feel comfortable, it doesn't cost you any extra to come back to me and we'll go dive together until you do.

## Rebreather applications

In the commercial field, there are companies out there that lease rebreather units and operators that are currently underbidding other companies because gas consumption is nil. You're talking about less than $9 an hour vs. open-circuit surface supplied. And how do they comply with OSHA? It's real simple. You have an umbilical and you provide redundant gas supply, communications, use hardhat helmets, and meet the requirements.

I get calls all the time from professional operators for training on this equipment. I also get quite a few whackos calling the academy. You've got to have a screening process to sort out the individuals. I think that some of the best people to train are photographers because they have a high attention to detail. They pay attention to what you teach them.

Previous metal recovery? I get calls about this all the time about, "Hey, this wreck has this and that; would you do this for me?" Of course they don't want to throw any money up front. One concern I have is that some people will want to buy rebreathers and think they can just jump into commercial diving. That's not going to happen. If they do it, they're going to kill themselves and kill the industry. I think that you need to dive the units for what they're intended to do and that's not carrying out heavy work.

Science? The fisheries people want training on the units. The problem, which they will openly admit, is that they've divers who have a problem maintaining proficiency on open-circuit. They admit to me, "We want your training but we just can't keep our guys current."

## Checklists and operations

The checklist is another thing. You need to go by a pre-dive check sheet all the way and initial it. You don't jump across and go around check sheets. If you're waiting for a two-minute check, don't drop further down the check sheet to do something else; guaranteed you'll miss something and it's always something important. An operational check sheet is important as well. It's part of your dive plan. And then you've got post-diving procedures, too, and you need to follow those.

Again, divers need to maintain currency by diving. You need to dive twice a week, a minimum of 80 to 160 minutes a month. I think that is the minimum. You need to stair step to experience. What you have do is build up the experience, and the way to do that is by diving, diving on your unit.

In Special Forces we learned to train the way you're going to fight. Accordingly, I believe that you should train the way you're going to dive. If you want to come to me and learn how to do gas switches right off the bat, I don't have a problem with that. Just as long as you learn successful habits from the very beginning. We treat rebreathers as an electro-mechanical extension of your body. They have advantages and disadvantages. You need to have a healthy respect for this piece of equipment.

What's the worst thing that can happen on a rebreathing apparatus? Number one, counter-lung failure; number two, you can blow your hoses. To my knowledge, I've been the only one that's done that. I've self-induced doing some experimental counter-lung. I'll tell you that story over a beer.

## Primary Alternate Contingency Emergency (PACE)

Has anybody here taken up mountain climbing, rappelling? What does your instructor tell you to do, to lean back on that one rope? I don't use two ropes; I never have. I use one rope and that's the way you need to look at it, put your faith and your trust in that rope. When you look down, you could have 200 feet or further below you, and that's how you need to treat the counter-lung and the double hoses. Yet, at the same time, you need to plan for any sort of contingency. A good way to go about it is called a PACE acronym: Primary Alternate Contingency Emergency. If you got that covered, I think you can pretty much do anything you want. PACE.

I do what I teach and I teach what I do. What type of diving do I personally do? My average depth is 155 to 200 feet/48-61 meters, with dives in excess of 350 feet/107 meters sometimes. I can pull off 186-plus minutes of decompression in 47 degree water. How do I do it? It's gets cold, it gets boring. So I would take a good book, lots of Argon and a really good drysuit. The unit of mine that some of you dived today was a 17 year old unit. I take pride in that. That technology's been out for over 25 years and that unit is still considered state of the art. That says something for the design of that particular system.

I even have a buddy hose on the units I teach on. I haven't on any other units. Yes, two people can breathe off a system. You have to be in concert with one another; you don't want to try to fight over the counter-lung. It can be miserable but once you're in synch, yes, two people can survive off the unit.

Maintenance schedules: You need to have a planned maintenance system. In the military we used the Navy system, maintenance requirement cards, the works. It worked fine but we still had failures. So you do need to be mechanically inclined or find somebody who is who you trust. Otherwise you send the unit back to the manufacturer. Find someone credible.

**Rob Farb:** I've been a rebreather owner for a couple of years. I've got about 170 hours on the Biomarine CCR 155. I've made some modifications to the rebreather to allow me to do the kind of work I do; I'm a professional photographer. I work on assignment. I also work with Jack McKinney Productions; I work with John. We do rebreather diving together. I also do very deep diving. I'm a East Coast wreck driver. I look at a lot of shipwrecks, new and used. I've taken this rebreather down to about 330 feet/100 meters. I also dive regularly on open-circuit.

## The trouble with rebreather instructors

I have been diving since 1963, and I've seen a lot come and go in the diving industry. One of the big gripes I have, and I have very few opinions about rebreathers (you've probably noticed that if you've been at this conference for the last few days) ...one of the gripes I have involves the whole concept of rebreather instruction. In my opinion, an instructor has to own a rebreather and has to have dived that rebreather before he can teach you. Quite frankly, one of the problems with the evolution of this industry from a manufacturer's standpoint is that you've got to sell or give a rebreather to an instructor and let that instructor use it for a year or so, before he or she starts offering units for sale and then training people. That's not happening.

You've got manufacturers out there who are getting ready to toss out rebreathers to anybody that has a rebreather certification card, whatever that means, and I think that's completely and patently absurd. Based on what appears to be some company's requirements, I certified about 17 people as rebreather instructors today alone. The ones that made a dive for 20 minutes became rebreather instructor trainers. This isn't a joke.

It's taken me almost two hundred hours to learn this rebreather, and I still haven't learned everything about the rebreather. I would say the first hundred hours of diving that rebreather is a minimum requirement for anybody to teach rebreather diving. A lot of the time, you learn things about rebreathers that you never pick up from a book or an instructor unless you did it yourself, or that instructor has the experience.

## More than one rope

I do a lot of deep diving with this unit. And I carry more than one rope—I'm sorry, Leon; I totally disagree with that one rope thing. I've been diving since '63, I carry backups to backups. I plumbed my rebreather with a third bottle to do trimix diving [To carry additional decompression mixes—ed.]. I got a gas-switching valve in there. I paid $3,000 to Desert Star Systems to design a computer to use with that rebreather that would allow me to do mixed-gas diving, gas switches, the whole nine yards. That unit is available today; you guys used it and a smaller version of that computer will be available on the new Biomarine CCR 500 unit.

## Dive computers

A computer certainly is prone to failure, but I'll tell you what. One of the biggest drawbacks and one of the biggest detriments to this industry, is that we don't have a computer to use with a rebreather. You could certainly use a Dive-Rite computer, you could use any of the nitrox computers. You have to set the fraction O2 at the maximum depths so if you come up shallower than that, then you're really being more conservative than you really need to be. You can cut your own tables, but you either have to carry a sheath of pages down for times and depths or just dive inefficiently. The only efficient way to dive a rebreather is to get a rebreather with a computer that monitors your PO2 constantly, has a reliable decompression algorithm for whatever gas mixes you're doing. So the idea that you're going to go out and buy one piece of equipment, a rebreather, is ludicrous. You're not. You're going to have to buy a lot of ancillary equipment besides, in addition to the maintenance. I'm not sure I agree totally with Richard's cost estimates relative to the unit I use; I think it's a little bit more. What you consume in a rebreather is oxygen and you consume scrubber; that's it. So if you want to pump your oxygen 3000 PSI, you got to have a Haskel pump. You got to have a source of oxygen. You got to carry that with you, have it available. You have to have scrubber material. You got to have extra oxygen sensors. You got to have tools. You got to have spare parts. And you've got to have the ability to fix it. 'm a traveling circus when I go on a weekend dive. But what I can do is to get gas on Friday and not have to worry about it again until I leave Sunday night after the dives.

## Dive boat protocol

One of the biggest problems with rebreathers right now is that there's not enough of them out there. So when I get on a dive boat, I've got to share the cost with other divers, I've got open-circuit divers on board. But if you're diving with a bunch of open-circuit divers, you're stuck. You basically have got to do stick with their dive schedule. You can stay a little bit longer, but if you stay down there for a couple of hours, you're going to come up to an angry mob who's been ready to move onto their dive. So you're at a disadvantage today being a rebreather diver. There are very few times when I go out and there are all rebreather divers onboard. That's the best of all possible worlds but that just doesn't exist. I dive alone.

**So the idea that you're going to go out and buy one piece of equipment, a rebreather, is ludicrous. You're not. You're going to have to buy a lot of ancillary equipment besides, in addition to the maintenance.**

## Diving protocols

The Navy doesn't like to dive alone. I do dive alone. I carry a lot of backup, I side sling bottom mix. I've got a couple of extra bottles plumbed in my unit. I've got open-circuit bailout. I've got certain procedures for the depths I'm diving, and I count on myself. Sometimes I dive with other people who are on open-circuit. I don't depend on the stealth of a rebreather; when you're with open-circuit divers, what good is stealth if you're the only guy with a rebreather.

I count on the rebreather to give me extra time underwater so I don't have to worry about my gas supply. That's basically it. I run my unit at PO2 of 1.4. Hundred eighty-seven feet is the crossover point. Deeper than 187 feet/57 meters, you don't get any decompression advantage from a rebreather [Farb is referring to the fact that air as a PO2 of 1.4 atm at 187 feet. A rebreather still has a decompression advantage over open circuit scuba due to the constant PO2—ed.]. The best depth to dive that rebreather for me is 80-100 feet 25-31 meters; you can stay forever, incur a relatively short decompression obligation. If you have some surface supplied 100% O2, you have got it made.

I routinely work on a Civil War shipwreck off the South Carolina coast; it's in 80 feet of water. I can make a three-hour dive there, work on that wreck while the other guys are going up on their surface interval and through their second dive, come up and make a 45-minute hang at

20 feet/6 meters on 100% O2 and that's it, I'm out of the water.

If you make deep dives on a rebreather, you're going to incur significant decompression obligations and you're going to have to have makeup gas if you are forced to bail out. You just have to carry it with you. I would love to take a Fieno or one of these other smaller rebreathers and just tear it apart, shrink it down, and clip it on the front of me as a bailout. That would be a perfect solution for me.

The Odyssey rebreather, now called the Halcyon. I laugh about it because it's kind of a funky looking unit, but the idea and the philosophy behind the unit is terrific. I wish that guy, instead of trying to promote that as a full-blown semi-closed unit, would shrink it down about a quarter of the size and give it to me as a backup unit, as a bail out. With a couple of hours of semi-closed bailout; I would be fine.

## Training market

The rebreather marketplace is where open-circuit diving was in the early '60s, late '50s; it's an infant. There are no standards. You've got agencies trying to position themselves in the marketplace by claiming they have the largest number of rebreather instructors, which is a big joke. Then you've people who don't know any better going to these so-called rebreather instructors to get their training. It's absolutely ludicrous. It's up to the manufacturers to say, "This is what I want to see done in the industry or you ain't going to get any rebreathers." Period. And lay it out like that. Otherwise, it isn't going to work because, quite frankly, as unbelievable as it sounds, there are some people out there in the industry that are just trying to make a buck. That's hard to believe, isn't it?

From my vantage point, what the rebreather industry needs is a group of manufacturers to get together and establish some basic standards, and then pass that on to the training agencies. They can then pass that on to the students, the people that want to be trained in rebreathers.

**Mark Thurlow:** I have been diving a CCR 155, working with underwater cinematographers, for about the past year and a half . Unlike my colleagues here, I would say probably 99% of our dives are 100 feet/31 meters or shallower, probably most of them are around 60 feet/18 meters. We use them for filming underwater wildlife.

Typically our dive profile is such that we'll go down with cameras, tripods, megawatts of underwater lights, set all this equipment up in front of some unsuspecting animal, and then wait for three hours for it to act natural, so we can film it. That's the reason I got into using the rebreathers. The advantage to them, obviously, is the amount of time you can comfortably spend on the bottom.

Two things go out the window when you use a rebreather at a relatively shallow depth. I'm talking about a fully closed-circuit rebreather. You almost never think about running out of gas. You've got anywhere from eight to ten hours' supply when you're just sitting on the bottom, so you aren't constantly checking your pressure gauge. The other thing that essentially goes out the window is your decompression. From about 60 feet, you almost have unlimited bottom time at no decompression, so that becomes real handy, real important. Being stealthy is kind of nice but the quiet is what's the unbelievable thing for me. I find diving a rebreather just the most fun I've ever had underwater. To the point where I've probably got cobwebs growing in all my scuba gear.

Like John and Richard have mentioned, the things that you have to consider are where you're going to get oxygen, what are you going to do about your scrubber material, and you also have to worry about how much excess baggage charges that you're going to pay the airlines, when you take all this equipment with you. Just to give you an idea, I recently got back from a job in British Columbia. We had 43 cases of film equipment, and about a third of those were dedicated strictly to the use of the rebreathers. It's a lot of work, but I wouldn't trade it for anything. Diving a rebreather is just great. So far I've got about 142 hours on my unit and love it.

**It's a lot of work, but I wouldn't trade it for anything. Diving a rebreather is just great. So far I've got about 142 hours on my unit and love it.**

# Questions & Answers

## Decompression tables

**Mike Steidley:** I've got a question for Rod. You seem to be pretty adamant about the standards for diving these things. But, yesterday, Dr. Thalmann pointed out that the dive tables don't really tell us what's going on within our body but merely draw a line: one side's statistically fairly safe and the other side's statistically unsafe. Yet you're telling us we got to have a computer that's going to change the algorithm based upon the partial pressure in your rebreather. It seems to me there's not much scientific background for that. Do you know something that you can share with us? You're so adamant on safety but it seems like you're getting out there on the experimental wing, making yourself a one-man experimental team on this one.

**Farb:** If it was up to science, bumble bees wouldn't fly. I absolutely respect what science has done. I'm a scientist. I worked for many, many years in the laboratory and I understand laboratory experiments, and I understand good science and I understand bad science. Quite frankly, I haven't looked at the literature. I can only say that the Buhlmann ZHL-16 Algorithm is certainly a reasonable one to start with. I add in a conservation factor which I can change in the computer quite easily. I also have the computer default to a lesser PO2 than I've actually been running, as an extra conservation factor. I'm a very conservative diver. I've been diving since '63 and I'm fine. I've never been bent. I am not out there to kill myself.

I cut a set of tables using Decom decompression software and carry them with me as a backup on all the dives. Basically I've done the dives over and over and over enough to know what the decompression is without a table or without a computer. I'm not saying the computer is the end all to any diving and absolutely Marco Flagg, the designer of the Desert Star computer, will tell you that you should not carry one piece of equipment to carry you through the dive. You absolutely carry backup dive tables. You don't depend upon that computer.

I will say that I firmly believe in safe diving. I know what's been safe for me and many other divers. I didn't invent this sort of stuff; I'm not out there on a limb by myself. I dive with a whole cadre of East Coast wreck divers that have established certain procedures. Look at the cave diving community. Cave divers were looked upon many years ago as a bunch of crazy nuts out there, but basically what we know about deep wreck diving we've gotten from the cave diving industry. I was looked upon as a heretic 15 years ago for suggesting that wreck divers carry pure oxygen in the water with them for decompression. I wouldn't be permitted on certain boats. Now I go on those boats and they act like they discovered oxygen decompression.

This is a problem with the diving industry. It's really, really difficult to take a group of scientists who don't do a whole lot of diving or who just do their testing in a hyperbaric chamber, and have them talk to you in a reasonable way about practical experiences. It's easy to say, "OK, don't do decompression diving" and give you all the reasons why not. But you got a whole bunch of people out there doing decompression diving. The better protocol is to say, "OK, you're doing decompression diving; let me suggest to you a safe way to do it."

For many, many years the diving industry has looked upon deep diving, deep wreck diving or pushing the limit, as something you shouldn't do. Let's look at nitrox. Go back and look at your skin-diver magazines and editorials that Bill Gleason wrote about nitrox within the last three or four years. Look at how his position that's changed. Look at PADI and their position on nitrox, and I love them all, and I work with them all, but look how positions have changed as the industry demands that it changes.

All I'm suggesting to you is that a dive computer is going to become an integral part of a rebreather. It's up to the manufacturers to make sure that the algorithms are safe. It's up to you to plug in the proper conservation factors, and it's up to you to dive them safely. Basically the proof is in the pudding. I'm firmly behind safe diving but I also will not stay on shore because somebody has told me that if I go out and try to be a bumble bee and fly, I can't do it.

**Thurlow:** I want to add to that. I think it's important to distinguish the more technical application of rebreathers and those that plan to use them for shallower depths. I agree with Rod. Personally I would love to have a dive computer that fits on my rebreather; it would certainly augment the work that I do in the water and the work that all of us do in the water. The problem is that outside of Rod's single unit and the computer on the Cis-Lunar no one has one [Note that Undersea Technology has an integrated decompression computer based on the DCAP algorithm—ed.]. A nitrox computer works adequately but it is inherently conservative. For the time being, that is an option. But I do think it is important to distinguish between those who are going to dive at extreme depths and those who aren't.

## Whose standards

**Jason Gilbert:** I was pontificating about the Navy and some of the regulations that govern the way we dive. Those standards were based on research. There's a whole industry within the Navy that sets those standards, and we're forced to adhere to them. I'm going to confess a fair amount of naiveté as far as the rest of the diving world goes, but to whose standards are you beholden and how did those standards come about in the kind of diving that you do, and the depths at which you dive?

**Pyle:** I have one priority whenever I go in the water, which is to ensure that my daughter doesn't become an orphan and my wife doesn't become a widow. I'm a reasonably intelligent kind of fellow. I can absorb information pretty well, and I've done my homework on the literature, and I try to learn everything that's ever been published. Then I tweak that with my own personal experience. Some of my own personal experiences, to me, are one helluva lot more convincing than tens of thousands of data points in a published paper. Not all of them; quite often published papers will override my personal experiences. But on a few occasions, my personal experiences override the published information. So my standards are Richard Pyle's standards; I'm going to follow Richard Pyle's standards until the day I die, which probably sounds like an ironic statement.

I think standards are important when you dealing with groups of individuals. In the military, you've got numbers of divers, masses of divers. In scientific institutions, you've got numbers of divers. In the recreational community, you're going to have training agencies and instructors with numbers of divers. These kinds of organization absolutely have to have standards; there's no way around it because you need a common footing to do it.

My standards change in response to my brain as it absorbs more published information, more conversations I have with physiologists, more times I come to these meetings and learn a few more things. My standards are dynamic and they can even change during the course of a dive under certain circumstances. And they're all focused toward ensuring that my daughter doesn't become an orphan and that my wife doesn't become a widow. That's the Golden Rule I'm always going to follow. It's because I don't have to manage a lot of divers; I only have to manage me.

**Gilbert:** We all adhere to standards. We drive our car to get point A to point B safely and quickly. My question was "Are there established standards or are they just your personal standards?"

**Robinette:** There are no standards as far as rebreathers go. Everyone up here has had a certain amount of training in certain things, but they are diving to their own standards. And that's how it's going to be until there is a standard out there and some type of organization and more time.

The gentlemen up here are pioneers; they do what they do because that's what their requirements are and they take responsibility for themselves. Except for Leon here, who does do training, these gentlemen here are doing their own thing. If they die doing their own thing, it was because of their own choices.

**Farb:** There's no standards written down, no training or organization for this. Among the 100 or so hard-core divers I know, there is an underlying set of principles that govern the way we dive. One of them is that we return alive.

I could refer you to the cave divers. They have a set of principles based on accident analysis. If you talk to the hard-core divers I know on the East Coast (and this certainly would apply anywhere in the world), you'll find that they have similar ideas about how you do things. So although there's not a written set of standards, there is an underlying set of principles that govern the way people dive. There is a difference between sport diving and what's called technical diving. It's a self-governing sort of thing and there's a lot of peer pressure. If you come into it and have a lot of goof ball ideas that are at odds with the prevailing thoughts, then you might come under a lot of ridicule or maybe the ideas will be incorporated, but you're right, there's not a set of standards and I don't know when that might come about.

**Among the 100 or so hard-core divers I know, there is an underlying set of principles that govern the way we dive. One of them is that we return alive.**

**Robinette:** Is this training by attrition?

**Unidentified:** Rich, I was curious, do you get hypercapnia headaches after you speak? And if so, you might want to think through that underwater communications.

## Conservatism & standards

**Scamahorn:** I'd like to say one more thing about standards. In the commercial field, you've got the Coast Guard, OSHA, and ADC consensus of standards. Then there is common sense and continued education, and I don't think just because you take up diving one day you should stop your education right there. You have to explore new avenues and new arenas.

I've been associated with the military a long time and military diving, and I wasn't truly happy with what was going on. That's one reason I left the service: I felt there were bigger, better horizons out there. Personally, I think the Navy is chasing after the civilian science and is rethinking a lot of things as far as set points and diving.

The basic rebreather that the Navy's used for such a long time, rated for whatever depth (250 or 300 feet), the current system has the capability of 1,000 feet for six hours [This is a theoretical statement , presumably referring to system capability i.e. gas and canister duration, that may not have a lot of meaning. Putting a diver to 1000 feet/307 meters for six hours would need to involve a lot more than a single rebreather—ed.]. I know it's been done. The Freedom of Information Act is going to be opened up with regard to past experiments and I think we're all going to be surprised it's really happened. There's a degree of conservatism that has been built in as far as military goes and I don't think its entirely relevant for the sport and professional diving communities.

**Unidentified:** I think what is going on here is extremely important; it's one of the most important discussions I've heard at this entire meeting. For a scientist like myself and for scientists I work with, you folks are extremely lucky. Most of us would like to be in their position in that you guys can dive a lot, dive your heads and butts off, day in and day out. and . . .

**Panel member:** We get paid for it.

**Thalmann:** Right, but you're accountable mostly for yourself or your buddy, a small number of people. These people find out their own personal limits. What they can get away with.

Rod is an extremely tough dude. If most people dove like he did, they'd be dead. He's been doing it for years and years now; he found out he can do this within his own personal limits which apply to him and not anybody else. The Navy's viewpoint, and I would say the industry's viewpoint, would have to be that the average consumer is not going to be a well-known who knows their limits. They're going to be a black box walking in out of the door, plunk down some money, and walks off with the rig. The seller, the Navy, any person working with that person is going to have no idea how prone they are to decompression sickness, how sensitive they will be to CO2 or oxygen toxicity.

The Navy has spent a lot of money taking all these black boxes, putting them together in a chamber, and trying to find out what the chances are that you'll end up with bent people. As a result, we found out that it is extremely difficult to predict ahead of time who is going to come out of a chamber with paralysis or who will come out wetting their pants because they're incontinent, who's going to come out dead, or who's going to come out with simple limb pain. We do know, if you take enough people and throw them in a situation, you're going to end up hurting some people. That is the rationale behind the Navy's conservatism and I would hope the industry's conservatism, because most people walking up to this Forum or up to the counter to buy a piece of equipment is going to be total unknown. So conservatism comes from trying to plan decompression profiles, decompression computers, which treat that person as a high-risk individual. The equipment is designed in such a way that the high-risk individual hopefully won't be a statistic. I know we have the greatest respect for you folks out diving. I wish, and think all the Navy folks, wish to devil we could have as much fun as you guys do. It's a wonderful way to live.

**The Navy . . . found out that it is extremely difficult to predict ahead of time who is going to come out of a chamber with paralysis or who will come out wetting their pants because they're incontinent, who's going to come out dead, or who's going to come out with simple limb pain.**

**Graves:** Grant Graves, potential end-user and maybe one-day instructor: Rod alluded to professional ethics and responsibility. I think we need to talk a lot more about this. If these instructors go forth and do some things we talked about in the last session we're going to have serious problems. Nobody in their right mind would think they could make a phone call and become a full cave instructor. I ask isn't it the same thing for rebreathers? Because we could have some serious problems down the road. If anybody has a doubt whether they should teach, don't. When you feel ready, then teach. But if we take this as a get-rich-quick scheme, a lot of people are going to get hurt that the industry's going to die again, for 20 more years probably, and we're all going to be left with nothing. So take a long-term view.

I'd like to hear more discussion on it. I know Rod and others have talked about what it should take, but if some of these people who aren't qualified are out there are teaching, may be someone should take them out for a beer and have a heart-to-heart with them.

## Teaching

**Pyle:** I think teaching diving is an awesome responsibility.

That person is literally giving you, the instructor, responsibility for their life. I take that very seriously. That's an incredible amount of trust and that alone just gives me gray hairs thinking about it. In order to teach on rebreathing apparatuses, you must be unit-specific as an instructor, not just a generic one. I feel you should have lots of time. Rod says 100 hours; that sounds good to me. Even today, when I dive my unit, I'm learning something new. I think that's a good point: no one in his right mind is going to ask to be a cave instructor because they've been in a cave a couple of times. I think on the rebreather should be the same classification.

**Robinette:** One thing that we talked a lot about is the instructor. Another thing that needs to be discussed is the qualifications of the person who walks in the door and says, "I want to take a rebreather course." We're heard nightmares of people who have gone into a certification course and couldn't make it past the waves to get into the water.

As far as ethics go, a rebreather instructor passing somebody just to get him through the course and to get the fee needs be looked at pretty hard. You can do a two-day resort training course now in the Caribbean and be certified. Is the rebreather training going to get the same thing? Or should standards be set where you have to have a month's worth of training on a rebreather before you're actually cut loose? It's a scary thing.

When I was talking earlier about incidents, just watching the people that I know and the incidents that have happened and the fact that they had so many hours on these units, they were able to work through these things. What is going to happen to the person who's not a very strong diver, who puts on a rebreather, jumps off the boat, happens to swim around a coral head and all of a sudden he has a problem. He's going to die. That's something that needs to be taken a hard look at.

**Somebody's got to figure out the best way to do certain protocols. Mine are really difficult because I'm doing 300 to 400-foot/92-123 meter dives which makes it many orders of magnitude more complex. I'm not going to even try to write a manual for that sort of stuff.**

## Recommendations

**Drew Richardson:** There seems to be a commonalty here between all the various presenting groups whether that be manufacturing, scientific, medical, operational, or occupational. If this process is to come up with a message, maybe we can start talking about certain messages that we might like to leave in our proceedings or for others who might look to this workshop down the road, to get to work on.

I might suggest along those lines that commonalty, in part, might come up with something that says before anyone takes this type of training or education, that the health and other hazards associated with either this type of diving or this type of training be identified, the associated risks be assessed specifically in the context of the health of that individual, and that the appropriate control measures for those hazards be put in place. And further, that the individuals concerned understand and accept the risks of that activity, especially in the context of their health.

Every one of those gentlemen have lived up to that measure; maybe that's what we're talking about in terms of leaving a mark for this three-day forum in part.

**Robinette:** This certainly is the vehicle to do that, if possible.

**Michael Lang:** A question for John McKinney since you mentioned that you have 101 hours in the water over past two years. When you first got your box of rebreather parts, what did you do for training?

**McKinney:** I flew to Pennsylvania and took a course at Biomarine, with Lou Ricchio, one of the engineers that worked on the unit. For subsequent training, I went to Washington and took a course with Leon.

**Lang:** If you go to the manufacturers, they must have some curriculum, working off some set of standards.

**McKinney:** Yeah, I was handed a Navy manual and checklists and everything else that went with the Mark 15.5 and told, "This is pre-dive, post-dive and you better be pretty anal about it." I am an anal person when it comes to my gear, and that comes from camera gear. I have a lot of expensive camera gear that, if I don't take care of it, it's going to cost me a lot of money whereas with a rebreather, if I don't take care of it, it's going to cost me my life.

**Lang:** We keep hearing there's no training standards but you just told me there's very gear-specific information and skills that you need.

**Robinette:** Where that gear-specific information is coming from is the military. There is material for certain units. The trouble is when a rig is brand new and manuals haven't been adequately prepared; that is a problem. Except for Richard Pyle, this panel is diving basically the same unit which has been used by the military. Richard Pyle is now diving the Cis-Lunar unit; do you have documentation?

## Cis-Lunar documentation

**Pyle:** There is no formal documentation or training course; it has to start somewhere. Bill Stone invents a rebreather, figures out how to dive it. I live at Bill Stone's house for 10 days, he tells me what he's learned over all these things how he designed it. I take it home and I spend a very conservative 50 or 60 hours in a pool and lagoon in very shallower water simulating emergencies, in a sense almost inventing how to train. No, there's no Cis-Lunar manual. I've offered to help them write it, they've accepted and I'll probably write portions of it. For a new rebreather, these things have to be developed slowly and cautiously.

I thank Cis-Lunar for trusting me to be a disciplined person and knowing to keep a safe margin between what I think my limitations are and how I actually implement my dives so that I keep that margin there. Somebody's got to figure out the best way to do certain protocols. Mine are really difficult because I'm doing 300 to 400-foot/92-123 meter dives which makes it many orders of magnitude more complex. I'm not going to even try to write a manual for that sort of stuff.

## Responsibility

I have an expression: rebreather diving can only be learned; it cannot be taught. People, like Leon, provide the information, and put people in the right situation to facilitate that learning, but the responsibility's on the shoulder of the divers to learn how not to get killed doing this stuff.

**Robinette:** Rebreathers are definitely the responsibility of the individual buyer/diver. They have to be looked at from that perspective. Until things change from documentation and training courses, they're going to be the responsibility of that person. If they're not going to do all the things these people have done, they're not going to be with us anywhere.

**Farb:** We do have standards that have been taught to us, in my case by a retired Navy SEAL, and also from the manufacturers that have given us guidance. We're all talking to each other all the time, so we're always coming up with new thoughts, ideas and ways of doing things; we communicate that with each other. What standards do we use? There isn't a definitive book that you can go out and buy that says "This is how to dive a rebreather" but we do have some standards that we go by. The standards I use during training are TDI standards; you have to have advanced nitrox to take the basic course on a Biomarine system. To get into the mixed gas portion, those are TDI standards also. I think standards among the technical agencies are all the same, pretty much.

**Unidentified:** I'd like to see an overwhelming response to, "Just say NO," to those kind of ads that we see in this magazine about rebreather instructors, "Come get a rebreather instructor certification."

At the very least completely reject it out of hand as total garbage, and say, "No, quit doing that sort of stuff." That serves to erase all this and start with a foundation that provides honest information about what's going on.

# Equipment Testing & Peformance

*"I would take anybody to issue who says, 'Well, sport diving is so different, we can't apply [military testing standards].' That's baloney. You're putting somebody in the water, you're putting them at depth, and you're trying to keep them alive. Those are the three goals of an underwater breathing apparatus. And there ain't no difference between recreational divers and military divers in that regard. None."*

*--Ed Thalmann*

## Session Summary

The session began with Dr. Hans Ornhagen detailing his experiences in building a "physiologically-correct" breathing machine to test rebreathers. It was pointed out that unmanned testing is an important component of testing that allows the testers to determine performance at the extreme range of operating conditions, which would be difficult to do with human subjects. Ornhagen finished his presentation with a list of things to be tested in rebreathers.

Gavin Anthony of the Defense Research Agency next discussed the challenges of creating consistent international test criteria and performance goals. Dr. Ed Thalmann then gave attendees a history of the US Navy's manned testing program, pointing out that in addition to unmanned tests, manned testing is critical. Thalmann went on to discuss EDU performance goals for breathing apparatus, which are readily available to any interested parties.

The session then moved to questions and answers, including discussion of independent testing. Whether manufacturers use independent testing facility or not, presenters agreed that the most important thing was that test results were published, and that it be made clear what standards the equipment will perform to, under what conditions an uses.

The consensus of the group was that rebreathers should be tested before being released to the market and that manufacturers should provide appropriate documentation and warnings.

The panel was chaired by Tracy Robinette, and consisted of Gavin Anthony/DRA, Dr. Hans Ornhagen/Swedish Defense Establishment, and Ed Thalmann/Duke University.

28SEP SAT 8:00-9:30 am:

# Transcript

**Tracy Robinette:** I'd like to welcome you all to the Equipment Performance and Standardization session. I'm the moderator this morning. I would like to introduce the panel, which is my pleasure to moderate. We're going to have a question and answer period after the three presentations are done. To my far left, your right, is Dr. Hans Ornhagen, to his right is Dr. Ed Thalmann; and to his right is Gavin Anthony. It's a little early this morning. We're going to start off with Dr. Hans Ornhagen this morning.

**Hans Ornhagen:** Thank you all for persuading me to come here and give me the opportunity to offer my opinion. Secondly, I have to apologize for being late [Ornhagen didn't arrive until Friday evening—ed.], but I couldn't do it any other way.

To test the unit, to see whether it functions well, you have to look into these different aspects of malfunction.

## Testing rebreathers

This all started in the end of eighties, when this unit [AGA DCSC ] was brought to our laboratory for testing. This is an AGA rebreather and it's mechanically controlled unit. During the manned testing we used at that time, we found that we have to put the test subjects through very extreme situations. We had some odd breathers who really caused this unit to malfunction because of their breathing pattern and their extreme high oxygen uptake from the rig. So I introduced oxygen experiments.

I've been playing around a little with catalysts and tried to think about the possibility of building a simulator. I got a good gradate student at the University of Technology in Baltenburg, his name is Mario Loncar, and he started looking at the literature. We found that the Bureau of Mines here in the United States had built a unit that was used to test rebreathers for rescue purposes in mines. But they had difficulties running that unit. It was fairly clumsy. We also found an alcoholic burning unit in a hospital in Sweden that was used to test breathing equipment and apparatus used for narcosis in operating theaters. But they had a couple of explosions with the alcohol.
So we were stuck with the possibility of the idea and Mario started looking into different fuels and different catalysts.

I know that you have been talking about rebreathers for two days here, so you have probably said most of what has to be said. But I prepared some new problems that I just want to run through quickly with you so you know the basic background behind the testing.

We have many accidents in our area with recreational divers and students, about 85% of the cases involved human factors errors that resulted in the fatal accidents. I would imagine that that will increase if we put rebreathers into common use without any serious change in the education. Also testing comes, of course, as part of this. The unit has to be safe from the beginning.

If we look at the major risk factors, we have the hypoxia, and you can see the different causes behind the hypoxia here. They are all well known to you. Then hyperoxia, we have the hypercapnia, excessive work of breathing, and then finally water entry and the caustic cocktail.

To test the unit, to see whether it functions well, you have to look into these different aspects of malfunction. If we start with the oxygen, the situation is like that—no one really wants to operate below a 24 kilopascals (KPa) of oxygen pressure [0.24 atm]. That is a 20% abnormal atmospheric pressure differential. Although we know from different studies of physiology that you humans can perform very well down to 15 kPA. When you're traveling on a commercial jet, for example, long distances, you are sitting in 15 KPa and most people function well in that environment. A kilopascal is a part of pressure and the normal pressure of the atmosphere is 100 KPa, which means that a kilopascal is equal to a percent if you talk about normal atmospheric pressure.

At the other end, the maximum allowable oxygen partial pressure is in dispute. And we have different ranges here. For simplicity, you can put the decimal point there and then you will have it in atmospheres. You see that we in Sweden accept a maximum of 190 kPa or 1.9 atmospheres oxygen partial pressure when diving nitrox. Then it ranges all the way down to 140 kPa in the civilian diving regulations that we have in Sweden. If you look at the ranges set by other organizations, you will find that most fall within that range.

## Basic simulator

Now the oxygen fraction in a rebreather unit, depends on how it is built; and there are, as you know, many different designs. The basic theory behind most of these is covered by this equation [slide], and I don't expect you to read it , it's just so I know what I'm talking about. What we have is oxygen consumption here, that's metabolism. We have the lung, which is a volume of gas, and from that volume of gas, the oxygen is extracted. We have an oscillation of gas between the gas flowing of the lung and the gas flowing out of the apparatus. Here at the bottom, we have a gas flow into the unit and we have a venting flow out of the unit here. The flow here in the bottom and at the top depends very much of the type of gas you are using. If you have pure oxygen and you dive the rig very carefully, the flow in here corresponds to the flow down there at metabolism and there will be no venting, hence no bubbles. You can do the type of stealthy operations you like without being detected.

Then of course you'll have a balance here between the extraction and the input, and that is regulated according to the equation you see in the bottom, with the left part here being the steady state and the right part here being the dynamics of this situation. With dynamics, I mean the way the oxygen goes to the steady state situation. This is steady state situation where you have time along the x axis here and the oxygen fraction on the y axis.

## Calculating oxygen fractions

If you start the unit without purging it, with air in the breathing apparatus and air in the lung, and you turn on the valve, and start breathing, the oxygen fraction in the apparatus will start with 21%, as you see here, and then it goes into a steady state level like this. For the steady state value, I have calculated 12 liters of gas per minute into the unit, the oxygen fraction of the supply gas is 40% and the oxygen consumption is 2.0 liters per minute. All these different parameters could be varied of course, and that would give you different steady state values here. The level will vary. If you purge the unit at surface, it will come with a concentration that is represented by the supply gas, that is the 40% and it will swing down like that. If you're diving the unit to 30 meters right away from the beginning, there will be a lot of gas added to the circuit and a lot of oxygen, and it will take a long time for the metabolism to actually consume it. So it takes a longer time to reach the steady state value.

Given the same parameters here, a 2.0 liter oxygen consumption, and in this case, a 60% oxygen and 40% nitrogen mix, and a mass flow of 6 .0 liters per minute, we can calculate the curve that follows the thick line here. So, you have the oxygen fraction here on the y axis, you have the time on the x axis as shown here and you'll see the steady state is reached within some 20 minutes or so in the situation here. Now, if you make a mistake here and load this machinery with a 40/60 mix (40% oxygen) instead of a 60/40 mix, a mistake that's easy to make, you will have a situation like this. The steady state value will be an oxygen fraction of some 15% instead of 40%. When you are at 15 meters, it doesn't really jeopardize your health. You will survive very well. You will be able to do the physical exertion if you need to out there, but it will make a great difference for your decompression calculations for the simple reason that the 30% or so missing oxygen here will be the 30% extra nitrogen or helium or whatever diluent gas that you have. So you believe that you can extend your diving beyond the air limits because of the fact that you believe that you have 40% oxygen in your breathing bag and the remainder being nitrogen. But instead you have some 85% nitrogen and only 15% oxygen. That's the difficult situation.

The third thing, or the other mistake you can make, instead of mistaking 40-60 for 60-40, is that you can feed the unit with air. In this case, you'll not only get decompression problems, if you ever get to the decompression, but you might run into survival problems because of the low oxygen partial pressure.

So you see that you have to be careful to feed the unit with the proper gas and there are no room for mistakes there. In the next example, I'm took values from a rebreather that's on the market. All of these calculations were made by Mario Loncar, my engineer, who is a great hand at this. I'm just responsible for the laboratory.

We have depth here and we have oxygen pressure in kilopascals this time. Put a decimal point here and we have it in atmospheres. We have three different oxygen consumptions: half a liter/minute, two liters/minute, and three liters/minute. Three liters per minute is a lot underwater and you know that. But it can happen and we've seen it, so that's why I have it included here.

If you now go for the upper limits of the system here, the mixture flow will be 8 liters/minute and 50.5% oxygen in the mix, and oxygen will fall in the top part of these gray areas. If you go for the lower limits, that means that you will be down to 6.4 liters of flow per minute, and a 49.5% oxygen and you will see that for low consumptions it doesn't really matter that much. But for higher oxygen extractions, you might find yourself in difficulty. You are down into real hypoxia situations here, especially when you are shallow. You have to know exactly what you are doing. The tolerances make difference actually.

## Building a test machine

With that background, you can now see what factors effect the physiology of divers. They're well-known to you. So our ideas was, what if you had a simulator that could test rigs so that you could make sure that you wouldn't have these type of problems; hypoxia, hyperoxia or decompression problems. We need a unit that could test all these things: the gas composition, the oxygen, CO2, inert gas, humidity, temperature, the dynamic breathing resistance, and the static load. We are not arguing for the use of machines to test rebreathing, that is not to say that I would not favor them over human testing. There has to be human testing before theses units are released. But the breathing machine can put the diving apparatus into an envelope that is difficult to test for ethical reasons.

So Mario looked into the chemistry book and he came up with propylene gas, C3H6 that together with the oxygen in the circuit produces CO2, water and energy. So if we add propylene so that we extract 0.3 liters/minute we release microwatts of heat into the breathing circuit at the same time. And that means that during this testing, we can also test the heat exchange of the unit. We add water in an amount that we contribute 50% of the relative humidity of the gas, which means that we can also test the condensation of water and see where it condenses, and where will that water eventually go?

We have a unit that can go up to 7.0 liters of oxygen extraction per minute. The equation as such has a respiratory quotient of 0.67, that is CO2 over O2. If we want to go for higher respiratory quotients. The respiratory quotient for a human eating average diets, at least in Europe, is supposed to be at 0.87 or 0.83. It varies, by the way. If you are in Sweden, people eat a lot of fish and the Italians eating a lot of pasta. Some Europeans read 0.83 and since the machinery itself has 0.67, we need to add extra CO2 to the unit. And so we can also mimic people with strange diets and strange breathing patterns.

## Breathing patterns

The breathing pattern that we are testing, that is ventilation in liters per minute for different oxygen extractions, is such that the majority of units will fall within this area here. With the apparatus we cannot test very low ventilations and high oxygen extractions because we run into explosive atmospheres in the unit, and we don't want to have that. So we can't go below this line here. But we can reach any point, any combination of ventilation and oxygen extraction on this graph here.

## Test machine

This is what it looks like [See Ornhagen's Paper for illustrations]. The control unit here is 19" wide for your reference. It could be made smaller but it's standard lab size. The unit itself is here; that's the catalytic converter. We have a cooler. We have a flow meter. We have a pump, side channel blower, the fan essentially. We have water trap, and a water pump with a cooling unit down here. So the gas coming out of the circuit is 37 degrees temperature while the combustion itself it taking place at 300 or so degrees Celsius.

This is the circuit that is actually consuming the oxygen. We feed the propylene in here, in the fan, and we mix it up with the gas coming from what we call the functional receiver capacity of the unit. It's burned here, cooled there, and the flow is managed there. Then it goes around like this. If we don't add any propylene here, we don't extract oxygen, so this fan has to be going all the time. The metabolism is controlled here, the respiratory quotient is controlled by this CO2 addition valve.

To turn this into a good simulator for breathing tests or apparatus tests, we need a pump that is pushing this gas in and out with a piston. We hook up the breathing apparatus to be tested here. When this piston goes back and forth, we add gas into the machine where it's burned. At that point, it's low in oxygen, rich in CO2, energy and water vapor. We then extract the oxygen and go back and forth. We can stop this pump here and that mimics a breath hold. That means that consumption goes on here and the next exhalation will be like a human after a breath-hold.

In the water tank here, we can then check the attitude of the rig to test the static load, and so on. The dynamic components are regulated here with frequency, rating pattern, and tidal volume changes. So you actually say that this is like the pulmonary circulation. Here is the lung, and we can change that FRC. Because of the very small volume of this loop here, we add extra volume here to simulate whether it should be a small female or a tall male, so we have the proper functional capacity. These volume factors are of importance when you let dive the unit o high pressures. If you have a large volume here, you get a different gas addition.

Now, I can actually put up the two graphs; this is the human and this is the machine. As you can see, we have oxygen up and down, breath by breath. We have CO2 breath by breath here, and we have the volume of the breath down here in this curve. One is a simulator, one is the human doing the same thing. You can see that they are very similar; it's a human-like machine.

How do you then use this to test a breathing apparatus? This is how we did it with the AGA trig. We have time here, we started the diver at rest, then we went to light work, hard work, then back to resting. During the rest, we compressed the diver. Then we did work at pressure, up to extremely hard work here and then we rested and decompressed during the rest.

## Canister testing

If we want to test the canister duration, we have to continue and continue to load it to such an extent that you get the canister breakthrough. There are some different ways of doing that. In many situations today, they just leak CO2 into the canister but that doesn't really tell the truth. In Norway they have a recommendation that there should be a cyclic variation in the CO2 addition. I know that US Navy also cycles the work that the test diver is doing. Here is the form we use. You can see that it's not a square, because a human is never square, at least not in his physiology. There are always factors to make the changes and transitions smooth. So that is why we have suggested this form, because when you are working hard then you are paying off your oxygen debt. That means that you will not have a square reduction. We suggest that you should continue with this profile until you have 0.5 kilopascals, that is 1/2% of CO2 in your inhaled gas. We can discuss whether this is the best way of doing it later. With this very standardized way of testing breathing apparatus; we can now validate a rebreathers function before it offered it to the Navy.

## Recommended test procedure

This will be my last view graph here, and this is a test procedure that I would like to see. You start with mechanical properties, durability of material, corrosion (a very important factor), oxygen compatibility, gaskets and other things. The human factors are weight, location of hands and buttons (you need to reach all the things in different situations), and that should be in the fully dressed diver of course, with all of the other things that should be done. Then there is how it fits to the body, maintainability (I apologize for maybe using words that are not in the English-American dictionary, but you understand what I'm trying to say), reliability of the system, and overall comfort. Instructions are also important things. Users should be able to understand what's written and there should be good illustrations. Then there should be a machine test, canister duration, work of breathing, inspiratory CO2 levels, the oxygen delivery system, how the set responses to compression and decompression. I'll leave the human testing to Dr. Ed. Thalmann to talk over the human system. Then we can come back with questions when we're all through.

**Robinette:** Next up is Gavin Anthony.

**Gavin Anthony:** My name is Gavin Anthony. I work for the Defense Research Agency in the United Kingdom. Our laboratory is responsible for diving research for the Royal Navy, and part of that work is manned and unmanned evaluation of breathing apparatus. The talk I'm giving this morning is slightly impromptu. I want to cover two aspects: the first is some of the testing that we do. Then I want to finish off with a slightly provoking aspect of standards and testing for breathing apparatus.

## Manned testing

Just to give you some idea of the testing we put our volunteer test subjects through, I'll show the link that we developed between unmanned and manned testing. John Clarke mentioned the fact that you can use a breathing simulator to determine the work of breathing. We developed in our lab, a technique of getting work breathing with manned testing. What we do is take a volunteer subject and have the body put two neoprene sleeves that are wired up. The technique is called RIP for short [Laughter].

We wire our subjects in this manner. And, then as best as possible, connect them into a drysuit which is highly modified to get all the leads from the recorders to the equipment. There's an awful lot of electric string hanging down there off of his leg. We then put them in the tank in quite cold water for several hours, with a little bit of light. In fact the technique was developed by Ed Thalmann.

If you're in cold water for up to six hours in a drysuit, you become very uncomfortable, so we plumb them in to make it more comfortable. This slide shows the diver fully dressed in the equipment within the chamber and full range of calibration techniques to go ahead. You can see pressure transducers on the face mask, the gas lines, the in and out hoses, all directly connected up all the electric strings. And believe or not, the subject is still smiling.

Once they are all connected up, we throw them in the water, down on the cyclodometer and simulate high ventilation rates. We have an electromagnetic brake on the bite, so you can make the pedal resistance harder and harder and harder. Nobody escapes from this chamber. But as you can see, it really is quite a complex method of testing. However, using this method, we can get nearly all the parameters that are important for the breathing apparatus.

## Performance standards?

That's all I'm going to say about the testing that we do. What I want to do at this stage is to talk about a not too thought-provoking aspect of standards. What is all this testing about?

The first question is, and I think it has come up throughout the forum over the last couple of days: What is safe? What does the actual consumer need to know to be safe? How about the manufacturer? What can be defined as safe from a liability-risk perspective. So thinking from that aspect, what do we know?

Well, we have a lot of information on the physiology to deal with: diving and physiology of people with respect to breathing apparatus. Yesterday you had a chance to see some of the equipment. We know an awful lot about the engineering side of rebreathers. And as we have discussed today, we know how to test them. We have a large core of knowledge but what do we do with that knowledge? How do we decide where to go? We need some sort of benchmark, something that you can relate this knowledge to.

**But what benchmarks can we use to evaluate a rebreathing apparatus? Something which is really quite obvious, but often forgotten, is putting down all of the specifications that you can measure, those that you can test. There is no point in specifying something that you can't check.**

I believe in benchmarks, something everyone can relate to as regards performance of breathing apparatus. But what benchmarks can we use to evaluate a rebreathing apparatus? Something which is really quite obvious, but often forgotten, is putting down all of the specifications that you can measure, those that you can test. There is no point in specifying something that you can't check. I mentioned manned and unmanned testing, and following along from what Hans has just said, there is a whole range of testing that you can do like ergonomics. A full scientific ergonomic evaluation is increasingly an aspect in our laboratory. Does it fit? Can you reach the controls? What is the field of view? There's a lot of formal testing to do on that. And then following a set of manned and unmanned tests in the laboratory is an operational field test. Go out there and use it, breathe it. I'm not saying to put it on a jump in the water. You have a very controlled conditions.

## Which test procedures?

Having said that, the next question is: what test parameters should we use? We talked about it over the last few days. There's the breathing performance of the equipment, the resistive effort, on a breathing machine and on a man. All these you can quantify 100%. Gas control. Hans has just given a very thorough presentation on gas control, oxygen levels, $CO_2$ levels. So we can test the levels. And finally, endurance. We've been looking at endurance of the set quantitatively with regard to its gas supply and its canister duration.

What standards are out there at the moment? What benchmarks could be applied? I'm going to take a slightly parochial view on the first point. In Europe, there's something called the personal protective equipment. The equipment has to be fit for service. It's got to fit the application. That requires a certain amount of testing. Equipment which comes up to the mark in Europe has a rubber stamp on it which you can see. Now there's still some debate as to whether that rubber stamp is valid or not. But at least it's a first step. You're on your way. Somebody walks into a shop for a demand regulator and he is going to see the CE stamp. That's for Europe.

## Dept. Of Energy guidelines

What is the standard for open circuit scuba. If there is a standard, shouldn't we also be looking at standards for rebreathers and diving in general? Other standards? Something which has been used in Europe quite extensively is a set of directives put together by the Norwegian Petroleum Director, and what was then the Department of Energy in the UK, for unmanned testing of breathing apparatus. It tells you how to do it and what sort of parameters to use. In addition, the US Navy has a technical manual that tells you how to do it. Within the Royal Navy we also produce specifications for any equipment we use. It takes the basics set out in the Department of Energy guidelines and puts on additional factors, particularly for rebreathers. The Dept. Of Energy guidelines are not good for specifying rebreathers. And, finally, and I think it's one of the more interesting things as regards this forum, I chair a NATO ad hoc working group on testing standardization of breathing apparatus. What we've actually managed to achieve in 1996 is the publishing of a first draft. It is a set of standards that all of the NATO nations have agreed to, so it's not only Europe—it's North America, as well. It lays down, although at the high level, how to test breathing apparatus. There is the start of a benchmark that's starting to become pan-world.

On that basis, where do we go next? What is the next thing to do? I think this forum is a place where we could probably debate that. Should we have an international standard, an ISO standard for tests and what the performance of a breathing apparatus should be? I think my view is "yes."

The reason is it would help the man in the street, the purchaser, the consumer with regard to the equipment that he is buying is. It will lead to an understanding, and I'm sure that the lawyers will like it. It creates a situation a specific breathing apparatus either meets or doesn't meet the standard. That's all I wish to say on that subject.

**Tracy:** Thank you Gavin Anthony. Next up is Dr. Ed Thalmann.

## The early days of USN testing

Ed Thalmann: This is a picture of what the state of the art was back when I first got in the Navy with the Experimental Diving Unit. This is a cross section of their test chamber at the time. The senior medical officer at the time came up with a revolutionary idea that the way you test breathing apparatus in the end is to hook it up to the diver and see how the diver does on it. So the idea was to monitor the diver's physiological response to the breathing apparatus to find out what its performance was.

In this case, if you look down here at the bottom, there's a fiberglass case filled with water and here's a diver who happens to be wearing a Mark XI. The diver pedals on a bicycle ergometer, and in this particular instance he was able to stick his arm out through a hole in the side of this thing and we were able to do arterial blood samples. We don't do arterial blood samples anymore. My point is that this method of containing the water down there was pretty cramped for the diver, but this is where we started in the first place. The Mark XI was the first to go through this type of physiological testing.

This is a picture of the world's best breathing apparatus. It was a setup that we put together up at the University of Buffalo. The idea was to see how the individual performed underwater. We found through experience that a bicycle ergometer is really the most reliable way to exercise somebody because you have pretty good control over his work rate and ventilation. It doesn't make any difference that the diver normally wouldn't have an ergometer; what we're trying to do is exercise his breathing apparatus; we're not doing ergonomic studies or anything like that. It is a good way to achieve rather high workloads.

This is what the thing looks like in a functional diagram. Basically the way it works is the diver is wearing a full face mask and we're able to sample the gas near his mouth so we can see the gas going in and the gas going out. Normally the diver exhales through the chamber, but when we actually want to make a measurement he inhales from a 55 gallon drum, a closed rebreather system. This is a breathing bag which is called a rolling steel speedometer. We collect gas that he breathed out, measure his oxygen, to some degree very accurately, and also for the five minutes or so that he's on this thing, we can see exactly what his lungs are doing.

The other thing that we wanted to investigate is static lung loading, and this is basically has got to do with where the breathing bags are placed. In this case [slide], the diver is at the zero static load. We can move him around a bit to change the pressure. This is a picture of what it looks like in use. The full face mask has a set of specially designed valves on it that we made ourselves and these things are almost an inch and a half in diameter. So the breathing resistance at the highest work load that we were able to sustain was less than 10 centimeters of water. This gives you an idea of the kind of testing we did.

We put the diver through three workloads up to about 150 watts and if the diver started at rest he did exercise for 3 minutes, we measured his response for 5 minutes, etc. This is called graded exercise. And the idea was to start off at a very low rate and eventually work up to a very, very high rate to see what his response was. We ended up generating things like this graph. This is supposed to be the mechanical workload and this is his oxygen consumption. As you can see, at the highest workload that we would normally use in the chamber, we were able to generate about 2.5 liters a minute; this is easily sustainable by most divers in good shape for a long period of time, so this is not an unreasonable workload. Then we did some maximum oxygen consumptions, and we got up to 3.5, almost 4, liters a minute on these. That's an oxygen consumption that you don't sustain for 4 or 5 minutes, but I would bet if you were in a situation of being caught in that net, that's what you'd be doing. So this is not out of the question.

## Ventilation studies

The other thing we were then able to do is to see how the diver ventilated over time. These studies basically went from the surface to 190 feet. This is what the CO2 response looked like. And this is a graph which basically says everybody became a CO2 retainer if you make the gas dense enough. The normal response to exercise is that your CO2 stays pretty flat as you begin exercising; it may even fall off a bit. And then as you begin exercising at higher and higher work rates, you begin to hyperventilate and normally you begin to ventilate a lot faster than you need, and drive your CO2 down. But you have got to remember this diver is not hooked up to a breathing apparatus in this case, so this is the best you can hope for. Now once you begin slapping breathing resistances on the diver, this curve is going to go up even more and this is something you need to know. Now what we found is by varying the static lung load, we found the diver breathing from different parts of his lungs. This is the total lung volume from full inhalation to full exhalation. When we introduce a positive static lung load, the diver tends to breathe at very high lung volumes. That means that at the end of exhalation you get a lot of gas flow. When a negative loading is applied, where the gas is getting sucked out of his lung, there's less gas flow.

## Dyspnea

But the most interesting part of the study was that we did dyspnea scores. Now one of the things that a breathing machine will do is tell you if there's a short breath. One of the things we found was that as static lung loading became very positive, or very negative, the more severe the dyspnea. And this dyspnea was really profound shortness of breath to the point where some of the divers actually had problems with maintaining consciousness. What we found was if the static load was outside of the range of about 10 cm of work, plus or minus, we had more dyspnea but what was worse when the static loading was negative. And the interesting part about this is the divers overcame CO2 when they got short of breath. So if I just gave you the data to look at on a strip chart recorder, and you look at the breathing pattern, and the CO2, and the O2 consumption, you would have no way of knowing that these guys were actually terribly short of breath and not doing well. This is why rebreathers have to be man tested, because we just don't know how all these things interact.

Now we were able to transport some of this technology to our lab. This is the wet pot in Panama City. It's a bigger room but you can see that it's the same setup. Here is a horizontal bicycle ergometer that a diver puts his shoulders in and he can pedal it. Down here is the speed indicator. It is kind of the backbone of manned testing. We were able to do the same kind of static lung loading test in Panama City using a slightly different method. Here we built a Plexiglas tube that was about 3 feet in diameter. It was like dipping a soda straw into a glass of water and by slightly compressing the chamber, we could then raise and lower the water level relative to the diver; and in fact, have them breathe through positive or negative static pressure.

What's interesting about this setup—I don't know how many people have seen the size of the wet pot in Panama City; this is it—but we were able to do some equipment testing at 1,000 feet and control the depth precision of this thing within an inch. One of the guys figured out how to do it. It requires a lot of precision, but in the end you're able to kind of get what you want and this gives you some idea of what the set-up looks like with somebody in it. In this case, the water level is just about even with his chest so under this situation he's breathing at a neutral static lung load. If we take the chamber above and we add a little gas and move the water level down, he'll be breathing gas at slightly greater pressure so it will be a positive static lung load. And if we move the water level up, it's negative. So if you move the water level down, that simulates the breathing bag on his chest. If you move the water level up, it's simulates the breathing bag on his back.

## Testing the Mark XI

Here is the first rebreather to be subjected to physiological testing. This is called a Mark XI which is a semi-closed breathing apparatus. In this case, the diver is wearing a helmet but as you can see, he's got himself on a bicycle ergometer and we put him through a great exercise to find out he would interact with the breathing apparatus. This picture isn't tilted; what's tilted is the frame of the ergometer. You can see that this thing is actually on a swivel, so we can tilt the ergometer from full up to full down to simulate different positions. All the stuff you see come off it are basically sample lines. They'll be a sample line going into the helmet monitoring helmet gas. Here's a sample line at the mouth. These are used to monitor what's going on in different parts of his rig.

The two types of testing we did was graded exercise and canister duration. The graded exercise was designed to see how much the rig impeded the diver's ability to work. So we started off at rest and we did three work rates. This would get up to about 2.5 liters/min of oxygen consumption. Our goal was to have a breathing apparatus that at its maximum operational depth should allow the diver to finish a150 watt workload without having any significant problems. We're not saying that the diver wouldn't notice some resistance to the rig, but in the end, he should be able to finish that workload and say that the rig did not significantly impede his ability to do exercise.

The canister duration study was designed to see how long the CO2 canister would last. Basically the diver is alternating between rest and 50 watts. This was initially developed empirically but some studies that we looked at, we found that alternating work-rest cycles were actually a more severe test condition than having the diver go continuously. Second of all, we found that the divers go much longer if work and rest. Some of them went for eight hours, so that's a long arduous test.

## Testing the Mark XVI

This is a diagram of the one of the rigs we tested, the Mark XVI, and it gives you an idea of the kinds of things we were able to measure. We were able to measure sensors directly, so we could measure the PO2, the oxygen and CO2 in the canister and the oral nasal. We were able to measure what the O2 bottle pressure was, and the oxygen consumption. We measured whether the solenoid wiped out, and exactly when it fired. We measured the battery voltage. We were able to monitor all the display functions remotely so we could tell whether the warning lights came on and off at the right time. These are all instrumentation, which was hooked up to the rig to verify that, in fact, it was functioning. Here you can see as the diver worked harder and harder, the oxygen bottle pressure dropped. The close circuit rigs were very nice pieces of physiology apparatus that you use for other purposes besides diving. That just gives you an idea of one of the breathing units that we studied.

## Canister duration testing

This is why you do manned testing. This is two canister durations, exactly the same diver. Diver hopped in the wet pot and started doing his canister duration exercise. Here you can see the CO2 goes up as diver exercises and as he rests it goes down, up, down, up, down. We drew a line to more or less average the peaks out, and you notice here's a half a percent surface equivalent [that indicates canister breakthrough—ed.] and after about 20 minutes the test was over. I wondered about that but when we pack the canisters, the same individual packed the canisters and weighs them. We knew how many grams worked with the canister and it was the exactly the same number of grams as all the other ones. So we had the diver come out and we said, "Well that was a really short one. Let's go ahead and look again, this canister duration's not very good." So he came out, the same individual repacked the canister, the diver got back in the water and he did that. Here he went on out to 240 minutes when he finally pooped out—that's 6 hours. This is one of the reasons why we need to look at these, because there was no way of predicting something like that would happen. That's incredible. So here we have a rig you'd think would go easily four hours, maybe five hours on a canister; yet under certain conditions it lasts as little as 75 minutes. How do you know if you have a high CO2 and you're going to break your canister? You don't; you're passed out. Because there is no CO2 monitor on these things. That's the problem.

What we found was, of course, is that if the water temperature is higher then the canister duration is longer. The technique that we used when I was at EDU was that we basically did a manned test at two water temperatures and then we'd use unmanned testing to try to extrapolate other water temperatures, simply because these canister tests are so long and arduous that you can't really expect the divers to do it all.

This is what a typical Mark XVI oxygen profile looks like at a high work rate. You notice that the set point here is 0.73 atm. The set point is where the rig fires. For the decompression profiles all of the computers were set at 0.7 atm. But you can see in reality what the thing does is when it fires; it goes up to about one atmosphere for a bit and then falls off and here as the solenoid Is firing, you can see the oxygen varies quite a bit because it's not mixed yet. But what you can see is that the oxygen tends to get to about 0.86 and fall off. This is probably one of the reasons why the 0.7 tables work so well because we tested them for PO2's way down here. In fact when the diver's actually breathing the rigs, the PO2s are actually a bit higher.

## Establishing performance goals

The first set of performance goals that EDU generated came out of some of the work that I did in the early '80s. You can get this report. The point is that based on all of our experience on all different types of UBAs we came up with some goals. We asked, How should a UBA perform before the Navy will buy it? Basically our attitude was if a breathing apparatus was far off these goals in unmanned testing, we were not going to waste our time because we didn't want to put divers at risk and we didn't want to spend all the money to do a man test when we didn't need to. The other thing these goals were used for is that if we made a slight modification to the UBA we didn't have to go back for manned testing. For instance in the Mark XVI, we went to several variations on inhalation hoses, exhalation hoses, valves and stuff. Once we had a benchmark of manned testing, and we knew how it performed, then if we added bigger hoses which dropped resistance, we would say," Well, it's going to be better. We already know it wasn't much of an impediment to the diver."

## The cost of testing

This gives you an idea of what happens when you change your breathing gases. Here's the nitrogen-oxygen at 70 degrees, and here's helium-oxygen at 40 degrees; you can see there's a big difference in canister duration. Currently, the only thing you can do with these is use statistical analysis that helps the diver before he gets in the water to know what to expect. Here's our table of canister durations that the operators use to determine how long he can dive these things.

So the point is, unless you strap a unit on a man and stress it to its maximum you really don't have anything important. All of this stuff is pretty high rent and I would dare to say that the amount of time, money and effort that the Navy put into testing its rigs is beyond the grasp of most rebreather manufacturers. Up at Duke University, we went and put together a package to determine how much cost if you can do these things at a lower level. A typical UBA test in which we do the graded exercise to two depths, and do canister duration at two temperatures. We will able to work out through all of those tests in about six working days for a total cost of $25,000. You can lump that in with what it cost to produce one of these rigs; it seems like a lot of money. But when you consider the time and money to develop one of these things, it's really not.

The point is that if you don't have that information, then you don't know what's going to happen when somebody is going to start pushing this rig apart, and, trust me, they will. The problem with diving is that for most people that get into it and, if they do it right, your grandma can do it. But then you get caught in a current, you get fouled, you end having to free yourself from some kind of obstacle, and you can start working pretty hard and your O2 can drive up really fast. The Mark XI, which was a semi-closed breathing apparatus had terribly static lung loading problems. We had divers who were breathing this thing at a thousand feet and actually panicked. We knew from talking to some of the divers out in the fleet that this had happened occasionally during an operation, so we had to investigate to find out why. You couldn't tell that that would happen by looking at the unmanned testing; there was no way to predict that was going to happen. It didn't happen to every diver. We found at the end of the study that the if static load was pretty high or pretty low they went into a period of uncontrolled ventilation. They were absolutely unable to control or slow down their breathing rate, which is very uncomfortable.

These are the things you can't find out from a breathing machine. There are a lot of benchmark out there now, so you pretty much take a UBA and do some unmanned testing and find out it stacks up against what has been done.

Robinette: Thank you, Dr. Thalmann. We're going to open up the floor now for questions and answers. Please come to the microphone, identify yourselves, and if you can, direct your questions to whomever you would like it or the panel in general.

**. . . the point is, unless you strap a unit on a man and stress it to its maximum you really don't have anything important.**

## The need for standards

**Mark Caney:** Something that has come out for me from this conference is that we could have a real problem with rebreathers. It's been mentioned before how the Electrolung was launched and it didn't seem to be ready at the time, because there were accidents; and as a result, they were pulled from the market. Now we're about to launch them again and I think we may have a similar situation, not necessarily because there will be deaths but by the fact there does seem to be a tendency on this side of the Atlantic for people to sue one another quite easily. I think that a number of court cases could squash rebreathers as effectively as the number of accidents did with the Electrolung. If I was a manufacturer about to launch rebreathers at this time, in this country, I'd be quite nervous, I think.

There are no clear standards by which you can measure the units against a particular set of performance criteria. I think that if we get anything out of this conference, it will be very useful if we could get what kind of standards we should be aiming towards. Gavin mentioned possible ISO standards, for example. If there were a set of standards in place, which were recognized by the industry, the manufacturers could then compare their units against it, whether it was unmanned or manned testing, whatever; and as long as they showed they had attempted or had met those standards, they have a form of defense. Without that, I think there could be one or two large cases which could dramatically set this industry back. And by the same token, I think we need similar standards for training and so forth. So I would like to ask Gavin or whoever else as to how we might achieve those kind of standards.

**Anthony:** Firstly, thanks for those comments. I can only agree with what's just been said. As to achieve the standards, I don't really know. I've attempted to do what I can by getting standards within NATO and certainly, in Europe; but how we do it on an ISO scale and who picks it up and runs with it, I don't really know. But the information is there, and I'm quite sure a lot of the technical experts would be quite prepared to develop the standards based on their knowledge. Then it's up to the administrators to say exactly how to get it out.

One thing that has proven to work is the concept of peer group pressure or market pressure. That is usually one of the best ways of invoking a set of standards for any piece of equipment.

**Michael Menduno:** You listed various groups that had set standards. Are they pretty consistent among themselves or are they wildly varying.

Anthony: The first thing to agree on is how to do the test, how to get the numbers, is almost entirely universal. I think it's quite convenient that it came out from an international exchange program between the US and UK; it was probably the first thing that we agreed on, how to test. That concept of how to test is still in place today. So everyone is testing the same way, and I think if we were going to start anywhere, we could actually standardize how to test now. It's there. As far as the actual numbers that you put on it, there are some variations and differences in approach. That would take more time and more discussion.

**Thalmann:** The table I showed you with design goals was not something that we dreamt up in a library with physiology books. The way those design goals came about is that we went back and we looked at the manned testing we had done, and we also looked at what we thought was achievable, and what was reasonable. So they were really pretty pragmatic standards. Right now I would be willing to bet that from the EDU design goals standpoint that a lot of these would come easily. The problem is you don't know until you test them. As far as the manned testing goes, that's much more subjective; and the reason is that your relying on the diver. You're measuring a lot; I think you should be relying on the diver to decide, to tell you how it breathed. You need fairly sophisticated subjects to do this; you just can't slap it on the back of anybody. Somebody has to have a lot of experience to be able to describe, " Well, there was too much inhalation effort, too much exhalation effort or I was getting short of breath and I noticed it was mainly when I inspired," or this that or the other. That becomes a lot more subjective, so it's really a two- prong process.

I think the sport-diving market could develop a set of standards, but there's one thing that's lacking in this whole deal. Until we begin to get real data on what the unmanned performance is and compare it to manned performance, and draw the link between the two, it's going to be very difficult to develop a set of standards which address the peculiarities of the sport diving market.

I think we can say in principle is there doesn't seem to be a lot of reason, outside or portability perhaps, why a UBA designed for the civilian sport market should be significantly different in its breathing characteristics from one designed for the military market. As I said, military and sport divers both breathe air and can't breathe water and both can sustain the same level of work in emergencies.

