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The AAUS Rebreather Colloquium was organized as an integral part of the scientific program of the 2012 AAUS Diving for Science Symposium in Monterey, CA on Saturday, September 28, 2012. The starting baseline for discussion was the recent thoroughly covered topics of Rebreather Forum 3.0, May 24-26, Orlando, FL, which were taken at face value and the Forum’s findings and recommendations briefly presented. Acknowledging the mixed audience present at the 31st annual AAUS scientific diving symposium, this elemental Rebreather Primer reviewed the technology for the benefit of Diving Officers and scientists starting their rebreather (RB) exposure from scratch. This effort may also help administrators of scientific diving programs in their deliberations on RB diving introduction and support at their organizations. The focus of this RB Colloquium effort was specifically for the benefit of the scientific diving community and addressed Standards of Practice, RB operational aspects, RB diver selection, and training issues that RF3 did not address in the context of our specific science needs.

The AAUS Rebreather Colloquium did not try to exhaustively cover all topics about RBs. We focused on fewer but high-priority subjects and allowed sufficient time for quality panel-audience discussions. As end product we envisioned some recommendations to further examine specific AAUS RB standards revisions, and perhaps the appointment of an AAUS subcommittee to further investigate RB issues that warrant further consideration.

In this Rebreather Colloquium volume the American Academy of Underwater Sciences presents a rebreather primer, the findings and recommendations of the May 2012 Rebreather Forum 3.0, rebreather perspectives from scientific diving user groups (AAUS, NOAA, NPS and USGS), the AAUS rebreather standards, rebreather equipment considerations, and finally a panel discussion with representatives of diving programs with rebreather experience (Scripps Institution of Oceanography, NPS, NOAA, USGS, University of Mississippi, University of New Hampshire, NEDU, The Florida Aquarium, University of Miami/RSMAS, University of Hawaii, California Academy of Sciences, and Boston University).

RBs have a place in the scientific diving community’s underwater research toolbox, but have been limited to date in their current state as predominantly technical diving instruments. Current RBs mandate continuous attention and monitoring of equipment life-support functions that may detract from the sole purpose of the scientific diving mission: to make scientific observations and data collections. The amount of time invested in training, pre- and post-dive equipment maintenance, and skill level requirements is generally not realistic for broad application within the SD community, i.e., there will be a selective process of identifying scientific RB divers. A more recent development is the recognition by the diving industry that there will always be a limited universe of technical diving RB users, but that there is a market for non-technical RBs that provides synergy with the needs of scientific diving community. RBs have in some cases been demonstrated to be a powerful tool for extended range and technical scientific diving. There exists an extraordinary potential to extend bottom times and scientific productivity in depths less than 30 msw, coupled with a reduced logistic footprint for remote site diving.
The Rebreather

A brown paper bag can be considered the simplest form of RB. Inhaling from, and exhaling into, a bag will allow two things to occur, neither of which is physiologically advantageous: CO$_2$ will accumulate and the air will become hypoxic. A RB is an underwater life-support system that consists of one-way valves to ensure a unidirectional gas flow, a counterlung and the ability to remove CO$_2$ through a scrubber (soda lime) and replace it with O$_2$. There is a finite absorbing capacity of scrubbers, requiring periodic replacement. Scrubbers are prone to installation and packing errors, although new models exist as pre-packed canisters.

Published sources exist that comprehensively cover the types of RBs currently available for recreational, technical, commercial, scientific, and military diving, RB history, applicable physics, physiology, and theory of RB diving, in addition to operational pre-dive, dive, and post-dive procedures, and RB maintenance. (e.g., Richardson et al., 1996; U.S. Navy, 2005; NOAA, 2011; Bozanic, 2012).

Rebreather types

**Oxygen RB**

this is a pure oxygen source supplied via a demand valve that feeds into the whole breathing loop. There is a depth- and time-dependent potential for oxygen toxicity. An example of scientific use for the study of sea otters was described by Tomoleoni et al. (2012).

**Semi-closed circuit RB**

this is a nitrox mix supplied via a constant mass flow regulator and a demand valve. A quantity of gas is periodically bled into the water column. The partial pressure of oxygen can be variable and uncertain and can change with workload and depths.

**Manual closed-circuit RB**

this system consists of a source of diluent gas and oxygen supplied via a constant mass flow regulator and a manual addition capability. Triple-redundant oxygen sensors with a PO$_2$ display warrant careful attention; the cells are prone to failure. No gas escapes into the water column. Normal operation of this relatively simple life-support system relies on the diligence of the diver.

**Electronic closed-circuit RB**

this system consists of a source of diluent gas, an oxygen source and a battery-powered microprocessor. Triple-redundant oxygen sensors monitor PO$_2$ in the loop. From this data the microprocessor sends information to a solenoid valve triggering when to open to add additional oxygen into the system. Normal operation requires little diver input but this is a complicated electronically managed system that can foster complacency and has many failure points.

Open-circuit scuba versus rebreather approach

To contrast the open-circuit scuba versus RB approach, Simon Mitchell (University of Auckland; 18 May 2012; RF3.0 Orlando) presented the following example on 18 May 2012 at the Rebreather Forum 3.0 for a 90 msw/20 min dive, summarized here.

**Open-circuit air approach**

The narcotic effect of nitrogen would incapacitate the diver at this depth of 10 ATA, so that work could not be accomplished on compressed air. The inspired PO$_2$ at depth would be 2.1 ATA (1.3 ATA is the generally accepted advisable maximum) with the concomitant risk of oxygen toxicity. Gas density would be quite high at 13 g/L (8 g/L is often considered the advisable maximum) rendering the work of
breathing very high. Further, decompression on air is known to be very inefficient. For the bottom depth of this profile, one would ideally use a helium-based mix (trimix 13:47 - 13% O₂ gives a PO₂ of 1.3 ATA, 40% N₂ gives an equivalent narcosis level as an air dive to 40 m, and the 47% balance will be He). Decompression would ideally consist of EAN₃₈ (36% O₂ and balance N₂) from 27 m and 100% O₂ from 6 m. The total run time for this open-circuit dive would be 131 min 18 sec. Gas required for such a dive is calculated by multiplying the ambient pressure by the time by the surface air consumption rate for each of the depth levels then adding the totals and include a 1.3 safety factor. For a 90 m/20 min profile with the decompression as described, this dive would require 7,852 L of trimix (expensive He), 1,365 L EAN₃₆, and 991 L of O₂. The big problem with open-circuit scuba for this dive profile is that it takes longer to decompress because the optimal PO₂ (1.3 ATA) is not breathed at each stage of decompression on ascent.

Rebreather approach

Using a RB eliminates the need to carry multiple bottles for various stages of the dive profile. No bubbles are emitted from the unit, warm humidified gas is breathed, there is minimal gas consumption, which is important on deeper dives, the optimal mix is always available during descent and ascent of a dive and the RB allows for constant optimal PO₂ diving. The logistical aspects of a 90 msw/20 min RB dive are more complex than open circuit. Besides dive platform and topside support, bailout gas requirements must be planned as they would for open circuit diving. Checklists are imperative; they are a step-by-step procedure of pre-dive RB preparation to ensure the unit will perform for the planned dive. Performance of the checklists demands no rushing, no shortcuts, no distractions and a methodical and meticulous attention to detail. The CO₂ scrubber needs to be packed and installed and the following items checked: one-way valves, general assembly of the unit, positive and negative pressure, diluent and oxygen pressures, and sensor calibrations.

Procedurally, for the four phases of a RB dive, Simon Mitchell (University of Auckland; 18 May 2012; RF3.0 Orlando) also observed that the diver must perform the final RB check, and ensure that: the cylinders are open; the set point for O₂ is appropriate for the surface and the descent; the mouthpiece is closed when it is out of the mouth; a leak check is done; minimal loop volume is maintained (poor buoyancy is exhibited with a high loop volume; note that if loop is open, it can be flooded and buoyancy is lost). On descent, ensure that: the ears are cleared, buoyancy adjustments are made; situational awareness is maintained; PO₂ and diluent are checked to maintain loop volume; the set point is changed at some point during the dive. Once on bottom, ensure that: bail out is checked and working; set point is changed to bottom mix and PO₂ checked. On ascent, ensure that: the PO₂ is frequently checked given that the diver’s life depends on it; minimal loop volume is maintained; buoyancy is monitored; situational awareness is maintained; oxygen is manually added as needed; and, the mouth piece is shut off before removing the unit at the surface.

Andrew Fock (Alfred’s Hyperbaric Service, Melbourne, 18 May 2012; RF3.0 Orlando) presented results of his survey on RB fatalities. Data were pulled from the internet and some cases did not have complete information or confirmation of information. Also, all fatalities and accidents have not been reported. There is also uncertainty about the following numbers: RB divers worldwide, RB dives logged per year and number of RB units currently being used. Data therefore are estimates pulled from Rebreather World, Dutch Survey, Diver Mole Survey, and British Slovakia Club Survey. For the survey time frame of 1998-2010 the following answers were provided: a. The increased potential for RB diving accidents includes high-risk behavior and RB unit cleaning and assembling procedures; b. approximately 20 RB deaths per year reported worldwide from 2005-2010 with the top three causes identified as hypoxia, CO₂ and oxygen seizure; c. consideration of the relative safety of manual and electronic RB units acknowledges that manual units have no electronic failure potential because they are human operated, but divers are required to know PO₂ at all times, whereas electronic units monitor PO₂ without distraction, which allows divers to become complacent and not worry about PO₂. It is accepted that both systems offer potential for failure; d. deaths involving manual and electronic units appear to be in
proportion to the current market share. There is no one brand of RB more dangerous than another; and, e. proper training and understanding of physics and physiology will make RB diving safer. It is clear that we are on our way of getting a simpler, more robust RB that will be available to more people.

