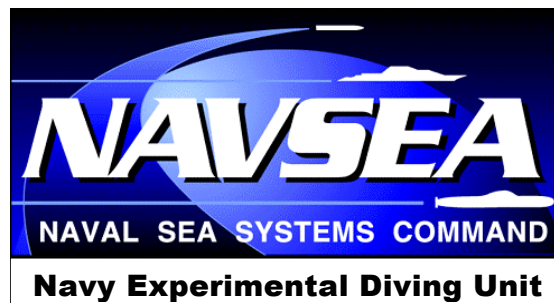


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321 Bullfinch Road
Panama City, FL 32407-7015**

**TA 21-09
NEDU TR 23-37
Sep 2023**

**MAN-TRIAL OF THE TWENTY-FIRST CENTURY
SURFACE-SUPPLIED HELIOX (He-O₂)
DECOMPRESSION TABLE**



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1. REPORT DATE (DD-MM-YYYY) 1-09-2023			2. REPORT TYPE Technical Report			3. DATES COVERED (From - To) Mar 2021 – Sep 2023		
4. TITLE AND SUBTITLE Man-Trial of the Twenty-First Century Surface-Supplied Heliox (He-O ₂) Decompression Table						5a. CONTRACT NUMBER		
						5b. GRANT NUMBER		
						5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) David M. Sherrier, Wayne A. Gerth; David J, Doolette; F. Gregory Murphy						5d. PROJECT NUMBER		
						5e. TASK NUMBER TA 21-09		
						5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Navy Experimental Diving Unit 321 Bullfinch Road Panama City, FL 32407-7015						8. PERFORMING ORGANIZATION REPORT NUMBER NEDU TR 23-37		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Sea Systems Command 1333 Isaac Hull Avenue, SE Washington Navy Yard, D.C. 20376						10. SPONSOR/MONITOR'S ACRONYM(S)		
						11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution Statement A: Approved for public release; distribution is unlimited								
13. SUPPLEMENTARY NOTES								
14. ABSTRACT The Surface-Supplied Helium-Oxygen (SS He-O ₂) Decompression Table in the current <i>U.S. Navy Diving Manual</i> (Revision 7, Change A) is an edited version of an original 1939 issue with a limited record of success in operational dives to depths of 240 feet sea water (fsw) or shallower. Recent theoretical evaluations indicate that schedules in this table, intended for longer and deeper dives that are becoming increasingly within the scope of desired U.S. Navy diving operations but have a limited historical usage, present unacceptably high risks of decompression sickness (DCS). Navy Experimental Diving Unit (NEDU) generated two tables of schedules with an updated linear-exponential multi-gas (LEM) probabilistic model to incur 2.3% maximum estimated risks of DCS as candidates to replace the current SS He-O ₂ Decompression Table. The second of these tables included a modification to accommodate a ±0.5% gas mixing error allowed in the <i>U.S. Navy Diving Manual</i> . 232 simulated man-dives were completed in the NEDU Ocean Simulation Facility by 56 diver-volunteers on 20 different depth/time schedules selected from the candidate tables. In 91 man-dives completed on the unmodified schedules, two cases of DCS Type II occurred and one case of surface interval pain occurred that resolved by the time of arrival at the 50 fsw first surface decompression chamber stop. In 141 man-dives completed on the modified schedules, one case of marginal DCS Type I occurred and one case of surface interval pain occurred that resolved by the time of arrival at the 50 fsw first surface decompression chamber stop. Pooling results from all 232 completed man-dives and omitting cases of surface interval pain that resolved within minutes of arrival at the first surface decompression chamber stop, as per provisions in the protocol, DCS incidence in this trial was 1.3% (3/232), from which it was inferred at 95% binomial confidence that the actual DCS risk of the schedules is less than 3.3%. If the cases of surface interval pain are not omitted from the pooled results, DCS incidence in this trial was 2.2% (5/232), from which is inferred at 95% binomial confidence that the actual DCS risk of the schedules is less than 4.5%. Either result failed to meet provisions in the protocol to reject the candidate schedules if evidence indicates that their actual DCS risk is greater than 5%. The second, slightly more conservative table of schedules modified to accommodate a ±0.5% gas mixing error is recommended to replace the SS He-O ₂ Decompression Table in the current <i>U.S. Navy Diving Manual</i> . The recommended schedules have considerably longer decompression times than their counterparts in the current <i>U.S. Navy Diving Manual</i> but incur estimated risks of DCS well-below those for the current schedules, especially for longer and deeper dives.								
15. SUBJECT TERMS diving, surface-supplied, heliox (He-O ₂), decompression tables, in-water, surface decompression on oxygen								
16. SECURITY CLASSIFICATION OF:				17. LIMITATION OF ABSTRACT Unclassified	18. NUMBER OF PAGES 65	19a. NAME OF RESPONSIBLE PERSON NEDU Librarian		
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	19b. TELEPHONE NUMBER (include area code) 850-230-3100					

