AAUS DEEP DIVING STANDARDS

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Background

The scientific diving community has been operating under self-controlled diver training and education programs since 1951. This tradition continues to flourish today. One of the first set of consensual diving standards was developed by the Scripps Institution of Oceanography of the University of California (Scripps) in the early 1950's. Further, in 1973, diving safety boards and committees from ten major educational institutions involved in scientific diving met and accepted the University of California Guide for Diving Safety as a minimum standard for their individual programs.

In 1977, the Occupational Safety and Health Administration (OSHA) adopted a permanent diving standard for "Commercial Diving Operations". This OSHA standard was designed to include scientific diving. It quickly became evident that this could present major problems for research facilities with scientific diving programs. These concerns were voiced and after a long hard fight on November 26, 1982, OSHA exempted scientific diving from coverage under 29 CFR Part 1910, Subpart T, Commercial Diving Operations, provided that the diving meets the Agency's 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 [47 F.R. 53357; §1910.401(a)(2)(iv)].

The American Academy Underwater Sciences (AAUS) was organized in 1977 and incorporated in the State of California in 1983. Its Standards for scientific diving have been around since the incorporation. The title of the original AAUS standards was "Standards for Scientific Diving Certification and Operation of Scientific Diving Programs". The AAUS standards for scientific diving were developed and written by compiling the policies set forth in diving manuals of several universities as well as both private and governmental scientific diving programs. This method set the pattern for the future development of all of the AAUS Scientific Diving Standards.

In the case of deep diving standards, the task was given to a specially formed "Technical Diving Committee". This committee would investigate which AAUS organizational members currently had existing standards for deep diving, approved by their respective Diving Control Board (DCB), in place within their scientific diving program. Once a data bank of existing standards was acquired the technical committee would review, amend and draft a set of standards that they thought would be most appropriate for the AAUS. Once a draft for the standard was developed, the technical committee would present the draft to the AAUS Board of Directors, who after review and comment, would present to the membership for review and comment. After all comments were taken into consideration a final product would be produced, voted upon and adopted into the manual.

AAUS Scientific Diving Standards Pertaining To Deep Diving

In the original "Standards for Scientific Diving Certification and Operation of Scientific Diving Programs" manual the standards that pertained to deep diving were in a separate section. This section was titled "Other Diving Technology". It included 9 different types or modes of diving. They were listed as follows:

1. Staged Decompression Diving
2. Saturation Diving
3. Hookah Diving
4. Surface Supplied Diving
5. Closed and Semi-Closed Circuit Scuba (Rebreathers)
6. Mixed Gas Diving
7. Blue Water Diving
8. Ice and Polar Diving
9. Overhead Environments

Staged Decompression Diving

The standards for staged decompression diving existed originally as Section 2.1 in the original AAUS standards manual. In 1987, it was moved in its original form to section 9.1. It was extremely brief.

2.10 STAGED DECOMPRESSION DIVING

No diver shall plan or conduct staged decompression dives without prior approval of the Diving Control Board.

This standard gives full authority to the organizational member's DCB to develop and adopt their own set of staged decompression diving standards as they should see fit. Several factors would come into play when adopting these non-consensual standards. The DCB must determine what level of safety is acceptable for their program when considering training, experience and proficiency. They must also consider what level of liability is acceptable since the standards they are producing are not consensual.

In 2001, the AAUS Technical Committee took on the task of addressing the need for consensual standards pertaining to Staged Decompression Diving. In 2003 a final draft was presented by the Technical Committee to the membership and the new Staged Decompression Diving Standards were adopted. The new standards addressed Staged Decompression Diving in its entirety. Upon completion Staged Decompression Diving was given its own separate section in the manual which was titled Section 9 Staged Decompression Diving.

SECTION 9.00 STAGED DECOMPRESSION DIVING

Decompression diving shall be defined as any diving during which the diver cannot perform a direct return to the surface without performing a mandatory decompression stop to allow the release of inert gas from the diver's body.

The following procedures shall be observed when conducting dives requiring planned decompression stops.

9.10 Minimum Experience and Training Requirements

Prerequisites:

Scientific Diver qualification according to Section 5.00.

Minimum of 100 logged dives.

Demonstration of the ability to safely plan and conduct dives deeper than 100 feet.

Nitrox certification/authorization according to AAUS Section 7.00 recommended.