William Stone (Stone Aerospace; 19 May 2012; RF3.0 Orlando) shared his views of three truths about RBs: a. Sensors are the eyeballs of any autonomous system; if you cannot see what is going on you are going to be in trouble. This translates to RB reliability and user safety. Being aware of partial pressure of oxygen and auto calibration is essential; b. Redundancy paths must exist for all critical systems. There has to be a clear and simple abort mechanism to a safe haven with no accumulation of a need for decompression; and, c. Mine data and learn more about the RB to better assess what the triggers are.

Conclusion

Thalmann (1996) remarked “A scuba regulator is the steam engine of diving gear. It has been around for a long time. It has been honed to a fine art and is incredibly reliable. By comparison, a rebreather is like a space shuttle.” RBs are re-emerging technology for the science community, first used extensively for underwater research in TEKTITE II (Collette and Earle, 1972). Notwithstanding this early RB use, the vast majority of the scientific diving community’s experience base is with no-decompression, open-circuit scuba (McDonald and Lang, 2013). Collette (1996) expressed disappointment at the failure to replace standard open-circuit scuba with RBs since 1970. He felt that RBs were more expensive, but if one could accomplish twice the work in a given unit of time and carry out investigations that took more bottom time than was available with scuba, was it really more expensive? Collette (1996) further questions the validity of all fish behavioral studies done with scuba because of the demonstrated disturbing effects of the noisy bubbles.

Rebreathers are intrinsically more likely to suffer mechanical failure versus open circuit scuba mitigate risk by carrying a redundant UBA, is an order of magnitude more dangerous than recreational diving. Rebreathers have facilitated many fabulous examples of research and discovery; however, they are very complex and are being used by fallible humans in a hostile non-respiratory environment that has the potential to create many problems. Most mishaps are preventable which puts important emphasis on the proper procedure, assembly and maintenance as well as on the checklist.

Acknowledgments

AAUS thanks C. McDonald, S. Sellers, G. McFall, B. Seymour, J. Tomoleoni, M. Slattery, E. Kintzing, J.R. Clarke, C. Coy and R. Gomez for their presentations and moderating efforts, and also additional panelists M. Terrell, D. Pence, E. Jessup and P. Lobel for their participation and sharing of rebreather insights.

References


The following Findings and Recommendations were promulgated at the Rebreather Forum 3.0 in May, 2012, Orlando, Florida, co-sponsored by AAUS, DAN and PADI.

Checklists
The Forum acknowledged the overwhelming evidence demonstrating the efficacy of checklists in preventing errors in parallel fields that share similar technical complexity. Three recommendations regarding checklists were consequently agreed upon:

1. The Forum recommends that rebreather manufacturers produce carefully designed checklists, which may be written and/or electronic, for use in the pre-dive preparation (unit assembly and immediate pre-dive) and post-dive management of their rebreathers;
2. Written checklists should be provided in a weatherproof or waterproof form; and,
3. The current version of these checklists annotated with the most recent revision date should be published on the manufacturer’s website.

The Forum recommends that training agencies and their instructors embrace the crucial leadership role in fostering a culture of safety in which the use of checklists by rebreather divers becomes second nature.

Training and Operations
1. The Forum applauds and endorses the release of pooled data describing numbers of rebreather certifications by training agencies and encourages other agencies to join ANDI, IANTD, and TDI in this initiative.
2. The Forum endorses the concept of making minimum rebreather training standards available in the public arena.
3. The Forum endorses the concept of a currency requirement for rebreather instructors. We recommend that training agencies give consideration to currency standards with respect to diving activity, class numbers, and unit specificity for their instructors.
4. The Forum recognizes and endorses the industry and training agency initiative to characterize “recreational” and “technical” streams of sport rebreather diver training. These groups will have different operational, training and equipment needs

Accident Investigation
1. The Forum recommends that training agencies provide rebreather divers with a simple list of instructions that will mitigate common errors in evidence preservation after a serious incident or rebreather fatality. These instructions will be developed under the auspices of the Undersea and Hyperbaric Medical Society Diving Committee in consultation with the relevant RF3 presenters.
2. The Forum endorses the concept of a widely notified centralized “on-call” consultation service to help investigators in avoiding errors or omissions in the early stages of a rebreather accident investigation and to facilitate referral to expert investigative services.
3. The Forum recommends that in investigating a rebreather fatality the principal accident investigator invite the manufacturer of the incident rebreather (or other relevant equipment) to assist with its
evaluation (including the crucial task of data download) as early as is practical.

4. The Forum endorses the DAN worldwide initiative to provide a means of on-line incident reporting with subsequent analysis and publication of incident root causes.

**Design and Testing**

1. The Forum recommends that all rebreathers incorporate data-logging systems, which record functional parameters relevant to the particular unit and dive data, and allow download of these data. Diagnostic reconstruction of dives with as many relevant parameters as possible is the goal of this initiative. Footnote: An ideal goal would be to incorporate redundancy in data logging systems, and as much as practical, to standardize the data to be collected.

2. The Forum endorses the need for third party pre-market testing to establish that rebreathers are fit for purpose. Results of a uniform suite of practically important unmanned testing parameters such as canister duration, and work of breathing (qualified by clear statements of experimental parameters) should be reported publicly. Ideally, this testing should be conducted to an internationally recognized standard.

3. The Forum acknowledges recent survey data indicating a poor understanding of rebreather operational limits in relation to depth and carbon dioxide scrubber duration among trained users, and therefore recommends that:
   • Training agencies emphasize these parameters in training courses; and,
   • Manufacturers display these parameters in places of prominence in device documentation and on websites.

4. The Forum strongly endorses industry initiatives to improve oxygen-measurement technologies, and advocates consideration of potentially beneficial emerging strategies such as dynamic validation of cell readings and alternatives to galvanic fuel cells.

5. The Forum identifies as a research question the issue of whether a mouthpiece-retaining strap would provide protection of the airway in an unconscious rebreather diver.

6. The Forum identifies as a research question the efficacy of a full-face mask for use with sport rebreathers.
The American Academy of Underwater Sciences provides for the promulgation of rebreather standards for the scientific diving community as a research tool. The current use of rebreathers is growing but remains at less than 1% of the overall annual scientific diving activity of 128,000 dives. Broader integration of rebreathers will likely occur through unit cost reduction, simplified engineering and user interface, reduced (yet safe and defensible) training requirements, reduced preparatory and maintenance requirements of rebreather units and hopefully production of a smaller, lighter package. The phase-in of rebreather technology into scientific diving programs will occur without compromising selection criteria and evaluation of divers based upon aptitude and discipline.

Introduction

Scientific diving is subject to U.S. Department of Labor Occupational Safety and Health (OSHA) regulations. An exemption exists from the OSHA commercial diving standards (cfr. 29 CFR 1910.402) if the diving is performed solely as a necessary part of a scientific, research or educational activity by employees whose sole purpose for diving is to perform scientific research tasks. Further, the scientific diving exemption requires that the nature of the underwater activity meet the OSHA definition of scientific diving and is under the direction and control of a diving program utilizing a safety manual and a diving control board meeting certain specified criteria (Butler, 1996). Restrictions in diving technology for scientific diving use are not explicit in the OSHA standard, thus allowing for saturation/habitat diving, mixed-gas diving, and rebreather diving for scientific purposes.

The American Academy of Underwater Sciences (AAUS) is an organization of organizations, formalized in 1980 in response to OSHA’s implementation of emergency commercial diving standards. We were organized to provide a context to the self-regulation that we have provided for many years. AAUS’ mission is to facilitate development of safe and productive scientific divers through education, research, advocacy and the advancement of standards for scientific diving practices, certifications and operations. In 2012, 136 current organizational member programs represent more than 4,700 individual divers logging over 128,000 dives annually, not an insignificant data set.
Rebreathers are not new technology and have historically been at home in the science community. Walter Starck and John Kanwisher’s (Woods Hole Oceanographic Institution) collaborative development of the Electrolung closed-circuit rebreather with polarographic oxygen sensors came about through their chance meeting aboard Ed Link’s diving research vessel in the Bahamas in 1968. In 1970, the General Electrics MK 10 Mod III rebreather was used during the Tektite II saturation missions. The Harbor Branch/Biomarine CCR1000 was further developed with Gene Melton and used at Harbor Branch Oceanographic Institution for deep reef work in the 1970s. Bill Stone later developed the sophisticated Cis-Lunar rebreathers for scientific exploration in the 1980s.

Current status of rebreathers

Rebreathers have a place in the scientific diving community’s underwater research toolbox, but their use has to date been limited as predominantly technical diving instruments by a very small group of dedicated divers. To protect the safety and health of the scientific diver, current rebreathers mandate continuous attention and monitoring of complex life-support equipment functions that detract from the sole purpose of the dive mission: scientific underwater observations and data collections. The amount of time invested in training, pre- and post-dive equipment maintenance, and skill level requirements is generally not realistic for broad application within the scientific diving community. In the academic world, very little credit is given to scientists for their time spent in rebreather training and skills maintenance. Although rebreathers are not a new technology, the scientific diving community’s 60-year experience and exemplary safety record is predominantly based on open-circuit, compressed air scuba.

