SCIENTIFIC DIVING: Medical, Training and Operational Standards

Michael A. Lang
Smithsonian Institution
Office of the Under Secretary for Science
900 Jefferson Drive SW
Washington, D.C. 20560-0415
U.S.A.

I. Introduction

General

The purpose of a research diving project is the advancement of science. Scientific divers, based on the nature of their activities, use scientific expertise in studying the underwater environment and, therefore, are scientists or scientists-in-training. The tasks of a scientific diver are those of an observer and data gatherer who uses scuba diving as a research tool. Information and data resulting from a scientific project usually are disseminated in a technical document or peer-reviewed research publication. *Scientific diving* is "diving 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." Scientific diving does not include performing any tasks usually associated with commercial diving such as: Placing or removing heavy objects underwater; inspection of pipelines and similar objects; construction; demolition; cutting or welding; or, the use of explosives.

Heine (1999) describes scientific diving projects as occurring in tropical and subtropical seas, temperate waters, fresh water lakes, polar environments, blue-water (open ocean) and submarine canyons, estuaries, and offshore platforms. Lang (2001a) and Lang and Baldwin (1996) present a wide variety of methods and techniques of underwater research in various habitats and geographical ranges, representing scientific disciplines in most of the natural sciences.

The scientific diving programs in the United States can be broadly categorized into three groups: research institutions (predominantly research), public and private universities, museums and aquaria (predominantly education and teaching, and research), and consulting companies (predominantly contractual environmental, geological and archaeological investigations). The current scientific diver population in the United States is estimated at 4,000 individuals. A minority of these are long-term, career scientific divers (*e.g.,* federal employees, university professors) who may be considered in the 40+ average age category. At the university level the turn-over of scientific divers can be rather high as evidenced by undergraduate students enrolled in diving courses, research technicians on grant funds or students in Master's degree or Ph.D. curricula. This population tends to be in the 18-34-age category. An upper age limit for scientific divers certification does not exist, the lower limit is generally 18 years of age. Of the total scientific diver population, approximately one fourth is estimated to be women.

Regulatory Authority

1. **USA:**
   - Federal regulations promulgated by the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), are contained in 29 CFR Part 1910, Subpart T - Commercial Diving Regulations, §1910.401(a)(2)(iv); §1910.402; and Appendix B to Subpart T - Guidelines for Scientific Diving.
   - State regulations may be issued by individual State authorities provided that these are not less demanding than those implemented by the Department of Labor (OSHA). In the absence of State regulations, Federal regulations are followed.

2. **International:**
   - Flemming and Max (1996) published a review of international scientific diving legislation and regulations. Several nations issue scientific diving licenses (occasionally under commercial diving regulations) and have national registries. In recent years there has been a move towards self-regulation and peer-promulgated standards (codes) of practice that replace government-mandated regulations.
   - The Confédération Mondiale des Activités Subaquatiques (CMAS) establishes diving qualification equivalencies and certification for scientific divers. National diving federations belonging to CMAS may avail themselves of these certifications and standards.

Scientific Diving Standards

An employer is responsible for publishing a Diving Safety Manual and appointing a Diving Control Board (DCB) that consists of a majority of active scientific divers who have autonomous and absolute authority over scientific diving program operations in accordance with procedures covering all diving operations specific to the program; procedures for emergency care, including recompression and evacuation; and, criteria for diver training and certification. At the institutional level, scientific diving projects are peer-reviewed by the Diving Control Board.

The American Academy of Underwater Sciences (AAUS) publishes *Standards for Scientific Diving Certification and Operation of Scientific Diving Programs*. The purpose of this document is to ensure that all scientific diving is conducted in a manner that will maximize protection of scientific divers from accidental injury and/or illness, and to set forth standards for training and certification that will allow a working reciprocity between organizational member institutions that adhere to these standards. This document sets minimal standards for AAUS-recognized scientific diving programs, the organization and conduct of these programs, and the basic regulations and procedures for safety in scientific diving operations. The AAUS standards are generally considered the standard of practice for scientific diving in the U.S.