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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ACKNOWLEDGMENTS

The authors are grateful to the U.S. Navy divers who volunteered to participate as diver-subjects in this study, to the Diving Medical Officers and Diving Medical Technicians who provided medical support of those divers, and to the remaining NEDU diving community personnel who provided engineering and operational support for the dives.

INTRODUCTION

The current *U.S. Navy Diving Manual*¹ contains procedures for surface-supplied helium-oxygen (SS He-O₂) bounce diving, where divers are supplied with pre-mixed heliox (He-O₂) breathing gas from the surface through a flexible hose to a helmet and open-circuit regulator. Bottom times in such dives are limited to only minutes or hours. The evolution of decompression schedules for such dives was recently reviewed in Navy Experimental Diving Unit (NEDU) Technical Report (TR) 23-11,² where it was shown that estimated risks of decompression sickness (DCS) for long deep dives in the current in-water Surface-Supplied Helium-Oxygen Decompression Table are unacceptably high.

NEDU was tasked to replace this table with a table of schedules computed with modern DCS modeling technology to incur more acceptable risks of DCS.³ As described in NEDU TR 23-11, candidate replacement tables were produced with probabilistic modeling technology to incur a 2.3% estimated risk of DCS (P_{DCS}). An NEDU man-test protocol was written and approved to test selected schedules from the first suitable candidate replacement table that emerged from this work in the NEDU Ocean Simulation Facility (OSF). After completion of 91 man-dives during execution of this protocol, however, it was realized that the schedules being tested failed to accommodate the $\pm 0.5\%$ gas mixing error allowed in the *U.S. Navy Diving Manual*. As also described in NEDU TR 23-11, a second table was produced to rectify this oversight.

This report outlines the procedures, results, and conclusions of man-trials conducted to support recommendation of a replacement for the Surface-Supplied Helium-Oxygen Decompression Table in the *U.S. Navy Diving Manual*.

OBJECTIVES

1. Man-test selected schedules from candidate replacement Surface-Supplied Helium-Oxygen Decompression Tables to establish with 95% confidence that the schedules incur risk of DCS less than 5%.
2. Recommend a candidate table with schedules shown to incur acceptable risks of DCS as a replacement for the Surface-Supplied Helium-Oxygen Decompression Table in the current *U.S. Navy Diving Manual*.

METHODS

OVERVIEW

Decompression tables in Appendices A and B were produced as candidates to replace the Surface-Supplied Helium-Oxygen Decompression Table in the current *U.S. Navy Diving Manual*. Schedules were selected from these tables for completion by human

diver-volunteers in the NEDU OSF to assess actual DCS risk. The dive profiles tested are listed in Appendix C. Diver exposure to unnecessary risk was limited by conducting the dives in accord with a group sequential design described in Annex D.