The recognition by the diving industry that there is a finite universe of technical rebreather divers, but that there is a market for recreational (non-technical) rebreathers provides synergy with the needs of the scientific diving community. Rebreathers are a powerful tool for extended range and technical scientific diving. There is extraordinary potential to optimize decompression, extend bottom times, and thus scientific productivity, in depths less than 30 meters. Rebreathers also offer a reduced logistical footprint for scientific diving at remote sites, which is very attractive to the science community.

Scientific rebreather applications and data

There is strong support for the value of rebreathers as a scientific diving tool. The consideration lies primarily in phase-in and their implementation in the scientific diving programs. Exemplars of successful rebreather use are in behavioral observations, fish population assessments and bioacoustics, ecological studies, disturbance-sensitive archaeological documentations, deep-reef specimen collections, marine mammal (sea otter) capture and release, scientific exploration of caves and mesophotic zones, and underwater manipulative algal experiments where dramatic bubble disturbance impact is disruptive.

The majority of AAUS scientific dives are open-circuit, compressed air scuba, no-decompression dives that represent over 99% of the total diving activity (Table 1). There has been a gradual growth of rebreather diving activity since 1998, but it has grown from very small to a still very limited component of science activities with much of this specialty being performed under training conditions by Diving Officers who are attempting to phase in rebreather programs (Fig. 1).

Table 1. AAUS data for CY 2010 for rebreather, required decompression, mixed gas and total number of dives, showing <1% of total dives as rebreather dives.

<table>
<thead>
<tr>
<th></th>
<th>Rebreather</th>
<th>Deco</th>
<th>Mixed Gas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational Members</td>
<td>20</td>
<td>29</td>
<td>15</td>
<td>124</td>
</tr>
<tr>
<td>Divers</td>
<td>71</td>
<td>125</td>
<td>57</td>
<td>4,769</td>
</tr>
<tr>
<td>Dives</td>
<td>1,236</td>
<td>981</td>
<td>794</td>
<td>128,502</td>
</tr>
</tbody>
</table>
AAUS acknowledges the potential of CCR use in scientific diving programs yet currently the majority of scientific diving work occurs in 30 meters of water or less, notwithstanding the scientific need and justification for expanding our working envelope to deeper depths (Lang and Smith, 2006).

**AAUS rebreather standards**

AAUS *Standards for Scientific Diving Certification* can be downloaded from [www.aaus.org](http://www.aaus.org). Standards include Staged-Decompression Diving (Section 9.0), Mixed Gas Diving (Section 10.0) and Rebreather Diving (Section 12.0 – Oxygen, Semi-Closed and Close Circuit).

A rebreather trainee, in addition to completing a 100-hour scientific dive course, must also meet prerequisites that include a 100-foot depth certification and 50 open water dives. AAUS standards allow scientific divers to work deeper in a measured progression so they will be assured to accumulate the appropriate amount of experience before venturing into deep water. Similarly, in order to effectively use a closed-circuit rebreather, a diver should have a firm understanding of gas laws and enriched-air nitox.

<table>
<thead>
<tr>
<th>Total Bottom Time (min)</th>
<th>60,188</th>
<th>47,383</th>
<th>32,644</th>
<th>5,185,730</th>
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<tr>
<td>Bottom Time/Dive (min)</td>
<td>49</td>
<td>48</td>
<td>41</td>
<td>40</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th># OMs</th>
<th># RB divers</th>
</tr>
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<tbody>
<tr>
<td>1998</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1999</td>
<td>15</td>
<td>30</td>
</tr>
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<td>2000</td>
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<td></td>
</tr>
<tr>
<td>2010</td>
<td>70</td>
<td></td>
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</tbody>
</table>

Figure 1. AAUS rebreather data: total number of divers logging rebreather dives and organizational member programs (OMs) supporting rebreather diving as a function of time (1998-2010).

**Conclusion**

The rebreather standards are a living document that undergoes periodic review and revision as technology and our experience develops. AAUS standards stipulate equipment selection criteria. Recognized quality assurance and quality control protocols should be in place for the manufacturers. Third-party testing and validation is important and the newly formed RESA group should be helpful in this evaluation process.

Scientific diving programmatic considerations of rebreather implementation include specific rebreather unit selection criteria for standardized maintenance/training and proficiency requirements. The importance of manufacturer support and their timely response to incidents and requests for technical assistance cannot be overstated. Diver selection criteria considerations will determine which divers can
undertake rebreather training. Rebreathers will likely never become a tool that is as applicable to the entire AAUS community as the comparatively bulletproof and forgiving open-circuit scuba.

Looking forward, the scientific diving community is not restricted by OSHA with respect to technology. We are free to use the best technology available in order to support our scientists in performing their research. We look forward to the opportunity to work with manufacturers and training organizations and within our own community to design and implement rebreather standard operating procedures. The academic community has a zero tolerance for risk and that is reflected in our approach to these technologies. Broader integration of rebreathers into scientific diving programs will require unit cost reduction (though this is not an overwhelming hurdle), a simplified engineering and user interface, reduced (yet safe and defensible) training requirements given the transient nature of the scientific diving community, reduced preparatory and maintenance requirements pre- and post-dive, and hopefully a smaller, lighter package. We cannot compromise on the evaluation and selection of users based upon aptitude and discipline!

As an action item of the Rebreather Forum 3.0, AAUS convened a Rebreather Colloquium at its 2012 annual scientific diving symposium to determine which of the RF3 findings could be integrated into our scientific diving standards. AAUS will need to work on unit-specific training modules, maintenance requirements and strategies for keeping scientific divers training and skill levels current.

Acknowledgments

We thank the American Academy of Underwater Sciences and RF3 co-sponsoring organizations Divers Alert Network and the Professional Association of Diving Instructors. Proceeds form RF3 were used, in part, to convene the AAUS Rebreather Colloquium at the Annual AAUS Symposium in Monterey, CA.

Literature Cited


Begin with a need

Begin with a need for the RB technology to meet the needs of your program’s mission.

Assumption of risk

“Living is risk inherent…diving is ‘ultra hazardous’...” (NOAA General Counsel, 2008, in response to the fatality). We would all agree that diving is risk inherent and that there exists the potential for higher risk with rebreather diving.

Will we adopt a model of risk aversion or risk management? Recognition of inherent risks and identification of where we think the risks will occur can be done with the “swiss-cheese model”. There is usually a trigger for accidents but there is not necessarily one particular cause for accidents to occur, i.e., it is usually a cascade effect. When accidents occur, the response is normally to increase the barriers to diving when the best thing to do would be to reduce the size of the holes (i.e., problems) in the “swiss cheese” to prevent future accidents from occurring.

Approaching risk mitigation

Start with the right unit and acceptance standards

It is important to use the right standards that are modified for the specific program.

Review unmanned and manned RB unit testing

Unmanned testing for safety (e.g., work of breathing, canister duration) that was once deemed safe needs to be validated with manned testing.

Identify and review applicable CE testing

European Union standards body addresses consumer electronics devices, including air purification equipment.

Identify and review a manufacturer’s FMCEA (Failure Modes, Effects and Criticality Analysis)

This information identifies potential component-level failures, how likely those failures are to occur, what effects those failures have on upper-level hardware and system effects, whether or not the failures represent a safety or health risk to the diver, and how to head off potential problems with better checklists and routine maintenance.

Identify and review other operational standards

Operational standards need to be reviewed and tightened by tweaking them to specifically fit your
particular operational parameters and considerations.

*Identify the right personnel*

Start the RB program with the most qualified people you can find and eschew the “club” mentality. Not all people are qualified or will make a good RB diver.

*Oversight*

At this point in time all oversight of CCR RB activities, exclusive of Air diluent, no-decompression diving, is governed by the NDCSB. We are working to develop tight standards using the AAUS model and the NOAA chapter on rebreathers, which has been reviewed and rewritten twice in the last eighteen months. The next revision of the NOAA Scientific Diving Standards and Safety Manual (NSDSSM) will be released in summer of 2013. In the future, we will need to re-convene the NOAA Technical Diving Advisory Panel to review and revise our RB standards and protocols.

*Checklists*

Always use a checklist to set up the rig and a “deckcheck” list to ensure that the rig is fit to dive just prior to entering the water. Develop a routine maintenance checklist for consumables and easily damaged or lost components. Consider developing subsystem checklists if you conduct routine maintenance on subsystems or components.

*Reciprocity*

Reciprocity will come but it will take the right people who have the experience to help the rest get up to speed, through practices and training, to the same level of RB standards.
Background

The National Park Service (NPS) has a long history of operational innovation to achieve agency goals. From Maine to American Samoa, Alaska to the Virgin Islands, NPS Rangers dive in all conditions to support the NPS missions of resource protection and visitor services. NPS divers work in a wide range of diving environments with a variety of tasks that vary from park to park. Of the 394 U.S. National Park units (approx. 5 million submerged acres), 146 have submerged resources, 40 ocean parks contain 3 million acres of submerged resources, and there are 5,100 miles of shoreline in 26 states and territories.

Initially established as the Submerged Cultural Resources Unit (SCRU) in the 1980s, it became the Submerged Resources Center in 2000. The divers are primarily underwater archaeologists, but also imaging specialists. There is a core team of experts around which to build projects and programs. The team works system- and world-wide with parks and partners. The operational parameters in 2005 were met with the Ambient Pressure Diving Platform due to availability, capabilities, and support.

Rebreather use

The use of RBs evolved from a need. Open-circuit diving on a plane wreck in 200 ft of water took a lot of equipment, mixed gas, time, and money. RBs were used exclusively for the 16 months of diving regardless of dive depth or profile.