University National Oceanographic Laboratory System (UNOLS) Research Vessel Diving Safety Standards amplify the AAUS standards for the special considerations and applicable legislation of diving from a research vessel platform. The UNOLS operates the U.S. academic research vessel fleet, funded primarily by the National Science Foundation.

II. Medical Standards

The employer determines that scientific divers who are exposed to hyperbaric conditions have passed a current diving medical evaluation and have been declared by the examining physician to be medically fit to engage in diving activities as may be limited or restricted in the scientific diver medical certification. All medical evaluations are performed by, or under the direction of, a licensed physician of the applicant-diver's choice, preferably one trained in diving/undersea medicine. The diver must be free of any acute or chronic disabling disease or conditions contained in the list of conditions (Bove, 1998) for which restrictions from diving are generally recommended. There currently are no fitness standards *per se* for scientific divers other than during the initial scientific diver training course, which includes in-water time/distance parameters for swimming, or a stress tolerance test prescribed by a physician based on coronary artery disease risk factor screening.

Medical evaluations are completed before a diver may begin diving; thereafter, at 5 year intervals up to age 40, every 3 years after the age of 40, and every 2 years after age 60. Any major injury or illness, or any condition requiring hospital care requires diving medical clearance. If the injury or illness is pressure related, then the clearance to return to diving must be performed by a physician trained in diving medicine.

Table I. Laboratory Requirements for Diving Medical Evaluations and Intervals

	Initial Examination	
	< age 40	**> age 40**
Medical history	X	X
Complete physical exam with emphasis on neurological and otological components	X	X
Chest X-ray	X	X
Resting EKG	n.a.	X
Spirometry	X	X
Hematocrit or Hemoglobin	X	X
Urinalysis	X	X
Any further tests deemed necessary by the physician	X	X
Coronary artery disease risk factor assessment including lipid profile and diabetic screening	n.a.	X
Exercise stress testing may be indicated based on risk factor analysis	n.a.	X

	Periodic Re-examination Intervals		
	< age 40 (5 yrs)	**> 40 (3 yrs)**	**>60 (2 yrs)**
Medical history	X	X	X
Complete physical exam with emphasis on neurological and otological components	X	X	X
Hematocrit or Hemoglobin	X	X	X
Urinalysis	X	X	X
Resting EKG	n.a.	X	X
Coronary artery disease risk factor assessment including lipid profile and diabetic screening	n.a.	X	X
Exercise stress testing may be indicated based on risk factor analysis	n.a.	X	X
Any further tests deemed necessary by the physician	X	X	X

Diving medical evaluations conducted initially and at the interval frequency specified above consist of the following: A diving medical history, a diving medical examination, and completion of a scientific diver medical certification by the examining physician.

Bove (1998) describes, among others, the following conditions that may be medically disqualifying:

1. Abnormalities of the tympanic membrane, such as perforation, presence of a monomeric membrane, or inability to autoinflate the middle ears.
2. Vertigo, including Meniere’s Disease.
3. Stapedectomy or middle ear reconstructive surgery.
4. Recent ocular surgery.
5. Psychiatric disorders including claustrophobia, suicidal ideation, psychosis, anxiety states, untreated depression.
6. Substance abuse, including alcohol.
7. Episodic loss of consciousness.
8. History of seizure.
9. History of stroke or a fixed neurological deficit.
10. Recurring neurologic disorders, including transient ischemic attacks.
11. History of intracranial aneurysm, other vascular malformation or intracranial hemorrhage.
12. History of neurological decompression illness with residual deficit.
13. Head injury with sequelae.
14. Hematologic disorders including coagulopathies.
15. Evidence of coronary artery disease or high risk for coronary artery disease.
16. Atrial septal defects.
17. Significant valvular heart disease - isolated mitral valve prolapse is not disqualifying.
18. Significant cardiac rhythm or conduction abnormalities.
19. Implanted cardiac pacemakers and cardiac defibrillators (ICD).
20. Inadequate exercise tolerance.
21. Severe hypertension.
22. History of spontaneous or traumatic pneumothorax.
23. Asthma.
24. Chronic pulmonary disease, including radiographic evidence of pulmonary blebs, bullae or cysts.
25. Diabetes mellitus.
26. Pregnancy.