Training shall be appropriate for the conditions in which dive operations are to be conducted.

Minimum Training shall include the following:

A minimum of 6 hours of classroom training to ensure theoretical knowledge to include: physics and physiology of decompression; decompression planning and procedures; gas management; equipment configurations; decompression method, emergency procedures.

It is recommended that at least one training session be conducted in a pool or sheltered water setting, to cover equipment handling and familiarization, swimming and buoyancy control, to estimate gas consumption rates, and to practice emergency procedures.

At least 6 open-water training dives simulating/requiring decompression shall be conducted, emphasizing planning and execution of required decompression dives, and including practice of emergency procedures.

Progression to greater depths shall be by 4-dive increments at depth intervals as specified in Section 5.40.

No training dives requiring decompression shall be conducted until the diver has demonstrated acceptable skills under simulated conditions.

The following are the minimum skills the diver must demonstrate proficiently during dives simulating and requiring decompression:

- *Buoyancy control*
- *Proper ascent rate*
- *Proper depth control*
- *Equipment manipulation*
- *Stage/decompression bottle use as pertinent to planned diving operation*
- *Buddy skills*
- *Gas management*
- *Time management*
- *Task loading*
- *Emergency skills*

7. ***Divers shall demonstrate to the satisfaction of the DSO or the DSO's designee proficiency in planning and executing required decompression dives appropriate to the conditions in which diving operations are to be conducted.***

8. ***Upon completion of training, the diver shall be authorized to conduct required decompression dives with DSO approval.***

9.20 Minimum Equipment Requirements

Valve and regulator systems for primary (bottom) gas supplies shall be configured in a redundant manner that allows continuous breathing gas delivery in the event of failure of any one component of the regulator/valve system.

Cylinders with volume and configuration adequate for planned diving operations.

One of the second stages on the primary gas supply shall be configured with a hose of adequate length to facilitate effective emergency gas sharing in the intended environment.

Minimum dive equipment shall include:

Snorkel is optional at the DCB's discretion, as determined by the conditions and environment.

Diver location devices adequate for the planned diving operations and environment.

Compass

Redundancy in the following components is desirable or required at the discretion of the DCB or DSO:

Decompression Schedules

Dive Timing Devices

Depth gauges

Buoyancy Control Devices

Cutting devices

Lift bags and line reels

9.30 Minimum Operational Requirements

Approval of ***dive plan applications to conduct required decompression dives shall be on a case-by-case basis.***

The maximum pO_2 to be used for planning required decompression dives is 1.6. It is recommended that a pO_2 of less than 1.6 be used during bottom exposure.

Divers gas supplies shall be adequate to meet planned operational requirements and foreseeable emergency situations.

Decompression dives may be planned using dive tables, dive computers, and/or PC software approved by the DSO/DCB.

Breathing gases used while performing in-water decompression shall contain the same or greater oxygen content as that used during the bottom phase of the dive.

The dive team prior to each dive shall review emergency procedures appropriate for the planned dive.

If breathing gas mixtures other than air are used for required decompression, their use shall be in accordance with those regulations set forth in the appropriate sections of this standard.

The maximum depth for required decompression using air as the bottom gas shall be 190 feet.

Use of additional nitrox and/or high-oxygen fraction decompression mixtures as travel and decompression gases to decrease decompression obligations is encouraged.

Use of alternate inert gas mixtures to limit narcosis is encouraged for depths greater than 150 feet.

If a period of more than 6 months has elapsed since the last mixed gas dive, a series of progressive workup dives to return the diver(s) to proficiency status prior to the start of project diving operations are recommended.

Mission specific workup dives are recommended.

Surface-Supplied Diving

The standards for surface-supplied diving existed originally as Section 2.4 in the original 1984 AAUS standards manual. In 1987 it was moved in its original form to section 9.4. The standards for Surface Supplied Diving consisted of a brief outline. The original standard:

9.40 SURFACE-SUPPLIED DIVING

Surface-supplied divers shall comply with all scuba diving procedures in this manual (except Sec. 2.31). Surface-supplied diving shall not be conducted at depths greater than 190 fsw (58 msw).

9.41 Divers using the surface-supplied mode shall be equipped with a diver-carried independent reserve breathing gas supply.