## Is the diver the limiting factor?

**Dan Wible:** I'm with AURA. It's a company that I founded about a year ago called Association of Underwater Rebreather Apparatuses. I started diving rebreathers about 15 years ago that were homemade and about a year and a half ago, I got a couple of the CCR1000, actually the PP 1's. Since then, I've started to manufacturer my own rebreather, which will be coming on the market.

The reason that I'm speaking now is that one of the big things that I found is that when you start testing rebreathers, you find out that they're so much more capable than open circuit, that you actually begin to limit out the diver's lungs and pipes as equally fast as you would limit out the equipment itself. It's kind of a combination problem;it's the breathing of the lungs as well as the unit. You brought this out a couple of times, where you found out there was very little impedance by the Mark XVI on the problems that the divers were having. That's exactly what I found in diving. One of the ways we could solve that is if we could coordinate communication, for example through AURA or DAN (Divers' Alert Network) with real simple e-mail loading of each dive. We could try to encourage that, like a fish-tagging process only we're tagging our rebreathers because of it's a new industry. But if we just keep the communication open and come out of the woodwork a little more, that's probably the best way to keep things stable as this develops.

I've dove for instance to 500 feet with the PP 1 within the last 12 months and made several dives below 300 feet, and this problem of your body limiting itself out, regardless of the unit, is a real one and it happens almost every time I dive below 300 feet. I feel that my body is not acting the way it would on the surface, it's something to do with the pressure and the density and the CO2 building up in my system. And it's a really bad feeling, and you have to watch out every time you're below 300 feet. So I'll mention that, too.

**Robinette:** Questions?

**Anthony:** Let me make one comment on that. How can you tell that it's your body and not the piece of equipment?

My point is basically that you can't go to 500 feet without a piece of equipment, so how do you know the difference?

**Wible**: That's a good question. I've done surface testing and compared it with surface testing with the equipment. I notice that there's not a limitation on the PP 1. You really can just sprint underwater with them. So I've concluded that, at depth—that's been a personal conclusion—I don't know how to explain it. I don't have a lot of testing in the chamber, with or without one, but my personal feeling is that I can just tell that I'm not really being limited by my equipment. There's something going on, and my ability to breathe; I can feel my lung resistance, working hard all through my body, and it just doesn't feel like it's the rebreather. It feels like it's just my body having the problem. That's all I can say right now.

**Thalmann:** I hope that you got that point from my lecture that testing at one atmosphere tells you nothing. Basically you turn on it will breathe fine. If you don't go to increased gas density, you really don't know how it is performing and the bottom line is you can't tell if it's your body or the rig. That was the reason we did the studies in Buffalo, to find out how the body would perform. But relying on subjective sensations like that without any data to back it up doesn't further design, make it better, or help establish standards. It's really of no use; strictly personal. UBA manufacturer can't take that information and run with it.

## Human-machine performance

**John Clarke:** I have both a comment and a question. First, I'll make the comment because it's related directly to what you said. For the past number of years, a hobby of mine has been trying to relate the engineering standards, which allow the work of breathing of underwater breathing apparatus to increase as you increase inhalation and depth, because that's a real-world engineering requirement. On the other hand, you had the physiological limitations which say that when you work very hard, or you work very deep, your own physiological limitations start clamping down on you. After a bit you reach a point where the equipment is doing all it can, and your body is doing all it can; and at that point, from then on, as you go deeper or work harder, the total package of man and machine becomes less and less capable.

The one changed departure from the historical standards, which I've been holding onto for the past five years or so, but I'm springing out of the box and meeting back on the West Coast next month, is a way to relate the engineering standards to physiological expectations. You can't really make the equipment much better than we are now. But you as the end-user, and us as the Navy, can at least be well-advised as to what's going to happen when you put this combined package in the water. If you have very good equipment, you're going to do better than if you have bad equipment. But if you take the best equipment in the world and go very deep and work very hard, you have to know what to expect. Again, the probability of having a problem is like tossing a dice, whether the equipment is having a problem or whether the body is having a problem. So what you say is a very real and very significant point: it's a limitation of diving under any circumstances.

Now the question. Let me say first that, I'm absolutely ecstatic. There are very few people working in this world on these issues and many of them are gathered right here, and what I heard today is thrilling. In particular what Hans has brought up is something very significant and new. The EDU is going to be writing out a check, I suspect, if I can find the people with the checkbook, and see how much of this equipment we can emulate. The one question I have: Ed, you mentioned an approximate cost back when you were at the unit, about $25,000 to test the equipment.

## The cost of testing a rebreather

**Thalmann:** That would be the cost to do it today. The cost at the EDU is probably ten times that.

**Clarke:** Several times at least. The question I have for Hans, actually you proposed tests which we normally don't do, tests that we have thought about doing: the durability test and equipment—things that are nice to do. I would like to know if you get a completely new piece of equipment and run through your entire tests, about how much time would be required to turn out a report. Maybe you could also give us a cost estimate, that would be nice as well.

**Ornhagen:** I have no idea. We've never done it, so I couldn't really tell how long a time it would take. It's a question of manpower and also how detailed the tests should be, and so on. So it's impossible to answer the question. But the only thing that I'd say is that using a machine, a simulator, you could run a test with only one person. You could hook the unit up with a chamber, and fill the chamber with water; then close the chamber and run the test. That way it's easier and so much cheaper to do the basic testing. But again, I'm repeating, it's not to exclude you and your need to have the manned tests on the rebreather, you need manned tests, but you can do the volume work by machine much cheaper than you can do it with manned testing, not to mention the fact that you can also squeeze the unit up to 3 liters and a half, or 4 liters without getting into difficulty. You don't need to have a doctor standing by there, and it's safer.

**Jim Brown:** Yes, I'd like to ask the scientists, and the reason why I'm asking this is because I see a difficulty in myself answering the question. As you know, there's a system in effect at Naval Safety Center that gathers statistics concerning military dives. The information is used for various safety purposes. Is there anything that you could use, as scientists, that could be reported from the field? Obviously there is a great deal less control than you can exercise in the wet pots and things like that. Would a dive reporting system be useful and then also, could you actually design a questionnaire format that would give you the useful information?

## The source of accidents

**Ornhagen:** Of course you can design questions, but at least my experience with Swedish recreational divers is that most of the real serious accidents and the fatal accidents are caused by human error; faulty behavior, bad dive-planning and so on. That's what really causing the accidents. Then, if you are talking about divers with rebreathers, there are very few, and I think maybe the best way would be to have them work together in groups, and then have these groups collect the information and send it on to some kind of body, whatever that would be: DAN or Sports Diving Federation or so on—I don't know.

**Anthony:** One thing from a scientific point of view. Correct experimental design is a very difficult thing to do. If you have almost a random data collecting procedure, which is something that you're suggesting, actually analyzing that data in a way that gives you really good information is very difficult and something we've attempted to do in the past. I use the word "data diarrhea, "data is there everywhere, literally. To try to sort it out and mop it up and make something of it is very, very difficult. If you had to do what you're suggesting, I think you actually need to design the experiment as to what you want to get out of it and then, the type of diving would have to be very controlled to get really good data.

## Tracking down problems

**Thalmann:** Within the military system, the Safety Center data will only tell you whether there's a local problem or not, but it's not useful for doing reports. What's useful there are the equipment logs, where you can go through the equipment logs, you see how long an O2 sensor's lasted, and how many times the electronics were replaced, etc., etc. etc. To give you an example on the Mark XI, word came in from the fleet that there were problems. Then one of the medical officer's went out to talk to the divers and began to get an idea what the problem was. At that point in time, the rig was brought to the EDU and we tracked the problem down. There was no way we could track those problems down in the field. It's almost impossible to do. It has to be tracked down in controlled conditions where you can decide, vary things in a very controlled manner. And we did find out what the problem was. In the end, the problem was the canister design, and eventually we got a new rig on line which would support the divers a little bit better.

## Give it to the lawyers

**Harwood:** Mike [Menduno] does someone have a camera. You should put John Clarke up here with these guys and just get the four people in a photograph because you won't get these guys together too often. And it's sort of historical for me, so if someone has a camera here so we can give it to lawyers and they can say that on this particular day, the manufacturers were told how you gotta do it by these four guys.

[Pictures are taken]

There you go.

## The CE-mark

I just want to lift a bit of the veil on this CE-mark that everybody hears about, because a lot of people seem to think the CE-mark means it's safe. Bullshit. (It's time to take the gloves off anyway.) It's a conformity assessment standard. This particular PPE that we are talking about is called, "Complex Design." What happens is that the manufacturer has two choices: he either conforms to a harmo-

I just want to lift a bit of the veil on this CE-mark that everybody hears about, because a lot of people seem to think the CE-mark means it's safe. Bullshit.

nized European standard (and there isn't one) or he conforms to another verified technical specification. And that's why it's very important for me to see at least a start in a consensus standard so that at least manufacturers have got some common point.

The manufacturer then produces a technical document, and then that goes to an approved body; and the manufacturer goes through a lot of other things, and in the end, if he gets it all right, there's a stamp put on it. Now the only company that attempted to do that with a rebreather is Dräger. And everybody's been walking around, kicking their backsides, saying "Did they get it right? Did they get it wrong?" Yesterday when Christian stood up to make a presentation, he flipped a bit, because what he said was, "Here's Dräger's tests" and then he said, they gave us the certificate. That wasn't quite how it happened. So I'd like him to say quickly how it happened so that he can quell that myth. Then you'll understand the importance of making sure that the information you've heard today gets out on the street.

What I would suggest is that you're the people who can put it out. If you give me the words (I'm not allowed to do it because I'd get in a whole heap of harm if I did that as a government official). I we give it to you on the Net or something like that, you could just throw it around so that the customer is informed. Then the manufacturer's going to have to say, "Oh, Christ, we better to do something about it." Christian, just fill the gap in so we can remove some of the myths.

## The Dräger experience

**Christian Schult:** Our background is not normally the recreation market; our background is the military and commercial markets. We have been in this business for a long time and have developed a lot of diving systems. We have done many tests on our unit, manned and unmanned tests, wet and dry tests, pool tests. We have also worked together for a long period of time with the GKSS for example and the German Institute for Aerospace Evaluation, the US Navy, UK Navy, Australian Navy. We wanted to have the Atlantis tested by an external institute. We wanted to have some x number of people say, "Yes, this is within the standards." There were no standards available, that I know of. What I know is that German Lloyds which is an external independent institute that has been certifying diving equipment for a long time. They collected all this information and standards, what we have seen before, and tested our equipment under these standards. We the manufacturer, are more to happy to have this CE mark. The mark itself is not so important, but to have external institute say, "Okay, under the standards that we know, the unit is working." That's the most important thing. We must start with this. We must start with something. I'm more than happy if we can have standards like ISO, but so far there are no standards. We as a manufacturer must work together with experts and external institutes to get proven technology out.

## Who decides the relevant standard?

**Ornhagen:** May I ask you a question here? What is when it says here, "The above mentioned protective equipment is in accordance with the relevant requirements of the directive so-and-so." Who decides what is relevant? And do you know which directives these are?

**Schult:** I can't speak for German Lloyds

**Ornhagen:** But there must be a document saying for which they were.

**Schult:** They must have a document.

**Ornhagen:** I'm just trying to draw out what the problem is.

**Harwood:** I sit on one of the standards' committees with Gavin, and we don't really have a vote. We shout a lot, but we don't really have a vote unfortunately, because of the two institutes we belong to. But when it says, "basis for examination," this is a typical certificate. What happens is when the manufacturer presents his document, he has decided what his conformity is going to be. And it's then judged by the approved body. Now the approved body, in many cases, would just look at what the manufacturer has put up and they probably have less than the manufacturer in this particular area. And they'll just take his word for it, not because—I'm not being rude about it—they've got nothing else they can do. That's why it's important that we have what I call an international standard. It takes ages to get an ISO standard, but at least if you've got a consensus standard on the street to get the ball moving, then when it says "basis for examination" you're still going to have to have the published bits and pieces, but at least the independent test houses and the manufacturers are going to speak the same language. You brought the point out completely: Who the hell knows whether that's right? I don't know, but that's the best shot—and Dräger has given it their best shot. So when we all sort of walk 'round quietly saying, "Did Dräger do it the right way?" They did it the right way. Whether the information available was the best information, that's the point we're discussing.

**Schult:** We started with this process, now we have to work with this.

**Ornhagen:** Am I right in believing that the CE mark of the Atlantis is only valid for the pressure vessel and its mechanical properties. It has nothing to do with the performance of the flow control or the flow of the valve and so on, the performance of the scrubber unit. The CE mark is only for the container of the supply gas. Is that right or is that a misunderstanding?

**Harwood:** No, that is not right. The PPE, when you do the CE mark, you can get lots of CE marks within the same piece of equipment. Each component should have its own mark. But the apparatus as a single body has, because it's a complex design, has to have this document. What the mark says is that it has got a document, the manufacturer's document, called in this case a "Conformity Document," and that each one produced will be produced to that same standard. The problem that I'm trying to draw out of this is who knows whether the basis for examination was right. There's no point sniggering around; the point that Christian made was that it was their best shot. It seems to me there's some better information, so we've got that better information into a document so that the people can get hold of.

**Schult:** Can we wait for a worldwide norm or standard worldwide? We cannot, so therefore we did the best we could do.

**Harwood:** It takes about seven years on a good day to get an ISO standard organized. The secretariat has just gone to Australia, which means not many of us will ever get to the meetings, which is also another problem: it's done by correspondence. What we've got to do, and I believe the way to do it, is to drive it from the consumer. You make the consumer an intelligent consumer. You tell them what they should be looking for, what they should be asking for. The manufacturers then could conform to that. Then it makes easier then to put marks on because it speeds the system up. So this forum should be able to push that system along.

**Robinette:** Thank you, Mike. Bev Morgan.

## Problems created for manufacturers

**Bev Morgan:** I'm Bev Morgan with Diving Systems International. We just received two CE marks and one of them was with Lloyd's. Unfortunately they have no criteria to test to for certain kinds of equipment. They can test to scuba standards the EM20, but they're really out there in the dark when it comes to testing any umbilical gear such as our EXO-26, or our 17, any of our surface-supplied equipment. They don't know what to do, so what we're doing is putting together a set of standards for them to test to.

Unfortunately we have the same problem Dräger had—we don't build a rebreather—but it's the same problem. If we put together a set of test criteria for CE marking and every other manufacturer does, we're going to have a Tower of Babel and it's going to be really mixed up and it's going to be a super bad deal. We really need to have some sort of consensus, and the only way to do that is to have the meetings and decide on it. Because unfortunately what'll happen is someone with a set of gear for operational depths of 4,000 feet will lay that on a mud diver who works in rivers in 10 foot of water and doesn't maintain his gear too good; he probably makes less per year than what that kind of equipment would cost. So there really has to be a consensus to give to these testing houses.

## What manufacturer plans?

**Menduno:** Yesterday, we asked the manufacturers if they planned to test their equipment, everybody raised their hands. I thought it would be interesting to re-ask everybody who was doing their testing if they're doing manned or unmanned testing and what their plan for that was. So take a couple of minutes and say what your test plan is.

**Derek Clark:** Derek Clark from Divex. I wanted to get up and make a couple of points anyway to probably amplify what's already been said. As a manufacturer, we've been wrestling with CE marking requirements coming out of the PPE directive for a number of years . And I used to sit on a technical committee within the Association of Offshore Diving Contractors, and we actually convened a committee to really try to come up with some harmonized rules. Gavin used to come up, and we would sit down and started to work our way through a pretty comprehensive document that was to cover all equipment in commercial use, from semiclosed circuit bailouts through to open circuit demand to reclaim. It's a very comprehensive overall requirement to try to define the standards that the equipment should meet, and, indeed, how you test them and how you interpret those results.

The problem was who has to do that, who has to come up with these standards? The European legislation has said, "Thou shalt have these things." And there's a very laudable intent behind it, because it recognized, yes, let's have some common standard. But what it totally overlooked was that there's no mechanism, no infrastructure to create that standard. The law became the law for the whole of Europe in July of 1995, I think, and the law says, "Thou shalt," if you're a manufacturer, "only sell equipment in Europe that has a CE mark." You're breaking the law if you don't, as a manufacturer. And if you're a procurer of the equipment, and again supply it to one of your employees, you are breaking the law unless you undertake an exercise to ensure that the equipment that you're purchasing is fit for the purpose for which you intend it to be used and is CE marked to cover that very sort of functionality.

The point that I really want to make before I can answer your question is this: if a product has a CE-mark certificate, then the end user is stuck having to identify which set of performance targets that the mark was measured against. Instead of harmonizing a standard, what it has actually done is to disharmonize the whole thing because it forced manufacturers, like ourselves, to write our own equipment standards. That's the only way a manufacturer can deal with it so as not to break the law.

Now we make an interpretation of how we think our equipment should perform. We actually use a combination of EN 250 and the MPT Guidelines, because that's what we think is appropriate. And you have to specify the depths, the temperatures, the respiratory rates that apply to the equipment you're selling it for. Now, if any body's under any illusion that when they come across a CE certificates and think, great, that's a safe piece of breathing gear, they're very sadly mistaken because you could well go operate the equipment in an area that it was never tested for. So a CE-mark gives you a false sense of security. You have absolutely no sense of security at all. You have to find out how the products going to be used.

Frankly, as a manufacturer, we could say, "Well, I think we're going to go and get a CE mark for a piece of breathing equipment that we don't intend to be used deeper than ten feet. It's going to operate at 20 degrees centigrade, or maybe 22, and the diver's only going to breathe a 40 RMV." I can go and get a certificate for exactly that and put it on the market, and you say, "It's got a CE-mark; great." Now you go and dive it on a cold day to 60 feet and you breathe a darn sight harder and you die. Have I covered myself? I've met the law in that I have the mark, but I've only met the law if I've made it quite clear under what conditions it's to be used under. That is the real dilemma I see for this business. As a manufacturer, I can't control who's going to sell, and what it's going to use it for, without going to a very broad range of testing criteria from the deepest depths to the highest breathing rates to the lowest temperatures, to the highest temperatures. Believe me, the sort of testing that you have to do to cover that is significant and these guys are the only people who can do that. Absolutely the only people. We have a very comprehensive test capability with breathing simulators and so on. And frankly we're just scratching the surface. We can't explore every depth, every pressure—we'd be there for years. And we can't afford to do that. And we're a professional equipment manufacturer. So if you're building rebreathers in your back yard, that's great for you to use (be wary) but they'll never get to the market because you haven't got the infrastructure to do the testing. These are the only people that can do that. And you're going to have to spend a lot of money, hundreds of thousands of dollars, if you want to do it properly.

**Robinette:** What about a standard?

## Creating a guideline/standard

**D. Clarke:** If these guys [G. Anthony, J. Clarke, H. Ornhagen, and E. Thalmann] went into a room for about an hour, they'd probably come out with pretty much what the standards should be in terms of the respiratory rates, the CO2 levels, the temperatures and things like that. What they won't say is how far, how deep, how fast, how high and all those sort of things because the market's got to say that, not these guys. These guys are just going to say if the breathing equipment can stay within a certain breathing resistance and maintain a certain CO2 level then go as deep as you want within that performance capability, and that's as far as it can go. So I think that's not really the problem. It just has to be made absolutely clear that equipment will only perform to certain standards under certain conditions; if you move outside those conditions, be very wary.

For our part, we sell equipment into the commercial market and to the military market. The commercial equipment, if it's saturation diving equipment, will typically be tested for use down to 350 meters/1144 feet, because that's where the equipment is actually being used. So if our equipment hasn't been tested at 350 meters and someone goes and uses it at 350 meters and gets hurt, we're going to get sued. So we have to test it. If it's going to get breathed under conditions up to 75 liters a minute, 90 liters a minute, we have to test it to that. If it's going to be breathed in water temperatures of 5° C or 30° C, we have to test it to that, and the certificate has to say that. As a professional equipment supplier, that's the only basis upon which you can proceed. But I think that this market is a totally different ball game in terms of the variations in parameters that you have with rebreathers compared to open circuit scuba. It's a very daunting task to undertake the testing and to get bona fide results out of bona fide test facilities. The guidelines are there; you just got to spend a lot of money. That's the problem.

I haven't answered the question yet. Do you want me to try and answer it?

**Menduno:** So the answer is that you do test your gear, and provide the results to your military and commercial customers?

**Clarke:** That's pretty much it. We do a limited amount of testing usually at the extremes of the ranges we expect the equipment to perform at. And at the end of the day, we also have to go to an approved tester like German Lloyds and get our mark because we have to have a piece of paper at the end. We can't issue a piece of paper. All we can do is to make sure it'll pass. That's all we can do. On the military side, it's no different. We'll submit the equipment and say, "Here's our testing," and these guys'll do ten times more testing than we've done and probably find out things that we didn't know about. It is an immense task.

## Military testing

**Thalmann:** I don't know if it's quite that complicated. The standard within the military is that the equipment has to be tested at what is considered its maximum operational depth, and then some judgments have to be made as to what range of environmental conditions the equipment will be used. Of course, when the testing is done, a report is generated which defines the characteristics of the rig. If you're diving a Mark XVI in the Navy, you go to the Mark XVI manual that says if you want to breathe nitrogen/oxygen, this is as deep as you can go. If you want to breathe helium/oxygen, this is as deep as you go. It will tell you what the canister durations are. It'll outline what the rig can be used for. OK? The problems come in if the manual doesn't tell you what the limitations of the rig were. That would be like buying a car and nobody tells you how fast you can drive it. Or what it's designed to do. So the fact that the manufacturers are providing their own test plan doesn't upset me too much, as long as when you open up the literature that comes with the unit, it tells you exactly what was done and under what conditions. Then as an end-user, you have to be smart enough to be able to read that and decide under what conditions it is safe to use the equipment. If you're not smart enough to read it, you have no business trying to dive it.

## The $25,000 question

**Menduno:** Do I understand you correctly that for $25,000 the manufacturer can hand Duke University their rebreather and you will test it for them?

**Thalmann:** As I said, what we can do for $25,000, as I said, is do graded exercises and to depths and canister durations under two temperatures. That would give you a good indication of what the rig will perform at. Now if you take the UBA and you give it to somebody like the military, they may test it at several different depths. They may test at several different temperatures, and do much more intensive testing. There you start to get into...well, if you double the number of parameters, you double the price. The package that we put together was intended to say if you put your UBA through this type of testing, we think that you're going to have sufficient data to be able to decide whether this thing is going to be reasonable safe and effective over the depth range that it was designed for.

## Ergonomic testing

Now this testing doesn't include other things that need to be done when the Navy prepares a new diving rig. They may spend a couple of months just in a test pool using some human factors, to make sure the thing is safe to put on. We haven't touched ergonomics at all, but I can tell you that the [EDU] medical department, which is responsible for all the manned testing, has basically four docs and we have a human factors engineer who's generally trained in psychologically. His job is to make sure you could reach the buttons, look at the field of view, make sure the bloody thing would perform ergonomically the way it was supposed to perform. That is the kind of work that a manufacturer can do fairly inexpensively in terms of facilities, but you need somebody that knows what they're doing, how to go about testing it, and then how to write the report. That's the thing that's got to come out of it. This is the document which describes how the UBA was tested, under what conditions, and how it was done. That, in combination with a written manual, should give the user the information he needs to know as to safely dive the thing.

## EDU regulator testing

A good example of a defacto testing standard is the infamous EDU Regulator Report. I don't know if everybody remembers what happened. Basically the Navy had an incredibly old standard for scuba regulators, which basically meant that if you had a soda straw with a ping-pong ball on the end of it, that would probably pass the test. What Jim Middleton said is: "We're going to do is go out and buy one of every scuba regulator that we can get our hands on and test them." When he did it, he simply went through and put them on a breathing machine and just looked at the inhalation/exhalation pressure, which is all you need to measure on a scuba regulator as far as the physiology goes, and he just ranked them from best to worst. He said, "OK, we're going to draw a line at ten," and he drew the line. And the Navy said, "You can buy any one of these top ten scuba regulators." Well, you want to hear the hue and cry from the manufacturers. Some manufacturers actually went out and were trying to convince divers that it's better to have the regulator that doesn't perform well because you'll get in trouble. Yeah, just as long as you don't breathe on it underwater. As a result of that report, manufacturers now were forced to have a target. By and large, once the report was made available, people began to use it. Scuba divers said, "Hey, here are 10 regulators that meet the EDU requirements better than the other 40." So they started buying those and pretty soon manufacturers wised up and began improving their product to the point now where regulators as whole all easily exceed the standard. As a result there's a lot better regulators on the market than there might have been if that report hadn't been written.

## Rebreather manufacturers test plans

**Menduno:** I'd like to have the manufacturers come up and present their test plans, what they plan to do.

**John Sherwood:** John Sherwood, Fullerton Sherwood. Our equipment has been tested by Gavin Anthony, Hans Ornhagen and John Clark, and others at DCIEM. Because of what Dr.Thalmann has said, the $25,000 to get the equipment tested in the US may well become the cost of entry into this market. But it seems to me that we've set ourselves a fairly lofty goal here of trying to harmonize our testing program so that we're all working on a level playing field. Each and every time we take our equipment to a new military end user, they in turn take our equipment and test it to their standards because they recognize that their standards may be different from those of other navies. So although they've been working toward harmonizing their testing, and accepting each other's data, it's been a long, slow process. It costs everyone a tremendous amount of money. So let's not kid ourselves into thinking that we can get collectively together into a committee and establish a set of guidelines that we can all meet and all get the same CE marking that means the same thing to each and every person. Thanks.

## Prism II

**Peter Readey:** Pete Ready, Prism. We actually started out by first laying down the ground rules of what we wished our rebreather to do.

Let me say that I'm very indebted to the panelists up there. We took a lot of the information in papers written by Ed Thalmann, Hans and John Clarke, but I haven't read anything from you, Gavin, I'll be speaking to you later. In fact, I think we were also responsible for the quote Ed sent to us some months ago. We found that it was easier for us to take a yardstick like the Mark XVI that has an awful lot of test data that the Navy spent many millions of dollars on gathering and we taken that information and are trying very hard to beat it. In some respects, we think we have.

When we've got to that particular level of capability, we then plan to go to somebody like Duke University or FOA or hopefully we'll be passing around the hat later to get contributions from you guys to go do some of this testing. We want to get some independent test data on what we have found. But I think a lot of the information that we need is out there. I think if you take something that has been extensively tested like the Mark XVI and can beat the results, and then you get it independently tested, there's anything else that we can do as a manufacturer. That's the path that we're taking. Thank you.

## Biomarine Instruments

**Dick King:** Dick King, Biomarine. Let's look at what we're trying to do here first of all. We're trying to bring a product into a marketplace that is previously been supplied to the military market. We just happen to have benefited from the fact that we designed the CCR 1000, we designed the Mark XV, and we designed the Mark XVI. So we had the benefit of all these gentlemen's testing that's been done over the years.

In order to make an affordable unit we have decided to re-create a product that we have already had on the market, rather than go out and create a new product that doesn't already exist. Everything that is in our product has already been through EDU. The electronic circuitry is exactly the same we used early on in all of our packages. The scrubber system is exactly the same system that we've used in all of our products. So all we have done is take what we already know works, and what has had millions of dollars of testing on it and will bring it out to the consumer market at an affordable price. Now there's a price to pay for that. We have a huge insurance liability now to do this, and quite frankly, I don't even know after being here for four days, whether I really want to be in this anymore. Because I don't know that we can afford to be in it if we're going to take the attitude that everyone that's come here as a manufacturer has no integrity. I sort of get the feeling that what we're saying here is that manufacturers have no integrity.

## The most over regulated business

I'm in one of the most over regulated businesses there is. I'm FM approved, I'm CSA approved, I'm UL approved, I'm NIOSH approved. I can go on and on and on and on. The fact of the matter is all those approvals don't even guarantee that my product coming out the door meets the standards the standards that it was tested too. You have a whole other standard for that; the ISO standards. If I sound like I'm getting a little heated, it's because I am. Because all that say is essentially that you have produced a product, that if produced that same way every time, will perform within these parameters given that you use the same test subjects in that same situation each time. So you've established that much.

The ISO's, the milQ9/58's, said that you have a self-auditing program in house and deal with procedures that you've established in-house to build these products, and that every time you build them, you build them in the same manner, using the same equipment, they're tested in the same manner, and that's fine. But even that, when you consider the fact that you have nine people doing exactly the same thing, working from the same procedures, and they all perform at different levels. They're all humans and they all think in different ways. So any one of those nine people making that piece of equipment have all made it different from the others. You've tried to control it because you're given them procedures. But you can't control the human element of what they're doing.

I was sitting here thinking. We're talking about controlling a piece of equipment when we have a bunch of people in here, tech divers, who go out and reconfigure their own equipment every day depending on what kind of tanks they're carrying, what kind of computers they're carrying. Who's regulating it? No one. It's all self-regulated. I have to worry about what I do from an insurance standpoint as well as a moral standpoint, and I do that. But to sit here and say that we're going to establish a standard that's going to control every manufacturer in here, then you might as well give up having rebreathers in this marketplace. I think there has to be standards. We've adopted the military standards because it was the easiest way to go, but we're talking apples and oranges. We've got semiclosed circuit units that cannot be bunched in with fully closed units. We've got combinations of fully closed with semi closed, which is a whole other animal. I could go on and on and on. I'm just a little frustrated.

I told you what I'm doing, we're doing about the same thing that Derek's doing and we're dealing with products that have been tested before.

## Importance of independent testing

**Thalmann:** I'm not sure what the problem here is. If you look at the EDU goals, for any type of diving apparatus, the people that do the testing, know what the heck they're doing. Could you come up with a standard? There's already test standards in place and the idea is uniformity. We're not talking here about manufacturer integrity. If I write a scientific paper and give it to somebody to review, he's not going to call me a liar. He's going to put it through the grinder to make sure I did a good job writing it. If somebody gives EDU a rig and they put it through the grinder, it's not because they don't trust the manufacturer. That's what is called "independent testing." That's the only way to do it.

I think the problem is getting everybody to agree that there is a test procedure which ought to be applied to UBA's and that there ought to be certain information which is supplied to the end-user so that he knows what's been done. But I don't see it as a big problem. It's going to cost money; there's no question about it. But I think the concept: that apiece of life support should be put through some independent testing to verify that in fact it works according to the manufacturer's specifications is valid.

I'm here to tell you that when we first tested the Mark XVI, it did not work according to manufacturer's specifications. There was a lot of kicking around, wailing and gnashing of teeth, and pointing of fingers but we stuck to our guns and the bloody thing got changed until it worked. So it's not a matter of not saying the manufacturers aren't reliable; it just turns out that when somebody independent, who has no vested interest in whether this thing works or not, tests the equipment, he can give it the kind of testing that is not influenced by the outcome. That's what you really need to do.

**Robinette:** Thanks, Ed. In the back.

**Wible:** I'm with AURA and I wanted to point out something. It's easy to pass a test, especially with rebreathers. It's easy if you say we have to make four liters a minute of oxygen; OK, we made that. You can't exceed 15 millimeters of CO2 buildup in the unit; OK, we met that. My point before was that you're interacting in a different way with a diver and rebreather, and that you need user communications. The other thing that'll happen is when a unit comes out, the tech magazines are going to write them up, and people are going to dive them, and the ones that have problems are going to fall out right away. So it's a different situation than a military situation because you have a free market.

**Robinette:** What about the divers who found out the hard way that there were problems?

**Wible:** Well, we could probably make those two things I just said a standard and that would basically save a lot of lives right there. The CO2 build-up limiter and an oxygen delivery capacity. Beyond that, though, there are other things like what I observed yesterday. I saw a person get in the water with a double breathing bag on the front. They got in and immediately the tendency was to roll off to the side which then limits the diver's ability to breathe. That, in itself, could go click-click. There's a death. So who's going to make a standard to deal with instability on the surface. Or what about your position on the surface where the breathing bag may get to a point where you're choking yourself. Who's going to make a standard for that? Another thing, I saw someone dump scrubber material and there was bright purple in one area. Well, that's a hot spot. Who's going to make a standard to catch that? There's so many possibilities and variances.

**Thalmann:** I think there are standards for that. OK, that's what human factors is all about. Those are exactly the things that are done at EDU before the rig is ever put to depth. OK? You put a diver in it and you look at the breathing bag choke-off. You look at the fact that when he turned his head in a certain direction he pinches his hose. You find out that if he's got a full drysuit on; he can't reach the bypass. OK, there are standards out there. I think everybody here is missing the point: the Navy's been doing it for years and there's a model out there which it can be based on which costs nobody anything, except your income tax. Methods of testing and how to put a rig through the ringer are well-known to the military. I would take anybody to issue who says, "Well, sport diving is so different, we can't apply those." That's baloney. You're putting somebody in the water, you're putting them at depth, and you're trying to keep them alive. Those are the three goals of an underwater breathing apparatus. And there ain't no difference between recreational divers and military divers in that regard. None.

**Menduno:** The question, Dan, is what is your plan for testing equipment?

## AURA test plans

**Wible:** Our plan is to develop with integrity, a unit that we feel will have much greater capacity than the human body that will perform at depths much greater than the human body would ever go. S o the unit itself will be high integrity and pass these tests that you're talking about. After this meeting, we will be building a very similar breathing machine [To Hans Ornhagen] to do these tests. That will be done, but we're going to try to rely heavily on user input. We don't have the resources that the Navy has to put out 3,000 divers a year, and we're going to have to rely on a club effect. It's the same way the Aqualung started in the fifties in California when people were pulling their fire extinguishers apart and putting on the little vacuum cleaner hoses. You have to go back a little bit to an infantile stage here, because we're not dealing with the military anymore, which has a huge resource and is funded by our tax dollars. We've got to depend on user input; that's what I've been trying to say.

We can pass these tests; that's not a big deal. Twenty five thousand dollars isn't a big deal. I appreciate that, if we can keep our testing that way, that'd be nice. But we're still not solving the problem. We have to have user input and we have to have kind of like I said, a fish tag routine where everybody logs their dives and presents their logs to some institution that can track this over time, and with subjective comments included. It's got to be done to keep this a safe sport. You can't do it with testing only.

## Undersea Technologies

Stuart Clough: Stuart Clough, Undersea Technologies. I think that your question was what do we plan to do as far as testing goes? We obviously internally benchmark our systems against everything else that's out there on the market and readily and easily available, specifically the Mark XVI that we've used for quite a while. All of our human testing, manned testing, is overseen independently by DDRC in England. And the machine testing goes out to independent laboratories. We have independent contractors who deal with the ergonomic side of the system. Essentially we have internal benchmarks and we get external people out, then it goes out to external labs. That's all we do.

## Personal preference

**Thalmann:** One of the things that I think everybody's losing sight of is that just because something passes a test doesn't mean it's good. What it means is it's not going to kill you. Now the point is that before you can get your users to give you feedback, you have to be bloody sure that the thing you're putting on their back is going to keep them alive so that they give you the feedback; that's where the market zings out. Of the top ten regulators that EDU published, there were differences between them so that diver A preferred one regulator, diver B preferred another. It's the same way with the UBA's. All the testing says is that these things were all tested more or less in the same way, under conditions in which we think they will, in fact, support a diver. Now whether he likes the way the thing breathes or he likes the way the buttons are or he likes the color, that's personal preference. Just because the Mark XVI passed the military standard does not mean that it's the kind of rig that I would want to dive. Because I dove it and I don't like it. But some other guys do like it, so just because it passes a test doesn't mean that the divers are going to like it. It just means that it's built to a specification which is going to perform the function that it was designed to; the rest is personal preference.

**One of the things that I think everybody's losing sight of is that just because something passes a test doesn't mean it's good. What it means is it's not going to kill you.**

**Ornhaagen:** It's quite obvious that there are rules and standards that could be used. But it's also quite obvious that the trouble today is that the manufacturers of, let's call them the new generation of rebreathers for recreational diving are not facing the same type of market as the old manufacturers who sold exclusively to the military. There were lots of dollars in the old programs.

The problem is, today, to try to adapt what "is "into something that is possible to reach, from an economic point of view. In Europe, the community is now putting a lot of emphasis onto the consumer organizations. In the future, I think that we will see the European consumer organizations putting up the demands for different specifications. Maybe that is the way to go, to try to have the consumers come together and say "This is the minimum standard for this type of equipment," selecting them from today's existing procedures and standards. That's the way I think we might proceed.

## Agreement for independent testing?

**Menduno:** Is it the consensus then of this body, that rebreathers coming on the market should receive some sort of independent testing and that there are some standards, and available testing facilities, and they can be tested against these? Is that a recommendation that show come out of this meeting. A show of hands, yes, these things should be tested?

[A largeportion raises hands]

**D. Clarke:** I don't think any body's not going to put their hand up to that question actually, but that wasn't what I was going to say. I probably come across pretty sort of doom-and-gloom as a manufacturer in showing no interest in the sport market, but I am here. And I'm here because I'm interested. My views haven't changed from the beginning of this event to pretty damn close to the end. But I can't quite see the circumstances upon which we would enter this market any time soon. The problem here is that you can test equipment supplied by manufacturers. Dick made the point that he's got a huge pedigree behind the product he's offering, and he's alluded to the point that he's got to maintain control of the production process he has to ensure that he's maintaining a common or the same standard of build as he goes through the evolution of the product's life. And that there's comparability to the standard equipment that was originally tested. Now he's got a huge body of data behind what he's got, and I would commend that to people who want to take rebreathers into their own sphere of influence and use these products on a one-of basis. I think the recreational industry will proceed on that basis pretty safely because you're going to have well-informed people who are going to control their own sort of destiny. We had a number up on stage yesterday who are doing just that, working well outside the regime of military would ever condone because they know their own limitations. That's fine, but to see this coming to the market like a scuba regulator, I can't comprehend that at the moment, to be honest.

## A difference in markets

The point I wanted to make is that if you build a piece of equipment, it leaves a factory identical to the one built 10 years ago, and it's been tested to that standard and everybody's happy, that's one thing. But don't forget, compared to a scuba regulator, the capacity for the end-user to dick around with the build state in service, which I can't control as a manufacturer, and kill himself is vast. And it's probably my fault if I don't make the equipment so that he can't do that, no matter what he does.

Jim Brown made the point that the military objective is to eliminate human error. The difficulty for one manufacturer to eliminate human error with rebreathers is tough unless you go down the route that I think Mike Cochran's going down with Peter Ready. Unless you really add a lot more technology to this stuff, and get it a lot more sophisticated to get it back to being pretty much foolproof, it's a tough call. How you get to that point? How you to evolve the product to that point? It's actually good that the military are so well represented here. They're looking at what the recreational market is doing because the recreational market is advancing the technology in this area. The military is generally working with 10 to 20 year old technology at the end of the day because of the way it's done there. It has a huge pedigree and but it's very slow in moving the state of the art forward. On the other hand, the recreational market, is moving very rapidly forward, leaps and bounds every month by the claims that are made. Now, it may well be that some of this will be transferred into the military, and will create a pedigree which will then come back out into the recreational field. I don't know. It's going to take several years. I don't have an answer for this; I really haven't. But I do know it's a very difficult area and that's the message I think everybody's getting here: rebreathers are more than a quantum leap compared to scuba.

**Readey:** Just a quickie on that, Derek. Surely some of the technology like CO2 detectors will certainly help the military. A lot of the sensor technology is out there, which will make rebreather diving safer. I don't think, as somebody said it earlier, we have to go back the dark ages and Jacques Cousteau technology, if we start off where the Navy's left off with something like a Mark XVI, with all those millions and millions of dollars of test data.

I really am greatly indebted to Ed and to John Clark and others because they have published all this information. If you start from that and make it better, I cannot see how we can really make a mistake. We have to develop the system specifically for the recreational market. I can't see what else we can do.

**Mike Wehrs:** I have a comment with regard to the profession I'm in, the marketing side of things. I'm hearing all about the number of certifications that manufacturers have to go through. Now I'm not a rebreather manufacturer, but I certainly know about this from past experiences with products that have had a transition this way—this certification-itis. I mean if you're going to take an end-user who's a certified diver who can go out in a weekend and become a certified rebreather diver and you're going to put 15 different certification labels on your product; no one is going to know at an end-user level what it will mean. This has got to stop. We got to pick something like is done with regulators, like a class 1, 2 or 3; define what those are, publish and publicize to the end-user community who's going to buy it. That way when they look at a piece of gear from buying decision viewpoint, it doesn't have 14 different stickers from every different country and organization that has looked at it. That's way too complicated for a recreational market at this point. So that's just a cautionary note. All of this stuff is good but it's missing the end-user perspective on how we have to market this thing if we're going to be successful at it.

## The shadow knows

**Robinette:** Thanks, Mike. One quick comment from somebody that's been doing this for a long time. I don't know if you realize it or not, but I also am a rebreather manufacturer or was at one time with the Shadow Pack. A number of people here have tested my rig and everything else, and I've gone through a lot of money trying to test on my own. Gavin tested the Shadow Pack, and EDU tested the canister on it. My experience is that we need communications like this meeting here. Without meetings like this and without reports from EDU—I have 20 years of EDU reports—I might not know that I should be looking at certain test data and things like that. I think the most important thing about this whole thing is continuing the process of communications and defining these standards that we need to have.

I realize that a lot of the manufacturers that are trying to get a product out there on the sport diving level probably don't have a budget like Ed's talking about. Even the $25,000 is a tough thing to come up with for a sport diver manufacturer that's trying to get into this market. But if we were to define these standards, it would certainly be an easier row to how.

We're now going to take a fifteen minute break and then come back for our next session.

# Military Rebreather Training

*". . . when you teach somebody in a rebreather, you're not teaching them to dive a rebreather; you're teaching them to survive in a rebreather. It's a completely different ball game."*

-- Lt. Rob Cornick/Royal Navy

## Session Summary

The militaries of the world have the most extensive training experience with rebreathers. In this session, trainers from the US Army, the Navy, and the British Royal Navy discuss their respective training programs for the Dräger LAR V, Carleton Technologies Mark 16, and the Royal Navy's DSSCCD.

All of the presenters emphasized significant differences between rebreathers and open circuit equipment and a healthy respect for closed circuit technology. The unit one group trains on is affectionately known as the "Clammy Death." Others discussed what, in their experience, can and has gone wrong in training military divers to use rebreathers.

From the discussion, it is clear that the military has the advantage of an enormous infrastructure and organization to support rebreather training, maintenance and logistics, which probably accounts for much of their success with this technology. This infrastructure is presently absent to a large degree in the civilian sport diving market, and as was pointed out, so are common training standards. Several panelists stressed that the use of full face masks, and always diving with a buddy could significantly improve safety in rebreather diving.

The panel was chaired by Karl Shreeves/PADI-DSAT, and consisted of Jim Brown/Spec Forces U/W Operations, Barry Burgess/EOD Training & Evaluation, Rob Cornick/Royal Navy, Jim Ruth/Naval Sea Systems Commands, and Mike Vogel/NAVSPECWARCOM.

# Military Rebreather Training

28SEP SAT 10:00-11:00 am

## Transcript

**Karl Shreeves**: Good afternoon. My name is Karl Shreeves. I'm a vice president at Diving Science and Technology (DSAT). This afternoon, we're going to talk about the military training experience. When we talked about the military operations yesterday, the interest seemed to be on training. Though we may run into what the HSE, which coined the term "transportable pressure receptacle," might call "duplicocity of effortation," we're going to overlap a bit and pick up where we left off yesterday. This community can learn from what we might call military "software"—the training of divers.

We'll lead off with Mike Vogel, a Navy SEAL, and Mark 16 trainer at the Navy Special Warfare Center, followed by Master Diver, Barry Burgess an EOD trainer and evaluator. He will be followed by instructor Jim Brown from the Army's Special Forces Combat Swimmer School, and Jim Ruth with Fleet Diving Engineering who's going to talk about some of the incidents they've had and what can be learned from them. Finally we'll hear from instructor Rob Cornick with the Royal Navy.

### Mark 16 Training

**Mike Vogel:** I work at the NAVSPEC Warfare Center in Coronado, California. Currently we run Mark 16 training which is the first part of the SDV Course [Swimmer Delivery Vehicle: a type of mini-sub—ed.].

A little background on myself. I spent four years at SDV Team 2, diving mini subs. We dived the Mark 16 on nearly every dive in the mini-sub, about 150 hours a year , the whole four years I was there. Then I left, ran around the world, and then went back to SDV Team 2 for two years. Now I'm at the NAVSPEC War Centre and have about eight years experience using the Mark16. I'm going to discuss how the Navy looks at training.

We have organizations that control training; CNET, the Commander Naval Education & Training, and the NAVSPEC War Center. CNET tells how us how to teach—the Navy is very specific on how teaching should be done, instructor qualifications, school house management etc. What we teach is dictated by NAVSPECWARCOM. They say, you're going to learn the Mark 16. You're going to dive it.

As far as instructor quals at our school house, everybody there is an E5 and above [Navy second class, equivalent to an Army sergeant—ed.]. They all go to a two week instructor school in addition to going through the MK 16 class.

Student control? We deal with students that have already graduated BUDS training; they're on their way to becoming SEALs or they are SEALs who've been in the community for awhile. So we're dealing with people who already are at a base level with respect to improving themselves.

Curriculum management is the Navy's big claim. We go through a very long approval process. Equipment must be approved and audited and maintained. We keep hard copies of any change that we make to training. These are recorded and logged, especially if we get new pieces of gear. We have TOs and EOs. A TO is a terminal objective, what you want to have after the unit course is completed. An EO is an enabling objective, a thing that helps you achieve the terminal objective. Then we have tests: these are all recorded, tracked and monitored. With any high-risk course, we have a yearly review, to make sure all this stuff is properly on-line. They come over and look at our schedule; if we're not teaching a particular course, and at the time we said we were going to teach it, then we're in trouble. It's all very, very exact.

The Mark 16 course is 80 hours over10 days. There's 16 hours of classroom, about 64 hours of lab and diving. A basic breakdown of our course; we begin by reviewing gas laws and the partial pressure math with this rig. We talk about the Mark 16's components, dive operations, pre and post-dive procedures. We spend a lot of time on emergency procedures. There's a full face-mask class, and we go into maintenance and record keeping, maintaining control forms and doing failure analysis reports.

As far as diving, the first dive is a full fam [familiarization -- ed.] dive, in clear shallow water. Then we do a tower dive, which is really deep for us. We have a tower, so we can do the depth changes and they can see what happens to the rig and partial pressures as they ascend and descend. We do two open-water dives in the bay, two open-water dives at night, a full face-mask, pool dive, a full face-mask open-water, and then a 120 foot bounce dive weather permitting.

### Mark 16 supervisor training

**Barry Burgess:** I'm a Master Diver at Explosive Ordnance Disposal Training and Evaluation Unit 2. We're based out of Ft. Story, Virginia. As the name implies, our mission is to train Atlantic fleet EOD personnel on pretty much all facets of EOD operations, and evaluate new equipment procedures. My division specifically deals with the diving. We teach scuba and a Mark 16 supervisor course, and we're currently working on a Mark 16 maintenance course.

For a student to go to a Mark 16 supervisor course, they have to complete the basic course; a little different from the SPECWAR and EOD basic course due to mission differences. Everything that Mike said as far as the training is exactly the same. Everything we do is high-risk training, under the same requirements.

When students come to us they've already been through the basic course and they're knowledgeable on the rig. However, the supervisor course does review some important subjects including; physiology, medicine, operational procedures, maintenance, and emergency procedures. We go over these subjects; and I can't emphasize this enough, we go over 'em and over 'em until everybody knows 'em.

Our course is taught in Guantanamo Bay, Cuba, an excellent location due to water depth, clarity and temperature. We also have a close proximity chamber, which makes life a lot easier for us.

The Supervisor course is 11 full days long. The first three days are conducted in the classroom where we cover physiology, medicine and a little breakdown. Some of the things we cover are dive formulas including CO2 absorbent, gas duration, emergency gas volume requirements for our UBS, the Mark 16 pre-dive check list (which is fairly extensive) and why it's important, and decompression tables for N2O2 and HEO2. We cover repetitive dives and the Navy Manual Volume 2 and also decompression in the water, how to maintain dive logs, dive supervisor checklists—there are plenty of checklists involved in all Navy diving—and again, emergency procedures.

One of the more important things that we also discuss during this time frame is the dive briefs. I can't emphasize dive briefs enough; we discuss every aspect of the dive during our dive briefs. There's a fine line-, but I'd rather have too much than too little. I like having everybody knowing exactly what they're supposed to do in any given circumstance.

We also let the students run mock dives; it breaks them in to using watches, and if you don't think that's hard, try it sometime. Stand up in front of a group without the hubbub of a dive station to distract everybody. Everybody's focused right on you and you actually have to run a dive. That's from descent, ascent, decompression stops, and emergencies that might occur. Currently communications for Mark 16 dives are accomplished by line pull signals.

**We dive systems with triple redundancy and procedures and tables designed with a great safe factor. I strongly recommend them or similarly safe procedures for the non-technical and non-professional divers.**

The fourth day of the course is spent building up the rigs, which takes up the whole day. Days five through ten are spent on dive stations. On a dive station, every student is going to supervise a dive of the day. The dive starts on the first day at 80 feet/25 m and we progressively go deeper until, on the tenth day, we hit 190 feet/58 m. On the shallower depths we use N2O2 [nitrox mixture] and as we get deeper, anything deeper than 150 feet/46 m we have to go with HEO2 [heliox mixture]. Each day the supervisor students are subjected to stress loading with emergency scenarios of every imaginable problem.

The final day after all the dives are completed is spent up cleaning up the rigs, post-diving, post-mission debriefing the entire course and maybe we'll drink a well-deserved beer or two. That sums up the Mark 16 supervisor course.

With regard to Mark 16 maintenance; there are twenty, what we call PMS checks, required as a part of the pre-dive check, that take about an hour per rig to perform. There are also twelve post—dive checks, after each dive, that take another hour with fully qualified personnel. Then there are overall checks and an annual over haul of the system, about 40 individual PMS checks in all associated with the Mark 16.

In my command, we own fifteen Mark 16 rigs, and if we dove all of them one time a year, that would come to 600 PMS checks and 242 hours and a few minutes. This is excluding any repair time that goes into the rigs. Obviously you'll easily increase the maintenance approximately two to three hours every time you take the rig out and dive it based on our standards. The point I'm trying to make is the Mark 16 is pretty maintenance intensive. My very humble opinion is that if we want to bring rebreathers to the general sport diving market, we have to keep it simple. Simple. I believe Dräger's on the right track.

In conclusion, there appears to me to be three stages of end-users: military users, technical diving users, and the general sport diver. Being military divers who use high-end rebreathers, it stands to reason that our training is going to be a little more intensive. However, after what I've heard over the last few days, I don't think we should confuse the general sport diving public with the technical community and hold them to the same standards. It would be a mistake.

Final thought. We dive systems with triple redundancy and procedures and tables designed with a great safe factor. I strongly recommend them or similarly safe procedures for the non-technical and non-professional divers. I have the Navy standards if anybody wants to see them later.

## LAR V training

**Jim Brown:** I'll tell you a story. A couple of years ago I was involved in testing some camouflage uniforms and personnel nets that you carry around with you. They like to send us these type of things to take out into the field to try out. When we started this gear, the first thing we noticed was that the uniforms stood out at night in our night vision goggles, when the material was wet. The manufacturer had never considered this. Granted it was a test. Right?

Take that same concept and apply it to rebreathers. The manufacturers know how their units work, they know how they go together at the work bench, and presumably they have had them tested. But they do not necessarily know how the end-user is going to use them. They may not know how the end-user is going to best learn their rig. I would pose this to both manufacturers and training agencies; share equally in the responsibility of transferring information and creating standards for the end-user. There should be equal sharing of responsibility and activity.

I would like to share with you my three favorite words. These are the words that we like to use when we conduct military operations. Dominate. Eliminate. And control.

The combat dive school where I work is not a gentlemen's course. It's physically and psychologically one of the three hardest schools in the Army. I think that we may share status with BUDS [Basic Underwater Demolition School --ed.] and some other training that represent the most difficult schools in the military. This approach isn't going to work for civilian divers. Nonetheless there are some points I'd like to put across as a rebreather trainer.

In our case, dominate means dominate our student to get their attention. There is a certain level of aggressiveness that we use, that would be inappropriate with people who are looking to learn a recreational sport. Military command tends to communicate vertically, so do men with respect to things like pecking orders and status. Women tend to communicate horizontally; they like networking.

You have to be aggressive as a rebreather instructor. Some of you may have noticed that we had bag dumps [Divers took their mouthpieces out without properly closing them, flooding the breathing bag—ed.] out in the lagoon. As an instructor, how do you convey the importance of mouthpiece protocol on your students? To do that, you have to get their attention. Right? So to a certain extent, you have to dominate them and establish a student—instructor relationship that's above and beyond what you might do with open-circuit scuba training where minor mistakes are not as catastrophic from an equipment standpoint, or from the point that you're going to lose your boys in the sink. That's a consideration, applying a very simple aggressiveness factor to getting the students' attention.

In addition to dominating, we eliminate the weak through stress and other kinds of testing. Then we control our students throughout the rest of the course.

We use performance-oriented training just like everybody else. The dive certifying agencies do a good job of that. It means the students have their hands on the equipment. You give them the amount of theory they need; they go to work with it.

With the LAR V, we're not that concerned with whether our students knows how many pounds of scrubber material the canister holds, or the volume of the breathing bag or things like that. We are very interested in having them know the appropriate operational parameters so they can get the job done.

**. . . my three favorite words. . . Dominate. Eliminate. And control.**

## Managing the human element

How do we manage the human element once we've dominated our students? Our supervisors interact with our students during the pre-dive portion of the dive. We have a briefing before every dive where we. are concerned with information overloading. We have an informal time standard of about 20 minutes for a dive brief. Too little is detrimental, too much is detrimental. We have refined our briefing so that 20 minutes is about all they need to get out the important information without sacrificing safety.

Pre-dive checks: the dive supervisor interacts with students usually in a one-to-five instructor to student ratio. On the checklist there are requirements for the students to get the attention of the dive supervisor to review their rig. There is a great deal of interacting there.

We have DSPI's, Dive Supervisor's Personnel Inspections. Once the diver has put their equipment using buddy assistance, the dive supervisors comes and inspects the equipment, for example, the one-way valves in the

LAR V breathing hoses (it's fairly catastrophic if your one-way valve stops working). It's a methodological, left to right, top-to-bottom look at twisted straps, mis-routed weight belts, equipment not properly donned, or unserviceable.

We all do supervisor-purge procedures, purging the oxygen rebreather of inert gas, along with the nitrogen in the lungs, the bag and the canister. We have a way of doing that across the board that tends to cut the passage. Then there are post-dive procedures. We have supervision for that too.

What happens when your student is not doing a good job? This is a problem faced by instructors whose students may not be ready to dive a rebreather, or who are somewhat scatterbrained to begin with, and having trouble assimilating the tasks involved in diving a new apparatus. We make on-the-spot corrections, but you have to do it in every time. You can't let it slip by. Just because you told a guy to shut the dive service valve before he takes the mouthpiece out of his mouth 20 times (and you probably shouldn't let this guy get to that point), you can't get bored and let him start getting away with it. You got to stay on him until he starts doing it right; you can't afford to let your student develop bad habits.

## Major and minor deficiencies

We categorize problems into major and minor deficiencies. We take a very close look at major deficiencies, and if it's a safety thing, a student can actually be thrown out of the course. After three major safety violations, we'll send the student home. Major safety violations are gross errors that will either get the diver or his buddy killed or seriously injured. An obvious one is forgetting to fill your scrubber canister. Pretty simple. Another example, that may be easy to relate to in open circuit training, is entering the water without the second stage in your mouth. Mis-routing a weight belt underneath another strap, so that you are not able to dump it. Not checking the pressures in your bottles or analyzing your gas. These are all very major safety violations. It may be constructive to add something like this in your program, whereby major safety violations can preclude a student from continuing in your course.

In the LAR V course we offer theory in four-hour training blocks, morning, afternoon, and at night in the classroom. History and theory are four hours, operations is four hours, pre-dive and post-dive procedures are done in the closed-circuit room where we actually assemble and dis-assemble the rigs.

We start in the pool and then move to open water. The students do 13 ocean dives combined with basic navigation skills. There's a transition at some point from learning how to use the rig, to purely using the rig and executing navigation dives. Whether or not the LAR V requires 13 dives is subject to interpretation because we're doing other training during these dives as well.

Thank you.

## The importance of full face masks/incident analysis

**Jim Ruth:** Unlike the other members of the panel here, I happen to be a sand crab that works as a supervisor of diving for the Navy. What that means is that I'm a lateral walking creature who lives on the land. I can't add to what these guy have said with regard to training, but I can discuss some of the experiences we've had over the last several years with rebreathers. Specifically, I'd like to talk about some incidents that have occurred—some good, some not so good, in order to give you some things to think about when you're developing your own training curriculums.

I have a pretty strong training background. I started diving when I was about 16 years old, became an instructor in 1977, and been teaching scuba dive ever since. But when I came to Supervisor of Diving's office about eight years ago, with 3,000 hours of bottom time, the first thing that they told me was that they didn't care; I had to go to Navy Dive School and learn it their way. So I did. I went to the basic diving officer's course and then, since that time, I've gone to the EOD basic course and then qualified on the Mark 16. I've been to BUDS and got qualified on the Dräger [LAR V]. In addition, I dive with the operators from time to time. I find that helps me in my position, because I can go out there and verify a problem that has been reported firsthand. I don't have to hear it secondhand.

Our office buys the equipment that the Navy uses. We oversee the testing that's done, and we have to fight with Congress to get the dollars to buy the things that we need. That's what we do. In my job, I not only get to look at the problems, but also the prototypes, and we evaluate whether these are something that we can use to enhance the guys abilities to do their mission.

We've had some incidents over the last couple of years with the Mark 16. Some of them have been manufacturing problems, some have been old problems that we weren't aware of, that just started to manifest themselves. For example, some of these are as simple as having potting problems—air bubbles beneath the potting or the epoxy mix that holds the electronics. The rig works fine at first. Then, after it's been used for a period of time, the air bubbles tend to crack the potting compound and next thing you know, there is water leaking in on the electronics, and we all know how that goes. That was a problem that we had; it was giving us false display readings on the effected units. We've also had some problems with wiring and connectors, and the epoxy adhering to the insulation. We had to do a lot of expensive testing on that and in the final analysis, we had the supplier change the insulation material and that solved the problem.

Yesterday, I made some pretty strong in my statements about diving a full face mask. The next two examples illustrate why I feel so strongly about this. The first incident involved an individual from the EOD community who was highly-qualified and had a lot of experience on the rig. The rig has been maintained properly.

If you know anything about the EOD community, which uses these rigs, you know that they tend to be real anal because if they make a snip in the wrong thing, a piece of ordnance is going to go up in their face. They apply that same attitude to their dive gear, so they tend to be very careful, very meticulous. We have auditable records, so we can go back and look to see when the rig was maintained; the last time an O2 sensor was changed, the last time the O-rings were changed, when was the last time it was cleaned. We can get all that. I don't think you're going to be able to get all that out of the recreational community because that kind of discipline just isn't there. There's nobody that can come into their house and say, "Let me see your maintenance records." And I wouldn't imply that that's something we should do.

In this particular incident, the rig had been overhauled. It was fine. It had been checked out. It went through predive procedures. Everything was great. The rig was working, everything was perfect. The guy gets in the water, and didn't realize he had a problem. A problem? It turned out that the rig had a pinched O-ring in one of the electrical cables. As the diver started to descend, he's got a high $ppO_2$. His diluent is working fine; he's making up the volume in the bag as he's going down. He's fat, dumb and happy. He's got a green light, he's good to go. All of a sudden he used up all the $O_2$ in his bag. Wham!

**He's fat, dumb and happy. He's got a green light, he's good to go. All of a sudden he used up all the $O_2$ in his bag. Wham!**

What happened? The pinched O-ring floated out the connector and prevented the electrical signals from going through to the $O_2$-add valve. By the time he recognized he had a problem, it was too late. He'd already consumed the usable amount of oxygen in his bag. This particular individual didn't make it. A lot of questions came out of the result of that investigation. Was there something else that happened?

The EDU went through that rig and probably rebuilt it three times in the process of evaluating it and trying to determine if there was anything else was wrong. Is that human error? Maybe it is, maybe it isn't, but I challenge anybody in this room to tell me that they're going to put a connector with an O-ring on something and know whether you pinched it or not. The only real test is once it got wet. On land it worked fine. Had the diver been wearing a full face mask in that particular scenario when he blacked out, he would not have drowned. That why the full face mask is important.

Another incident went unreported though we were aware of it. The individual was wearing a full face mask, had a problem with the rig, and blacked-out. The good news was he had a full face mask on; his buddy took care of him, changed the rig around and he was fine. He's here to live to tell the tale. That pretty much emphasizes why I think a full face mask needs to be worn. The difference between a rebreather and open circuit scuba is like night and day. The number of problems that you can have as far as hypoxia or $CO_2$ build-ups, the number of things that can go wrong is significant. A full face mask may make the difference as to whether you come back to talk about the tale or not.

I'm not saying that's the panacea. You pay a price for using a full face mask. The first price you pay is that you lose some mobility with your head; you've got two hoses that's going to restrict head movement somewhat, and you're going to have to get used to using the mask. Some people are not going to like that ; it constrains their freedom, but I think it's a necessary price to pay for that particular piece of gear.

Overall, we've had 16,000 hours on the Mark 16 and we'd had 4 incidents, one of them a fatality. That's a pretty good track record, but I don't think that's directly translatable over to the sport market because we have a rigorous system in place. The manufacturers and the training agencies are going to have to address how you do this in the sport market. We have a specific organization set up to record and monitor Failure Analysis Reports (FARs) that come in whenever they have to replace an O-ring, a connector, a wire, or an $O_2$ sensor. We have a whole engineering organization that tracks that type of data and is able to spot a trend. We have many different operators all over the world and they're not necessarily talking to each other. That sounds a little like the sport diving market, however, we have a central group that is gathering and analyzing the data to determine if there is a trend to a problem. An $O_2$ sensor problem? A connector problems? What? They do the investigative work and get it fixed. It may not be an isolated problem, even though to an individual operator it appears to be isolated.

It's going to be incumbent on the manufacturers to tell the training agencies, or whoever the trainers are going to be, what their rigs will do, how they're to be maintained, what's the recommended maintenance rate, what spares are needed etc. The training agencies can take that information, package it, and put it in cellophane and come out with a pretty good program. But it's going to be incumbent on the manufacturers to do that. They are going to have to supply a lot of data on how to use the rig in addition to supplying data on independent testing.

## The Royal Navy experience

**Rob Cornick:** Some of you might recognize my accent as early American and anyone who's out there is entitled to wear feathers.

I'd like to give you the perspective on Royal Navy diving. At the moment, we're probably the only people represented on the stage that are using a semi-closed set rather than a fully-closed set.

I've been a rebreather diver for about eight years, diving a rig that is affectionately known as the "Clammy Death." The fact that we use this piece of equipment, is the main thing that drives our training.

Our basic training course for mixture divers is nine weeks long. The students dive about four to five hours per day. The first four weeks are on pure $O_2$ in seven meters of water. We've got a nice lake that was built for torpedo testing by French prisoners of war at the turn of the century. It fits our needs very nicely. It's about a thousand meters long, and these guys just swim up and down and up and down and up and down. The reason for this monotony is the fact that they're getting used to having a rebreather on their back.

At the end of the four weeks, we run what we call affectionately the "Live-In Week." The guys live at the island; they sleep and eat and do everything there. During that time, we take them to the maximum of O2 tolerance that they can endure in one day. We quite often wake them up a two o'clock in the morning. They go down to the dive site to find that their kit has been completely dismantled to the lowest component, and give them 30 minutes to build the whole lot, and they're put back in the water to swim for another hour. It's only by breeding this amount of familiarity with this piece of equipment that these guys can survive in it.

The average age of the recruits seeking to do mixture diving in the Royal Navy is about 24, 25 years old. We used to take guys direct from school but we found that the average 17 year old did not have the maturity or the responsibility required to use these beasts. Rebreathers kill. They're expected to have done a four weeks basic scuba course before they come to us. They then do a five-day diving aptitude test. We test their mental ability by putting them through basic math and science tests. We then take them out and give them a little bit of PT to make sure that they're going to stand up to the physical endurance side of life, and then finally we put them in the water for a couple of hours on O2 just so they get the hang of the rig. If you've been used to diving open-circuit and the freedom that it gives you, and then switch to a semi-closed or closed-circuit rig, it's a whole different ball game. Some people just don't like it, so it's easier to weed them out at the beginning.

During the first week of the course, we chamber dive the students to 50 meters, again to see if they've got any funny habits. After that they go into the classroom and they spend a whole week doing the physiology of diving, Great fun. It's even more fun teaching it, I can assure you. Then we get them back up to the lake and they start getting wet. I can say conclusively that at the end of every dive, they simulate an emergency. As they start to get more and more comfortable with the rig, we'll start priming the guy's buddy to simulate an emergency (in Royal Navy diving, you're tied to your buddy and you don't lose him). One of the guys will be prompted to flake out on the bottom, or start an O2 convulsion, or something like that to spur his buddy into taking appropriate reactions. It's not much good to practice by yourself, because by that time you have a problem, you're normally incapable of helping yourself; you need someone there who can help you out.

After Live-In Week, things tend to get a bit more fun. By that stage, we've normally weeded out the weak ones. Typical drop out rate in our courses is probably about 40% at the moment; for every ten we start, we get six through. Currently we are training about 30 mixture divers a year in the Royal Navy and that figure is unlikely to rise. Similar to all other military organizations, we're suffering from cutbacks. We're downsizing all the time, and we find it very hard to justify keeping extra manpower just in case you need them. This is a problem that's going to materialize into the rebreather market. Things are going to start slowing up in the future because the militaries of the world are not buying as much new equipment and they're not training as many people.

For the final part of the diving course, we take the students up to the northwest coast of Scotland to a place called Volvin or the Caswell Couch. The water is generally quite clean at 54 meters/175 f, which is our maximum training depth. They're not going down somewhere which is dark and nasty. It's cold and dark but not quite so nasty. Operationally, we dive operationally as a four-man team. We have a supervisor in the boat, a safety diver, a diving attendant and the guy on the end of the line. That's it. We operate at 54 meters/175 f on a 50 year old piece of equipment, so you've got to instill that discipline that the guys are going to obey all the time.

The other point that needs to be made about military training is the fact that we're training for a completely different mission than sport divers. I dream of going to 300 feet/92 m in 87 degrees of water to take pictures of fish. Most of my diving takes place in zero visibility in about 32 degrees Celsius if I'm lucky, and it's normally dark and horrible. That's why every instinct that we train has got to be completely reactionary. If something goes wrong, you've got to deal with it as if it's second nature. At the end of the training course, you feel naked if that set is not on your back, something's missing. That's how familiar you've got to be with your equipment.

The final thing my course instructor said to me as I left the course is "You will never be as good of a rebreather diver as you are today." At that stage I'd gone through nine weeks of using that thing every day. I had my head in the manuals every day. I was constantly being quizzed on the performance of the machine and what it was going to do to me if I got it wrong. We all know that we leave that course, we go away, and things start to get worse. We can't devote as much time as we need to reading the manual. Or actually getting into the water and using the beast. Therefore your skill will deteriorate. This is a very, very, very perishable skill. If you don't use the thing regularly, it's not going to do you any good at all.

**The final thing my course instructor said to me as I left the course is "You will never be as good of a rebreather diver as you are today."**

What does the training give me as a diver? It gives me a buddy who I know has attained a certain standard while on course, who I can probably rely on to assist me if I get into trouble. That, again, depends on the guy's experience and his level of continuity in training. From a supervisor's perspective he is still an unknown quantity. Until he is thoroughly familiar with the working practices of the team that he is working with, you cannot rely on him to be able to function as part of the team. That, again, is a function of the military diving thing. We have to do a specific job with a small numbers of people and get the guys back safely. The problem that I see with transition to the sport-diving market is that you're going to have a different bunch of divers turning out each weekend, probably on different pieces of equipment. You're not going to have a common standard of training amongst your divers, so you guys are going to have to be much better at it than we are.