RBs were dived with air diluent for 60+ hours before switching to mix. The heliox diluent was not more than 1.0 ATA O$_2$ at depth (in practice we used 10/90) and wanted a lean diluent in case of a stuck solenoid. The normoxic heliox bailout was 20/80.

Tables were cut on a 1.1 ATA O$_2$ level, dived on 1.4 ATA O$_2$, with up to 1.6 ATA O$_2$ at decompression. Dive tables were used, with dive computers for emergencies/bailout only. We were concerned with the nitrogen side of the decomposition equation and preferred longer deco times that come with heliox diluent than nitrogen loading/narcosis on deeper dives. We were willing to accept higher oxygen exposures for our dives and remained skeptical about Oxygen Toxicity Units (OTUs). A tested and validated straight Bühlmann algorithm was used for dive computers and tables. We do not object to decompression and do not believe that “because it gets you out of the water faster” is a reason to select a particular decompression algorithm.

We were willing to put some staff in CCR full-face masks for filming or due to individual medical reasons. In 2009, we switched some people over to the VR Technologies Sentinel because of its advanced
life support system and back-mounted counter lungs. In 2011, more divers were moved over to the Evolution, a more robust, expedition unit with a CO₂ sensor.

Results to date

We found the “sweet spot” for RB diving to range from 50 to 100 feet. We believe that RBs are the best and safest available technology for most of NPS diving, including, but not limited to, deep, cold, and overhead environments.

The RB training requirements and diving complexity have increased, but not inordinately so. Switching to RBs is a “do it or don’t do it” decision that requires follow through and commitment by the program and agency.

With the use of RBs, project logistics have decreased and research time has increased, i.e., we are more productive and efficient in the field. The greatest benefit of RBs to NPS is in the shallower (<130 ft/40 m) range due to decreased decompression and increased repetitive dive times. Our time conducting in-water work in remote and inaccessible places has increased significantly. One thing the numbers draw out is our average bottom time per dive. In 2010 we logged 817 dives with 536 hours, which is about 39 min/dive. In 2011 that number jumped to nearly 54 min/dive due to RB use. Not every dive was done closed circuit, however most were. A bottom time increase of 15 min/dive may not seem like much on any given dive, but across an entire year it equals a lot more bottom time (i.e., work performed) per dive, a 38% increase in productivity.
U.S. GEOLOGICAL SURVEY PERSPECTIVE

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Closed circuit diving techniques for wild sea otter capture

A full paper describing sea otter (*Enhydra lutris*) natural history, sea otter program history, dive team and equipment methods, and sea otter capture techniques was presented at the 31st AAUS Annual Scientific Symposium (Tomoleoni et al., 2012).

There are six divers in California and three divers in Alaska who participate in the type of sea otter capture described in this document. Initially, dip netting was used, but this technique works better in aquaria than in the wild. Tangle nets are modified gill nets that are also effective but there is little selection on which otter to catch and a large potential for unwanted by-catch. RB diving aids significantly in sea otter capture and is very selective (i.e., we can catch 1 animal in a group of 15). RB diving for sea otter capture has been conducted for the last 35 years at USGS.

Using a custom built Wilson trap with a purse net, the RB divers can sneak up underneath the otters more easily for capture. This was done initially on open-circuit diving, required two divers and was inefficient (the success rate was less than 10%). Otters were scared away by the bubbles from open-circuit scuba, making a stealth approach difficult.

The introduction of underwater scooters (diver propulsion vehicles) that pushed the trap through the water gave much more steering control and also allowed two divers to each have a trap to increase chances of capturing one or two otters during one dive. Thus the combined use of RBs with scooters has led to the successful approach described here.

Equipment considerations

Divers wear black from head to toe to cut down on reflection and the boat is also a stealth color to make the divers’ presence less obvious to the otters.

Initially, the diving was done with a front-mounted RB unit, and a Cobra back-mounted unit was also used. Currently we use the FROGS (Full Range Oxygen Gas System) RB manufactured by Aqua Lung for the French Navy. It is a full-range gas rebreather with 100% O₂ and a compact design. No nitrogen, no gas mixing, and no electronics are used with this unit. Multiple water traps are incorporated for added safety. The unit is modular and easy to adjust, and breakdown and assembly is done without tools. The FROGS has a breathing resistance adjustment feature. It was originally designed to be front mounted but has also been modified as a back-mounted unit. The depth limitation of this unit is 6 meters.

All divers wear DUI combat drysuits made of black trilaminate with Kevlar overlays. A small pony bottle is worn close to the upper thigh inflation valve. Custom hoods with a high visibility yellow panel on the back aids the boat tender in locating divers in the water. Divers wear a VHS radio in a pocket on
their hood that is vacuum sealed to receive coordinates and direction from the boat tender when searching for otters to capture. Divers also perform periodic surface checks with course corrections from the boat tender if they are off. These transmitters also alert the boat tender when divers are at the surface for pick up.

**Otter capture**

Once otters are spotted 500-600 m away, there is the gear up phase on the boat. Movements must be slow and silent in the boat to not spook the otters. Divers perform final RB gear and drysuit checks then slide into the water where the boat tender hands down the scooters and Wilson traps. Divers start swimming their compass bearing. The compass is mounted on the trap for everyone but the lead diver, who has wrist mounted compass. Periodic surface checks are done to see if course is being maintained. Once the otter is located, the lead diver sets up underneath the otter then releases the trap and captures the otter. Divers alert the boat tender to come get them, the boat pulls up and processing of the animal begins. The otter goes into a custom built box, the boat runs back to shore/vessel, where the animal is etherized and processing begins (blood sample, swabbing, flipper tag, morphometric data, VHS radio transmitter is installed). Shore support tracks the data from otters every day for years after.

Using RBs for wild sea otter capture and data collection has allowed for a wealth of information and otherwise unobtainable data to be collected.

**Reference**

Our goal is to look at the existing AAUS rebreather standards (below) and from the information collected at this AAUS Rebreather Colloquium update these standards if need be. Rebreathers are the most dynamic area of scientific diving. AAUS section 12 is the rebreather section of the standards, general descriptions, definitions and operational procedures as well as training, equipment and operational requirements.

SECTION 12.0 REBREATHERS (AAUS, 2013)

This section defines specific considerations regarding the following issues for the use of rebreathers:
- Training and/or experience verification requirements for authorization
- Equipment requirements
- Operational requirements and additional safety protocols to be used

Application of this standard is in addition to pertinent requirements of all other sections of the AAUS Standards for Scientific Diving, Volumes 1 and 2. For rebreather dives that also involve staged decompression and/or mixed-gas diving, all requirements for each of the relevant diving modes shall be met. The Diving Control Board reserves the authority to review each application of all specialized diving modes, and include any further requirements deemed necessary beyond those listed here on a case-by-case basis. No diver shall conduct planned operations using rebreathers without prior review and approval of the DCB. In all cases, trainers shall be qualified for the type of instruction to be provided. Training shall be conducted by agencies or instructors approved by DSO and DCB.

12.10 Definitions and General Information

a) **Rebreathers** are defined as any device that recycles some or all of the exhaled gas in the breathing loop and returns it to the diver. Rebreathers maintain levels of oxygen and carbon dioxide that support life by metered injection of oxygen and chemical removal of carbon dioxide. These characteristics fundamentally distinguish rebreathers from open-circuit life support systems, in that the breathing gas composition is dynamic rather than fixed.

1. Advantages of rebreathers may include increased gas utilization efficiencies that are often independent of depth, extended no-decompression bottom times and greater decompression
efficiency, and reduction or elimination of exhaust bubbles that may disturb aquatic life or sensitive environments.

2. Disadvantages of rebreathers include high cost and, in some cases, a high degree of system complexity and reliance on instrumentation for gas composition control and monitoring, which may fail. The diver is more likely to experience hazardous levels of hypoxia, hyperoxia, or hypercapnia, due to user error or equipment malfunction, conditions which may lead to underwater blackout and drowning. Inadvertent flooding of the breathing loop and wetting of the carbon dioxide absorbent may expose the diver to ingestion of an alkaline slurry (“caustic cocktail”).

3. An increased level of discipline and attention to rebreather system status by the diver is required for safe operation, with a greater need for self-reliance. Rebreather system design and operation varies significantly between make and model. For these reasons when evaluating any dive plan incorporating rebreathers, risk-management emphasis should be placed on the individual qualifications of the diver on the specific rebreather make and model to be used, in addition to specific equipment requirements and associated operational protocols.

b) **Oxygen Rebreathers.** Oxygen rebreathers recycle breathing gas, consisting of pure oxygen, replenishing the oxygen metabolized by the diver. Oxygen rebreathers are generally the least complicated design, but are normally limited to a maximum operation depth of 20 fsw due to the risk of unsafe hyperoxic exposure.

c) **Semi-Closed Circuit Rebreathers.** Semi-closed circuit rebreathers (SCR) recycle the majority of exhaled breathing gas, venting a portion into the water and replenishing it with a constant or variable amount of a single oxygen-enriched gas mixture. Gas addition and venting is balanced against diver metabolism to maintain safe oxygen levels by means which differ between SCR models, but the mechanism usually provides a semi-constant fraction of oxygen (FO2) in the breathing loop at all depths, similar to open-circuit scuba.

d) **Closed-Circuit Mixed Gas Rebreathers.** Closed-circuit mixed gas rebreathers (CCR) recycle all of the exhaled gas and replace metabolized oxygen via an electronically controlled valve, governed by electronic oxygen sensors. Manual oxygen addition is available as a diver override, in case of electronic system failure. A separate inert gas source (diluent), usually containing primarily air, heliox, or trimix, is used to maintain oxygen levels at safe levels when diving below 20 fsw. CCR systems operate to maintain a constant oxygen partial pressure (PPO2) during the dive, regardless of depth.