9.42 Each surface-supplied diver shall be hose tended by a separate dive team member while in the water.

9.43 Divers using the surface-supplied mode shall maintain voice communication with the surface tender.

9.44 The surface-supplied breathing gas supply shall be sufficient to support all surface supplied divers in the water for the duration of the planned dive, including decompression.

9.45 During surface-supplied diving operations when only one diver is in the water, there must be a standby diver in attendance at the dive location.

The AAUS standards for Surface-Supplied Diving listed above are how they currently exist in the 2005 revision. The AAUS Standards Committee is currently considering the review, revision and adoption of a more comprehensive set of standards for Surface-Supplied Diving. Until such a revision is completed and adopted by the AAUS the responsibility for such standards will fall on the OM's DCB should an OM decide to utilize Surface-Supplied Diving. The existing set of standards, listed above, would act solely as minimum standards.

Closed- and Semi-Closed Circuit Scuba (Rebreathers)

As was the case in each of the topics listed above, the original standards for closed- and semi-closed circuit scuba (Rebreathers) were incorporated in the 1984 version of the AAUS manual. They were also moved to a new section in the 1987 revision and finally rewritten and adopted in 2005. The 1984 AAUS standards:

9.50 CLOSED AND SEMI-CLOSED CIRCUIT SCUBA (REBREATHERS)

Closed and semi-closed circuit scuba (rebreathers) shall meet the following requirements:

9.51 Oxygen partial pressure in the breathing gas shall not exceed values approved by the organizational member's DCB. The generally accepted maximum value is 1.5 atmospheres ppO_2 at depths greater than 25 fsw (7.6 msw).

9.52 Chemicals used for the absorption of carbon dioxide shall be kept in a cool, dry location in a sealed container until required for use.

9.53 The designated person-in-charge shall determine that the carbon dioxide absorption canister is used in accordance with the manufacturer's instructions.

9.54 Closed and semi-closed diving equipment will not be used at a depth greater than that recommended by the manufacturer of the equipment.

In 2003, the AAUS Standards committee identified an increasing trend towards the use of rebreathers in the Scientific Diving arena. The Technical Diving Committee was charged with providing standards for the use of rebreathers within AAUS programs. In 2005, the final draft was presented to the membership, approved and adopted by the AAUS. The final version was given its own section, Section 12 in the AAUS manual and consists of 8 pages..

SECTION 12.0 REBREATHERS

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. 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

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.

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.

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.***

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.

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 (FO_2) in the breathing loop at all depths, similar to open-circuit SCUBA.

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 (PPO_2) 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).

Training Prerequisites

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

Completion of a minimum of 50 open-water dives on SCUBA.

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.

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 130 fsw and shallower, for dives that do not require decompression stops, using nitrogen/oxygen breathing media.

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.

Classroom training shall include:

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.

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*
- *Decompression sickness*

Rebreather-specific information required for the safe and effective operation of the system to be used, including:

- *System design and operation, including:*
- *Counterlung(s)*
- *CO_2 scrubber*
- *CO_2 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*
- *Emergency protocols and bailout procedures.*
- *Practical Training (with model of rebreather to be used)*

A minimum number of hours of underwater time.

Type	*Pool/Confined Water*	*O/W Training*	*O/W Supervised*
Oxygen Rebreather	*1 dive, 90 min*	*4 dives, 120 min.**	*2 dives, 60 min*
Semi-Closed Circuit	*1 dive, 90-120 min*	*4 dives, 120 min.***	*4 dives, 120 min*
Closed-Circuit	*1 dive, 90-120 min*	*8 dives, 380 min.****	*4 dives, 240 min*

** 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.*

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

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.*
- *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*
- *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)*
- *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.

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.

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.

Type	*Pool/Confined Water*	*O/W Training*	*O/W Supervised*

Oxygen Rebreather	*1 dive, 90 min*	*4 dives, 120 min.**	*2 dives, 60 min*
Semi-Closed Circuit	*1 dive, 90-120 min*	*4 dives, 120 min.***	*4 dives, 120 min*
Closed-Circuit	*1 dive, 90-120 min*	*8 dives, 380 min.****	*4 dives, 240 min*

** 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.*

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.

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.

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.

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

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.

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

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

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.

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

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.