The scientific diver medical certification is submitted to the Diving Officer (DO) by the examining physician, reviewed by the Diving Control Board and a copy is made available to the individual scientist. The diver medical evaluation report and laboratory results are maintained by the examining physician consistent with all applicable federal and local regulations and guidelines for storage and release of medical records.

III. Diver Training

Scientific Diving Authorizations

There are three types of scientific diving authorizations.

1. **Diver-in-Training.** This authorization signifies that the diver has completed entry-level training requirements through a nationally or internationally recognized scuba certification agency (*e.g.*, PADI, NAUI, SSI, BSAC) or scientific diving program.
2. **Scientific Diver.** This certification is a permit to dive with compressed air within no-decompression limits of current U.S. Navy Dive Tables or, if using an approved dive computer, within no-decompression limits specified by the dive computer manufacturer. This permit is valid only while it is current and for the depth and specialty intended (see below).
3. **Temporary Diver.** This authorization is issued only following a demonstration of the required proficiency in diving and if the person in question can contribute measurably to a planned dive. It is granted by the DCB and is valid only for a specified time, as determined by the DO. Temporary diver authorization is restricted to the planned diving operation under the host institution's auspices and complies with all other scientific diving policies, regulations and standards, including medical requirements.

Depth Certifications

The scientific diving community has long adhered to a proven experience-accumulation schedule. Depth certifications provide a mechanism to incrementally gather diving experience. The scientific diver certification authorizes the holder to dive to the depth indicated on the scientific diver card and DO-approved dive plan. A diver shall not exceed his/her depth certification, unless accompanied by a diver certified to a greater depth. Under these circumstances the diver may not exceed his/her depth limit by more than one step. Diving with compressed air is not permitted beyond a depth of 58 msw (190 fsw).

1. Certification to 9 msw (30 fsw) depth.
   This is the initial certification, approved upon the successful completion of the training listed above.
2. Certification to 18 msw (60 fsw) depth.
   A diver holding a 30 fsw certification card may be certified to a depth of 60 fsw after successfully completing, under supervision of a scientific diver certified to that depth or greater, 12 logged training dives to depths between 31 and 60 fsw, for a minimum total time of 4 hours.
3. Certification to 30 msw (100 fsw) and 40 msw (130 fsw) depths.
   A diver holding a 60 fsw certification may be certified to depths of 100 and 130 fsw respectively, by logging four dives near the maximum depth, and successfully completing a check-out dive approved by the DO. These qualification dives are validated by the signature of an authorized scientific diver certified to at least that depth. The diver also demonstrates proficiency in the use of the U.S. Navy Decompression Tables.
4. Certification to depths over 40 msw (130 fsw).
   A diver may be certified to depths of 150 and 190 fsw by logging four dives near each depth, and successfully completing a check-out dive approved by the DO. Dives are planned and executed under close supervision of a scientific diver certified to this depth.

The diver also needs to demonstrate knowledge of the special problems of deep diving, and of special safety requirements.

Diving Specialties

Diving specialties require additional training and approval by the DO. Scientific diver certification is a prerequisite for engaging in the following specialties: Decompression diving, surface-supplied diving, mixed-gas or oxygen-enriched air (nitrox) diving, semi- or closed circuit rebreather diving, lock-out and saturation diving, blue-water diving, dry suit diving, overhead environment (ice, cave or wreck) diving, altitude diving, and diving with dive computers as the sole source for monitoring decompression status.

Swimming Evaluation

The applicant for training performs the following tests, or their equivalent, without swim aids, in the presence of the DO: an underwater swim for a distance of 25 m without surfacing, a 400 m swim in less than 12 minutes, a 10-minute water tread (or 2 minutes without the use of hands), the transport of another person of equal size for a distance of 25 yards in the water.