As a final note, I don't claim (and I'm sure none of the guys up here claim) that the military has got its training completely right. The very fact that we're constantly reevaluating the way we do our training is a pretty good guide to what we're trying to achieve. The only thing that I can really say to justify the way we do things is that we've had very few fatalities for all the time we spend in the water, so we must be getting it almost right.

# Questions & Answers

## Classroom vs. time in the water

**Robinette:** I was interested in the ratio of time spent doing classroom work vs. time spent diving. It appeared from several of your presentations that about three quarters of the course was spent in the water. Would you comment on the thinking behind this instructional format?

**Burgess:** From the EOD community standpoint, when I got to my command, I was told that, "we train like we operate." We want to give our students hands-on training, OJT, as soon as possible, and put them pretty much in the same conditions they're going to be in while they're actually diving. They've already been trained in the basic skills. We reemphasize those and then we go out and start diving.

**Vogel:** You could teach someone to use a rig in fewer dives. One of the reason that we make as many dives as we do is that the students get to do more pre- and post-dives. It's such an important part of setting up a mixed-gas rig.

**Robinette:** By that, do you mean that it's not so much the diving, but rather the preparation that's the longer part of the learning curve?

**Vogel:** Exactly. Our students have already proven themselves as divers. Otherwise, they're just going out there punching holes in the water. Keep in mind that in NavSpecWar Center, we dive horizontally [riding SDVs—ed.]; we don't dive vertically like EOD or other members of the diving community. Diving for us is just a method for us to get to where we want to go. We never dive heliox at the

NavSpecWar Center and I don't think we'll ever intend to; we don't have the need to go that deep.

## Surviving the dive

**Cornick:** My personal opinion is that when you teach somebody in a rebreather, you're not teaching them to dive a rebreather; you're teaching them to survive in a rebreather. It's a completely different ball game. So many things can happen to the diver that have never happened before that you've got to try to make them aware of what can go wrong.

That way, when something happens, they know why it's happening and what they need to do.

We had a classic case in a controlled environment of the dive school. The guys were changing out of their rigs. One of the students reported that he was ready, and his buddy had checked him and reported he was ready. The Dive Sup went down the line and as he went round, he shook the canister and the canister was obviously empty. It was a controlled environment, so we decided to let the guy learn the hard way. We always do a two-minute purge routine on the bag before the guy enters the water, so we put him on gas and we watched him, and we watched him. He did his two minutes, he went to the side and collapsed. That's how long it takes to get CO2 hit you in that set. To this day, the first thing that this guy checks and the last thing that this guy checks is that his Sodasorb is full before he dives.

**. . . the canister was obviously empty. It was a controlled environment, so we decided to let the guy learn the hard way. . . He did his two minutes, he went to the side and collapsed. . . To this day, the first thing that this guy checks and the last thing that this guy checks is that his Sodasorb is full.**

**Brown:** The LAR V is a very simple unit. We spend, I guess, two days in what I call the classroom; that's in the classroom and also down in the locker hands-on with the unit, and then in the pool. Over the rest of the eleven days of the course they're doing day and night dives; it's all practical application. It's really not that hard to learn how to dive this rig. The primary emphasis has to be on pre-dive and then staying within your limits. The diving it is a piece of cake. If you got the pre-dive down, you're probably going to survive, provided that you don't go too deep.

**Shreeves:** I gather, based on what you gentlemen are saying, is that one of the biggest differences between open-circuit scuba and closed-circuit equipment is the disproportionate differences in maintenance and set-up compared to open-circuit and something. The training load is significantly greater. We need to consider this as we look at a leisure market.

## High risk training

**Jeff Bozanic:** Barry and Mike referred to this kind of training as being considered high-risk training. How are you defining high risk? Would things like open-circuit scuba or surface supplied be considered to be high-risk as well?

**Burgess:** Yes. Anything to do with diving is high-risk whether it's surface supplied, closed-circuit rebreather or scuba.

**Brown:** The official definition of high-risk is anything that has the potential to kill and maim. Instructor training is not high-risk but of course shooting, diving, jumping, repelling all are considered high-risk.

## Hypoxia training

**Michael Menduno:** Two questions. Do you do any form of hypoxia training, giving people the experience of going hypoxic? Question two, are there common problems or trends that you see in training people to use rebreathers?

**Vogel:** We don't put them in a hypoxic state, no. We try to give them the tools to not do that. One of the protocols on the Mark 16 is to continually monitor your primary and secondary displays. That's not going to help the CO2 but it is going to give you a good idea where your O2 is at. The second part is E[mergency] P[rocedures]'s. You've got checkoff loads for pre-dive, check off loads for post-dives and building your rig up, but you don't carry those EP's down with you. If you don't know them by the time you need them, it's too late. If the rig goes bad, there are a lot of things that can happen. You need to know what to do to correct the situation.

**Cornick:** From our point of view, as much as it's great fun to watch your buddy to go and do his version of St. Vita's Dance, it's not really a morale-building thing and not a very positive character-building experience either. The drop outs we have are primarily caused by physical limitations. The students don't like how hard we push them, which is really mission-driven and no so much to do with the rebreather. We feel they don't make the cuts because they're not paying enough attention or they keep making the same silly mistakes again and again and again. Even if it's simple and probably not life-threatening, at that stage of the education process when they're supposed to be highly retentive, it doesn't bode well for their future.

The problem that you guys in the industry are going to have is that if someone comes forward and have paid their dollars, it's going to be hard to give him a refund because it's not a cheap business. The average cost of training one of our guys is in the region of £190,000/$285,000.

[Whistles from the audience]

**Brown:** As far as our training with the LAR 5 goes, we don't do hypoxia training. The LAR V has is definitely capable of putting you in a hypoxic situation, particularly if you leave some inert gas in the rig during a bad purge procedure.

I talked to our DMO [Diving Medical Officer] about it. He said, "It's not good for you" so that's a pretty good reason for me. Also, you've got 40 students and if you wanted to put each and every one of these guys into hypoxic situation, your nails would be bitten down to your knuckles from watching these guys go up and down. It's a very stressful thing to watch. One thing it does do however, it gives you respect; even though you can't feel it coming on. You don't remember, that's what gives you the respect for hypoxia, so maybe it has some value in certain situations.

**But then again, our training is so safety-oriented that you could probably teach a monkey to pre-dive a rig... But at the end of the course, I'm always wondering, "Do they truly understand what's happening to a rig that maintains a constant partial pressure?"**

**Vogel:** I want to add one thing to that. The only hypoxia training we do in the Navy is in a high-altitude chamber. That's a whole different thing. Our students dive within the limits.

At the end of a course, the only thing I'm not really sure of, is whether the class fully understands partial pressure set points. That's one thing I've gained from this meeting. I look around at the people in this room who are diving nitrox and going deep and I realize that they have an intimate understanding of partial pressures and maintaining their ppO2. But then again, our training is so safety-oriented that you could probably teach a monkey to pre-dive a rig, I guess, if you stay within these parameters. That's why the Navy parameters are so conservative: to keep people safe. But at the end of the course, I'm always wondering, "Do they truly understand what's happening to a rig that maintains a constant partial pressure?"

# Sport Rebreather Training

*"If you want to be an instructor, get a unit. Then what you should do as an individual is simply to use the unit without any idea of becoming an instructor. Get out and use the unit. Learn how to use it. Dive it. Understand the unit. Then you will then understand what's required to teach others. This a no-brainer; it's not rocket science."*

--Rod Farb

## Session Summary

It's fair to say that civilian or "recreational" rebreather training is in its infancy, and there is considerable posturing and misinformation in the market. It has been suggested that a number of certified rebreather instructors may have limited, if any, experience. One of the problems in establishing recreational programs appears to be inexperience with this technology in the sport diving community. A second problem is an unavailability of units for the general public on which to gain experience.

In this session, various training organization representatives, and several manufacturers presented their plans and ideas relative to rebreather training. While there appears to be significant interest and fanfare for this technology in the sport market, it was pointed out that it's still hard to predict where it is going. One representative made it clear that he felt that his training organization must respond to this interest, or interested divers will simply go somewhere else.

The consensus of the panel group, seemed to be that to qualify as an instructor, an instructor should own or have on-demand access to the rebreather on which the individual will train students, so as to afford experience in diving the unit. A hundred hours of in-water time was mentioned repeatedly as a minimum experience requirement, though the basis for this number wasn't presented, nor was this suggestion adjusted for closed versus semi-closed units. It was also emphasized that manufacturers have an important role in assuring that training organizations have the information needed to teach equipment use adequately. At the present time there are no community training standards for rebreathers. Rather than relying on existing training organizations, some manufacturers plan to conduct their own training initially.

During the discussion, several participants suggested that semi-closed systems may represent the most promising area of growth in the recreational market, because of their relative simplicity [Though this technology can be problematic as well . See Semi-closed Systems: Problems & Solutions—ed.].

The panel was chaired by Michael Menduno, and consisted of; Dave Crockford/BSAC, Billy Deans/IANTD, Rod Farb/Biomarine, Max Hahn/RAB, Dietmar Luchtenberg/RAB, Mike Cochran/Cochran, and Karl Shreeves/PADI-DSAT.

28SEP SAT 11:30-1:00 pm

# Transcript

**Menduno:** We have a very interesting group of people up here. I'm going to give everybody five minutes to get up and present what you or your organization are doing with respect to rebreather training. Please feel free to raise any issues or concerns, and give us your thoughts. I'm going to began with my colleage, Capt. Billy Deans.

**Billy Deans:** I'm putting on my hat as Vice President of IANTD, the International Association of Nitrox and Technical Divers. Our philosophy is to promote diver safety through performance education, and quarterly publication, the IANTD Journal. It's called "The Nitrox Diver." It doesn't have a lot of pretty pictures in it, or a lot of color. But it does cover accident analysis, the current state of the art, and just what's happening on the technical diving field.

But more importantly, we stress and we teach survivability through a tiered stress-inducing aggressive water program. i.e., we practice our emergency procedures over and over. Our training programs are designed around What Ifs: What if this happens? What if that happens? Technical training demands close attention to detail because of the nature of technical diving, i.e., having a virtual or physical overhead environment.

What's interesting about our program is that we've experienced good growth without a correspondingly increase in diver incidents. So at least we're doing something right in the open circuit field. Again, our best approach to incident prevention is the anticipation of problems.

We also promote diver responsibility. I think Richard Pyle, who I consider to be an expert in closed-circuit diving, he says, "Nobody's forcing you to go in the water." We promote that.

An interesting point that has not been brought up yet is the psychological aspects of mixed gas diving, both open circuit and closed circuit. That has not been touched on at all, and at IANTD we touch on that because we do think it is important.

We have a worldwide infrastructure and an international Board of Advisors. We have standards and procedures, and training curriculums. Any changes are sent out to our Board of Advisors for review.

Currently we have two generic rebreather modules, part 1 and 2; and our game plan is to teach generic terminology and concepts through our instructors in conjunction with the manufacturer's specific training. That way we both can share the liability.

This is an interesting point. Yesterday Tony Zarikos brought up an advertisement on page 17 of *tec.asia*. It is an advertisement for a gentleman who teaches three or four different types of rebreathers, and that gentleman is qualified in our generic rebreather instructor program, number 1. Number 2: he's qualified as an instructor on each one of those units. So I wanted to bring that up. [Note that several of the units mentioned in the ad are not yet manufactured—ed.]

That's who we are, that's where we're at. We don't have all the answers, but we're definitely working on them. We're moving forward on this. We have the infrastructure and are we are moving forward because we want to get this information out there in a responsible manner.

One of the things we do want to do is have a pool of rebreathers available at our headquarters for our instructors, so that they can accumulate time and they can teach classes. I think that's going to be a real critical point in the future—accessibility of the rebreathers. Thank you.

## British Sub Aqua Club

**Dave Crockford:** Mike didn't come to work today so I'll introduce myself and a little bit of the philosophy behind the British Sub Aqua Club (BSAC) for those of you who don't know us. My name is Dave Crockford. I work for Maurice Cross at the Diving Diseases Research Center, and we get to see and do some fairly leading-edge stuff. But I have an interest in recreational diving which brings me right back down to ground.

The BSAC itself is an organization that is good at some things and bad at others. It's good at training divers, but it's bad at its marketing. We "take too long," is often the message we get back. But our divers worldwide are safe.

We are committed to looking at the rebreather market and looking in years hence to enabling the use of rebreathers within the BSAC. Our membership is worldwide, so we want to get it right from the start. This is, in many ways, a message for manufacturers as well as yourselves out there.

Our training: we have very well-qualified instructors that go through four, in some cases five, tiers of instruction level and we're looking at the third tier of instructor before we put them through a nitrox or enriched air nitrox course, as some of us say in Britain. So they are fairly well down the instructor route before we ask them to get involved in nitrox.

## Rebreather training

On the rebreather side, we would be looking more toward the individual that's already done that route or is nitrox certified and is showing a keen interest in the use of rebreathers. We believe our well-programmed instructor base will help in that area. Our strength in the past has been independence. We fiercely maintain that, and we will with rebreather manufacturers, as well. We will not go on-board with one manufacturer. We want to provide a level playing field. We will happily work with anyone who's interested in approaching us, .

Much the same as IANTD, we are looking at generic courses, a means to get the ground rules out to the membership. Then we will be looking at unit-specific courses. And we'll be looking towards the manufacturers to help us on that side. We believe that through our instructor scheme, we have a vehicle to carry manufacturers words across. We have to work a symbiotic relationship with manufacturers to achieve that.

We have a full appreciation of some of the issues we have been discussing. We know full well that we can't turn 'round and say, "You've been a nitrox instructor; you're now a rebreather instructor." We know that, we'd be shot at dawn for that. What we're looking at doing, and we're still playing with the idea, is to take an individual who's indicated that they want to be a rebreather instructor, assuming that they've already achieved a certain instructor level, and put them through at least a hundred hours of use on the specific rebreather that they're wanting to do training people with. If you listened to the talks yesterday, in some cases, a hundred hours of use may be two years. We need to, as industry, accelerate that a little bit. So, as Billy says, we would have to make sure our instructors have access to or own rebreathers.

We toyed with the idea, and I guess other training agencies have done as well, about the idea of recertification. I think at rebreather level, we would not toy with it; we would have to do it. We would have to look at people keeping up to speed on rebreathers, so that is one of the things we would like to put in our agreement.

One of the technical issues that have arisen in Britain is the matter of bail-out. We're looking for octopus bailouts, pony bailouts, whatever. We would like to carry that through to the rebreather. Whatever way the manufacturer would deem appropriate.

We'd also look towards you, as the industry, manufacturers especially, coming together and thrashing out some specifications. Where are you going to put set-points? We've seen ranges from 0.7 bar to 1.45 bar. That's a very wide bound. Ours is one of caution and we'd probably urge you to look towards 1.2 bar.

We'd also want some form of electronic monitoring onboard. Certainly when I came here, it was looking at the voting 2 out of 3 system for oxygen sensors. My views have marched on somewhat, and CO2 does rear its head a lot, so we would probably work alongside, quite happily, with the people that say, "It needs CO2 monitoring as well," [Note that according to the EDU, there are no reliable means of sensing CO2 in a rebreather at the present time—ed.]

One final issue; as a training agency, we view rebreather training similar to learning to drive a car. You can provide us with wonderful cars that meet all the specifications. We must provide you with drivers that meet the specifications. They is wide range of experience in the market; from people we term as Sunday Drivers, the once-a-weekers, right down to the commercial salesmen that get on the road day after day after day. We need programs to accommodate them. We're looking at three, four, maybe even five years down the road, but we are sure it's going to happen. We want to be ready for it. Thank you.

## Rebreather Advisory Board

**Hahn:** My name is Max Hahn,. I'm president of the Rebreather Advisory Board which is an association of experts in diving, diving physics, diving physiology, diving practice, and technology. It was founded in January 1995 and now comprises 16 members. The purpose is the development of standards, and teaching programs in rebreather diving including closed, semi-closed circuit equipment and nitrox and trimix diving.

We started with nitrox semi closed instruments because these were the only units which are on the market for recreational divers at the present time. We are giving courses for recreational divers to learn how to operate semi-closed circuit rebreathers, especially the Atlantis I which is available in Germany and all over the world. Another objective we have is to cooperate with diving federations, companies, and scientific and regulatory bodies, to promote the safe use of rebreathers.

Today we have four master trainers, four instructor trainers, 85 trainers and 36 certified users. The number for the users might be higher because some of the certified people are not in our files yet. We have developed strategies for teaching which my colleague, Dietmar Luchtenberg will explain.

I would like to give you a short vitae of our master trainers. All of our master trainers have considerable experience in diving closed circuit or semi-closed circuit apparatus. They range in age and experience. Two of them, that is Dietmar and I, come from the recreational diving field while the other two come from the military field. Thank you.

**Dietmar Luchtenberg:** Ladies and gentlemen, first of all I would like to thank Michael Menduno for giving us the opportunity to talk to you at this Rebreather Forum.

I would like to discuss our training philosophy. First of all, our training course is based on the procedures of the German Navy scaled down to the recreational market. We are not an agent for Dräger, but an independent group of members, though we work closely together with Dräger.

At the present time, all our training courses have been on the Atlantis I. It is the only unit that has been manufactured in large numbers and has been formally approved and certified. The other aspect is that the Atlantis I is very simple and uncomplicated.

When I talk about training procedures today, I am referring to, procedures with Atlantis I. You will see that some of these procedures are specific to this unit.

Our aims and tasks are the following. To promote and support rebreather diving in case of recreational diving, scientific diving and commercial diving. Support rebreather training. Support scientific research in semi-closed rebreather diving. Setting safety standards for rebreather diving.

To fulfill these aims, we have several degrees, several qualification degrees. For example, we start with a user, trainer, instructor trainer, and master trainer. In our case, the user has to be an advanced open-water diver or equal CMAS three star diver. We want to have experienced divers who do not have to think about basic diving practices. So the student has to ensure, when he or she starts the training course, that they have 30 dives during the year before starting the training course.

Our training course has a modular structure. For example; diving practice, knowledge, theory, physics, medicine, the technology and the psychological and physiological requirements. Our training and safety standards are similar to other training agencies in the following areas; diving depth limits according to oxygen pressure of 1.4 and 1.6, no dives without decompression stops, a maximum instructor-student ratio of 1 to 2, and divers emergency equipment to be present at any time for use.

## RAB courses

The course is a five-day course that can be done over two to three weekends. We have 10 classroom sessions for about 20 hours, 4 sessions on the technology, 2 to 3 pool sessions, 4 to 6 open water sessions, with a total amount of about 46 hours. Forty-six hours in five days is hard work. The five-day course finishes with a written exam and also with examination in practical diving and technology. The students have to be familiar with the components of a semi-closed rebreather, in this case the Atlantis I.

The practice includes the following exercises: assembling, disassembling the SCR, safety drills, emergency drills, breathing gas management, and in the case of an instructor training course, trial lessons.

**Our philosophy is to make the user sensitive to the special requirements of a rebreather, and self-control in the water.**

Our philosophy is to make the user sensitive to the special requirements of a rebreather, and self-control in the water. We want to make the diver sensitive to what the rebreather will tell him or her. For example to see no bubble chains while leak-testing, to hear one's breathing noise; the constant flow, the one-way valve, the periodic working of over-pressure relief valve, and to listen for low-gurgling noises. What do they feel? What do they feel when they use Atlantis I as the extension of the breathing bag at their back?

In the last year we conducted seven courses in Germany, two in Switzerland, and one in the Maldives, over a range of water conditions from the cold water of the Baltic Sea and Swiss and German lakes, and the warm tropical water of the Indian Ocean.

Finally, I want to say that we can't get rid of safety issues in rebreather diving by increasing technology standards. To do that, we have to get rid of the human factor and that is quite a hard job to do. We have one set of human factors in the recreational market and our main point is that we wanted to start with a simple unit. And we want to go further on, step by step. We hope to be in the loop for a long time. Thank you for your attention.

## PADI perspective

**Karl Shreeves:** My name's Karl Shreeves. I'm the Vice President of Technical Development for PADI, and Diving Science and Technology. Most of the people in this room are familiar with PADI; we're an organization of mainstream recreational dive instructors. We have approximately 75,000 members in 120 countries, the last time I checked; and ten international offices counting our main office in Santa Ana, California.

I've been asked quite a few times over the last couple days what PADI's position is on closed circuit technology. When will we have a course in development and how far into development is the course? Like the military folks who were here before, "I could tell you but then I would have to kill you."

Actually the best answer I can give you is that we have no immediate plans to develop a recreational rebreather course. It's hard to predict where this market is going, and therefore hard to determine what PADI's philosophy should be. We see ourselves as certifying mainstream recreational diver and, at least at present, our belief is that rebreathers are more in the niche market of the technical diver. Therefore the evolution could be similar to the way enriched air went. It could be something that happens very quickly or something that happens very slowly. That's part of what we're here to determine. PADI might be looking at something in two years or it might be 20, probably somewhere in between.

## Instructional design

From our perspective, the biggest question that's remaining out there for the recreational diver and PADI's entrance into this field, is the issue of instructional systems. We've talked a great deal about design of the units. We've had some discussion of training from the military model, but there's not been a lot of discussion in bringing instructional system design to this technology.

From PADI's point of view, and that of the recreational diver, we have to settle the question, "Who is our customer? Who is going to use this technology?" before we can even begin develop an instructional methodology for recreational divers. This still has yet to be defined. We also have to answer "Under what circumstances will the equipment be used by this person?" And that ranges from environmental to supervision to lack of supervision. Then, finally, we have to answer those questions and do a task analysis specific to the equipment; and every time you change a variable, you're going to change the instructional prescription. From our point of view, we feel that when we look at mainstream diving we're putting the cart before the horse to begin predicting an instructional methodology for recreational divers.

Technical divers are a bit of a different breed and I could go into a long learning theory discourse and bore the heck out of everybody, so I won't. I'm sure there will be a few questions about this and PADI's view of the future. I'll be happy to answer the questions you have when we get to questions and answers. Thank you.

**Menduno:** Not all manufacturers are expecting the training agencies to provide training for their units. Other manufacturers are dealing with different approaches and our next panelist, Rod Farb, will be discussing the Biomarine perspective

**Rod Farb:** I do a couple of things in the rebreather industry. I'm a working professional photographer and I use a rebreather professionally. I've used a rebreather intensively for the last couple of years, so I think I have a pretty good perspective of what's needed. I've made all the mistakes so far, and I'm leaning about rebreathers every minute of the day that I use a rebreather. I've sat through the conference for the last couple of days and it's been a tremendous experience. And I've heard all sorts of perspectives from one end of the spectrum to the other.

I am working with Biomarine, which has been in the rebreather business for many, many years. I won't belabor that point. Biomarine is working to bring out a new rebreather to the marketplace. I tried to help Dick King and Biomarine bring this to the marketplace. I commissioned a very expensive computer to be built to interface with the unit that will be offered on their new unit. I think this unit will be very applicable to sport diving, to technical diving, to whatever level of diving you want to do. I think it's a good, very basic platform to learn about rebreather diving. It's a fully closed circuit system.

Biomarine's philosophy is to work not only with instructors but with agencies. They're not locked in to working with any one group or the other. However, having said that, I think Dick would say that Biomarine believes that things need to happen in a certain way and Biomarine is going to control that. If you're not interested in pursuing that program, then look for another rebreather. Biomarine has a very competent instructor, an instructor with many years of rebreather use. It's not a person that's just been recently certified as a rebreather instructor. This guy has worked in the military on rebreathers; he knows 'em up and down. This fellow has trained a number of people in this room on the use of the Biomarine rebreathers and will continue to train for them. He probably, in all likelihood, will train rebreather instructors for Biomarine down the line.

Biomarine feels very strongly about two things: To be a Biomarine rebreather instructor, you will have to own the unit that you're going to instruct on and you will have to have a lot of experience using that unit. I don't know the individual that ran the rebreather instructor ad that Billy mentioned. Billy says he has a lot of experience with four units, and I'll certainly take Billy's word for that. I have a great deal of respect for Bill Deans.

I will say that a generic rebreather course, a generic rebreather instructor course that turns out people that do not use the unit and have very limited access to the rebreather except for the time of the course should really result in a new classification of rebreather instructor, a rebreather instructor in-training or a rebreather instructor apprentice. And after the rebreather instructor has a certain amount of hours on the unit and owns the unit, then they can move on down the line. But I think it's ludicrous to take an instructor course as a novice diver, as most of you might be on rebreathers. You might want to ask these people up here on the panel, "How many rebreather dives have they made in the last 36 months on a rebreather?" We hear talk about people being certified as rebreather instructors over the telephone—these are ludicrous concepts to me. I can't believe it.

Biomarine is not going to go along with that program. Biomarine has, in its hands, one of the best rebreather instructors in the business, Leon Scamahorn. Leon offers a 70-hour course over a period of 7 days. It's advertised as a 40-hour course but you'll spend 10 hours a day, 7 days a week learning in the classroom all the details of diving rebreather in terms of the physiology required. There's a minimum entry requirement for his course: an advanced nitrox diver. And your skills will be evaluated on a daily basis. If you don't meet the water skills of the course, then you're not going to be given a certification simply because you paid for the course. This is the sort of commitment we have to have in the industry.

Rebreathers are not very simply things. They're very complex things. And when you add them on to another area of interest such as photography or wreck-diving or reef-watching, then you've really added to the task loading of the diver. I think that in order for the industry to grow, we have got to adopt a set of basic, common sense standards in the training of divers and the training of instructors in order for the process to move forward. I think there has to be a very detailed manual with every unit that's sold, not a very superficial manual. And I think the diver has to take the responsibility to follow the instructions in the manual.

**Rebreathers are not very simply things. They're very complex things. And when you add them on to another area of interest such as photography or wreck-diving or reef-watching, then you've really added to the task loading of the diver.**

I would like to suggest that any agency that wants to take a look at training, should look at the Rebreather Advisory Board. I knew nothing about these folks until I heard their presentation just now, but their approach seems excellent. They've got instructors, they've got units that the instructors use, and the instructors use the units a lot. They train people on that unit. That's the approach the training agencies ought to take. This business of having a pool of rebreathers where a bunch of instructors can come in there and use 'em all on sort of a haphazard basis is totally absurd.

I have about 170 hours on my unit; I'm learning every day about that unit. I learn something every week I dive it. And I dive it very intensely. This is not something where you plateau your knowledge base; you've got to keep diving it.

In summary, Biomarine's approach is to work with instructors, qualified instructors, and with certifying agencies that will follow Biomarine's program and promote very safe and good diving with rebreathers. I'll be happy to answer any questions you might have, or Leon could answer any questions about his training program. Thank you very much.

## Manufacturer certification

**Mike Cochran:** I'm Mike Cochran, with Cochran Undersea technology. We've decided to have our own manufacturer certification. We believe that we know our product best. We've put together a team of individuals within our company and outside of our company with experience in putting together training programs. That, coupled with our own experience with our own product, makes me believe that we can put together a superior manufacturer's certification training program. Whether that continues indefinitely into the future, I'm not prepared to say. All I'm prepared to say is that that's the way we're going to start off.

Basically the program is intended to provide certification our system not on any other rebreather or product. The course is designed to be a manufacturer's certification. We will issue all certifications as well as specify and provide quality assurance to standards and procedures for the course structure and instructor to student ratios, prerequisites, minimum course durations including things like liability insurance, things of that nature. For the prerequisites for a user, not an instructor, you have to possess advanced open water or equivalent and have 50 logged dives, some of those recent. You have to be 18 years of age, current medical, and complete a knowledge and in-water pretest. The course will be a minimum of 40 hours. Not everybody is going to complete it in that period of time, so don't come prepared for that. The minimum quality for hours is 16 hours of classroom theory, 16 hours of combined water training and 8 open-water dives with a minimum of 8 hours of bottom time including one simulated decompression dive. We're specifying the student-instructor and assistant ratios, as well. The course fee for this is $875; it's going to include manuals, rebreather rental, processing fees, consumables and that sort of thing.

Additional certification levels are also going to be made available. There's a need, as an example, to establish a Prism II technician certification that will allow the Prism II diver to completely surface and repair a Prism II in the field or at their facility. And this certification will be issued to dedicated individuals at an authored Prism II rebreather facility. In addition, we will begin a gradual building of an instructor corps. Prism II divers who complete a minimum of 100 verifiable hours of diving and are already an experienced instructor will be considered. Right now user-wise, we'll still try to sort out how to confirm and keep users current. This is an issue that we're looking at now and will be addressing.

Our current thinking for instructors right now, and we haven't cast this in concrete yet, is that they have to have completed a user course, they have to own or have on-demand access to a Prism II, they have to have 100 in-water hours on the Prism II, and they have to provide us with complete uploads from their unit, including a log book that has to be filled in. There's a written pre-test and in-water pre-test. You have to have one year of active instructor experience, in other words we're not trying to teach people how to be instructors. You have to be attached to a Prism II facility.

We've been talking about how to ensure that individuals are qualified and continue to be qualified as an instructor. One of the things that we've talked about is having an instructor send his dive uploads every perhaps three to six months. We feel this is pretty important, this ability to have the diver, potential instructor, send us this information because with the Prism II we can tell by looking at these uploads how often the diver changes his batteries, how often he refilled his canister; how often he replaced his sensors, oxygen and diluent cylinders; how full they were, how they started, how often; we can also tell how often and when the $ppO_2$ sensors were re-calibrated.

Some other issues that we can tell from looking at these uploads is how well the diver is handling buoyancy control. One of the key issues in a rebreather. We can look at his oxygen consumption rate, his diluent consumption rate, how close to the end of the canister life before the canister was recharged, how many mask clears the diver did on each dive and whether he blows bubbles out his nose. Just basic general diving habits. We're putting this together right now. Our plan is to have this put together when the Prism II will be available to the public in first quarter next year. Thank you.

**Menduno:** There are a couple of groups not represented. First of all, I'd like to ask Jeff Bozanic, a former NAUI Board member and is active in the cave and scientific diving community to say a few words. Jeff.

## NAUI perspective

**Jeff Bozanic:** I may be active as a diver but I can't figure out how to make the speaker stand go up a little higher. There I've got it.

I've served on the Board of Directors for NAUI for eight years, and came off the Board in December of last year. NAUI, as most of you know, is an open-water diving agency primarily that was formed in 1960. They have about 15,000 certified instructors. They also teach a whole variety of courses from entry level through many advanced or what some people consider to be technical specialties. One of the things they've done is they try and give the ability to their instructor members to both develop and train in a wide variety of environments and work on developing standards that will be safe or improve diving safety. In fact that's their primary mission statement, is to improve diver safety and diver education.

As a nonprofit association, they really have no axes to grind with any manufacturers, with dive stores or with any particular user groups. All they want to do is to be able to make dive training as safe as it possible can be. Their stated goal is zero diver deaths. Many of us recognize that that's an extremely optimistic goal, but that's what they're trying to do.

The way NAUI looks at advanced level training is to set up a model that will enable that kind of training to go forward in a reasonable yet progressive manner. If you look at what they did with enriched air nitrox, for example, in 1990, they put forth a policy statement that allowed their instructors to start using enriched air nitrox on a developmental basis in their training classes. Yet that policy statement, while it allowed selected instructors to use that technology, didn't become codified in terms of a standardized specialty course until four or five years later. NAUI's is following that same route with rebreathers at this point in time. In fact, in their 1996 standards issue, they implemented a rebreather policy statement that will allow their qualified instructors to go out and run a program. The way that reads is that the use of rebreathers for recreational diving is permitted providing formal training has been obtained through a program which meets NAUI approval. The procedures used in such diving should follow those detailed in this training program.

The programs that NAUI's going to recognize at this point in time, are going to be approved on a case by case basis by their national training director because this is such a new endeavor in the recreational community. In fact, instructors that are approved to teach under this are also going to be approved on a case by case basis. What they typically look for is a résumé from the instructor, a course curriculum or course content outline; these are evaluated at headquarters and quite frequently other members in the community that are working with these kinds of units are consulted on a referral basis or for recommendations for the person submitting the application. To the best of my knowledge, NAUI is not going to come out with a program, a standard program for the rebreather community at this point in time. But what they have done is to open up the doors to allow their instructor members that have the qualifications to develop a program and to work with the development of programs that would be suitable to the recreational community. What NAUI does to look to a lot of user groups and get input from a wide variety of sources.

I've been told by Jed Livingston, the national training director, that with regard to rebreathers, that they're primarily looking toward the manufacturers to tell NAUI what it is that should be taught in this kind of a program. What Jed and what other NAUI instructors will then do is to overlay that information on top of their experience, that is, how to teach diving to come up with a program that will meet the needs of the recreational community.

For those people who are interested, I ran off about 75 copies of the page that has NAUI's rebreather policy statement on it [see NAUI Standards & Policies in Presented Papers—ed.]. I've got them on a stack there. I'll just kind of start them on either side of the table and if you're interested, go ahead and take one. If we run out by the time we get to the end of the room, give me a business card or your name or something on a list and I'll make sure you get one. Thanks.

**Menduno:** Next I'd like to hear from Mike Lang. He's been very active with the American Academy of Underwater Scientists and other organizations. Mike, would you like to say a few words, comments, concerns?

## Smithsonian diving protocols

**Mike Lang:** I'm here as the Smithsonian Scientific Diving Officer. Those of you who are not familiar with the Smithsonian might look on the worldwide web and also note that this year it's our 150th birthday celebration. The institution is an instrument of Congress. We are the largest civilian science diving program in the country.

As far as diving activities, the people I supervise are research scientists mainly in the fields of biology, geology and archaeology. Our diving programs are in accordance with the standards of the American Academy of Underwater Scientists. When a non-diver scientist knocks on our door, we have a program that entails a 100 hour training course, including 12 open-water dives resulting in a 30-foot certification authorization. The diver who comes in will be evaluated as to his or her skills and then additional training will be provided as needed. We offer depth certifications for 30 f, 60 f, 100 f, 130, 150, and 190; those are air diving certifications. We have always felt that progressively certifying divers to different depths based on their experience is very valid. That means after the first 12 dives, you're authorized to 30 f, another 12 dives between 31-60 f results in a 60 f certification, another 4 dives between 61 and 100 f to a 100 f and so on to 190.

**When a non-diver scientist knocks on our door, we have a program that entails a 100 hour training course, including 12 open-water dives resulting in a 30-foot certification authorization.**

We have a requirement in the science diving community for logging 12 dives per year; divers should not go longer than six months without logging at least one dive, and you need to make 2 dives to your depth certification—otherwise you get bumped shallower. As far as operations, just two points I want to mention: 1) we always require two comparably equipped scuba divers in the water at the same time as buddies, so no solo diving. 2) We require a safety stop on every dive, between 3 and 5 minutes anywhere between 10 and 30 feet. As far as specialty training, we provide additional modules for dive computer use, full face masks, dry suit, decompression, nitrox diving and others.

As far as the authorization requirements, and this is what any diver can do in the recreational community, even on their own, the diver must get a thorough medical diving examination, an initial exam. In the recreational community, we've been getting by having individual applicants fill out diver medical history form. We have a responsibility as an employer for due care for staff that dives. So the medical exam is required; every three years until age 40, and every two years thereafter.

At some point, every diver should be certified and maintain active status in CPR, first aid, and oxygen administration. It's a very simple duty of care you have towards your buddy; we require that as well. Regulators should be inspected and maintained annually, according to the manufacturers' recommendations. I generally supervise the diving before a diving expedition, they're required to file a dive plan; the emergency plan has to be accurate, too, as far as the closest recompression chamber to that particular facility or dive site where they're diving. Then they're required to log the dive so that we can track it in our database and make sure everything's going according to plan.

Essentially, the diving safety programs across the country at major universities, government agencies, and some ecological consulting companies serve a risk-management function. We are regulated by OSHA. We operate under an exemption from the commercial diving regulations, and that essentially specifies two major elements. One is that there's a diving control board that has autonomous and absolute authority over the program's operations. That board should be constituted by a majority of active scientific divers. And the second thing is the diving safety manual, which covers all operational aspects and emergency procedures.

At our management meetings, I frequently get a finger pointed across the table to me saying that I run the highest risk program in the institution. Of course I immediately whip out our data sheets and say, "Look, we've been accident free logged since I joined the program in 1990—28,000 dives without a single accident in a number of very remote sites. And approximately 500 of those dives were planned decompression dives."

**What I recommend to the recreational community is that they exercise a fairly slow phasing-in. Constant mass flow semi-closed circuit is probably the product to begin with.**

For the scientific diving community as a whole, the incident rate has been one incident per 100,000 dives. On that basis, OSHA granted us an exemption from the commercial diving standards. It turns out that the recreational diving community averages two incidents per 10,000 dives and in the commercial diving sector, it's one incident per 1,000 dives. You have to realize that's a ten-fold increase in the commercial sector, but they operate under very different standards, have a recompression chamber close by, diver medical technicians and so on.

Had we been forced to comply with those commercial diving standards, it would have essentially stopped the underwater research effort in the United States. Therefore, we're very keen on keeping our exemption as it currently stands.

As far as rebreathers, the only thing that I can recommend as I go back to our scientific diving control board is that we wait another year and see how things settle out. We would like to have a choice of commercially available products. What I recommend to the recreational community is that they exercise a fairly slow phasing-in. Constant mass flow semi-closed circuit is probably the product to begin with. Thank you.

**Menduno:** There are a couple of other technical diving agencies that aren't represented here, and I'm hoping there will be someone in the audience who will talk. Ed Betts told me he would be teaching a rebreather course this weekend so he wouldn't be able to be here for the forum. Are there any ANDI (American Nitrox Divers Inc.) instructors in the room who could say something about ANDI's rebreather program? No? How about TDI (Technical Diving International)? Leon can you give a brief summary on TDI?

**Leon Scamahorn:** I'm Lt. Scamahorn, National Marine Rescue Academy. I don't teach for TDI, but I do offer their certification as a part of our training. I've looked at other the agency programs, have offered to talk to them about the academy has to offer and I've been turned down. That's been disappointing because it would be a benefit to all agencies and the community to have open communication and an exchange of ideas in order to minimize our liability in this whole venture.

## Better communications

**Menduno:** Excuse me Leon. Someone was talking and I didn't hear you. Did you just recommend that there be some kind of council or group representing all of the different training organizations? Is that what you just said?

**Scamahorn:** You know that's something to consider. I think everybody should communicate because that's how we're going to increase our safety, minimize liability. People are trying to protect information and that's wrong. We need to have an open [forum] like this. This is probably the best thing I've ever seen, here, this forum. The last two days has been pretty interesting. I have other ideas and I highly respect other individuals here like Richard Pyle, who's definitely a credit, and other people that are sitting up there. I've been impressed with what I've seen. But on the other hand, I'm really upset about this kind of rubber-stamping of instructors. That's all I have.

**Menduno:** Thank you.

I haven't commented yet, but I'd like to for the record. I obviously know many of the people involved in training and the different training agencies. At the present time, training is one area where there's a lot of hype, and a lot of smoke and mirrors. I think that we've acknowledged over the last two days. Tracy made a comment the other day that there's a lot of "ego and dollars" driving rebreathers.

## Are you experienced?

I think the real problem is that there is no appreciable experience with rebreathers in the US sport diving community . The only people who really have experience are military divers, and a handful of sport diving people. These latter fall into one of two groups; ex-military divers who have current rebreather experience, meaning they were in the military recently; or the handful of people, probably not many more than a dozen people, who actually own a rebreather and dive it regularly. Other than that, even though people are very experienced divers, very experienced technical divers, etc. they aren't experienced with rebreathers and have very little operating experience. Diving for themselves, day in and day out, and having had the rig crap out on them enough times so that they know the problems.

It's a real hard problem for the training agencies and for manufacturers, "How do you get this thing started." As I said in my opening talk, the early days of tech diving were a little easier because there were a lot of people with deep diving experience, albeit on air. They had operational experience; they had experienced the problems; catastrophic gas failures, entanglements, etc. and it was relatively straight forward for them to incorporate mix into their diving operations. It's really a different thing with rebreathers. So I'd like to second the idea of communications and just cutting through the bullshit.

We're all in the business here. People want to make money. Companies want users to come and spend their money and train with them. And yet we all know it if we have a bunch of instructors out there who don't know what they're doing, and they kill a bunch of consumers, it won't matter whose agency they're with, or probably whose unit they training on. It's just going to give the whole thing a bad name.

To the extent that all of the people here go away from this meeting and try to cut the bullshit and provide reality checks where appropriate, I think that would help a lot.

We had a couple goals set out for this session; obviously we're not going to design a rebreather training program here or come up with all of the standards or any of that. But there are a couple of things that we could do, rather than focus on training end-users right now, the first issue's got to be training the trainers. These are the first people who are going to buy the units, if you assume that a trainer should own a rebreather or have daily access to it. They're the first wave, so I would like to hear some more discussion on what it will take to become a rebreather instructor, and how we go up this learning curve in the early phases of this business.

Some people have already made comments about the number of hours required and the importance of owning a unit, I'd like to hear more discussion on that, and some discussion on the effectiveness of having a training council like the RSTC, to ensure that all the different groups training rebreathers talk to one another and there is a mechanism for them to share information.

I think it's fair to say that there are now consistent training standards in technical diving among all the different agencies. There isn't a lot of variation. But it's taken four or five years to get there. If it takes that long to come up with consistent and effective rebreather training, we may never get there, too many divers will have died.

So I'd like to open the floor for comments or questions. Pardon me for just spewing, but I needed to do that. Comments or questions maybe addressing the training of instructors and what it's going to take?

## Training the trainers

**Deans:** It's all of us. My biggest concern is, what Lt. Rob Cornack and Mike Cochran said, is the issue of re-qualification. You can make these guys razor-sharp but they've got to keep that razor-sharpness. That's why IANTD is taking a multi-tiered approach; X number of hours at a specific depth before you can progress. It may take a year or two to get your minimum 100 hours of operating experience to be an instructor as Mike Cochran said. That sounds pretty good and what it has to be—a small logical progression. That's what we're shooting for.

**Jim Brown:** I've got something to add to that. As I look at the organization of the personnel that are involved in the rebreather training capability, I tend to kind of look for a pyramid structure. You have to have a base, to be able to have the cream of the crop raise to the top. That's where your instructors are going to come from.

It would seem that if you have a small organization, that would tend to preclude large numbers at the top. An analogy is high school or college sport teams. A good strong team will have a large base of potential players to pick from. Conversely the losers always tend to be the small high schools that have small student bodies. That's not to say that size is necessarily a factor in our case but I would think that a pyramid type of structure would be something to look at. How do you filter out the best to become your instructors?

## Get a unit

**Farb:** If you start from the standpoint (we're talking about instructor training now), that at the very basic minimum an instructor has to own the unit he's going to teach or have immediate, on demand access to it, then there have got to be units. How many units are on the market right now?

So my advice, being an end-user and knowing what problems these things can cause, and how demanding they are and how intensive you have to deal with them, I would just simply say to you, that if you are interested in becoming a rebreather instructor forget about going to an agency, forget about getting into a structured environment where there are no units for anybody, and there are all these "generic"—whatever that means—generic rebreather instructor courses. If you want to be an instructor, buy a unit.

**The two of the biggest military rebreather users in the world only have about 240 units in service between them.**

This is going to take some time because closed circuit rebreathers have yet to really come to the marketplace. We've heard that the Cochran unit will be out in the spring, first quarter next year; the Biomarine unit will be out toward the end of this year. Then what you should do as an individual is simply to use the unit without any idea of becoming an instructor. Get out and use the unit. Learn how to use it. Dive it. Understand the unit. Then you will understand what's required to teach others. This a no-brainer; it's not rocket science. If you use it, you will understand and you'll have a much better foundation to be able to provide the input that the agencies will need to incorporate in a real rebreather training course.

It's going to take some time. It won't be five years down the line, but units have to out there; and that's why I think that the only "agency" that has done anything approaching reality in this business right now is the Rebreather Advisory Board—this is the first I've heard of them. They've got units and they've got people that use them, and they have a program. That's what's going to have to happen. This is the paradigm you should look. This is what is eventually going to have to happen with every single model down the line, but the point is: you go to have units to do this.

## Installed base of rebreathers

**Menduno:** Here, here. I would guess that there are probably not more than 50 rebreathers in the hands of the entire US sport diving community. Do you think that there is even that many? I know that some units are being sold, but I also don't know many people that have them.

**Rob Cornack:** On that same point, could we just get some perspective. I know in the Royal Navy, we've got about 140 of these things in service and they are not all being used. Jim, can give us some idea of how many Mark 16s are in use in the US Navy.

**Jim Ruth:** Right now I think we have about 400 in inventory but only somewhere around 100 that in service that are being used.

**Cornack:** That gives you some idea of the dilemma. The two of the biggest military rebreather users in the world only have about 240 units in service between them.

**Menduno:** Out of curiosity, how many people in this room own a rebreather? OK, of course all the manufacturers raised their hands but there aren't many others. The gentleman in the back, please state your name.

Are rebreathers a viable recreational option?

**Chris Jaffey:** Chris Jaffey from Cornell University. I have a quick question for you. Being a rebreather user and owner myself, I understand the increase in task loading and the complexity of these systems. Everyone in this room is probably a fairly disciplined diver or technical diver. We've been through the training. Look at the problem that we're having just getting the instructors out that are qualified. I think Rod Farb has done a great job to bring that to our attention and solidifying that point over the last few days.

My question is specifically is for Capt. Deans and

Karl Shreeves, do you really think that rebreathers are a viable option for recreational divers? I have spent several years in the retail side of recreational diving, and the more hours I put on my unit , the more I'm really not sure its for recreational divers. I'd be curious to hear what others think when you get it away from the technical, very sophisticated, very diligent user. What do they think about the recreational market itself?

**We could give that away by saying, "No, we're not going to do it" and people will go elsewhere. So we have to far-reaching view and say, "Yeah, we want to gather as much information on this and assist where we can."**

**Crockford:** The British perspective is that the manufacturers want to sell these units. The training agencies have to decide, whether we're going to allow our members to use them within our organizations or not.

We can put the blank door up and then people will drift away from the agencies. Certainly talking about the British Subaqua Club, we do have elements of control there. We could give that away by saying, "No, we're not going to do it" and people will go elsewhere. So we have to far-reaching view and say, "Yeah, we want to gather as much information on this and assist where we can."

**Jaffey:** How are we going to get to that point? Do we have to wait for x number of fatalities? At what point are we going to have to drop this back? Who's going to make that decision as to whether or not the technology is easy enough for people to learn?

**Crockford:** I'll give you our view and it might answer some of Rod Farb's questions as well. The British Sub Aqua Club is lucky in many ways. We have a very strong membership and amongst our membership we have people in this room like Gavin Anthony, people like Dr. David Elliot, Maurice Cross, and people like Peter Ready—he may still be a member. I know Stuart Clough is a member, Kevin Gurr, Dave Thompson at AP Valves who is developing the Buddy Inspiration rebreather. These are all BSAC members. These are the people at the top of our pyramid.

## Rebreathers a "recreational" device?

**Menduno:** I want to go back to this question. Are rebreathers really a recreational type device? I think it was directed to Billy and Karl . Do you want to go first, Karl?

**Shreeves:** That's the big question, is it viable? I think it remains to be seen whether it will be viable. Of course, on a theoretical basis it could be viable. I think the Atlantis is showing that. I'm talking recreational, not technical; it's definitely viable for technical divers on the basis of this Forum alone. I was just joking with Mike [Cochran] and said, "The market's here in this room."

Certainly there is some interest in what PADI would define as the recreational level. I think whether it becomes viable depends on a number of factors. There are technological solutions to some of the complexities that would be a burden for a recreational diver. There are supervisory solutions to some of the burdens, particularly supervision of post-dive and pre-dive setup. We don't currently use supervisors in recreational diving but that's an option. So if we, as an industry, want to see mainstream divers begin to use this technology, we will need to look at some of these solutions, and decide whether it's worth it. It may cost too much to make it viable for that application.

**Deans:** Recreational diving is supposed to be fun. Most recreational divers don't have the mind set to go through a twenty page checklist procedure. I think Dräger's barking up the right tree with semi-closed systems. It's the KISS principle—Keep it simple, stupid. With a real short checklist, you can go diving. That's what going to happen.

Case in point, look at the liveaboards. They are buying semi-closed systems and I think that is the way to go because you can keep the recreational diver in a no-stop obligation in a semi-closed system; he can enjoy some enhanced performance and also a higher degree of safety, yet he doesn't have that long logistical or that complicated nightmare.

A person is not going to spend 10 to $15,000 on a unit and have to go through a two-to three-hour checklist to go diving. Trust me. I have two boats, ten full-time employees, and I work every day at the recreational/technical market. It's written on my face.

**Luchtenberg:** We can't answer the question if rebreathers will work for the recreational market, but we can say that we see that people want to dive rebreathers and are actually are doing it. This was the reason that we came into the market with our training procedures. I think it's characteristic of the people today; they want to get a kick out of everything. And they aren't satisfied with traditional diving. They will do it once or twice and then they see a rebreather diver and suddenly there's a group standing around him and they ask him, "What kind of breathing apparatus is that? May I try it? Where can I try it?"

In Germany, when the border between East and West fell, rebreathers from the Russian military suddenly flooded into the West. That was another reason why we got into the market; to set some safety points so that the sensitive scenery of sports diving would not be overwhelmed by bad fatalities or by accidents. But to your question if they will work for the recreational market, I can't answer that.

## The Fieno has proven it?

**Barry Brisco:** Barry Brisco from *Asian Diver* in Singapore. I just want to say that there's a company that's unfortunately not represented here today. I'm not in a position to speak for them. I simply want to bring up the point that there's already a company that has, according to their reports, have proven that rebreathers do work in a recreational market and that is Grand Blue in Japan, manufacturers of the Fieno. They reportedly have trained well over 3,000 consumers to dive their product. Now their product is specifically designed for the recreational market. It has its own limitations and its own restrictions, but it is a rebreather. It's very simple. I've seen their training manual. They are willing to accept people who are not certified divers and train them to dive their unit. They start out at ground zero in their training, and as near as I can tell, they seem to be making a success of it in their market. Now, of course their market is very different from the market here in North America or in Europe. But there is somebody who seems to be doing this successfully, so I just offer that in response to the question, "Can this be done in the recreational market?" They would say, "Definitely, yes." It's too bad they're not here to give us their own input.

**Jason Gilbert:** Hi, Jason Gilbert. Just like to throw out a couple of comments and offer some food for thought. First of all, I'd like to commend those of you up on stage there who're taken the time to form, or become a part of organizations interested in furthering rebreather technology and getting people involved. Just by the mere establishment of organizations, you've set the basis for standards that we've all kind of agreed really don't exist. However, by having organizations, you provide a forum where those standards can be formed. I urge and challenge the people here and certainly the people that are part of these organizations to take advantage of this gathering to further solidify those standards, to try to establish something a little more concrete for the industry.

## Instructor quality

My second item concerns the quality of instruction. We've talked about our credentials, whether it be military experience, commercial diving or professional diving, ownership of a rig, the number of hours and the depths that we've all dove to. Those in themselves are merely credentials; they don't make you qualified or competent teachers. Teaching is a whole, separate skill; and what I would urge you to do as a part of your organization to define those items that would qualify people not only as competent divers but to further that as competent teachers who can instruct divers that are up and coming.

**Dick King:** One of the positions that we [Biomarine] took as a manufacturer, and I think probably Mike Cochran and Peter share this view, is our concern over the overall quality of large training organizations. We've seen where, in some instances, people are more interested in making money than they are interested in ensuring that the student they have meets some minimal level of training and is competent in that particular class that they're trying to get through. So that's why we've sort of taken the attitude of a turtle and pulled our head back in and said let's just do it ourselves until we get a feel for what direction this is going to take overall.

**Semi-closed systems are probably the correct approach for the recreational diver, the individual that's going to go out and dive to 65 feet and take pictures of fish for a half hour and come home.**

Semi-closed systems are probably the correct approach for the recreational diver, the individual that's going to go out and dive to 65 feet and take pictures of fish for a half hour and come home. I think that's probably the right way to go, and I wouldn't sell them one of our units. We've already turned down people who were interested in buying Biomarine units because we just didn't think that they meet the preliminary qualifications to even discuss it with them at this point. I'm getting the same feeling out of the agencies.

## Depth-tiered training

I want to hit on one other thing, the idea of a tiered approach to training. We like the concept but we haven't figured out how we can do that? How can we give a guy a rebreather that's capable of going to three or four hundred feet and tell him, "You can only dive it to 60 feet" and then monitor that and then say, "Now you can only go to 120 feet"? Because it's the nature of the beast. The people that are buying these things have already been to two or 300 feet. And now you're going to tell them, they have to wait. These are some of the questions we have as a manufacturer.

[Applause ]

**Menduno:** Let's hold applause until the end unless somebody really lights your lights or something. That will make it fairer for everyone.

**Richard Pyle:** I just want to follow up on what Dick King said. I think it is really important.

Attention needs to be paid to the students almost more than the instructors. I think it should be the standard in the rebreather industry to turn away students who might not be up to stuff, at least for the fully closed rebreathers, because it's in their best interest in the long run to keep people alive on these things. That's a point that always seems to get overlooked in these big discussions. I mean the manufacturers and the instructors are the ones who are here, but the students are the ones that are going to die. And those are the ones that attention needs to be paid to. I guess that's all I wanted to add to what Dick already said.

## User groups at risk

**Menduno:** What would you say to someone who wants to become a rebreather user, Richard?

**Pyle:** To someone who is qualified or not qualified?

**Menduno:** Yes. Someone who wants to buy a rebreather and dive it.

**Pyle:** I don't have any experience with teaching. I'm not qualified to teach at all. I never intend to be, never will be a rebreather instructor. But I have an observation, at least a gut feeling, and that is that the people at highest risk are the experienced, open-circuit trimix divers, because they're the ones with the confidence, the ones who are going to be very comfortable on these units really quickly, and the ones who are not going to have the patience to do the right thing, which is spend a lot of time in shallow water in these things before they go back to doing the dives they used to be doing on open circuit.

I had that attitude and a lot of people, I'm sure, have that attitude, " I've been to 400 feet on trimix a whole bunch of times. I'm pretty good at this. The rebreather is going to give me better safety margins, all sorts of longer gas times. Hell, I'll go through the training course just to fill out the paper work, but as soon as I get home with this thing, I'm going to go back to what I had been doing because of all these great things about rebreathers."

It takes an enormous amount of discipline to prevent yourself from taking one of these things farther than you're really capable of going. The real discipline is recognizing the discrepancy between your confidence and your abilities and keeping your confidence safely below your abilities, and recognizing for real what your limitations are. I'm just afraid that those are the ones who are at the greatest risk. You take someone who has no diving experience at all, but a good sense of discipline and a good reason to stay alive, they're probably going to approach this stuff a lot more cautiously. They're the ones who are going to get the hours in shallow water and get comfortable with it before they start going off and doing radical things.

That's why I think more attention needs to be paid to what sort of person who's coming in to learn how to dive a rebreather. Like I said yesterday, maybe I'm wrong about this, but my experience is that rebreather diving is learned a lot more than it's taught. And you have to have the right "transportable information receptacle" as the student to pick up that information and use it correctly. That's the point I'm trying to make.

**Menduno:** How many hours did you do on your rebreather before you went to 300 feet? I'm just curious. Do you know roughly?

**Pyle:** I did 35 hours before I got deeper than 30 feet. I was supposed to do another 30 hours before I got deeper than 60 feet, but at about 50 hours I decided to do an 80-foot dive that almost cost me my life. So that's when I backed off and did a whole bunch more hours at 30 feet. I think 300 feet was awhile. Close to or over 100 hours before I was doing 300 foot dives. I was doing decompression dives before that, but only quick bounce

**. . . after 10 hours I was a rebreather expert; after 20 hours I was a novice, after 40 hours I was a beginner; and now, after 200 hours, I'm a weenie.**

decompression dives. I'd have to go look at my logs, which is 40 megabytes long I might add, but it logs a lot of data. But, yeah, something on that order. At the tek.Conference in January, I said that, after 10 hours I was a rebreather expert; after 20 hours I was a novice, after 40 hours I was a beginner; and now, after 200 hours, I'm a weenie. It takes direct experience to realize how easily you can kill yourself on these things.

The fundamental difference between closed circuit and open circuit and , in my mind, and the reason why all of this is such a big headache, is that 99.9% of the time when something fails on a open circuit system, it's self-evident. You know there's a problem. It's obvious. Your hose blows, whatever. The big killer on the rebreather's insidious. You don't know there's a problem until it's potentially or probably too late.

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**Deans:** I agree with Rich that the people at most risk are probably the experienced open circuit trimix diver. The lowest risk group is probably going to be women divers because their egos aren't going to get in the way and they're more likely to network with others.

[Applause]

[Transcript tape ends]

# Liability & Regulation

*"We don't try and write a prescriptive regulation any more... And that's the philosophy... If you try to create a prescriptive regulation, then technology stands still. "*

--Mike Harwood

## Session Summary

The panel began with a review of strict product liability law, and negligence with Bill Turbeville of Hruska and Lesser. Rick Lesser discussed some of the nuances, including ways users can shift liability onto themselves or how unauthorized uses can create liabilities for manufacturers.

Next PADI's Al Hornsby gave an update on the status of the US Occupational Health & Safety Administration (OSHA), which regulates the workplace in the US. OSHA has so far declined to grant consumer rebreather instruction the same exemption as exists for recreational open circuit diving. As Hornsby pointed out, that means that agencies, retailers and instructors, fall under commercial regulation until the issue can be resolved. The community will have to accumulate a track record and data to take their case forward.

Health & Safety Executive representative,Mike Harwood, and former superintendent for Royal Navy Diving, presented the HSE's innovative approach to regulation based on "goal setting."

The panel, chaired by Bill Turbeville, Hruska & Lesser and consisted of Mike Harwood, HSE, Al Hornsby, PADI, and Rick Lesser, Hruska & Lesser.

28 SEP SAT 3:30-4:30 pm

# Transcript

**Bill Turbeville:** Well, here we are, the four cockroaches in Dr. Bill's special mix. My name is Bill Turbeville. Actually, the news is not all bad from the liability and regulation front. Some of you were in Key West two years ago at the first rebreather forum when I first spoke on the liability concerns of rebreathers. If my memory serves me correctly, I told you all back then that there were not any distinct liability problems that should keep rebreathers off the market. That was true then; I think it's true now. That does not mean there aren't serious concerns—lawsuits waiting to happen. In fact there most certainly are. What I meant then, what I continue to believe, and what I think the panel will agree, is that these concerns manageable. They can be dealt with appropriate forethought in design, in manufacture, in training, and in particular in the instructions and warnings provided with the products.

On the panel with me today is my partner Rick Lesser. He'll be briefly discussing the concept of liability law and how it relates to rebreathers. Next to him, the lawyer's best friend, is Al Hornsby of PADI, who may know as much about OSHA regulations and the diving industry as any one, and he certainly has the most current information, since it just came in two days ago. In fact, he has news, some of which is extremely good for those of us in the technical community, and some other news which not quite so good for those of us in the subset of that community known as the rebreather market. Finally, we have Mike Harwood from the Health and Safety Executive office in the UK. He'll be discussing a bit of the UK's perspective on these issues, and more importantly, in my view, is his philosophy of regulation.

## Overview of concern

I'd like to begin by giving you a brief overview of what you'll be hearing in this session. There will be two different threads that have a commonalty and yet are distinct. We have liability concerns, and we have regulatory concerns. Liability, at least, as far as I'm using that term today means litigation; private party vs. private party. That's the plaintiff's lawsuit brought against the manufacturer or instructor. In this case, the government, i.e. the court, is simply a mediator between a private dispute. In this country, at least, there's virtually never a criminal prosecution for a fatality that occurs in the dive industry, although there can be a quasi-criminal prosecution through the aegis of either the Coast Guard or the Occupational Safety and Health Administration (OSHA), should there an accident or fatality occur within their jurisdiction.

Regulatory concerns are different and, in my view, are by far the most significant issue that we're facing right now, and probably the most overlooked. OSHA has tremendous authority because they're backed by the Federal Government. They regulate the employer/employee relationship within this country. They, in fact, stand in stead for employees, when one is hurt, or one is killed. They determine, based upon their regulations and guidelines, whether or not a work place is safe, or a practice in a work place is safe. But I'm not going to steal Al's thunder; he has some interesting information to bring back from Washington concerning that.

In terms of the private liability, which most of you all in the manufacturing business are probably familiar with, and most concerned about, very briefly, there is a form of liability called "strict liability," "strict product liability," which basically means that you can be held responsible for an injury or death caused by one of your products regardless of whether or not there is any fault involved. It's faultless liability.

There's also a concern about negligence claims which Rick will be covering in his presentation. Without further ado, Rick Lesser.

**Rick Lesser:** Thanks Bill. A couple of years ago at the tek.Conference, Bill was asked to give a talk on product liability concerns in the technical community. It was going along, and Michael [Menduno] came up and said, "Hey Bill, listen, we're running a little behind, will you keep it short." He said, "Sure. You guys are screwed. Thank you. "

That's how he summarized it! It's not quite that bad, but actually, the concerns are pretty much the same whether you're putting out a rebreather or snorkel. The law is the same. It's a product, and as a manufacturer, you're subject to the relevant product liability laws.

## Strict Liability

What we're talking about is strict liability, Section 402 A in the Restatement of Torts. It is not a dessert, just like OSHA is not a small town in Wisconsin. It is a set of laws that have been promulgated to protect the public against products that don't work. Basically, what it says, if that if the product's found to be defective or unreasonably dangerous, and these become artistic terms, and the seller's selling the stuff and there's no substantial change, then strict liability applies.

The important part here is that the seller's engaged in the business. If you're like a liquidator and you happen to sell off a piece of dive equipment, you're not a seller in that line of work, so you kind of get away with it. If you're a dive shop, you don't.

Here is the text, "Strict liability: Any product in defective condition, unreasonably dangerous to the user or to his property is subject to liability for physical harm." Again, what Bill pointed out, and what's most important is that you don't have to be at fault. The classic case is if you have a lion, it's considered a strict liability item. No matter how careful you are to keep your lion in your back yard, if he gets out and eats somebody, you can't go in and say, "I had a 25 foot fence that was electric, I had sensors, I had this, I had that." The will say, "Tough luck, your lion got out, and ate somebody. Pay up." It's the same thing with products.

**Negligence requires fault; strict liability doesn't.**

The defective condition may be found in the design, manufacture, or, and most importantly for a lot of people here in this room, the warnings and instructions. A good analogy for rebreathers is dive computers, because they're kind of an esoteric item, and they do magical things. We've seen a number of cases, where a computer goes out the door, somebody uses it and he winds up filing a lawsuit saying, "They gave me this thing. I used it the way I thought I should, but I didn't have a manual, and didn't know that I wasn't supposed to make repetitive square wave dives to the edge of the table and I got bent so pay up." And sometimes they pay up.

From a manufacturing viewpoint, if the product is obviously put together wrong, you create a situation where liability ensues. The interpretation of "unreasonably dangerous" varies from state to state, but most of the time, this is an across the board type of rule and again, if somebody gets hurt, you can presume that that's what they're going to be saying.

Now retailer of this product is also a seller. That's why it's important to know what the manufacturer is giving you. The liability can run back up from the user, through the retailer, and if your manufacturer is gone, the retailer is still stuck; he doesn't have anybody to go out and chase. So this concerns the people who may be selling a company x's rebreather. Or, if the guy who sold you the product happens to live in Sri Lanka, then you can't get at him, and you'll wind up with the liability on it.

As Bill said, there's also negligence. Negligence requires fault; strict liability doesn't. This slide shows you a jury's instruction for negligence. This is not a law school class, so we'll let you read it real quick. When somebody's suing you for negligence, the jury gets this read to them, and they get to decide whether you did it or not.

## Who is the manufacturer?

Another important point, particularly if you're dealing with a rebreather that you don't make. Suppose that you get the unit in, and say, well, I don't like this, I'm going to change it a little bit. And you do. You just became a rebreather manufacturer, and let the guy, who made the unit originally off the hook.

If somebody says, "Gee we've got this nice Atlantis unit, but they charge too much for the soda lime. We're going to go buy it in bulk from the hardware store." You just created a problem, especially if the granule size is different from Dräger's or if it doesn't function the same. You're creating a new problem. That's it. The manufacturer comes off the hook, and you go on it.

This was an example that I used in a seminar we gave at DEMA. What we had was a Poseidon first stage regulator, a US Diver Second Stage, and a ScubaPro Air 2. We asked the guy who put this together, who's the manufacturer? The answer is, the guy who decided to assemble. The Poseidon has a intermediate pressure of 190 PSI which doesn't match the US Diver second stage. If somebody tweaks it to make it work, all of the manufacturers that are involved in making this equipment walk away and the guy who decided to configure it gets stuck. So, when you start fiddling with a rebreather, you either do it with the written instruction on behest of the company, or you don't do it, unless you plan on assuming the liability for it.

## Product use

Here is another question; what is the piece of equipment really going to be used for? Is a screwdriver only for turning screws? The answer is, that there's a bunch of product liability cases where manufacturers of screw drivers were basically assessed damages because the court said look, everybody knows that you use a screw driver to open a can of paint. The screw drivers you made broke as soon as they were used to pry open the paint. The plastic handle broke, the guy put the shaft through his hand and he's hurt. You've got to make them stronger. So, even though it says "screw driver," everybody knows it's also a paint opener, and a pry bar and this and that.

## Rental releases

Before I get to OSHA problems, I want to say a couple of other things of what we're doing trying to sort things out and make life a little easier for you. I'm a member of the manufacturer's committee for DEMA, and as you may or may not know, we represent a lot of the manufacturers in the industry as well as training agencies and sundry other folks. In that capacity, we've seen product liability problems that come from people that rent equipment and later say, well, it didn't work when I rented it. It had this problem. I just didn't notice it-. I went on the dive and got hurt and now I'm suing.

Taking a page from the snowboard and the parachute industries, I'm working on a release—a rental agreement—that will include some of the warnings that are given to product renters in other areas. Hopefully, if we get it around the committee, I would like to see it come out as a DEMA form that could be distributed at dive shops, along with protocols as to how to use the equipment and how to service it. I think that this dovetails perfectly into rebreathers. You need to have fixed rules as to how to use this thing, and the people who are going to be renting it and diving with it have got to have a specific set of instructions.

One of the things we talked about at lunch is, what do you do with a semiclosed rebreather, knowing that a lot of people are going to get blown down current from the dive boat, be swimming back, two feet under the surface, huffing and puffing, and wind up in an hypoxic situation.

**Turbeville:** Rick, let me point out that we're going to try to cut this a little bit short today, so we can give the audience more time to ask questions. I'd like to address that issue then. Although you're hearing about some of these problems now, we also have some solutions which we can describe in some detail, based upon your specific questions.

**Lesser:** Okay. On that note, let's go to Al and hear about the good news.

**Turbeville:** Next is Al Hornsby. He comes from the "mount" with tablets of clay, although not feet of clay, and he has good news and some disturbing news from OSHA. I think that this is probably the most critical information you might hear today on the litigation/liability/regulatory front. Al?

**Al Hornsby:** Thank you, Bill. And I appreciate Michael [Menduno] preserving my reputation just a little bit, by clarifying earlier that I'm not one of the attorneys here. In fact, when I was over at the law offices last night for the party, I was so impressed during the first few minutes about how friendly everybody was. It took me about a half hour to realize that they all couldn't take their eyes off of my neck brace [Hornsby was wearing a neck brace at the meeting].

## OSHA & the diving world

I was asked to talk about the OSHA issues involving rebreathers and to some extent, technical diving in general. OSHA regulates employees at work, so when you think about the OSHA situation, that is what we're considering. It's not applicable to diving in general, it's not about what consumers are doing, but it involves employees, while they are working—that could be instructors teaching, etc. etc.

