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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 03-91

U.S. NAVY NITROX DIVING APPLICATIONS

LCDR JAMES M. CHIMIAK, MC, USN

JUNE 1991

Navy Experimental Diving Unit

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Nitrox diving is any diving using a nitrogen-oxygen (Nitrox) mixture where the percentage of oxygen is greater than 21%. Its primary advantage is the marked decrease in decompression stress when a given dive profile is compared to air. The use of Equivalent Air Depth (EAD) calculation is employed to decrease or eliminate the decompression obligation that would be required if that same dive profile was conducted using air. Nitrox can benefit scuba, surface-supplied, SDV and recompression operations. The disadvantages entail extra provisions for its handling, identification, mixing, and training.

Formal course of instruction and open water Nitrox diving were conducted at NEDU. In addition, a Nitrox seminar was conducted and a questionnaire was ued to explore the application and administration of Nitrox to U.S. Navy diving.

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CONTENTS

I. INTRODUCTION

NAVSEA task 90-026 directed Navy Experimental Diving Unit (NEDU) to study Nitrox diving procedures and equipment. Nitrogen-oxygen (Nitrox) diving is an old concept. Dwyer calculated tables at NEDU in 1955 [1]. Nitrox diving was used by the U.S. Navy in the past for MK 6 underwater breathing apparatus operation. Nitrox is simply a nitrogen-oxygen breathing mix in which the percentage of oxygen in the mix is increased above the 21% found in air and is even referred to as "enriched air breathing mixtures" by some professional divers [2]. The benefits result in equivalent air depths (EAD) that are shallower for decompression purposes than the actual depth. This results in longer no decompression (no "D") dive time or shorter decompression times than the same depth using air. The effectiveness of decompression is also increased when the partial pressure of oxygen is increased.

The disadvantages of Nitrox are an enhancement of the oxygen toxicity dangers of breathing oxygen at pressures greater than ambient. In addition, the extra training, equipment, and operating procedures may offset the net gain certain dive lockers would achieve if they become Nitrox capable.

II. METHODS

A. NITROX TRAINING

Twelve Navy divers at Navy Experimental Diving Unit conducted formal Nitrox classroom and scuba diving training. The divers were selected due to their interest and consequent assignment to the task. Instruction was formally administered by the International Association of Nitrox Divers and a representative from National Oceanic and Atmospheric Association (NOAA) 25 September - 2 October 1989 [3]. Approximately 40 Nitrox dives were made. Preparation of the Nitrox mixtures was performed by the Mixmaker (Airco Cryogenics, Irvine, CA) in order to produce Nitrox with oxygen percentages of 32% (NOAA I) and 36% (NOAA II).

B. NITROX QUESTIONNAIRE

A Nitrox diving seminar was held for all the divers at NEDU. The application of Nitrox to Navy needs was addressed. In addition, the logistic problems were equally emphasized. Afterwards, a formal questionnaire was administered to solicit a cost/benefit analysis of adding a Nitrox capability to Navy diving. In addition, any unique applications where Nitrox would be beneficial was also solicited. These divers had a mean average of 14.7 years Navy diving experience that spanned the full range of Navy diving operations.

III. RESULTS

A. DIVING

No difficulty was noted during open water diving in the Gulf of Mexico. Strict adherence to the specified safety procedures such as cut-off depths was observed. Predive oxygen concentration checks were conducted with the Teledyne O_2 meter (Teledyne Analytical Inst, San Gabriel,CA).

B. MIXING

Both NOAA I (32% oxygen percentage) and NOAA II (36% oxygen percentage) were mixed without difficulty. Therefore, procedures employed by NOAA diving units were not employed for mixing [2].

C. QUESTIONNAIRE

The following was obtained from the 22 respondents:

1. <u>Adding Nitrox Capability to Navy Diving</u>

When questioned, 82% of NEDU's divers felt Nitrox diving should be available to Navy diving units. Over half of those favoring the use of Nitrox, recommended it be restricted to specific application or level of training. The remainder recommended its unrestricted use after initial Nitrox diving instruction. Eighteen percent of NEDU's more senior divers (a mean of 21 years Navy diving experience) felt that the cost/benefit ratio did not warrant the addition of any Nitrox capability to Navy diving other than recompression treatments.