Scuba Training

1. **Practical Training**
   At the completion of training, the trainee must satisfy the DO of his/her ability to perform the following, as a minimum, in a pool or in sheltered water: Water entry with full scuba equipment; face mask clearing; air sharing (including both buddy breathing and the use of an alternate air source as both donor and recipient, with and without a face mask); alternate between snorkel and scuba while kicking; underwater signs and signals; simulated in-water mouth-to-mouth resuscitation; rescue and transport, as a diver, a passive simulated victim of an accident; removal and replacement of scuba equipment while submerged; and, an in-water level of competence that is acceptable to the DO.
2. **Open Water Evaluation**
   The trainee must satisfy the DO of his/her ability to demonstrate at least the following in open water: Surface dive to a depth of 3 msw in open water without scuba; air-sharing proficiency (including both buddy breathing and the use of an alternate air source, as both donor and recipient); open water or surf entry and exit, or leaving and boarding a diving vessel, while wearing scuba gear; a 400 m surface kick while wearing scuba gear without breathing from the unit; judgment adequate for safe diving; the ability to maneuver efficiently in the environment, at and below the surface; a simulated emergency swimming ascent; mask and regulator clearing while submerged; maintenance of neutral buoyancy while submerged; ascent at a rate not to exceed 30 fsw/min (10 m/min) and a hovering stop; self- and buddy rescue; underwater navigation; dive planning and execution with a buddy; and, completion of 12 supervised open-water dives in a variety of dive sites for a minimum cumulative bottom time of 6 hours. No more than 3 training dives are made in a single day.
3. **Theoretical training**
   Theoretical aspects beyond the Diver-in-Training level (minimum cumulative time is 100 hrs.) include principles and activities appropriate to the intended area of scientific study. Suggested topics include, but are not limited to, data gathering techniques, collecting, common biota, behavior, installation of scientific apparatus, use of chemicals, site

selection and relocation, animal and plant identification, ecology, tagging, underwater photography, scientific dive planning, dive rescue and accident management, CPR/Oxygen/First Aid and field neurological examination, coordination with other agencies, appropriate governmental regulations, small boat operation, and diving specialties. The theoretical aspects are tailored to the individual scientific diver based on his/her academic background and research methodologies. This theoretical knowledge is documented through the satisfactory completion of a written examination.

Continuation of Certification

During any 12-month period, each certified scientific diver must log a minimum of 12 dives, two of which are within the certified depth range. Divers certified to 45 msw (150 fsw) or deeper may satisfy these requirements with dives over 40 msw (130 fsw). If no dive is made for a 6-month period, a check-out dive must be made with the DO. Once the initial scientific diver certification requirements are met, divers whose depth certification has lapsed due to lack of activity may be requalified by procedures adopted by the DCB. If a scientific diver's certification expires, is suspended or revoked, he/she may be recertified after complying with such conditions as the DO may impose.

IV. Operational Procedures

Diving Supervision

1. **Diving Officer**
   The Diving Officer has full responsibility and accountability to the Diving Control Board in all operational, diving and safety matters. The Diving Officer is appointed by the appropriate administrator on the recommendation of the DCB; is a certified scientific diver; is usually certified by a nationally recognized scuba certification agency to teach basic and advanced scuba diving courses; and, is responsible for the conduct of the diving program. The Diving Officer also oversees scientific diving activities, ensures compliance with all diving policies, requirements and procedures established in the diving safety manual. The DO is responsible for maintaining diver and medical certification records, and dive logs; and, has the unilateral authority to suspend diving operations or scientific divers whose diving activities he/she considers unsafe and refers such actions to the DCB.
2. **Lead Diver**
   For each dive, one scientist is designated as the Lead Diver, who is present at the dive location during the entire diving operation. The Lead Diver is responsible for coordination, briefing, dive planning, and emergency equipment and procedures.
3. **Individual Scientific Diver's Responsibilities**
   The scientist initially submits a scientific diver application to the DO and obtains a scientific diver medical certification. The scientist must maintain himself/herself in good physical condition and at a high level of diving proficiency commensurate with the frequency, scope, and type of diving activity being undertaken. The individual has the right to refuse to dive if in his/her judgment the conditions are unsafe or unfavorable for the type of diving operations planned, for any reason he/she believes his/her diving participation might jeopardize human life, he/she is not in proper physical or mental