**12.20 Prerequisites**

Specific training requirements for use of each rebreather model shall be defined by DCB on a case-by-case basis. Training shall include factory-recommended requirements, but may exceed this to prepare for the type of mission intended (e.g., staged decompression or heliox/trimix CCR diving).

a) Active scientific diver status, with depth qualification sufficient for the type, make, and model of rebreather, and planned application.

b) Completion of a minimum of 50 open-water dives on scuba.

c) For SCR or CCR, a minimum 100-fsw-depth qualification is generally recommended, to ensure the diver is sufficiently conversant with the complications of deeper diving. If the sole expected application for use of rebreathers is shallower than this, a lesser depth qualification may be allowed with the approval of the DCB.

d) Nitrox training. Training in use of nitrox mixtures containing 25% to 40% oxygen is required. Training in use of mixtures containing 40% to 100% oxygen may be required, as needed for the planned application and rebreather system. Training may be provided as part of rebreather training.
Training

Successful completion of the following training program qualifies the diver for rebreather diving using the system on which the diver was trained, in depths of 130fsw and shallower, for dives that do not require decompression stops, using nitrogen/oxygen breathing media.

a) Satisfactory completion of a rebreather training program authorized or recommended by the manufacturer of the rebreather to be used, or other training approved by the DCB. Successful completion of training does not in itself authorize the diver to use rebreathers. The diver must demonstrate to the DCB or its designee that the diver possesses the proper attitude, judgment, and discipline to safely conduct rebreather diving in the context of planned operations.

b) Classroom training shall include:
   1. A review of those topics of diving physics and physiology, decompression management, and dive planning included in prior scientific diver, nitrox, staged decompression and/or mixed gas training, as they pertain to the safe operation of the selected rebreather system and planned diving application.
   2. In particular, causes, signs and symptoms, first aid, treatment and prevention of the following must be covered: Hyperoxia (CNS and Pulmonary Oxygen Toxicity), Middle Ear Oxygen Absorption Syndrome (oxygen ear), Hyperoxia-induced myopia, Hypoxia, Hypercapnia, Inert gas narcosis, and Decompression sickness
   3. Rebreather-specific information required for the safe and effective operation of the system to be used, including:
      • System design and operation;
      • Counterlung(s);
      • CO2 scrubber;
      • CO2 absorbent material types, activity characteristics, storage, handling and disposal;
      • Oxygen control system design, automatic and manual;
      • Diluent control system, automatic and manual (if any);
      • Pre-dive set-up and testing;
      • Post-dive break-down and maintenance;
      • Oxygen exposure management;
      • Decompression management and applicable decompression tracking methods;
      • Dive operations planning;
      • Problem recognition and management, including system failures leading to hypoxia, hyperoxia, hypercapnia, flooded loop, and caustic cocktail; and,
      • Emergency protocols and bailout procedures.

Practical Training (with model of rebreather to be used)

a) A minimum number of hours of underwater time.

<table>
<thead>
<tr>
<th>Type</th>
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<th>O/W Training</th>
<th>O/W Supervised</th>
</tr>
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<tbody>
<tr>
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<td>1 dive, 90 min</td>
<td>4 dives, 120 min.*</td>
<td>2 dives, 60 min</td>
</tr>
<tr>
<td>Semi-Closed Circuit</td>
<td>1 dive, 90-120 min</td>
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<td>Closed-Circuit</td>
<td>1 dive, 90-120 min</td>
<td>8 dives, 380 min.***</td>
<td>4 dives, 240 min</td>
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</tbody>
</table>

* Dives should not exceed 20 fsw.
** First two dives should not exceed 60 fsw. Subsequent dives should be at progressively greater depths, with at least one dive in the 80 to 100 fsw range.
*** Total underwater time (pool and open water) of approximately 500 minutes. First two open water dives should not exceed 60 fsw. Subsequent dives should be at progressively greater depths, with at least 2 dives in the 100 to 130 fsw range.

b) Amount of required in-water time should increase proportionally to the complexity of rebreather system used.

c) Training shall be in accordance with the manufacturer's recommendations.
Practical Evaluations

Upon completion of practical training, the diver must demonstrate to the DCB or its designee proficiency in pre-dive, dive, and post-dive operational procedures for the particular model of rebreather to be used. Skills shall include, at a minimum:

- Oxygen control system calibration and operation checks;
- Carbon dioxide absorbent canister packing;
- Supply gas cylinder analysis and pressure check;
- Test of one-way valves;
- System assembly and breathing loop leak testing;
- Pre-dive breathing to test system operation;
- In-water leak checks;
- Buoyancy control during descent, bottom operations, and ascent;
- System monitoring and control during descent, bottom operations, and ascent;
- Proper interpretation and operation of system instrumentation (PO2 displays, dive computers, gas supply pressure gauges, alarms, etc., as applicable);
- Unit removal and replacement on the surface; and,
- Bailout and emergency procedures for self and buddy, including:
  - System malfunction recognition and solution;
  - Manual system control;
  - Flooded breathing loop recovery (if possible);
  - Absorbent canister failure;
  - Alternate bailout options;
  - Symptom recognition and emergency procedures for hyperoxia, hypoxia, and hypercapnia; and,
  - Proper system maintenance, including:
    - Full breathing loop disassembly and cleaning (mouthpiece, check-valves, hoses, counterlung, absorbent canister, etc.);
    - Oxygen sensor replacement (for SCR and CCR); and,
    - Other tasks required by specific rebreather models.

Written Evaluation

A written evaluation approved by the DCB with a pre-determined passing score, covering concepts of both classroom and practical training, is required.

Supervised Rebreather Dives

Upon successful completion of open water training dives, the diver is authorized to conduct a series of supervised rebreather dives, during which the diver gains additional experience and proficiency.

a) Supervisor for these dives should be the DSO or designee, and should be an active scientific diver experienced in diving with the make/model of rebreather being used.

b) Dives at this level may be targeted to activities associated with the planned science diving application. See the following table for number and cumulative water time for different rebreather types.

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* Dives should not exceed 20 fsw.
** First two dives should not exceed 60 fsw. Subsequent dives should be at progressively greater depths, with at least one dive in the 80 to 100 fsw range.
*** Total underwater time (pool and open water) of approximately 500 minutes. First two open water dives should not exceed 60 fsw. Subsequent dives should be at progressively greater depths, with at least 2 dives.
c) Maximum ratio of divers per designated dive supervisor is 4:1. The supervisor may dive as part of the planned operations.

**Extended Range, Required Decompression and Helium-Based Inert Gas**

Rebreather dives involving operational depths in excess of 130 fsw, requiring staged decompression, or using diluents containing inert gases other than nitrogen are subject to additional training requirements, as determined by DCB on a case-by-case basis. Prior experience with required decompression and mixed gas diving using open-circuit scuba is desirable, but is not sufficient for transfer to dives using rebreathers without additional training.

a) As a prerequisite for training in staged decompression using rebreathers, the diver shall have logged a minimum of 25 hours of underwater time on the rebreather system to be used, with at least 10 rebreather dives in the 100 fsw to 130 fsw range.

b) As a prerequisite for training for use of rebreathers with gas mixtures containing inert gas other than nitrogen, the diver shall have logged a minimum of 50 hours of underwater time on the rebreather system to be used and shall have completed training in stage decompression methods using rebreathers. The diver shall have completed at least 12 dives requiring staged decompression on the rebreather model to be used, with at least 4 dives near 130 fsw.

c) Training shall be in accordance with standards for required-decompression and mixed gas diving, as applicable to rebreather systems, starting at the 130 fsw level.

**Maintenance of Proficiency**

a) To maintain authorization to dive with rebreathers, an authorized diver shall make at least one dive using a rebreather every 8 weeks. For divers authorized for the conduct of extended range, stage decompression or mixed-gas diving, at least one dive per month should be made to a depth near 130 fsw, practicing decompression protocols.

b) For a diver in arrears, the DCB shall approve a program of remedial knowledge and skill tune-up training and a course of dives required to return the diver to full authorization. The extent of this program should be directly related to the complexity of the planned rebreather diving operations.

**12.30 Equipment Requirements**

**General Requirements**

a) Only those models of rebreathers specifically approved by DCB shall be used.

b) Rebreathers should be manufactured according to acceptable Quality Control/Quality Assurance protocols, as evidenced by compliance with the essential elements of ISO 9004. Manufacturers should be able to provide to the DCB supporting documentation to this effect.

c) Unit performance specifications should be within acceptable levels as defined by standards of a recognized authority (CE, US Navy, Royal Navy, NOAA, etc.)

d) Prior to approval, the manufacturer should supply the DCB with supporting documentation detailing the methods of specification determination by a recognized third-party testing agency, including unmanned and manned testing. Test data should be from a recognized, independent test facility.

e) The following documentation for each rebreather model to be used should be available as a set of manufacturer's specifications. These should include:

- Operational depth range;
- Operational temperature range;
- Breathing gas mixtures that may be used;
- Maximum exercise level which can be supported as a function of breathing gas and depth;
- Breathing gas supply durations as a function of exercise level and depth;
- CO₂ absorbent durations, as a function of depth, exercise level, breathing gas, and water temperature;
• Method, range and precision of inspired PPO₂ control, as a function of depth, exercise level, breathing gas, and temperature;
• Likely failure modes and backup or redundant systems designed to protect the diver if such failures occur;
• Accuracy and precision of all readouts and sensors;
• Battery duration as a function of depth and temperature; and,
• Mean time between failures of each subsystem and method of determination.

f) A complete instruction manual is required, fully describing the operation of all rebreather components and subsystems as well as maintenance procedures.

g) A maintenance log is required. The unit maintenance shall be up-to-date based upon manufacturer’s recommendations.