2. Restricted Application

The respondents favoring restricted Nitrox diving usage recommended the following Nitrox application for approval:

a. SDV Operations. A Nitrox mix would allow switching between "boat or open circuit air" and the closed circuit underwater breathing apparatus (UBA) without altering the decompression.

b. Underwater Construction and Ship's Husbandry. Work conducted at a single depth that requires decompression when conducted on air could become a no "D" dive. Multilevel dive computers or tables lose most of their decompression advantage when a square or single depth profile is conducted. Nitrox demonstrates its unique advantage when working at one depth. The advantage increases for depths greater than 40 fsw where no "D" bottom times become increasingly restrictive. This capability could be particularly important for Trident submarine bases or underwater construction work.

c. Search and Recovery. Bottom searches in water greater than 40 fsw could be more efficiently done using Nitrox since greater no "D" bottom times are allowed for the same dive using air.

d. Miscellaneous Operations. Any command where the depth of a particular operation would make the use of Nitrox an advantage should be given a one-time authorization to use Nitrox.

e. Flyaway Capability. A flyaway Nitrox dive team should be readily available to augment a diving operation with the Nitrox capability.

IV. DISCUSSION

Nitrox is a diving capability where the percentage of oxygen in the breathing mixture is increased. This addition of oxygen subsequently lowers the percentage of the inert gas nitrogen. Since current decompression procedures are based on the elimination of inert gas to prevent decompression sickness (DCS), it follows that reducing the partial pressure of inert gas with oxygen also reduces the risk of decompression sickness [4]. This relationship is quantified by the calculation for equivalent air depth (EAD). In addition, increased partial pressures of oxygen are universally employed as a benefit during both decompression and recompression therapy [5]. The following are areas of specific interest to the Navy's application of Nitrox:

A. EQUIVALENT AIR DEPTH

Nitrox diving procedures are not complicated nor exotic. They are based on the U.S. Navy air decompression tables, with the additional requirement to compute 0_2 limiting factors in accordance with U.S. Navy mixed gas diving procedures. The primary difference between air and Nitrox diving is that with a given mix of Nitrox one must compute the "equivalent air depth" based on the PN_2 of the Nitrox and then compare that figure with the equivalent PN_2 for air. This is done using the formula:

$$EAD = \frac{[(1.0 - PO2)(D+33)]}{.79} - 33$$

By computing EAD, and using the USN Standard Air Decompression tables, a diver can compute the maximum no-decompression time limit for a given depth. Using a maximum limiting factor of 1.6 will enable a diver to use standard mixed gas computations to compute maximum allowable depth for a given mix. In the case of a 64/36 Nitrox mix (NOAA II), the calculation shows that the maximum allowable depth for a 1.6 limiting factor is 113 fsw [6].

$$COD = \frac{(1.6 \times 33 \text{ fsw})}{.36} - 33$$

$$= 146.666 - 33$$

$$= 113.666 \quad \text{or } 113 \text{ fsw}$$

At NEDU, all Nitrox dives using 64/36 mix were limited to 100 fsw or less. If a diver did the calculations for a 100 fsw dive using 64/36 Nitrox to find his equivalent air depth, that would show:

$$EAD = \frac{[(1.0 - 36)(100 + 33)]}{.79} - 33$$

$$= \frac{.64(133) - 33}{.79} = 107.7 - 33$$

$$= 74.74 = 75 \text{ fsw}$$

In essence, the 80 foot Standard Navy Air table would be used to compute maximum no-decompression bottom time for a 100 fsw dive using 64/36 mix Nitrox. NMRI demonstrated the effectiveness of Nitrox by safely performing manned dives to 60 fsw on 60/40 Nitrox mix for 6 hours without a decompression obligation [7]. NMRI's profile exceeds the conservative guidelines used currently for Nitrox diving but illustrates its benefits for diving applications.

For a given depth, an EAD may be calculated and used to enter the USN Standard Air tables. The use of inert gas partial pressure is currently used in the helium-oxygen (HeO_2) partial pressure tables. The difference is that Nitrox uses EAD to determine partial pressures. EAD is referenced to a 79% inert gas table (standard air table) instead of 100% inert gas table (HeO_2 partial pressure table).

B. NOAA NITROX TABLES

NOAA has even formulated specific tables for an oxygen percentage of 32% (NOAA I) and 36% (NOAA II) [8]. The NOAA Nitrox tables are the USN Standard Air tables with the depth of the dive already adjusted for EAD. They are rigid and do not optimize the Nitrox mixture for the given depth of operation. Dinsmore has optimized the percentage of oxygen in his Nitrox mixtures to maximize its benefits with success [9].

C. DECOMPRESSION

Since the decompression is performed using the USN standard air table's decompression stops with a higher partial pressure of oxygen, an increased margin of safety is the resultant dividend. The lower partial pressure of the inert gas increases the pressure gradient that increases tissue offgassing. The increased partial pressure of oxygen has been seen to be beneficial as long as the partial pressure remains below 2 atmospheres absolute (ATA). The experimental cases of oxygen DCS have occurred when breathing 100% O_2 at ambient pressures in excess of 2 ATA [10].

D. OXYGEN DCS

Oxygen DCS is described as mild and resolves spontaneously. This phenomenon has been attributed to the fact that the oxygen inside of the bubble is metabolized by the body and therefore eliminates the bubble before the effects present as anything more than transient [11].