condition, and/or, he/she believes the scuba equipment to be used is in faulty condition. Each scientific diver receives current emergency care training, has an annual scuba equipment maintenance performed and conducts a pre-dive functional check of diving equipment. The diver is responsible for terminating the dive while there is sufficient cylinder pressure to permit a safe ascent to the surface, including a stop. The diver submits a dive plan for DO approval prior to engaging in any diving activity. Periodic submission of dive log sheets or dive files from downloading dive computers are used by the DO to monitor diving activities. The ultimate responsibility for personal safety and compliance with the diving safety manual regarding a planned diving operation is borne by the diver.

Diving Procedures

Each scientific diver wears the following equipment: Mask and fins (snorkel is optional), regulator and alternate breathing source, scuba cylinder, underwater timing device, depth indicator and pressure gage (a DCB-approved dive computer is authorized after the diver receives training in its use). A buoyancy compensator that provides the diver with the capability of attaining and maintaining positive buoyancy is equipped with a low-pressure power inflator. A dive knife, sharp enough to cut through monofilament line, and appropriate thermal insulation must also be worn.

All scientific diving is planned and executed in such a manner as to ensure that every diver maintains constant, effective communication with at least one other comparably equipped, certified scientific diver in the water. This buddy system is based upon mutual assistance, especially in the case of an emergency. If loss of effective communication occurs within a buddy team, all divers surface and re-establish contact. A dive flag is displayed prominently whenever diving is conducted.

Scientific diving is not conducted unless procedures have been established for emergency evacuation of the diver(s) to a hyperbaric chamber or appropriate medical facility, and these procedures have been approved by the DO. Emergency care training (CPR, oxygen administration, first aid, field neurological evaluation and dive rescue) is a requisite for scientific diver certification. First aid and emergency oxygen kits are present at the dive location. Hyperbaric chambers, as a rule, are not required to be in close proximity of the diving operation. Where an enclosed or confined space is not large enough for two divers, a diver is stationed at the underwater point of entry and an orientation line is used.

A set of appropriate dive tables, approved by the DCB, are available at the dive location, even if approved dive computers are used. These tables must be at least as effective as the United States Navy Diving Tables. In the case of an asymptomatic diver diving within the U.S. Navy tables during the previous 48 hours, there should be a minimum 12-hour delay period with no diving prior to flying. The longer the diver delays an ascent to altitude, the lower the probability of onset of DCS symptoms.

Scientific dives are planned around the competency of the least experienced diver. Before conducting diving operations, the Lead Diver for a proposed project submits to the DO a dive plan for approval that lists all divers' qualifications, emergency contact information, emergency plan, nearest hyperbaric chamber location and method of transport to be used, and Divers Alert Network (DAN) emergency phone number, the location and approximate number of proposed dives (including estimated depths and bottom times), proposed work, equipment and boats to be employed, and any hazardous conditions anticipated.

Scientists log dives made under the auspices of their employer that are periodically submitted to the DO for review. If pressure-related injuries are suspected, or if symptoms are evident, the following additional information is recorded and retained by the DO, with the record of the dive, for a period of 5 years: Complete accident report, description of symptoms (including depth and time of onset), and description and results of treatment. The DO maintains permanent records for each scientific diver certified and retains the following: Scientific diver medical certifications (5 years), records of dives (1 year, except 5 years where there has been an incident of pressure-related injury), pressure-related injury assessment (5 years), and equipment maintenance records (current entry).

All diving accidents requiring recompression or resulting in moderate or serious injury are reported to the DO. The DCB records and reports occupational injuries and illnesses as established by OSHA: The occurrence of any diving-related injury or illness that requires any dive team member to be hospitalized for 24 hours or more, or after an episode of unconsciousness related to diving activity, or after treatment in a recompression chamber following a diving accident.