TEST DECOMPRESSION SCHEDULE SELECTION

The initial table (Appendix A) was used for the first 91 man-dives. The final table (Appendix B), which was computed to accommodate a $\pm 0.5\%$ gas mixing error, was used for the remaining 141 man-dives. Twenty decompression schedules were selected that covered the operational depth range of the tables and included no-stop, in-water decompression (IWD), and surface decompression on oxygen (SurDO₂) dives. For decompression dives, bottom times near the normal exposure limit line were selected. SurDO₂ oxygen breathing is prescribed in 30-minute periods; the number of these periods was computed by rounding-up the IWD oxygen breathing time to the closest 30 minutes and dividing by 30. For instance, IWD oxygen time of 35 minutes resulted in two 30-minute SurDO₂ oxygen breathing periods. SurDO₂ test schedules were selected from the initial table to minimize such round-up so that the least conservative SurDO₂ schedules were tested. The same depth / bottom time combinations were retained when testing switched to the final table. Although these final test schedules were not explicitly selected to minimize round-up of SurDO₂ oxygen breathing times, the round-up was not excessive.

DIVER RECRUITMENT AND REQUIREMENTS

NEDU protocol 21-25⁴ was reviewed and approved by the NEDU Institutional Review Board before any subjects were recruited to commence man-diving. Subjects were volunteer military-trained divers who had read and signed the informed consent document in the protocol as a condition for admission into the study. All divers were assessed by an Undersea Medical Officer (UMO) to be physically qualified to dive before admission into the study. The pre-participation assessment included a medical record review and medical examination, results of which were recorded on a Diver Baseline Data Sheet. Individual data, including the diver's birth date, height, weight, waist circumference, and neck circumference were collected (See Appendix F). A smoking history was obtained, and any orthopedic injuries, abnormal neurological findings, and use of medications was noted to aid in the differential diagnosis of any suspected decompression sickness. Further, no medications were allowed, unless they had been cleared by the duty UMO as not a contraindication to diving. Since many divers normally take daily ibuprofen or vitamins, such use was allowed with appropriate notation in the Diver Baseline Data Sheet. Female divers were able to participate, but were required to post a negative pregnancy test in the pre-participation medical examination.

All subjects were qualified MK 20 MOD 1 divers trained to be familiar with the standard operational and emergency procedures of the OSF. Of the 58 qualified military-trained divers that gave informed consent, all but 2 participated as subjects in a dive. At the time of their enrollment in this study, the subjects had mean (standard deviation) age of 35 (5) years, body weight of 199 (27) lbs or 90.4 (12.2) kg, height of 70 (3) in or 1.78

(0.07) m, body mass index of 28 (3) kg/m², and body fat percentage estimated from body dimensions⁵ of 20 (5) %.

Divers were required to complete a work-up dive in the 3- to 10- day window prior to participation in an experimental dive if they had not otherwise participated in a decompression dive to 80 fsw or deeper in that 10-day time period. The “work-up dive” was a dry air decompression dive to 130 fsw with 20 minutes bottom time, decompressed on the in-water oxygen schedule in the Air Decompression Table in the current *U.S. Navy Diving Manual*.

Divers were permitted to engage in their regular exercise programs prior to participating in a dive profile for the study. However, they were prohibited from performing physical training or athletic exercise for 18 hours after surfacing from a dive. Divers were prohibited from diving or flying, or other exposure to hyperbaric or hypobaric pressure, other than as experienced as a participant in this study, during a minimum of 48 hours before participating in a study dive.

Consumption of more than one standard alcoholic drink (14 g alcohol, e.g., one 12 oz beer) by divers during the 24 hours before a dive and 24 hours after a dive was prohibited to avoid dehydration or masking of symptoms. Divers were required to consume a minimum of 500 mL of non-alcoholic non-caffeinated liquid the morning of their dive to ensure that they were adequately hydrated.

Initially, each individual diver was limited to participating in 10 experimental dives. As it became impossible under this limitation to fill the dive bill with a planned minimum of three divers per scheduled dive with a minimum of three days between consecutive dives, the number of dives an individual could complete was increased to 17 with the same minimum of three days between consecutive dives maintained.

Divers were not randomized to different schedules. However, the dive bill was designed to accrue a roughly equal number of man-dives on each schedule and to minimize repeated participation in the same decompression schedule by divers who had participated in more than one dive. The schedule of each diver’s participation in workup and experimental dives is given in Appendix G.