E. NITROX DIVING CONSIDERATIONS

Diving Nitrox requires only basic instruction once the theory is understood. The actual diving procedures are the same as air diving with the following differences:

1. Handling.

Nitrox requires strict attention to its proper marking as to the oxygen percentage. No difference between Nitrox mixtures and air can be positively identified without appropriate instrumentation. There is no voice change, scent or taste that is a reliable indicator.

2. Sampling.

All gas sources require sampling by an O_2 meter at a Nitrox capable diving command prior to diving. The inadvertent filling of cylinders or misalignment of cross connecting-valves can result in an unplanned gas mixture. These same precautions are taken for helium-oxygen (heliox) capable diving units and would be necessary for Nitrox as well.

3. Cut-off Depths

Shallower cut-off depths than air are imperative to avoid CNS toxicity. Calculations show that air also has this same limitation but only at a depth of 218 feet of seawater and greater.

4. Additional Training

Additional training is required to maintain proficiency in Nitrox diving procedures to ensure its safe use. The training is basic and emphasizes the precautions to prevent oxygen toxicity. Much of the training given to first class divers covers the theory and precautions necessary for Nitrox diving.

F. NITROX RECOMPRESSION APPLICATION

Increased partial pressure of oxygen is the basis for hyperbaric oxygen therapy. Oxygen's proven efficacy has been implemented in the Navy treatment tables. The use of 100% oxygen is limited to 60 fsw in the chamber due to its toxic effects on the central nervous system. Nitrox mixtures afford the recompression chamber operator the ability to administer higher partial pressures of oxygen when recompression therapy is conducted deeper than 60 fsw. Procedures for using Nitrox for treatments have been approved [12, 13]. These procedures were outlined by Cowdin [14]. Naval Medical Research Institute (NMRI) has proposed the use of Nitrox mixtures during the new treatment table 8 found in Annex A. The efficacy of the treatment would be enhanced at depths greater than 60 fsw compared to air.

G. SWIMMER DELIVERY VEHICLE APPLICATION

Swimmer Delivery Vehicle Operations

Hermann proposed the use of 60/40 Nitrox mix for boat air to enable the diver to switch to it below 25 feet and still remain on the 0.7 partial pressure tables [16]. NMRI reviewed this proposal and approved this Nitrox application [7]. This would functionally extend the CO_2 scrubber duration of the underwater breathing apparatus as well as provide an alternate gas supply should the UBA fail. This would be accomplished without altering the decompression profile. However, its use is limited to a 99 fsw depth to avoid exceeding 1.6 ATA partial pressure of oxygen.

H. UNDERWATER DECOMPRESSION MONITORS (UDMs) AND NITROX

Nitrox increases the safety of an air UDM diver in regards to prevention of DCS when the diver adheres to the profile displayed on the UDM. The UDM computes the decompression obligation from the perspective of multilevel diving on air and actual depth of the diver. With Nitrox, the body's decompression stress is at a shallower depth than the actual depth of water breathing air and imparts a favorable effect for the diver. This concept was discussed during the formal Nitrox training at NEDU. The emphasis was that if a diver combines Nitrox with a UDM, the UDM profile must be followed and obeyed. If the UDM indicates the diver must ascend and decompress, that command must be followed even if the allowable bottom time for the Nitrox mix has not been expended.

Thus, with the very few simple rules that follow, it is very easy to see that Nitrox diving using an air UDM provides a higher degree of decompression safety than air diving.

1. The maximum depth for the Nitrox mix must be known prior to the dive and not exceeded.

2 The time restrictions based on the oxygen partial pressure limiting factor for the mix used must be followed [6]. For example, a limiting factor of 1.6 allows a maximum exposure of 30 minutes and a limiting factor of 1.0 allows a maximum exposure to 240 minutes.

3. The UDM profile should be followed without any EAD modification (other than 1 and 2 above) to enhance the decompression safety.

V. CONCLUSIONS

1. Nitrox diving is no more involved than helium-oxygen diving. The dangers of Nitrox diving can be safely handled by its professional execution typical for all Navy diving.

2. Mixing and analyzing the desired Nitrox concentration could follow many of the proven guidelines used for Heliox operations. The imposition of cut-off depths or limits to avoid O_2 toxicity is found in all Navy diving, including air. And the diver using Nitrox has only to be aware of his cut-off depth to use it.

3. Nitrox for use in recompression therapy should be included in the dive manual. A 50/50 Nitrox mix should be available and specially marked banks be installed for all Navy chambers. Its therapeutic use should be supervised by a Diving Medical Officer (DMO). Commands unable to mix 50/50 Nitrox could procure it from an authorized commercial vendor.

