# The USA scientific diving medical and safety experience

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**Key words**
Scientific diving, research, operations – diving, medicals – diving, standards, safety

**Abstract**

(Lang MA. The USA scientific diving medical and safety experience. *SPUMS J*. 2005; 35: 154-61.)
The scientific diving community has very effectively used scuba as a research tool for over 50 years, since the first programme was established at the Scripps Institution of Oceanography. Lang and Vann published decompression sickness incidence rates that were by a factor of 10 lower than those for recreational diving and commercial diving. This is, in part, due to thorough medical, training and operational standards and programmatic supervision of relatively conservative diving activities. Safety considerations are of primary concern for the diving programmes and regulations are promulgated by the underwater scientists who live by them. This community has also been proactive over the last 15 years in addressing physiological and operational questions related to diving that directly impact the safety and health of the scientific diver. The results of the scientific diving safety projects have benefited the recreational diving community in many ways as evidenced by the incorporation of consensus guidelines and operational practices into recreational diver training curricula and operations. 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. 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, the investigation of many topics of current scientific interest, including marine biodiversity, coral-reef health, sea-level change and global warming, largely depends on placing the trained scientific eye under water to sample, record and interpret the underwater environment.

## Introduction

The purpose of a research diving project is the advancement of science. Scientific divers, by the very 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 defined by the Department of Labor's Occupational Safety and Health Administration (OSHA) as "*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*."[1] Scientific diving does not include performing any tasks usually associated with commercial diving such as: placing or removing heavy objects under water; inspection of pipelines and similar objects; construction; demolition; cutting or welding; or the use of explosives.

The scientific diving programmes in the United States can be broadly categorised into three groups: those of 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 average age category of 40+ years. At the university level, the turnover 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 or doctoral programmes. This population tends to be in the age category of 18–34 years. An upper age limit for scientific diver certification does not exist; the lower limit is generally 18 years of age. Of the total scientific diver population, approximately one quarter is estimated to be female.

The American Academy of Underwater Sciences (AAUS) publishes *Standards for scientific diving certification and operation of scientific diving programs*.[2] The purposes of this document are to ensure that all scientific diving is conducted in a manner that will maximise 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 organisational member institutions that adhere to them. This document sets minimum standards for AAUS-recognised scientific diving programmes, the organisation and conduct of these programmes, 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 US.

## Diving medical surveillance

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 condition contained in the list of conditions by Bove for which restriction from diving may be recommended.[3] There currently are no fitness standards *per se* for scientific divers other than those imposed during the initial scientific diver training course, which include 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 five-year intervals up to the age of 40, every three years after age 40, and every two years after age 60 (Table 1). Any major injury or illness, or any condition requiring hospital care requires diving medical clearance. If the injury or illness is pressure related, the clearance to return to diving must be performed by a physician trained in diving medicine. 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.

**Diver training**

SCIENTIFIC DIVING AUTHORISATIONS

There are three types of scientific diving authorisations.

*Diver-in-Training*

This authorisation signifies that the diver has completed entry-level training requirements through a nationally or internationally recognised scuba certification agency (e.g., PADI, NAUI, SSI, BSAC) or scientific diving programme.

*Scientific Diver*

This certification is a permit to dive with compressed air within no-decompression limits of current US 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).

*Temporary Diver*

This authorisation 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. Temporary diver authorisation 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 by which diving experience may be gathered incrementally. The Scientific Diver certification authorises the holder to dive to a specific depth as indicated on the approved dive plan. A diver shall not exceed his/her depth certification, unless accompanied by a diver certified to a greater depth. Under these

**Table 1**
**Laboratory requirements for diving medical evaluations and intervals (ECG – electrocardiogram)**

| | Initial examination Age in years | | Re-examination intervals Age in years (interval) | | |
|---|---|---|---|---|---|
| | < 40 | > 40 | < 40 (5 yrs) | > 40 (3 yrs) | > 60 (2 yrs) |
| Medical history | X | X | X | X | X |
| Physical exam (emphasis on CNS and otological components) | X | X | X | X | X |
| Chest X-ray | X | X | | | |
| Resting EKG | n/a | X | | | |
| Spirometry | X | X | | | |
| Haematocrit or haemoglobin | X | X | X | X | X |
| Urinalysis | X | X | X | X | X |
| Any further tests deemed necessary | X | X | X | X | X |
| Coronary artery disease risk-factor assessment including lipid profile and diabetic screening | n/a | X | n/a | X | X |
| Exercise stress testing (if indicated by risk-factor analysis) | n/a | X | n/a | X | X |
| Resting ECG | n/a | n/a | n/a | X | X |

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 metres' sea water (msw).