Back in 1974 when the commercial diving regulations were updated, there was an exemption negotiated for recreational scuba instruction. And that's the reason that our community has never really thought a whole lot about OSHA all these years , because we've had this exemption in place. The other exemptions were for the scientific community, as Mike Lang had talked about before, and for public safety divers in rescue, police work, and so forth.

## The enriched air (nitrox) exemption

The exemption that the recreational community has always used, however, is quite specific, and we haven't really thought about much, as technical diving has developed. The exemption is for diving instruction for open circuit scuba using air, and air is defined by OSHA as 20-22% O2. It's not for decompression diving and it covers dives to not more than 130 feet. A couple of years ago, when tech diving started becoming popular and enriched air started being used, the question was finally raised: what about the recreational exemption?

**The exemption is for diving instruction for open circuit scuba using air, and air is defined by OSHA as 20-22% O2. It's not for decompression diving and it covers dives to not more than 130 feet.**

At the time, a lot of people said, oh, it doesn't really matter; enriched air is just air, it's just had the percentages changed. Well, probably most mixes are just air with the percentages changed a little bit. I don't think we've invented any new elements. So, when PADI decided to get involved in enriched air training, we made the decision before we would do that, that we needed to go look into the OSHA matter. Because the ramifications of being outside this exemption are huge, if you think of it.

For enriched air training, actually any gas that's not compressed air, that's 20 to 22% O2, balance nitrogen, it puts you into commercial diving regulations, which includes things like having to have a dual-lock multi-place chamber on site; standby divers, a tender for each diver in the water, an in-water stage for decompression, two-way communication between the surface and the diver, etc. etc. So for all of us who have been out teaching enriched air and so forth over these last few years, these are the kinds of regulations, the kinds of requirements that we should have been following under OSHA regulations. The same, applies to rebreather instruction.

It should also be understood, that when you're dealing with OSHA regulations, they don't play games with tricky language, little exemptions, like you deal with in court;OSHA doesn't really do that. They don't have to. Also, for individuals, if you're the owner of a company or corporation, then you are going to be counted as an employee yourself, if something were to happen.

## The meeting with OSHA

Karl Shreeves and I have been working on this project for the last few years and finally we got to the point of hiring some good lobbyists in Washington. We went and met with OSHA officials last December. We were concerned. You know, it's that question: when do you wake up the big dog? When do you talk to them? Maybe they don't realize that we're all out there doing this stuff, and maybe we're going to cause a problem. We found out very quickly they knew full well what was happening in the recreational community and they told us clearly that they were not going to be pro-active on enforcement, however, if there was an accident, they would prosecute. And if you look at the number of regulations that are involved, and the number of requirements there are, if you had an incident, the number of violations that there would be would probably involve 20, 30, 40 different regulations and they typically charge about $1500 bucks a piece when they start naming those up, so it's an important issue.

## A variance for closed circuit diving

Since that time, and basically, as of December of last year, they agreed that they would try to work with us to create a variance—another exemption to allow enriched air to be included in the recreational exemption. There also was a proposal made to have closed circuit included in this; to do away with just the using open circuit part of it. PADI had led one effort, Oceanic had a separate, but cooperative effort going at the same time. We've been in contact with each other back and forth.

In late June, we got the draft set of conditions. And basically, what they do when they want to do a variance is to say, we will allow this under the following conditions and then they start laying out what the conditions are. They came back with the additions for enriched air which looked reasonable. There were a few things that had to be attacked; we had to create some research studies and a lot of different things to get there. With regard to rebreathers, their only notation was that NOAA was uncomfortable with closed circuit because it was a far more complicated issue.

We then heard in July that they intended to have the variance completed and the official application in our hands by the end of August (last month). It was unclear whether they were going to include closed circuit or not, but at one point, after being pushed and pushed, they said it was their intention to include closed circuit with the variance when it came out.

Thursday of this week we received this little document from OSHA—this is the first group to hear about this. The good news is that this is the variance for using enriched air up to 40% within the recreational diving exemption. So, that is a big deal for the community. There are still a few questions, a few fill-in-the-blanks if you will, but it's reasonable. Within the next couple of weeks, PADI will file this application on behalf of the diving community. There'll be a 45 day review period, when it'll be printed in the Federal Register. There will be a chance for public comment and opposition. We hope there won't be any with enriched air—there may be some from the ADC [Association of Diving Contractors] or others; individuals can object. They promised us, if there are objections, then they will put us on the fast track for a hearing, because they want to get this done. So, we're not there yet, but at least we have OSHA on our side in terms of getting this variance through.

What was interesting is that when we got the document, the only commentary on equipment was that open circuit scuba must be used. So we got our attorneys in Washington to go back to OSHA, and find out what happened with the intention to include closed circuit. As of yesterday, we got to talk with one of the attorneys who worked on this draft for OSHA, and basically the quote was that they just are not yet ready to deal with closed circuit; it's too complicated, both from the technical point of view and from a regulatory point of view. So that's one that we will have to keep on. They have pointed out to us that it is a much more problematic issue than enriched air was. NOAA has used a lot of enriched air, and they backed our effort because they felt that it was a safe situation; we did have some history of use, we had some statistics and so forth.

With closed circuit, as I said, the position that NOAA has taken with OSHA was negative relative to closed circuit, and obviously we don't have a safety record out there to rely on, or a lot of use and so forth. So, I would expect that it still is going to be some time before we can be successful having closed circuit use included in the recreational exemption.

At this point in time, I think everybody needs to realize that having employees, and that means an instructors teaching people to use closed circuit and so forth, means that you have to be aware that the commercial diving regulations apply. Calling somebody an independent contractor, rather than an employee, when they're under your direction is not going to fly. Again, you're not going to be able to get slick with OSHA; they'll probably see through that. Thank you.

## The work ahead

**Turbeville:** Thank you, Al. One point I would like to bring up on the whole question of OSHA exemptions and the possibility of getting one for closed circuit, and when we say closed circuit here, we mean both closed circuit and semiclosed circuit rebreathers, is this whole process of review and the Federal Register. There's a 45 day review period after OSHA has indicated it will grant an exemption in which interested parties may comment. Now, that may not be a very big deal here with nitrox, but think about closed circuit technology. Who do you think is going to be making the biggest comment about that when the technical/recreational community tries to get exemption for rebreathers? It's going to be Ross Saxon and his friends at the Association of Diving Contractors, and rightfully so, from their perspective. They will put up one hell of a fight to keep any of us from using these devices if they think it's a threat to their economic well being. That is going to be a tremendous battle some time in the future.

Again, we can talk about this later on at some length, but for now, let's get on to Mike Harwood, with HSE and the British perspective.

## The British perspective

**Mike Harwood:** Recreational instructors are people who are getting paid for instructing groups of divers in the recreational market are at work. Therefore the law applies. The Health & Safety Work Act is there to protect everybody who's at work. There's an employer bit, there's an employee's bit, there's a bit to the public, and there's a bit to self-employment.

When the risks are considered to be fairly high, we create regulations and diving's one of these areas. Underneath the regulations, you get Approved Codes of Practice and they have a funny rather strange legal position. Below that there are guides that we put out that don't have any status and we put out a heck of a lot of information.

In 1981, the HSE produced some diving operations at work regulations. They were then lifted, and the reason was that a certain friend of Prince Charles didn't like the way we treated the scientific and archeological communities like the other people. As a result they were changed before they came out. It amazed me, because by the time we got them on the street, four exemptions were granted. The exemptions were for the scientists, the archeologists, the journalists, and training amateurs. Don't ask me why they have the exemptions, they're not exempt from the law. What exemption means is that you're exempt from certain parts of the law and there are conditions in the exemption which have to be complied with. Unfortunately, there were two amendments that came along. And the exemptions were changed to prevent people in those groups, from having to comply with the amendments. So what you ended up with was a series of certificates, that you had to hold. The first one was the certificate of mental fitness to dive. Instead of costing the 45 pounds which the sports council had set up for the recreational community, they cost about 180 pounds a year. there was also a certificate of diving first aid, which you had to have no matter whether you held a recreational first aid certificate; you have to have it. That would cost you about 250 quid. And there was a certificate of diver training, that you had to have unless you were exempt from this regulation. Now for some odd reason, recreational instructors were not exempt. The other three exempts were not recreational instructors. And the dumb thing was that all you had to do was send your card in and photograph, and fill the paper out and we sent you a certificate. It seems a bit dumb to me, but that's the way it was.

Some other rather weird parts of this general exemption. The strangest one was you could only use air. No one else in the regulations had that put against them, it only applied to instructors. So if you guided a party of people you had to use the full regulations.

Well we started to look at all these exemptions, and realized that it was such a mess we had to completely throw the regulations away and start again. And that's effectively what we've done, and in trying to do that, to make sure that when we got the new regulations out, we didn't get in the same mess.

We then looked at the market and we identified seven diving communities where you can't write a single set of regulations. Our head of policy is a rather bright lady, thank God, and quite forward thinking. She read the rules and said you can't have one code of practice, let's give everybody one. In fact two groups didn't need it, so we have five approved codes of practice. one specifically aimed at recreational instructors, another for scientists and archeologists who have jumped together, etc. The people who did the work to get these into practice represented the communities. Douglas Nash from PADI, and Chris Allen from the BSAC led the recreational group. And I was the qualified diver within our organization. So there we are.

We've now done our second consultation. It's part of the process. This book right here is the consulting document. An important point to make is that they're are not prescriptive. If you try to create a prescriptive regulation, then technology stands still. We have a situation with the commercial regulations that if someone came up with an improvement for air diving, every time they used it, I would have to write a special exemption. It wouldn't work; it takes to get that done. It offers no flexibility. So the regulations are very much goal setting.

After we finish this second consultation period, then we take it to a commission. a group of people, appointed from all different perspectives, employers, employees etc., and if they're happy, we'll go on through Parliament, and by next year the new package will come in.

Unfortunately after going to tek last year, I realized that guys were just out there breaking the law out there. That's the down side of attending these sort of meetings. Because I had to go back and force the agency to accept that we needed a replacement exemption, because you don't normally change exemptions when you are re-writing regulations. The problem was I now had forseeability; some people I considered friends were breaking the law. So I was breaking the law as well by doing nothing about it. It's quite clear in the Health & Safety Work Act. That's the downside of coming to these sort of conferences.

We made the regulations such that you could use any mixture that you like but not more than 1.4 bar partial pressure of oxygen. We do 1.5 bar offshore with surface supplied, and 1.4 bar for scuba. You could use your own first aid certificate from your group; that's the other thing we picked up on. Medical is a controversial point so we're not allowed to change that right now. We stopped you sending the certificate in and us sending it back. What I said in the case of fully closed or semiclosed breathing apparatus, is that the dive operation must be carried out in accordance with the documentation published by the equipment manufacturer or importer. Your certificate to train must be drawn on an organization that we recognize. In the case of rebreathers, your training certificate must be also endorsed by the manufacturer on the specific equipment that you are going to be training people on. So we have really taken the jump as far as I'm concerned. You can do a generic course to understand the business, but if you are going to teach, say on the Atlantis, you need a manufacturers endorsement that he's happy that you have the appropriate training to teach on his equipment.

**Our philosophy is that if a risk is being properly controlled, then don't try to try to regulate it. Because if you regulate it you can't usually force people to do what they're not familiar with.**

A couple of points more. Our philosophy is that if a risk is being properly controlled, then don't try to try to regulate it. Because if you regulate it you can't usually force people to do what they're not familiar with. If there's no need to tell someone to do something, don't do it because all you are doing is making him in a probably in a less safe situation. Another thing is don't write a regulation that you can't enforce. That's just dumb. So unless you get both those ticks in the box, the regulation doesn't go.

And who is it that decides all this? The public is very strange about risk. If people die, then the press will pick it up and put more pressure on the regulators to regulate you. So the community needs to be self-controlled, and then we can back off. We're passing the control and responsibility back to you, the manufacturers, the training agencies and the only down side of that is, we'll be taking the issue higher up. If we feel that the training agency screwed up, that's the level we will be taking it at. Thank you.

**Turbeville:** Thank you, Mike. As I said before there's a relationship between the public regulatory aspect of this whole liability/regulation field and the private litigation aspect of it. One quick anecdote: I tried a couple of years ago up in the upper mid-west, involving a double fatality; an instructor and her student both died during a dive. There was a lawsuit filed by the estate of the student who died. They went to trial, we succeeded in getting a defense verdict. But that was only half the battle. OSHA also came in, and brought a claim against the dive operation because, in their words, it was an unsafe working environment; it was an upper mid-western quarry, where temperatures drop below 45 degrees, beyond 60 feet. OSHA said that the employee ought not to be diving in that environment. That was their point, they tried to bring out. We were fortunate in that we had a justice department attorney who came into the case, and agreed at my suggestion to pull the transcript of the trial we just successfully completed, and read it . He did that, came and said, "You know, you're right. We'll let this one drop," But let me tell you something. They're out there right now looking for cases like that to bring up again. If there are fatalities involving employer/employee relationships, not just because there was an exemption of scuba diving, and not just because they're trying to make life hard for us. It's just that is part of their duty and part of their charge from Congress and they will try to fulfill it.

With that, I would like to have your questions—anything regarding liability, regulation, or insurance. Fee; free to direct them either to the panelists or myself. Yes, Bill Delp.

## Video and text warnings

**Bill Delp:** Bill Delp with Undersea Breathing Systems. In terms of warning the customer or potential end user regarding proper operations, or to equipment, are text and video on a par? If you make a video, does it have to be backed up with text, or vice versa?

**Turbeville:** It doesn't have to be. Any time you put a product on the market, if there is a concern over its effectiveness under the strict liability criteria for 2A, they look for warnings, both on the product itself, i.e. stickers on the rebreather in this particular case, instructions that are contained in a manual that goes along with it, and anything else that you might have (videotapes, wavers, releases, things like that) can be layered upon that to increasingly shift the risk of the activity away from the manufacturer and the trainer onto the participant. That is really the whole goal of liability, proactive reduction of risk, to the extent we can do it. It's risk management; we're trying to first reduce the risk by making a good product that is not too terribly dangerous, and then shift the residual risk, which is always going to be there since you're diving in a hostile environment, onto the participant to the extent that can be done ethically and legally. It's a matter of learning and instructions.

**It's risk management; we're trying to first reduce the risk by making a good product that is not too terribly dangerous, and then shift the residual risk, which is always going to be there since you're diving in a hostile environment, onto the participant to the extent that can be done ethically and legally.**

The answer is yes, those things are useful. They don't have to be there but the more you have, the better off you are. You do not have to have a text for video, that can be considered something entirely separate, and it can be very good and very effective. Look at what Dick Long does with the DUI dry suits, for instance. That's the sort of approach which the rebreather manufacturers can do to minimize—not eliminate—the risk of litigation and of an adverse judgment should a lawsuit be brought. Anything else?

**John Sherwood:** What about reasonable care? What I mean is that when you release a product into the market, it's reasonable to expect that they're going to make modifications to it. Now what steps do I have to take to ensure that I've exercised reasonable care. Because I know they're going to modify it-. What did I do to prevent them from modifying it?

**Turbeville:** The term you really want to use is foreseeability. Reasonable care goes to the concerns of negligence and that really doesn't have anything to do at all with the strict liability claim, but foreseeability does. Primarily it means that you have to know what your market is. What are people doing with your product, once it's out there on the market. If you know for a fact that they're adjusting a particular valve for instance, to do a type of dive on a semiclosed unit which you know isn't safe, but they're doing it because people want to do it, and you do nothing to stop it, then you're definitely dead in the water. You have to warn against that specific practice, in fact, you might even be held to the standard of making it; it's not impossible, but much more difficult to do. So you need to know your market, because if you can be charged with a foreseeable risk, you really have a problem.

For instance, the point that was brought up by Dr. Thalmann today about the oxygen metabolism rates of these divers who are working very hard. I mean, some of these units today on the market now are offering or are delivering 2.5 liters per minute, but some divers can go to 3.0, 3.5, maybe. Is that a product defect? It certainly could be argued as one. Even if you warn against that type of activity, it's still possible to get around a summary judgment motion by saying, I don't care what they warned. This is an inherently dangerous aspect of this product and they should not have allowed this to get on the market with that defect in there. Rick, do you have anything to add to that?

**Lesser:** No, that was well said. That was a point that we discussed at lunch, what do you do with something that won't deliver sufficient oxygen to somebody swimming back to the boat against a current that may actually need and then some. It's a problem. I think warnings only go so far. I think you may have to restrict the use of the product and be very specific. For example, there's a case in California involving a snow board, and the argument was made, "Hey you know, they do crazy things with snowboards. They're upside down in snow banks, they can't get their feet out and they're going to die. That's an unsafe product." The court in that particular instance said, "Yeah, that's exactly what happens and in fact, not only does that happen, when the guy rented the snowboard, it said right on there that your feet aren't going to come out and you can land upside down in a snow bank and die. He took it out, and he did it anyway. He's out of court." So, if you can specifically warn against the activity that is the result of the use of the product or the way the product is designed, you may be able to escape liability under those circumstances.

## HSE perspective on warnings

**Harwood:** Can I just follow up. It's quite interesting, because a lot of American equipment comes across into Europe and particularly into UK. We have a rather strange consumer law. The consumer safety act is handled by another enforcement agency, but if it is foreseeable that the equipment can be used in the commercial at-work situation, it comes across to us. Graeme Lawrie, and I have been going out to the associations that represent manufacturers groups, and telling them that we think that their documentation is absolutely rubbish.

There are some pretty good examples. But to give you a simple example, you can put a metric cylinder valve into a PSP thread. And it goes in quite easily. They can come out quite easily, usually, when it gets to 200 bar. We've had three incidents so far this year. I just put a notice out suggesting that everybody put a warning label in the bag with a cylinder valve saying this is metric, it should only be fitted by a competent person.

To give you some idea of the potential hazard, the second incident took the top of the dive store roof out. a ten foot by eight foot piece, and blew it across to the garden next door. If the young girl had been another meter, say three feet, closer to the panel she'd be dead. She's got bits of metal embedded right in her hand. Now, when I said that to manufacturers, they simply have got to put warnings on everything—it is foreseeable—they did nothing. I'm pretty sure we'll prosecute them.

**Turbeville:** Richard Pyle?

**Richard Pyle:** I just wanted to mention to Mike that you'd be pretty hard pressed to demonstrate that I'm working when I do what I do , but that's a side issue.

**Harwood:** We have a relationship with our income tax people. So we look at your receipts and who's paying you, if you're paid, you're in.

**Pyle:** Well, you can check. We'll talk about this later. [Audience laughter]

**Harwood:** No jurisdiction.

## Can consumers waive their rights?

**Pyle:** There's not coral reefs in Europe anyway. Coming from the perspective of a consumer looking at a liability waver from the other side, if I found Aladdin's Lamp and was granted three wishes, my first wish would be for a liability release that stood up in court, and my second wish would be that anyone who ever went under water for any reason had to sign this before buying any piece of equipment. My question is, if I'm a consumer who's willing to waive all rights possible, and I want to give assurances to a manufacturer so that they'll let me use something that they might not otherwise let someone use, can I take steps to go do that.

**Harwood:** No.

**Turbeville:** Yes. Let me explain. Releases are very effective within the realm of their competence. Their competence, their effectiveness, is as to negligence claims. You can give a release to an instructor, you can give a release to a manufacturer or anybody else you like, or they can give one to you that you can sign, which is very effective in most states in this country, that will preclude you, or your estate, or your heirs from ever filing suit against that manufacturer or instructor or distributor or retailer.

However, there's fairly specific case law, in fact, I just read another case that came down a couple of weeks ago in California that says, because product liability is not fault-based, it's not a negligence concept, it's really a shifting of risk. It's a public policy statement of this country; you can not have a release that's going to effectively bar a claim for strict product liability.

Now, they still can be used to shift risk. It's called assumption of risk. It's a partial defense to a claim, but you could never insulate a manufacturer totally from the wrath of your family, your daughter, and your wife, for instance. You can't do that on a strict product liability claim. Now, the fact of the matter is, somebody like you, as experienced as you are, as knowledgeable as you are in this field, even though you might be a weenie, would be considered to be an expert and your estate would have a very, very hard time in bringing an effective claim. That's another reason that I firmly believe that at least within the technical community, you can control the risk. The end users ought to know better. These are not basic, or even intermediate level divers who are really just learning their fins and who will panic at the slightest provocation. These are divers who understand the risk, who know what the risk is, who have experienced before, and who are accepting it. If they bring a claim, they have a much harder time of it in court than would somebody not quite so trained.

**Pyle:** OK, thanks.

**Lesser:** By the way, in the middle of all that, the magic words were , public policy. In California, we have a civil code section 1941 and 1942 that has to do with landlord-tenant. It says that if the landlord leaves the house in such neglect, stairs are rotting out from termites and dry rot, and you as the tenant live in there, walk up the stairs, and it all collapses and you land in the shrubbery, the lease is going to say that you owe the landlord for the flowers that you squash and you have to replant them. The section of the code says no. It's our public policy that there are certain things you can't waive and that's one of them, product liability is another one.

**Turbeville:** OK. Thanks. Anything else? Remember to state your name, please.

## An exemption for rebreathers

**Michael Lang:** Michael Lang. I have a question for Al. Did OSHA specifically say closed circuit systems, or was the wording specifically termed rebreathers?

**Hornsby:** Actually, it's the other direction. The conditions for the variance that came through, specifically require open circuit scuba.

**Lang:** OK, so there was no specific wording regarding closed circuit or rebreathers.

**Hornsby:** It's entirely not mentioned. And a part of the effort had been to have closed and semiclosed systems allowable. The variance that came back strictly addresses enriched air under all other conditions remaining the same, plus a few more, but specifically what is mentioned is open circuit scuba.

**Lang:** Now, in the comment period, is there not opportunity to further drive at least, semi closed rebreather system?

**Hornsby:** Well, when the comment period is open, people will be able to say, whatever they want. I think, from a strategic point of view, there's a part of this that's not all bad as far as enriched air goes, because enriched air is going to be a far easier thing to get through and finished than closed circuit is going to be. We know that already. So, I think from a strategic point of view, now that it has come back as just enriched air, we would like to have that go ahead and be done so we have it in hand. The need for that is far larger at this point in time. It would be a shame to hold up the enriched air exemption fighting over closed circuit, which we already know is going to be far more problematic.

**Lang:** My last quick comment is that the commercial industry doesn't use rebreathers. So, I'm not sure how much of a fight it will be with the United Brotherhood of Joiners and Carpenters who represent the commercial guys as a union. I don't know if it's going to be such a fight.

**Turbeville:** Talk to Ross Saxon

**Lang:** Well, we already did, and we talked to Steve Butler [OSHA] as well, in connection with some other things at OSHA, and I'm not too sure that'll be such a big thing.

**Turbeville:** Hopefully not. We definitely hope it will not be.

**Harwood:** That's the point I was just going to ask about, I guess, the sequence of American law. The way we cover that—we don't have a problem with the different communities certainly with the new regulations, but when we give the exemption, we specifically state at the top what diving operations it applies to, and so, it's defined in this particular run, for instance. Nobody else could say, that you can't let the recreational people do that; they're going to steal work from us, because those are the guys aren't supposed to be teaching recreational diving. We don't recognize them. We don't recognize ADC companies as capable of teaching recreational diving, and we write that into our exemption.

The other thing I was going to say is how many of these guys at OSHA actually know how to dive?

**Turbeville:** Few.

**Harwood:** I think we've got 14 inspectors who were selected because we are divers. Three are specifically recreational divers. One of them is a lady who is highly qualified, and the rest of us are former military/commercial divers. The 14 inspectors that are involved with this and advise on regulations have a very thorough diving background. I think that may be one of the problems you're wrestling with here.

**Turbeville:** I know, Mike Lang mentioned Steven Butler, Steven C. Butler with OSHA, and he is in charge of the diving branch, as I understand it. He's a very competent. I think he's an ex-navy diver, maybe ex-commercial, but he's one of the few at the upper echelons in this country who's very, very knowledgeable. He's not an unfriendly voice out there either.

Karl Shreeves?

## Clarification on the exemption

**Lesser:** Karl, before we get to you, let me just clean it up for the record for people who want to hear. The exemption as it's proposed says that, "The employees will use only open circuit scuba while using a nitrogen/oxygen breathing gas mixture. That's point one. Point two is, that I think it's not so much the function of the rebreather that's going to put the commercial community up in arms, it's the possibilities of what you can do with the rebreather as opposed to basic open circuit air diving. That's going to have them crying wolf or crying something. They'll say, "Hey, this guy could take one of these super closed circuit systems, go down and do a 280 foot dive for an hour, that we charge $50,000 an hour for and this guy's doing it for a thousand with his slick little unit. We don't want that."

**Lang:** But most of the time, they're looking at the nature of the underwater activity. I'm just wondering, if it was the mere fact that you had to go and get a variation for nitrox because it was considered mixed gas, that triggered them to come to the original tek.Conference.

**Lesser:** I don't. It think it was the fact that some technical divers were starting to get in their bailiwick. I mean, ADC people hate boat cleaners. They want a guy who goes down and scrubs hulls in the harbor to be a commercial diver. If you're out making money on a dive, they want you to be under their auspices. II think rebreathers ultimately will open up the possibilities of divers doing things that are now done with heavy gear, or at least Superlites and the like, and they don't want that. That's their job.

**Karl Shreeves:** Karl Shreeves, PADI. To expand on this discussion there's been a lot of talk about what if OSHA comes in to enforce the regulations. Al and Bill have been talking primarily about when an accident occurs, but it's important to realize that not having accidents isn't necessarily going to keep you from OSHA's wrath. They will also come in for a complaint, and so you could have a disgruntled employee, angry competitor, ADC, any of these things can bring OSHA upon you.

**Lesser:** Yeah. That's the classic example. The guy gets hurt on the job who is a independent contractor and as soon as he realizes he doesn't have workmen's comp, he says, "Wait a minute, man I'm getting paid by the hour. This is just a deal, and somebody pay my medical bills, please.

**Turbeville:** Mike do you have a comment?

**Michael Menduno:** A short comment. No one has mentioned this, but it's clear that trimix diving wasn't included in the exemption.

**Turbeville:** No, I've kept away from that, because we're not at tek.Conference, we're at a rebreather conference, but you are absolutely correct; trimix training is not exempted.

**Lesser:** If you press that, you'll blow the exemption four ways from Sunday. You're deeper than 130 feet, you're on a helium mix, you're doing decompressions stops. I wouldn't hold my breath on that one.

**Turbeville:** Hold your breath and speak in a very squeaky voice. It will not happen any time soon.

**Hornsby:** I think also, strategically for the community, I would hope before a bunch of people run out and start pushing really hard on these others, that we get enriched air through the system.

**Turbeville:** Yeah, let's not cause a problem.

**Hornsby:** You get them all nervous and they will pull back, because again, for the moment, this is a very significant issue that affects large numbers of people in our market place, at this time. We would like to get that one finished, tied up and done, and then go on with these other ones that may be more difficult.

**Turbeville:** A topic for DEMA perhaps.

## Setting an upper oxygen limit

**Russell Peterson:** Russell Peterson. A question for the attorneys: In view of the prominent position that US Navy diving procedures and policies have had in decisions relating to litigation and commercial diving, do you feel that there would be special concern with rebreathers in setting an upper PO2 or an operating PO2 limit that was above the 1.3 atmosphere limit that the US Navy now uses for routine operations for mixed gas diving?

**Turbeville:** Yes, that's certainly a possibility. Rick, you may have another observation on this, but my feeling is that any time you have a standard set by an agency as authoritative in the diving field as the US Navy, is it definitely behooves a close look at it. Now, the fact is they're doing different types of work, and you may be able to make a very cogent and acceptable case for the reason why we have a different limit in the technical community; a PO2 standard of 1.45 up to 1.6 in decompression. But it must be based upon empirical data not just a theoretical believe. That's where I think we're a bit weak right now. Still. We're doing a lot of dives, but not a lot compared to the air diving community. We're still not quite in a position where we have the empirically data to say, "We have something we can prove to you is equally useful to us and it's beyond the Navy standard. It's an issue that's not come up yet. There's been no litigation on that point.

**Lesser:** Also to the point is at that the draft of the exemption is limiting to 1.3, so we'll see what happens.

## FDA regulation?

**Chris Parrett:** Chris Parrett with Abysmal Diving. A question that's hung over my head with my business for the last few years; Has anybody in the rebreather industry considered the fact that the FDA may step in and label a closed circuit rebreather as a class three artificial life support device and require the testing and regulation, authorization, issuance, etc., etc. They can do that in a heartbeat, because it falls underneath that. The problem that I have with the software we sell is that, we're an inch away from them stepping in at any moment and saying "Stop! This is life support, artificial medical life support equipment. The person's life is in danger when they're using your software or using this device, and thou shalt meet all of our regulations from this day forward.

**Lesser:** Isn't it also true of nitrox?

**Parrett:** It may be. I'm asking. I'm not sure. Open circuit generally is exempt from that, I think, in all cases. But closed circuit is a completely controlled artificial environment, and the FDA may—and I don't know that they have any impetus to do so—but they may decide to step in and assume responsibility for this. Certainly that same device, or a similar device used in a hospital, in a respiratory situation absolutely falls under that control.

**Turbeville:** We should ask the Dräger people They make anesthesiology machines. Al?

**Hornsby:** I don't specifically know the answer to that, but related, in New York, FDA did issue a directive that if you are mixing enriched air using medical oxygen, you are manufacturing, and you do fall under the FDA.

**Turbeville:** Buy aviator's gas.

**Lesser:** Now everybody's using welding oxygen, so there's no problem. [Laughter]

**Turbeville:** And I have advised people who have called me, did you buy the aviator's gas, if that's an issue. Any other questions? By the way, you can always buttonhole us individually, if you have a specific question you don't want to share with the rest of the group.

## HSE trimix instruction exemptions

**Harwood:** I just have one other thing. I was waiting to see if anyone was going to ask the question. In the recreational community, the regulations limit dives to 50 meters to 20 minutes of minutes decompression. What we've done for the guy who's offering trimix instruction is that they have to have an individual exemption. I drop a line to them, they write to me, I send out a letter, they fill the form in. I look at what comes back and I recommend to my management that I'm content that this individual can be exempt and go to 75 meters for a maximum of 20 minutes bottom time. I appreciate that the decompression depends on a lot of other things, and so far, I've approved two people, and their exemptions should have been signed by my director last week. I'm quite happy with that. If all goes wrong, my ass is in a sling but I'm quite happy with the individuals.

## Military regulation

**Gavin Anthony:** Right. I have a question. Which of the new categories for the HSE Executive are you hoping that the military will try and comply with?

**Harwood:** The military has made a mess of things you know. Right? Well we're trying to straighten them out. There was a meeting on Wednesday. They are exempt under the law from the Health and Safety Work Act, but one of the Chiefs of Defense signed a piece of paper that said they would sign up to it, although they're exempt in a way. We can't go in and take prosecutions or anything like that. But then we have to go and define when it will apply, for example when they do civil work. Of course, the bird flies at the moment, if it's operational warfare, or training for operational warfare; they are exempt and they just follow their own regulations. If they step across that line and do work which could be done by commercial people, then they have to switch back, and that's being put across them at the moment. Especially during aid to the civil party. If there's a big storm in the country, the army turns out to put up the bridges and sort the thing out. They'll just use a civil Approved Code of Practice. There's no trouble with that.

I suppose the people that are having the hardest time right now are the inshore group. Recreational, media, scientists, archaeologists, I think we've got that all sorted out. They know what they're doing. Police are exempt from the Health and Safety Work Act at the moment. The laws are being changed to bring them in next year. They've got a voluntary code of practice which we've written with them anyway. So we feel quite comfortable.

But the whole principle is that you just control the risk back at the person who's got the responsibility. We don't try and write a prescriptive regulation any more. We dump it back on the people who have got it because if we write a prescriptive regulation, all the guy does is think, "If I follow the regulations, I must be safe." Not true. If you keep the regulations very small, and tell him that he's got to do his risk assessment, sort it out himself, he becomes a much better person at protecting the public, himself, and other people. And that's the philosophy. I believe in it. I feel quite happy with it and I don't understand why other countries get so locked up with it. The idea of regulating health and safety is to get there and talk. As I said at tek, diving is folklore, and if you go don't go out and speak to the folk, you don't understand the lore.

## Establishing a defense fund

**Lesser:** One other short point that I'd like to make, and it's kind of specific to the people who are doing the manufacturing and distributing of these products here. As you know, you're are probably having a very difficult time with product liability insurance. Like small plane manufacturers where you double the price of the plane, and that's your insurance premium for each plane. We've been talking about it for some time with a number of the manufacturers Tracy Robinette and I have gone over this on several occasions. There is no real solution, but at least we can assist in solving the problem by setting up a program where we would provide defense to any kind of product liability claim for a manufacturer, or the guy who just flat can't get insurance at anything that approaches reasonable pricing. It's sort of like a pre-paid legal defense fund that you pay in to us, that sits there until such time as you get your product liability claim and then we defend it. But it's a whole lot less than the cost of insurance if it's even available, and watch this space. We're working on it now. We're motivated to get it finished in the very near future and make it available. So, it's not an ideal solution, but it's better than what exists or it's better than putting everything on the line each time you sell a unit.

**Turbeville:** OK, anything else? Again we're available for any questions you might have in the course of this seminar which is rapidly running down. Michael?

**Menduno:** We'll take a 15 minute break and then come back here for our last session.

# Surviving the Loop

*" We not only need to go step by step into this market, but we also have to fulfill a lot of requirements, and name all of the problems, and document them so that we can move forward. We have to continue to develop guidelines for using rebreathers and we have to continue to communicate with each other—what we have been doing here. . ."*

--Christian Schult

28 SEP SAT 4:45-5:45 pm

## Transcript

**Michael Menduno:** This is our last session of the day. We're calling it, "Surviving the Loop." It's actually a combination of several sessions. A group of us met at lunch to strategize on how we might try to get closure on this thing. I have the rudiments of a plan, and we're going to go through it here.

### Proceedings

First of all, I want to say that we are going to do a proceedings. We've been taping everything. We have papers. One of my tasks is going to be working with others to get it done. My goals are to produce a document that hopefully represents what it was like to be here for these last three days, and to be able to convey the important information that I think came out of this meeting. The goal is to have it ready in January for the DEMA show. So that's our goal. And I will be contacting some of you in that process. If you have a paper and you haven't gotten it to me yet, please do. I prefer hard copy and disk, it doesn't really matter what format, as long as I know what it is.

**I think it came through really loud and clear that rebreathers can kill a diver in many, many insidious ways; there are many ways to die on a rebreather. It just kept coming out over, and over and over and over again these last three days; all the little intricacies . . .**

### The plan forward

Over the last three days, we have exchanged a large amount of good information, there have been a lot of ideas, recommendations, and I would say themes— common ideas or feelings that everyone seemed to share. Trying to summarize all this is very difficult, and certainly trying to come up with a definitive set of recommendations today, on the spot, is going to be impossible. But I wanted to start somewhere.

What I'd like to do, is to give a five minute rendition of what I believe are some of the key, salient points of this meeting. I'm sure I'm leaving out things, and that's why we have transcripts, so I'd like to go through it later. If I miss something or didn't get something right, please let me know when we open things up for discussion. That way it will be on the record. So, if there are no disagreements with that, that's how I'd like to proceed.

### Organizers' real-time summary

Sense of the Group—I think overall, what I came away with was really an increased respect, and concern for rebreather technology. I very much like Ed Thalmann's comments about open circuit being the steam engine of diving, and rebreathers being the space shuttle. Perhaps there are several levels of space shuttle out there, but they are shuttles none-the-less.

I think it came through really loud and clear that rebreathers can kill a diver in many, many insidious ways; there are many ways to die on a rebreather. It just kept coming out over, and over and over and over again these last three days; all the little intricacies; the pinched O-ring incident, all the various subtle physiological issues, user near-miss stories. I think that out of that, I have concluded that the move to rebreathers is actually a much bigger step then I think most of us here may have imagined. Am I right?

**Not to pick on the manufacturers, but each of them has specified a duration for their canister. My question is, on what basis are these claims being made? Has canister testing been done? It's kind of eye opening.**

### An ambitious and formidable task.

I have been promoting rebreathers through my writing, and through *aquaCORPS Journal* for the last six years. We ran our first article about rebreathers in the summer of 1990, *aquaCORPS* issue #2, and had an article in every issue since until this year, when I closed the publication. But after sitting here for the last three days and really listening to the information that's been presented, it seems clear to me that bringing rebreather technology to the diving public is an ambitious and formidable task.

The military has been very successful with rebreathers because they have a huge supporting infrastructure, they're incredibly anal and tough, and the weak just get weeded out; dominate, eliminate and control. I think that their example raises the question, which we can't answer here, and that is; "Is the recreational market really ready for rebreather technology? People here are asking that question. "Are the retailers ready to deal with this technology? That's where the rubber meets the road. Again, it's not a question we can answer here, but it's a question we can raise.

One of the things that came out of this meeting, that seems really important, is that we inform potential rebreather users, and provide clear warnings regarding the risks involved and make them aware of all of the various things that can go wrong with this kind of technology. That was over all.

### Semi-closed systems

With regard to semi closed systems, I found it interesting that a lot of the collective rebreather experience, perhaps most of the rebreather experience up until now has been with semiclosed systems. One of the main problems with these types of systems is the problem of not knowing exactly what you are breathing. This can be a killer problem.

We learned that mass flow semiclosed systems have potential hypoxia problems that we went through in some great detail. We learned that civilian oxygen consumption can be as high as 2.5-3.0 liters per minute for short durations, contrary to the assumptions that some manufacturers have been using. Unfortunately, solving the problem by cranking up flow rates, also serves to decrease performance of the units.

What I found particularly interesting, and perhaps a bit frightening, was that very small changes in oxygen consumption and flow rates can have very large changes on the diver's PO2s. It seems pretty clear that both manufacturers, and consumers thinking about buying one of these systems really need to be aware of these potential problems, and that it is the manufacturers responsibility to address these problems. We talked about the fact, that testing is critical in this regard, and Christian Schult from Dräger, got up and talked about the tests that they've done to ensure that hypoxia will not a problem on the Dräger unit.

We learned that properly calibrating this equipment is extremely important; making sure that a system is properly working, and that there are operational procedures that need to be drilled into the people that are going to use this equipment, like refreshing the counterlung before ascent. Yet there may still be situations, for example, swimming to the boat at the surface in a heavy current and seas with the mouthpiece in, that the user may out-breathe the system and have problems. So, it's an issue. Interesting enough at the same time, a number of people have remarked that semiclosed may be the right technology, or at least a good starting technology for the recreational market, because it is simpler in many ways.

### Independent testing

Equipment testing: The consensus of the group was that rebreathers should be tested before being offered on the market, presumably by an independent testing facility. Manufacturers need to specify the performance of their equipment and be able to support and document those claims through product testing. I think that was the sense of what came out of our discussions. We learned that both human and machine testing is needed to fully shake down a rig, and that there are testing standards or guidelines that are already in place, as the result of the work done at EDU, Han Ornhagen's lab, DRA, the NATO specs etc.

I found a couple of the side points with respect to testing very interesting. The first was that canister duration is a statistical phenomenon, like decompression. Canister one packed by diver A lasts 240 minutes. Diver A re-packs the canister, same material, same day, same dive and gets 80 minutes out of it this time. Determining a canister's duration is a matter of running statistical tests, and using an average. Not to pick on the manufacturers, but each of them has specified a duration for their canister. My question is, on what basis are these claims being made? Has canister testing been done? It's kind of eye opening.

## Calculating decompression

Another area of interest is decompression. Ed Thalmann told us that just taking the Navy's air tables, and tweaking the math so that you could run at a constant PO2 of 0.7 atm [The USN has used a 0.7 atm set point on the MK 16 for some time—ed.], didn't work; they bent too many people. They had to go back and run tests and change the model accordingly. But it appears that many of today's deco-engineers are taking that same approach, tweaking a Buhlmann or other constant FO2 [fraction of oxygen—ed.] algorithm to run a constant PO2, to generate rebreather tables and/or s/w. The interesting question of course is, how well will they work? Some of you may be the first to find out.

## Lists, dive supes & full face masks

In the category of operations, I think the key thing as we heard from Jim Brown and others, was to work to try to eliminate or cut the possibility for human error. I think that's really critical. Certainly pre- and post-dive check lists and procedures have just "got to be." There's no question about this. We need checklists and have to be very anal about this. People who aren't prepared to deal with that, probably shouldn't be diving rebreathers, because they're just going to die.

Full face masks? Boy, that came through over and over and over. We may be able to really save a lot of lives by just incorporating full face mask technology into rebreathers. There's a lot of good reasons to do it. There are some mask options out there now. I think that Bev's [Bev Morgan, DSI] new mask, the S-1, that will be in production sometime next year is very exciting and promising. Full face masks are important. And oh, by the way, if you have full face masks, we have an easy way to have communications as well.

Another area, where lives could be saved is CO2 monitoring. As we learned, by the time that you feel you may have a CO2 problem, particularly if you are exercising, you're already in deep shit. Unfortunately, none of the systems on the market have a CO2 monitor. I know that different companies are working on this, and hopefully one or more will prove out a reliable sensing technology.

## The buddy system revisited

We have moved from the buddy system to the team system in technical diving, where a team of one can be an acceptable alternative, but we probably need to take a real good look at the buddy system again in our operational specs for rebreathers. This was stressed over and over by our military colleagues. Training agencies and dive operators need to really look at that.

Training? One thing that came out of the meeting is that there's still a lot of hype and lots of BS right now in training area. Everyone is posturing and positioning, and there's a lot of noise and unreality and we need to move past that. I liked what Rob Cornick/Royal Navy said, that they're not so much teaching people to dive rebreathers, as teaching people to survive. I don't know quite how that translates to recreational divers, or how we want to state that, but I've always think that it's a little better to err on the conservative anyway. Bill Hamilton used to say that about tech diving. The first thing he'd do if someone was interested in doing deep dives, was to try to discourage them by scaring them away. If they wouldn't scare and still wanted to do it, he would help them. He figured if he didn't , they would do it anyway, and probably get hurt, so he would try to show them the right way to do it. I also liked what Rod Farb had to say. If you want to be an instructor, you should buy a unit, forget about being an instructor, and then dive the be'jesus out of it, live it, breathe it, learn it. And then you'll know what needs to be taught.

## Getting divers attention

It came through over and over that we really need to get people's attention, if they're going to dive with this stuff. It's not just another breathing system. It really needs some attention, that people have to dive it a lot to stay current, that instructors probably do need to own a unit, or have on-demand access to a unit so they can be current, and that open circuit divers are going to have to go slow, and really learn how to dive these things before they start pushing them. I agree with Richard Pyle, that the people at most risk are probably the experienced tech divers, who are used to doing deep open circuit dives. We have already seen this problem on "Tech Diver" [A technical diving mailing list on the net—ed.], and other places where people are just pushing these units and going way deep. Rich Pyle said, that it took him 30 to 50 hours to dive to 80 feet, and then he had an incident that nearly cost him his life, so he backed off and slowed down. Today of course, he's doing some mind boggling dives to 300 to 400 feet, but he took the time to get there. I overheard Billy Deans, looking at a bunch of units, and say, "I wouldn't take ANY of theses units below 60 feet until I had a whole lot of hours on it." So, I think that's a real important principle to get into people. There are people out there that are diving the Atlantis to 200 feet plus—wah wah diving. We really have to drive some of this stuff home.

## What sayest the lawyers...

That brings us to the lawyers. In the legal session, we learned that the legal risks involved with rebreather technology are manageable. And that the OSHA exemption, or rather the lack of it, is a big thing. Because if OSHA comes down on rebreathers, it's going to cause a lot of problems. I think Al [Hornsby] had a really good point that we need to get our enriched air exemption through first, and then there's mix, which is still hanging out there, as well as rebreathers. Hopefully, if no one gets hurt, let me rephrase that, if not too many people get hurt, not too many employees, and OSHA doesn't bug us, the community will be able to build-up the records and the data that are needed to get exemptions.

That's my summary from my notes. I am looking forward to going back through the transcripts, sharpening my pencil a bit and trying to tell the story of this meeting for the proceedings. Are there any comments; questions, things that you'd like to add?

**Unidentified:** A lot of people couldn't make it, but they're interested in what went on here. Are you going to have a way to send them things, or for us to get, buy more copies, or something?

**Menduno:** I think what we need to do first off is to get some press releases, some information, out that this happened, and what our plan is for getting out the proceedings. The proceedings will be sold. We haven't worked out the details yet. My own personal feeling is that if you attended this thing, you need to get special treatment on proceedings. Again, I don't know what they're going to cost you. That needs to get scoped out. They will be sold. Does that answer the question? It's gotten really quiet!

## Brood about it

**Rick Lesser:** I'll come up here and say that I hope that everybody doesn't walk away from this three day venture and just go back to business as usual, and wait for something to happen. If that's the case, nothing will happen. I've been in a lot of these things where that is exactly what happens. We sit around, we have a meeting, we talk about all the wonderful things we're going to do, and nothing happens.

I think what everybody needs to do is think about how the ideas that have been brought here can be put together to make a commercially viable organization or operation so that this technology can be presented to the world, and not just the people who are sitting here and their friends and neighbors. Unfortunately that's going to require some work. It's going to require contributions by a number of people. But if everybody here does a little bit, it's going to go a lot further. II think that we're way ahead of where we were three days ago as far as understanding what this market's all about and what these products are all about. From my perspective—as I said at the opening three days ago, I was going to shut up and listen—I heard an awful lot, and I think I know a whole lot more now about where we are, and what needs to be done. I'm going to brood about it for quiet a while, and hopefully we can all do something to advance the market.

## A proactive stance

**Unidentified:** Just to comment on that. I think we can be proactive. I plan to be. I learned a whole lot over these last few days, and when I hear stuff, or hear people say stuff that's bullshit , or not accurate, or a myth, I'm personally going to take kind of an active role correct any mis-information.

**Menduno:** Jeff Bozanic

## Not invented here.... NOT

**Jeff Bozanic:** One of the things that was said yesterday, was that the cave diving community should be looked to as a model for how the rebreather community can advance forward. In part, that's true. The cave diving community did some things that were really right. The cave diving community also did some things that were really wrong. One of the things that they did wrong, is that when they heard from someone outside their community, they said, "No, that doesn't pertain to us. We don't need to listen to outsiders because we're the experts in caves." As a result, some very good cave divers died, and it didn't have to happen that way.

Part of what I picked up in this three day forum, is that some of the civilian people are saying, we're civilian rebreather divers, and we know what we're doing in the civilian sector for out kind of diving. That stuff we don't want to hear doesn't apply to us. I think that is not a real strong concern at this point, and I think a meeting like this is really important because we've gotten a lot of input from people outside of our normal information channels and communities. But we need to keep really open minds and make sure that we take the information that's coming in from all sectors, and integrate and internalize it into what we're doing, because that's the way that we're going to keep it moving forward and much safer.

**Blueprint for Survival 2.0" . . . contains 20 guidelines to help you survive the dive. Mike's point is well taken. Maybe it should be updated to include rebreather technology.**

I'd like to say to Mike that I thought you did a really good job with this meeting. I'd really like to thank everybody that spoke here and prepared presentations. I personally got a lot of information out of this, and I hope that everybody takes all of the information that we got here to heart, and brood on it, as Rick said, mull it over, and formulate your opinions based on all of that information, and not dismiss some of it out of hand. Mike and everybody, thank you very much.

## Get a plan

**Mike Innis:** As an ex-IBMer, having attended a whole lot of large meetings in which there was a great deal to be accomplished, one of the things that concerns me a little bit is that, we don't leave this room without a series of action plans—if not a whole raft of them, at least one or two things. Somebody needs to take the lead to say, "we're going to begin the work to put together the National Association of Rebreather Divers, Inc."

Several people have mentioned that some kind of clearing house for messages needs to be established. In this day of electronics, we should be able to do that with no problems at all. And I think if we leave this room without something material that we are going to do—put together committees, subcommittees, something, I'm telling you, folks we're going to get together 18 months from now and we're going to say, OK, now what did we do last time? We didn't do anything last time.

A lot of good stuff has come out. If we don't capture it, if we don't start moving forward with the thing, I'm afraid this is going to be another lost opportunity. I think it's important that we do something as a body, as opposed to all the different tendrils that we have hanging out here. So, my plea to you all based on a lot of experience is that for pete's sakes, decide on one thing, at least, that you absolutely are going to accomplish as a group.

## Blueprint for Survival 3.0?

**Mike Harwood:** What I've got in my hand here is my own personal print-up of the Blueprint for Survival 2.0 [Technical diving guidelines prepared by Billy Deans and Michael Menduno, *aquaCORPS Journal* #12, NOV 1995—ed.] . It makes interesting reading after you've sat through this particular conference. Are you going to make the third version of it? Because it needs to be updated. One of the things that is missing (and I spoke to Billy about this before) is discussion of the thermal package.

There's one thing I learned working with Ed [Thalmann], and that was you have got to think system. Rebreathers allow you to go shallower for longer—forget the deep bit for a minute—shallower for longer. If you come from a place where the water doesn't get very warm and you jump in with your normal thermal kit, you are going to die a different way: The set's not going to crap out, you're body's going to get cold and you're going to disappear as well. The training agencies have got to bring that into their package. You've got to think in triangles. That's how organization's think. Don't ask me why. There's the Fire Triangle; in that case, you're trying to keep the three sides apart. In diving you're trying to get three things together: One's the BA, the breathing apparatus, the other's a thermal package, and there's what I call the compression/decompression package. Those three have got to be together. And I think if you just take the points that have come up, we're saying, "what medium shall we use to put this together?" Perhaps you guys in Key West can think about updating this package to take in what we've learned here.

**Menduno:** For those of you who aren't familiar with Blueprint For Survival 2.0, let me explain briefly. These guidelines are actually based on the work of Sheck Exley, a cave explorer and friend of many of us here, who's now dead. Sheck wrote a book in the early days of cave diving, called *Blueprint for Survival* that analyzed cave diving accidents and derived a set of safety principles in order to help cave divers survive. Back in the early days of tech diving, Billy Deans and I took on the task of trying to codify a set of community guidelines- safety principals, following Sheck's work. We named it, "Blueprint for Survival 2.0." It contains 20 guidelines to help you survive the dive. Mike's point is well taken. Maybe it should be updated to include rebreather technology. Okay.

## Have him continue

**Bev Morgan:** I appreciate everybody being here and really appreciate all the information. It certainly helps me out in what I'm trying to do—building my gear. In particular, I'd like to thank Michael Menduno, and I think we all owe him a big applause.

Rather than all of us taking our time going home thinking about organization, and god, another meeting to go to, or something with another group, I think we ought to figure out how to get this guy profitable. I want to make him be the guy that puts these things together because he can do it. We've seen him do it, but he's got to be able to make some money out of it to continue.

## Picking a leader

**Jim Brown:** I talked to Bev just seconds before he stepped up, the NARD, Inc. right, the National Association of Rebreather Divers, Incorporated, that's an interesting abbreviation. We've got a big group of expertise here that has outstanding ideas. But you know, I've seen groups of people without leaders not get a whole lot accomplished, so at some point we've got to pick a leader. Right? Somebody who can at least coordinate the effort——play the guitar, so to speak. Obviously this leader doesn't have to lay down the law, but a natural leader can coordinate people in a decentralized manner to accomplish a variety of tasks. Perhaps there's a way to make it a not-for-profit organization and get a leader kicked in, who can take and coordinate this kind of stuff. Mike? Would you make a good leader for this? You got all of us all together?

[Applause]

**Menduno:** I have always viewed my position as more of the "Pied Piper." Thank you. But we still have work to do before we get to all of the thank you's and stuff like that.

**Innis:** Mike, sure understands the concept of not-for-profit.

**Menduno:** Thank god for *aquaCORPS*! I understand it real well.

[Laughter]

## God bless the military

**Grant Graves:** I'd just like to thank the military for being here, because this is the best, most open interaction I've ever had with them. Invite them back, always.

**Menduno:** We've come a long way baby. I remember the first Rebreather Forum only two and a half years ago. The general mindset of the sport diving community towards the military was, "Well, their experience isn't too relevant because the military doesn't care if they lose their divers. How does that apply to recreational diving?" Can you believe it? That was the mindset. It sounds like what Jeff was saying about the cave community in the early days. It's obviously not true. We're really fortunate to have the military here. They're fun guys, you know; Dominate, eliminate and control.

[Laughter]

We're not done yet. We should save all the of niceties for another 25 minutes from now. There are really some important people here, that I would like to hear from, and that's the manufacturers. None of us would be here without the manufacturers. And I'm kind of curious what they are thinking about all of this. They may be sitting out there going. "Jesus, these people are crazy..." Without rebreathers, all of this is just a moot point. I'd like to hear what the manufacturers have to say. Who's first? Peter Readey.

**Peter Readey:** Since, Michael Cochran spilled the beans about me getting my green card, and with the news about OSHA, maybe I should be heading back to the UK now. Because it sure seems like the HSE have got their act truly together. I'm very impressed about that.

In regards to the Forum, it's been extremely useful to us to hear what everyone's had to say. We have a lot to think about. There are certainly some changes that we're

**For me, this was a very important meeting. I got a lot of information and the impression that we are still on the right way. We not only need to go step by step into this market, but we also have to fulfill a lot of requirements, and name all of the problems, and document them so that we can move forward.**

going to be putting into our system, on the basis of what we've learned here today. And I thank all of you for coming here. I know that every one of you has put their hand into their pocket to come here. I for one would like to go forward, and I'd like rebreathers to be out there in the recreational diving sector, and in the technical diving sector sooner rather than later. And I'd like to thank Michael; yet again, he's out there doing his thing.

## Continued information

**Christian Schult:** This is the second Rebreather Forum I have attended, and as I told you at the opening session, I was really confused after the first Rebreather Forum, what is the market, and what do we want to do? For me, this was a very important meeting. I got a lot of information and the impression that we are still on the right way. We not only need to go step by step into this market, but we also have to fulfill a lot of requirements, and name all of the problems, and document them so that we can move forward.

We have to continue to develop guidelines for using rebreathers and we have to continue to communicate with each other—what we have been doing here—communicate with the training agencies and experts. As a manufacturer, we have to continue to support the training agencies and work closely together with them and we have to give updates. I think that's a very important thing—updates on the technology, like this testing, like what's going on with sensors, what's going on with absorbent materials, and all of these things. We have to continue to push for quality in the market. And we have to work to eliminate accidents, and we can't forget the human factors in this.

As far as our corporate outlook, I'm more and more convinced that we are on the right way, but every process must be improved and we have to listen to all of the experts in this scene, and we have to work together. We have already shipped units; they are on the market. We now plan to listen very carefully to our users. Our users will get questionnaires, and we urge the training agencies to do the same. Ask the trainers, ask the users: what is your experience? What has to be improved? We want to continue. It was a great forum-. Thank you.

**Stuart Clough:** Stuart Clough, Undersea Technologies. We're out reiterating what the rest of the guys have said, we've certainly found it very, very interesting. I think it serves to give us some information to re-prioritize the various tasks that we're currently working on and re-sequence developments that are going into the new systems.

**Menduno:** Thank you, Stuart. Derek Clarke, Divex.

## Dominate, eliminate and control

**Derek Clarke:** I think that I've expressed my views several times about the efficacy of bringing rebreathers into the recreational market and our interest. I wouldn't be here if I wasn't interested. We are a professional manufacturer of equipment, and do believe a day will come when we will see rebreathers more generally available somewhere between the technical and the recreational markets. And we aim to be a company involved in that. It's a question of having all of the items in place to make that happen. I've certainly learned a hell of a lot, and I would like to contribute if a form could be found in which to contribute.

I think that there is going to have to be some cohesive body come out of this which can "Dominate," to use Jim's terminology (I'll never forget these), dominate the market. This is a peer group which is very strong. I've never been to an event as effective and as significant as this. Because it's been very free, and open and very candid and it really hasn't groveled around in the mud, which is very, very good. It's been very constructive and no one's really held back and it's not been vindictive yet, maybe it's too young in its life, I don't know. I don't know what form it should take, but it does need some form of cohesion. We've got all of the elements here.

I think it needs to "Eliminate" the bullshit. Michael you're right, and we need to eliminate those that could really bring it down. And then we need to take Control, and ensure that quality products get out on the market. Dominate, eliminate, control. I love those things.

Divex will not be immediately entering into the recreational rebreather market. But we certainly would like to contribute to the proliferation of it ,in whatever form we can as a company, and I certainly wish the venture well.

Thank you.

**Menduno:** John Sherwood

## Some sort of body

**John Sherwood:** I think that we've all heard both questions that needed to be answered and answers that needed to be questioned. And for that, I thank Michael, the sponsors and the organizers for providing us with this Forum. I also agree that it would be a great shame if we all just got up and left with this sense that there's an awful lot of information here, there's an awful lot of things that have gone on, and there's an awful lot yet to be done. I agree there should be some sort of body and we would be ready to support that. Thanks.

**Menduno:** Dick King

## Association & user guidelines

**Dick King:** I waited until last, because I figured everybody would say everything by the time I got up here. You know, coming into this thing, I thought, well, it's really happening. It's finally happening and everybody's willing to accept the fact that rebreathers are coming into the recreational community, and I was willing to be a part of that. I have some reluctance at this point. I'm not saying I won't do it, don't plan to do it, but I do have some reluctance, and naturally, the legal concerns are paramount with me.

I think that we need to get together, as a number of people here have said, and form an organization. At the minimum, I think that there needs to be a rebreather manufacturers association, which I would very much enjoy being a part of, and sharing what we can with each other. I think there needs to be a standards committee that comes out of this meeting that sets some—I won't say regulations, but at least guidelines for us as manufacturers, because it's a little dangerous for the manufacturers to be setting the guidelines. It would be much better if the user community established these because they're ultimately the ones that are going to suffer if in fact the equipment is not up to snuff. I think that this is paramount that we do this. And then if we can get these two groups working in unison to exchange ideas, then maybe we can at least get it started. I do happen to agree, though, if we don't do something, we'll walk away from here and nothing's going to happen. Thank you for allowing me to be a part of this.

**Menduno:** Dan Wible

## The joy of rebreathers

**Dan Wible:** Thank you. I'm Dan Wible. The only thing I'd like to add is that I have an extreme respect for the Navy and their tremendous expertise that they've developed over the last 20 years. I was extremely flattered and falling in love with these guys for even coming here and sharing with us like they have [The guys with crew cuts in the front row we're getting a little nervous here—ed.]. It makes me almost wonder with some glee if they might be interested in actually serving as consultants to us as we try to grow, as babies and become more mature as we promote rebreathers to individuals in this country. It would be fascinating if we could get some coordination from them, and a commitment that they will continue their interaction with us. And other than that, it's just been a great joy.

I find rebreathers such a joy in life that I even sleep and dream about them. They're exciting. My girlfriend dives a fully closed system and I'm one of the few lucky guys that have been able to approach these from a totally recreational viewpoint. I've never been involved with anybody other than just to have fun on them, and as a result I want to manufacture them, and have the funds and the time to start doing that. I'm at a very early stage and I definitely need the Navy's involvement and appreciate everything they've had to offer. Thank you.

**Menduno:** I'd like to thank my co-chair, Tracy Robinette. Tracy has been quietly working behind the scenes for the last three months to make this Forum, and our lagoon-diving session possible. What do you have to say Tracy?

## Representing the pinacle

**Tracy Robinette:** As Michael just said, I'm the co-chair of the Forum. I was also the co-chair for the first Rebreather Forum, that we held in Key West. You may also have seen me at the tek.Conferences.

I'm very pleased that this venue has grown so much from what we had two and a half years ago. At one point in time, we were trying to create an association and everything else has been put forward, and I think that we're definitely on our way. This has been a better vehicle than I ever had anticipated. We are actually further along than what I thought it was possible. And one of the big things that has made this event successful is the military involvement that we have.

**All these things are aimed at ongoing communications, and I guess my bias as a communicator, is that more communications is usually a good thing.**

This group clearly represents the pinnacle of the rebreather world, I have never seen a greater group of people with regard to rebreathers, gathered in one room. The nice thing about it is that they're willing to do something, to put forward standards, and get this technology out into the market place without all of the problems that we have had in the past. I'd like to thank everybody for coming.

## The military is going to benefit

**Gavin Anthony:** I want to actually just try and make a bridge between the manufacturers and the military. One of my sincere statements to the manufacturers is that, "I really hope you that make it, and you come out with a lot of good rebreathers." Because one of the problems that the military has got and will increasingly been facing in this. In the past, the military has developed its own rebreathers. That's not the way—particularly in the UK—that we are going to get equipment in the future. The military is looking at what's on the shelf and then making it fit the military purpose. Now if you, the manufacturers, are successful in the recreational market, then there's going to be a lot of new rebreather technology out there. Let's turn it full circle, the military has a lot to offer, but if you make it, the military is going to benefit. They have a lot to offer, and I think a lot to gain. Thank you.

## Action items

**Menduno:** We need to wrap up. I'd like to address the action item thing. We are going to do proceedings. There will be a communication. You'll each be hearing from me with respect to a finalized program and attendees list, so that everyone will get these. I think that the major action item right now is getting the proceedings out. That's the first step. And I think a big step; just getting the information out.

What are people's feelings regarding setting up some form of an organization, or council? At the last Forum we discussed forming an organization. We nick-named it, "Deja Vu,' but it really never got off the ground.

Several people, Dick King, and others talked about forming an manufacturers association. That's obviously just up to you guys. Boy, I certainly encourage that. But maybe it should be a broader group? We've talked about the idea of a training council—something representing all the training agencies involved in rebreather training. All these things are aimed at ongoing communications, and I guess my bias as a communicator, is that more communications is usually a good thing. Are there more action items other than the two I've mentioned; getting the proceedings out, and the idea of forming a manufacturers association?

**Mike Innis:** Could I suggest that we just start with those two. Will someone in the vendor community raise their hand and say, Yes, I will take responsibility for contacting the other manufacturers. I'll make the contact, I'll pull them together, and will give you an update of what's going on at DEMA. I would suggest that's an order of business that we gotta do. So, Dick [King], what do you think? Will you do it?

**Menduno:** Will you take that action?

**King:** Yeah, I'll take it.

**Innis:** All Right! And Michael, on the standards thing; you may be the logical lightening rod for pulling this stuff together by tapping into all the expertise that we have here.

## Testing standards

**Menduno:** Let me throw this out to you. Guidelines is a good word. We went through this discussion big time in the tech diving community; standards-, guidelines. Someone suggested that the five people that we had on stage this afternoon; Gavin Anthony, John Clarke, Mike Harwood, Hans Ornhagen, and Ed Thalmann, has a whole lot of knowledge and experience in this area, and that they might be willing to pool their collective expertise and come up with a testing standard or guideline for rebreather testing. That would go along way as a big first step. The market needs to have quality equipment that works. This in turn could be circulated back to the manufacturers for comment and review. So that's an approach. If that all seems acceptable to the manufacturers and the people involved we can certainly do that— a general set of performance guidelines. Does that sound reasonable? Manufacturers? Anybody? John?

## More than manufacturer association

**John Clarke:** I think Mike is getting out of this entirely too easily. One reason that I think we need something other than just a manufacturer's association or group, as good as that is, is because people like us who work in the government have to keep a certain distance from the manufacturers. Basically because they come to us to test their equipment; we have to be completely impartial. We turn out a lot of information and it's very impractical for us to turn that information directly over to the manufacturers. We want them to have it, but we can't do it directly.

If we have a group, headed up by Mike, where the people in this room could be involved, it could be a focal point where we could send information. It could be a vehicle where that information could be disseminated, and would be a proper target for us to relay standards information or anything else, simply anecdotes which have relevance to this diving community. So I would strongly like to urge that besides just the manufacturers' association that there be something more spearheaded by this fellow here. Thank you.

**Menduno:** Thank you John. I'm going to get out the pipe and start playing.

[Tape ends]

# Findings & Recommendations

**1. There are many outstanding issues that must be addressed if rebreather technology is to safely and reliably be incorporated into non-professional diving applications.**

The challenge involved should not be dismissed lightly. At the present time, the two largest users of rebreathers in the world—the US and British Navies—combined only have about 240 mixed gas rebreathers in service (excludes pure oxygen sets) from an inventory of approximately 600, and an extensive infrastructure to support them. With nearly a dozen manufacturers offering or planning to offer rebreathers to nonprofessional divers, the industry hopes to produce and support many times the military number on a regular basis.

**2. Rebreathers are far more complex than open circuit scuba equipment due to their design and function.**

A rebreather is a closed life-support system that is designed to extend gas supplies by providing the required amount of oxygen to meet the diver's metabolic needs, while conserving the diluent gas in the system, and removing CO2. Fully closed systems control oxygen levels by means of a series of electronic sensors; activating an injection valve when the partial pressure of oxygen (PO2) is too low, and an alarm when the PO2 too high. Semiclosed systems perform this function mechanically by attempting to match a preset flow of oxygen-rich gas to the diver's consumption and exhausting excess gas into the water. In both cases oxygen levels dynamically vary around a target range.

Rebreathers passively remove excess carbon dioxide by passing the gas through a canister of CO2 absorbent material, the duration of which may vary significantly even under seemingly identical conditions.

**3. Because of their complexity, rebreathers have a number of insidious risks not found in open circuit scuba.**

Major risks include: hypoxia (too little oxygen), hyperoxia (too much oxygen, i.e. CNS oxygen toxicity), and hypercapnia (too much CO2). All of these can lead to unconsciousness, usually with little or no warning. Drowning is likely to occur, especially when using a conventional mouthpiece rather than a full face mask. In addition, there are the secondary risks such as inhaling a "caustic cocktail" — a toxic mixture of CO2 absorbent material and water, and decompression illness due to increased duration or in semiclosed sets, due to unanticipated variations in PN2. Thermal considerations and mechanical and electronic failures pose other risks.

**4. The military have been successful in managing the risks through the use of a large supporting infrastructure, a high degree of discipline and training. Comparable infrastructure, discipline and training have not been needed in sport diving until now, and currently don't exist in the market.**

The military objective is to eliminate human error and exercise a degree of control over rebreather usage through written procedures, testing and certifying units before they are released to the fleet, mandatory pre and post-dive checklists, adherence to the buddy system, reliance on dive supervisors, and tracking problems in the field.

According to military spokesmen, the US Navy has had four incidents in 16,000 hours on the Mark 16 rebreather, one of them a fatality. It was pointed out, however, that this record may not directly apply to the sport divers because they do not have a comparable training and support program.

Some participants questioned the relevance of military protocols to the sport market. In response, it was pointed out that both military and civilian divers breathe air, neither can breathe water, and aside from the possibility of being shot at, little separates the risks of rebreather diving within the two communities.

**5. Manufacturers and training agencies must provide appropriate warnings and documentation to the risks of rebreather diving, with an emphasis on those that differ from open circuit scuba.**

**6. Some attendees stated that the relative simplicity and low cost of constant mass flow semiclosed systems, which have no electronics, may make them more suitable for recreational divers.**

However, not all the experts agreed. They countered that electronically controlled closed circuit systems provide much better oxygen control, alarm systems, and user feedback increasing the potential safety for users.

Either way, it should be noted that diving a semiclosed set is still a lot more complicated than open circuit enriched air diving. With semiclosed systems, enriched air training is only the first step.

**7. In spite of their relative simplicity, mass flow semiclosed systems can be problematic. A major concern is dilution hypoxia. A secondary concern is decompression illness.**

Mass flow systems supply a preset flow of enriched air (nitrox) to the diver based upon an assumed oxygen consumption rate. However, actual oxygen levels in the system depend on the diver's actual workload relative to the preset flow and are independent of depth and manufacturer. If a diver is working harder than anticipated and "out-breathes" the system (i.e. oxygen consumption exceeds the range designed in by the manufacturer), hypoxia can occur very rapidly, particularly at or near the surface or during ascent where there is insufficient depth to maintain a safe PO2, and the diver may drown. Published data suggest that a diver's oxygen consumption can be as high as 3.0 liters per minute in extreme conditions, such as swimming hard against a current or struggling to free oneself from underwater entrapment, particularly in athletic individuals.