Compressor Systems and Breathing Air Quality

Gas analyses and air tests are performed on each breathing air compressor at regular intervals of no more than six months. The results of these tests are entered into a log by the DO who also records hours of operation, repair, overhaul, filter maintenance and temperature adjustment for each compressor.

Breathing air for scuba meets the Grade E specifications as set forth by the Compressed Gas Association (CGA Pamphlet G-7.1) and referenced in OSHA 29 CFR 1910.134:

Table II. CGA Grade E Specifications

Maximum O_2	20-22%
Maximum CO_2	500ppm
Maximum CO	10ppm
T.H.C.	25ppm
Water Vapor	67ppm
Dew point	-50F
Condensed Hydrocarbons	5mg/m^3
Odors	none

Low-pressure compressors used to supply air to the diver are equipped with a volume tank with a check valve on the inlet side, a pressure gauge, a relief valve, and a drain valve. Compressed air systems over 500 psig have slow-opening shut-off valves and all air compressor intakes must be located away from areas containing exhaust fumes or other contaminants. These compressors are operated and maintained according to the manufacturer's specifications.

Equipment used with oxygen or mixtures containing over forty percent (40%) by volume oxygen are designed, dedicated and maintained for oxygen service. Components exposed to oxygen or mixtures containing over forty percent (40%) by volume oxygen are cleaned of flammable materials before being placed into service. Oxygen systems over 125 psig must be equipped with slow-opening shut-off valves.

V. Scientific Diving Safety

The scientific diving community has a traditional proactive record of furthering diving safety. The first scientific diving safety program was established at Scripps Institution of Oceanography in 1954 in preparation for the Capricorn Expedition to the South Pacific. This program pre-dated the national recreational scuba training agencies by five years. Most scientific diving programs today trace their ancestry to common elements of the original Scripps diving program.

Diving safety programs can be generalized as fulfilling a two-fold purpose. The first being a research-support function, which assists the diving scientist with specialized underwater equipment, advice, and diver support to assist in fulfilling the scientific objectives of the diving project. The second is a risk management function that protects the safety and health of the individual scientist, and the employing organization from excessive liability exposure, by providing state-of-the-art diving equipment, breathing air, training and medical surveillance programs.

More recently, ongoing scientific diving safety research has been conducted to consider a more effective means of decompression status monitoring using dive computers (Lang and Hamilton, 1989). DCB's approve specific makes and models of dive computers that may be used as a means of determining decompression status. Each diver relying on a dive computer to plan dives and indicate or determine decompression status must have his/her own unit and pass a practical and written training session. On any given dive, both divers in the buddy pair follow the most conservative dive computer. If the dive computer fails at any time during the dive, the dive is terminated and appropriate surfacing procedures are immediately initiated. A scientific diver is not allowed to dive for 18 hours before activating a dive computer to control his/her diving, and once in use, it is not switched off until complete outgassing has occurred. Multiple deep dives and/or decompression dives with dive computers require careful consideration.

Lang and Egstrom (1990) investigated the slowing of ascent rates and performance of safety stops to provide scientific divers with a greater margin of decompression safety. It has long been the position of the American Academy of Underwater Sciences that the ultimate responsibility for safety rests with the individual diver. Scientific divers are trained to slow and control their ascents, of which buoyancy compensation can be a significant problem. This is fundamental to safe diving practice. Before certification, the diver demonstrates proper buoyancy, weighting and a controlled ascent, including a "hovering" stop. Ascent rates are controlled at a maximum of 30 fsw/min from 60' and are not to exceed 60 fsw/min from depth, at the rate specified for the make and model of dive computer or table being used. Scientific diving programs require a stop in the 10-30 fsw zone for 3-5 minutes on every dive. Scientific divers using dry suits receive additional practical training in their use. Dry suits must have a hands-free exhaust valve and buoyancy compensators a reliable rapid exhaust valve that can be operated in a horizontal swimming position. A buoyancy compensator is required with dry suit use for ascent control and emergency flotation. In the case of a runaway ascent, breathing 100% oxygen above water is preferred to in-water air procedures for omitted decompression.