- Certification to depth of 9 msw – This is the initial certification, approved upon the successful completion of the Scientific Diver training.
- Certification to depth of 18 msw – A diver holding a 9 msw certification card may be certified to a depth of 18 msw after successfully completing, under the supervision of a scientific diver certified to that depth or greater, 12 logged training dives to depths between 10 and 18 msw, for a minimum total time of four hours.
- Certification to depths of 30 msw and 40 msw – A diver holding a 18 msw certification may be certified to depths of 30 and 40 msw respectively, by logging four dives near the maximum depth, and successfully completing an approved check-out dive.
- Certification to depths over 40 msw – A diver may be certified to depths of 45 and 58 msw by logging four dives near each depth, and successfully completing an approved check-out dive.

Dives are planned and executed under the close supervision of a scientific diver certified to these depths. 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. 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, drysuit 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:

- underwater swim for a distance of 25 m without surfacing
- 400-metre swim in less than 12 minutes
- 10-minute water tread (or two minutes without the use of hands
- transport of another person of equal size for a distance of 25 m in the water.

SCIENTIFIC DIVER TRAINING

The 100-hour Scientific Diver training course consists of theoretical training, practical skills training in confined water, and completion of 12 supervised open-water dives in a variety of dive sites for a minimum cumulative bottom time of six hours.

CONTINUATION OF CERTIFICATION

During any 12-month period, each certified scientific diver must log a minimum of 12 dives, including two dives within the certified depth range. Divers certified to 48 msw or deeper may satisfy these requirements with dives over 40 msw. If no dive is made for a six-month period, a check-out dive must be made. Once the initial Scientific Diver certification requirements are met, divers whose depth certification has lapsed due to lack of activity may be requalified. If a scientific diver's certification expires, is suspended or revoked, he/she may be recertified after complying with such conditions as the scientific diving programme may impose.

**Operational procedures**

DIVING SUPERVISION

*Diving Officer (DO)*

The DO has full responsibility and accountability to the Diving Control Board (DCB) in all operational, diving and safety matters. The DO is appointed by the appropriate administrator on the recommendation of the DCB; is a certified scientific diver; is certified by a nationally recognised scuba certification agency to teach basic and advanced scuba diving courses; and, is responsible for the conduct of the diving programme. The DO also oversees scientific diving activities, and 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 refer such actions to the DCB.

*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.

*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 him/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 unfavourable for the type of diving operations planned; for any reason he/she believes his/her diving participation might jeopardise human life; he/she is not in proper physical or mental condition; and/or, he/she believes the scuba equipment to be used is faulty.

Each scientific diver receives current emergency-care training, has maintenance performed on their scuba equipment annually 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 safety stop. The diver submits a dive plan for DO approval prior to engaging in any diving activity. Dive log sheets or dive files from down-loading dive computers are periodically submitted to 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 EQUIPMENT

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 gauge. An approved dive computer is authorised after the diver receives training in its use and is preferable to monitoring decompression status with dive tables. 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.

## DIVING PROCEDURES

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 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 to 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.

In the case of an asymptomatic diver diving within the US Navy tables or dive computer no-decompression limits during the previous 48 hours, there should be a minimum 12-hour delay prior to flying. The longer the diver delays an ascent to altitude, the lower the probability of onset of symptoms of decompression sickness (DCS).

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, an emergency plan, the nearest hyperbaric chamber location and method of transport to be used, the Divers Alert Network (DAN) emergency phone number, the location and approximate number of proposed dives (including estimated depths and bottom times), the proposed work, equipment and boats to be employed, and any hazardous conditions anticipated.

Scientists log dives made under the auspices of their employer and the logs 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 five 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 (five years), records of dives (one year, except five years where there has been an incident of pressure-related injury), pressure-related injury assessment (five 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 hospitalised 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 2).

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.