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*
- CO_2 *absorbent durations, as a function of depth, exercise level, breathing gas, and water temperature*
- *Method, range and precision of inspired* PPO_2 *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*
- *Mean time between failures of each subsystem and method of determination*

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

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

Minimum Equipment

A surface/dive valve in the mouthpiece assembly, allowing sealing of the breathing loop from the external environment when not in use.

An automatic gas addition valve, so that manual volumetric compensation during descent is unnecessary.

Manual gas addition valves, so that manual volumetric compensation during descent and manual oxygen addition at all times during the dive are possible.

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.

SCRs 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.

CCR shall incorporate a minimum of three independent oxygen sensors.

A minimum of two independent displays of oxygen sensor readings shall be available to the diver.

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.

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.

Redundancies in onboard electronics, power supplies, and life support systems are highly desirable.

12.40 Operational Requirements

General Requirements

All dives involving rebreathers must comply with applicable operational requirements for open-circuit SCUBA dives to equivalent depths.

No rebreather system should be used in situations beyond the manufacturer's stated design limits (dive depth, duration, water temperature, etc).

Modifications to rebreather systems shall be in compliance with manufacturer's recommendations.

Rebreather maintenance is to be in compliance with manufacturer's recommendations including sanitizing, replacement of consumables (sensors, CO_2 absorbent, gas, batteries, etc) and periodic maintenance.

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*
- *Other specific details as requested by DCB*

Buddy Qualifications.

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.

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

Planned oxygen partial pressure in the breathing gas shall not exceed 1.4 atmospheres at depths greater than 30 feet.

Planned oxygen partial pressure set point for CCR shall not exceed 1.4 atm. Set point at depth should be reduced to manage oxygen toxicity according to the NOAA Oxygen Exposure Limits.

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

DCB shall review and approve the method of decompression management selected for a given diving application and project.

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:

Oxygen rebreathers: Not applicable.

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 SCRs in the event that exertion level is higher than expected.*
- *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 SCRs in the event that exertion level is higher than expected.*

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 FO_2 predicted using the PPO_2 set point at the maximum planned dive depth.*
- *Air dive computer, or air dive tables used above the maximum operating depth (MOD) of air for the PPO_2 setpoint 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*
- *Final operational verification immediately before to entering the water:*
- *PO_2 in the rebreather is not hypoxic*
- *Oxygen addition system is functioning;*
- *Volumetric addition is functioning*
- *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:

Open-circuit bailout cylinders or sets of cylinders, either carried or pre-positioned

Redundant rebreather

Pre-positioned life support equipment with topside support

CO_2 Absorbent Material

CO_2 absorption canister shall be filled in accordance with the manufacturer's specifications.

CO_2 absorbent material shall be used in accordance with the manufacturer's specifications for expected duration.

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.

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

Oxygen rebreathers shall not be used at depths greater than 20 feet.

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.

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

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 atm, even at maximum exertion at the surface.

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 FO_2.

The intermediate pressure of supply gas delivery in active-addition SCR shall be checked periodically, in compliance with manufacturer's recommendations.

Maximum operating depth shall be based upon the FO_2 in the active supply cylinder.

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

The FO_2 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 PPO_2 greater than 0.20 atm but no greater than 1.4 atm.

Maximum operating depth shall be based on the FO_2 of the diluent in use during each phase of the dive, so as not to exceed a PO_2 limit of 1.4 atm.

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).

The PPO_2 set point shall not be lower than 0.4 atm or higher than 1.4 atm.

Mixed Gas Diving

The standards for Mixed Gas Diving existed originally as Section 2.6 in the AAUS standards manual. In 1987 it was moved intact to section 9.6. It existed as nothing more than a title.

9.60 MIXED GAS DIVING

If an AAUS OM were to conduct any Mixed Gas Diving their DCB would have to produce Mixed Gas Diving standards in their entirety. Similar to the way the Technical Diving Committee took on the task of adopting standards for rebreather diving they the task to develop standards for mixed gas diving. In 2003 the AAUS adopted the Mixed Gas Diving standards. They designated Section 10 of the AAUS Standards manual to Mixed Gas Diving. Following are the standards for Mixed Gas Diving as they appear in the 2005 version of the AAUS Standards:

section 10.00 MIXED GAS DIVING

Mixed gas diving is defined as dives done while breathing gas mixes containing proportions greater than 1% by volume of an inert gas other than nitrogen.