The next phase of this scientific diving safety project was to consider multi-day, repetitive diving physiological aspects (Lang and Vann, 1992). Although diving is a relatively safe activity, all persons who dive must be aware that there is an inherent risk to this activity. In 1992, the risk of decompression illness in the United States was estimated at 1-2 incidents per 1,000-2,000 dives for the commercial diving sector, 2 incidents per 10,000 dives for recreational diving activities and 1 incident in 100,000 dives for the scientific diving community. Scientific diving programs provide continuous training, recertification and dive site supervision, which helps maintain established safe diving protocols. Recreational divers, who may lack such direct supervision, need to be aware of their need to stay within established protocols, especially when making repetitive dives over multiple days, in which the risk of DCS may be higher. Increasing knowledge regarding the incidence of DCS indicates that our ability to predict the onset of DCS on multi-level, multi-day diving is even less sensitive than our ability to predict DCS on single square-wave dives. There appears to be good evidence that there are many variables that can affect the probability of the occurrence of DCS symptoms. The ability to mitigate these variables through education, good supervision and training appears to be possible for hydration, fitness, rate of ascent, fatigue, etc., and are continuously promoted. Scientific divers are subject to a host of specific conditions that may increase risk if precautions are not taken. There is adequate technical support for the use of oxygen-enriched air (nitrox) and surface-oxygen breathing in scientific diving where higher gas loadings are anticipated in multi-level, multi-day dives. We must continue to remember that DCS is generally recognized as a probabilistic event, which tends to lean the scientific diving community towards a more conservative diving position.

The order of dive profiles was investigated (Lang and Lehner, 2000), in part, because of the difficulty for scientific divers to adhere to the “dive progressively shallower” rule while on projects investigating coral reefs at varying transect depths. More importantly, the genesis and physiological validity of the “dive deep first” rule was in need of examination. Historically, neither the U.S. Navy nor the commercial sector have prohibited reverse dive profiles. Reverse dive profiles are acknowledged as being performed in recreational, scientific, commercial, and military diving. The prohibition of reverse dive profiles by recreational training organizations cannot be traced to any definite diving experience that indicates an increased risk of DCS. There is no convincing evidence that reverse dive profiles within the no-decompression limits lead to a measurable increase in the risk of DCS. Lang and Lehner (2000) found no reason for the diving communities to prohibit reverse dive profiles for no-decompression dives less than 40 msw (130 fsw) and depth differentials less than 12 msw (40 fsw).

Oxygen-enriched air (nitrox) has been used in the scientific diving community since the early 1970’s. Lang (2001) reports for entry-level, open-circuit nitrox diving, that there is no evidence that shows an increased risk of DCS with the use of oxygen-enriched air (nitrox) versus compressed air. A maximum PO_2 of 1.6 atm is generally accepted based on the history of nitrox use and scientific studies. Routine CO_2 retention screening is not necessary for open-circuit recreational nitrox divers. Oxygen analyzers should use a controlled flow-sampling device for accurate mix analysis, which should be performed by the blender and/or dispenser and verified by the end user. Training agencies recognize the effectiveness of nitrox dive computers. For recreational diving with oxygen enriched air, there is no need to track whole body exposure to oxygen (OTU/UPTD), the "CNS Oxygen Clock" concept is taught based on NOAA oxygen exposure limits. However, it should be noted that CNS oxygen toxicity could occur suddenly and unexpectedly. Based on history of use, no evidence is available to show an unreasonable risk of fire or ignition when using up to 40% nitrox with standard scuba equipment. The level of risk is related to specific equipment configurations and the user should rely on manufacturer's recommendations.

Operational guidelines for remote scientific diving operations were promulgated on a consensual basis by the senior practicing scientific divers for blue-water diving (Heine, 1986) and polar diving operations (Lang and Stewart, 1992).

VI. Summary

The scientific diving community has very effectively used scuba as a research tool for over 45 years, since the first program was established at Scripps Institution of Oceanography. Lang and Vann (1992) published decompression sickness incidence rates that were by a factor of 10 lower than recreational diving and commercial diving. This is, in part, due to thorough medical, training and operational standards and programmatic supervision of diving activities. Safety considerations are of primary concern for the diving programs and regulations are promulgated by the underwater scientists who live by them.