Oxygen levels in the breathing loop are extremely sensitive to small changes in mixture flow rates. For example, decreasing mixtures flows from 6.0 to 5.1 liters per minute with a 60% enriched air mix, and without an effective bypass, can reduce oxygen levels in the system from 20% to 3% in a hard working diver. At or near the surface, this could cause hypoxia.

A higher than anticipated oxygen consumption can also affect equivalent air depth (EAD) decompression calculations used when diving these systems. The problem is that because actual inspired oxygen levels can fluctuate, it may be unclear what the decompression schedule should be based on.

**8. Military semiclosed units are designed to handle workloads as high as 3.0 liters per minute oxygen consumption. However, at this time, there are no similar specifications for consumer rebreathers, and some systems may not handle this high of an oxygen requirement.**

Several solutions were offered including designing in adequate flow rates, thorough testing of the rig under extreme conditions, always "flushing" the system before ascent, and incorporating oxygen monitoring systems as soon as possible.

It was also pointed out that these systems should be calibrated by the user or retailer before each dive, because any blockage in the mass flow reducer valve can dramatically reduce flows and therefore oxygen levels.

**9. Compared to open circuit scuba, rebreathers require significant ongoing maintenance and support to function properly. Manufacturers must provide written procedures, pre and post dive checklists, and a schedule for required maintenance.**

Supporting a rebreather in the field can require as much as an hour or more preparation before each dive, an hour or more after the dive, and includes disinfecting the unit between uses and often between users (as in a training situation). There is also regularly scheduled maintenance.

These are probably best accomplished through the use of mandatory pre and post dive checklists, and written maintenance procedures supplied with the product. Having a dive supervisor oversee the checklist process also appears valuable.

**10. Supporting rebreathers on a retail level will likely involve far more work and expense than open circuit scuba equipment.** Proper oxygen cleaning and handling procedures will need to be used.

**11. Consumer rebreather training is in its infancy and is not yet standardized.**

Though many agencies have rudimentary programs in place, there are no common standards. One of the challenges is the lack of hands-on rebreather experience within the community. A second is the lack of sufficient rebreathers to enable trainers to get that experience. Typical training courses range anywhere from about 30 hours on a semiclosed system to 40 or more hours for closed circuit training.

**12. Taking a manufacturer-approved rebreather course is only the first step. Rebreather diving must be learned by experience, and some times may require many more hours than open circuit scuba to attain comparable competence as a result of their complexity.**

Experienced users pointed out that, among the hazards of rebreather diving, two of the most critical are complacency, and allowing confidence to exceed ability. It was strongly recommended that divers gain extensive experience with systems in shallow water until sufficient user competence is developed before making deeper dives. New users were advised to go slowly.

**13. Ideally, rebreather instructors should own, or have on-demand access to the rebreather that they plan to train other divers on.** It is recommended that they have the necessary experience for competence before qualifying as instructors, which may be more than 100 hours with some models and types.

It was recommended that training emphasize manual operation of automated systems in the case of electronically controlled rebreathers as well as proper response to different types of failure modes.

**14. Because many aspects of training are specific to individual models, manufacturers need to work closely with training organizations that are developing instruction courses.** Manufacturers need to include documentation and manuals with their units.

**15. There is no way to know how a rebreather will perform in the field without conducting manned and unmanned testing, which can determine performance under worst-case conditions.**

Testing should look at the system as a whole, scrubber duration, and recommended decompression procedures. As noted above, canister duration times may vary considerably even under what appear to be identical conditions. In addition they will be affected by type of inert gas used (N2 and He duration's are not the same) and the water temperature. The military determines an average duration for each set of environmental conditions usually based on 5 or 6 trials. They then specify an operational limit taking into the statistical variation among the runs, usually one standard deviation below the mean.

The only validated constant PO2 tables to date are the US Navy 0.7 ata constant PO2 in N2 and He tables. The Canadian forces are working on tables for their semiclosed rebreather. Simply reprogramming a dive computer to calculate oxygen levels according to what the rebreather supplies may not work. Using EAD tables may be more appropriate since the air stop times are still used, but a higher PO2 is breathed at each stop.

**16. Manufacturers should ensure that proper testing has been conducted before releasing their product to the market.** The tests document performance over the entire range of conditions for which the rebreather is designed.

The results of this testing should be made available, with the recommdnation that the rebreather be used only under conditions in which it was tested. Documented rebreather testing and performance standards exist and are readily available. Navy Experimental Diving Unit reports can supply a wealth of information and document testing and standards for just about all USN breathing apparatus. [An index of NEDU Reports can be obtained by writing to: Commanding Officer, Navy Experimental Diving Unit, 321 Bullfinch Road, Panama City, FL 32407-7015 ] In the future, it is hoped that an international testing standard will be established for consumer rebreathers.

**17. In many circumstances, the use of full face masks and adherence to the buddy system can improve rebreather diver safety.** It's recommended that organizations and individuals using rebreathers look closely at incorporating these into their products, programs and operations.

Though the use of full face masks is not widely used in open circuit sport diving applications; the body of comments at the Forum emphasized their importance in rebreather diving. No opposing views were offered.

It was also noted that the addition of an onboard CO2 monitor would represent a great improvement in safety. Though several manufacturers are developing such devices, at the present time there are no proven CO2 monitors on the market. The use of dive supervisors is also recommended for rebreather diving, particularly in technical diving operations.

It should be noted that the US Navy has adopted a PO2 of 1.3 ata as its maximum for closed circuit diving. Though a maximum PO2 of 1.4 to 1.6 ata is the community standard in open circuit mix diving, sport divers were advised to consider adopting the lower USN standards for rebreather diving, as a result the dynamic variability of PO2s within a given system, and the nature of constant PO2 diving versus that of open circuit equipment.

**18. There don't appear to be any unusual product liability problems that should keep rebreathers off the market, but, regulatory concerns appear to be a more significant issue.**

During the third quarter of 1996, the Occupational Health & Safety Administration (OSHA), which regulates the US workplace, declined to grant a recreational exemption to instructors engaged in rebreather training. That means that those who use rebreathers as employers/employees fall under commercial diving regulations until the issue can be resolved. The sport industry will have to accumulate a good track record for rebreather use to make its case for an exemption.

In the UK, the Health & Safety Executive office has included non-professional rebreather use as a part of the recreational exemption, and has put the responsibility for safe practices back on the manufacturers and training organizations.

**19. Developing a consumer market for rebreathers will take time.** To be successful, the industry must move forward one step at a time, fulfill requirements, identify and document problems, and communicate with each other.

**20. The forum consensus was that holding another rebreather forum would be desirable in the coming year to share experience and data gained since Forum 2.0.**

# Papers and Articles

# The Development of Health and Safety at Work Legislation in Great Britain with Respect to Diving Operations in the Recreational Diving Sector

by Mike Harwood

## The Health and Safety at Work Framework

Within the jurisdiction of Great Britain the Health and Safety at Work etc. Act 1974 applies to a person who is:

> *an employer who employs persons under a contract of employment; or an employee who works under a contract of employment; or a self employed person who works for gain or reward other than under a contract of employment, whether or not they employ others.*

The Health and Safety at Work etc. Act 1974 sets out the general duties which employers and self employed have towards employees and members of the public, and employees and self employed have to themselves and each other.

What the law requires is what good management and common sense would lead employers and the self employed to do anyway: that is, to identify the hazards, look at what the risks are and take sensible measures to control them.

Where it has been identified that a hazard is so great, such as diving, it is not appropriate to leave management to decide how to control the risk and Regulations are made under the Health and Safety at Work etc. Act 1974. Regulations are law.

Wherever possible Regulations are goal-setting, setting out what must be achieved, but not how it must be done, leaving the employer or self-employed to develop adequate measures to control the risk. However where the risk is high the Regulations will be prescriptive and set out specific action that must be taken.

**However where the risk is high the Regulations will be prescriptive and set out specific action that must be taken.**

For the purposes of providing practical guidance with respect to any provisions of the Health and Safety at Work etc. Act 1974 or Regulations, Approved Codes of Practice are issued. Approved Codes of Practice have a special legal status. An employer or a self employed person does not need to comply with an Approved Code of Practice but if they do not they must show that their alternative was as safe as the Approved Code of Practice. This means that if a person or company is prosecuted for a breach of health and safety law, and it is proved that they have not followed the relevant provisions of the Approved Code of Practice, a court can find them at fault unless they can show that they complied with the law in some other way.

Guidance is also published on a range of health and safety subjects, following this Guidance is not compulsory and employers and the self employed may take other action.

The Health and Safety at Work etc. Act 1974 establishes two bodies corporate called the Health and Safety Commission and the Health and Safety

Executive.

The ten members of the Health and Safety Commission are appointed by Government and consist of representatives of employers, employees (unions), local authorities (local government), consumer affairs, and professional bodies. They are responsible for developing polices in the health and safety field, and for making proposals for new health and safety regulations to the appropriate Government Minister.

The Health and Safety Executive consists of three people appointed by the Health and Safety Commission and are tasked with executing the day to day work of the Health and Safety Commission.

The mission of the Health and Safety Executive is:

*"To ensure that risks to people's health and safety from work activities are properly controlled."*

To execute its duties the Health and Safety Executive employs some 4000 people located in offices across Great Britain.

Enforcement of health and safety law is spilt. In the industrial sector the Health and Safety Executive inspect and enforce, and in the non industrial sector Local Authorities, under the guidance of the Health and Safety Commission, inspect and enforce. The Local Authorities are not a single body but a large number of locally elected councils.

The Health and Safety at Work etc. Act 1974 is extended offshore to cover British oil and gas related installations and out to the territorial limit (normally 12 nautical miles) for specified work related activities including diving operations.

**In 1981. . . it was recognised that four sectors of the diving industry could not comply with the Regulations and as a result four General certificates of exemption were issued under the Regulations.**

## Current Diving Legislation

The Regulations governing diving in force today are:

**The Diving Operations at Work Regulations 1981**, as amended by **The Diving Operations at Work (Amendment) Regulations 1990**; and **The Diving Operations at Work (Amendment) Regulations 1992.**

The 1990 amendment is mainly concerned with changes relating to provisions in connection with first-aid. The 1992 amendment added requirements that all diving contractors are registered and that diving operations in relation to offshore installations and pipelines be notified to the Health and Safety Executive.

A Guidance booklet was issued with the Regulations which has been updated once.

A large number of Information leaflets have been issued in various guises the majority being Diving Safety Memorandum aimed at the offshore diving sector.

The Diving Operations at Work Regulations 1981 allow for exemptions to be made under specific conditions. The term exemption with respect to health and safety legislation is often misunderstood. It does not exempt the person or class of persons completely from the Regulations, it only exempts them from specific parts of the Regulations and replaces them with specified alternative "conditions" that will at least maintain the same level of health and safety.

In 1981, while the Health and Safety Executive was bringing in the Diving Operations at Work Regulations 1981, it was recognised that four sectors of the diving industry could not comply with the Regulations and as a result four General certificates of exemption were issued under the Regulations. They were primarily for the purposes of: archaeology; scientific research; and journalism; and solely in connection with the training of amateur divers. These four sectors tend to normally use scuba and recreational diving techniques. The scientific research exemption has been revised and reissued twice, the last time in 1988. As these certificates of exemption were issued before the two amendment Regulations came into force, no one is exempt from the content of the amendments.

The Regulations require specific certificates to be held by divers' before they can dive at work. This included persons at work conducting diving training in accordance with the conditions of the exemption even if they held similar certificates from a recreational diving agency. These are:

- an annual certificate of medical fitness to dive which must be conducted by "an approved doctor", that is a doctor approved by an Employment Medical Advisor appointed under the Health and Safety at Work etc. Act 1974;
- a certificate of diving first-aid issued by a person or body approved by the Health and Safety Executive (These are only valid for three years.); and
- a certificate of diver training issued by the Health and Safety Executive or a certificate allowed by the transitional provisions of the Regulations.

The certificate of diver training issued to recreational diving instructors who were at work was called, "Part IV Restricted - Training of amateurs in the techniques of sports diving only". This certificate was issued on production to the Health and Safety Executive of an instructor certification card from those recreational diving agencies recognised by the Health and Safety Executive.

## Original Certificate of Exemption

Certificate of Exemption No. DOW/4/81 (General) - **Extracts with comments in italics.**

The certificate exempt diving operations:

. . . which are solely in connection with the training of amateur divers, and in which no person at work dives at a greater depth than 50 metres or his routine decompression time exceeds 20 minutes, from a number of Regulations subject to a number of conditions.

*Only persons with instructor qualifications could work under this exemption; anyone of a lower qualification could not be at work and take part in diving operations in accordance with the conditions of this exemption.*

The extracts of conditions that have caused the greatest comment are the plant and equipment he will use:.

. . . include a means of supplying a breathing mixture (including a reserve supply for immediate use in the event of an emergency or for therapeutic recompression or decompression) suitable in content and temperature and of adequate pressure, and at an adequate rate, to sustain prolonged vigorous physical exertion at the ambient pressure for the duration of the diving operation; . . .

*Using a pressure gauge as a warning device that the breathing mixture had reduced to the reserve capacity was not allowed by the exemption thus requiring a reserve system such as spare air to be carried by the instructor. This was contrary to recreational training and operational standards!*

. . . each gas cylinder he will use is legibly marked "breathing air". . .

*Could be seen to clash with the previous condition that referred to "breathing mixture". Also meant that the instructor could only use air when the students, who are not at work, could be on mixed gases i.e. nitrox and trimix, an undesirable situation!*

. . . that every person diving at work ensures so far as is reasonably practicable that: the diving operation is carried on in accordance with a code of safe diving practice; . . .

*The recreational diving organisations' rules and regulations.*

. . . when he is diving other than in a swimming pool or training tank there is a person on the surface in immediate control of the operation; . . .

. . . there is another person available to render assistance in an emergency, that other person being either on the surface in immediate readiness to dive or in the water in a position to render assistance. . .

*i.e. In open water there are three people required to fill the duties of: instructor; stand-by diver; and person in control. In a swimming pool two people are required the instructor and the stand-by diver. The person in control does not need to be a diver but of sufficient maturity to be capable of activating the planned emergency procedures.*

. . . that every person diving at work enters the following particulars of every operation in his personal log book and in an operations record book: specific particulars are listed.. . .

*Some recreational diving agencies do not have a log book or operations record book that meets with the requirement.*

## Review of Current Diving Regulations

During a review of the General exemptions to either revise, replace or incorporate them as an amendment to the Diving Operations at Work Regulations 1981, it became obvious to the reviewing team that a fundamental review of the Regulations and the 1990 and 1992 amendments was also required. It was apparent that they were not totally effective, further minor amendments were not appropriate and there was a need to replace the whole regime. Some of the points noted were:

- too biased towards the offshore sector;
- prescriptive in some areas and vague in others;
- inflexible and not able to cope easily with developing technologies and procedures;
- although they achieved their original aim in reducing fatalities and improving health and safety in the offshore diving industry they had not had a similar level of success with the onshore sector;
- the training standards imposed skill requirements that were not needed by some sectors of the diving industry but left out skills they did need. The standards needed updating based on vocational qualifications which means concentrating on the diving skills only and not on other technical skills;
- the additional first-aid and medical fitness to dive standards imposed on the instructors of amateur divers, had been subject to criticism;
- the recreational diving sector was expanding rapidly and the use of the term "amateurs" was totally inappropriate and misleading;
- they were generally dated; and
- the industry called "diving" conducted diving operations using a diversity of diving techniques that could not be treated as a single entity.

## Proposed New Diving at Work Regulations [1997]

These proposed Regulations are goal-setting and set out the legal framework but are less specific and prescriptive than the existing Regulations.

To overcome the problem of producing one set of Regulations for an industry with clearly identifiable differences between the various sectors of divers at work, it has been proposed to have five Approved Codes of Practice. These are:

| Approved Codes of Practice | Who this covers |
|---|---|
| Offshore | All saturation diving and oil and gas related diving |
| Inshore | Inshore diving from civil engineering to fish farming |
| Scientific & Archaeological | Scientists and archaeologists |
| Recreational | Instruction and guiding of recreation al divers |
| Media ers etc. | Underwater journalists and perform- |

New diving competencies have been developed, reducing from the current four main parts to three and abolishing the five restricted levels. In the case of diving operations for recreational diving activities the recreational diving agency certification card will be accepted at the appropriate level.

Further proposals have been made to revert diver first-aid requirements to standards that are accepted by the rest of industry and place the onus on the employer or self employed person to ensure appropriate levels of first-aid are available at the dive site. Appropriate recreational qualifications will be approved under the Recreational Approved Code of Practice.

A review of the medical fitness to dive requirements has been completed. It is proposed that a diver medical examination developed by the British Sub-Aqua Club in consultation with the British Sports Council is used by instructors and guides diving at work under the Recreational Approved Code of Practice.

In drafting the proposed Recreational Approved Code of Practice the Health and Safety Executive worked in close liaison with representatives of the various recreational diving agencies recognised by the Health and Safety Executive. This should ensure that the content does represent the operational and technical requirements of this particular sector.

In summary, for instructors and guides diving at work conducting recreational diving operations it is the intention to use their organisation's standards, certificates of competence, and procedures, without additional legislative burdens. This includes the use of nitrox, trimix and rebreathers.

There are still some issues to be finally resolved and until the results of the second round of consultation are known it is not possible to predict the final outcome.

The planned programme of work to introduce the proposed new Regulations [at the time of this writing] is:

Second consultation period ends:
31 October 1996
Final proposals to Health and Safety Commission:
Early 1997
New legislative package introduced:
Autumn 1997

## The Recently Issued Revised Exemption Certificate

During the process of redrafting Regulations it is normal to incorporate the substance of the General and individual exemptions that are in force at the time. The aim being to draft Regulations that should not require exemptions to be made when the Regulations come into force or for the foreseeable future. It is also the practice to avoid issuing or revising General exemptions during the drafting and consultation period of new or revised Regulations.

This was the intention with the proposed new Diving Regulations. However over the last 12 months it was becoming obvious that the recreational diving market was demanding diving equipment and techniques that would require a level of instruction that the exemption did not permit.

Research to establish that the expanding market was a reality and had arrived in Great Britain, and was not just a prediction for the future, confirmed that there was an immediate need to revise the recreational exemption pending the introduction of the new legislative package. The aim was to include as many of the proposed changes from the new Regulation package without pre-empting the outcome of specific areas put to the public for consultation.

The outcome of this activity was the issuing of Certificate of Exemption No. DOW/1/96 dated 24 June 1996. This certificate exempts diving operations which are carried out:

. . . solely in connection with the instruction or guidance of recreational divers; or divers who are at work and are being trained to instruct or guide recreational divers; so that no person at work either dives to a greater depth than 50 metres or dives in such a way that routine decompression time exceeds 20 minutes; and in accordance with operating instructions and codes of safe diving issued by a recreational diving agency and accepted in writing by the Health and Safety Executive.

from a number of Regulations subject to a number of conditions.

A summary of the conditions is:

- Recreational instructors no longer have to hold an Health and Safety Executive Part IV Restricted qualification. Instead they must hold a relevant qualification from their recreational diving agency at the required level for which they are teaching.
- Dive guides (i.e. divers paid to lead a group of recreational divers) are now covered by the exemption. They must be trained to an appropriate level and hold the relevant qualification for the recreational diving agency they represent.
- Nitrox, trimix and rebreathers can be used under the exemption, providing the instructor holds an appropriate qualification from the recreational diving agency they represent. Rebreathers require additional training in their use to a standard stated by the manufacturers.
- The staffing levels remain as in the previous exemption.
- The Health and Safety Executive accepts that diving first-aid qualifications from the appropriate recreational diving agencies will be satisfactory to comply with the Regulations.
- Log books should conform to the relevant agency advice and the conditions set out in the exemption.

Diving deeper than 50 metres and dives requiring more than 20 minutes decompression are prohibited by the General exemption. However arrangements have been put in place to allow individuals who have met a number of additional requirements to be issued with an individual exemption. This will allow them to dive to 75 metres with a maximum a bottom time of 20 minutes provided that the decompression procedures have been agreed between the Health and Safety Executive and the appropriate recreational diving agency.

This was deemed necessary because 50 metres and not more than 20 minutes decompression are established limits in the current Diving Regulations and in the early days of establishing recreational diver training in Great Britain with deeper and longer decompression, the Health and Safety Executive needed to be assured that adequate safety procedures are in place.

The need to hold an annual Health and Safety Executive Certificate of Medical Fitness to dive remains, as does the need to register as a Diving Contractor (if required by the amendment to the Regulations) because although the Health and Safety Executive proposes to change these requirements they are issues raised for public comment in the proposed new Regulations consultative document.

The previous exemption is revoked.

## In Conclusion

It must be made clear that the Health and Safety Executive does not see the above changes to the Diving Regulations that effect recreational diving operations at work as being either a relaxation or lowering of health and safety standards. In fact the reverse is true. It emphasises that all parties concerned in this activity have a duty of care to all those involved, and places the responsibility for controlling the risk with those in a position to do so, in particular the recreational diving agencies.

**Diving deeper than 50 metres and dives requiring more than 20 minutes decompression are prohibited by the General exemption. However arrangements have been put in place to allow individuals who have met a number of additional requirements to be issued with an individual exemption.**

*This article was prepared by Mike Harwood, who is one of Her Majesty's Inspectors of Health and Safety and a diving specialist, with assistance from colleagues in the Health and Safety Executive's Diving Policy Branch and Diving - National Responsibility Team based in London, UK.* 20 September 1996

# Lab Testing Today's Rebreathers

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*The graphs and tables with comments in this manuscript were used in a presentation about basics, risks and test procedures for rebreathers at the Rebreather Forum 2.0, Redondo Beach, CA, USA, September 1996.*

When evaluating breathing equipment, the work of breathing (WOB) is one of the important parameters. In addition, the level and stability of the inhaled oxygen partial pressure has to be evaluated together with the efficiency and duration of the carbon dioxide scrubbing system.

Today the scrubbing capacity of a rebreather is normally tested using a CO2-injection technique. The oxygen supply system is evaluated both theoretically and during human test dives. Theoretical models describing the behaviour of rebreathers are available. In some of the simpler designs it is possible to solve the equations explicitly, but in most designs it is only possible to estimate the steady state gas fractions under ideal conditions.

To address the shortcomings of the present testing methods, a respiratory simulator incorporating both the ventilatory and the metabolic components of the human respiration has been developed. The respiratory simulator uses catalytic combustion of propylene, resulting in an oxygen consumption directly proportional to the flow of fuel added.

We suggest that an evaluation procedure for rebreathers shall include:

• Measurements of WOB and static load at different diving attitudes.

• Measurements of CO2 and O2 fractions and partial pressure and also their rate of change during compression and decompression.

• Determination of the risk for caustic "cocktails" and other malfunctions.

• A number of verifying dives with human subjects after the unmanned testing.

Advantages with Rebreathers

- Gas savings
- Long action duration
- Silent diving
- Stable buoyancy

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Rebeathers are not a new invention. The advantages with closed breathing circuits were realized early during the development of the self contained underwater breathing apparatus, scuba. Rebreathers, mainly oxygen rebreathers, have been and are still used by military divers because they release no bubbles. Cave divers have also used oxygen rebreathers but the reason was small dimensions, low weight, and long action duration. In recent years other groups of divers have become interested in using rebreathers for example, underwater photographers to take advantage of extended gas supplies and absence of bubbles and recreational divers for extended exposures using nitrox.

**Disadvantages with Rebreathers**

- More complicated than open circuit equipment
- Difficult to find supply gas and absorber material
- More expensive to buy and to dive
- "New" risk scenario, requires special education

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The rebreather has been developed for divers who have good training and extensive surface organization and for situations when economy is not a limiting factor. When recreational divers start using rebreathers they will not always have the same backup.

**Major Risk Factors w/Rebreathers**

| Problem | Possible cause |
|---|---|
| Hypoxia | Gas supply not opened or empty<br>Wrong supply gas or setting of supply flow<br>Break down of sensors, control circuit or valves<br>Inappropriate purge procedures<br>Too high oxygen consumption |
| Hyperoxia | Wrong supply gas or too deep dive<br>Failure of sensors, control circuit or valves |
| Hypercapnia | Scrubber not filled or material worn out<br>Inappropriate scrubber performance at low temperature<br>Scrubber flooded |
| Excessive work of breathing | Wrong type of scrubber material (granule size)<br>Lack of maintenance<br>Scrubber flooded<br>Restriction of counterlung movement<br>Bending of hoses |
| Water entry and Caustic cocktail | Leaks because of lack of maintenance or error in the assembly (e.g. missing gaskets)<br>Inefficient water trap (design or maintenance)<br>Inappropriate use of mouth piece valve<br>Mechanical damage on hoses and casing |
| Loss of breathing gas | Rupture of hose or bag. Technical failure |

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The listed risk factors are some of the more obvious hazards to divers using an underwater breathing apparatus of a rebreather type. When open circuit scuba is used, these risk factors are not an issue because of its less complicated design.

**Factors that affect human physiology**

- Gas composition
  - Oxygen
  - Carbon dioxide
  - Inert gas
  - Humidity
  - Temperature
- Dynamic breathing resistance
- Static load

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Human physiology requires an environment within certain limits for an optimal function. The parameters listed are of relevance for the lungs and the gas exchange.

**Maximum allowable $PO_2$**

| | $PO_2$ [kPa] |
|---|---|
| Swedish Navy, nitrox | 190 |
| US Navy, bounce dive heliox | 180 |
| CMAS, mixed gas diving | 160 |
| UK commercial diving regulations | 160 |
| Norwegian commercial diving regulations | 160 |
| PADI, mixed gas diving | 140 |
| Swedish civilian diving regulations | 140 |

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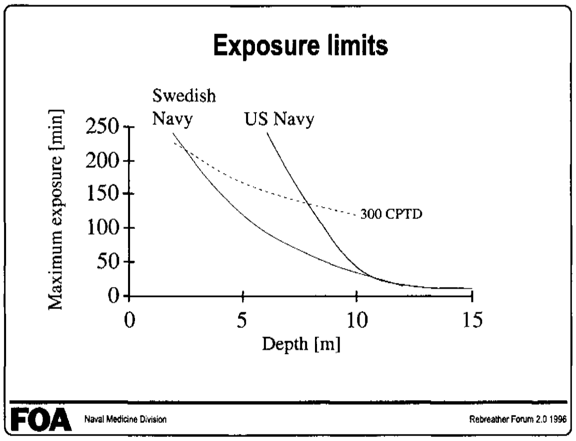
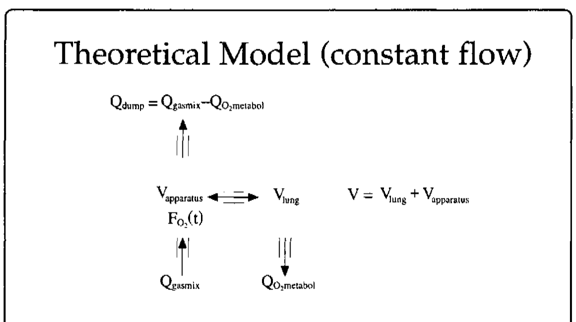
Our metabolism uses oxygen to convert the food we eat into energy for muscles, brain and many other functions. Because of hemoglobin, the transport of oxygen in the body is effective and sufficient amounts of oxygen can be delivered also when we live at reduced oxygen partial pressures as we do at high altitude. Humans can function well down to inspiratory oxygen partial pressures of 15 kPa (0.15 atm). However, for diving the lower limit is usually set to 20 kPa (0.20 atm) which is the PO2 in air at sea level. The upper limit that is recommended depends on two factors. These are the central nervous system sensitivity and the lung sensitivity. In general, a working diver in water is more prone to develop oxygen toxicity than a resting person in a chamber, and hence the limits are lower for working divers in water than during decompression or medical treatment in chambers. The list gives values for max PO2 in mixed gas used by some different authorities [Note that it is reccomended that technical divers maintain a PO2 of less than 1.45 atm during the working phase of the dive, boosting the PO2 to a maximum of 1.6 atm during decompression where the diver is presumably at rest—ed.].




There is a time component in the sensitivity to oxygen. The graph shows the allowed exposure at different depth when diving with oxygen rebreathers in the US and Swedish Navies. The dotted line shows the maximum exposure 300 CPTD (calculated according to Wright 1972) (Örnhagen, Hamilton, 1989). This is a suggested max dose for divers using nitrox daily. Please note that when diving on pure



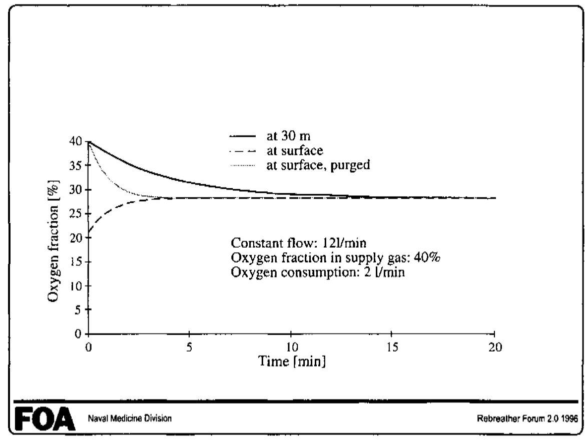

$$F_{O_2}(t) = \frac{Q_{gasmix} \cdot F_{O_2 gasmix} - Q_{O_2 metabol}}{Q_{gasmix} - Q_{O_2 metabol}} + \left( F_{O_2 start} - \frac{Q_{gasmix} \cdot F_{O_2 gasmix} - Q_{O_2 metabol}}{Q_{gasmix} - Q_{O_2 metabol}} \right) \cdot e^{-\frac{Q_{gasmix} - Q_{O_2 metabol}}{V} \cdot t}$$

oxygen the PO2 exceeds 150 kPa (1.5 atm) at 5 m.

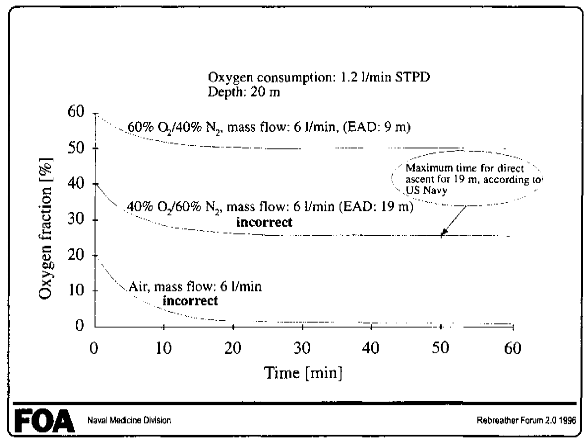
The gas composition in a constant flow rebreather can be described by a theoretical model. In this example the first part of the equation is the steady state component and the second part describes the dynamic component.

Vapparatus = total volume of apparatus
Vlung = the lung volume of the diver
F02gas mix = fraction of oxygen in supply gas
Qgasmix= flow of supply gas
QO2metabol = oxygen consumption
FO2(t) = oxygenfraction in the apparatus at time t

Using the previously described model for a diver consuming 2 lpm oxygen from an apparatus fed with 12 lpm of a gas containing 40% oxygen, results in the curves shown. The difference between the solid and hatched grey lines is caused by different starting procedures. If the apparatus is not purged, the equilibrium oxygen fraction is reached from the air oxygen



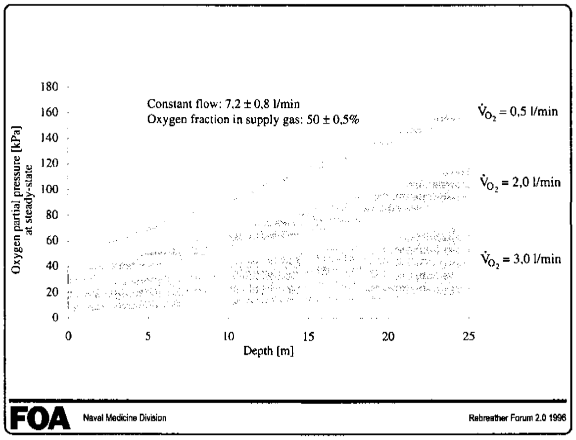

fraction of 20.9 %. Because of the large amount of oxygen in the compressed supply gas at 30 m in a purged apparatus it takes longer time to reach the



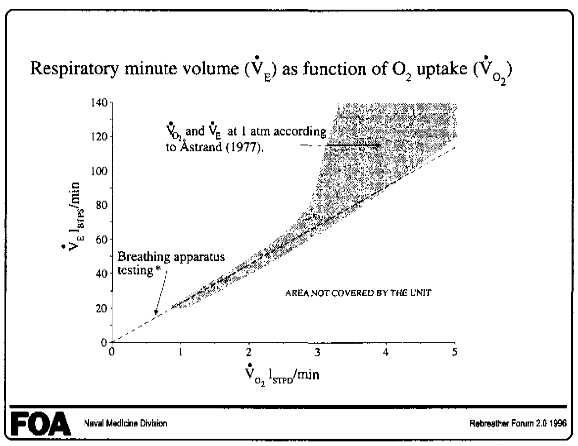

steady state.

In the graph. the curves show what happens in an apparatus designed for a supply gas of 60% oxygen at a flow of 6 lpm if the diver consumes 2 lpm of oxygen (top curve, solid line). Two types of mistakes must be taken into account. The first being a misinterpretation of what 60/40 means and supplying the unit with 40/60 (that is 40 % oxygen instead of 60). This will not cause any immediate risk for life during the dive but the nitrogen fraction and hence the nitrogen loading will be much higher, which may cause decompression illness if equal air depth decompression is used. The second mistake that can be made is to connect an air bottle without changing the flow of supply gas. This will result in an oxygen fraction below 5% which will jeopardize the life of the diver when coming close to the surface. To minimize the possibility for mistakes and increase the safety there should be some kind of matching between gas composition and gas flow so a bottle with low oxygen fraction can not be connected to the UBA without a change of the constant flow orifice.

Using the parameters from a commercially available rebreather in the equation above, the influence

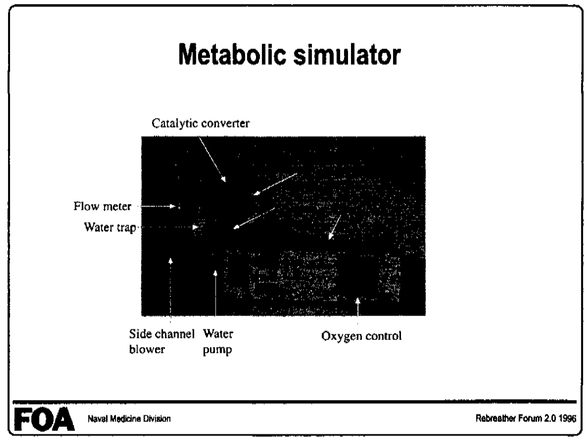



of the divers oxygen consumption on the oxygen partial pressure at different depths can be seen. The width of the line indicate the span from the accepted plus to minus tolerance for the flow and oxygen fraction of the supply gas. Hard work close to the surface can create hypoxia under soem circumstances. At 20 m the nitrogen partial pressure is 50 kPa higher during hard work, 2 lpm O2 than during rest, 0.5 lpm O2. This corresponds to almost 6 m deeper air equivalent depth. During hard work the vascular system also has a higher inert gas transporting capacity than during rest. This may result in a different decompression




need than calculated and hence a risk for decompression illness.

Some rebreathers are designed to deliver oxygen in relation to the metabolic need. The human ventilation is regulated by the production of CO2. Assuming a stable respiratory quotient (relation between consumed oxygen and produced carbon dioxide) the CO2 production can be recalculated into a ventilation per liter oxygen consumed. Åstrand (1977) measured this relation and published material on which the presented graph is based. Most of the data points from different measurements of ventilation in relation to oxygen uptake at normal and elevated pressure fall into the gray area. The oxygen fraction in these rebreathers can also be calculated, but because of the more sophisticated design, there is an increased need for testing. To be able to standardize tests of the oxygen delivery systems, a metabolic simulator has been developed. Any combination of ventilation and oxy-




gen extraction in the upper part of the diagram can be used.

A photo of the metabolic simulator. In the front is shown the control unit (19" wide) which is placed outside the chamber.

$$C_3H_6 + \frac{9}{2}O_2 \qquad 3CO_2 + 3H_2O$$

RQ=0,67

$\dot{V}_{O_2}$ = 0,3 l/min
$\dot{V}_E$ = 7 l/min
$\Longrightarrow$
released power: 90 W
50 % relative humidity (dry inhalation gas)
extra $CO_2$ for RQ=0,85: 0,06 l/min

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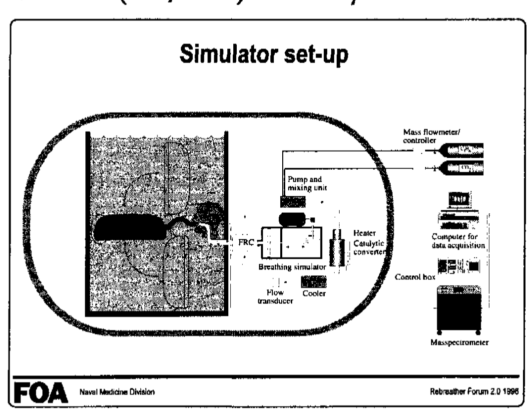
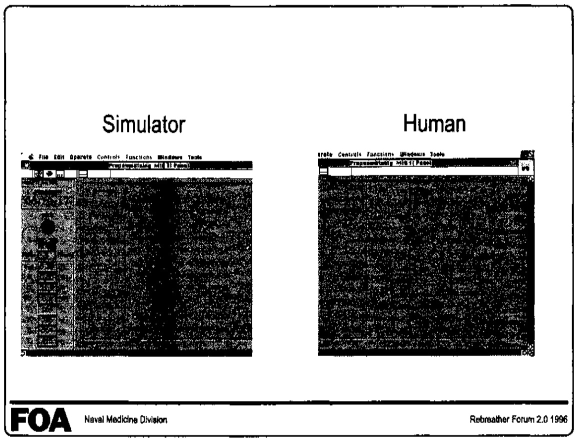
The fuel used for simulating the metabolism is propylene, which according to the presented reaction formula, gives a respiratory quotient of 0.67. By adding more CO2 the quotient can be increased to values above 1. When burning 0.3 l oxygen the reaction releases 90 W and enough water to increase the ventilated air (7 l / min) from dry to 50 % RH at 37



°C. In this situation 0.06 lpm CO2 has to be added to reach a physiological RQ of 0.85.

A schematic drawing of the unit during a test of a rebreather in a water tank in a pressure chamber. Please note that the rebreather should be moved to




different attitudes to also include hydrostatic imbalance in the UBA during the test.

Screen dumps from the data logging system showing the variations in oxygen (top), CO2 (middle) and tidal volume (lower) from the simulator and a human. Please note the similarity between the simu-

### Example of test procedure

| Work intensity | $\dot{V}O_2$ [l/min] | RMV [l/min] | |
|---|---|---|---|
| rest | 0,67 | 15 | |
| work | 1,00 | 22,5 | |
| hard work | 1,78 | 40,5 | |
| rest | 0,67 | 15 | Compression |
| rest | 0,67 | 15 | |
| work | 1,00 | 22,5 | |
| hard work | 1,78 | 40 | |
| extremely hard work | 2,78 | 62,5 | |
| rest | 0,67 | 15 | Decompression |
| extremely hard work | 2,78 | 62,5 | |
| rest | 0,67 | 15 | |

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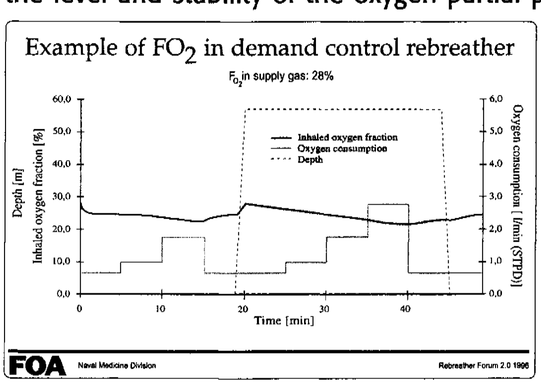
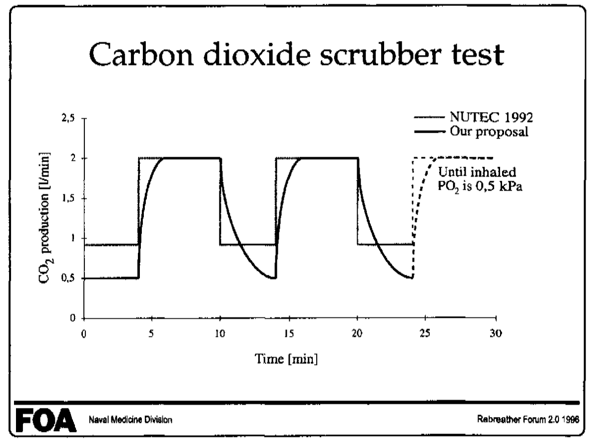
lator depicted to the left and the human recording to the right.

Based on the NPD accepted test procedure for scuba, a test procedure for a rebreather could look like the one suggested. Using the metabolic simulator, the level and stability of the oxygen partial pres-




sure in the breathing circuit during different phases of the dive can be tested.

When the Interspiro DCSC was tested according to the suggested test protocol oxygen fractions according to the graph were found (the extremely hard work at surface,right after the decompression, suggested in the protocol above, was not performed in this test). As expected the oxygen fraction reaches a maximum right after compression because of the addition of supply gas and a minimum during hard work. However, please note the small variation of FO2 between rest and extremely hard work due to




the fact that supply gas addition is based on a demand function.

The duration of the scrubber has to be tested using different "working levels". The NPD accepted procedure is to vary between 0.9 and 2 .0 lpm CO2 addition until the outflow gas contains 0.5 % CO2.

### Test procedures

**Evaluate Mechanical properties**
- Material Durability
- Corrosion
- Oxygen compatibility

**Man-Machine factors**
- Weight
- Location of handles and buttons
- Fitness to the body
- Don and ditch
- Maintainability
- Reliability
- Comfort

**Manual and instructions**
- Readability
- Language
- Illustrations

**Machine test**
- Canister duration
- Work of breathing
- Inspiratory $CO_2$ levels
- Oxygen delivery system
- Hydrostatic responses (compression-decompression)

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We suggest that a more "human like" protocol is followed.

It is important to point out that the use of a respiratory simulator is only one of several different steps when approving a breathing apparatus. The list to the left may give some hints to the complexity of the procedure and can maybe serve as a base for the discussions on how we best reveal the weak spots of rebreathers so diving using them can be safe and pleasant.

## Acknowledgement

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# A Physiological Primer on Rebreather Technology

by R.W. "Bill" Hamilton

## What is a Rebreather?

The word "rebreather" is both simple and descriptive. A rebreather is a breathing system that enables the user to retain and reuse some or all of her expired gas.

To be suitable for reuse, the expired gas has to be processed to some extent–a function performed by the portable processing unit that comprises part of the rebreather. In contrast, a device that saves and reprocesses the expired gas remotely from the diver is generally called a "reclaim" system. These are designed for commercial bell operations and are not of interest here.

Humans operate optimally at an oxygen partial pressure (PO2) of about 0.2 bars (or atmospheres) with some "inert" background gas making up the balance, and without too much CO2. The rebreather reuses expired gas while maintaining these limits.

**Even though oxygen is the most vital gas physiologically speaking, the inert gas is also important in this discussion because oxygen must be diluted with some other gas when at an absolute pressure much beyond about 1. 5 bars . . .**

Even though oxygen is the most vital gas physiologically speaking, the inert gas is also important in this discussion because oxygen must be diluted with some other gas when at an absolute pressure much beyond about 1. 5 bars (in terms of depth, beyond about 20 fsw or 6 msw). Of course, the inert gas is also important to decompression, since it is the source of decompression problems, and technical diving includes a lot of tricks to try to reduce it.

The inert gas component is crucial in rebreathers, because its' conservation is the main purpose of the unit. In addition to conserving inert gas, the rebreather has several other tasks. The first is to provide an appropriate oxygen level. In addition it has to remove carbon dioxide (CO2). Finally, it must provide a space for the diver to breathe in and out of.

## Carbon Dioxide Removal

Carbon dioxide is a normal product of body metabolism. It is usually given off at a level of about 0.8 times the amount of oxygen consumed. For practical purposes, a rebreather has to remove about one liter of CO2 for each liter of oxygen consumed in the body. This is not the amount of oxygen breathed, but the amount consumed.

Carbon dioxide is relatively easy to remove, and most rebreathers do this well during low or moderate work levels by passing the expired gas through a canister filled with chemical absorbent such as soda sorb. However, when the canister gets cold, the absorbent becomes far less effective–enough so as to create a serious problem under certain conditions. This on-going problem has been dealt with by redesign of the chemistry and physical structure of the absorbent, or by warming the canister–itself a difficult task.

Most standards call for CO2 to be kept below about 0.5 kPa (they usually say "below 0.5% sea level equivalent," which is the same as a partial pressure of

0.5 kPa).1 Lower $CO_2$ levels than this are no problem, and higher levels to about 3 kPa may be distracting, but are tolerable, although they can lead to serious problems if the diver exercises and the level increases. Excess $CO_2$ causes an increase in the urge to breathe, and above levels of 15 kPa or so can cause severe narcosis, unconsciousness, and convulsions.

## Oxygen Control

The task of controlling oxygen is much more complex than regulating $CO_2$ levels. This gas has to be kept between strict upper and lower limits for physiological safety, but there is a strong incentive to run the oxygen level as high as possible to improve decompression.

While the oxygen level can be as low as the familiar 0.21 bars $PO_2$ (21% at sea level), there are advantages to having it higher. First, should the level fall below about 0.10 to 0.12 bars, the diver may suffer symptoms of hypoxia (oxygen starvation). Below this, it can cause unconsciousness, and if the oxygen level gets too low, it can be fatal. Maintaining a $PO_2$ higher than 0.21 bars makes hypoxia less likely.

In the other direction, it is necessary to keep the oxygen below the level that could cause oxygen toxicity. The degree of any oxygen toxicity is a function of both oxygen level and duration of exposure. The main toxicity problem is a neurological one: the risk of a convulsion. This type of nervous system (CNS) toxicity is a relatively short-term effect.

Another manifestation of oxygen toxicity is a general effect on much of the rest of the body besides the central nervous system—particularly the lungs – resulting from longer exposures at somewhat lower levels of $PO_2$ than cause convulsions.

For optimal decompression viewpoint a technique that has been found to be effective is to maintain a $PO_2$ of near to but no greater than 1.4 bars. This is safely below the threshold for CNS toxicity, and this level can be tolerated for the duration of all practical rebreather runs2. It gives near-optimal decompression because the oxygen is about as high as can be tolerated for the entire run, but there is no concern about CNS toxicity as long as the rebreather works properly. [Note that the USN currently specifies a "set point"—the target $PO_2$ level— at 0.7 bar, though they are considering raising this to 1.2-1.3 bar— see Oxygen Tolerance Management by Richard Vann—ed.]

## The Counterlung

One other function of a rebreather is that it has to provide a "counterlung"—a kind breathing bag for the diver to breathe in and out of. This cannot be a rigid space, and it has to be as large as the largest expected breath. In addition to this counterlung, the rebreather hardware must include absorbent canisters, a means of regulating gas flow, a housing pack of some sort, gas storage, and a mouthpiece or mask.

Regulation of the rebreather's counterlung function is affected by changes in depth, and this can be the source of some problems. As depth changes, the rebreather unit must adjust to both a change in the gas volume and a change in the oxygen fraction in order to maintain counterlung volume and a constant $PO_2$. Thus, ascents cause a release of bubbles (since gas cannot be put back into the high pressure containers) and descents require addition of gas to maintain system volume. As a result, too many depth changes can deplete the gas supply even though the diver does not actually use gas. Another problem is the placement of the breathing bag relative to the lungs. If it is above the lungs, it is harder to breathe; and if below, the gas is under slight positive pressure. This, of course, may change when the diver shifts position.

## Types of Rebreathers

In general there are two main categories of diver-carried rebreathers: fully closed and the semiclosed. Fully closed rebreathers have oxygen controllers that sample the gas in the breathing circuit and add oxygen or inert gas as needed by operating a solenoid valve or its equivalent.

Semiclosed unit works by feeding an oxygen-rich mix into the breathing loop at a rate adjusted to match the consumption by the diver. Semiclosed units are of two main types: those that control oxygen input by flow control, such as passing the gas through a calibrated orifice, and those that use the counterlung to adjust the gas by a mechanical ratchet or bellows arrangement. Still another type of rebreather is the pure oxygen unit. This apparatus needs no oxygen controller nor inert gas, but is limited in depth because of oxygen toxicity. This type of unit seems to have fewer applications for technical divers.

**The most obvious use of the rebreather is to provide extended diving time independent of gas supply.**

## What Are Rebreathers Good For?

The most obvious use of the rebreather is to provide extended diving time independent of gas supply. This in turn allows longer bottom times than can be obtained with carried gas, and makes decompression dives far more feasible than they are with scuba.

Once decompression is a factor, the optimal gas mix with the right tables makes decompression about as efficient as it can get. Having no need for predetermined gas mixes tied to bottom depths makes it easy, at least with fully closed units, to use gases other than nitrogen for the oxygen-diluting gas.

Candidates for alternative diluting gases are helium and, for some, neon. While neon is far too expensive for normal open-circuit scuba diving, the gas conservation of a rebreather makes gas costs just a small part of the overall cost when diving with a rebreather.

The U.S. Navy has developed extensive procedures using nitrogen as the inert gas for shallow rebreather dives. But a case can be made that one would be better off using helium for even the shallowest dives, at least those in which decompression is a factor.

Another factor in rebreather use—at least the fully closed models —is that they do not make many bubbles. This has obvious military implications, but it can also be important in cave and scientific diving and photography.

Rebreathers also have some negative aspects. First is their high cost. This is likely to change as the market develops. Not far behind are their complexity, need for maintenance, and the extra training required. Complexity brings with it more places for technical failure.

In some situations the extra endurance provided by a rebreather merely shifts the factors limiting the dive from decompression and gas supply to thermal exposure. For instance, in really cold water there may be no good way to provide adequate thermal protection to take advantage of the diving time allowed by a good untethered rebreather.

To date, the biggest user of rebreathers, both closed and semiclosed, has been the military. Their use generally has involved swimming relatively long distances at relatively shallow depths. In this circumstance, there is no real need for redundancy or even a bailout; the surface is a safe haven in most cases. Another important application is ordnance disposal and mine clearance. Here, greater depth may be needed, and there is a need for silence, no bubbles, decompression, and non-magnetic construction.

So far, the commercial diving world has not embraced rebreather technology. There are a number of reasons for this, including the matters of cost, complexity, training required, and perceived reliability. But probably the most important is that rebreathers just don't fit into the established patterns for typical commercial diving work.

To date, practically all of the operational experience has been with military rebreathers. This has made it possible for these units to be developed and used extensively without a bailout capability built into the system, since most of their use has been in shallow water where a bailout bottle is not normally needed.

In contrast, most technical applications involve diving to depths that makes a carefully planned bailout system essential. This means having enough gas of the right composition to get to the surface or another gas source under all conditions of operation. This must be factored into rebreather operations.

Clearly, considerable work remains before rebreathers can be readily embraced by the sport diving community. But in time, they will undoubtedly become a important tool for the few who can afford the cost and training necessary.

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**Footnotes:**

1. the kPa, or kilopascal, is a metric pressure unit with great utility. A pKa is 1/100 of a bar - very close to 1/100 atm - and this makes it handy to use. In time, most physiological pressure will use kPa.

2. For a method of calculating allowable exposures at different levels of oxygen, see R.W. Hamilton, Tolerating Exposure to High Oxygen Levels: Repex and Other Methods, Marine Technological Society Journal, Vol. 23, No. 4, 1989; or see the U.S. Navy Diving Manual, 1981, Figure 9-20 and Section 15.2.1, which has been reprinted in the NOAA Diving Manual and in many other places.

# Safe Oxygen: How Low Can You Go?

## Potential Hypoxia Problems In Constant Mass Flow Semi-closed Circuit Rebreathers

by David Elliott, O.B.E.

Just how low can the oxygen percentage safely go in a constant mass flow semi-closed rebreather? The obvious answer is that the minimum percentage depends how deep you are but the real problem may arise *in getting back to the surface* The underlying challenge for semi-closed rebreathers that do not have oxygen sensors, *is maintaining a safe oxygen percentage throughout the dive.* This can be achieved by adopting appropriate diving procedures and by setting the variables of the apparatus as safely as possible.

## Is there a problem?

As far as I am aware, to date, there have not been any serious incidents associated with recreational use of semi-closed rebreathers. However, in comparison to recreational scuba diving, the hours of use on semi-closed rebreathers is small [currently there are only two mass flow semi-closed sets on the recreational market—ed.], and we do not know on how many occasions these sets have been used in real emergencies or under the extreme conditions when hypoxic incidents would be most likely to happen. Also, by one manufacturer's admission, there has not even been any manned testing of their particular configuration with monitoring of O2 and CO2 levels in the breathing bag (the counter-lung). But although it may be too early to confirm the apparent safety of semi-closed breathing apparatus within the defined boundary conditions, it is not too early to examine the potential hazard of hypoxia that may be associated with some diving circumstances, and to suggest preventive action if that risk is assessed as being real.

In the last year, PADI and the British Sub Aqua Club have followed the example of specialist training agencies, and have began offering oxygen-enriched air, i.e.. nitrox or EAN, training to the diving public. Diving with nitrox on open-circuit scuba equipment is a variety of recreational diving in which the gas contents is known and remains constant throughout the dive The advantages and hazards of this type of nitrox diving must be distinguished from the use of a nitrox semi-closed circuit rebreather in which the composition of the breathing gas (the FO2 or fraction of oxygen) is changing throughout the dive.

Avoiding an oxygen convulsion has been a primary focus of the safety efforts in sport diving when using alternative gas mixes and/or in deep diving . The importance of this hazard is increased for those who use a conventional scuba mask and regulator mouthpiece; without a full face mask, a hyperoxic convulsion is likely to result in drowning. In contrast, problems in rebreathers associated with hypoxia, too little oxygen in the breathing mix, are less dramatic but can be equally fatal.

Some of the rebreather designs that are now being introduced into recreational diving are based on military semi-closed breathing apparatus that use a nitrox pre-mix and do not have oxygen sensors. These military sets are used primarily for their low acoustic signature when defusing mines. In this application, the potential risk of exertion hypoxia ("beating the flow") is not the major concern. In contrast to closed-circuit rebreathers, in which the level of the inspiratory oxygen is maintained within preset limits and monitored, the semi-closed uses a premix at a predetermined flow rate and provides a breathing gas with a composition which varies during the dive based on the diver's level of physical activity. At rest oxygen levels will approach that of the EAN premix, but the greater the level of exertion, the lower the oxygen level drops. According to one manufacturer, in the worst case scenario, the diver is provided "with a minimum of 17%," but unless the by-pass is effective or the apparatus limits the minute volume of the diver, it could go lower.

This tendency to a lower oxygen level (and corresponding higher N2 level) will also decrease and possibly eliminate the decompression advantage in comparison to open circuit scuba (as calculated by the principle of equivalent air depth, or EAD). The possibility of reducing decompression is often cited as one of the advantages of the nitrox rebreather. The EAD can be calculated for any percentage of oxygen (FO2) estimated to be in the breathing bag:

EAD = (Actual Depth + 33) *(1-FO2)/79% - 33

But erosion of the EAD advantage may not be the only problem.

The purpose of this review is to remind one of basic counterlung theory, which is independent of specific manufacturers, and to suggest that until human trials can show otherwise, some of the recommended flow rates should be considered insufficient for fit divers in an emergency activity. Counterlung theory

In the semi-closed nitrox rebreathers now available to the recreational diver, pre-mixed gas is supplied at a pre-determined flow rate to a counterlung or breathing bag. The fresh gas is mixed with the gas already present in the bag, much of which has just been exhaled and scrubbed of CO2. The diver breathes in from the counterlung and exhales through the scrubber back to the counterlung from which excess gas is vented at virtually the same rate that fresh gas is being supplied. In the steady state, the oxygen percentage in the breathing bag is given by a simple formula:

O2 % =[(O2 flow - O2 consumed)/(Mixture flow - O2 consumed)] * 100

As can be seen from the equation, the oxygen percentage is independent of depth and, once the supply flow rate has been set for a particular premix, the only subsequent variable is that of the diver's oxygen consumption, (VO2). Note that, the oxygen percentage is also independent of the volume of the breathing bag. The volume of the counterlung, or more strictly that of the whole breathing circuit including the lungs, will affect the rate of change from one steady state of oxygen consumption to the next. The rate of change of oxygen content in the counterlung when the diver's work level changes can also be calculated (Loncar & Ornhagen, 1996) but typically, with the small circuit volume of a rebreather relative to the divers respiratory minute volume of around 20 lpm, this transient phase is brief in relation to the ability to sustain hard work.

**This tendency to a lower oxygen level (and corresponding higher N2 level) will also decrease and possibly eliminate the decompression advantage in comparison to open circuit scuba. . .**

Given a pre-determined constant mass flow rate to the breathing bag of a gas with a known composition, the formula above can be used to calculate the oxygen range within predictable upper and lower limits. The dominant variable during the dive is that of oxygen consumption and this will be determined by activities ranging from minimal muscular effort (perhaps when composing a photograph) to maximum sustainable breathing capacity (in some life-threatening situation).

An oxygen consumption of around only 0.25 lpm is widely accepted as a lower limit but, because of the operational procedure of flushing the counter lung with pure pre-mix before leaving maximum depth, the Royal Australian Navy uses a zero value for oxygen consumption in their safety assessment calculations. Given a maximum allowable PO2, either value of oxygen consumption (VO2), zero or 0.25 lpm, can be used to determine the highest percentage of oxygen that could be found in the counterlung. This value is then used to calculate the maximum depth permitted for that mixture. Using the standard mixtures and flow rates. Based on the a maximum PO2 of 2.0 used the British and Australian navies (the USN no longer uses a semi-closed rebreathers) and their standard mixtures and flow rates we can calculate the following:

FO2 = 60% at a 6.0 lpm mixture flow:

Maximum depth is 24 m/79 f at a max PO2 of 2.0 bar
(Max depth is 17 m/55 f at a max PO2 of 1.4 bar)

FO2 =40% at a 12.0 lpm flow:

Maximum depth is 42 m/138 f at a PO2 of 2.0 bar
(Maximum depth is 29 m/95 f at a PO2 of 1.4 bar)

These seemingly high values for peak oxygen have been in the navy manuals for some 50 years but represent an extreme that, if reached, should persist for only a few seconds in persons who have the protection of a full face mask (guaranteed airway). It is generally agreed that sport divers should maintain a PO2 of 1.4 or less during the working portions of their dives.

## Maximum Sustainable Oxygen Consumption

The other extreme, the maximum sustainable oxygen consumption, is more difficult to predict and manufacturers' estimates should be based on published data. For a diver of average size and reasonable fitness, a VO2 max of at least 3 lpm ( can usually be expected and is almost universally accepted (Lanphier & Camporesi, 1993). For the elite athlete performing out of the water an oxygen consumption exceeding 7 lpm can be sustained (Whipp & Ward, 1994). However, it has been correctly pointed out that maximum voluntary ventilation (MVV) and maximum breathing capacity (MBC) are significantly reduced at raised environmental pressure, and by as much as around 50% at 45 m/150 f. Exercise capacity would be reduced accordingly. This may be a limiting factor at the deeper depths but the same apparatus and settings are used at all depths of a dive, from leaving the surface until returning there.

For counterlung calculations the U.S. Navy and at least one manufacturer use a VO2 of 2.5 lpm and the Royal Navy and Royal Australian Navy use a VO2 of 3 lpm. *Given that there are some exceptional athletes among the sport diving community, a value of at least 3 lpm for maximum sustainable O2 should be used as the value appropriate for setting safety limits in semi-closed apparatus.* Using the formula to calculate the oxygen level in the breathing bag based on this range of VO2, and the mixtures and flow rates above, we have;

FO2 =60% at a 6.0 lpm flow:
Bag FO2 = 20% at a VO2 =3 lpm or 31% at a VO2 =2.5 lpm

FO2 =40% at a 12.0 lpm flow:
Bag FO2 =20% at a VO2 = 3 lpm or 24% at a VO2 = 2.5 lpm

Note that these oxygen levels are safe at the surface as well as at depth.

## Semi-closed Rebreathers for Recreational Diving

Manufacturers have used the same constant massflow semi-closed principles for designing recreational rebreathers, but in doing so some have appeared to introduce their own interpretations of human physiology. *According to figures that have been confirmed by one manufacturer, its semi-closed rebreather provides the diver with 5 lpm flow of 40% oxygen. Its maximum depth is given as 30m/ 100 f which means that it has a maximum PO2 of 1.6 bar. The problem is that this apparatus would seem to be safe at the surface only if the VO2 is 1.0 lpm or less; in a steady state, at a modest exertion VO2 of 1.5 lpm, the oxygen percentage in the breathing bag would be around 14%. At this percentage one can only hope that all their serious training sessions are deeper than 5 m/16 f and that there is enough gas left in the bottle for a good flush through the breathing bag before leaving bottom.* This equipment provides a maximum of only 2 lpm VO2 to the diver. It is not hard to predict the consequences associated with exertions that may be needed in a life-threatening emergency, even if there is a manual or other by-pass to provide extra gas (though none is shown in the published flow chart).

At a VO2 of 1.75 lpm this apparatus will supply the diver with PO2 of 0.3 bar at its maximum depth of 30 m. However, this partial pressure would be achieved with only around 8% oxygen in the breathing bag. This would not only result in an equivalent air depth (EAD) of 36 m/118 f at 30 m/100 f but also that it would not be a safe mixture for making a rapid ascent. Would an initial flush through before leaving the bottom, or would a very slow gentle ascent be sufficient to restore a safer oxygen percentage before reaching the surface? One hopes so, but I doubt that it has been evaluated in trials, manned or unmanned. The only cautionary note offered with this set is that it is meant for only those who weigh less than 198 lb./90 kg. Perhaps it is presumed that these people have lower oxygen consumption, but on the basis of what evidence?

This example of a 5 lpm flow rate with a 40% oxygen mixture is particularly extreme because others recommend double that flow rate. Yet even these higher flows do not solve all the potential problems. At a VO2 of 3 lpm with a 40% oxygen premix at the manufacturer's flow setting of 9.2 lpm could bring the counterlung content down to 11 % oxygen. This is not an isolated example. Consider the flow rate of 11.4 lpm proposed for a 32% O2 mixture which, at a VO2 of 3 lpm without bypassing, would lead to less than 8% oxygen in the breathing bag.

A number of these calculations were sent to the manufacturer who confirmed their recommended basic flow rates and responded that "in periods of higher workload and breathing, the diver needs to exhale through the nose in order to make sure that fresh gas is supplied through the bypass valve." Exhaling out the nose instead of into the system is one way of boosting the flow of fresh gas to the bag.

Without using the bypass, these levels of oxygen consumption give a maximum EAD depth for a dive which would be deeper than the actual depth dived. How effective is their recommended procedure to exhale through the nose? Has it been validated?

## Decompression Considerations

Because decompression tables are based on the deepest depth of the dive, one should similarly estimate the deepest EAD of the dive. Is it really valid, as suggested by one training agency, to make an estimate which is based on an average oxygen consumption of 1.5 lpm? As the actual EAD may sometimes be deeper that the actual depth, how can one plan for a safe decompression? It is possible that there is sufficient padding in the decompression tables that these questions about unpredictable nitrogen exposures are relatively academic, but the data does need to be collected and published. In the meanwhile, a physically active diver using semi-closed apparatus might be wise to use the air decompression tables for the actual depth dived.

One of the training agencies using a particular semi-closed set have increased the manufacturer's recommended flows and reduced their recommended maximum depths. For example, the flow rate quoted by the manufacturer of 11.4 lpm for a 32% $O_2$ mixture has been increased to 15 lpm, thus increasing the bag $O_2$% at a $VO_2$ of 3 lpm from 8% to 15%. It is not known if such decisions are based on measurement or, more probably, by judgment. Since bringing this problem to the attention of the relevant parties, one manufacturer has increased its flow settings to achieve, theoretically, a minimum 15-16% $O_2$. A request to that particular manufacturer for the basic data from manned testing on actual levels of oxygen in the breathing bag during hard work revealed that no such data had been collected. From this it follows that the effectiveness of the $CO_2$ scrubber during hard work has never been validated either.

## Recommendations

Diving with semi-closed rebreathers introduces several hazards which are not encountered by those diving enriched air with open-circuit scuba. The hazards should be assessed and the procedures for the control of risks defined and validated before diver training begins. Oxygen levels need to be measured in the breathing bags of semi-closed breathing apparatus and, because of the contribution of the build up of carbon dioxide to in-water incidents, so also do carbon dioxide levels. This recommendation should apply also to other types of semi-closed apparatus, besides those based on constant mass flow, such as those made on the constant ratio principle. Manufacturers should ensure that gas samples are analysed from breathing bags in unmanned trials and during shallow dives at sustained maximal $O_2$ by exceptionally fit divers. This needs to be done at a laboratory experienced in diving physiology and the results made available before settings such as flow rates are finally decided.

**. . . but, in case insufficient gas is left in the supply cylinder, the diver should always carry a mini-bottle of air or nitrox. . .**

Until then a wise precaution would be to use the higher flow rates quoted above which are based on providing 20% oxygen in the breathing bag at a 3 lpm $O_2$ consumption, or possibly to measure the maximum oxygen consumption with a direct method for each diver and set individual flow rates accordingly. The procedure of flushing through the breathing bag with fresh gas before leaving maximum depth is always a wise routine because the bag mixture may cause hypoxia during ascent but, in case insufficient gas is left in the supply cylinder, the diver should always carry a mini-bottle of air or nitrox with a demand regulator. It could be used routinely for surfacing.

*David Elliott, O.B.E., is coeditor of* The Physiology and Medicine of Diving, *first published in 1969 and revised in 1993. He is a civilian consultant in diving medicine for the Royal Navy.*

**Further reading**

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# Rebreather Basics

by Ed Thalmann

The problem with open circuit scuba equipment is that it wastes gas. The diver inhales a lung full of gas, consumes a small amount of oxygen, adds a small amount of $CO_2$ from the venous blood, then exhales the whole amount into the water through the exhaust valve. The next breath is drawn entirely from the tank. In contrast, if oxygen alone could be supplied to the diver, average gas consumption would be 1.5 slpm (standard liters per minute) or about 0.05 cubic feet per minute. In this case, a free swimming diver could carry enough gas in a 20 cubic foot (cf ) cylinder for a six hour dive. This fact was not lost on the early underwater breathing apparatus (UBA) designers of the World War II era; the first closed circuit rebreathers used 100% oxygen. While attractive in theory, oxygen rebreathers have limitations imposed by oxygen toxicity, as discussed below.

In addition to supplying oxygen to the diver, a rebreather must get rid of the diver's exhaled $CO_2$. There are a variety of compounds which will readily absorb $CO_2$, the earliest used was sodium hydroxide (NaOH). As exhaled gas is passed over this compound the carbon dioxide is removed releasing water and heat. While very effective at removing $CO_2$, NaOH is extremely caustic and can cause severe burns if it comes in contact with human tissue. There are other less caustic compounds based on metal hydroxides which are sold under brand names such as Sofnolime, Sodasorb, or Baralyme. A rebreather's duration in cold water is limited by $CO_2$ absorption duration and not gas supply. For that reason, absorbent technology is still the subject of US Navy studies.

**While attractive in theory, oxygen rebreathers have limitations imposed by oxygen toxicity. . .**

## Breathing Circuit

The breathing circuit shown in Figure 1 is basic to all types of rebreathers. Along with a scrubber, floppy breathing bags are supplied which serve two functions. They allow inhalation and exhalation with little or no pressure change in the breathing loop and also provide a method of buoyancy control. $CO_2$ is removed by the scrubber and $O_2$ is added to the loop by a variety of mechanisms (not shown in the figure) that are discussed below.