10.10 Minimum Experience and Training Requirements

Prerequisites:

Nitrox certification and authorization (Section 7.00)

If the intended use entails required decompression stops, divers will be previously certified and authorized in decompression diving (Section 9.00).

Divers shall demonstrate to the DCB's satisfaction skills, knowledge, and attitude appropriate for training in the safe use of mixed gases.

Classroom training including:

Review of topics and issues previously outlined in nitrox and required decompression diving training as pertinent to the planned operations.

The use of helium or other inert gases, and the use of multiple decompression gases.

Equipment configurations

Mixed gas decompression planning

Gas management planning

Thermal considerations

END determination

Mission planning and logistics

Emergency procedures

Mixed gas production methods

Methods of gas handling and cylinder filling

Oxygen exposure management

Gas analysis

Mixed gas physics and physiology

Practical Training:

Confined water session(s) in which divers demonstrate proficiency in required skills and techniques for proposed diving operations.

A minimum of 6 open water training dives.

At least one initial dive shall be in 130 feet or less to practice equipment handling and emergency procedures.

Subsequent dives will gradually increase in depth, with a majority of the training dives being conducted between 130 feet and the planned operational depth.

Planned operational depth for initial training dives shall not exceed 260 feet.

Diving operations beyond 260 feet requires additional training dives.

10.20 Equipment and Gas Quality Requirements

Equipment requirements shall be developed and approved by the DCB, and met by divers, prior to engaging in mixed-gas diving. Equipment shall meet other pertinent requirements set forth elsewhere in this standard.

The quality of inert gases used to produce breathing mixtures shall be of an acceptable grade for human consumption.

10.30 Minimum Operational Requirements

Approval of dive plan applications to conduct mixed gas dives shall be on a case-by-case basis.

All applicable operational requirements for nitrox and decompression diving shall be met.

The maximum pO_2 to be used for planning required decompression dives is 1.6. It is recommended that a pO_2 of less than 1.6 be used during bottom exposure.

Maximum planned Oxygen Toxicity Units (OTU) will be considered based on mission duration.

Divers decompressing on high-oxygen concentration mixtures shall closely monitor one another for signs of acute oxygen toxicity.

If a period of more than 6 months has elapsed since the last mixed gas dive, a series of progressive workup dives to return the diver(s) to proficiency status prior to the start of project diving operations are recommended.

Potential ramifications that come into play with the acceptance of consensual standards

When standards are purposely left vague such as the original Mixed Gas Diving standards the onus to produce safe workable standards is put on the individual DCB. The DCB must develop specific standards that best fit their own scientific diving program while at the same time it must realize it opens the door for additional problems. One such problem is the concept of reciprocity between OMs. If an OM has adopted standards specific to a type of diving their program utilizes then if they were to try to utilize reciprocity with another AAUS OM the accepting OM would have to have their DCB review and accept that specific set of standards. This could become a very long laborious process.

AAUS Statistics – Is Underwater Research Moving Towards Deeper Water?

In order to understand the AAUS statistical process you must first take a look at who is submitting the data. Each AAUS organizational member (OM) must submit their organization's diving data on an annual basis. In 1998, the AAUS revised its process for collecting dive data. The following tables utilize 1998 as a starting point.

When I first started looking at the AAUS statistics I thought that the diver per OM while on surface-supplied data would prove valuable. It quickly became evident that

AAUS had an issue on what was being reported as surface-supplied diving. After a few telephone calls it was quickly determined that some organizational members were confusing surface-supplied diving with hookah diving. As you can see in the first portion of this paper, the AAUS standards for surface-supplied diving are very limited. When the surface-supplied diving standards are readdressed a definition needs to head the section. The same applies to the AAUS standards for hookah diving. Ironically, with a bit more searching I found that the AAUS Statistical Committee had a definition in place for the purpose of reporting statistics. The problem may lie in the fact that some of the organizational members may have been incorrectly labeling their dives since the beginning of reporting, prior to the stats definition. It will be proposed that, at the very least, the AAUS Standards Committee consider the following definition for surface-supplied diving for immediate incorporation:

Dives where the breathing gas is supplied from the surface by means of a pressurized umbilical hose. The umbilical generally consists of a gas supply hose, strength member, pneumofathometer hose, and communication line. The umbilical supplies a helmet or full-face mask. The diver may rely on the tender at the surface to keep up with the divers' depth, time and diving profile.