Minimum Equipment
a) A surface/dive valve in the mouthpiece assembly, allowing sealing of the breathing loop from the external environment when not in use.
b) An automatic gas addition valve, so that manual volumetric compensation during descent is unnecessary.
c) Manual gas addition valves, so that manual volumetric compensation during descent and manual oxygen addition at all times during the dive are possible.
d) The diver shall carry alternate life support capability (open-circuit bail-out or redundant rebreather) sufficient to allow the solution of minor problems and allow reliable access to a pre-planned alternate life support system.

Oxygen Rebreathers
Oxygen rebreathers shall be equipped with manual and automatic gas addition valves.

Semi-Closed Circuit Rebreathers.
SCR's shall be equipped with at least one manufacturer-approved oxygen sensor sufficient to warn the diver of impending hypoxia. Sensor redundancy is desirable, but not required.

Closed-Circuit Mixed-gas Rebreathers.
a) CCR shall incorporate a minimum of three independent oxygen sensors.
b) A minimum of two independent displays of oxygen sensor readings shall be available to the diver.
c) Two independent power supplies in the rebreather design are desirable. If only one is present, a secondary system to monitor oxygen levels without power from the primary battery must be incorporated.
d) CCR shall be equipped with manual diluent and oxygen addition valves, to enable the diver to maintain safe oxygen levels in the event of failure of the primary power supply or automatic gas addition systems.
e) Redundancies in onboard electronics, power supplies, and life support systems are highly desirable.

12.40 Operational Requirements
General Requirements
a) All dives involving rebreathers must comply with applicable operational requirements for open-circuit scuba dives to equivalent depths.
b) No rebreather system should be used in situations beyond the manufacturer's stated design limits (dive depth, duration, water temperature, etc.)
c) Modifications to rebreather systems shall be in compliance with manufacturer's recommendations.
d) Rebreather maintenance is to be in compliance with manufacturer's recommendations including sanitizing, replacement of consumables (sensors, CO₂ absorbent, gas, batteries, etc.) and periodic
maintenance.
e) Dive Plan. In addition to standard dive plan components stipulated in AAUS Section 2.0, all dive plans that include the use of rebreathers must include, at minimum, the following details:
- Information about the specific rebreather model to be used;
- Make, model, and type of rebreather system;
- Type of CO$_2$ absorbent material;
- Composition and volume(s) of supply gases;
- Complete description of alternate bailout procedures to be employed, including manual rebreather operation and open-circuit procedures; and,
- Other specific details as requested by DCB.

**Buddy Qualifications.**
a) A diver whose buddy is diving with a rebreather shall be trained in basic rebreather operation, hazard identification, and assist/rescue procedures for a rebreather diver.
b) If the buddy of a rebreather diver is using open-circuit scuba, the rebreather diver must be equipped with a means to provide the open-circuit scuba diver with a sufficient supply of open-circuit breathing gas to allow both divers to return safely to the surface.

**Oxygen Exposures**
a) Planned oxygen partial pressure in the breathing gas shall not exceed 1.4 atmospheres (ata) at depths greater than 30 feet.
b) Planned oxygen partial pressure set point for CCR shall not exceed 1.4 ata. Set point at depth should be reduced to manage oxygen toxicity according to the NOAA Oxygen Exposure Limits.
c) Oxygen exposures should not exceed the NOAA oxygen single and daily exposure limits. Both CNS and pulmonary (whole-body) oxygen exposure indices should be tracked for each diver.

**Decompression Management**
a) DCB shall review and approve the method of decompression management selected for a given diving application and project.
b) Decompression management can be safely achieved by a variety of methods, depending on the type and model of rebreather to be used. Following is a general list of methods for different rebreather types:
1. Oxygen rebreathers: Not applicable.
2. SCR (presumed constant FO$_2$):
   - Use of any method approved for open-circuit scuba diving breathing air, above the maximum operational depth of the supply gas;
   - Use of open-circuit nitrox dive tables based upon expected inspired FO$_2$. In this case, contingency air dive tables may be necessary for active-addition SCR's in the event that exertion level is higher than expected; and,
   - Equivalent air depth correction to open-circuit air dive tables, based upon expected inspired FO$_2$ for planned exertion level, gas supply rate, and gas composition. In this case, contingency air dive tables may be necessary for active-addition SCR's in the event that exertion level is higher than expected.
3. CCR (constant PPO$_2$):
   - Integrated constant PPO$_2$ dive computer;
   - Non-integrated constant PPO$_2$ dive computer;
   - Constant PPO$_2$ dive tables;
   - Open-circuit (constant FO$_2$) nitrox dive computer, set to inspired FO$_2$ predicted using PPO$_2$ set point at the maximum planned dive depth;
• Equivalent air depth (EAD) correction to standard open-circuit air dive tables, based on the inspired $\text{FO}_2$ predicted using the $\text{PPO}_2$ set point at the maximum planned dive depth; and,
• Air dive computer, or air dive tables used above the maximum operating depth (MOD) of air for the $\text{PPO}_2$ set point selected.

**Maintenance Logs, CO$_2$ Scrubber Logs, Battery Logs, and Pre-And Post-Dive Checklists**

Logs and checklists will be developed for the rebreather used, and will be used before and after every dive. Diver shall indicate by initialing that checklists have been completed before and after each dive. Such documents shall be filed and maintained as permanent project records. No rebreather shall be dived which has failed any portion of the pre-dive check, or is found to not be operating in accordance with manufacturer's specifications. Pre-dive checks shall include:

- Gas supply cylinders full;
- Composition of all supply and bail-out gases analyzed and documented;
- Oxygen sensors calibrated;
- Carbon dioxide canister properly packed;
- Remaining duration of canister life verified;
- Breathing loop assembled;
- Positive and negative pressure leak checks;
- Automatic volume addition system working;
- Automatic oxygen addition systems working;
- Pre-breathe system for 3 minutes (5 minutes in cold water) to ensure proper oxygen addition and carbon dioxide removal (be alert for signs of hypoxia or hypercapnia);
- Other procedures specific to the model of rebreather used;
- Documentation of ALL components assembled;
- Complete pre-dive system check performed; and,
- Final operational verification immediately before to entering the water:
  - $\text{PO}_2$ in the rebreather is not hypoxic;
  - Oxygen addition system is functioning;
  - Volumetric addition is functioning; and,
  - Bail-out life support is functioning.

**Alternate Life Support System**

The diver shall have reliable access to an alternate life support system designed to safely return the diver to the surface at normal ascent rates, including any required decompression in the event of primary rebreather failure. The complexity and extent of such systems are directly related to the depth/time profiles of the mission. Examples of such systems include, but are not limited to:

a) Open-circuit bailout cylinders or sets of cylinders, either carried or pre-positioned.
b) Redundant rebreather.
c) Pre-positioned life support equipment with topside support.

**CO$_2$ Absorbent Material**

a) CO$_2$ absorption canister shall be filled in accordance with the manufacturer's specifications.
b) CO$_2$ absorbent material shall be used in accordance with the manufacturer's specifications for expected duration.
c) If CO$_2$ absorbent canister is not exhausted and storage between dives is planned, the canister should be removed from the unit and stored sealed and protected from ambient air, to ensure the absorbent retains its activity for subsequent dives.
d) Long-term storage of carbon dioxide absorbents shall be in a cool, dry location in a sealed container. Field storage must be adequate to maintain viability of material until use.
Consumables (e.g., batteries, oxygen sensors, etc.)
Other consumables (e.g., batteries, oxygen sensors, etc.) shall be maintained, tested, and replaced in accordance with the manufacturer's specifications.

Unit Disinfections
The entire breathing loop, including mouthpiece, hoses, counterlungs, and CO₂ canister, should be disinfected periodically according to manufacturer's specifications. The loop must be disinfected between each use of the same rebreather by different divers.

12.50 Oxygen Rebreathers
a) Oxygen rebreathers shall not be used at depths greater than 20 feet.
b) Breathing loop and diver's lungs must be adequately flushed with pure oxygen prior to entering the water on each dive. Once done, the diver must breathe continuously and solely from the intact loop, or re-flushing is required.
c) Breathing loop shall be flushed with fresh oxygen prior to ascending to avoid hypoxia due to inert gas in the loop.

12.60 Semi-Closed Circuit Rebreathers
a) The composition of the injection gas supply of a semi-closed rebreather shall be chosen such that the partial pressure of oxygen in the breathing loop will not drop below 0.2 ata, even at maximum exertion at the surface.
b) The gas addition rate of active addition SCR (e.g., Draeger Dolphin and similar units) shall be checked before every dive, to ensure it is balanced against expected workload and supply gas FO₂.
c) The intermediate pressure of supply gas delivery in active-addition SCR shall be checked periodically, in compliance with manufacturer's recommendations.
d) Maximum operating depth shall be based upon the FO₂ in the active supply cylinder.
e) Prior to ascent to the surface the diver shall flush the breathing loop with fresh gas or switch to an open-circuit system to avoid hypoxia. The flush should be at a depth of approximately 30 fsw during ascent on dives deeper than 30 fsw, and at bottom depth on dives 30 fsw and shallower.