**Table 2**
**Compressed Gas Association Grade E specifications for scuba breathing-air quality (THC – total hydrocarbon content; ppm – parts per $10^6$)**

| Component | Specification |
|---|---|
| Maximum $O_2$ | 20–22% |
| Maximum $CO_2$ | 500 ppm |
| Maximum CO | 10 ppm |
| THC | 25 ppm |
| Water vapour | 67 ppm |
| Dew point | -50 °Fahrenheit |
| Condensed hydrocarbons | 5 mg.m$^{-3}$ |
| Odours | None |

Compressed-air systems over 500 psig (34 bar gauge) 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 per cent (40%) by volume oxygen are designed, dedicated and maintained for oxygen service. Components exposed to oxygen or mixtures containing over forty per cent (40%) by volume oxygen are cleaned of flammable materials before being placed into service. Oxygen systems over 125 psig (8.5 bar gauge) must be equipped with slow-opening shut-off valves.

**Scientific diving safety**

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

Diving safety programmes can be generalised as fulfilling two purposes. The first being a research-support function, which assists the diving scientist with specialised 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 organisation from excessive liability exposure, by providing state-of-the-art diving equipment, breathing air, training and medical surveillance programmes.

More recently, ongoing scientific diving safety research has been conducted to consider a more effective means of monitoring decompression status using dive computers.[4] DCBs 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. After such a failure, 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 out-gassing has occurred. Multiple deep dives and/or decompression dives with dive computers require careful consideration.

Lang and Egstrom investigated the slowing of ascent rates and the performance of safety stops to provide scientific divers with a greater margin of decompression safety.[5] 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 9 msw.min$^{-1}$ from 18 msw and are not to exceed 18 msw.min$^{-1}$ from depth, at the rate specified for the make and model of dive computer or table being used. Scientific diving programmes require a stop in the 3–9 msw zone for three to five minutes on every dive.

Scientific divers using drysuits receive additional practical training in their use. Drysuits 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 drysuit 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 the consideration of the physiological aspects of multi-day, repetitive diving.[6] 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 one to two incidents per 1,000–2,000 dives for the commercial diving sector, two incidents per 10,000 dives for recreational diving activities and 1 incident in 100,000 dives for the scientific diving community. Scientific diving programmes provide continuous training, recertification and dive-site supervision, which help to maintain established safe diving protocols (Table 3). 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, during which the risk of DCS may be higher.

**Table 3**
**2003 summary of scientific diving of the American Academy of Underwater Medicine**

| | **Total scientific dives** | | | |
|---|---|---|---|---|
| **Organisations** | **Dives** | **Minutes** | **Divers** | **Incidents** |
| 76 | 104,921 | 4,133,207 | 4,478 | 2 |
| | **Dives by depth range** | | | |
| **Depth (msw)** | **Dives** | | **Divers** | **Incidents** |
| 0–9 | 65,355 | | 2,508 | 1 |
| 9–18 | 28,650 | | 1,881 | 0 |
| 18–30 | 8,650 | | 985 | 1 |
| 30–39 | 1,524 | | 451 | 0 |
| 39–45 | 459 | | 103 | 0 |
| 45–57 | 147 | | 54 | 0 |
| 57+ | 136 | | 28 | 0 |
| | **Dives** | **Minutes** | **Divers** | **Incidents** |
| **Dives by classification** | | | | |
| Scientific | 90,014 | 3,695,919 | 3,032 | 2 |
| Training/ proficiency | 14,907 | 437,288 | 1,809 | 0 |
| **Dives by mode** | | | | |
| Open circuit | 95,492 | 3,737,229 | 3,742 | 2 |
| Hookah | 5,949 | 313,190 | 415 | 0 |
| SSBA | 3,035 | 70,192 | 194 | 0 |
| Rebreather | 445 | 12,596 | 31 | 0 |
| **Dives by breathing gas** | | | | |
| Air | 95,295 | 3,701,615 | 3,708 | 1 |
| Nitrox | 9,470 | 420,276 | 770 | 1 |
| Mixed gas | 156 | 11,316 | 27 | 0 |
| **Dives by planning method** | | | | |
| Dive tables | 47,993 | 1,803,510 | 1,852 | 1 |
| Dive computer | 48,345 | 2,131,931 | 2,160 | 1 |
| PC-based software | 107 | 7,357 | 20 | 0 |
| **Dives by specialty** | | | | |
| Decompression | 435 | 40,520 | 75 | 0 |
| Overhead | 600 | 28,790 | 78 | 1 |
| Blue water | 366 | 12,027 | 80 | 0 |
| Ice/polar | 708 | 22,730 | 80 | 0 |
| Dives during saturation | 179 | 28,318 | 11 | 0 |
| Aquarium | 44,389 | 1,043,435 | 868 | 0 |

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 variables such as dehydration, lack of fitness, rapid ascents, undue fatigue, etc., and preventive measures to minimise these factors 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 recognised as a probabilistic event, which tends to lean the scientific diving community towards a more conservative diving position.