It will also be proposed that, at the minimum, the AAUS Standards Committee consider the following definition for hookah diving for immediate incorporation:

While similar to surface-supplied diving in that the breathing gas is supplied from the surface by means of a pressurized hose, the supply hose does not require a strength member, pneumofathometer hose, or communication line. Hookah equipment may be as simple as a long hose attached to a standard scuba cylinder supplying a standard scuba second stage. The diver is responsible for the monitoring his/her own depth, time, and diving profile

Due to the fact that there is no way to differentiate between the data supplied for hookah diving from the data supplied for surface-supplied diving it becomes pointless to make any conclusions using either data.

AAUS Statistical Data

Total # of OM reporting, # of Divers, # of Dives and # of Minutes

	1998	1999	2000	2001	2002	2003	2004
OM Reporting	64	52	47	65	69	79	87
# of Divers	3749	2802	4176	4044	3218	3719	3872
# of Dives	68,970	66,271	63,956	85,273	101,046	107,414	119464
# of Minutes	3,060,689	2,947,656	2,831,959	3,319,630	4,079,629	4,345,642	4,947,650

The data submitted by the AAUS organizational membership must be categorized utilizing several criteria. The next table illustrates how the total numbers, listed in the table above, is broken down when viewing by type of dives.

AAUS OM Dives By Mode

	1998	1999	2000	2001	2002	2003	2004
Open Circuit	51 OM 64,277	51 OM 59,521	47 OM 57,121	63 OM 79,704	66 OM 97,191	76 OM 102,046	84 OM 110,518

	dives	dives	dives	dives	dives	dives	dives
Hookah	9 OM 223 dives	14 OM 5,680 dives	12 OM 993 dives	10 OM 2,452 dives	12 OM 3,064 dives	19 OM 6,615 dives	19 OM 5,528 dives
Surface Supplied	7 OM 141 dives	9 OM 969 dives	7 OM 3135 dives	13 OM 1,395 dives	9 OM 1131 dives	9 OM 3,033 dives	9 OM 2598 dives
Rebreather	9 OM 22 dives	5 OM 53 dives	5 OM 100 dives	11 OM 322 dives	8 OM 308 dives	9 OM 445 dives	13 OM 289 dives

Each AAUS Organizational Member must submit statistics which would indicate any diving which would require decompression as well as dives utilizing mixed gases.

AAUS OM Dives on Mixed Gas and Required Decompression

	1998	1999	2000	2001	2002	2003	2004
Mixed Gas	5 OM 31 dives	5 OM 57 dives	5 OM 112 dives	7 OM 241 dives	13 OM 236 dives	12 OM 183 dives	14 OM 214 dives
Required Decompression	8 OM 310 dives	10 OM 175 dives	10 OM 275 dives	13 OM 370 dives	16 OM 377 dives	20 OM 493 dives	22 OM 545 dives

The AAUS utilizes a series of stepped depth ranges when recording diving statistics. This has been in place since the AAUS started collecting scientific diving data. Each step towards a deeper diving certification has specific requirements that must be met before a deeper range is granted to the diver. The depth ranges are as follows:

- 0 fsw – 30 fsw
- 31 fsw – 60 fsw
- 61 fsw – 100 fsw
- 101 fsw – 130 fsw
- 131 fsw – 150 fsw
- 151 fsw – 190 fsw
- 191 fsw and deeper

Although the AAUS records all dives regardless of depth, the tables below will only list those dives completed in the depth range of 101 fsw and deeper.

Dives by AAUS OM per Depth Range per Year

	1998	1999	2000	2001	2002	2003	2004
101 – 130 fsw	37 OM 1277 dives	40 OM 990 dives	39 OM 1217 dives	50 OM 1264 dives	48 OM 1522 dives	49 OM 1556 dives	58 OM 2052 dives
131 – 150 fsw	17 OM 158 dives	19 OM 101 dives	23 OM 359 dives	24 OM 374 dives	25 OM 377 dives	28 OM 489 dives	32 OM 449 dives
151 – 190 fsw	9 OM 79 dives	11 OM 57 dives	10 OM 100 dives	14 OM 158 dives	20 OM 131 dives	22 OM 157 dives	18 OM 162 dives
191 and deeper	6 OM 25 dives	8 OM 31 dives	2 OM 66 dives	8 OM 149 dives	13 OM 200 dives	13 OM 161 dives	9 OM 84 dives