Additional gas must be added to the system during descent since the actual volume of gas in the system must be kept constant in order to keep the breathing bag from collapsing. If the diver ascends, then the gas in the loop will expand and a pop-off valve vents the system to keep it from blowing up. At present there is no convenient way to retain this vented gas. It is lost to the system. Even if no gas is lost from the breathing loop at a constant depth, there must be additional gas available, above that required to replace consumed oxygen, to refill the system each time there is a descent. This can impose additional limitations on duration especially if the dive involves a lot of depth excursions.

While all rebreathers have the same basic breathing circuit the details differ. The size and type of hoses and piping can effect the breathing resistance of the circuit. The type of $CO_2$ absorbent and the design of the scrubbing canister can affect the amount time before the absorbent is spent (the canister duration time) and the inhaled $CO_2$ level begins to rise.

The method by which oxygen is added can also vary. In 100% oxygen and electronically controlled

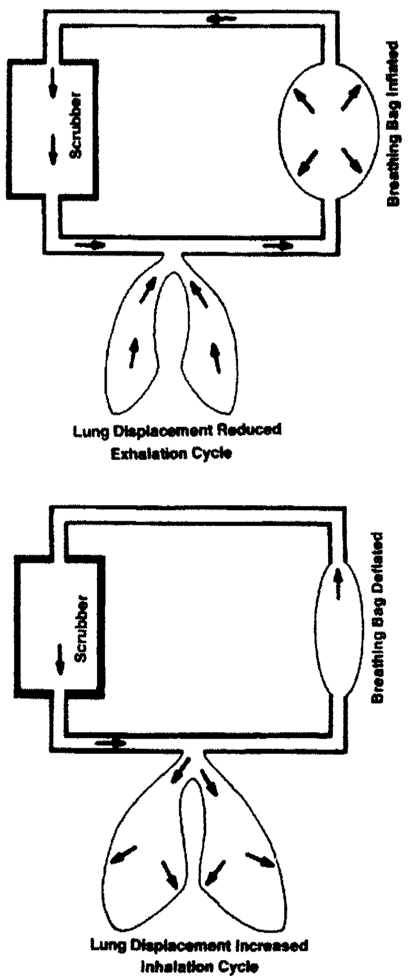



**Figure 1: Basic breathing circuit**

closed circuit rebreathers, the exact amount of oxygen consumed is added as long as depth is held constant. In other designs, oxygen mixed with an inert gas is injected into the system resulting in some gas wastage even at a constant depth. These rigs are known as semi-closed rigs have the advantage of a simpler more reliable design than electronically controlled rebreathers. While avoiding the oxygen toxicity problems of oxygen rebreathers, hypoxia and decompression problems can arise in certain types of semi-closed rebreathers as a result of not knowing the exact oxygen fraction in the system [see "Oxygen in Semi-closed Systems: How Low Can You Go, " by David Elliott–ed.]. Oxygen toxicity weighs heavily in the design and operation of rebreathers and it's useful to take a few minutes to discuss here.

## Oxygen Toxicity

In 1878, Paul Bert showed that breathing high partial pressures of oxygen caused convulsions and death in living animals. While initially of academic interest, the problem of oxygen toxicity became a practical problem during W.W.II with the invention of the oxygen rebreather. From 1942-1945, Professor Kenneth Donald undertook what was the largest study of oxygen toxicity in humans. His work has been documented very nicely in the book "Oxygen and the Diver" (available from Best Publishing Co. Flagstaff, Arizona). Most of our understanding of the effects of high oxygen pressures on divers has come as a result of Donald's studies.

In the course of metabolism, oxygen molecules are broken apart into species called free radicals as they participate in the energy releasing chemical reactions with fats or carbohydrates. As a chemical species, these free radicals are bad actors and would result in cellular dysfunction (and sometimes damage) if the body did not have mechanisms for containing them. Under normal conditions very few of these free radicals get loose, they are rapidly sopped up by various protective mechanisms which render them harmless. However, under conditions where the oxygen partial pressure is very high these mechanisms are though to become overwhelmed resulting in oxygen toxicity.

Oxygen is potentially toxic to all tissues but the most common organs affected in diving are the lung and the central nervous system. Initially oxygen toxicity in the lung causes a mild burning sensation in the chest which progresses to severe pain on inspiration if exposure continues. The result is an inability to take full inhalations. In conscious individuals the pain can become so intense that they will refuse to breathe oxygen before severe permanent lung damage results, however once O2 breathing is stopped, lung function returns to normal.

Central nervous system toxicity is usually manifested by tunnel vision, ringing in the ears, nausea, twitching, or grand mal convulsions, itching, dizziness [the so called V-E-N-T-I-D mnemonic–ed.] When convulsions occur they usually do so with little or no warning and the presence of the other symptoms mentioned does not necessarily mean that a convulsion is imminent. Studies have shown that the convulsion itself causes no damage. However, if it occurs underwater the diver may lose his mouthpiece resulting in drowning and death. The

**Studies have shown that the convulsion itself causes no damage. However, if it occurs underwater the diver may lose his mouthpiece resulting in drowning and death. The limits placed on the inhaled oxygen partial pressures in 100% O2 rebreathers are designed to avoid oxygen convulsions.**

**Table 1**
**USN single-depth oxygen exposure limits**

| Depth | Maximum [illegible] | |
|---|---|---|
| [illegible] | [illegible] | 1.6 atm |
| 30f/9m | 80 minutes | 1.9 atm |
| [illegible] | [illegible] | 2.1 atm |
| 40f/12m | 15 minutes | 2.2 atm |
| [illegible] | [illegible] | 2.5 atm |

**The 240 min limit at 20f/6m allows a single downward excursion at any time so long as the following limits are not exceeded**

| | |
|---|---|
| 21-40f/6-12m | 15 minutes |
| [illegible] | [illegible] time<br>[illegible] minutes |

limits placed on the inhaled oxygen partial pressures in 100% O2 rebreathers are designed to avoid oxygen convulsions.

**. . . we know that immersion, cold, and increasing levels of exercise all make oxygen convulsions more likely. . . some evidence that increases in inhaled CO2 levels may also increase the likelihood of a convulsion.**

Table 1 gives the current US Navy 100% oxygen exposure limits and shows that as depth increases the permissible exposure time decreases. [Note that technical divers are advised to hold their working PO2's below 1.45 atm when using open circuit equipment- ed.]

As a result of Donald's work we know that immersion, cold, and increasing levels of exercise all make oxygen convulsions more likely. Also, there is some evidence that increases in inhaled CO2 levels may also increase the likelihood of a convulsion. This means that the limits in Table 1 may not apply under conditions of extreme exercise or cold, or at breathing gas densities at depths below 50 f/15 m. In designing rebreathers, the average oxygen partial pressure is usually controlled to some level below 1.6 atm, although peaks as high as 2.0 atm have been allowed under some conditions.

## Types of Rebreathers

The simplest form of rebreather is a helmet supplied by a hose attached to an air pump at the surface, typified by the US Navy MK V. Helmet ventilation supplies oxygen and eliminates exhaled carbon dioxide (CO2). In these types of systems, CO2 elimination

## Metabolism Simply Explained

All bodily functions including muscular exercise require energy derived from converting fats and carbohydrates to carbon dioxide and water in a reaction involving oxygen. Under optimal conditions, we generate about 114 kilo calories (kcal) of energy, of which approximately 53% is converted to mechanical energy and 47% converted to heat, for each mole of oxygen consumed (one mole of gas has a volume of 22.4 liters and contains 6.022 x 1023 molecules under standard conditions of 1 atm pressure, 0° degrees Celsius, dry).

Since the numbers of moles of oxygen can easily be converted to a volume under standard conditions, and since metabolic rate is usually measured by observing the volume of oxygen consumed, oxygen consumption is usually expressed in standard liters/min (slpm), using the symbol VO2. In performing calculations for rebreather operations, the lowest assumed VO2 is 0.5 slpm (rest) and the highest 3.0 slpm (1.5 knot swim). In computing O2 supply duration, a mean VO2 valve of 1.5 slpm (0.8 knot swim) is usually assumed.

For each liter of oxygen consumed, between 0.8 and 1.0 standard liters of CO2 are produced depending on the relative amounts of fats or carbohydrates being metabolized. The ratio of CO2 produced to O2 consumed is called the respiratory quotient. This quotient is usually assumed to be 0.9 on average for the purpose of rebreather design.

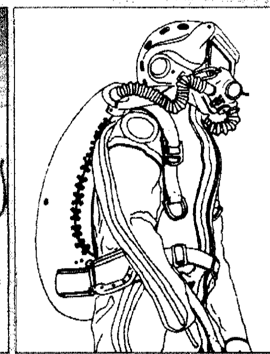
Note that oxygen and carbon dioxide limits are dependent on partial pressure, not the fraction being breathed. The minimum O2 partial pressure is defined to be 0.16 atm, a mix of 16% at the surface, or a 4% mix at 99f/30 m or 4 atm.

| UNITS | |
|---|---|
| cf | cubic feet (= 28.3 liters) |
| f | feet of seawater |
| FBO2 | bag oxygen fraction |
| FO2 | oxygen fraction |
| FSO2 | oxygen supply fraction |
| lpm | liters per minute (=.0353 cubic feet) |
| m | meters of seawater |
| Pamb | ambient pressure absolute |
| PCO2 | partial pressure of CO2 |
| PO2 | partial pressure of O2 |
| slpm | standard liters per minute |
| VO2 | CO2 production |
| VHE | helmet ventialtion rate |
| Vin | gas injection rate |
| VO2 | O2 consumption |

USN MK V

Lambertsen Amphibious Respiratory Unit (LARU)

Dräger LAR V



USN MK 11 UBA

USN MK 6 UBA

determines the required ventilation's rate. Ideally, there should be no CO2 in the inspired gas but as a practical matter CO2 partial pressures up to 0.02 atm can be tolerated. Above this level performance is impaired and if high enough the diver will lose consciousness.

Contrary to what some people believe, CO2 in and of itself does not usually cause death (While too low a blood oxygen level definitely can.). Very high CO2 levels can be tolerated but the resulting changes in blood chemistry leading to unconsciousness may cause drowning, leading to hypoxia and death.

The equation governing helmet ventilation is fairly simple assuming that the helmet gas is well mixed and in a steady state, and can be expressed as:

$PCO2=1.07*VCO2/VHE$

Where PCO2 is the partial pressure of carbon dioxide expressed in atm (divide by 1.013 to convert to bars), VCO2, carbon dioxide production in standard liters per minute (slpm), and VHE is the helmet ventilation rate in liters per min. (lpm).

At a maximum working oxygen consumption (VO2) of 3 slpm (see Metabolism box), VCO2 could approach 2.7 slpm. The US Navy requires that at least 5 cubic feet per minute (cfm)/142 lpm, be available from the compressor for helmet ventilation. At these heavy work rates the inhaled CO2 could be as high as 0.02 atm. At 66 f/20 m (3 atm) supplying 5 cfm requires that 15 cfm be pumped (15 lpm x 3 atm= 15 lpm). A standard 100 cfm scuba cylinder would last just over six minutes at this rate. There in lies the impetus for inventing the scuba demand regulator and incorporating it into the helmet.

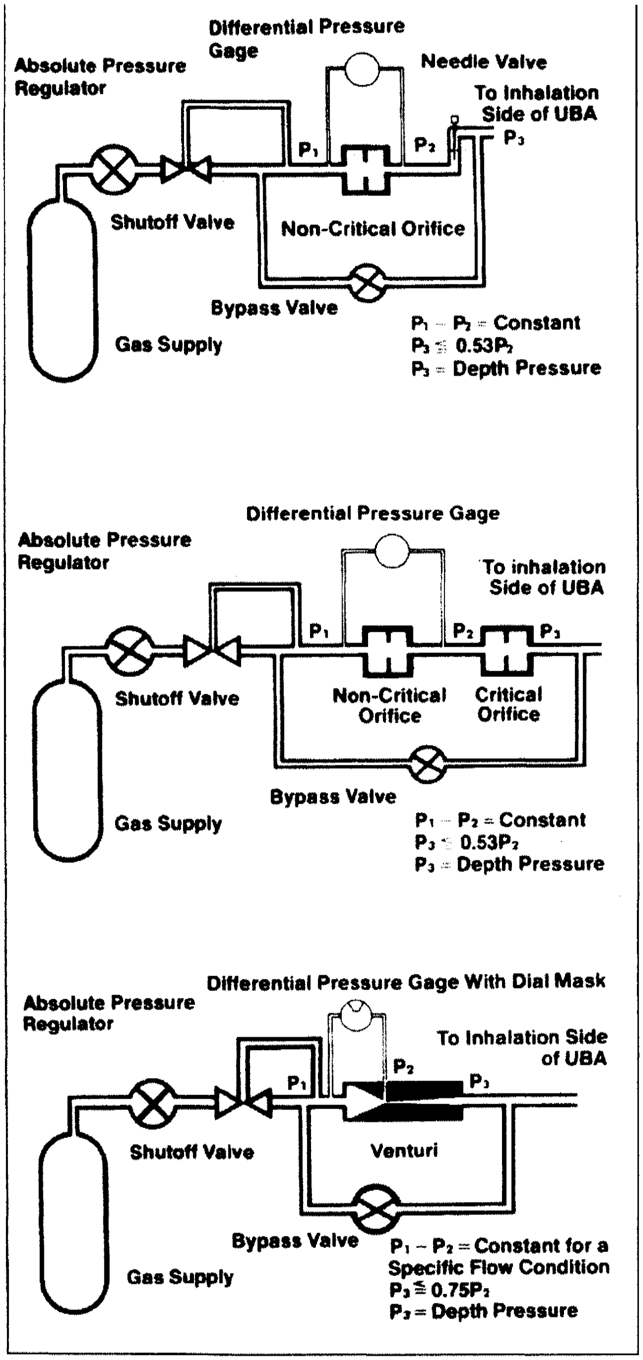
The rate at which we move gas in and out of our lungs, called minute ventilation or VE, expressed as actual volume per minute, is approximately 25 times our rate of oxygen consumption. At an average consumption rate of 3 slpm, minute ventilation is 75 lpm or about 3 cubic feet a minute. Every minute, about three cubic feet of gas is moved in and out of the lungs. This means that at 66 f/20 m, or three atmospheres, the VE would be 9 cfm and a 100 cf of scuba cylinder would last just over ten minutes. In practice however, VE is about one cfm and a 100 cf cylinder can last 33 min. at 66 f/20 m. This is not very impressive from a gas utilization point of view and places a severe limitation on available bottom time, especially on deep dives.

## Dräger LAR V (Oxygen Rebreather)

The breathing loop in 100% O2 rebreathers is completely filled with oxygen, presumably the diver will have flushed as much nitrogen from his lungs and the system as possible when going on the mouthpiece. Once this is done, oxygen is added to the loop as it is consumed and no gas is wasted.

The granddaddy of US Navy oxygen rebreathers is the LAR U invented by Dr. C.J. Lambertsen during W.W.II which was eventually replaced by the Emerson-Lambertsen rebreather. Today, the Emerson has been replaced by the German Dräger LAR V, as is now in use by US combat swimmers. The LAR V is small, lightweight and simple to use. As oxygen is consumed, the breathing loop gas volume decreases and the breathing bag will eventually collapse. When this occurs, a demand add valve is activated during inhalation which adds oxygen to the loop. When gas is added through the demand valve breathing resistance increases so seasoned operators prefer to manually add oxygen by activation a manual add valve. In fact W.W.II combat swimmer controlled bag inflation by turning a needle valve which constantly bled oxygen into the breathing loop in contrast to the LAR V. If too much oxygen was added, telltale bubbles would be vented to the surface potentially alerting the other side. As a result, W.W.II swimmers became adept at determining exactly how much gas to bleed in to keep the breathing bag volume constant but not overfull.

If it weren't for oxygen toxicity the LAR V would be the ideal rebreather. It's 300 liter/x cf oxygen bottle is enough for 3 hour swims and the CO2 canister




***Three approaches to controlling gas mass flow rate.***

Figure 2.

will function adequately for 2 hours in cold water, and over 3 hours in warmer water. But the limits in Table 1 must be adhered to restricting depth to 20 f/6 m or shallower with only short excursions deeper. Sport divers who tend the large aquarium at Disney World use oxygen rebreathers because they usually don't need to go deeper than 20 f/ 6 m and the absence of bubbles lets them get close to marine life. The only practical problem is that all of the plumbing exposed to high oxygen pressures must be cleaned to very strict standards during maintenance which requires special equipment and training.

## Semi-Closed Systems; the USN MK 6 and MK 11

Semi-closed rebreathers inject an oxygen rich mixture into the breathing loop at a controlled rate. The various designs control the rate of the mass of gas injected (thus the rate of oxygen molecules added) in such a way that metabolic demands are met. Figure 2 shows three approaches to controlling the mass flow rate. The top figure illustrates the scheme used in the USN MK 6, an adjustable needle valve. The non-critical orifice is used as a flow meter, measuring the pressure drop across the orifice on a differential pressure gauge that shows the mass flow rate. The middle figure shows the approach taken in the MK 11. Here, the needle valve has been replaced by a sonic or critical orifice. In this case, a different orifice is used for each different injection rate. So long as the upstream pressure at the orifice is more than twice the downstream pressure, the mass flow is independent of the downstream pressure, ensuring a depth dependent mass injection rate. The mass flow is still proportional to the upstream pressure but is maintained at a fixed value by the regulator. In the bottom illustration, a venturi is used to control flow, a technique used in some present day rigs.

In spite of the different mechanisms used to control flow, the inhaled oxygen level in all semi-closed rebreather is governed by the same basic equation. Mass balance requires that the mass of oxygen exhausted from the breathing loop must be equal to the mass injected less the amount consumed or:

$$(Vin - VO2) * FBO2 = Vin * FSO2 - VO2$$

where Vin is injection rate in slpm, VO2 is the oxygen consumption in slpm, FSO2 is the oxygen supply fraction and FBO2 is the oxygen level in the breathing bag. It is assumed that the gas in the breathing loop is well mixed following the oxygen injection so that the oxygen level in the breathing bag and inspired levels can be assumed to be the same.

The oxygen levels in the breathing bag must be controlled to prevent oxygen partial pressure from falling below 0.16 atm (causing hypoxia) or exceeding 1.6 atm (causing an oxygen convulsion). Since the partial pressure of oxygen is the O2 fraction times ambient pressure, the above equation can be rearranged and rewritten as:

$$PBO2=\{(Vin * FSO2-VO2) / (Vin-VO2)\} * Pamb$$

where PBO2 is the partial pressure of oxygen in the breathing bag in atm and Pamb is the absolute

**Table 2**
**Semi-closed UBA inhaled oxygen level characteristics**

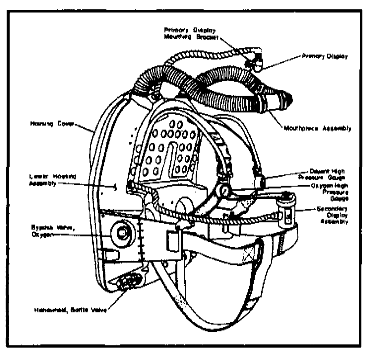
| FSO2 | Max (fsw) for PO2 of 1.6 ata | Vin (lpm) | Rcrit @ Work VO2 of 3 lpm | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0.28 | 0 |
| 20% | 231 | 60 | 0.16 | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | 3 | 0.15 | 3 |
| | | | [illegible] | 20 | 0.14 | 5 |
| 10% | 495 | 150 | 0.08 | [illegible] | [illegible] | [illegible] |
| | 40 | 0.03 | 150 | [illegible] | [illegible] | [illegible] |
| | 28 | ok if VO2 is 2 lpm | | | | |
| | 14 | ok if VO2 is 1 lpm | | | | |

pressure at depth calculated as (Depth (fsw) + 33) / 33. The oxygen supply fraction is chosen to keep the PO2 above 0.16 atm at the shallowest depth. The term in the bracket, {}, is called the critical ratio (Rcrit). Multiplying Rcrit by Pamb, the absolute ambient pressure gives the inspired PO2 level at that pressure. The interplay between the breathing bag pressure, PBO2, injection rate, FSO2, and VO2 is complicated and a multitude of graphical representations have been made. Here are some simple examples to illustrate the design limitations [ See discussion of NEDU's semi-closed system simulation software in Semiclosed Systems; Problems & Solutions—ed.].

Table 2 shows the results with different supply gases. A 28% O2 gas can be dived to 155 f/ 48 m without exceeding an inspired PO2 of 1.6 atm. At the maximum VO2 of 3 lpm, Rcrit is 0.16 meaning that at the surface (1 atm) the inspired PO2 will not fall below 0.16 atm. If the VO2 drops to 0.5 lpm, Rcrit will increase to 0.28. To go deeper than 155 f/48 m a lower oxygen fraction gas must be used resulting in a higher injection rate.

A 20% gas allows dives to 231 f/71 m and will still allow ascent to the surface because Rcrit is 0.16. However, the injection rate has almost tripled. A 15% gas is good to 319 f/98 m but only at a very high injection rate. Since Rcrit at a VO2 of 3 slpm is 0.13, the minimum depth the system could safely be used while exercising is (0.16/0.13=1.23) 1.23 ata or about 8 f/2.5 m. Even if we assume that a lower VO2 is used, the last two columns show that only a small decrease in the minimum depth is possible. Increasing the injection rate doesn't help since equation (3) shows that even at an infinite injection rate, Rcrit will not exceed 0.15. One strategy would be to lower the injection rate, to say 60 lpm. In this case the minimum depth is 20 f/6 m requiring a switch to a higher O2 breathing gas upon ascent.

A 10% gas allows a very deep dive with an injection rate of 150 lpm. This allows the system to be dived as shallow as 31 f/10 m (20 f/6 m at rest). But it would require significant gas consumption: 5 cubic feet per minute (150 lpm/28.32 liters per cubic foot). The injection rate could be knocked down to 40 lpm than 150 f/46 m unless a gas switch (with at least 22% O2) was made. Gas could also be conserved by matching the injection rate and exercise level. The last two rows of the table show the required injection rate for two lesser levels of exercise. US Navy rigs do not use this option but a Swedish rebreather called the ACSC, built by AGA does [see discussion on dosage-based semi-closed systems in Types of Rebreathers by Tracy Robinette—ed.].



USN MK 16

## Electronically controlled Closed Circuit: USN MK 16

Conceptually the MK 16 is one of the simplest rebreather designs though from a hardware standpoint it is one of the most complex. A diagram of the breathing loop is shown in Figure 3. Three oxygen sensors (for redundancy) measure the oxygen partial pressure in the breathing bag and the electronic control systems periodically opens a solenoid valve to inject just enough oxygen to keep the PO2 constant. The minimum oxygen level or set point can be adjusted by the user. The US Navy uses a set point of 0.7 atm [Reportedly the USN is raising the Mk 16 set point to a maximum of 1.3 atm—ed.].

When the bag PO2 level reaches 0.7 ata the solenoid opens admitting oxygen. Since it takes some time for mixing to occur and because the flow through the solenoid valve is somewhat depth dependent, the PO2 is the breathing loop may increase to 0.75 or 0.8 atm before the add stops. This will be breathed down over a period of time until the PO2 again falls to 0.7 atm causing another add.

The MK 16 uses two gas supplies; 100% oxygen

**USN MK 15/16**

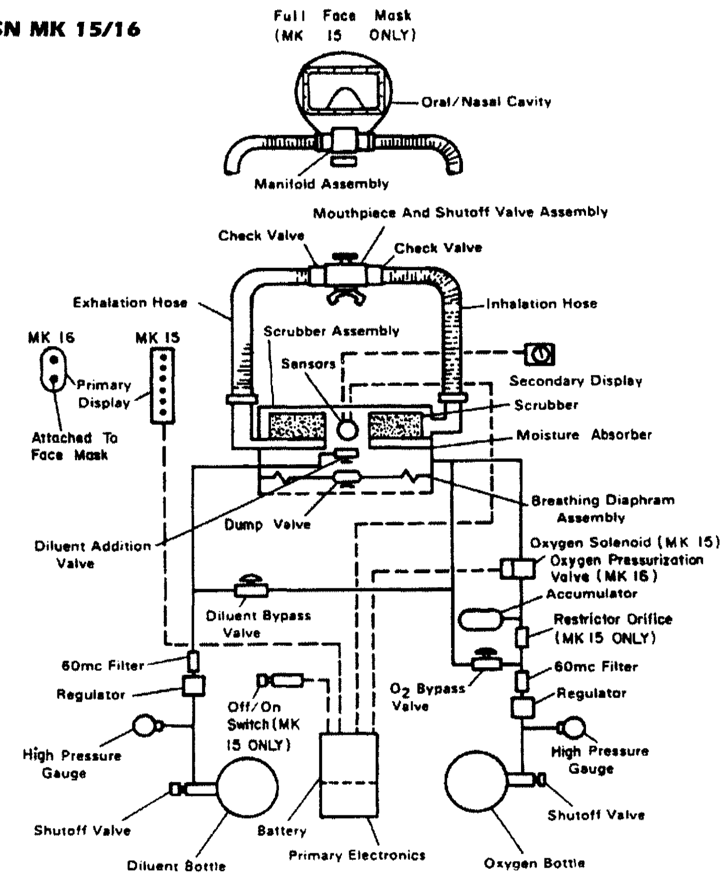



Figure 3

and a diluent gas. The diluent is need to keep the breathing loop for collapsing during descent and in principal could be 100% nitrogen or helium depending on the maximum desired depth. Operationally an oxygen/inert gas mix is used that can be breathed in an emergency such as in case of an O2 add system failure. PO2 is displayed electronically and there is a manual oxygen bypass that can be used to add O2 manually in the case of a control system failure. The 490 liter/17.2 cf oxygen bottle provides enough gas for dives lasting over 6 hours at a mean oxygen consumption of 1.5 liters per minute. Gas is only "wasted" during depth excursions when it is vented to the water during ascent and added during descent by a demand valve when the breathing bag nears collapse.

Operationally, the duration of the MK 16 is determined by the amount of time the CO2 absorbent continues to scrub all expired CO2 and is dependent on depth and water temperature. Typical CO2 canister duration times below 50 f/16 m are 100 minutes in 29° Fahrenheit/-2° Celsius water increasing to 200 minutes at 40° Fahrenheit/4° Celsius. At shallower depths the duration is 5 hours over the entire temperature range and at 70 Fahrenheit/21 Celsius a 400 minute duration is possible.

Closed circuit systems are the most efficient from a gas consumption standpoint but the sophisticated electronics and relatively fragile, and expensive oxygen sensors create more failure modes than some semi-closed rebreathers. The US Navy has designed an even more sophisticated rebreather, the MK19 which has improved breathing characteristics and doubly redundant electronics combined with an ultra long duration lithium hydroxide CO2 absorbent. However it appears that the high cost of the system may delay its entry into the operational arena.

## Other Considerations:

In this article I have presented the basic operational characteristics of rebreathers. However, there are many factors which determine how these UBAs perform in the water which will be discussed in the "Evaluating Rebreather Performance". The placement of the breathing bags can profoundly affect breathing characteristics to the point of causing major problems. CO2 canister design and the type of CO2 absorbent can have a major impact on rig duration. There are also physiological problems not directly related to the rebreathers themselves but rather a result of the great depths and long duration's that can be achieved with them. These include High Pressure Nervous Syndrome (HPNS), immersion dieresis, and hypothermia. Finally, the inspired oxygen level supplied by a rebreather can have a profound effect on decompression times.

*Retired USN Captain, Ed Thalmann, M.D., was responsible for writing the physiological specifications for all of the US Navy's breathing apparatus, and conducting manned testing for the MK 11, MK 15, MK 16, and LAR V rebreathers. Having served for ten years at the Navy Experimental Diving Unit, four as the senior medical officer, he is currently with the Division of Occupational and Environmental Medicine at Duke University and is the Medical Director at the Divers Alert Network.*

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# Evaluating Rebreather Performance

by Edward Thalmann

Rebreathers are designed to allow long duration dives, sometimes at considerable depth. The reliability and ruggedness of the system design are critical under these conditions because returning to the surface immediately may not be feasible if a system problem occurs. In addition, the long duration dives allowed by rebreathers make breathing comfort a much bigger issue than with underwater breathing apparatus (UBA) used only for an hour or so. What may be tolerable for a 30 to 60 minute dive may become unbearable after several hours in certain positions. A poorly designed rebreather will produce dyspnea (shortness of breath), leading to discomfort that will limit the diver's ability to exercise. A good design will never be a limiting factor in exercise.

During exercise, the rate at which gas is moved in and out of the lung (the respiratory minute ventilation, RMV, measured in liters/min)is approximately 25 times the rate of oxygen consumption. This means that a diver performing moderate work at an oxygen consumption rate of 2 liters/minute will have an RMV of 50 liters/min. This gas moves through the breathing loop as a result of pressure differences. The respiratory muscles create negative pressures during exhalation. A well-designed rebreather will supply the diver with gas regardless of his RMV, without requiring excessive inhalation or exhalation pressures. Excessive breathing resistance results in a lower RMV which in turn results in a higher than normal blood CO2 level for a given level of exercise, eventually producing dyspnea.

**Once a rebreather is designed and built, it's ability to support a working diver must eventually be evaluated.**

## Human vs. Machine Testing

Once a rebreather is designed and built, it's ability to support a working diver must eventually be evaluated. One method of evaluating performance is to look at the pressure excursions in the mouthpiece to get a direct estimate of the energy required to move gas through the breathing loop, the "external work of breathing." The advantage of this approach is that a breathing machine (basically a motor driven piston) can be used to move the gas through the loop—a diver is not required. This is the basis of machine testing. A more direct method of evaluating a rebreather is to have a diver exercise on the rig and measure the CO2 concentration at the mouth using a fast response analyzer such as a respiratory mass spectrometer.

During exhalation, the CO2 level at the mouth increases and reaches a peak value just before inhalation begins. This peak value is known as the end tidal partial pressure of CO2, or PetCO2, and is related to the arterial blood CO2 level. During exercise at the surface, the PetCO2 rises slightly, with increasing intensity to levels just above 40 mmHg (millimeters of mercury)/ 0.05 bar , and then falls as the intensity increases further. At higher gas densities (such as encountered while diving), the PetCO2 does not plateau but continues to rise with increasing exercise even when the diver is in an open chamber breathing without a UBA. When using a rebreather, any excessive breathing resistance will cause the PetCO2 to be even higher at a given level of exercise, and if too high, will result in shortness of breath, limiting exercise. Experience has shown that a good rebreather should keep the

PetCo2 below 50 mmHg/0.0625 bar (at the highest anticipated exercise intensities.

Table 1 shows the test results of a Carleton Technologies pre-production MK-16 mixed gas rebreather conducted in 1980. Since the MK-16 is a fully-closed circuit system that supplies oxygen only as needed, the diver's oxygen consumption could be measured by monitoring the oxygen bottle pressure drop with a pressure transducer. Note that the oxygen consumption exceeds 24 liters/min. at the 150-watt work rate, which is equivalent to a very hard swim. The mouthpiece differential pressures are shown from full inhalation to full exhalation and the PetCO2 levels are around 50 mmHg/0.0625 bar. These results, combined with favorable diver evaluation of subjective breathing comfort, showed that the resistance of the MK-16 breathing loop did not significantly impede exercise.

Though human testing is expensive and requires a chamber and sophisticated instrumentation, the advantage to it is that the critical control parameter, arterial blood PCO2, can be measured more or less directly. In addition, subjective factors, such as breathing discomfort and dyspnea, can be evaluated. The U.S. Navy relies heavily on human testing, in which divers exercise at resting levels to very heavy workloads at the maximum depths that the rebreather will be used. Exercises (six minutes of work interspersed with four minutes of rest) are conducted on a bicycle ergometer which has been especially modified for underwater use at settings of 50, 75 and 150 watts). While the Navy uses a bicycle ergometer, any method of exercise that would generate the same oxygen consumption would work. The advantage of a bicycle is that a diver can efficiently exercise up to levels of maximal exertion in almost any position, from full head up to head down.

**One school believes that meeting breathing machine goals is sufficient to allow field used of a UBA. . . . Currently, the U.S. Navy requires that human testing be conducted before a new UBA is accepted into the fleet, no matter how well the system did on machine testing.**

In 1981, the Navy Experiment Diving Unit published it's Standardized NEDU Unmanned UBA Test Procedures and Performance Goals, which built on earlier NEDU work down by Steve Reimers. The report specifies a range of breathing machine settings designed to simulate mild to very severe exercise (up to 75 liters/min. RMV), and also sets desirable values for the maximum mouthpiece pressures at these settings. Other standards used plots of mouthpiece pressures vs. volume to get a measure of actual work, and use this as a measure of performance. These goals were used as benchmarks for developing many of the breathing standards employed today, but there is controversy as to whether or not they can supplant human testing.

One school believes that meeting breathing machine goals is sufficient to allow field used of a UBA. For example, machine studies appear sufficient for evaluating the performance of scuba regulators and demand hard hat systems. In these types of systems, performance depends mainly on the flow resistance and the ability to deliver high gas volumes with a very small inhalation effort. However, in closed circuit rebreathers, flow resistance is only one component, and breathing bag placement can be equally important. A poorly placed breathing bag can cause significant breathing discomfort, even with little or no flow resistance in the loop. While there are studies indicating optimal breathing bag placement, only a diver exercising at the maximum operational depth can verify that the UBA will not limit exercise. Currently, the U.S. Navy requires that human testing be conducted before a new UBA is accepted into the fleet, no matter how well the system did on machine testing.

**TABLE 1: Graded Exercise Results for the Pre-Production MK-16 UBA** NEDU Report 13-80

| Depth/Gas | Work Rate (Watts) | $O_2$ Consumption (l/min stdpd) | Mean mouthpiece differential pressure (cm $H_2O$) | $P_{et}CO_2$ (mmHg) |
|---|---|---|---|---|
| 150 fsw/$N_2$-$O_2$ | Rest | 0.48 (0.15) | 7.3 (2.7) | 36 (2.9) |
| | 50 | 1.48 (0.33) | 10.8 (0.33) | 47 (5.0) |
| | 100 | 1.80 (0.33) | 14.5 (5.1) | 49 (5.0) |
| | 150 | 2.64 (0.41) | 20.5 (2.9) | 50 (8.0) |
| 300 fsw/He-$O_2$ | Rest | 0.46 (0.07) | 7.5 (2.0) | 33 (4.6) |
| | 50 | 1.30 (0.12) | 9.3 (1.0) | 43 (6.1) |
| | 100 | 1.87 (0.18) | 11.3 (1.6) | 48 (7.6) |
| | 150 | 2.47 (0.34) | 15.8 (3.4) | 48 (7.6) |

Standard deviations shown in parenthesis.

## Breathing Loop Performance

There are basically three components which determine the performance of a breathing loop. One is the flow resistance, another the static load placed on the lung by breathing bags, and the third is the dynamic load during exercise.

## Flow resistance

Assuming that gas flows are laminar within the breathing loop, breathing resistance can be computed by dividing the flow rate by the driving pressure. The lower the flow resistance the better, but oddly enough, a zero resistance is not necessary. The reason is that the passages in the lungs have an inherent flow resistance and will become the limiting factor in attaining the necessary RMV for CO2 elimination, even if there is no flow resistance in the external breathing loop. As gas density increases, a point is reached where the lung itself prevents further increases in the RMV, and blood CO2 levels become excessive, leading to dyspnea. The only option at this stage is to decrease the exercise level.

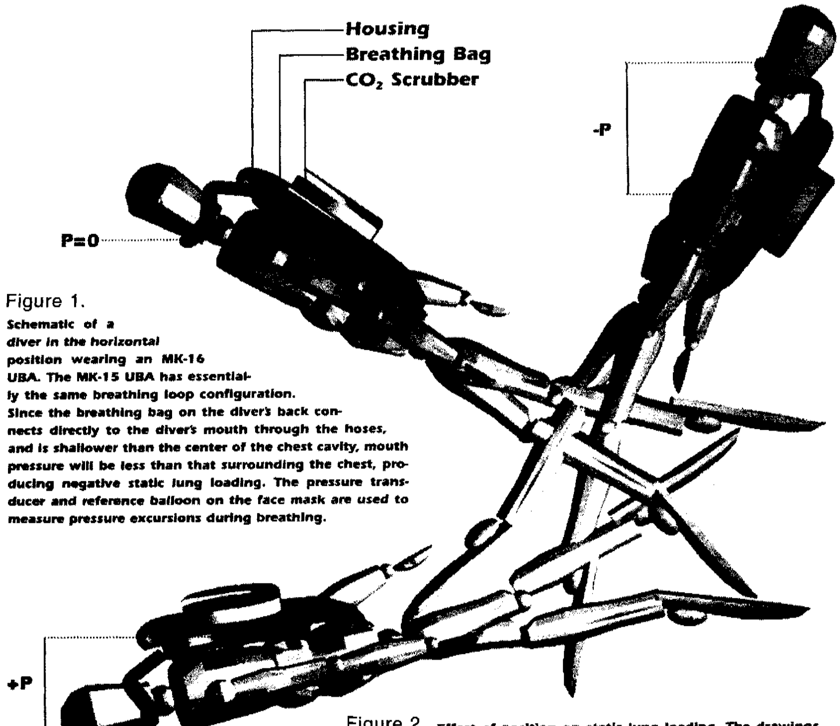


Figure 1. **Schematic of a *diver in the horizontal* position wearing an MK-16 UBA. The MK-15 UBA has essentially the same breathing loop configuration. Since the breathing bag on the diver's back connects directly to the diver's mouth through the hoses, and is shallower than the center of the chest cavity, mouth pressure will be less than that surrounding the chest, producing negative static lung loading. The pressure transducer and reference balloon on the face mask are used to measure pressure excursions during breathing.**

Figure 2. **Effect of position on static lung loading. The drawings show the difference between pressure outside the face mask and the breathing bag, but the sign would be the same if referenced to the lung centroid, the black dot in the center of the chest. The most comfortable position for the diver is where P≈0, the center position.**

While divers have performed exercise at depths in excess of 2000 f/614 m breathing heliox (oxygen-helium mixtures), gas density was sufficient to cause some exercise limitation . Exercise limitation of this sort can be seen at 190 f/58 m breathing air, although many of the effects are overshadowed by nitrogen narcosis. Breathing lower density heliox eliminates any significant breathing impediment to depths in excess of 500 f/153 m, with minimal effect even at 1000 f/307 m. Decreased breathing resistance and the absence of narcosis are the reasons that heliox is preferred for deep diving by military and commercial users.

Flow resistance in rebreathers occurs mainly in the one-way valves and in the CO2 absorbent canister. Modern valve technology can eliminate problems in this area. Carbon dioxide canister design is another problem.

Decreasing the size of the absorbent granules in order to improve the efficiency of CO2 absorption results in increased breathing resistance for a given sized canister. Designers thus have a tradeoff between CO2 scrubbing efficiency and canister size. The test results shown in Table 1 indicate that the MK-16 has a good breathing loop design and that flow resistance will not significantly impede exercise.

## Breathing Bag Placement: Static and Dynamic Lung Loading

Static lung loading is the pressure difference between the mouth and a point on the chest called the lung centroid during a period when no gas movement is taking place . In a horizontal diver, the centroid is on an imaginary plane running through the shoulders, dividing the chest into equal top and bottom halves. When upright, the centroid is on an imaginary horizontal plane passing through the about 15 cm below the larynx.

Figure 1 shows a diver wearing a MK16 in a horizontal position. The diver's mouth is connected to the breathing bags so the mouth pressure and breathing bag pressure are the same. Since the bags are on his back, mouth pressure will be less than the hydrostatic pressure at the plane of the lung centroid, a condition called "negative static lung loading." Figure 2 shows how this static lung load changes with position. It will be negative if the diver is horizontal or slightly head down (top), near zero if he is a 45-degree head up position (center), and positive as he begins rolling over on his back. Studies done at the University of Buffalo have shown that excessive positive or negative static lung lading can produce significant dyspnea and that having a slightly positive pressure differential at the mouth was optimal. There has been some debate over whether the static load which is perceived as the most comfortable by the diver is optimal, but the studies indicate that it's close. Essentially, if a rebreather feels comfortable in all positions, producing neither too high nor too low a static lung load as perceived by an experienced evaluator, the breathing bag placement is probably near optimal.

Divers using the MK-16 find a 45-degree heads up position more comfortable than other positions, indicating that the breathing bag placement is not optimal. The chest-mounted design on the Dräger Lar V oxygen rebreather is better, giving more optimal loads in both the horizontal and upright position. The Interspiro/AGA ACSC uses a counterweight to keep the static lung loading near optimal in all positions. The most recent UBA developed by the Navy, the MK-19, uses front chest breathing bags which pass over the shoulder, similar to those found in the older USN MK-6 rebreather [see Rebreather Basics by Ed Thalmann]). These produce near optimal static lung loading in all positions without the need for mechanical assistance.

Simply providing a new breathing bag design which optimizes static lung loading on paper is not good enough. Human evaluation is necessary because all of the factors involved in static load's contribution to dyspnea are not well known. The good news is that static loading can be evaluated in a pool, without having to go to depth, and consequently can be tested rather inexpensively.

**Simply providing a new breathing bag design which optimizes static lung loading on paper is not good enough. Human evaluation is necessary because all of the factors involved in static load's contribution to dyspnea are not well known.**

Besides static lung loading, the behavior of the breathing bags during exercise is also important. The volume of the bags, and the amount of positive and negative pressure at the mouth, change throughout the breathing cycle, producing what is known as dynamic loading. While not yet incorporated into a U.S. Navy standard, Dr. John Clarke at NEDU has done some theoretical work indicating that optimizing this dynamic load may significantly improve rebreather breathing performance [ see "Work of Breathing," by John Clarke] .

Though the interplay between breathing loop flow resistance, static lung loading, and dynamic loading are complex, the best indication is that something is awry is shortness of breath, resulting in exercise limitations. Under conditions of heavy exercise and high gas density, these factors, if not optimized, can result in uncontrollable hyperventilation. In this case, breathing discomfort continues to increase for the next minute or so even after exercise stops, and unless the diver has experienced this condition before and knows how to respond, it can lead to panic. If, for some reason, even a small amount of water enters the breathing loop during this period of hyperventilation, it could be inhaled, leading to laryngospasm, choking and drowning. This is the worst that could happen because of a poor breathing loop design.

## Canister Duration

In most rebreathers, the limiting factor for dive duration is the amount of time that the canister will eliminate exhaled CO2. Unfortunately, at the present time, there is no good method of measuring the amount of CO2 in the inhaled breathing gas during operational dives. For this reason, the U.S. Navy has developed a method of determining the amount of time a CO2 canister will function under certain conditions, the so-called "canister duration time." Duration time is a function of the canister design, the type of absorbent material used, water temperature, depth, and level of exercise. Once a canister duration time has been determined, the mission is planned so that this time is not exceeded.

One might suppose that a given volume of a particular CO2 absorbent would absorb the same amount of CO2 under all conditions. This would generally hold true in the laboratory, but doesn't in the field. Most chemical CO2 absorbents in use today use alkali metal hydroxides (sodium hydroxide, barim hydroxide, calcium hydroxide, lithium hydroxide), which chemically react with CO2. The degree to which this reaction can take place depends on the type of absorbent material , granule size, the canister flow path, temperature, moisture, depth, and breathing pattern. There are several manufacture's of CO2 absorbents. Determining which is the best has been the subject of extensive research in the U.S. Navy and there is still no easy way to evaluate how well they will perform using only laboratory studies.

In addition, large granule size may result in channeling; that is, the creation of flow paths through the canister bed that have lower resistance than others. When the absorbent material close to these paths is spent, the CO2 level will increase even though only a fraction of the total absorbent material in the canister has been used.

Designers try to make canister flow paths that will compensate for this, the goal being to ensure that all absorbent material is equally exposed. Using a smaller particle size increases absorbent efficiency, but the flow resistance through the canister may increase. Another consideration is how well the canister is packed with absorbent. If not done properly, voids are created that result in channeling. Some rebreather designs use pre-packed absorbent inserts to avoid this problem. In some packages, the material surrounding the absorbent passes gas but not water, which will prevent the very caustic absorbent from entering the breathing loop if flooding occurs.

The absorbent reaction with CO2 is exothermic and will not proceed efficiently if the material is too cold. As a result, canister durations are usually shorter in colder water. Since the reaction produces heat, insulating the canister to retain it will markedly improve cold water performance. (In some cases the Navy has piped water from the diver's hot water suit to heat the outside of the canister, but this is not an option for free swimming divers.) Another factor determining canister duration is the breathing gas and depth. How these relate is not well understood, but since gas heat content is proportional to density, decreased duration times at increased depth might be due to a more rapid canister heat loss, which in turn leads to a lower scrubbing efficiency. The thermal conductivity of the gas may also play a role.

## Measuring Canister Duration

Before believing manufacturer claims about canister duration time, ask to see the test data. Unless backed up by actually measurements made at various depths and temperatures and exercise levels, the claims are hollow. Canister duration studies performed by the U.S. Navy are long, arduous procedures, but do provide the measure of confidence needed to set reasonable operation canister times. Divers exercise on a bicycle ergometer at 75 watts for 6 minutes, followed by 4 minutes of rest. Studies are done over a range of depths and water temperatures.

**Before believing manufacturer claims about canister duration time, ask to see the test data. Unless backed up by actually measurements made at various depths and temperatures and exercise levels, the claims are hollow.**

Figure 3 shows some test results from the MK 15 mixed gas rebreather. The traces show the CO2 partial pressure leaving the canister at surface equivalent value, SEV (1%=0.01 atm), as the test progresses. The levels rise during exercise, reaching a maximum just as the diver stops exercising and begins his rest period, after which time they fall. The smooth curve approximates the mean peak levels. The point at which it crosses the 0.50% SEV mark (0.005 atm) is defined as the canister duration time. In the top panel, this occurs in 75 minutes; in the bottom it has not occurred even after four hours. Both of these traces are from the same diver, using the same rebreather with the same amount of absorbent material each time. This variability is the reason human testing must be done, but as technology improves it should become less of a problem. After several such runs (usually at least 6), the mean duration time for all funs is computed and one standard deviation subtracted to get the operational time.

The 0.05% SEV level does not imply that breathing higher CO2 levels is dangerous. Levels up to 2.0% SEV (0.02 atm) are well tolerated during exercise. The low level was chosen to provide a safety factor to account for the potential variability in canister duration times so that it would be unlikely that levels

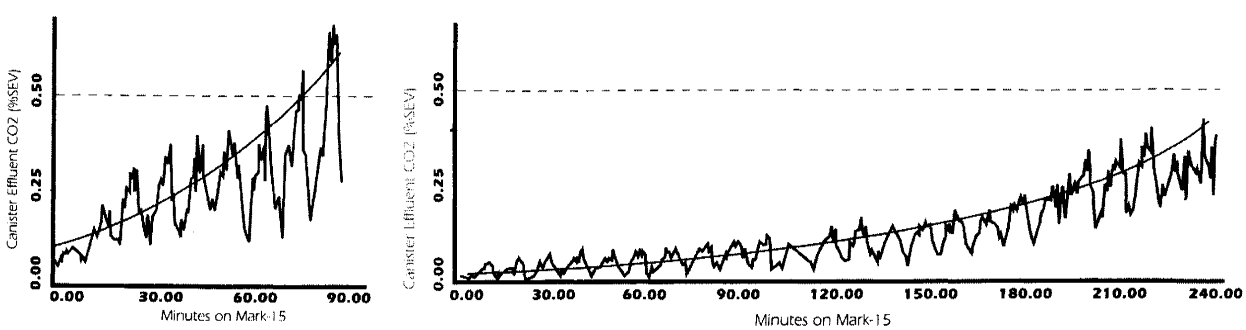


Figure 3. Results of canister duration runs for the MK-15 UBA in 13.4$^{0}$ C water at 65ft/20m and a diver $O_2$ consumption of 1.58 liters/min. [stpd]. Both runs are with the same diver using the same rig with exactly the same amount of $CO_2$ absorbent in the canister. The $PCO_2$ is measured at the canister exit in % SEV (surface equivalent value) (1% sev = 0.01ata). The $PCO_2$ rises and falls with each 6 min. exercise/4 min. rest cycle and the trend of the peak values is upward as time goes on (solid smooth line). The first run [left], the smooth fitted line crossed the 0.5% SEV (breakthrough) at a 75 mi. canister duration time. In the subsequent run [right], breakthrough had no occurred even after 4 hours.

above 2.0% SEV would be encountered.

Since increasing canister duration is the limiting factor in rebreather diving, it is of primary concern to operation units. The alternating work rest cycle seems to give shorter durations than if the same amount of CO2 is passed through ata constant level. However, this worst caste condition may not reflect realistic exercise patterns. Research has been done trying to relate the canister duration time to level of exertion, so credit can be given for those long periods where little or no exercise is done. The problem is determining just what exercise levels over what time periods should be used for duration studies. Canister duration limits will continue to be an area of concern until some real-time method of measuring CO2 during operations is found. Until then, it is probably best to rely on duration times determined under worst case conditions where the exercise level is slightly higher and water temperature slightly cooler than it would be during actual diving operations.

**Simply getting into a pool for some test swims is not adequate since breathing characteristics can deteriorate rapidly as gas density increases.**

## CO2 Intoxication (Hypercapnia)

Conventional wisdom holds that divers can detect when CO2 levels are too high by noting that they are breathing faster, or that they are getting a sensation of "air hunger." In fact, under certain conditions, these are unreliable indicators and the first sign of hypercapnia could be unconsciousness. The sensation of "air hunger" can be brought about by both low oxygen levels and high CO2 levels. In diving, oxygen levels are usually high, so the more powerful hypoxic component is removed, leaving only high CO2. Carbon dioxide is a narcotic and at high levels dulls the judgment, and in fact decreases the discomfort produced by the dyspnea. Under these conditions, divers may continue exercising to the point where unconsciousness is the first symptom that occurs.

## The Bottom Line

Any rebreather should be subjected to some sort of testing so that it's performance can be compared to other UBAs whose characteristics are well known. Simply getting into a pool for some test swims is not adequate since breathing characteristics can deteriorate rapidly as gas density increases. During most open sea dives, work rates equivalent to the 50 watts shown in Table 1 would be the norm. However, in emergencies, the 150-watt work rates would be more typical and it would be a bad time to find out that there were significant breathing limitations. NEDU reports are available which document the test results of most Navy rebreathers in fleet use. These can be used as benchmarks for comparison, assuming that similar test results are available for the rebreather in question.

Since the conditions producing dyspnea are a function of both depth and exercise, only testing done at the maximum operational depth and highest anticipated exercise level is adequate. Sufficient experience must be gained under these conditions with any new design so that any performance limitations are known well in advance. Ideally, divers using any rebreather should be able to experience these limitations firsthand under safe, controlled conditions before using it on any operations. Only with this type of experience can divers decide if a rebreather will meet their needs on a particular dive and that it can be used both safely and sanely.

*Retired USN Captain, Ed Thalmann, M.D., was responsible for writing the physiological specifications for all of the US Navy's breathing apparatus, and conducting manned testing for the MK 11, MK 15, MK 16, and LAR V rebreathers. Having served for ten years at the Navy Experimental Diving Unit, four as the senior medical officer, he is currently with the Division of Occupational and Environmental Medicine at Duke University and is the Medical Director at the Divers Alert Network.*

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An index of available NEDU reports can be obtained by writing: Commanding officer, Navy Experimental Diving Unit, 321 Bullfinch Rd, Panama City, FL 32407-5001.

**Footnotes**

1.RMV is measured in actual liters per minute; the physical volume of gas is independent of depth. But as depth increases, the gas denisty increases proportionately, so the number of gas molecules in that volume increases with depth.

2. Other systems such as gas reclaim systems involve back pressures which can simulate static lung loads. Discussing the role of human testing in these types of UBA is beyond the scope of this article.

# Oxygen Exposure Management

by Richard D. Vann

Abstract

*Oxygen metabolism is the primary energy source in higher life forms, but when oxygen enters the metabolic process prematurely, reactive oxygen species can form which interfere with normal function and cause convulsions or other symptoms of oxygen toxicity. Immersion, exercise, and inspired carbon dioxide increase susceptibility to oxygen toxicity by elevating cerebral blood flow and oxygen delivery to the brain. The risk of toxicity is reduced by limiting oxygen exposure, but exposure limits are based on limited data. Limits for oxygen in mixed gas appear shorter than for pure oxygen. Open-water experience indicates that convulsions can occur near the accepted exposure limits. The risk of oxygen toxicity can be modeled statistically but with uncertain accuracy. The choice of "safe" exposure limits depends upon the risk of convulsions one is willing to accept. The maximum "safe" oxygen partial pressure for open circuit air or nitrox diving in the water appears to be in the range of 1.2-1.4 bar though some individuals set the limits as high as 1.6 bar. For pure oxygen, 1.6 bar has been used safely for in-water decompressions of up to 30 min.*

Knowledge of central nervous system (CNS) oxygen toxicity is unnecessary in order to breathe oxygen underwater safely at a partial pressure of one bar or less. Considerably more knowledge is needed at higher partial pressures or when the oxygen pressure changes with time. The real questions are; how much oxygen can be used safely given our current knowledge, and how can oxygen be used more effectively without sacrificing safety?

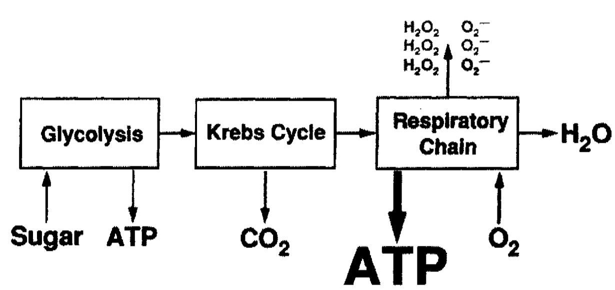
## The Biochemistry of Oxygen Toxicity

(Stryer 1988)

Oxygen metabolism is the primary energy source in higher life forms. Because heat energy produced by oxygen reactions such as fire would damage tissue, metabolic pathways have evolved that safely capture small packets of reusable chemical energy. This energy is stored in molecules called adenosine triphosphate (ATP).

Figure 1 illustrates some features of ATP production during the breakdown of sugar at normal oxygen partial pressures. The biochemical processes known as glycolysis use no oxygen and produce relatively little ATP. The major product of glycolysis, pyruvic acid, enters the Krebs cycle which releases carbon dioxide and supplies electrons needed to form ATP. Most ATP is produced in a series of electron transport reactions called the respiratory chain.

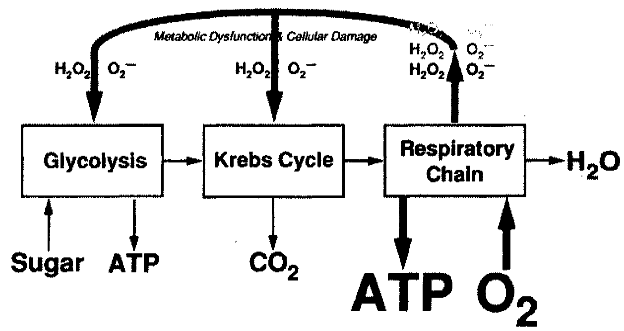
Oxygen usually does not enter the respiratory chain until the very end where it reacts with hydrogen to form water. Should oxygen enter the respiratory




1. The production of ATP during the breakdown of sugar at normal (normoxic) oxygen partial pressures.

chain prematurely, molecules like the superoxide anion (O2-) and hydrogen peroxide (H2O2) can form. These reactive species of oxygen are potentially toxic but are deactivated by protective enzymes such as superoxide dismutase and catalase.

When the oxygen partial pressure is raised (Fig. 2), the production of reactive oxygen species increases and may overwhelm the protective mechanisms. This can initiate biochemical and physiological changes that interfere with normal function and cause signs and symptoms we know as oxygen toxicity.



2. The production of ATP and reactive oxygen species during the breakdown of sugar at elevated (hyperoxic) oxygen partial pressures

## Signs and Symptoms of CNS Oxygen Toxicity

(Donald 1992; Clark 1993)

Convulsions are the most spectacular and objective signs and symptoms of CNS oxygen toxicity, but there is no evidence they lead to permanent damage if the oxygen exposure is discontinued promptly. This assumes, of course, that drowning or physical injury are avoided. Experimental oxygen exposures are often terminated by less specific symptoms including abnormal breathing, nausea, twitching, dizziness, incoordination, and visual or auditory disturbances. These symptoms do not necessarily precede convulsions.

**Convulsions are the most spectacular and objective signs and symptoms of CNS oxygen toxicity, but there is no evidence they lead to permanent damage if the oxygen exposure is discontinued promptly.**

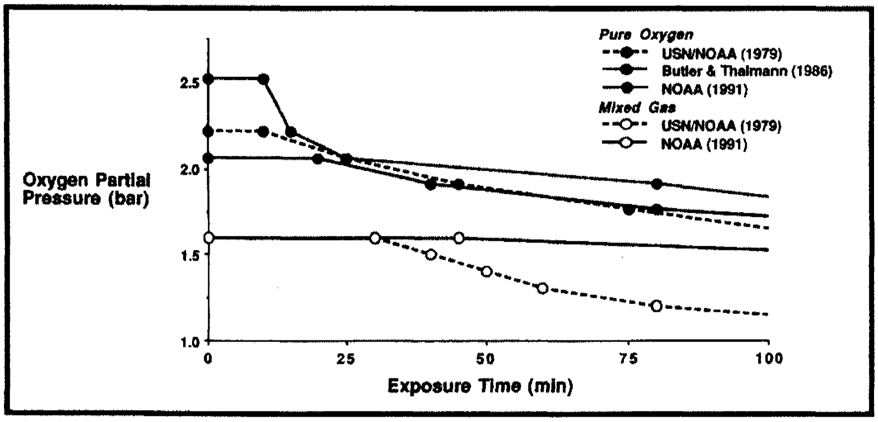
Factors which elevate cerebral blood flow, thereby augmenting oxygen delivery to the brain, appear to increase susceptibility to oxygen toxicity. These factors include immersion, exercise, and carbon dioxide. Carbon dioxide may be present in the inspired gas or may be retained due to inadequate ventilation. Inadequate ventilation can be caused by high gas density, external breathing resistance, or poor ventilatory response to carbon dioxide by "CO2 retainers" (Lanphier 1982; Warkander et al. 1990).

## Oxygen Exposure Limits

Oxygen exposure limits like those of Fig. 3 were established to decrease the risk of convulsions for divers breathing pure oxygen or oxygen in mixed gas. Figure 3 shows three sets of pure oxygen limits and two sets of mixed gas limits. The U.S. Navy limits from the 1973 Diving Manual (USN 1973) were published in the 1979 NOAA Diving Manual (NOAA 1979). The Navy has since modified its pure oxygen limits (Butler and Thalmann 1986) while NOAA has modified both the pure oxygen and mixed gas limits for its 1991 Diving Manual (NOAA 1991). Compared with the 1973 Navy/1979 NOAA limits for pure oxygen, Fig. 3 shows that the 1986 Navy limits are less conservative while the 1991 NOAA limits are more conservative. For mixed gas, the 1991 NOAA limits are less conservative than the 1973 Navy/1979 NOAA limits.

The changes to the exposure limits of Fig. 3 reflect uncertainty concerning which limits are best and suggest an examination of the type of data upon which oxygen limits are based. These data are shown in Fig. 4 and represent most of the CNS toxicity episodes that have occurred in U.S. experiments during wet, working dives at a single depth for pure oxygen or for oxygen in mixed gas (Lanphier and Dwyer 1954; Lanphier 1955; Piantadosi et al. 1979; Vann 1982; Schwartz 1984; Butler and Thalmann 1984, 1986; Butler 1986; Lanphier 1992). The squares represent convulsions, and the triangles represent symptoms. The 1991 NOAA limits are shown for comparison. While the discussion below is confined to U.S. data, Donald (1992) has recently published a large body of British data which will be very important.

The mixed gas incidents occurred at lower oxygen partial pressures than the pure oxygen incidents. Lanphier, who conducted oxygen research for the Navy in the 1950's, postulated that high breathing resistance during deeper mixed gas dives caused carbon dioxide retention which potentiated oxygen toxicity by increasing cerebral blood flow (Lanphier and Dwyer 1954). This led him to propose more restrictive limits for mixed gas than for pure oxygen. In subsequent studies, the lowest partial pressure and shortest exposure time at which a mixed gas convulsion occurred was 1.6 bar for 40 min (Vann 1982; Vann




3. Oxygen exposure limits for pure oxygen and for oxygen in mixed gas as published by NOAA and the U.S. Navy. The 1973 U.S. Navy limits (USN 1973) were adopted for the 1979 NOAA Diving Manual (NOAA 1979). These are indicated as USN/NOAA 1979. The Navy revised its pure oxygen limits in 1986 (Butler and Thalmann 1986). NOAA revised its pure oxygen and mixed gas limits in 1991 (NOAA 1991). Exposure times and pressures are connected by line segments to facilitate comparisons. Field application requires step changes at the indicated points. The original references should be consulted for operational use.

and Thalmann 1993). The corresponding exposure for pure oxygen was 1.76 bar for 72 min (Butler and Thalmann 1984).

The mixed-gas convulsion occurred after 40 min at 100 fsw during a wet, working nitrox chamber dive with a 1.6 bar oxygen set-point in a rebreather (Vann 1982). Heavy exercise and high breathing resistance appeared to be contributing factors. Upon decreasing the breathing resistance and reducing the oxygen pressure to 1.4 bar, 110 dives were conducted with no further oxygen incidents during 60 min exposures at 100 and 150 fsw with both nitrox and heliox.

Is an oxygen partial pressure of 1.4 bar sufficiently conservative given the potential for depth control error, the unpredictability of carbon dioxide retention, and the minimal mixed-gas exposure data? The Navy is leaning towards a set-point of 1.2-1.3 bar for rebreathers where the oxygen partial pressure fluctuates during control around a pre-determined set-point (Thalmann, personal communication).

The data of Fig. 4 suggest a need for separate mixed gas and pure oxygen limits but are insufficient to conclusively prove this need. As a convulsion underwater is potentially fatal, however, a cautious diver might wish to use separate oxygen and mixed gas limits until further data firmly establish they are unnecessary.

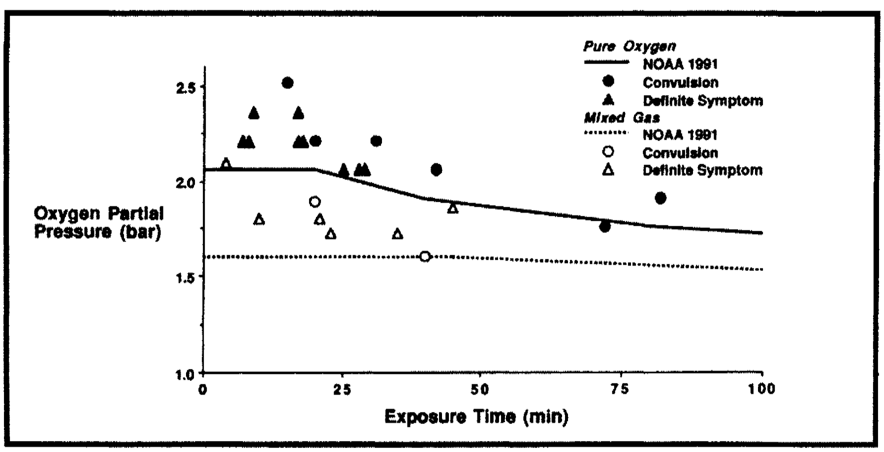
## Open-Water Experience

What can we learn about oxygen toxicity from open-water diving with mixed gas and pure oxygen? The incidents described below took place in 1993.

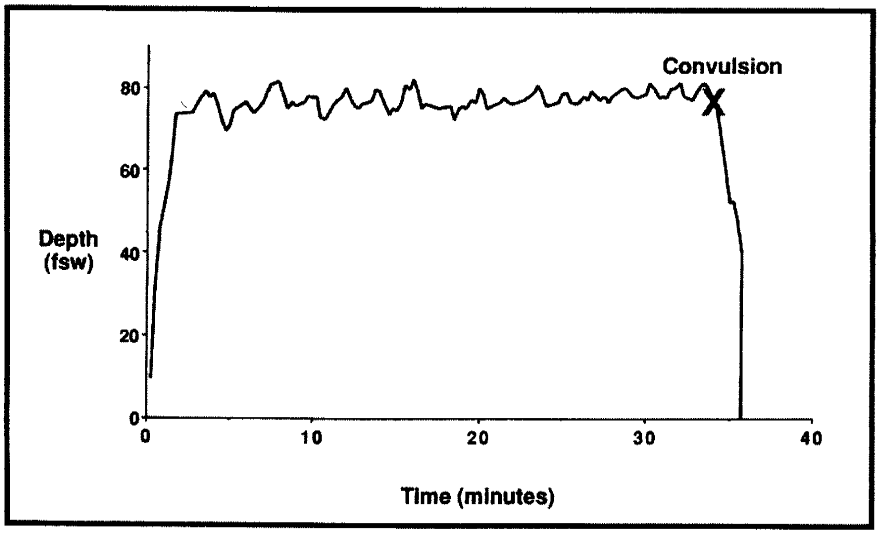
A mixed gas fatality occurred in a southeastern U.S. cave where two divers breathed air for 15 min and EAN 40 (40% O2, balance N2) for 45 min at depths of 80-105 fsw (Menduno 1992). The oxygen partial pressure was mostly 1.4 bar but occasionally reached 1.5-1.7 bar. After 45 min of hard swimming on enriched air nitrox, one diver convulsed and lost his regulator. His buddy could not reinsert the regulator, and the diver drowned after a failed attempt to swim him out of the cave. The oxygen exposure was, for the most part, less than the 1991 NOAA limit of 1.6 bar for mixed gas diving.

Another enriched air diver who drowned after an apparent convulsion had told friends that the NOAA limits did not apply to him (Menduno 1992). His oxygen partial pressure was estimated at 1.7-2.0 bar for a bottom time of 45-50 min.

An incident involving pure oxygen occurred in a southeastern U.S. lake (Menduno 1992). After an 8




4. CNS oxygen toxicity data (convulsions and symptoms) from U.S. experiments with wet, working divers exposed to constant oxygen partial pressures (Lanphier and Dwyer 1954; Lanphier 1955; Piantadosi et al. 1979; Vann 1982; Schwartz 1984; Butler and Thalmann 1984, 1986; Butler 1986; Lanphier 1992). The 1991 NOAA exposure limits for pure oxygen and mixed gas are shown for comparison (NOAA 1991).




5. The depth-time profile recorded by a dive computer for an exposure on 32.8% nitrox at a nominal depth of 80 fsw and oxygen partial pressure of 1.26 bar. The dive was terminated at 34 min by a convulsion. After rescue, the diver was found to have an unreported history of convulsions and to be on anti-convulsant medication.

min exposure at 300 fsw on a trimix 14/33 (14% O2, 33% He, and 53% N2) a diver decompressed on EAN 32 to 20 fsw where he switched to pure oxygen. Prior to breathing oxygen at 20 fsw (1.6 bar PO2), his PO2 was 1.4 bar except for 7 min at 1.5-1.7 bar. After 20 min on oxygen, he unclipped from his decompression line to visit a nearby diver but drifted down to 35 fsw (2.05 bar PO2) and dozed off. (An Emergency Medical Technician, he had slept only 2 hrs the previous night.) He was awakened by abnormal breathing and the onset of convulsions but inflated his buoyancy compensator before losing consciousness. He recovered from near drowning after rescue on the surface.