EQUIPMENT AND INSTRUMENTATION

All experimental dives were completed in Bravo, Charlie, and Delta chambers, the trunk, and wet pot of the NEDU OSF.

OSF Wet Pot

The wet pot was set up to accommodate four divers at a time. The wet pot was filled with water intended to be maintained at a temperature of 86 ± 4 °F (27.8 – 32 °C). This temperature range was chosen to result in similar skin temperatures and self-assessed thermal status in divers wearing shorts and t-shirts as in divers wearing wet suits in cold water that had been used in a previous dive series.⁶

A high stand with a bench on which divers could be seated with heads and torsos out of the water was installed adjoining the ladder to the OSF trunk. The high stand provided a platform with limited head space for staging to start and end each dive and for refuge in case of emergency. The in-water phase of each dive was completed with divers standing on a low stand in front of the high stand where their torsos were approximately 7 feet below the water surface.

The thermistor for control of wet pot water temperature was mounted at a level below the low stand close to the inlet port of the water recirculating system. A different thermistor for monitoring wet pot water temperature on the Medical Deck was mounted near diver mid-chest level in the water column on one of the stanchions supporting the high stand. Deviations of water temperature from the intended range occurred in some dives due to different readings from these thermistors as described in Results.

Four exercise stations were positioned on the low stand:

- Stations 1 and 2: Treadmill stations, each with one treadmill with a standard 10 degree upward incline.
- Stations 3 and 4: Weight Lifting stations, each with a 62 lb (28.1 kg) kettlebell on a table, positioned such that the top of the table was at diver waist level while standing (approximately 28-30 inches high).

Underwater Breathing Apparatus

Breathing gas and communications during the in-water phase of each dive was supplied to each diver by a MK 20 MOD 1 UBA via an umbilical from the OSF Trunk.

Two additional MK 20 MOD 1 UBA, one for each pair of divers on the paired treadmill/weight-lifting stations, were available to serve as Emergency Gas Supply (EGS). EGS gas mixtures were the same as supplied in the primary gas supply to each diver MK 20 MOD 1 (see below).

The gas supply in the umbilical for each diver depended on the planned dive bottom depth and the prevailing diver depth. See Tables 1 and 2 below:

- Air for breathing from surface to 20 fsw if bottom mix $FO_2 < 16\%$;
- Bottom mix for breathing from surface (or 20 fsw if $FO_2 < 16\%$) to first in-water stop or to surface if no in-water stops;
- 50%-50% N_2-O_2 for breathing during in-water stops at depths of 90 fsw and shallower through completion of any 40 fsw stop, or through decompression to surface if no in-water stops shallower than 40 fsw;
- 100% O_2 for breathing during in-water O_2 stops at 30 and 20 fsw.
- Air for air-breathing breaks during in-water O_2 stops at 30 and 20 fsw.

Table 1. Bottom Mixes in Initial Candidate Replacement Surface-Supplied He-O₂ Decompression Table (Appendix A)

Dive Depth (fsw)	Percent O ₂ (Balance He)	PO ₂ Range (atm)
60-170	21	0.592 – 1.292
180-230	16	1.033 – 1.275
240-320	12	0.993 – 1.284

Table 2. Bottom Mixes in Final Candidate Replacement Surface-Supplied He-O₂ Decompression Table (Appendix B)

Dive Depth (fsw)	Target or “nominal”	Minimum actual	Maximum actual	PO ₂ Range (atm) ^a
60-160	21	20.5	21.5	0.578 – 1.257
170-220	16	15.5	16.5	0.973 – 1.265
230-310	12	11.5	12.5	0.917 – 1.299
320-380	10	9.5	10.5	1.016 – 1.314

^a Includes accommodation for ±0.5% gas mixing error

EGS gas mixtures were the same as for the MK 20 MOD 1 umbilicals.

Bravo chamber was used for SurDO₂. Chamber bunk mattresses were stacked on the deck and against the wall to construct couches for seating. Delta chamber was available, if needed, for treatments of DCS or arterial gas embolism (AGE).