AAUS Organizational Members reporting dives deeper than 151 fsw in the last five years:

1. Bermuda Biological Station for Research
2. California Department of Fish and Game
3. East Carolina University
4. Florida Fish and Wildlife Research Institute
5. Harbor Branch Oceanographic Institution
6. International Innerspace Institute, Inc.
7. Louisiana Universities Marine Consortium
8. Marine Biological Laboratory
9. MBC Applied Environmental Sciences
10. Mote Marine Laboratory
11. Northeastern University
12. Perry Institute For Marine Science (CMRC)
13. Scripps Institution of Oceanography
14. Smithsonian Institution
15. Texas A & M University – Galveston
16. The Florida Aquarium
17. The Oceanic Institute
18. University of New Hampshire
19. Underwater Archaeology Branch
20. University of California – Santa Barbara
21. University of California – Santa Cruz
22. University of Connecticut – MSTC
23. University of Florida
24. University of Hawaii
25. University of Miami – RSMAS
26. University of North Carolina at Wilmington
27. University of South Florida
28. University of Southern California
29. Virginia Institute of Marine Science

AAUS Organizational Members utilizing Mixed Gas or Rebreathers:

1. Aquarium of the Pacific
2. California Department of Fish and Game
3. California State University
4. Florida Fish and Wildlife Research Institute
5. International Innerspace Institute, Inc.
6. J F White Contracting Company
7. NIWA – New Zealand
8. Scripps Institution of Oceanography
9. Shannon Point Marine Center
10. Texas A & M University – Galveston
11. University of Alaska
12. University of California – Davis
13. University of California – Santa Cruz
14. University of Connecticut – MSTC
15. University Of Hawaii
16. University of North Carolina at Wilmington
17. University of Southern California
18. University of South Florida

Do the AAUS statistical data show a trend towards deeper diving?

Each year the AAUS has continued to increase its membership. In 1998, the AAUS had 64 organizational members report their statistics. The number of AAUS organizational members reporting in 2004 had increased to 87 – a 36% increase. The easiest way to measure whether there is a trend towards deeper diving is to compare the ratio of the number of dives completed divided by the number of OMs completing those dives. Then we can compare this ratio from the earliest years to the most current year.

Dives utilizing Rebreathers (% increase in the number of dives/OM)

	1998 dives/OM	2004 dives/OM	% increase dives/OM
Rebreather Dives/OM	2.4	22.2	+825 %

Depth Ranges (% increase in the number of dives/OM)

Depth Range	1998 dives/OM	2004 dives/OM	% increase dives/OM
101 – 130 fsw	34.5	35.4	+2.6 %
131 – 150 fsw	9.3	14.0	+50.5 %
151 – 190 fsw	8.8	9.0	+2.3 %
191 fsw and deeper	4.2	9.3	+121.4%

Decompression and/or Mixed Gases (% increase in the number of dives/OM)

	1998 dives/OM	2004 dives/OM	% increase dives/OM
Mixed Gas Dives/OM	6.2	15.3	+146.8 %
Deco Dives Dives/OM	38.8	24.0	- 38.1 %

Trends

Mixed-gas diving

AAUS statistical data suggests a strong trend in the increased use (+ 146%) of mixed-gas diving over the past 7 years.

Deep diving technology – Rebreathers

Depending on the design, rebreathers are not necessarily depth restricted and can be ideally suited for the deepest depths. They are included in this comparison but it is impossible, due to current AAUS data collection methods, to extract the depth ranges for rebreather dives. AAUS statistical data does suggests a strong trend in the increased use (increase of 825%) of the rebreather in the past 7 years.

Surface-supplied diving

AAUS statistical data is of no use when analyzing this mode of diving for “deep” dives as defined by this workshop.

Dives at deeper depths

There seems to be a clear trend towards increased research activity in deeper depths, particularly over 190 fsw, showing an increase of 121% in the past 7 years.

The final trend

The AAUS had recognized the trend towards deeper water research early on. In the past 5 years, the AAUS has concentrated the resources of its Standards Committee towards deep diving standards. In the past few years, the AAUS Technical Committee has completed standards for stage decompression, mixed-gas diving and rebreathers. Standards for blue-water diving are progressing and the AAUS Standards Committee will probably address surface-supplied diving standards in the near future.