Scientific research objectives, whether through mensurative or manipulative experiments, in many instances could not have been accomplished without scientific diving techniques, as evidenced in materials and methods sections of peer-reviewed published literature. The complimentary use of diving and remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and remote sensing equipment has greatly advanced our underwater research capabilities in recent years. One-Man Atmospheric Diving Systems (OMADS) have also become more sophisticated and affordable in recent years and are more widely used by the marine research community. At some point in the future, decompression, dive training, and medical issues may no longer be of major concern to scientists, as emerging technologies develop. In the meantime, many topics of current scientific interest, including marine biodiversity, coral reef health, sea-level change and global warming are to a large degree dependent on placing the trained scientific eye underwater to record, interpret and sample the underwater environment.

VII. Literature Cited

American Academy of Underwater Sciences. 1996. *Standards for Scientific Diving Certification and Operation of Scientific Diving Programs* (3rd ed.). AAUS, Nahant, MA. 54 pp.

Bove, A.A. 1998 (ed.). *Medical Examination of Sport SCUBA Divers*. (3rd ed.) Medical Seminars, Inc. San Antonio, Texas. 74 pp.

Flemming, N.C. and M.D. Max (eds.). 1996. *Scientific Diving: A General Code of Practice*. UNESCO Technical Paper. Best Publishing Co. 278 pp.

Heine, J.N. 1986. *Blue Water Diving Guidelines.* Calif. Sea Grant Publ. No. T-CSGCP-014. 46 pp.

Heine, J.N. 1999. *Scientific Diving Techniques: A Practical Guide for the Research Diver*. Best Publishing Co. Flagstaff, AZ. 225 pp.

Lang, M.A. (ed.) 2001a. Chapter 9: *Scientific Diving Procedures*. *In:* NOAA Diving Manual, J. Joiner (ed.) Best Publishing Co., Flagstaff, Arizona.

Lang, M.A. (ed.) 2001b. *Proc. of the DAN Nitrox Workshop.* Nov. 3-4, 2000. Divers Alert Network, Durham, NC. 205 pp.

Lang, M.A. and C.C. Baldwin (eds.). 1996. *Methods and Techniques of Underwater Research: Proc. AAUS 16th Scientific Diving Symposium.* Smithsonian Institution. Washington, D.C. 236 pp.

Lang, M.A. and G.H. Egstrom (eds.). 1990. *Proc. of the AAUS Biomechanics of Safe Ascents Workshop*. Woods Hole, MA. American Academy of Underwater Sciences Publ. AAUSDSP-BSA-01-90. 220 pp.

Lang, M.A. and R.W. Hamilton (eds.). 1989. *Proc. of the AAUS Dive Computer Workshop*. USC Catalina Marine Science Center. USC Sea Grant Publ. USCSG-TR-01-89. 231 pp.

Lang, M.A. and C.E. Lehner (eds.). 2000. *Proc. of the Reverse Dive Profiles Workshop.* Smithsonian Institution, Washington, D.C. 295 pp.

Lang, M.A. and J.R. Stewart (eds.). 1992. *Proc. of the AAUS Polar Diving Workshop.* La Jolla, CA. American Academy of Underwater Sciences Publ. AAUSDSP-PDW-01-92. 100 pp.

Lang, M.A. and R.D. Vann (eds.). 1992. *Proc. of the AAUS Repetitive Diving Workshop.* Duke University, NC. American Academy of Underwater Sciences Publ. AAUSDSP-RDW-02-92. 339 pp.

OSHA, Labor. 1999 ed. Subpart T – *Commercial Diving Operations*. 29 CFR para. 1910.401, 402 and Appendix B to Subpart T: Guidelines for Scientific Diving. U.S. Government Printing Office, Washington, D.C.

University-National Oceanographic Laboratory System. 1996. *Research Vessel Safety Standards.* Chapter 16: Diving Operations. UNOLS Office, Moss Landing Marine Laboratories, Moss Landing, CA. 58 pp.