12.70 Closed-Circuit Rebreathers
a) The FO₂ of each diluent gas supply used shall be chosen so that, if breathed directly while in the depth range for which its use is intended, it will produce an inspired PPO₂ greater than 0.20 ata but no greater than 1.4 ata.
b) Maximum operating depth shall be based on the FO₂ of the diluent in use during each phase of the dive, so as not to exceed a PO₂ limit of 1.4 ata.
c) Divers shall monitor both primary and secondary oxygen display systems at regular intervals throughout the dive, to verify that readings are within limits, that redundant displays are providing similar values, and whether readings are dynamic or static (as an indicator of sensor failure).
d) The PPO₂ set point shall not be lower than 0.4 ata or higher than 1.4 ata.

Discussion
We recommend that at least the following sections be re-evaluated and updated.

Section 12.20 Prerequisites
• Table [redundant: used for “practical training”- a) hours; and for “supervised dives”, and b) targeted activities].
• Maintenance of Proficiency [a) at least one rebreather dive every 8 weeks, and for extended range, at least one dive per month at a depth near 130 fsw practicing deco protocols].
Section 12.30 Equipment Requirements

- General Requirements [b) manufacturing QA/QC “as evidenced by compliance with ISO 9004”; c) unit performance acceptability- recognized authorities (= CE, U.S. Navy, Royal Navy, NOAA, etc.); d) manufacturer documentation from recognized independent test facility].
- Minimum Equipment [b) ADV; c) manual gas addition valves- on new rigs?; d) alternate life support-onboard vs. off board].
- Closed Circuit Mixed Gas Rebreathers [a) minimum of three independent O₂ sensors; b) minimum of two independent displays; d) manual diluent and oxygen addition valves; e) redundancies “desirable”].

Section 12.40 Operational Requirements

- General Requirements [b) manufacturer’s design limits; e) rebreather dive plan].
- Decompression Management [b.3) CCR PO₂ EAD correction; air computer/tables above MOD].
- CO₂ Absorbent Material [c) left in sealed unit?].
SEMI-CLOSED REBREATHERS

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Semiclosed rebreathers fill a multitude of diving roles from shallow water recreational diving to deep cave diving and very deep saturation diving. They are preferred over electronic rebreathers in many applications due to their robust mechanical nature and dependability.

The large and bulky military semiclosed rebreathers of the fifties and sixties have been replaced by smaller and lighter units, reflecting changes in the diver population. However, those design changes have made constant mass flow (CMI) rebreathers more susceptible to hypoxia than the older high-flow designs due to high diver workload at shallow depths. Whereas CMI rebreathers are about as simple as a rebreather can be, their safe use is not guaranteed without careful diver education. With low flow rate CMI rebreathers, an oxygen monitor is highly advisable.

The U.S. Navy's semiclosed UBA inventory only uses CMI devices (Carleton Viper SC and Divex SLS MK IV backpack). Constant volume injection (CVI, Interspiro DCSC) and variable volume exhaust (VVE, Halcyon RB80 and the Aqualung Oxymix 3C) rebreathers have overcome some of the operational vulnerabilities of the CMI rebreathers, but at a cost in size and complexity. Nevertheless, the fact that some VVE devices are used for critical and deep underwater cave exploration is a testament to the value of the entire class of semiclosed rebreathers.

As semiclosed rebreathers have shrunk in size, potential physiological issues have become more likely. Improved education and oxygen monitoring can offset the potential hazards of semiclosed rebreather diving.

Ed. Note: Please refer to the detailed paper on this topic by Dr. John R. Clarke, currently in press as a contribution to the Proceedings of the Rebreather Forum 3.0 sponsored by AAUS, DAN and PADI.
OPERATIONAL REBREATHER CONSIDERATIONS

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The following commentaries were made during the panel discussion on operational rebreather considerations co-chaired by Casey Coy and Rick Gomez.

Panel Moderators:
• Casey Coy, The Florida Aquarium
• Rick Riera-Gomez, University of Miami

Panelists:
• John R. Clarke, U.S. Navy Experimental Diving Unit
• Elliott Jessup, California Academy of Sciences
• Elizabeth Kintzing, University of New Hampshire
• Phillip R. Lobel, Boston University
• Greg McFall, NOAA National Marine Sanctuaries
• David Pence, University of Hawaii
• Steven Sellers U.S. National Park Service
• Brett Seymour, U.S. National Park Service
• Marc Slattery, University of Mississippi
• Mike Terrell, The Florida Aquarium
• Joe Tomoleoni, U.S. Geological Survey

Institutional buy-in

Foci: Risk management, resources (time, expertise development and finances), DCB support, DSO qualification.

R. Gomez: We had to make sure that University of Miami risk management and legal counsel were OK with adding rebreathers (RBs) into the diving program. We sat down and explained RBs to risk management, why they were advantageous to the program, how they worked, the training that was required, maintenance, pros and cons, etc. Neither the insurance underwriters, nor risk management, knew what RBs were and had to be educated on what they were all about.

D. Pence: After you have established the need, risk management often thinks that if the Diving Control Board (DCB) is OK with RBs, then risk management is OK with moving forward. This means
that the DCB and the DSO need to be fully familiar with RB technology and have the ability to know which RB is needed for which application. The DSO must achieve proficiency in a particular system. It is hard to be in charge and the person responsible when you do not know or understand what is going on.

C. Coy: We had difficulty convincing The Florida Aquarium to incorporate RBs into the program because of the initial investment and financial resources it would require to get started. Also, mirroring what D. Pence said, if the DSO does not have RB training, looking at and approving dive plans for RBs is difficult.

B. Seymour: The National Park Service jump to RBs was mission based. Risk management did not have the same problems with underwriters but had a certain amount of risk management to do. NPS turned to specialized diving people to be experts in the area of RBs. Some people on the risk management board were also part of a project that wanted to move forward with RBs and asked if their plan was acceptable. The DCB was unfamiliar with RBs and did not have the knowledge to make decisions. They went into the field to get the answers from the people who were trusted from NOAA, hyperbaric physiologists, AAUS, and other professionals with knowledge in this area, and put these people on the board. Seek out people to talk to about RBs who do not have a vested financial interest and who are using them in an operational and objective way.

E. Jessup: California Academy of Sciences considered funding; buy-in requires a lot of money. It is important to write up an extensive budget that consists of purchase of units, training, and other equipment needed.

R. Gomez: For informed DCB support of RBs, there should be a RB diver on the DCB.

G. McFall: Development of a program is difficult when you do not know about RBs. Three NOAA DCB members are trained on RBs.

D. Pence: Smaller programs have individual labs that own their own equipment and maintain their gear on their own. Larger programs allow for the dive program to maintain and purchase equipment. At UH, equipment is available at a day rate of $100/day/unit to the scientists. Also take into consideration whether there is trained staff available for field support. Some labs will buy RBs for specific projects and then the units sit stagnant for years until they are used again. The cost of reactivating the RB units is 20-30% of acquisition cost. By having a central program that leases the units out, the RBs are maintained on a consistent basis and the overall cost of maintenance is decreased.

B. Seymour: Having a cache of RB units that go out with divers takes the sting away from the individual parks and keeps maintenance and upkeep within a national capacity so that they know where they are at any given time. This way researchers can use the RB, then return it and the NPS maintains the equipment.

Who should dive a RB?

Foci: Awareness, discipline, comfort under water

S. Sellers: If the diver does not have the discipline to dive the RB, they are not allowed to dive. This was the attitude and approach to the DCB and it was how they moved forward with incorporating RBs into the program.

E. Jessup: Selection of divers is important; experience with technical diving translates into being able to manage your gear and having situational awareness that a RB diver requires.

D. Pence: I have noticed an inflated self-view of proficiency in divers as they move on from open-circuit to RB diving. Things do not often go wrong with the RB but when they do, the situation calls for a specialized skill set that is very different from that developed from open-circuit diving. Even technical divers need to take the time to come up to speed with the technology surrounding RBs.

P. Lobel: A lot is determined from how you let people get into RBs. During the training phase, keeping people shallow while they are learning to use the RB is a safe approach.
M. Terrell: There are a lot of technical aspects to diving a RB. It takes a different sort of mentality and we worry that the scientist who uses the RB is not going to have that mentality, i.e., is the science going to distract the diver from focusing on the RB’s technical needs while diving the unit, or will focusing too much on the RB distract from the science that needs to be done? Before trying to combine performing science and diving a RB, the diver needs to develop the skill necessary to operate the RB proficiently.

C. Coy: Regarding task-load diving, is previous experience on open circuit and the ability to focus on science and the parameters of the dive, situation awareness, required before looking at technical diving or experience in order to determine if the diver is ready or even capable of diving a RB?

P. Lobel: It helps to have two people look at a checklist prior to diving. It is preferable to have someone with you who is an equipment expert so that someone is there to review the work.

M. Slattery: I echo this statement about having an equipment expert and having two people go over the checklist.

D. Pence: I want to see a level of humility in RB divers who are willing to step back and realize that they have something to learn and are open to learning about RBs.

E. Kintzing: You have to say to yourself that you are going to put the time and effort into learning how to dive a RB. You have to have the humility and be willing to accept that you need to learn the RB from scratch without acting like you know what is going on. Those are the qualities you should look for when deciding if a diver is capable of diving on a RB.

Selection: Equipment and Training

Foci: Instructor selection, diver training.

C. Coy: The Florida Aquarium chose a RB unit used within the scientific community based on familiarity of what other people were using in their programs.