**Table 4**
**Data set submitted to OSHA covering years 1965–1981, leading to exemption of scientific diving from commercial diving regulations**

| | | |
|---|---|---|
| **Scientific diving** | | |
| Certified scientific divers | | 5,441 |
| Dives to depth | 10 m | 172,546 |
| | 20 m | 154,751 |
| | 30 m | 40,199 |
| | 40 m | 7,002 |
| | 50 m | 3,202 |
| | 60 m | 917 |
| | 60 m+ | 40 |
| Total no. dives | | 380,295 |
| No. decompression dives | | 1,638 |
| No. pressure accidents | | 18 |
| No. deaths | | 4 |
| **Scuba diving training** | | |
| No. classes | | 835 |
| No. trainees | | 18,421 |
| No. training hours | | 242,979 |
| No. training dives | | 57,886 |
| Max. training depth (m) | | 60 |
| No. certified scuba divers | | 13,786 |
| Programmes with decompression chamber | | 4 |

The scientific diving safety record is remarkably clean. The national scientific diving statistics snapshot of 2003 (Table 3) is representative of the period from 1981–2003. The data set submitted to OSHA that resulted in the scientific diving exemption from commercial diving regulations covered the years 1965–1981 (Table 4). Eighty-eight diving programmes submitted information to the national scuba safety survey conducted at that time through UCLA.

A comparative analysis of pre-and post-1980s diving incidents becomes increasingly difficult due to the lack of descriptive data and the changing ‘incident’ collection parameters. ‘Pressure accidents’ from before the 1980s do not solely represent the number of DCS presentations, but also include incidents of other reported barotrauma. That period possibly also represents a significant amount of under-reporting of mild DCS, a period when mild aches and pains associated with diving were accepted as minor miseries of life. Since the early 1980s, scuba divers have been oversensitized to recognition of DCS signs and symptoms, resulting in a significant emphasis on diving safety training in CPR, field neurological examinations, first aid, and oxygen administration. The early reporting of potential DCS and activation of emergency plans coupled with oxygen administration unquestionably results in high percentages of resolution. However, once a diver enters the decision-making tree, it is difficult to extract the number of cases of non-DCS, because invariably they end up at the chamber where precautionary treatment is more often than not provided. This results in over-reporting of DCS cases. Scientific diving DCS data collection criteria need to be refined for a better approximation of rates. No detailed information is available on the four deaths from 1965–1981. Since 1981, there have been at least three scientific diving deaths under the following circumstances: blue-water diving, under-ice diving, and missed decompression.

After 50 years, the DCS rate of 1:100,000 continues to appear acceptable within the scientific diving community. Compared with other sectors of the diving community, the recreational diving profiles most closely resemble those of scientific diving. However, the scientific diving incident rates are an order of magnitude lower, and we attribute this to thorough entry-level and continued training and supervision, and controlled medical and operational procedures. Incident rates in military and commercial diving communities are much higher, but, taking into account the commensurately riskier profiles, are efficiently handled with on-site chambers and diving medical personnel.

The order of dive profiles was investigated by Lang and Lehner, 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.[7] More importantly, the genesis and physiological validity of the 'dive deep first' rule was in need of examination. Historically, neither the US Navy nor the commercial sector has 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 organisations 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 found no reason for the diving communities to prohibit reverse dive profiles for no-decompression dives less than 40 msw and depth differentials less than 12 msw.

Oxygen-enriched air (nitrox) has been used in the scientific diving community since the early 1970s. Lang 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.[8] A maximum $PO_2$ of 162 kPa (1.6 ATA) is generally accepted based on the history of nitrox use and scientific studies. Routine carbon dioxide retention screening is not necessary for open-circuit, recreational nitrox divers. Oxygen analysers 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 recognise the effectiveness of nitrox dive computers. For recreational diving with oxygen-enriched air, there is no need to track whole-body exposure to oxygen (e.g., oxygen toxicity units or unit pulmonary toxic dose); the 'CNS oxygen clock' concept is taught instead, based on NOAA oxygen exposure limits.[9] 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 practising scientific divers for blue-water diving by Heine, and polar diving operations by Lang and Stewart.[10,11]

**Acknowledgements**

The Smithsonian Institution's Office of the Under Secretary for Science, and the American Academy of Underwater Sciences.

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