**It is commonly assumed that convulsions do not occur at oxygen pressures of less than about 1.6 bar, but this assumption depends on a normal seizure threshold.**

It is commonly assumed that convulsions do not occur at oxygen pressures of less than about 1.6 bar, but this assumption depends on a normal seizure threshold. Figure 5 shows the depth-time profile of an 80 fsw dive that terminated with a convulsion at 34 min (Vann et al. 1992). The diver breathed EAN 33 with an oxygen partial pressure of 1.26 bar. After rescue, he was found to have an unreported history of convulsions and to be on anti-convulsant medication. While such a situation is rare, it emphasizes the uncertainty of our knowledge, the need to expect emergencies such as oxygen convulsions or decompression illness, and the necessity for emergency management plans.

## Statistical Modeling

Do these open-water incidents over emphasize rare events? What is the risk of a rare event? We can estimate this risk by statistical modeling of oxygen exposure data (Vann 1988).

Suppose the risk of oxygen toxicity increased with the concentration of the reactive oxygen species produced during hyperoxic metabolism (Fig. 2) and represented below by "X." Suppose also that the rate of change of the local concentration of X were equal to its production minus its removal. If X were produced in proportion to the local oxygen tension (c •PO2) and removed at a fixed rate (k), its rate of change would be

$$dX/dt = c \cdot PO2 - k$$

where c and k are constants. When integrated, this first order differential equation gives

$$(1) \quad X = (c \cdot PO2 - k) \cdot t$$

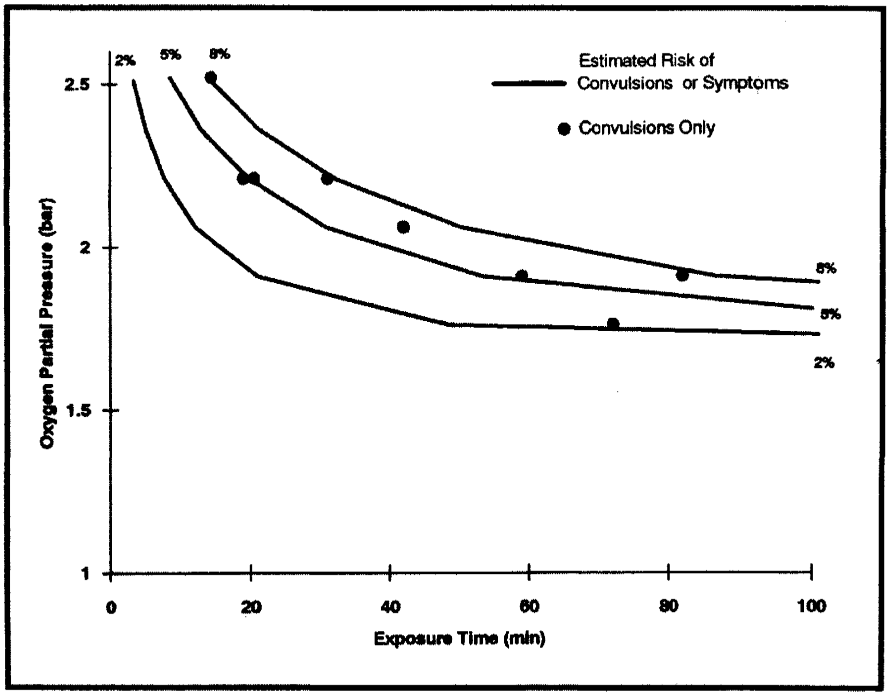
The risk of toxicity is specified by a separate function of X.

Equation 1 defines a family of rectangular hyperbolas proposed empirically for the pressure-time relationship of pulmonary and CNS oxygen toxicity (Clark 1974). Statistical modeling derives this relationship theoretically and finds the constants c and k directly from experimental data (Vann 1988). This allows the risk of toxicity to be estimated for any oxygen exposure.

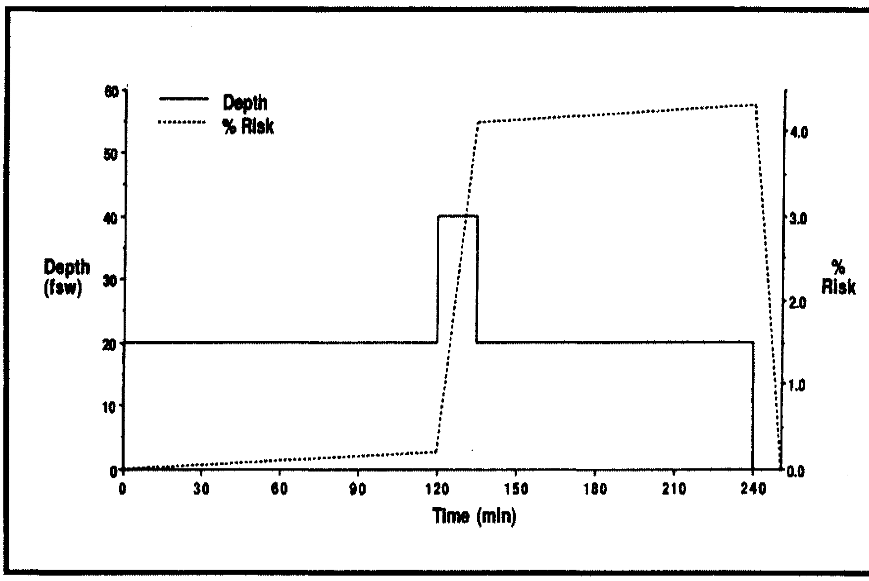
Figure 6 shows three rectangular hyperbolas for 2%, 5%, and 8% risks of either symptoms or convulsions. These were estimated from data on 773 pure oxygen exposures. The convulsions, represented by black dots in Fig. 6, occurred at estimated risks of 2-8%. In a context of risk, an oxygen exposure limit is the depth and time at the level of risk which is judged to be acceptable. In Fig. 6, for example, the limit for a pure oxygen exposure at 25 fsw (1.76 bar) would be 49 min if a 2% risk of either symptoms or convulsions were judged acceptable. The level of acceptable risk for a chamber dive where immediate rescue is possible after a convulsion is greater than for an open-water dive where drowning is the likely outcome.

Statistical modeling can track the resolution of risk as well as its development. In Fig. 7, for example, a pure oxygen diver spends 120 min at 20 fsw, 15 min at 40 fsw, and 105 min at 20 fsw. His risk increases gradually to 0.2% while at 20 fsw and rapidly to 4.1% at 40 fsw. The maximum risk of 4.3% occurs just before surfacing after which the risk resolves in 10 min.

Unfortunately, the accuracy of the risk estimates of Figs. 6 and 7 is uncertain because human oxygen exposure data are limited and their results variable (Donald 1992; Clark 1993). This uncertainty encourages conservative exposure limits, at present, instead of permitting the oxygen exposure to be adjusted continuously such that the estimated risk never exceeds the risk judged to be acceptable. For mixed gas, even less data are available than for pure oxygen, and the potential for carbon dioxide retention introduces further uncertainty which makes modeling of mixed gas risk even more problematic.




6. Estimates of CNS oxygen toxicity risk based upon a statistical model (Vann 1988). The model was fitted to experimental data from 773 pure oxygen exposures which resulted in 11 convulsions and 33 incidents of symptoms. Exposures for estimated risks of 2, 5, and 8% are shown with the observed convulsions.




7. The development and resolution of CNS oxygen toxicity risk according to the model of Fig. 6 during a multi-level dive on pure oxygen.

## What Are "Safe" Oxygen Exposure Limits?

The choice of "safe" oxygen exposure limits depends upon the risk of convulsions that one is willing to accept. This subjective judgment is rendered all the more difficult because so few data are available from which to estimate risk and because there is so much variability in the response to oxygen exposure. Variability can be due to exercise, carbon dioxide retention, gas analysis error, oxygen set-point control, and susceptibility to oxygen toxicity from inter- and intra-individual differences.

For air or enriched air diving, a maximum exposure limit of 1.2 bar would appear to be conservative while allowing a "cushion" for oxygen partial pressure increases due to unplanned depth excursions. Perhaps 1.4 bar would be acceptable if depth could be carefully controlled. On the other hand, there are those who testify to diving safely at 1.6 bar. This may well be true, but skepticism is appropriate until these divers document their claims in the form of computer-recorded depth-time profiles with certified breathing mixtures (Fig. 5). Denoble et al. (1993) describe a project and data acquisition software which might help to provide such documentation.

For pure oxygen, commercial (Imbert and Bontoux 1987) and scientific experience (Fife et al. 1992) suggests that at least 30 min of in-water oxygen decompression may be possible at 1.61 bar (20 fsw) with little risk of CNS toxicity. Experimental data (Fig. 4) also suggest a low risk at 1.76 bar (25 fsw), but a small depth excursion can cause large increases in oxygen pressure. Pure oxygen diving at depths below 20 fsw is more hazardous.

**A particularly important advance that might eliminate much of the current unpredictability would be a mouthpiece sensor for measuring end-inspired and end-expired carbon dioxide. In the meantime, a patient and conservative approach to oxygen exposure management is appropriate to minimize the frequency of mishaps. . .**

Improvements in our ability to manage oxygen exposure are expected as basic studies illuminate the fundamental biochemistry and physiology, as additional exposure data become available, and as statistical modeling methods develop. Basic studies have already led to pharmacological methods for extending oxygen exposure in mice (Oury et al. 1992), but further work is needed before such methods are applied to humans. The diving community itself can provide some of the necessary exposure data should it adopt a rigorous approach to data collection. Statistical modeling and computer tracking of oxygen exposure may eventually lead to guidelines for variable oxygen partial pressures to supplement single stage oxygen limits (Fig. 3). A particularly important advance that might eliminate much of the current unpredictability would be a mouthpiece sensor for measuring end-inspired and end-expired carbon dioxide. In the meantime, a patient and conservative approach to oxygen exposure management is appropriate to minimize the frequency of mishaps such as those of the past year.

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# Learn From Other's Mistakes: An Analysis of Military Closed Circuit Diving

by James D. Brown

I've written this article for technical diving agencies, operators, and divers who want to use mixed-gas rebreathers. Since mixed-gas closed circuit equipment is the most complex of several available rebreather options, its potential users face the greatest challenge, and it behooves manufacturers to effectively communicate with these individuals who represent their greatest source of liability.

First of all, let me explain that I'm not just another military diver ready to tell you about what you should or should not do with rebreathers. In addition to teaching the LAR V rebreather course at the US Army's Special Forces Underwater Operations School, I'm an IANTD Trimix Dive Supervisor, who is interested to see the recreational rebreather industry grow. As a member of the recreational diving community, I know that your bottom line is to make a living in this industry, or if you're a diver, to enjoy the marvelous underwater world. Some of the material below may be basic for current civilian users of mixed-gas closed circuit rebreathers who undoubtedly have their own insights to contribute. It's important to note that the military is not a perfect world, but most of it's members strive for perfection.

Why should technical divers consider the military's experience with rebreathers? The military has made just about every mistake possible with rebreathers over the last 50 years, and there in lies the answer. Rebreathers are complicated machines, and the military has run the gamut of medical, operational, and equipment problems during its rebreather operations with both mixed-gas and oxygen rebreathers [Note that the US Military does not use semi-closed systems—ed.].

Failure is one of the many factors that stimulate human creativity, and in the case of the US Military, has contributed to the evolution of its closed circuit diving programs. Recreational programs can benefit from the military's mistakes by carefully examining current programs for concepts that are applicable. When reasonably applied to civilian diving, these concepts can provide a safer, more effective and responsible operation that is required for rebreather use.

**These principles serve as a repository of the lessons that have been learned by military operators through experience, and can be reasonably adapted to fit the needs of civilian closed circuit diving.**

What aspects of the military's closed circuit diving program can civilian rebreather divers benefit from? After all, the military has refined rebreather diving to suit it's way of doing business. This has resulted in operations that are significantly different from those found in recreational diving.

At first glance, it's hard to find detailed information that can be directly applied to recreational rebreather diving. The analysis is further complicated by the fact that rebreather training and operation is product specific. Some divers may decide that there can't possibly be anything to learn, since they will probably not be diving a military rebreather.

The key is to step back and look at the basic principles that guide military operations. These principles serve as a repository of the lessons that have been learned by military operators through experience, and can be reasonably adapted to fit the needs of civilian closed circuit diving. This may cost some additional time and money; but probably not much.

What I'm proposing is a different way of conducting your operation, and the transition will primarily involve your time. Material acquisition is minimal. Consider the following point. If you are seriously thinking about getting involved with closed circuit diving, then you must provide a complete, quality operation to your customers. The increased costs of doing so can be passed on to the consumer. Your customers will appreciate the enhanced safety and support environment that you provide, and will respond by giving you repeat business, and bringing new divers to your operation.

**If you don't invest in upgrades to your operation, you will likely pay more money later, assuming that you are still in the closed circuit business.**

A quality dive operation is hard to find. If you don't invest in upgrades to your operation, you will likely pay more money later, assuming that you are still in the closed circuit business. If the industry doesn't adequately support the customer's closed circuit diving from the beginning, you'll likely be paying more for your insurance, and possibly having to deal with the heirs of your former customers who have drowned. This potentially unsatisfactory state of affairs applies to the entire rebreather industry, not just your operation.

Having laid the ground work, I'd like to summarize the fundamental concepts of military diving. Note that I left out the word "rebreather." That's because most of these concepts are the same for all military dives, independent of the equipment used. These can be found in the *USN Diving Manual,* Volume 1 (Air Diving) and Volume 2 (Mixed-Gas Diving) which heavily references Volume 1. Other concepts have evolved separately from the USN Diving Manual, and can be found in various regulations, operations and maintenance manuals, as well as the training philosophy of the various services involved.

Having identified a key concept, I will address its application within the context of the current capabilities and practices of the technical diving community. I've used technical divers as an example, but this does not discount the capabilities of the rest of the recreational diving world. Some technical agencies, retailers, and divers already apply these fundamentals in their own programs to various degrees, however, most of the community does not effectively use these concepts to their maximum advantage. Some individuals appear to be actually working against these principles, and in my opinion, are not suitable candidates to teach or manage rebreather operations.

## Key Concepts

1) Strict written procedures form a body of comprehensive references. When performing certain tasks, for example, rebreather pre-dive procedures, divers always use checklists. This requirement exists no matter how expert the individual has become at performing the task.

Technical dive training agencies have proprietary reference materials which combined with outside references, provide the recorded basis for their operation. The quality and depth of the material vary widely, and generally few if any references are taken along on a diving operation. The use of field planning and operational guides and checklists is inadequate in most cases compared to military standards.

2) A formal qualification process provides consistency and quality control for personnel. When it comes to qualifying individuals at a dive school, there is no "good 'ol boy network" to allow substandard performance. Instructors know that they might be diving with the diver they graduate one day, and their lives may depend upon that individuals performance in the event of emergency.

The good 'ol boy network appears to be alive and well in technical dive training. I'm may anger someone here, but I'll relate a recent event. A very experienced cave diver reportedly approached one of the technical certifying agencies for rebreather instructor certification. The agency presented the requirements and costs of getting the certification. The applicant stated that he would think about the requirements, then called another agency. The second agency reportedly qualified the applicant over the phone for a fee. The manufacturer of the rebreather recognized the inadequacy of the qualification, and correctly decided not to honor the instructor status of that individual. Events like this clearly work to the detriment of the community.

3) The qualification process is supported by a detailed and comprehensive qualification program in which the tasks, the conditions under which the tasks are to be performed, and the standards for satisfactory completion of the task are clearly stated. In the military, we use the same performance-oriented training that civilian trainers use. We emphasize maximum "hands-on" exposure to the equipment, using a crawl-walk-run methodology.

Most if not all civilian agencies follow the above concepts to varying degrees. However, the greatest divergence between the military and civilian operations involves the following concepts:

4) Without exception, the military conducts it's diving in teams. A military diving operation uses a specific task organization in which every individual has specific duties and responsibilities. As the complexity of the operation goes up, so too does the number of personnel and quantity of equipment required to support it.

There are very few technical dive operators who provide adequate support crew for a decompression dive from a military perspective [Operations are the key to technical diving safety. See Blueprint For Survival 2.0 by Billy Deans & Michael Menduno, *aquaCORPS Journal* #12]. At a minimum, four people are required on site. A dive supervisor who stays on the surface, a safety diver, who meets the ascending dive team at their first stop or gas switch, and a two diver team. Once the first team has completed their dive, the team can change over, and the two support personnel can conduct their dive, supported by the first dive team. Many sport diving operators provide only a ride to the dive site, and leave the rest of the operation to the divers. Their supervisory or safety involvement is minimal or nonexistent.

5) As a rebreather user, you must provide a sanitary area for storage. If you intend to service rebreathers, or if you currently service components that come into contact with pure oxygen, you should seriously consider acquiring the various reference documents that relate to the use of pressurized oxygen in the workplace. You might find out that you're breaking the law. The Compressed Gas Association, OSHA, Code of Federal Regulations, and state laws address this subject.

6) Cross-training allows team members to fill the roles of others. This gives an element of flexibility to the organization; the unexpected absence of any single individual within the team will not necessarily jeopardize the safety of the dive team. Understanding each members duties allows appropriate action in the event of an emergency.

Within the civilian community, cross-training is a natural progression for a technical diving team organization.

7) Comprehensive, standardized briefings, given by the dive supervisor or dive team leader, convey the essential knowledge which team members need to do their jobs. The information has to be clear and concise; there is obviously a balance that has to be found between too little and an overload. To control this aspect of the briefing, the dive supervisor is challenged by an informal time limit standard of 20 minutes. Complex briefings can last longer, if necessary. To support the dive briefing, operation and apparatus-specific references are available, briefed, and understood by everyone involved. This is understood even by the safety diver, who is essential to the safe conduct of the dive. The boat crew should know the plan so they can react appropriately to unforeseen events. The briefing includes the following minimum points:

- The mission; what is to be accomplished during the dive.
- Protocols stating primary, alternate, and contingency decompression schedules.
- Operating procedures (OPs) and emergency procedures (EPs) for the diving system.
- Predive, postdive, and operational checklists are used extensively to reduce errors.

The worst-case civilian scenario offers little or no briefing. This is often the case where dive operators view their role as no more than transportation to the dive site.

8) A strong organization provides leadership to focus the team's effort, and to provide role models for less members of the team. This serves as a valuable tool for propagation of good rebreather diving practices. The supervision exercised in the military dive operation is intended to reduce natural human errors, and does not burden the activity. There are several predive checks by dive supervisors intended to ensure the highest level of perfection attainable.

Civilian diving leaders must consider the effect of their actions upon the rest of the community. Their actions, good and bad, are copied by their followers. The ideal form of supervision for independent-minded tech divers might be a standardized interaction intended to reduce the chance of error during the predive phase of the operation. This is particularly useful during setup and testing of rebreathers. Two heads are better than one when attention to detail is critical.

9) The leadership of a military rebreather diving operation has a comprehensive knowledge of rebreather diving. The leader of the group may dive, and need not be the dive supervisor for the dive. Dive supervisors in the military are thoroughly familiar with the apparatus and the operation. This is allows them to be able to make the right decisions if something goes wrong.

In technical diving, the leader is often the most experienced diver and like his or her military counterpart, should have comprehensive knowledge of the equipment and operation. It is tempting to say that

**The worst-case civilian scenario offers little or no briefing. This is often the case where dive operators view their role as no more than transportation to the dive site.**

the a dive supervisor and support crew must be qualified on the equipment and the dive. This may not always be the case for divers who travel away from their home area. In this case, it may be practical for training agencies to develop a guide for divers to use when briefing an unfamiliar support crew. It would certainly be prudent to make a couple of work-up dives with the crew before committing yourself to their support.

10) Military divers have a strong buddy protocol that provides sub-surface assistance if needed. In some situations, this has been overdeveloped and has become a weakness. The military has used antiquated equipment in it's open-circuit scuba program for years. Believe it or not, the Navy requires it's divers to use only a single second stage on open-circuit regulators. A spare second stage is not required, compromising diver independence. This has caused open-circuit divers to rely on each other for their own safety by making buddy-breathing their only bailout. For rebreather diving, however, there is a great reduction of risk when another diver is close by. The military does not allow a closed-circuit diver to dive with an open-circuit buddy. This is because of dissimilar capability. The open-circuit diver can out swim the closed-circuit diver, and if not qualified on his buddy's apparatus, may not be able to offer effective assistance in an emergency.

**The military does not allow a closed-circuit diver to dive with an open-circuit buddy. This is because of dissimilar capability. The open-circuit diver can out swim the closed-circuit diver, and if not qualified on his buddy's apparatus, may not be able to offer effective assistance in an emergency.**

11) Combat diver training uses stress loading and confidence building exercises that provide tools for assessment and selection of candidates for training. The intent is to inoculate the student, using a controlled environment, against the very factors which will cause him or her to panic in a real emergency.

Correctly applied, the same kind of exercises could produce strong, confident divers for the civilian rebreather community. This type of drill evaluation could be a prerequisite for entry into a course, and perhaps reduce the economic pressure to certify a student who has already paid a paid for a training course.

In summary, I would like emphasize the three most important elements of the rebreather military program. They are:

- Use checklists and supervision to eliminate human error.
- Don't rely on memory; use the expertise around you to double check your setup, particularly during predive procedures.
- Don't accept minor deficiencies in your equipment during the predive check. If the rebreather doesn't pass, don't dive it until it's fixed.

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WARNING AND DISCLAIMER: *The opinions and recommendations in this article are the author's alone and in no way constitute an official endorsement by the US Government or it's agencies.*

# A Learner's Guide To Closed-Circuit Rebreather Operations

by Richard L. Pyle

## Abstract:

I have been using a Cis-Lunar Mk-4P mixed-gas, closed-circuit rebreather since 1994 for exploration of coral reefs at depths of 200 to over 400 ft /61-122 meters (the "Twilight Zone"). On a recent expedition to Papua New Guinea, my diving partner and I discovered nearly 30 new species of reef fishes as well as several new invertebrates. Among the most important lessons I have learned about decompression diving using rebreathers are: 1) the importance of knowing the oxygen partial pressure in the breathing loop at all times; 2) vast amounts of open-circuit diving experience does not help one learn how to dive with a rebreather as much as a solid understanding of gas physics and diving physiology does; 3) rebreather training regimes should place emphasis on manual operation and bailout procedures; and 4) divers should always have an alternate safe route to the surface, even in the event of a catastrophic, unrecoverable breathing loop failure. I have developed an assortment of protocols for conducting decompression diving using multiple diluent mixtures with closed-circuit rebreathers, as well as procedures for various emergency bailout scenarios. I believe that it is vitally important that past, current and future rebreather divers maintain an open line of communication in order to share experiences and techniques, in an effort to minimize the potential for fatal or otherwise harmful accidents.

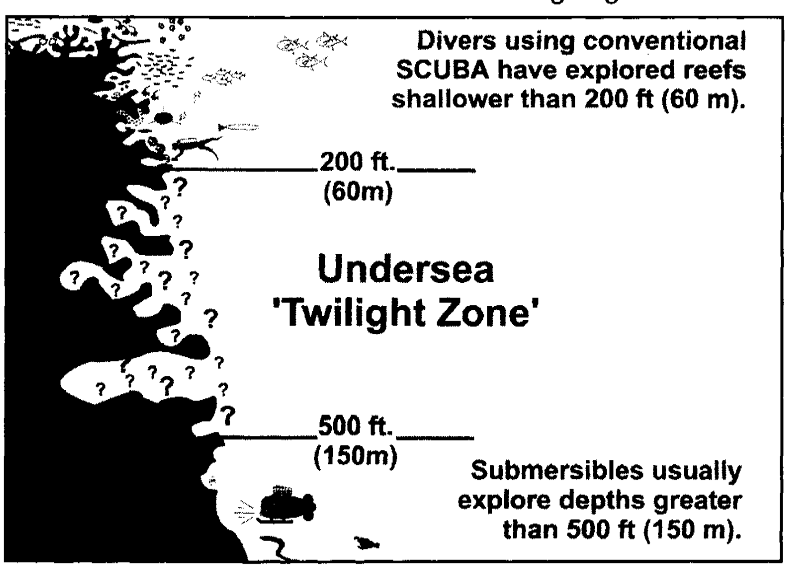


Figure 1. The undersea "Twilight Zone."

## Introduction

My interest in advanced mixed-gas diving technology, including closed-circuit rebreathers, stems from my ongoing endeavor to document marine life inhabiting deep coral reefs. Biologists using conventional air scuba have been limited to maximum depths of about 130-190 ft /40-57 m for productive exploratory work. Scientific research utilizing deep-sea submersibles has primarily focused on habitats at depths well in excess of 500 ft /150 m. The region in-between, which I have referred to as the undersea "Twilight Zone" (Fig. 1), remains largely unexplored (Pyle, 1991; 1992a; 1996a; 1996b; Montres Rolex S.A., 1996).

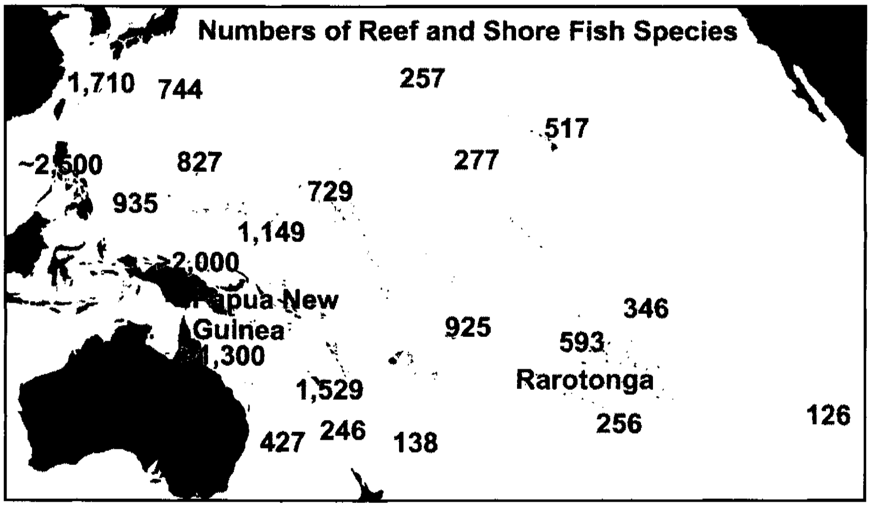


Figure 2. Diversity of coral reef fishes across the Pacific Ocean

In an effort to safely investigate this region, I designed an open-circuit mixed-gas diving rig that incorporated two large-capacity cylinders, two pony-cylinders, five regulators, and a surface-supplied oxygen system for decompression (Pyle, 1992b; 1996c; Sharkey & Pyle, 1993). Using this open-circuit rig, Charles "Chip" Boyle and I discovered more than a dozen new species of reef fishes on the deep coral reefs of Rarotonga in the Cook Islands (e.g., Pyle, 1991; 1994; Pyle & Randall, 1992). The extent of these discoveries was remarkable not only because of the extremely limited amount of time spent at depth (12-15 minutes per dive), but also because Rarotonga lies far from the center of coral reef species diversity (Fig. 2).

Given the unexpected wealth of diversity in the "Twilight Zone," it was clear that I would need to conduct dives with longer bottom-times in order to adequately explore this region, especially if I was to examine the deep reefs of the more species-rich western Pacific. Unfortunately, transporting large quantities of oxygen and helium to remote tropical islands can be extremely expensive and logistically difficult, if not impossible. The obvious solution was to use closed-circuit mixed-gas rebreather technology.

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In 1994, Cis-Lunar Development Laboratories provided me with two of their MK-4P closed-circuit, mixed-gas rebreathers, so that my diving partner John Earle and I could continue exploration of deep coral reefs. After nearly a year of training in Hawaii, we shipped the rebreathers to Papua New Guinea for a series of exploratory dives on the deep reef drop-offs. Diving from the M/V Telita (live-aboard vessel), we logged a total of 96 hours on the rebreathers, including 28 trimix dives to depths of 200-420 ft/61-122 meters. Although we only intended to conduct preliminary observations during this expedition, we nevertheless discovered nearly thirty new species of fishes and several new invertebrate species (e.g., Gill et al., in press; Earle & Pyle, in press; Allen & Randall, in press; Randall & Fourmanoir, in press).

## Staying Alive on a Closed-Circuit Rebreather

Having spent the past two years developing my own procedures and protocols for decompression diving using closed-circuit rebreathers, I have learned some important lessons (Comper & Remley, 1996; Pyle, 1996d). After my first 10 hours on a rebreather, I was a real expert. Another 40 hours of dive time later, I considered myself a novice. When I had completed about 100 hours of rebreather diving, I realized I was only just a beginner.

Now that I have spend more than 200 hours diving with a closed-circuit system, it is clear that I am still a rebreather weenie. In my experience, the underlying quality that divers must have to consistently survive rebreather dives is discipline. The first step in exercising this discipline is to realize that it takes a fair amount of rebreather experience just to comprehend what your true limitations are. You should leave a wide margin for error between what you think your limitations are, and what sort of diving activity you actually do. To help new rebreather divers survive the early overconfidence period, I offer these suggestions:

**1. Know your PO2 at all times.**

Without doubt, the single most hazardous aspect of closed-circuit rebreathers is the fact that the oxygen content of the breathing mixture is dynamic. With open-circuit scuba, inspired gas fractions are constant. Thus, as long as gas mixtures are not breathed outside their respective pre-defined depth limits (assuming proper filling and mixture verification procedures have been followed) an open circuit diver can be confident that the inspired gas is life-sustaining.

One of the fundamental advantages of closed-circuit rebreathers is their ability to maintain an optimal gas composition at all depths. However, the disadvantage of this dynamic gas mixture system is the potential for oxygen content to drop below or exceed safe levels without any change of depth. The real danger is the insidious nature of hypoxia and hyperoxia. Neither malady has any reliable warning symptoms (although see Pyle, 1995), and both can be deadly in the underwater environment. It is therefore of utmost importance that rebreather divers always know the oxygen partial pressure inside the breathing loop.

**Ironically, the most reliable rebreathers can potentially be the most dangerous to an undisciplined diver. If the primary oxygen control system virtually never fails, then a diver may become complacent about checking the secondary display.**

Simply checking the primary electronic instrumentation on a regular basis is not sufficient. Most electronically-controlled rebreather designs incorporate at least three oxygen sensors, and most will provide divers with at least two different displays of the oxygen sensor values. Many people refer to these as the "primary" and "backup" displays; however, I prefer the term "secondary" to "backup" because most backup equipment is used only after the primary component has failed. Instead, the secondary oxygen display of a closed-circuit rebreather should be monitored almost as regularly as the primary display, to verify that both displays are giving the same value.

Ironically, the most reliable rebreathers can potentially be the most dangerous to an undisciplined diver. If the primary oxygen control system virtually never fails, then a diver may become complacent about checking the secondary display. Due to the oxymoronic nature of the phrase "fail-safe electronics" (especially in underwater applications), complacency of this sort can have disastrous consequences.

**2. Open-circuit scuba experience is not as useful for rebreather diving as a good grasp of diving physics and physiology.**

Many experienced open-circuit divers who are new to rebreathers may fall into the "trap" of overconfidence. While vast amounts of open-circuit diving experience can increase a person's over-all comfort level in the water and enhance one's respect for the hazards of sub aquatic forays, these qualities alone are insufficient for consistent rebreather survival. Diving with closed-circuit rebreathers differs considerably from open-circuit diving in many respects, ranging from methods of buoyancy control, to gas monitoring habits, to emergency procedures. Development of the proper knowledge, skills, and experience takes time and practice, regardless of how many open-circuit dives (mixed-gas or otherwise) one has successfully completed.

What is probably the most dangerous period in any rebreather diver's learning curve occurs relatively early on; after enough time to be comfortable with the basic operation of the unit, but before there has been enough practice and experience to adequately recognize problems and correct them before they become serious (the period when one's confidence exceeds one's abilities). In some ways, experienced scuba divers may be at greater risk than non-divers when learning how to dive with a rebreather for the first time, because the initial discrepancy between confidence and abilities will be larger.

On the other hand, a good working knowledge of gas physics and diving physiology is probably more important for rebreather diving than for open-circuit mixed-gas diving. Well-designed closed-circuit rebreathers will provide users with many ways to control the gas mixture in the breathing loop, and divers must have an intuitive understanding of the effects their actions (gas additions, loop-purges, depth changes, etc.) will have on their breathing gas and decompression status. With the additional control a diver has over the inspired breathing mixture in a closed-circuit rebreather, comes the need for greater discipline and understanding of the dynamics involved.

**3.Training should emphasize failure detection, manual control and bailout procedures.**

Diving with closed-circuit rebreathers is relatively easy when the system is functioning correctly. Recognizing component failures before they lead to serious problems and knowing how best to respond to various failures is a bit more tricky. The solution to problem response is fairly straight-forward: training regimes should include a great deal of time simulating failure situations and practice of appropriate response actions.

Manual control of the rebreather is probably the most important skill to learn; in fact, I recommend that new rebreather divers first learn to control the unit manually, and only be allowed to activate the automatic control system after manual control has been mastered. Unfortunately, even the most well-practiced skills, and all the best backup systems in the world, are completely useless to an unconscious diver. Thus, perhaps even more important than knowing how to respond to a problem is knowing how to recognize a problem before it is too late.

The most critical failure conditions a rebreather diver may encounter are hypoxia, hyperoxia (due to failure of the oxygen control system), and hypercapnia (due to failure of the absorbent canister). Although the former two do not provide any reliable physiological warning, some people in some circumstances may detect symptoms of hypoxia or hypercapnia prior to blackout or convulsion.

Text descriptions of possible "pre-cursor" symptoms might help but, as any teacher knows, first-hand experience is much more useful. The question is: should a rebreather diver be exposed to hypoxia and hyperoxia under controlled conditions during training? (Obviously, "controlled conditions" would not include a diver experiencing these things underwater, or without trained supervision.) Hypoxic symptoms probably occur with more consistency than hyperoxic symptoms. Furthermore, hypoxia can easily be experienced on dry land using a rebreather with a disabled oxygen injection system, whereas hyperoxia (to the point of convulsion) would require a hyperbaric chamber.

Therefore, it seems that experience with hypoxia would be both more useful and logistically more feasible during a training regime than experience with hyperoxia would be. Nevertheless, even for hypoxia the answer to the question is not obvious. While having first-hand experience with symptoms might save a diver's life in some situations, it might also falsely boost a diver's confidence in his or her ability to detect the onset of such conditions (i.e., induce complacency). Another consideration is that any exposure to hypoxia likely results in the death of brain (and other) cells. Thus, even with the discipline to avoid the complacency problem, it is not clear whether the benefits of first-hand experience of possible warning symptoms outweigh the cost of lost brain cells during a "hypoxia experience" session. In my case, I believe the experience was well-worth the cost.

Less ambiguous is the issue of hypercapnia. Although testing by the U.S. Navy indicates that symptoms of hypercapnia cannot be considered as reliable pre-cursors to blackout, the experience of several civilian rebreather divers (myself included) indicate that they can be considered reliable. One possible explanation for this discrepancy of experience may be individual variation. Perhaps some individuals (e.g., so-called CO2-retainers") cannot reliably detect the onset of hypercapnia, while others (perhaps including the aforementioned civilian rebreather divers) can. If this is the case, it makes a great deal of sense to include deliberate exposure to hypercapnia (again, under controlled conditions) as part of a rebreather training regime. This can easily be accomplished on dry land by breathing off a rebreather without a carbon dioxide absorbent canister installed.

**Although testing by the U.S. Navy indicates that symptoms of hypercapnia cannot be considered as reliable pre-cursors to blackout, the experience of several civilian rebreather divers (myself included) indicate that they can be considered reliable.**

**4. Cover your ass.**

This is probably the most important piece of advice that my rebreather instructor, Bill Stone, gave to me. This point doesn't need much elaboration, but is nevertheless vital to rebreather survival. It is fundamentally the same principle that all cave divers and mixed-gas divers should already understand: always have an safe alternate pathway back to the surface. For open-circuit divers, this usually means a second regulator and following "rule of thirds" for gas consumption.

On rebreather dives, especially those requiring extensive decompression, the logistics of providing for an alternate means to safely return to the surface, even in the event of catastrophic, unrecoverable breathing loop failure, can be difficult. See the section on bailout procedures below for a description of some of the solutions I have developed for my rebreather dives.

## Procedures and Protocols for Closed-Circuit Rebreather Diving

Procedures and protocols for closed-circuit rebreather diving will vary according to specific rebreather models and specific diving conditions and objectives. In this section, I will outline the procedures and protocols that I have developed for rebreather model I use, in the environments that I it.

## I. System Configuration and Equipment

### A. Diluent Supplies

#### 1. Dives Without Required Decompression Stops

Most closed-circuit rebreather dives that do not involve 'required' decompression stops will be conducted using a single diluent gas (usually nitrogen or helium). If only one non-oxygen cylinder is carried by the diver on such a dive, that cylinder must be accessible via an open-circuit regulator, and the mixture in that cylinder must contain a fraction of oxygen that will sustain the diver at all depths during the dive (air is usually the easiest choice). Furthermore, that cylinder must be of sufficient capacity that all buoyancy control gas, drysuit gas (if applicable), and rebreather gas needs are met with enough remaining that a safe, controlled ascent to the surface in open-circuit mode can be accomplished with sufficient margin for error at any point during the dive.

**2. Dives With Required Decompression Stops**

Rebreather dives that require substantial decompression times often (although not always) involve more than one diluent gas type (usually nitrogen, helium, and/or a combination of both). More often than not, it would be entirely impractical for a diver to carry a large enough gas supply to complete full decompression in open-circuit mode. This leaves two options: 1) the diver carries a completely independent rebreather system (including independent breathing loop, counterlung, and absorbent canister); or 2) the diver carries enough gas supply to safely reach a staged life-support system (e.g. another rebreather, more open-circuit gas supply, an underwater habitat, etc.) while breathing the carried gas in open-circuit mode.

The difficulty with option number 1 includes not only the problem of physical placement of the secondary rebreather, but also the need to monitor and control the gas content within the secondary breathing loop during depth changes. More frequently, one form of option number 2 will be used, in which case much thought must be given to the question of how much of each type of gas will be carried by the diver, and how much will be staged. There are many variables that affect this ratio, including whether or not buddies can be relied upon for auxiliary open-circuit gas supplies, whether or not full face masks are used, whether there is a guideline physically connecting the diver with the staged gas supply, maximum depth and duration of the dive, strength of current, among many others.

The oxygen content of the diluent gas mixture(s) should be such that the diver has access to at least one life-sustaining mixture in open-circuit mode at any point (depth) during the course of the dive. Choosing a diluent configuration to optimally meet the needs of the dive is among the most difficult aspects of decompression diving with rebreathers.

I have experimented with a wide variety of configurations, and have settled upon one basic configuration that I use for almost all dives to depths in excess of about 220 ft (66 m), with total 'required' decompression times exceeding about 15 minutes. This configuration includes a total of 80 cubic feet (cf) of gas in three cylinders: one 20 cf "on-board" cylinder, and two 30 cf "off-board" cylinders. One of the 30 cf cylinders will contain a trimix that is safe to breathe at the maximum possible depth of the dive. The other two cylinders will include one with air, and one with heliox-10 (10% oxygen, 90% helium); which of these two gases that is in the 20 cf "on-board" cylinder and which is in the 30 cf "off-board" cylinder will depend on the planned decompression profile of the dive. The placement of the staged gas cylinders will depend on a variety of factors (discussed below under the "Bailout" section).

## B. Oxygen Supplies

Most dives without required decompression stops can be safely accomplished using only one oxygen cylinder. If the single oxygen cylinder is accessible via open circuit mode, then dives with limited 'required' decompression can also be conducted safely with a single oxygen supply (limited by whether or not the oxygen supply can sustain the diver in open-circuit mode for the duration of the shallowest decompression stops, with appropriate margin for error).

**The oxygen content of the diluent gas mixture(s) should be such that the diver has access to at least one life-sustaining mixture in open-circuit mode at any point (depth) during the course of the dive.**

Although dives requiring extensive decompression can be conducted with a single oxygen supply (provided a large supply of open-circuit decompression gases can be reliably accessed in an emergency bailout situation), it is usually better to carry a backup oxygen supply on such dives. If any part of a single oxygen delivery system fails on a closed-circuit rebreather, then the diver will essentially be forced to conduct an open-circuit bailout (or perhaps some form of semi-closed circuit bailout), at least for as long as it takes to access a staged rebreather oxygen supply. For dives requiring extensive decompression, I carry two independent oxygen supplies, both contained in 13.5 cf cylinders. Either cylinder contains enough oxygen to complete the entire dive in closed-circuit mode, and both can be accessed in open-circuit mode should the need arise.

## C. Full Face Mask Considerations

The question of whether or not a full face mask should be used on a rebreather dive depends on several factors; primarily whether or not electronic through-water communications systems are to be used, whether or not the dive is conducted solo or with other divers, and to what extent a diver must "go blind" in order to access additional gas supplies (either closed-circuit or open-circuit). In most cases, a full face mask is preferable, but there are some costs to using them.

Obviously, if the dive requires electronic through-water communications, a full face mask is probably needed. A full face mask can mean the difference between life and death if the diver blacks out due to hypoxia or hyperoxia, but this advantage is diminished if the dive is to be conducted solo (especially with regard to hypoxia) or with an inattentive buddy. Conversely, a full face mask can increase the risk of drowning if the diver has to "go blind" by removing the mask in order to access additional gas supplies (if the need to access an open-circuit bailout gas supply arises, it is likely to be the least convenient moment to lose one's ability to see).

**A full face mask can mean the difference between life and death if the diver blacks out due to hypoxia or hyperoxia, but this advantage is diminished if the dive is to be conducted solo. . .**

This hazard can be minimized to some extent by masks and mouthpieces that allow access to additional gas supplies without the need to remove the mask (or the part of the mask that allows the diver to see). In any case, divers should carry a spare conventional mask if a full face mask is to be used.

Once the decision to use a full face mask has been made, an additional consideration is what sort of mask to use. Some full face masks have a single airspace that includes the eyes, nose and mouth. Others divide the airspace into two isolated compartments; one for the mouth, and one for the eyes and nose. This latter type of mask (often referred to as a "half-mask") is preferable for rebreather diving for three main reasons.

First, a single-compartment full face mask increases the amount of "dead space" in the breathing loop (especially if an oral-nasal cup is not sealing properly), which increases the risk of carbon-dioxide build-up in the mask. Second (as is detailed below), a convenient way to vent excess gas from the breathing loop is by exhaling through the nose; if the compartment that seals the diver's nose is part of the breathing loop, then the excess loop gas must be vented by some other means. Third, the entire mask can serve as a diaphragm, contracting and expanding on inhalation and exhalation, increasing the overall work of breathing (Rod Farb, personal communication). The relative costs and benefits of full face masks must be taken into account for each different set of dive parameters.

## D. Emergency Line and Float

Each diver carries a reel with line, and an emergency float of some sort. The length of line on the reel depends primarily on the depth of the dive, and the depth of the first "required" decompression stop, but is usually a minimum of 200 ft (60 m) in length. The ideal emergency float for the sorts of dives I do is inflatable, cylindrical in shape, about 3-6 ft /1-2 m in length and 2-6 inches /5-15 cm in diameter, is bright orange in color, and has an over-pressure relief valve. It is often useful to have a small slate with its own pencil attached to the emergency float. This float is used mainly to alert the surface-support personnel that a diver has commenced a bailout from a dive (see discussion below).

## E. Surface-Support

For all dives involving substantial decompression, additional equipment associated with the surface-support vessel is usually needed.

### 1. Decompression Line

A basic decompression line includes a relatively large float, a relatively thick line, and a weight. The length of the line depends on the decompression profile expected, but is usually at least as long as the depth of the first anticipated "required" decompression stop. A float is attached at one end of the line, and a weight, not exceeding 10 lb. (2 kg) is tied to other end. The end with the weight also has a large clip of some sort (ideally a stainless steel, slip-locking carabiner). Sometimes markers or loops are placed at 10-ft/3-m intervals along the line. This line serves as the decompression "station" (to which additional equipment or gas supplies may be connected), and may or may not be deployed prior to the start of the dive.

### 2. Open Circuit Gas Supplies

*a) Self-Contained Gas Supplies*

It is always a good idea to keep extra supplies of breathing gas aboard the surface-support vessel in case of an open-circuit bailout situation. In most cases, supplies of both oxygen and oxygen-nitrogen mixtures (air or EAN) should be on hand, and mixtures incorporating helium may be needed for more extreme dive profiles. In some cases, some or all of this gas will be staged underwater prior to the dive, but in other cases, it will remain in the surface support vessel until (and if) it is needed. Of critical importance is that the diver can reliably reach additional gas supplies, with at least a 30% margin for error, should the need arrive. If only one diver is conducting a decompression rebreather dive (i.e., a solo dive), the volume of total gas supply should be twice that required by the diver for a complete decompression on open circuit. If two divers are conducting the dive simultaneously, then the total supply should be three times the amount that any one diver would need to complete decompression in open-circuit mode.

Teams of three or more divers might require even larger gas supplies.

*b) Surface-Supplied Oxygen*

The emergency open-circuit oxygen supply could include a surface-supplied oxygen system. Such a system reduces the bulk of equipment in the water, which can be beneficial for extended shallow-water decompression stops (especially for in-water recompression treatment of DCI). A full discussion of these systems is beyond the scope of this article, but it should be noted here that if two or more divers are conducting decompression dives simultaneously, there needs to be at least one self-contained oxygen supply per diver to guard against the unlikely event that two or more separated divers simultaneously need additional supplies of oxygen.

**3. Other Equipment**

Most other equipment for decompression dives using closed-circuit rebreathers will depend on the particular objectives and environmental conditions of the dive. Two items that most divers should carry are a sharp cutting tool, and one or more sets of decompression tables. The knife should be small and easily accessible by either hand, and the decompression tables should include a variety of depth and bottom-time contingencies, as well as schedules for both closed-circuit (constant oxygen partial pressure) and open-circuit (constant oxygen fraction) decompression with available gas mixtures.

# II. Pre-Dive

In addition to general gas mixing, equipment testing, rig preparation, team briefing, and other obvious pre-dive activities, rebreather divers should perform several additional pre-dive routines.

## A. Loop Leak Test

An essential pre-dive test for any rebreather is a loop leak (or "positive pressure") test. This step involves adding gas to the rebreather loop until the over-pressure relief valve vents, and observing for a subsequent drop in remaining loop volume or pressure that might indicate a poorly sealed connection or leak somewhere in the breathing loop.

## B. Oxygen Control System Test

Another test prior to commencing the dive is a verification of the oxygen control system function. Minimally, this test involves flushing the loop with diluent, activating the oxygen control system, and verifying that the solenoid fires correctly. If the unit allows the user to easily adjust the PO2 set-point, the test could be conducted with a low set-point (such as 0.3 atm) to verify that the solenoid stops firing after set-point has been achieved. If this latter test is conducted, it is imperative that the PO2 set-point be returned to the correct value prior to the dive.

## C. Final Checklist

Beyond the standard checklists frequently used by open-circuit mixed-gas decompression divers, a separate checklist should be developed specifically for the particular rebreather unit that is to be used. Minimally, this checklist should include verification of absorbent type and remaining canister life, accurate oxygen sensor calibration, correct PO2 set-point, oxygen and diluent cylinder pressures, diluent gas composition(s), and correct position (open or closed) of all valves in the system. Additional model-specific verifications may also be required for certain rebreathers.

# III. Descent

If the descent is abrupt (i.e., a straight, fast descent to depth), the breathing loop should be flushed with diluent prior to commencement of the dive. If the oxygen partial pressure is allowed to increase at the surface prior to the dive (for example, by the action of the oxygen injection solenoid), there is a risk that the oxygen partial pressure in the breathing loop will exceed safe levels during a rapid descent. Correction for this would involve flushing the loop with diluent at depth, which results in an unnecessary loss of potential open-circuit breathing gas supply.

**If the oxygen partial pressure is allowed to increase at the surface prior to the dive (for example, by the action of the oxygen injection solenoid), there is a risk that the oxygen partial pressure in the breathing loop will exceed safe levels during a rapid descent.**

If the dive is to be conducted with only helium and oxygen in the loop during the deep portion of the dive, the loop should be flushed with heliox before beginning the descent. Some people (myself included) have experienced impaired concentration when breathing heliox at depths in excess of about 250 ft /75 m following rapid descents. This impairment seems to be alleviated when the nitrogen partial pressure in the breathing loop is maintained at about 2.5-3.0 atm (less than the level at which significant narcosis is usually experienced).

There are two basic methods of introducing trimix into the breathing loop. The most obvious is to use a blend of trimix as the diluent supply. The advantage of this method is that the helium-to-nitrogen ratio remains relatively constant; the disadvantage is that nitrogen partial pressure in the breathing loop increases with increasing depth (hence, the trimix must be blended for the maximum depth of the dive, and will be ideal only at that maximum depth). A less obvious method is to blend trimix from separate air and heliox diluent supplies. With this method, the descent begins with a loop full of air, and air as the diluent supply. Upon reaching a depth of about 100 ft /30 m, and allowing the oxygen partial pressure to achieve set-point, the diluent supply is changed to heliox and the descent continues. This results in a relatively constant partial pressure of nitrogen in the breathing loop (calculated as [ambient pressure at time of diluent change] minus [oxygen partial pressure at time of diluent change]).

The advantage of this method is that the nitrogen partial pressure does not increase with increasing depth. The disadvantage is that there may be deviations from the predicted nitrogen partial pressure in the event of loop volume fluctuations and loop gas venting (as from mask clearings, etc.). Combinations of these two methods are also possible, but it is vitally important that, whichever method is followed, the software used to generate the decompression profiles (both for real-time decompression and backup decompression tables) take into account the predicted fluctuations of the helium-to-nitrogen ratios.

**Each rebreather diver should become intimately familiar with the rates at which their metabolism affects the oxygen partial pressure within the breathing loop at different levels of exertion, on the specific rebreather that diver intends to use.**

## IV. System Monitoring & Control

### A. PO2

The most critical variable to monitor on a closed-circuit rebreather is the oxygen partial pressure in the breathing loop. The PO2 set-point of the oxygen control system should be no less than 0.5 atm, and no greater than 1.4 atm. The lower limit maintains a margin for error above hypoxic levels, and the upper limit maintains a margin for error below dangerously hyperoxic levels.

Although some standards allow for inspired oxygen partial pressures as great as 1.6 atm, such partial pressures would be unsafe set-points on a closed-circuit rebreather for two reasons. First, oxygen partial pressures in the breathing loop can "spike" above set-point during short, rapid descents; and second, rebreather divers should incorporate a more conservative upper oxygen partial pressure limit than open-circuit divers due to the fact that the diver is exposed to that partial pressure throughout the entire dive (as opposed to open-circuit dives, where the PO2 limit is experienced only at the deepest depth of each breathing mixture).

Each rebreather diver should become intimately familiar with the rates at which their metabolism affects the oxygen partial pressure within the breathing loop at different levels of exertion, on the specific rebreather that diver intends to use. For example, with the oxygen control system disabled on the rebreather model that I use, the oxygen partial pressure will drop from 1.4 atm to 0.2 atm over the course of about 30-40 minutes at low to moderate exertion levels. My diving partner consumes oxygen at about twice the rate I do at a given workload, and thus causes the same PO2 drop to occur in about 15-20 minutes at the same exertion level.

Once a diver knows the oxygen consumption rates, the PO2 levels in the loop should be checked with a frequency no more than one-half the amount of time it would take for the PO2 to drop to dangerous levels. For the example above, if the PO2 set-point was 1.4 atm, I would check the PO2 in the breathing loop at least every 15 minutes, and my diving partner would check his at least every 7 or 8 minutes. The PO2 should also be monitored during and after every substantial depth change.

Divers should also be in the habit of frequently comparing the primary PO2 display with the secondary PO2 display, should note whether or not all oxygen sensor readings are in synchrony, and should note whether the readings are dynamic or static (static readings are often indicative of some sort of oxygen sensor failure). Some rebreather designs allow divers to verify that sensors are providing correct readings; such tests should be performed periodically throughout the dive, and whenever some reason to doubt about the accuracy of the readings presents itself.

### B. Gas Supplies

Although cylinder pressures are of critical importance to open-circuit divers, they are somewhat less critical to closed-circuit rebreather divers. Diluent supply pressure(s) should be monitored to ensure a safe open-circuit bailout can be performed at any point during the dive. Oxygen supply pressure(s) should be monitored to ensure there is a sufficient quantity of oxygen remaining in each oxygen cylinder to complete the remainder of the dive in closed-circuit mode (with a comfortable margin for error).

## C. Remaining Absorbent Canister Time

The amount of time that a given canister of carbon dioxide absorbent will sustain a diver should be clearly and confidently known prior to the commencement of any dive. For dives requiring substantial decompression, there should be at least a 50% margin for error and preferably a 100% margin for error (i.e., an absorbent canister should be able to last one and a half to two times the predicted total dive time).

In the absence of reliable carbon dioxide sensors, the ability to reliably predict the remaining life of an absorbent canister can be difficult. The most frequently-used method is a simple "clock" of how much dive time is spent using a particular canister of absorbent. Unfortunately, the rate of this clock can vary among different divers and different workloads by as much as a factor of ten. In the same amount of time that one diver may have completely exhausted the canister, another diver may have used up only 10% of the active life of the absorbent (considering the maximum possible extreme cases).

An alternative method of monitoring canister life is to monitor the amount of oxygen consumed. This includes the total volume of oxygen entering the loop, both from oxygen and from diluent supplies. Calibration of this value should be done empirically under controlled conditions (i.e., minimal venting of gas from the breathing loop), with each particular canister design of each particular rebreather (values cannot necessarily be extrapolated based only on volume of absorbent material). A sample size of empirically-derived values should be large enough such that scale of variation can be inferred. Venting of loop gas during dives (e.g., ascents, mask clearings, etc.) will result in a more conservative estimation of remaining canister life. If done correctly, this method of canister life prediction is probably among the most accurate (assuming consistent and proper canister packing techniques and absorbent quality).

Divers should be on the alert for potential symptoms of hypercapnia (e.g., shortness of breath, headache, dizziness, nausea, a feeling of "warmth," etc.) during all phases of the dive. If such symptoms are suspected, the dive should be immediately terminated and the ascent should commence. Short-term relief of symptoms following an ascent should not be interpreted as evidence that the canister is functioning properly, because ascents will inherently lead to a short-term drop in the carbon dioxide partial pressure in the breathing loop, and often involve a concurrent reduction of workload (i.e., $CO_2$ production rate).

Hypercapnia symptoms might also be a result of improper breathing techniques (i.e., the "skip-breathing" pattern that many scuba divers do, which, of course, confers absolutely no advantage to a rebreather diver). Canister failure can be tested with short-duration periods of high exertion (in shallow water). If a diver feels unusually "starved for breath" after such short bursts of exertion, the canister is probably near the end of its effective life (note, these periods of high exertion should be kept brief, so as not to unnecessarily waste remaining absorbent life). As discussed earlier, it is probably beneficial for rebreather students to undergo first-hand experience with hypercapnia symptoms as part of their basic training course.

**Hypercapnia symptoms might also be a result of improper breathing techniques (i.e., the "skip-breathing" pattern that many scuba divers do, which, of course, confers absolutely no advantage to a rebreather diver).**

## D. Loop Volume

The volume of gas contained in a rebreather loop (the hoses, canister, and counterlung(s) of the rebreather plus the diver's lungs) is seldom fixed. I define "minimum" loop volume as that volume of gas occupying the rebreather loop when the counterlung(s) are completely "bottomed-out," and the diver has completely exhaled the gas from his or her lungs. Conversely, "maximum" loop volume is the volume of gas in the breathing loop when the counterlung(s) are maximally inflated, and the diver has maximally inhaled gas into his or her lungs. Although the magnitude of the difference between these two volumes, ([Vmax] - [Vmin]), will vary from one rebreather design to another, it will always be non-zero.

Rebreather divers must learn to maintain the loop volume close to its optimal level for their particular model of rebreather. If the volume is maintained too close to Vmin, the counterlungs will tend to "bottom-out" on a diver's full inhalation. If the loop volume is maintained too close to Vmax, the over-pressure relief valve will tend to vent excess gas at the peak of a diver's full exhalation. Furthermore, total loop volume will influence work of breathing due to hydrostatic effects.

On rebreather models with a relatively large value of ([Vmax] - [Vmin]), the optimal volume should ideally be closer to Vmin; for models with a relatively small value of ([Vmax] - [Vmin]), the optimal loop volume should be ideally close to Vmin. In either case, the diver should maintain the loop volume at whatever level results in the minimum total work of breathing and gas loss.

## E. Buoyancy

Scuba divers have two main components of "compressible buoyancy"; namely, the buoyancy compensator, and the thermal protection suit. Rebreather divers add to this a third component of "compressible buoyancy"; the breathing loop. Many rebreather divers utilize fluctuations in breathing loop volume as fine-tune control of buoyancy. To maintain a constant PO2 in the breathing loop and a constant loop volume while changing depths, a diver must be skilled in minor gas addition and venting techniques.

On descents, most rebreathers will automatically compensate for a dropping loop volume by the addition of diluent. Depending on the fraction of oxygen in the diluent, this may also lead to a concurrent drop in loop PO2 (it should never lead to a rise in loop PO2, because the PO2 of the active diluent at ambient pressure should not exceed the PO2 set-point of the breathing loop). This then leads to subsequent injection of oxygen into the loop by the solenoid, which increases the loop volume.

**Ideally, a fully-dressed rebreather diver should be neutrally buoyant (or very slightly negative) at the surface, with optimal loop volume, and empty buoyancy compensator. Under such conditions, gas needs to be added to the buoyancy compensator only to compensate for compression of the thermal protection suit, if any.**

Practiced rebreather divers should be able to indirectly detect changes in loop volume based on changes in buoyancy and work of breathing. Increases to loop volume can be made by the addition of diluent or oxygen (depending on whether the current PO2 is greater than, or less than [respectively] the PO2 set-point). Decreases to loop volume can be accomplished by manually venting gas from the loop, either by exhaling through the nose (except for certain kinds of full face masks), allowing gas to escape from the seal of the lips to the mouthpiece, or dumping gas from a valve somewhere on the rebreather loop. Ideally, a fully-dressed rebreather diver should be neutrally buoyant (or very slightly negative) at the surface, with optimal loop volume, and empty buoyancy compensator. Under such conditions, gas needs to be added to the buoyancy compensator only to compensate for compression of the thermal protection suit, if any. In any case, a diver should be weighted such that he or she is close to neutral when the breathing loop volume is at or near optimal.

# V. Ascent

During an ascent from a rebreather dive, especially a deep dive, the oxygen partial pressure in the loop will begin to drop (due to the dropping ambient pressure). The oxygen control system will likely begin to compensate for this by injecting oxygen; however, except for the slowest of ascents, the solenoid valve will not likely be able to keep up the with drop in loop PO2 due to drop in ambient pressure. Although it may be tempting for a diver to "help" the solenoid achieve PO2 set-point by manually adding oxygen to the loop, this is probably not a good idea in most cases.

During the ascent, loop gas will be vented from the breathing loop due to expansion. The diluent component of this lost gas is unrecoverable (it cannot be put back in the cylinders, and it is not used by the body), and assuming a continuous ascent, no more diluent will need to be added to the loop for the remainder of the dive.

The oxygen component of the vented gas, however, is wasted - especially if the system continuously injects more into the loop to bring the PO2 back up to set-point. This waste of oxygen can be minimized by allowing the PO2 to drop relatively low during the ascent. Obviously, the PO2 level in the loop should be continuously monitored to ensure that it does not drop dangerously low (i.e., below about 0.5 atm). There is seldom any real advantage to adding additional oxygen into the loop manual in a futile attempt to maintain PO2 set-point.

My procedure is to allow the PO2 in the loop to drop during the ascent. I manually add oxygen to the loop only if the PO2 drops below 0.5 atm, or when I reach the first decompression stop. At the first decompression stop, I will usually manually add oxygen to the loop to bring the PO2 back up to set-point. Proper manual oxygen addition requires a great deal of practice and training; it's easy to accidentally overcompensate by adding too much oxygen, escalating the loop PO2 to dangerously high levels. If oxygen is manually injected in large bursts (rather than several short bursts), a "pocket" of high-PO2 gas will move around the breathing loop for several breaths.

On most decompression dives involving helium during the deep phase of the dive, the diver will want to flush the helium out of the loop and replace it with nitrogen. I usually do this during an ascent at a depth of about 130-150 ft/40-45 m, and start the flush by venting gas from the loop until the loop volume is at

Vmin. I then inflate the loop to Vmax with air, and repeat this cycle at least three times. The partial pressure of any remaining helium in the loop is negligible, and will continue to drop as more gas is vented from the loop during the remainder of the ascent. When I reach the 20-ft /6-m decompression stop, I shut the diluent input supply, and flush the loop with oxygen until the loop PO2 reaches set-point. I will generally remain at this depth until the decompression ceiling has been cleared. If I ascend shallower, I reduce the PO2 set-point to 1.0 atm.

## VI. System Recovery and Bailout

The most valuable skills a rebreather diver must learn are the skills which enable recovery and/or bailout from various failure modes. These skills should be practiced routinely, because a diver should only rarely have to use them in a real emergency situation.

### A. Oxygen Control System Failure

**1. Solenoid Failure**

One potential failure mode of most closed-circuit rebreathers is that the solenoid valve can potentially get stuck in the open position. In such a case, oxygen would be continuously injected into the breathing loop, and the PO2 of the breathing loop would reach dangerously-high levels relatively quickly. The first response to this situation (which is usually immediately evident to the diver via audible cues and an increase in loop volume) is to temporarily switch to open-circuit mode. After the oxygen supply to the solenoid has been manually shut, the diver can flush the loop with diluent until the gas is safe to breathe, return to closed circuit mode, and abort the dive while manually maintaining the PO2 in the breathing loop.

The obvious response to a solenoid valve that is stuck shut is to abort the dive and maintain PO2 set-point manually.

**2. Partial Electronics Failure**

If either the primary or the secondary PO2 display systems fail at any time during the dive, the dive should be aborted. If the automatic oxygen control system has concurrently failed, the diver should manually maintain the PO2 in the breathing loop following the functional PO2 display.

**3. Total Electronics Failure**

A total electronics failure generally means both the primary and secondary PO2 display systems have failed simultaneously. Although an open-circuit bailout will often be the most appropriate response to this situation (especially if there is no "required" decompression stop and the dive is relatively shallow), there are at least two alternative solutions.

*a) Semi-Closed Operation*

Any closed-circuit rebreather can be manually operated as a semi-closed rebreather by the diver. To accomplish this, the diver simply vents every third, fourth, or fifth exhaled breath out of the loop, replenishing it with more diluent. The optimal rate at which exhaled breaths should be vented from the loop depends on the depth, the fraction of the oxygen in the diluent, and the metabolic rate (workload) of the diver. This system is not perfect, but a well-trained rebreather diver should be able to maintain a life-sustaining breathing mixture in the loop until reaching staged bailout cylinders, or a depth where it is safe to use the "Oxygen Rebreather" method (see below), while consuming substantially less gas than a bailout in full open-circuit mode would. This method requires a great deal of practice while the PO2 displays are fully functional to master. Obviously, appropriately conservative decompression schedules should be followed following this bailout method.

*b) Manual Gas Mixing*

A more difficult, but more gas-frugal method of maintaining a life-sustaining gas mixture in the breathing loop is to manually mix oxygen and diluent within the breathing loop. During the initial bailout ascent, the diver occasionally adds just enough oxygen to the loop manually to prevent hypoxia from occurring (the proper rate of gas injection can only be learned after much practice and experience). Upon reaching the first decompression stop, the diver blends the first pre-calculated gas mixture.

Available to the diver are at least two known gas mixtures (oxygen and at least one diluent with some known fraction of oxygen in it), and two known breathing loop volumes (Vmin and Vmax). Presumably, the difference between the two, ([Vmax] - [Vmin]), will not be identical to the absolute value of Vmin. With these known variables, the diver can create (within reasonable limits of accuracy) at least four different gas mixtures. The first gas mixture is achieved by flushing the loop completely with diluent. Once doing this, the diver can manually add oxygen to compensate for the drop in volume of the breathing loop (as oxygen is metabolized and carbon dioxide is absorbed by the absorbent, the loop volume will drop).

If a diver is sufficiently sensitive to changes in loop volume, the PO2 in the loop can be maintained relatively constant. The diver continues using this method until reaching a depth shallow enough where the next mixture can be blended. To create the second mixture, the diver flushes the loop with diluent then Vmin is achieved, then manually adds oxygen until Vmax is reached. After allowing the gases to mix for a few breaths, the loop is vented back to optimal volume (if the gas mixture is sufficiently mixed, the FO2 should remain constant). The diver then maintains optimal loop volume with the addition of oxygen.

The third mixture involves flushing the loop first with pure oxygen followed by venting until Vmin is reached. The loop is then "topped-off" with diluent until Vmax is achieved, and the loop is vented back to optimal volume after mixing has occurred. This is the most difficult mixture to create, because the diver must breathe in open-circuit mode to avoid hyperoxia during the gas mixing process.

The fourth gas mixture is pure oxygen, which can be maintained by using the "Oxygen Rebreather" method outlined below.

With two diluent supplies with different oxygen fractions, the number of gas mixtures that can be created increases to 9. With three diluent supplies, there are 16 possible gas mixtures that can be blended. This method is most difficult in deep water, because with a given PO2, the FO2 is relatively small. This means that relatively small changes in loop volumes equate to relatively large changes in PO2. This makes the task of trying to replenish metabolized oxygen considerably more difficult. It cannot be over-emphasized that these methods require a great deal of practice to master. Practice sessions should be conducted while the rebreather electronics are fully functional, so the diver can monitor the various gas flushes and how they affect actual PO2.

*c) Oxygen Rebreather*

The simplest and most reliable method of manual oxygen control is to maintain only oxygen in the breathing loop. Unfortunately, this method can only be used at depths of about 15-20 ft /3.5-6 m or less (depending on the maximum PO2 the diver wants to be exposed to). The diver simply flushes the loop with pure oxygen, and replaces and drop in loop volume with more oxygen. Regardless of how precise the diver is at maintaining a constant loop volume, the PO2 in the loop stays constant at any constant depth, and life-sustaining at any depth shallower than about 20 ft /6 m.

## B. Partial Absorbent Canister Failure

A partial failure of the absorbent canister usually means that the absorbent in the canister can nolonger remove carbon dioxide from the loop as fast as the diver is producing it, leading to a rise in loop PCO2. If this occurs during a high-workload portion of the dive, the diver may be able to reduce workload during a dive abort and continue in closed-circuit mode for a potentially substantial period of time. If the partial canister failure occurs at a low workload, the diver will likely need to either periodically flush the breathing loop with diluent and/or oxygen in a manual semi-closed mode (as outlined above), or resort to an open-circuit bailout. Once again, only first-hand experience will help guide the diver towards the appropriate course of action. However, if ample breathing gas supplies are available (a they should be in all cases), it is certainly more prudent to complete the dive in open-circuit mode.

## C. Catastrophic Unrecoverable Loop Failure

The "worst-case scenario" for any rebreather dive is a catastrophic unrecoverable loop failure. This can be caused by a severed breathing hose, badly torn counterlung, or completely failed (e.g., flooded) absorbent canister. In such cases, if a diver does not have access to a secondary rebreather system, a bailout in open-circuit mode is inevitable.

**1. Dives Without "Required" Decompression Stops**

If there is no "required" decompression time, an open-circuit bailout is the simplest solution. If the diluent gas supply was monitored properly, there should be plenty of breathable gas to conduct a slow, controlled ascent to the surface. If the rebreather system allows open-circuit access to the oxygen supply, a "safety" stop can be conducted at a depth of 10-20 ft/3-6 m to reduce the probability of DCI.

**2. Dives With "Required" Decompression Stops**

As stated earlier, the most logistically difficult aspect of any rebreather dive requiring substantial decompression is accommodating the possible need for completing the full required decompression in open-circuit mode. Two general scenarios that I have developed are outlined below. In both cases, divers carry a total of 80 cf of diluent and as much as 27 cf of oxygen (as described above in the "System Configuration and Equipment" section).