4. Nitrox diving capability should be developed fully to meet specific applications. Its implementation at Navy diving commands should be controlled by NAVSEA. Its implementation should be based on a clear operational benefit versus cost and the presence of adequate support personnel. The increased in-water productivity may be offset by the increased manpower cost to operate and maintain a Nitrox capability.

5. Recommend that one diving command be tasked with maintaining a flyaway Nitrox diving capability. This capability would enable the Navy to augment selected operations where Nitrox would improve the efficiency and safety. Since this flyaway team would be on site supervising the Nitrox administration, that on-site command would be allowed to dive any qualified second class diver with instruction. Operations such as the Challenger salvage operation would have benefitted from such a flyaway team.

6. Incorporate EAD calculation into the combat swimmer multilevel dive (CSMD) table when 77 fsw is exceeded while on a 0.7 ATA oxygen underwater breathing apparatus (UBA). Since the CSMD tables are calculated for air, a decrease in decompression stress is obtained when using a constant 0.7 ATA oxygen partial pressure up to 77 fsw. Therefore, the diver should add 10 fsw if he exceeds 77 fsw (if the maximum depth of operations is 120 fsw). This 10 fsw correction accounts for the difference between 120 fsw and 77 fsw (or 43 fsw) since the additional nitrogen uptake comparing 100% nitrogen to 79% nitrogen in air would be 21% of 43 fsw or 9 fsw. Hence, an additional 10 fsw would cover any operation between 77-120 fsw when using the CSMD.

7. Establish procedures to facilitate the implementation of Nitrox at each Navy diving organization. These procedures would be utilized on a case-by-case basis to expedite the use of Nitrox for a particular application authorized by NAVSEA.

VI. RECOMMENDATIONS

1. Incorporate the procedures and application for 50/50 Nitrox into recompression treatments deeper than 60 fsw.

2. Recommend all Navy chambers have a specially marked 50/50 Nitrox bank to allow at least a two-hour supply for one diver at 165 fsw. Explore the use of portable man carried Nitrox systems that can be carried into the chamber. This would enable chambers without an installed Nitrox capability to supply it in an emergency treatment.

3. Designate a diving command to maintain a Nitrox flyaway capability.

4. Recommend Nitrox diving be strictly controlled by NAVSEA where cost/benefit is carefully evaluated for the proposed application.

5. Incorporate the recommendation that 10 fsw be added to the depth when entering the CSMD tables between 77-120 fsw on a 0.7 ATA oxygen UBA.

6. Specifically mix oxygen concentrations for the particular application to maximize its decompression benefits and minimize its CNS toxicity risk.

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ANNEX A

TABLE 11-4. U.S. NAVY TREATMENT TABLE 8 FOR DEEP BLOWUP

DEPTH (FSW)	MAX TIMES AT DEPTH (HRS)	2-FSW STOP TIMES (MIN)
225	0.5	5
165	3	12
140	5	15
120	8	20
100	11	25
80	15	30
60	Unlimited	40
40	Unlimited	60
20	Unlimited	120

Notes:

1. Enter the table at the depth which is equal to the next greater than deepest depth attained in the recompression. Descent rate is as fast as tolerable.

2. The maximum time that can be spent at the deepest depth is shown in the second column. The maximum time for 225 fsw, is 30 minutes; for 165 fsw, 3 hours.

3. Decompression is begun with a 2-fsw reduction in pressure if the depth is an even number. Decompression is begun with a 3-fsw reduction in pressure if the depth is an odd number. Subsequent stops are carried out every 2 fsw. Stop times are given in column 3. The stop time begins when leaving the previous depth. Ascend to the next stop in approximately 30 seconds.

4. Stop times apply to all stops within the band up to the next quoted depth. For example, for ascent from 165 fsw, stops of 12 minutes are made at 162 fsw, and at every two-foot interval to 140 fsw. At 140 fsw, the stop time becomes 15 minutes. When traveling from 225 fsw the 166-foot stop is 12 minutes; the 164-foot stop is 15 minutes.

5. A 50-percent nitrogen/50-percent oxygen mixture may be given to the diver at 165 fsw and shallower. Pure oxygen may be given to the diver at 60 fsw and shallower. For both gas mixtures, a schedule of 25 minutes on gas and 5 minutes on chamber air should be followed for a total of four cycles. Additional oxygen may be given at 60 fsw after a two-hour interval of chamber air. See USN Treatment Table 7, Volume One, Chapter Eight, for guidance.

6. To avoid loss of the chamber seal, ascent may be halted at 4 fsw and the total remaining stop time of 240 minutes taken at this depth. Ascend directly to the surface upon completion of the required time.

7. Total ascent time from 225 feet is 56 hours, 29 minutes. For a 165-fsw recompression, total ascent time is 53 hours, 52 minutes; and for a 60-fsw recompression, 36 hours, 0 minutes.