B. Seymour: In terms of instructor selection, NPS shares the agreement with humility-type attitude and has zero tolerance for chest beating technical divers; this crosses over into instructor selection. Choose someone who will teach with the basement-up mentality, who will not assume that the diver being trained knows anything about the material being taught. Pick an instructor who will teach and can target your needs, education, and what needs to be accomplished. Find someone who can specifically target your mission and program.

S. Sellers: We are not looking for someone to help you teach to dive RBs, you are trying to find someone who can work with you and the unit.

D. Pence: On the RB diver training process, once a diver was deemed trained on operation and use of the RB unit, there needs to be a series of more dives under a senior diver-mentor where the new diver learns to use the RB for their science. This capacity takes time to build up, but should be included in the progression of training.

M. Terrell: You are looking for someone to teach you to work on the RB unit, not just to dive on it. There needs to be a full-picture point of view and each RB requires unit-specific training.

Operations

Foci: Deep versus shallow differences, mixed-mode diving

M. Slattery: Whatever the dive, deep or shallow, or mixed mode, it needs to be done well by someone who is properly trained.

R. Gomez: We will see shallower diving done with these RB units as we start to see more and more automated units coming on line. These new units will do everything for you except plug in the bottles and turn themselves on.

S. Sellers: New units will turn themselves on but will not breathe for you.
C. Coy: The newer RB units will allow the divers to focus more on the science and less on the unit.

J. Tomoleoni: Shallow diving on a RB allows the diver to stay in for much longer periods of time on 100% oxygen.

B. Seymour: RBs are a single unit to dive across the board, meaning one piece of equipment is used to dive shallow or deep. The difference comes in with the knowledge of the specifics of diving deep versus shallow while wearing the same equipment. Have the starting point be the same, then tailor the dive profile according to the mission.

R. Gomez: Diving RBs has logistical advantages. On a deep or shallow dive there is not a need to take all that diving gear along. This is a huge operational advantage. On a recent dive trip using RBs, we took approximately 10% of the gas we normally would have needed. It would have taken 55 K cylinders but instead took only 20 (10 diluent, 8 O₂, and 2 He).

E. Kintzing: We started RB diving specifically for deeper dives but have been using RBs for all dives to put time in to get comfortable in the rig.

D. Pence: Mixed mode can be done but takes training and practice in order to switch back and forth as the situation arises.

S. Sellers: In the evolution of RBs, mixed mode is hard to avoid. A good briefing needs to be planned. The diver using mixed mode also needs a basic understanding that it is different than what they are used to (e.g., there will be no stream of bubbles to locate your buddy).

B. Seymour: Mixed mode is a great educational opportunity. Part of what we wanted to do was to get the voodoo out of the mixed-mode rebreather; to demystify it. From a dive buddy perspective, you can help them and they can help you.

Discussion

T. White: How much time (task load) would be spent getting across the room versus making observations?

D. Pence: No difference. On most modern systems there is a “heads-up” display with at least nominal system status information. There are audible sounds to let the diver know the solenoid is being activated and oxygen is being delivered into the system. Many of these “signals” have to be learned cues to enable the diver to efficiently use the RB while diving and to have enough training to pick up on the cues to be able to detect failure mode if it should occur.

S. Sellers: No more time than it requires for open circuit.

M. Terrell: It is about having the training required to be comfortable with the equipment, not about psyching yourself out because of the equipment’s technology.

S. Sellers: With open circuit a diver is looking at their gauge frequently as opposed to looking at oxygen level twice an hour with a RB but the rest of the time you are checking your PO₂ or heads-up display. Reprogram yourself to become comfortable with the new language of the RB and task load efficiently without going over the edge of safety.

D. Pallett: With the ECRB (electronic closed-circuit rebreather) what is the difference between diver controlled and electronic controlled RBs? There is a concern that those divers will not check their oxygen levels with electronically controlled RB’s.

E. Jessup: Manually controlling the unit is important and should be incorporated into training. Electronic control is a nice option as a backup but everyone should know how to manually fly the unit.

M. Lang: As a general rule, hard-core scientists will preferentially not be checking their oxygen frequently on RBs but rather focus on collecting data or specimens and making observations. Do we predict an initial spike in incident rates in the rush to make RBs mainstream tools?

D. Pence: Out of 30-40 RB divers in the UH program, only 5 are professional divers, the rest are scientists, which means they have the capability of using RBs and working simultaneously without dying. There will always be individuals within the community who are absent minded or so dedicated to open circuit that they cannot make the shift. It is easier for younger scientists
versus the older generation to shift to RBs.

P. Lobel: RBs are not for everyone, diver selection is critical and needs to be driven by science. A RB unit is not a toy. When you get into operational mode, that is when a DSO as part of the team becomes more important than when diving open-circuit scuba. As a community we will need to shift how we supervise divers over the next 10 years. It is not complicated but you want someone there who has the understanding and training on the unit.

S. Sellers: It will be important to develop a culture of acceptable behavior in the people that are going to use the RB units.

J. Clarke: A USN diver who uses the manual version of the Megalodon rebreather was asked why he opted for the manual versus electronic unit. He stated that he never wanted to get lax enough to where he did not check his oxygen levels. The RB unit he selected requires him to check his oxygen levels so that he does not forget.

K. Buch: Are there RB standards elements right now that need to be incorporated quickly? Are there any general elements that we are behind on?

M. Slattery: Yes. AAUS standards sections are obsolete because RBs have evolved and been updated but the standards have not. Hopefully they will be up to speed over the next year.

D. Kesling: Weaknesses in standards involve equipment issues, not so much with training.

D. Osorio: For live boating operations, how do you keep track of divers using RBs?

C. Coy: It is a non-issue by usually having divers shoot a surface marker buoy every 5-10 min. For decompression stops an SMB is also shot up. The same sets of rules apply for shallow dives.

B. Gray: Environment Canada mitigates issues by using underwater communication with the surface.

J. Christiansen: Are you looking at fundamentally changing the open-circuit training standards at the entry level to build the level of awareness as the gateway to the RB training?

M. Slattery: No, it is more an issue of training the RB divers on the new technology, not changing the fundamental standards of the open-circuit training.

P. Lobel: RB diving is overly complicated, but you have to keep up with it.

D. Pence: As DSOs, if we are doing it correctly, we are already imparting that attitude of meticulousness and attention to detail into our working divers as opposed to what we would see coming out of a recreational dive shop.

J. Reid: Would you recommend funding programs by using recreational RB models that are less expensive for programs that the finance department will not fund on a large scale to build the program up?

E. Jessup: For recreational RB depths, sure.

M. Slattery: For me personally, I would have liked to have started out on a better rig.

J. Reid: Will there not be changes in rigs anyway when technology improves, which would require switching units to the upgraded models?

D. Pence: It is like changing from one airplane to another. The fundamentals are the same, the ergonomics are going to change and there are nuances that will be different.

J. Reid: What is the recreational RB depth?

R. Gomez: 40 m (130 ft).

W. Dent: How do you handle the researcher who goes out and does 1-2 years of diving, writes publications, then comes back to use RBs again? Do you retrain from scratch?

M. Slattery: Standards state that you should be diving every 8 weeks on the RB rig to stay proficient. They would have to get themselves back up to speed on their own dime if they chose to become inactive for an extended period of time.

W. Dent: When graduate students who are trained on RBs leave, new ones come in and their PI wants to
stay up to speed with new graduate students and train them on the RB. How do you handle this turn over?

D. Pence: It is part of the nature of the beast. Build in time to ramp up at the beginning of the project for the new graduate student training. Concepts and knowledge will not go away; the PI will just need some time to get back into the swing of it.

T. White: Are any OMs offer training to external people?
D. Pence: J. Godfrey, D. Pence, C. Coy and S. Sellers offer RB training that can be arranged on a contractual basis.
S. Sellers: There are regional agreements where you can swap resources back and forth to benefit everyone.

J. Nimz: How can you guarantee RB units will not be outdated 5 years after buying them?
D. Pence: For UH, the purchase contract from the manufacturer included upgrading to the next generation. The upgrade was put into the budget and when upgrades were available they were installed. Work proactively at it.
S. Sellers: Look at history, upgrades, demonstrated ability.
B. Seymour: Some things are overkill but the bottom line is that RBs work now so it is not so much hit or miss, obsolete or outdated or smaller because they are a few years old. It will still work in 5 years when properly serviced and maintained.

G. McFall: I alluded in my talk that tech divers would make the best RB divers, but want to clarify that it would actually be the opposite. NOAA is eager to look at, tighten up and revise current standards and to talk about important issues like mixed-mode diving, open-circuit and closed-circuit diving, etc.

R. Gomez: Current technology is not applicable to all divers and missions. DSO and DCB needs to be conversant in the technology before it is implemented. Capital investment, initial training, maintenance, consumable cost of 10% per unit per year.
RB COLLOQUIUM RECOMMENDATIONS

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The following rebreather colloquium summary recommendations for scientific diving programs were promulgated by agreement of the panel of experts with input and discussion by the workshop participants:

1. Based upon current levels of rebreather system complexity, the current technology may not be applicable to all scientific divers and missions.

2. It is incumbent upon the OM to ensure that the DSO and DCB are conversant in rebreather technology before it is implemented.

3. Financial considerations include capital investment in equipment acquisition and initial training, a recommended maintenance and consumable cost of 10\% per unit per year, and personnel support.

4. Selection of a trainer should include competencies in scientific diving and rebreather diving.

5. Rebreather diver selection should include qualities such as awareness and discipline.