*a) Drift Dives*

Our most frequent diving method involves a "live" boat following free-drifting divers. There are many advantages to this method, a discussion of which is beyond the scope of this article. Herein I will describe our standard protocol for open-circuit bailout from this type of dive.

Figure 3a illustrates the normal dive plan: divers pull a "tow line" (made from thin but strong, brightly-colored line) that is attached to small but highly visible "surface float." The boat captain follows this float throughout the course of the dive, keeping a watchful eye for any "emergency floats" that come to the surface. A normal ascent from such a dive (assuming no rebreather failures) involves divers commencing their ascent along the tow-line. At a pre-determined time, the surface-support crew clips a "decompression line" (as described above in the "System Configuration and Equipment" section) to the tow line via the carabiner (or other similar clip) at the weighted end of the decompression line (Fig. 3b). The weight of the decompression line slides down the tow line until the divers rendezvous with it. The divers then detach the decompression line from the tow line (the tow line is either pulled-in by the surface-support crew, or left to drift until all divers have surfaced), and complete the decompression on the decompression line.

Depending on wind and swell conditions, the boat may or may not be physically attached to the decompression line via a "tether" (Fig. 3c). If one or both divers are forced to conduct a bailout in open-circuit mode while the pair is still together, both divers commence the ascent together. The diver conducting the bailout inflates the "emergency float" that he or she has carried throughout the dive, clips it to the tow line, and allows it to slide along the tow line back to the surface. Depending on the particular parameters of the bailout situation, the diver may attach a note of explanation written on a slate that is attached to the emergency float (Fig. 3d).

As soon as the float reaches the surface, the surface-support crew responds by deploying the decompression line as described above. In this situation, however, the surface-support crew also attaches a pre-determined configuration of open-circuit breathing gas supply (usually air or EAN) to the weight of the decompression line (Fig. 3e).

If both divers are simultaneously conducting an open-circuit bailout, both emergency floats are sent to the surface, and the surface-support crew attaches an appropriate volume of open-circuit gas supply. In either case, the float or floats are usually deflated and returned to the divers along with the open-circuit gas supply by attaching them to the weight of the decompression line and allowing them to slide down the tow line to the divers (Fig. 3f). When the divers rendezvous with the bottom of the decompression line, they detach the tow line as described above, and continue decompression. A additional supply of oxygen is then sent down the decompression line by the surface-support crew to a depth of 20 ft /6 m.

If weather conditions allow the boat to be tethered to the decompression line, a surface-supplied oxygen rig (as described above in the "System Configuration and Equipment" section) may be deployed instead of a self-contained oxygen supply (Fig. 3g).

The ultimate worst-case scenario involves a separated pair of divers who both independently and simultaneously require open-circuit bailout. If the first emergency float to the surface is attached to the tow line, then the procedures as outlined above are followed, just as if the divers were ascending together (the only difference is that in this case, the diver might not detach the tow line from the decompression line). If a diver becomes separated from the tow line, he or she will commence an ascent to the sur-

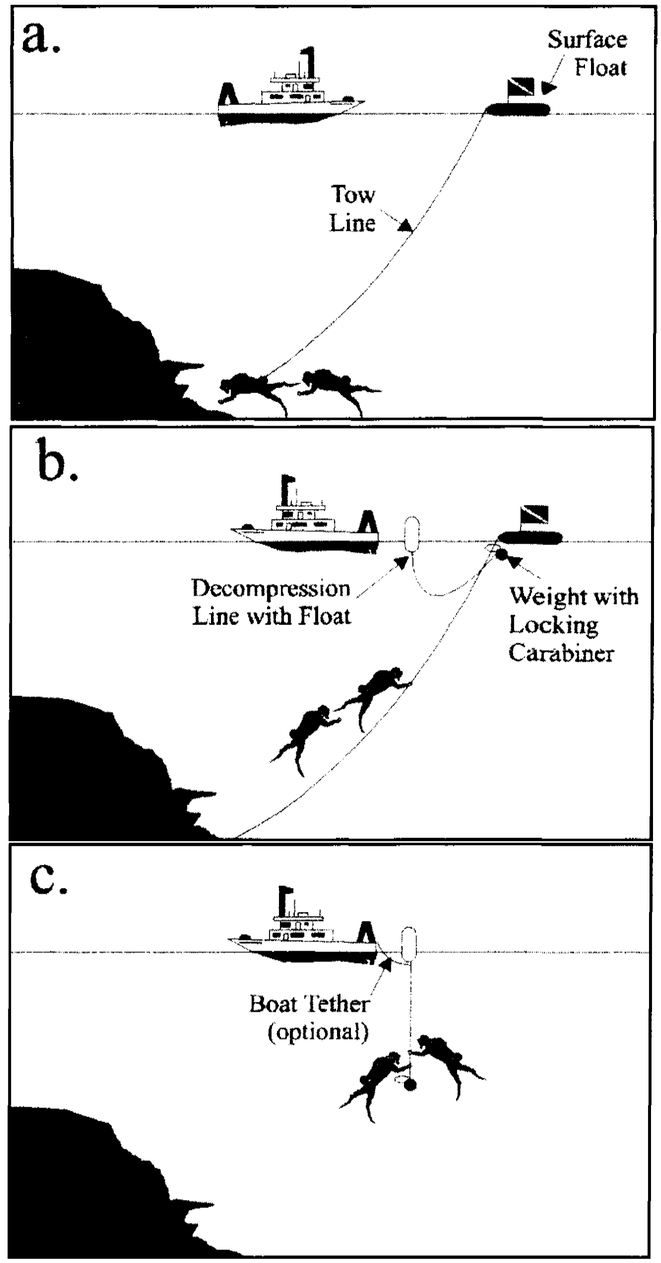


Figure 3. Open-circuit bailout decompression protocol for a pair of rebreather divers free-drifting under a "live" boat; a)divers pull tow line attached to small but highly visible surface float; b) divers begin ascent while surface-support clips-off weighted decompression line to tow line; c) divers rendezvous with clipped weight, detach from tow line, and complete decompression in closed-circuit mode. [Continued next page.]

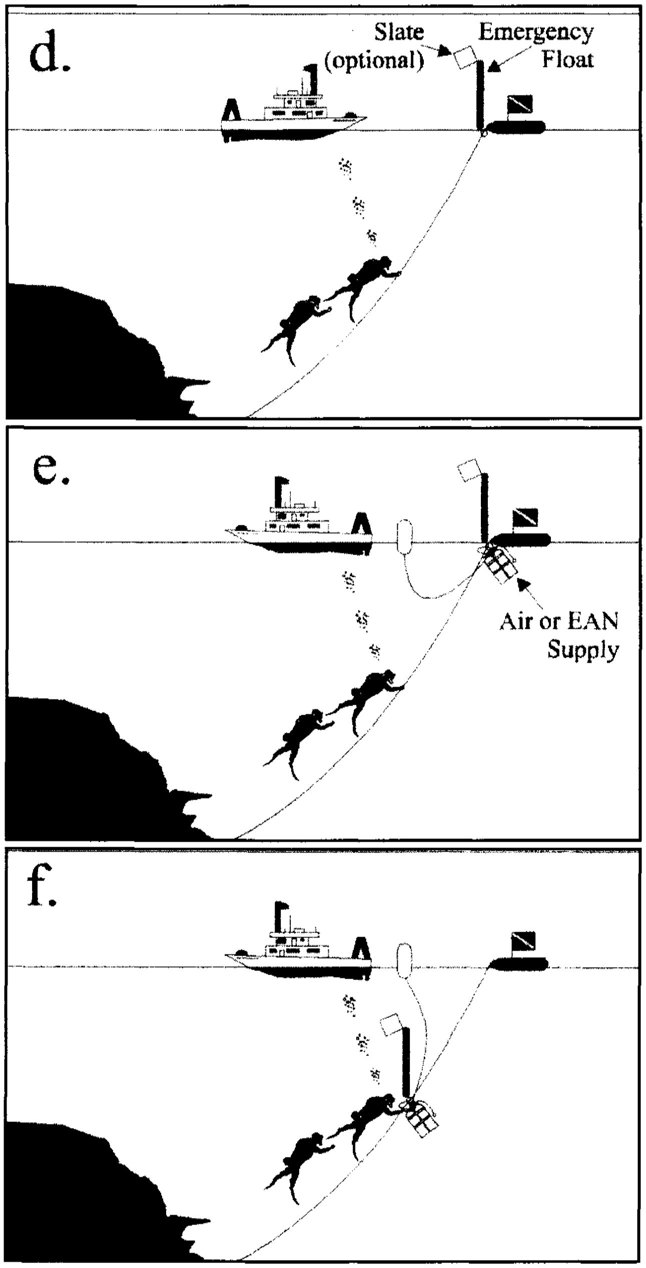


Figure 3 (continued from previous page) d ) one or both divers require open-circuit bailout, emergency float is sent to surface clipped to tow line; e)surface support attaches open-circuit air or EAN supply to weighted decompression line and clips it to tow line; f)divers rendezvous with clipped weight and open-circuit gas supply and detach it from tow line; (continued next page.)

face and will deploy an emergency float to the surface, attached to the line of the reel that the diver has carried (as described above in the "System Configuration and Equipment" section). If the diver does not require open-circuit bailout gas supply, he or she writes a note to that effect on a slate, and attaches the slate to the emergency float.

When the second emergency float is spotted by the surface-support crew, they deploy a self-contained open-circuit oxygen supply down the first decompression line, and deploy a second decompression line to the isolated diver. If there is no note on a slate to the contrary, the surface support assumes the second diver is also engaged in an open-circuit bailout, and supplies gas accordingly (Fig. 3h). In general, the surface-supplied oxygen system is not deployed whenever a diver pair is decompressing separately – it is better to allow the boat freedom to move back and forth between the decompressing divers. If possible, the surface-support crew communicates to each diver the direction of the other diver, so that the divers may swim towards each other and complete decompression together. If the separated diver sends his or her emergency float to the surface first, or if the two divers are both separated (independently) from the tow line, the response procedure is similar, but in the reverse order (i.e., first come, first served).

*b) Fixed Station Dives*

In cases where the reef extends nearly vertically from the surface to the depth of operation (i.e., a "drop-off" or "wall"), the primary surface-support vessel may anchor on-site. In this case, divers run a continuous guide-line from the anchor to the point at which the dive is to be conducted, and set staged emergency gas supplies at various appropriate intervals along the guide line.

In these conditions, general cave diving protocols are followed in terms of returning to the surface along the same path that the descent was made. Ideally, both divers will carry emergency floats and extra reels with line, and a secondary "chase" boat will be on-site to accommodate a bailout situation as described above (in case a diver becomes separated from the guide line).

## VII. System Maintenance

Specific rebreather maintenance procedures will be defined by individual manufacturers for their particular units. Described below are some general considerations for basic rebreather maintenance.

### A. Absorbent Canister

Methods for calculating remaining absorbent canister life were described above. Whether or not the absorbent should be replaced between dives depends on a variety of factors, including how much use the canister has previously been subjected to, how much time has elapsed since the previous dive, what sort of profile is anticipated for the subsequent dive, and various other factors. A general rule of thumb is: "absorbent is cheap, lives are not."

Nevertheless, it is not always necessary to replace the canister between every single dive. In all cases, however, a canister should be removed from the breathing loop if the surface interval exceeds a few minutes. If the surface interval exceeds a few hours, the canister should be sealed and protected from ambient air if the absorbent is not going to be changed prior to the next dive.

In any case, if a canister has not been used for more than a few days, the absorbent should be changed. When packing the canister with absorbent, it is important to ensure that all the absorbent material has completely settled. This usually involves filling the canister, sealing it, vigorously tapping it, topping-off the absorbent level, and repeating the process several times. If the absorbent is not properly packed, a bumpy car or boat ride could lead to subsequent absorbent settling, which may allow channeling of gas through the canister, and a greatly diminished canister life-span.

## B. Breathing Loop

The breathing loop should be opened and ventilated and dried as much as possible at the end of each diving day. The entire loop (including mouthpiece, hoses, counterlung(s), canister, etc.) should be disinfected with an appropriate disinfectant periodically (as often as every dive day, but no less-frequently than once per dive week).

## C. Oxygen Sensors

Oxygen sensors should always be kept as dry as possible. The life-span of the sensors can be extended if they are sealed in an anoxic environment (i.e., nitrogen or helium) during long inter-dive periods. Sensor calibration should be verified frequently (before every dive) and re-calibrated as needed. Sensors should be replaced according to manufacturer specifications, and spares should be kept on hand (it is strongly inadvisable to conduct a closed-circuit rebreather dive with two or fewer oxygen sensors). As with all aspects of rebreather diving, common sense mixed with a healthy dose of discipline is the best protection against dangerous mistakes.

**Sensor calibration should be verified frequently (before every dive) and re-calibrated as needed.**

## Lessons Learned

Below I describe several incidents from which I have learned valuable lessons. Although these by no means represent all of my experiences, they do underscore a few of the points made previously in this article.

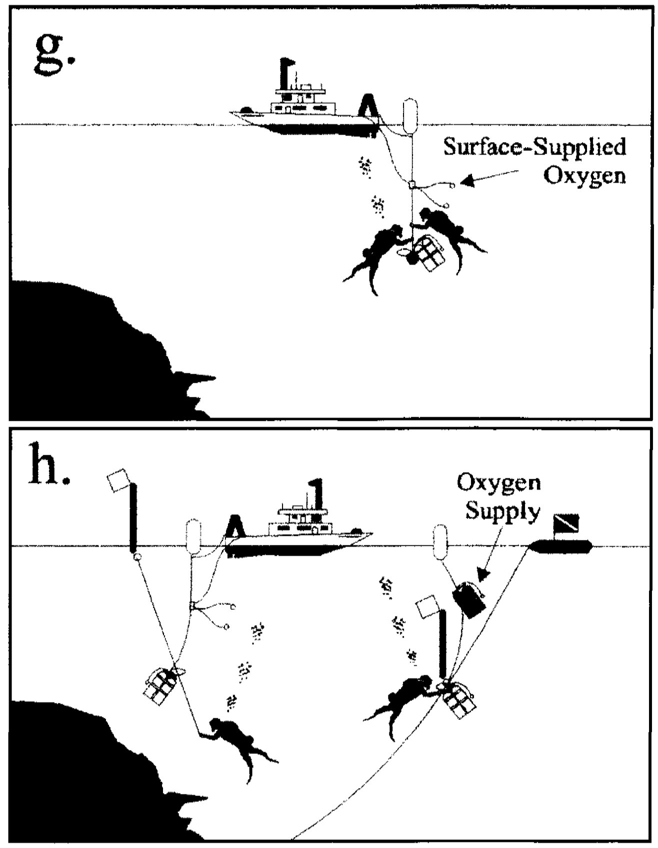


Figure 3 (continued from previous page) g) surface support deploys open-circuit oxygen supply; h) separated pair both independently require open-circuit bailout, diver with tow line follows standard procedures while separated diver deploys emergency float via reel line.

## Over my head.

*Here's What Happened:* After about 35 hours of practice dives in shallow water, I felt ready for the "big leagues," so I decided to make a dive to 85 ft /26 m. The rebreather had proven so reliable that I decided I didn't need to use the heads-up display, so I pushed it out of my field of vision. The current was strong, so I made a rapid descent to the bottom, manually adding gas to the breathing loop to compensate for the increasing pressure of depth. Once on the bottom I found myself down-current of the dive site, so I immediately started swimming against the current without checking any of my gauges.

I fought hard for at least 5 minutes, and I wasn't quite experienced enough to notice that the oxygen injection solenoid had not fired since my initial descent. Only after I finally arrived at the dive site, huffing and puffing, did it occur to me to check the gauges. The PO2 was 3.5 atm! I later realized that I must have been manually adding oxygen, rather than diluent, during the initial descent. If, after 5 minutes of heavy workload, the PO2 in the breathing loop was 3.5 atm, I can only imagine what it was when I started swimming against the current. That I did not convulse from CNS oxygen toxicity under those circumstances can only be described as miraculous. I was not wearing a full-face mask.

*Take-Home Messages:* 1) Distinguishing manual diluent addition from manual oxygen addition valves should be as reflexive and intuitive as breathing; such mistakes should simply not happen. 2) One must know the PO2 in the breathing loop at all times; besides disabling the heads-up display, I made the mistake of not checking the PO2 displays after a substantial depth change. 3) Had I convulsed, a full-face mask would have saved my life; chalk one up in favor of the use of full-face masks with rebreathers. *Lesson learned:* rebreather divers should not let their confidence exceeded their abilities.[Nor should any other divers --ed.]

**1) Distinguishing manual diluent addition from manual oxygen addition valves should be as reflexive and intuitive as breathing; . . . 2) One must know the PO2 in the breathing loop at all times . . . 3) Had I convulsed, a full-face mask would have saved my life; chalk one up in favor of the use of full-face masks with rebreathers.**

## Between a Rock and a Hard Place

*Here's What Happened:* My rebreather partner John and I descended on our first deep dive of our expedition to Papua New Guinea. We followed the slope down to a depth of about 330 ft /100 m, and found a rock with some interesting fishes.

About 10 minutes into the dive, John caught my attention and showed me that his PO2 had fallen to about 0.7 atm. His solenoid had been firing correctly, but the PO2 was not being maintained at set-point. He tried to manually add oxygen, but when he pressed the valve, nothing injected into the loop.

Although his primary oxygen cylinder gauge indicated that it was full, he switched over to his backup oxygen cylinder (also full) – but he was still unable to inject oxygen into the breathing loop. At about this time, I began to notice that the PO2 in my breathing loop had also fallen below set-point. When I tried to inject oxygen into my breathing loop, I had the exact same set of failures as John. Four different oxygen supply systems had independently and simultaneously failed! By that time, the PO2 in John's breathing loop had fallen to 0.5 atm, so we aborted the dive. As we started to ascend, the PO2 in John's breathing loop fell sharply as the ambient pressure dropped, until we reach 275 ft /83 m when it was 0.2 atm – dangerously close to hypoxic. John's only option at this point would have been to abort in open-circuit mode. He tried one last time to manually add oxygen to his breathing loop, and finally it began to trickle in. I also noticed that the PO2 in my breathing loop had returned to set-point. Perplexed, but nevertheless relieved, we completed our decompression with perfectly functional rebreathers.

Only after the dive were we able to figure out the cause of the problem. All four oxygen first-stage regulators (primary and backup on both rebreathers) had environmental protection systems that included a rubber diaphragm sealing the ambient pressure balance chamber of the first-stage regulator. Unbeknownst to me, this chamber was supposed to be filled with a fluid (such as alcohol), but the fluid had long-since evaporated out. Because this chamber in all four oxygen regulators was gas-filled, the rubber diaphragms stretched inward in response to increasing ambient pressure until they had "bottomed-out" on the adjustment nut for the inter-stage pressure spring. Once the diaphragms had "bottomed-out," the inter-stage pressure was no-longer compensating for increasing ambient pressure. At 330 ft /100 m, the inter-stage pressure was equal to the ambient pressure, so there was no movement of gas from the regulator to the breathing loop. Back in shallower water, the regulators had returned to normal function.

*Take-Home Messages:* 1) Know the functional design of every component of rebreather, inside and out; I should have been familiar with the oxygen regulator first stages and should have known how to maintain them properly. 2) It is important to intimately understand gas physics and physiology; it should have been obvious to us right away what the problem was, and how best to solve it. 3) Different people work at different rates; John's body burns oxygen about twice as fast as mine does at low to moderate workloads, which is why this particular problem was much more acute for him than it was for me. 4) Understand the bailout options; the diluent regulators were functioning correctly; we could have injected diluent into the loop to maintain a safe PO2. *Lessons learned:* Rebreather divers should have an intuitive understanding of the mechanical aspects of the rebreather, gas physics, rates of oxygen metabolism, and bailout options.

## Knowing thy mix

*Here's What Happened:* John and I descended on our way to 220 ft /67 m. At about 115 ft /35 m, we switched our diluent supplies from air to heliox, and continued our descent. Shortly before reaching the bottom, John noticed that the PO2 in his breathing loop had climbed to 1.6 atm. He correctly responded by flushing the loop with heliox, but the PO2 escalated to nearly 1.8 atm. Additional diluent flushing had no effect on the PO2. Both primary and secondary PO2 displays were giving identical readings, and there was no indication of sensor malfunction. He switched back to air as a diluent and flushed the loop, and the PO2 dropped down below 1.5 atm (but the narcosis level increased). We immediately aborted the dive. I had filled both of our heliox cylinders more than a month earlier, and at the time, I confirmed that both contained 10% oxygen. I had not re-analyzed the heliox cylinders prior to this dive, but after the dive we discovered the FO2 of the heliox on John's rig was now 25%.

*Take-Home Messages:* 1) Always analyze, label and log your gas mixture, and know what you're breathing prior to the dive; had we done this, we never would have encountered a problem. 2) Don't bypass the brain when solving problems; although John had believed the oxygen content of the heliox was 10%, and although his training was to automatically respond to high PO2 by flushing the loop with diluent, he was still savvy enough to realize what had happened, and cleverly switched back to air to bring the PO2 back down (under the circumstances, he regarded narcosis as the lesser of two evils compared to the high PO2). *Lessons learned:* It is imperative that diluent gas supplies be mixed properly and analyzed immediately prior to the dive; the brain should not be bypassed when responding to a problem; an intuitive grasp of causes and effects of rebreather operations is critical; laws of physics don't lie.

## Starved for Breath

*Here's What Happened:* While in Papua New Guinea, I rushed to assemble the rebreather for a dive on which Bob Halstead was to take photographs of John and me. I quickly calculated (in my head) how much dive time I had used on that particular canister of absorbent, and decided it was about 8 hours. Because I was typically getting 11 hours out of a canister, and because this was to be a short dive, I decided not to spend the time to re-pack the canister with fresh absorbent.

We fought a strong current down to a depth of 130 ft /40 m, where we were to take the photographs. I found it extremely difficult to catch my breath once we were down. Although I had worked hard against the current, I was unusually short of breath. When I was still starved for breath after about 5 minutes of posing for the camera (low exertion), it was obvious that I should abort the dive. During the ascent, the symptoms subsided slightly, but then quickly re-appeared with a vengeance during my safety decompression stops. I flushed the loop with air, and was soon able to breathe normally again. Within a few minutes, however, the shortness of breath returned.

**Gasping and coughing at the surface, it occurred to me that I had very nearly drowned.**

After I surfaced (with a splitting headache), I looked over my dive logs and discovered that I had actually used that particular canister of absorbent for thirteen previous hours of dive time.

*Take-Home Messages:* 1) Managing rebreather expendables must be done carefully; I should not have calculated a variable as critical as remaining absorbent life so flippantly. 2) Carbon dioxide absorbent is cheap, lives are not; regardless of my miscalculation, I should have changed the absorbent long before. *Lessons learned:* Knowing the remaining life of a canister of carbon dioxide absorbent is critical.

## Slow Down There, Young Feller

*Heres What Happened:* This involves two incidents which occurred on the same day. One morning in Papua New Guinea, I was rushed to get the rig ready for a deep dive. I had prepared the rebreather the night before, so I just climbed into it, did a quick pre-dive check of the system, and decided to forgo the "positive pressure" loop test. Tightening the straps on my full face mask, I deflated my BC and made a "giant stride:" entrance off the dive platform. My first inhalation filled my throat with water, and I began to cough and choke. Because I was negatively buoyant, I had to struggle to ascend the two or three feet to the surface, and then hastily rip the full face mask off.

Gasping and coughing at the surface, it occurred to me that I had very nearly drowned. I assumed the water had leaked into the masks oral cup when I jumped into the water, so I carefully replaced the mask, started descending, took a breath, and inhaled water down my throat again! Once more, I struggled back to the surface, ripped off the mask, and gasped for air.

After I climbed back aboard the boat and removed the rebreather, I saw the source of the problem: I had neglected to connect the inhalation breathing hose to the rebreather – it was just dangling free! Not only had I almost killed myself (twice!), but I had completely flooded the rebreather loop.

Later that same day, I neglected to replace the plug over the data download jack on the main electronics housing. Within seconds of the rebreather entering the water, the main electronics completely flooded with salt water and were destroyed.

*Take-Home Messages*: 1) Pre-dive check routines are very important and should not be bypassed; conducting a positive-pressure loop test would have alerted me to the fact that the breathing hose was disconnected. 2) Pre-dive checks should be thorough; my routine previously did not include checking to see that the plug is replaced on the data download jack – now it does. *Lesson learned:* Haste makes waste, and can potentially lead to costly, and even deadly consequences.

## A Long Way on Two Breaths of Air

*Here's What Happened:* It was the last day of our Papua New Guinea expedition, and we had time for only one more dive. My advisor, Jack Randall, had seen what he believed represented a new genus and species of fish at a depth of 80 ft /24m. Because he had been diving all day using conventional air scuba, he had no remaining bottom time left at that depth. I had been using the rebreather all day (optimized gas mixtures), so I had plenty of remaining bottom time.

We decided that Jack would bounce down with me to show me the spot where he had seen the fish, then I would look for it and try to collect it. We rushed to gather our equipment together in the chase boat, had our guide motor us out to the correct spot, and Jack rolled over the side. Just as I was about to follow, I noticed that my diluent cylinder was completely empty. Jack was already gone, and if I had returned to the Telita for more air, I never would have found him again, and he would never be able to show me where the fish was. I manually flushed the loop with air using my mouth and rolled over the side to follow Jack.

During my descent, I had to add oxygen to the breathing loop to compensate for the drop in loop volume. By the time I caught up with Jack at 60 ft /18 m, the PO2 in my breathing loop was 1.6 atm (too high already, and it would have been way too high at 80 ft /24m). The only way I could get more air into the breathing loop was to get it from Jack's cylinder. I motioned to him that I needed to buddy breathe, and he assumed I needed to abort the dive. I did my best to explain to him that all I wanted to do was to take a few breaths of his air and exhale them into my rebreather (to add more nitrogen to the breathing loop), but I wasn't getting the message across. After two breaths of his air, I gave up trying to explain, and simply motioned that everything was O.K. He pointed to where he had seen the fish, and headed back to the surface. When I got to 80 ft/ 24m, the PO2 in the loop was just over 1.4 atm. However, if I exhaled any gas from the loop, I would have lost nitrogen, which would have been replaced by oxygen, and the PO2 would have been too high. Thus, I had to be very careful managing my loop gas.

Jack had said the fish was light brown with a black spot near the tail. All of a sudden, a small light-brown fish with a black spot near the tail swam by. I spent nearly an hour chasing the fish, all the while being very careful not to loose any gas from the loop. Remarkably, I was able to stay the whole hour without any increase in the PO2. Even more remarkably, I managed to catch the fish! I completed the dive, proud of my accomplishment (both for catching the fish, and for stretching so much dive time out of only two breaths of air).

Then the error of my ways suddenly dawned on me: what if I needed to make an open-circuit bailout from the dive? I would have been screwed. To add to my failure, when I showed the fish to Jack, it was the wrong one! Apparently there is another light-brown fish with a black spot near the tail at 80 ft/ 24 m off Papua New Guinea.

**Then the error of my ways suddenly dawned on me: what if I needed to make an open-circuit bailout from the dive? I would have been screwed.**

*Take-Home Messages:* 1) Always ensure that at any time during the dive, at least one gas supply is safe to breathe in open-circuit mode; had I needed to abort from the dive on open-circuit, I would have had to breathe pure oxygen at a depth of 80 ft /24 m. 2) Rebreathers really can go a long way on only a small quantity of diluent! *Lessons learned:* Always make sure there is enough gas to make a safe abort to the surface; and make sure you have a more specific description of a new genus and species of fish than "light brown with a black spot near the tail," especially if it's the last dive of an expedition.

## Conclusions

In this article I have described my reasons for using closed-circuit rebreathers, some of the lessons I've learned from my experience with this equipment, and an outline of the procedures and protocols I have developed for diving with rebreathers in the sorts of environments and conditions that I do (deep coral reefs). While this article may contain some useful tidbits and "words of wisdom" of general applicability, in no way is it intended as a template for generalized rebreather standards.

Military divers have used closed-circuit rebreathers for many decades, and represent the single largest experience-base for closed-circuit rebreather operations. Certain commercial divers and other individuals also have independent experience that spans many years to decades. Specific rebreather designs are many and varied and will likely continue to change in the years to come. No single user or user-group has all the answers for all possible conditions.

Present and future rebreather divers will continue to experiment with new combinations of equipment, environments, and diving objectives; and new procedures will need to be invented and refined. Perhaps the single most important step to take in minimizing the number of accidents involving rebreathers is to create and maintain an open exchange of information between past, current, and potential future rebreather divers. Expanding the collective body of knowledge, experience, and wisdom to its maximum scope can only enhance the progression of our individual levels of safety and productivity with this evolving technology.

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# Work of Breathing in Underwater Breathing Apparatus and CO2 Build-up

by John Clarke

Editor's note: This paper is a text format version of the author's presentation to the Rebreather Forum 2.0, with the text matched to slides presented by the author.

In this talk I'll explain briefly where the term "work of breathing" came from, how it's measured, and the meaning of some of the new terminology appearing in UBA test reports from the Navy Experimental Diving Unit (NEDU).

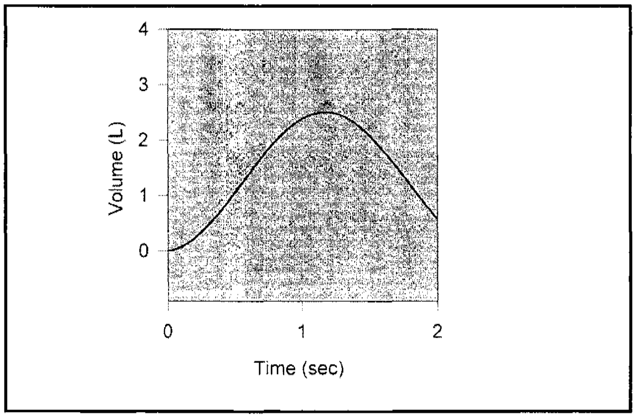
The intuitive definition of work of breathing or WORK (W) is simply "a measure of how easy it is to breathe on a UBA." The non-intuitive definition of work of breathing is the physicist's definition.

| Intuitive Definition | Non-Intuitive Definition |
|---|---|
| The work of breathing (W) is a measure of how easy it is to breathe on a UBA. | When forcing gas through the UBA with a breathing machine, W is the product of pressure and volume integrated over one breathing cycle. |

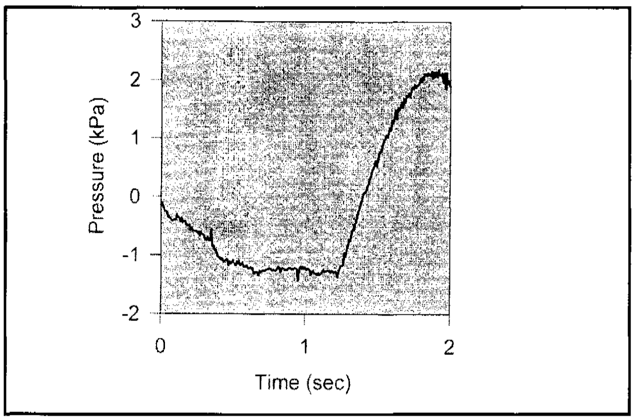
In simple terms, when NEDU tests a piece of breathing apparatus, we push gas through it in a sinusoidal, up and down wave form, mimicking a diver's breathing. We then measure changes in pressure as a function of volume in the UBA. From that we compute work (W).

$$W = \oint P dV$$

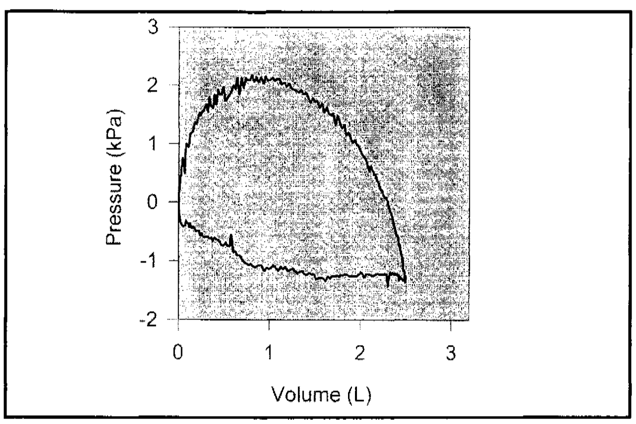
$$W = \int_0^{V_T} P_{\exp} \cdot dV - \int_0^{V_T} P_{ins} \cdot dV$$



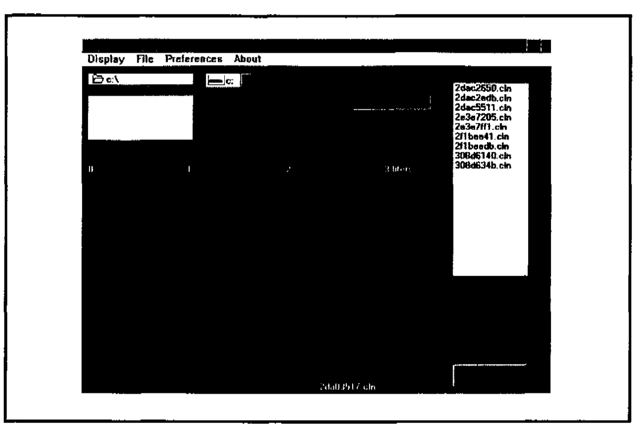

If we look at volume over time, as plotted here, with time on the horizontal axis and volume on the vertical axis, you see, as you would expect, a sinusoidal motion of the volume tracing - a movement up and down. (Based on Mark 16 UBA --ed.)




Now if we look at pressure, in this case going through a modified Mark 16 UBA, pressure measured at the "mouth" drops to negative values during inhalation when the diver or breathing machine is sucking gas out of the rig. Then during exhalation, pressure goes up, becoming in this case quite positive over time.




Now if we take the volume tracing against time, and combine it with the pressure tracing against time, and plot both volume and pressure against each other, we obtain a breathing loop. This should not be confused with the "breathing loop" on the UBA - the pathway for gas within the UBA. This breathing loop is more properly called a P-V loop, a pressure-volume diagram. The resistive work involved in breathing this UBA is simply the area inside the P-V loop.

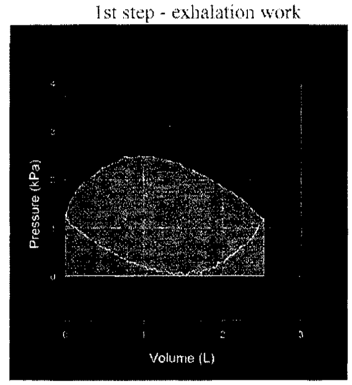



For example, here is a P-V loop of gas being pushed through a simple orifice resistor, nothing more than a pencil sized hole in a small metal cylinder. The work involved in pushing gas back and forth through the orifice is found by the area inside this loop.

Now let's look at how we find the area inside the loop. To ease visualization, we show a loop that has been repositioned so that the minimum pressure is set to zero.

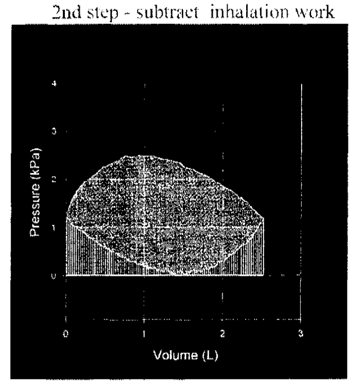
The computer measures the area from the minimum pressure all the way up to the top of the loop (shaded area).

1st step - exhalation work




Then the computer subtracts the area underneath the loop during inspiration. What we're left with is the gray area inside the loop. This area is the work (W) coming from resistive sources, like hoses and CO2 canisters, during a single breath.

2nd step - subtract inhalation work




The resistance or impediment to breathing that one experiences when diving comes from two sources. One is external to the diver, the UBA itself; the other is internal, the diver's airways.

UBA designers can decrease external work of breathing by expanding the sizes of breathing hoses, by opening up mouthpieces, by low resistance absorbent canisters and even altering breathing bag designs. However, the UBA designer-manufacturer can do nothing about internal resistance. That is derived from the size, caliber and length, of one's respiratory airways.

## The Total Work of Breathing Comes From

- external sources (UBA)

+

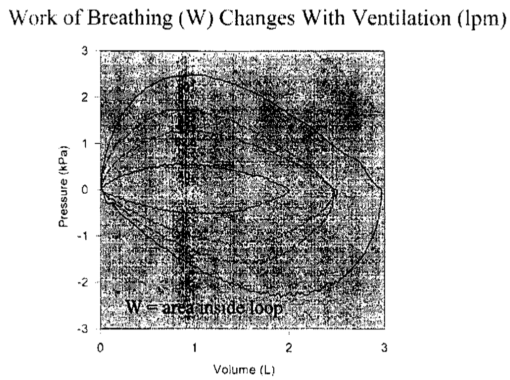
- internal sources (diver's airways)

Given a fixed UBA design and a fixed internal anatomy, the total work involved in breathing can still change dramatically throughout a dive. For instance, work (W) increases with increases in gas density. The deeper you go, the more dense the gas becomes. (Of course if you go very deep, a large part of this density increase can be offset by using low density helium-oxygen mixtures). Whenever gas density is increasing, then the work, the effort required to breathe, will increase. Also, the harder you work, the harder you breathe, which also increases flow resistance and breathing work.

The use of fine grain size CO2 absorbents is great for extending canister durations. However, their use comes with a physiological cost; by breathing through a bed of fine, well-packed soda lime granules, the work of breathing goes up.

## The Work of Breathing Increases With

- increases in gas density
- increases in diver ventilation
- Use of smaller grain size $CO_2$ absorbents




This graph is a good example of increases in work of breathing with increasing ventilation. These are P-V loops for the same orifice resistor discussed earlier. Various amounts of gas are being pushed through the orifice. A Respiratory Minute Volume (RMV) of 40 liters per minute (inner most loop) was generated when the breathing machine was moving 40 liters of gas into and out of the UBA each minute. At a ventilation rate of 62.5 liter per minute, a larger loop is formed; it takes more effort to harder. Each increase in ventilation yields a progressively larger loop area, and therefore a progressively larger value for W. While this illustration is for a simple orifice, the same thing happens with a UBA as complex as the MK 16.

What the Navy has long called Work of Breathing, isn't!

What the U.S. Navy has long called the work of breathing really isn't the work of breathing. It's very close to it, though. As we have seen, the work involved in breathing for a single breath is defined as W, the area inside of a P-V loop. Because W changes so much with changes in ventilation, as seen on slide 12, the Navy found it useful to divide W by tidal volume, which is a measure of how deeply one breathes. However, a physicist can tell you that when dividing P-V work by volume, the result is a pressure.

$$\overline{P}_V = \frac{W}{V_T}$$

Used to be WOB. Now called:
volume averaged pressure - NEDU
volume weighted average pressure -SUNY Buffalo
resistive effort - NEDU

A proper term for this pressure is volume averaged pressure, or as the University of New York at Buffalo says, volume-weighted average pressure. Because both of these physically correct terms are difficult to say and understand, we prefer the more intuitive term "resistance effort." This phrase, which appears in recent NEDU reports, appropriately avoids the word "work," and yet it describes something we intuitively understand - the effort involved in breathing.

Some NEDU Reports Plot UBA Resistance

$$\overline{R} = \frac{120 \cdot \overline{P}_V}{\pi^2 \cdot RMV}$$

Average resistance can be easily calculated from resistive effort.

Fortunately, we can take the measurement of resistive effort, formerly called work of breathing, and convert it into a true measure of breathing resistance. Resistance is a property of a UBA that is both easily understood and has real scientific meaning (unlike the word "effort").

In recent NEDU reports on UBA tests, plots of both resistance and resistive effort are frequently found. However, in every instance we're simply describing in one form or another how easy or difficult it is to breathe a particular UBA.

What happens when the work of breathing is too high?

As most of you know, when encountering a high breathing resistance, divers tend to slow their breathing down. It takes a lot of effort to breathe against something with a high resistance. Unless you take much deeper breaths at the same time you're slowing your breathing rate down, you are going to hypoventilate or under-breathe.

### When a diver encounters high breathing resistance

- There is a tendency to slow down breathing.
- Unless larger breaths are taken, the diver under-ventilates.

Most of you know that when you start "skip-breathing" or conserving your breath, bad things tend to happen. Carbon dioxide levels within your bloodstream begin to increase due to hypoventilation; you're breathing too little to get rid of the CO2 building up. Furthermore, the longer that the amount of CO2 that you're producing is outstripping your ventilation, the greater the likelihood of your passing out. I think we can all appreciate that losing consciousness underwater could be considered a bad event.

### When a diver encounters high breathing resistance

- $CO_2$ levels in the blood stream begin to rise due to low ventilation.
- The longer diver work rate outstrips diver ventilation, the greater the risk of Loss of Consciousness (LOC).

Furthermore, high carbon dioxide levels tend to make a diver more susceptible to oxygen toxicity. Even in a closed circuit rig, if you're diving rapidly to deep depths, oxygen levels can get very high. If you have high CO2 levels at the same time, that considerably increases your chances of getting an oxygen convulsion or seizure - very much like an epileptic seizure.

### Even if LOC Does Not Occur

- High $CO_2$ levels make a diver more susceptible to oxygen toxicity: a constant concern in semiclosed and oxygen UBA.

You can have elevated CO2 levels because of mixing between fresh and exhaled gas in a full face mask with communication between the oral-nasal and the rest of the mask. If you rebreathe your previously expired CO2 and you're not able to blow the CO2 out because of breathing resistance, then your arterial CO2 will begin to rise. You also have a CO2 absorbent which has a finite lifetime, and if you're working hard and working long, sooner or later that CO2 absorbent is going to become depleted. That means the canister will start bypassing CO2, in an almost exponential manner. Unfortunately, you may not be aware of it until too late.

### Arterial $CO_2$ Can Also Increase From Elevated Inspired $CO_2$

- Due to mixing between fresh and exhaled gas in a diving helmet - "dead space"
- Depletion of the $CO_2$ absorbent in the scrubber canister of closed and semi-closed UBA

### The U.S. Navy Allows

- Inspired $CO_2$ levels equivalent to a 0.5% surface value in closed and semi-closed UBA.
- A canister is said to have "broken through" when inspired $CO_2$ reaches 0.5%.

Expired levels of CO2 equivalent to 0.5% at the surface is all that the US Navy will allow in closed- and semi-closed UBA. A UBA is said to have broken-through the CO2 canister, has started leaking CO2, and the CO2 in the breathing loop is reaching 0.5%. When NEDU publishes a canister duration for a closed-circuit UBA, we measure the average time required for a large number of canisters to break-through, and add appropriate statistical safety measures to come up with a usable dive time for that canister.

- Any increase in inspired $CO_2$ causes either an increase in ventilation which increases breathing resistance
- Or accelerates the rise in arterial $CO_2$ caused by resistance induced under - breathing (hypoventilation).

Any increase in inspired CO2 is bad. It either causes an increase in ventilation, which increases breathing resistance, or causes a diver to skip breathe, hypoventilate. As already mentioned, hypoventilation can result in loss of consciousness.

### Canister Durations Are Determined Statistically

The last point you need to remember is that canister durations are right now determined statistically. Some day the diver will have a monitor that tells him not only how much oxygen he has in his breathing loop, but also how much CO2is being inhaled. However right now we don't have that luxury.

What you do have are facilities like NEDU that run literally hundreds of hours of tests to determine break-through times for a large quantity of canisters under various conditions of water temperature and simulated exercise rate. From that massive amount of data we derive what we hope are safe canister durations.

Unfortunately, even measurements made under identical conditions of temperature, dive depth, absorbent , will vary considerably. The important thing for you, as an individual diver, to remember is that a dive duration yielding a 0.5% inspired CO2 in the average canister can easily reach 1% or more in any particular canister. If you're diving that particular canister, and you stop right at the published canister duration limits, keep in mind, that you may nevertheless be breathing twice the so-called allowed limit in closed-circuit UBA.

On the average, you'll be safe if you follow published limits [Where there is statistical data to base it on—ed.]. However, that does not mean that you're always going to be safe. Just as in decompression, there is a risk. In closed- and semi-closed circuit UBA, we have a considerable accumulation of risk. A diver is accumulating risk for decompression sickness, for oxygen toxicity, and if you dive long and hard, you can accumulate a risk for developing CO2 narcosis.

- A large number of canister duration measurements, taken under identical conditions, will vary widely - especially in "long duration" canisters.
- A dive duration yielding a 0.5% SEV inspired $CO_2$ in the *average* canister may easily reach 1% or more in a significant percentage of dives.

Work or resistance effort is important to the Navy because high breathing resistance causes divers either to quite working, because of breathing discomfort–the term dyspnea mentioned earlier–or lose consciousness due to CO2 narcosis.

### Work or Resistive Effort

Is Important to the Navy Because

- High breathing resistance causes divers to either quit working because of breathing discomfort or
- lose consciousness due to $CO_2$ narcosis.

One thing we observed while conducting medical research at the Navy Medical Research Institute in Bethesda, MD, was that the magnitude of respiratory pressure is related to the probability that a dive will end eventfully. If you're working hard, breathing hard on a high resistance UBA, then the higher the respiratory pressures, and the greater the chances that something is going to happen. Either you're going to become out of breath and abort the dive, or you're going to remain quite comfortable up to the point of unconsciousness.

### Work or Resistive Effort

Is Important to the Navy Because

- The magnitude of respiratory pressures are related to the probability that a dive will end eventfully.

*Dr. John Clarke is senior scientist at the US Navy Experimental Diving Unit in Panama City, FL.*

# Rebreather Terminology & Common Units

**Absorbent:** The chemical material such as soda lime or lithium hydroxide used to remove CO2 from the breathing loop usually known by their trade names; Sofnolime, Sodasorb, Baralyme, etc.
**Bailout:** Emergency procedures designed to return the diver to safety in the event of a system malfunction.
**Breathing bag:**See counterlung. The flexible bag(s) or diaphragm inside of a rebreather that allows the diver to breathe in and out.
**Breathing loop:** The breathing pathway through a rebreather including the hoses, counterlung, canister. Note that when a diving a rebreather the divers lungs become a part of the breathing loop.
**Bypass valve:** Manual controls on the diluent and oxygen gas supplies that allow the diver to manually add gas to the system in the event of a malfunction.
**Bubblers:** Slang for open circuit scuba divers.
**Canister:** The component of a semi-closed or fully closed circuit system that contains the chemical CO2 absorbent. Cannister duration is a function of work rate, water temperature, depth, and the type of absorbent used. It's estimation is more of an art than a science.
**Cannister break-through:** The point at which CO2 absorbentin the canister begins to quit and starts allowing CO2 to pass back into the breathing loop so that it is reaching or exceeding 0.5%. Once the CO2 begins to leak through the absorbent , it begins to do so at an exponential rate.
**CCUBA:** Acronym for "closed circuit underwater breathing apparatus."
**CNS Oxygen Toxicity:** Central nervous system toxicity due to excessive oxygen levels as measured by PO2 often resulting in convulsions. The threshold for CNS toxicity is recognized to be about 1.5-1.6 atm, though incidents have reportedly occurred at PO2s as low as 1.3 atm.
**CO2:** Carbon dioxide. The human body produces about 0.8 liters of CO2 for every liter of oxygen consumed.
**Cocktail:** AKA "caustic cocktail." Breathing in a solution of CO2 absorbent that has come into contact with water as a result of flooding the canister. This is less of a problem in contemporary systems that utilize water traps and hydrophobic filters.
**Constant mass flow:** A regulator used in a semi-closed circuit system to deliver a constant mass of premixed gas to the diver, independent of depth.
**Constant PO2 decompression table:** A decompression schedule based on maintaining the constant partial pressure of oxygen used in a rebreather versus the constant fraction of oxygen in open circuit systems. Several new generation rebreathers include a real-time dive computer.
**Consumables:** The materials that are "consumed" during rebreather diving operations including gas supply, the chemical absorbent used to remove the CO2 and batteries. Typically consumables costs per dive amount to a few dollars for gas, and US $10-20 worth of absorbent depending on the dive(s), assuming the unit has rechargeable batteries.

# Appendix

**Counterlung:** The flexible bag or diaphragm inside a rebreather that allows the diver to breathe in and out.
**Cryogenic scrubber:** A next generation concept in CO2 scrubbing that freezes out the CO2 in the divers breathing loop using a super cooled refrigerant. First used in Sterling Electronics SS-1000 in the 1970s.
**Dyspnea:** Shortness of breath caused by a high CO2.
**Diluent:** The carrier or make-up gas used to dilute the oxygen in a closed circuit system in order to maintain PO2s within physiological safe limits and to maintain the ambient pressure in the breathing loop. Typically the diluent contains an inert gas such as nitrogen (N2), helium (He) or Neon (Ne) mixed with sufficient oxygen (O2) to sustain the diver at the maximum planned diving depth in case of emergency.
**Disinfectant:** Used to clean out the breathing loop in a rebreather after use.
**Fully closed circuit system:** A self-contained breathing apparatus that recirculates all of breathing gas exhaled by the diver, adding oxygen as it is consumed, and removing the exhaled CO2.
**Galvanic cell:** An electro-chemical sensor which reacts to oxygen to provide an electrical signal corresponding to the partial pressure of oxygen (PO2) in the gas.
**Gas switches:** Switching gas mixes during the decompression phase of the dive in order to improve decompression efficiency and reliability.
**Hypercapnia:** The result of excessive levels of carbon dioxide as measured by its partial pressure. Most standards call for CO2 to be kept below about 0.5 kPa/0.005 atm.
**Hyperoxia:** An excess of oxygen, typically above about 1.6 atm. May lead to CNS toxicity and convulsions.
**Hypoxia:** Insufficient oxygen to sustain metabolic needs, typically below about 0.10- 0.12 atm.
**KYAG:** What you should do if your breather craps out and you don't know the proper emergency procedures.
**Membrane scrubber:** A next generation CO2 scrubbing concept that utilizes a molecular sieve to selectively remove CO2 molecules from the divers breathing loop.
**Mixing on the fly:** Slang for one of the key features of a closed circuit rebreather: onboard gas mixing.
**Onboard gas:** Gas supply carried within the rebreather normally connected into the breathing loop.
**Off board gas:** Gas supply carried external to the rebreather but selectable into the breathing loop for decompression or in case of an emergency.
**Open Circuit:** A self-contained breathing apparatus where all exhaled gas is vented to the water.
**Oxygen sensors:** Used to measure the PO2 in the divers breathing loop. Typically an electronic rebreather will use three sensors for decision-making clarity.
**PO2:** Partial pressure of oxygen. Also referred to as PPO2. Must be maintained between about 0.16-1.6 atm.
**Primary Display:** Primary information display on a rebreather that shows PO2, gas volume, battery status, and in some cases decompression and PCO2 information.
**Scrubber:** The component of a semi or fully closed circuit system that removes CO2 from the breathing loop.
**Secondary display:**A back-up rebreather display that typically runs on an independent battery.
**Scuba:** Self contained underwater life support, originally from "SCUBA," a 1950s acronym for "self-contained underwater breathing apparatus." Commonly, though not accurately, used to mean "open circuit" scuba.
**Semi-closed circuit system:** A self-contained breathing apparatus system that recirculates a portion of the gas exhaled by the diver and vents the remainder in the water.
**Set:** A name for a divers life support system, i.e. a scuba set.
**Set Point:** The preset partial pressure of oxygen (PO2) to be maintained by a closed circuit system, and some semi-closed systems. Note that the US Navy has historically run their mixed gas rebreathers at 0.7 atm, while newer models are targeting a PO2 of 1.3 atm. Sport models run as high as 1.4 atm in order to minimize decompression. Note that some of the newer digital control systems allow the user to vary the set point during various phases of the dive, for example boosting the set point from 1.4 atm to 1.6 atm during decompression.
**UBA:** Underwater breathing apparatus.
**What Goes Around, Comes Around:**Karmic implications of rebreather diving.

# UNITS

| | |
|---|---|
| cf | cubic feet (= 28.3 liters) |
| f | feet of seawater (fsw)=1/33 standard atmosphere (atm) |
| FBO2 | bag oxygen fraction |
| FO2 | oxygen fraction |
| FSO2 | oxygen supply fraction |
| lpm | liters per minute (=.0353 cubic feet) |
| m | meters of seawater (msw) = 3.2586 fsw=1/10 bar |
| Pamb | ambient pressure absolute |
| PCO2 | partial pressure of CO2 |
| PO2 | partial pressure of O2 |
| slpm | standard liters per minute |
| VO2 | CO2 production |
| VHE | helmet ventialtion rate |
| Vin | gas injection rate |
| VO2 | O2 consumption |

# Rebreather Vendors

**AP Valves** +44-1326561-040, f: +44-1326-573-605
**Biomarine**, Dick King 610-873-7200, f: 800.220.2850
**Carleton Technologies**, Tim Curtiss p: 813-623-3711 f: 813-623-5373
**Cis-Lunar Labs**, Richard Nordstrom p: 617-859-2888, f: 508-368-0542
**Cochran Consulting**, Peter Readey: P: 214-644-6284, f: 214-644-6280
**DIVEX**, Derek Clark p: +44-1224-740-145, f: +44-1224-740-172
**Dräger**, Christian Schult p: +49-4502-883-229, f: +49-4502-883-202
**Environmental Support**, Barnie Lambert p/f: 408-227-0743
**Fullerton Sherwood**, John Sherwood p: 905-670-0656, f: 905-670-8318
**Grand Bleu**, Yutaka Furichi p: +81-3-3796-1541 f: +81-3-3796-1542
**Halcyon**, Jack Kellon p: 954-462-5570, F; 954-462-6115
**Interspiro** AD p: p: +46-8-767-94-80
**National Drager**, Russ Orlowski p: 412-788-5699 f: 412-788-5944
**Rebreather Mfrg & Distribution**, Harry Wengatz p: 604-716-3391 f: 604-716-3381
**Undersea Technology**, Jack Kelley p: 918-585-2511, f: 918-584-3409
**US Divers**, Dave Stancil p: 714.540-8010 f: 714.432.9340.
**UWATEC**, Bret Gilliam p: 207-442-0998 f: 207-442-9042

# South Pacific Undersea Medical Society (SPUMS) Policy on Technical Recreational Diving

by Des Gorman, Drew Richardson, Bill Hamilton, and David Elliott

## Introduction

The Society dedicated the 1996 Annual Scientific Meeting to a Workshop on emergent recreational diving practices - the so-called technical diving - in recognition of the need for some pragmatic guidance in this area from an organisation with no commercial interest in the activity and as a responsible medical society.

The Society has presented opinions on the subject previously in the form of an Editorial in the Journal. [1] This included two basic statements: first, that the risks involved needed to be understood by aspiring divers and trainees; and that the Society A) would not argue with attempts at relevant regulation. The latter has to be interpreted in the context of the debate at the time, the nature of the then-intended diving practice and the absence of well-established diving systems outside the conventional (open circuit demand scuba-air diving to 40 msw) recreational diving clubs and instructor agencies when the Editorial was written. It also needs to be emphasised that, with the exception of "employed" divers where a regulated "duty of care" for employers is essential, the Society has never supported the external regulation of recreational diving. Indeed, the Cave Divers Association of Australia, has been and will continue to be advocated by SPUMS as a role-model of effective self-regulation.

**It also needs to be emphasised that, with the exception of "employed" divers where a regulated "duty of care" for employers is essential, the Society has never supported the external regulation of recreational diving.**

The debate about technical diving has often been acrimonious, to the discredit of those involved, and has consequently distracted the attention of the debaters - from the essential and necessary description of appropriate and relevant risk management. In addition, many commentators have become obsessed with the nature of the diver (e.g.. recreational versus employed), rather than paying attention to the nature of the diving. The issue is further complicated by the uncertainty as to what is technical diving. Comprehensive definitions consequently include diving practice with widely divergent risks - thus a debate on the "safety" of technical diving per se becomes nonsensical.

# The SPUMS Workshop on Technical Diving

The SPUMS Workshop on technical diving was free of both acrimony and rancor, indeed it was vigorous and entertaining—much to the credit of all those who presented papers (published in this edition of the Journal) and those who became involved in the debate. An acknowledgment here of the high quality of conference convening by Drs. Guy Williams and Chris Acott is also appropriate. There were no written submissions.

# The SPUMS Policy on Technical Diving

## 1. Recognition of technical diving.

The Society recognises, but does not necessarily endorse technical diving. Such diving includes activities "outside" the conventional recreational limits of open-circuit demand scuba-air diving to 40 msw and often involves special techniques, equipment, gas mixtures and decompression procedures. Although a common definition of technical diving limits practice to those which involve a rebreather or a change in breathing gas during the dive (and hence excludes shallow enriched air diving and deep air diving), it is still considered that for the purpose of risk management that "technical diving" is not a sufficiently specific term. This is because the types of diving referred to by this title are widely divergent in nature and risk. Instead, a consideration of each type of diving in isolation is necessary. It is also follows that unique training and diving conduct measures are necessary for each type of diving activity.

The Society believes that the critical issue in assessing diving practice is the nature of the practice and not the intent or employment status of the divers.

## 2. Risk management in technical diving.

Many of the following comments are generally applicable to diving, but are especially poignant in the context of technical diving and hence are included in this policy statement. In general, the Society encourages those who engage in any form of diving to have the requisite training, experience, attitude, equipment and support (both in the water and at the surface), operational planning and organisation to be able to dive "safely."

The Society believes that before anyone undertakes any form of diving education or diving practice, it is important that:

the health and other hazards associated with either the diving or the training be identified, the associated risks be assessed and specifically in the context of the health of that individual, and that appropriate control measures for these hazards be in place;

the individuals concerned understand and accept (in writing) the risks of that activity and especially in the context of their health;

where an employer-employee relationship exists, that an appropriate duty of care be exercised in accordance with local health and safety legislation, such as occupational diving fitness standards.

Although this is again generally true for all diving, the Society also believes that given the current level of undergraduate education in diving medicine for medical practitioners, some form of post-graduate training is a pre-requisite to the effective conduct of diving fitness examinations.

## 3. Self-regulation of technical diving.

The Society encourages recreational diving instructor agencies and dive organisations to critically evaluate all forms of diving technique that they intend to teach or practice. This recognises the current low rates of risk involved in conventional recreational diving (defined above). It is also reasonable to assume that effective control (i.e.. risk management) of emergent diving techniques will result in the following:

individual morbidity and mortality rates and associated costs to local health systems will not increase; relevant health and life insurance premiums will, at worst, remain unchanged, and at best, may decrease; the public perception of recreational diving in general will either be maintained or improved; and consequently, there will be no substantial stimulus for any increase in external regulation of recreational diving activities.

Although the Society believes that occupational health and safety agencies should be encouraged to produce codes of diving training and practice (and especially for operational dive organisation and planning) and technical codes for such things as equipment design, gas standards, gas mixing and testing, it is strongly recommended that these be seen as templates and that recreational diving groups become self-regulating. It is also recommended that this regulation should be visible in the form of standards and activities such as independent audits of incidents and accidents as part of an overall quality management program.

The Society is also concerned at the currently extravagant and occasionally inaccurate advertising of diving equipment and practice made by some manufacturers and training agencies; and at the likely consequent misleading of the diving public. A self-regulated code of practice is recommended in this context. Members of the Society are also reminded that regulations concerning the accuracy of advertising do exist in most countries and that they should be active in alerting the relevant regulators.

## 4. Specific forms of technical diving.

Compressed air diving is not recommended deeper than 40 msw. Deep air diving below these depths in pursuit of individual or community records is considered foolish and should be discouraged.

Open-circuit demand scuba enriched air diving in accordance with proposed limits is not considered to represent a significantly greater risk to divers than conventional recreational diving practice (defined above). The PADI EAN program is acknowledged by the Society as being excellent and is recommended as a benchmark in this context.

Rebreathers currently available to the "diving public" may have operating instructions that are based on inappropriate assumptions concerning semi-closed diving apparatus and respiratory physiology. This could and has been shown to result in hypoxia and equivalent-air-depths that under-estimate the inert gas exposure. All semi-closed diving apparatus should be assessed for inspiratory gas content (at least over the oxygen consumption range of 0.5 to 3 litres.min-1) by a suitable laboratory before sale to the "diving public." Closed circuit diving apparatus also need testing, but with a greater emphasis on technical reliability.

## 5. Treatment of technical diving accidents.

The first-aid management of an injured technical diver should be determined by the nature of the injury and will not differ from that recommended in general.

Although the majority of technical divers developing a decompression illness will be well treated with a conventional treatment schedule such as USN 6, the Society encourages medical practitioners who may have to treat such divers to be aware of techniques such as oxygen-helium gas mixtures and "saturation" decompressions.

**References**

1. Gorman DF. High-tech diving. SPUMS J 1992; 22(1): 1-2

# NAUI Policy on Rebreathers

The use of rebreathers for recreational diving is permitted, provided formal training has been obtained through a program that meets NAUI approval. The procedures used in such diving should follow those detailed in the training program.

Note: Active-status NAUI Instructors who are currently recognized as rebreather instructors and authorized to award certifications through NAUI-recognized rebreather training organizations may apply for authorization to teach a NAUI specialty course or recognition program in the recreational use of rebreathers.

# In the Loop: A Report on the Rebreather Forum

*The following is a press release/report of the first Rebreather Forum.*

Key West, FL—Like the "Enriched Air Nitrox Workshop" it hosted three years ago, aquaCorps' Rebreather Forum, held 22-24 May94, drew industry and tekkie aficionados from around the diving circuit including: Canada, China, Germany, Sweden, the UK, and the U.S., to clear up the many myths associated with rebreather technology and discuss where it will go from here. The difference was there wasn't much controversy; attendees were interested in getting into the loop.

Over 90 industry participants representing the spectrum of end user communities were in attendance including: nine rebreather manufacturers, a host of companies and training agencies including: BSAC, IANTD, IADRS, PADI and Dr. Max Hahn of the German Federation of Sport Divers (VDST), government agencies from NOAA and NMRI to EDU, the U.S. Army Special Forces and the UK's HSE, commercial representatives, scientific organizations, several police groups, and special guests: U.S. Navy physiology guru, Dr. Ed Thalmann, Alan Krasberg—one of the godfathers of closed circuit systems—and forum co-chair and circuit guru in his own right, Tracy Robinette of Divematics, "I have been involved in rebreathers for nearly 25 years and a meeting like this has simply never happened before." Heady stuff to be sure. Beamed technical dive store owner, Dennis Pierce, Epic Divers, HI "The level of collective [diving] consciousness in the room was almost overwhelming."

First conceived of in the 17th century, rebreather technology has a 50 year history of successful use by the militaries of the world and is a fundamental component of commercial gas diving reclaim systems. Now with declining military budgets, inexpensive computer chips and a burgeoning non-military diving community ready to take the plunge, many people believe that rebreathers represent the wave of the future. Observed Krasberg, "Rebreathers seem to come back ever 30 years and now it looks like they will remain with us for some time."

The forum kicked off with a "No Bubbles: No Troubles" tour of the U.S. Army's Combat Swimmer School where participants were ushered into a room full of rebreathers—racked, stacked, and ready to rock 'n' roll. An appropriate starting point; the school has been training closed circuit divers continuously for over 27 years, and provided a healthy reality check for rebreather wanna-haves. From there, the forum got down to business; dissecting the knotty issues surrounding rebreather technology; technical requirements, closed vs. semi-closed systems, market economics, training and liability concerns.

Similar to nitrox in the pre-tekkie era, established rebreather manufactures, whose revenues are derived solely from military coffers, approached the forum cautiously, though those in attendance were seen frantically scribbling notes throughout the 'dollars and sense' session on new market applications and economics. Who wants rebreathers? A lot of divers, public safety officers, scientists, photographers, videographers, harvesters, specialized commercial users and, of course, the tekkies. And most of these users appear to have the money to pay, "My clients think nothing of spending U.S.

$5,000-10,000 for camera equipment," said photographer and wildlife guide Amos Nachoum. "I don't think rebreathers are any different." NOT.

The market? Confessed, John Sherwood, one of the principals of Fullerton-Sherwood, that builds the CUMA system for the Canadian Forces, "I was the cynic in our company. But it seems clear to me now there's a real emerging market that we had better address." The message from users? Do it now. As always-to-the-point wildlife photographer, Marty Synderman chided "The world is waiving them [rebreathers] in front of me, but they won't let me have one." (This while threatening the stony-faced panel of manufactures-pen drawn-with a raised check book the hand. Uggh.) Later, the Dräger and Carleton Technologies delegations were separately observed wooing Snyderman over conch fritters and Key lime pie. No free lunches? Where there's a dollar there's a way.

Next, Dr. Thalmann gave a refreshing and enlightening luncheon discourse on diving physiology, sponsored by legal defense heavies, Hruska & Lessor. The bottom line? There's till a whole hell of a lot of diving physiology we just don't understand. Case in point; CNS oxygen toxicity. According to Thalmann, "Convulsions appear to be in a random even at PO2s above 1.3-1.4 atm—"this in an era of computerized oxygen toxicity tracking!#? Hmm. Which algorithm did you say you were using? Think hard.

Training? Forum participants learned they'd be lucky to survive a week with combat swimmer staff instructors, Sgts. Dennis Wardlow and Rob Gardener, as they presented the grueling details of their six week training course. A weekend rebreather certification? How about something in between? Of course, the real problem with training was right there under our nose; or not as the case was. "It's hard to talk seriously about rebreather training, when none of us can even buy one," Ocean Odyssey's Wings Stocks, CA, made his point. Though it apparently hasn't dissuaded some companies from thinking through the loop; offered PADI's Karl Shreeves, "When rebreather technology is ready for the mainstream, PADI will be there to offer training." That should keep those wheels spinning (couldn't resist).

Getting down to brass tacks, the hazards and potential liability problems associated with rebreather diving were discussed at length, and included a closed circuit fatality report from Dr. Bill Stone's Huatla Expedition, and a perspective from a different kind of diver, Billy Booth, the inventor of the single point release parachute and avid "skydiver." Overall, the results of the liability session were better than expected. According to diving plaintiff attorney, Bobby Delise of Vosbein, Delise, Amedee, Bertrand, LA "As long as manufactures and distributors give the end user a full disclosure relative to a rebreather specifications, limitations, risks and most importantly, the requisite training and maintenance demands, product liability should not present formidable barriers." Divemaster Insurance Consultants of London apparently agrees; the company sent a solicitation flyer to be distributed at the forum. The scariest line of the session? "They're [referring to a particular rebreather] so simple what could go wrong?" The comment was followed by a full 30 seconds of silence. You wanna list?

After three grueling days of discussion, attendees had the opportunity to finally dive a rebreather, courtesy of Carleton Technologies and Key West Diver, assisted by JR Hott of NMRI. "It's like going back to the womb of the mother," said Amos Nachoum, "very natural, very pleasurable." Others were equally enthralled. "Rebreathers are the way of the future. There's no doubt in my mind," asserted London's Health and Safety Executive, Graeme Lawrie. Most everyone seemed to agree.

The conclusions? The consensus at the forum seemed to be that semiclosed rebreathers will likely represent the first wave of product due to their simplicity and relatively low cost. Even so, it will be a while before technology is general available on a broad scale. Several rebreather start-ups reportedly plan to offer systems with in the year: Cis-Lunar Labs, Prism Life Support Systems and Oceanic. Expect to see them offered at the 95tek.Conference and receive some hands-on pool training. Note that training will be an important component of purchasing a rebreather; a typical training course will likely run about 40-60 hours.

Finally, forum participants expressed the desire to form an association for advanced diving technologies, code name, "Deja Vu." After all, there's more to come. Confessed, Bishop Museum's Richard Pyle, "I always figured that open circuit was just a stop gas until I got my rebreather. Then I spent a weekend with Phil Nuytten [inventor of the NEWTSUIT]. Now I'm wondering whether rebreathers aren't just another stop gas along the way." Something to think about—M2

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# Rebreather Forum 2.0

[*Note: This list was derived based on registrations and actual attendance lists. Some of those listed may not have been present for all or part of the forum, and there may have been attendees who are not listed.*]

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