Diver depth and wet pot water temperature were digitized and recorded by a data acquisition system (DAS) on the OSF Medical Deck at one-second intervals throughout each dive. When the divers were in the wet pot, diver depth was recorded as Charlie chamber pressure plus 7 fsw to account for the pressure of the water column when the divers were submerged on the wet pot low stand. When divers were in Bravo chamber for SurDO₂, diver depth was recorded as Bravo chamber pressure in fsw. Diver breathing gas during SurDO₂ in Bravo chamber was supplied by the built-in-breathing system (BIBS).

DIVING PROCEDURES

The duty UMO interviewed divers on the mornings of their scheduled dives to verify their fitness to dive and obtain other pre-dive diver status information such as decongestant use, alcohol consumption, any change in drug usage compared to the pre-participation medical evaluation, the amount of sleep obtained in the night preceding the dive, the amount and type of exercise performed within the 24-hour period preceding the dive, and verification that 500 mL of non-alcoholic non-caffeinated liquid had been consumed that morning. This information for test dives was documented

in the pre-dive section of the Diver Data Sheet. A diver was excluded from diving for any of the following reasons: inability to clear, upper respiratory infection, new or changing joint pain, acute infectious disease, new traumatic injury, or any other complaint judged by the duty UMO to compromise the diver's fitness. On the basis of this self-report and a brief interview, the duty UMO either cleared or disqualified subjects for participating in each experimental dive.

Preparation

Typically, four subjects — designated Red (R), Green (G), Yellow (Y), and Blue (B) — participated in each experimental dive. Prior to entering the OSF, divers assembled in the OSF gallery for a pre-dive brief. After the pre-dive brief, divers proceeded to the staging area outside OSF Alpha Chamber and, if the planned dive included SurDO₂, assembled clothes to be worn during SurDO₂ time (cotton shorts, t-shirt, sweatpants, sweatshirt, socks, and shoes). For such dives, tenders placed towels, food, and drinks in Bravo Chamber before SurDO₂ was commenced. Each diver then dressed in shorts, t-shirt, dive skin (optional), booties, weight belt, and an emergency recovery harness for the in-water phase of each dive.

One at a time in order R, G, Y, B, divers entered the OSF trunk where, with the help of tender(s), they donned their MK 20 MOD 1 UBA and breathed surface-supplied air. They then climbed into the wet pot, completed their in-water checks, and remained seated on the high stand bench breathing air to await arrival of any remaining divers. Once all divers had descended to the high stand bench, the tenders exited the trunk, and the Charlie/Bravo and Charlie/Delta hatches were closed. Divers were then instructed to move to the OSF low stand and assume a standing position.

Compression

All OSF compressions were to depths allowing for the water offset depth at a target rate of 45 ± 5 fsw/min. Compressions were completed as described:

Dive depth < 240 fsw. As soon as possible after reaching the low stand, divers were shifted to the appropriate bottom mix for the planned depth (Tables 1 and 2). As On-Gas time was recorded in the Control Room log, the Medical Deck Operations Checklist, and the Medical Deck DAS, divers ventilated their UBAs to confirm the shift. As soon as possible thereafter, and once divers had given their OKs to travel, OSF compression to bottom depth commenced with Leave Surface time recorded in the Control Room log, the Medical Deck Operations Checklist, and the Medical Deck DAS.

Dive depth ≥ 240 fsw. Dives to depths of 240 fsw or greater required a bottom mix with a percent oxygen less than 16%. In such dives, divers were compressed from surface to 20 fsw on air, shifted to the appropriate bottom mix per Tables 1 or 2 and ventilated for 20 sec. Leave Surface time was recorded in the Control Room log and the Medical Deck Operations Checklist. Five minutes was allowed for the descent to 20 fsw and UBA ventilation with bottom mix. Compression to bottom depth continued after Control confirmed the switch to bottom mix by divers' voice change in response to queries for OKs to proceed. If descent to 20 fsw and UBA ventilation was completed

in less than 5 min, dive bottom time started when divers left 20 fsw. If the process took longer than 5 min, bottom time started 5 min after leaving surface. This time was noted as On-Gas in the Control Room log, the Medical Deck Operations Checklist, and the Medical Deck DAS.

A delay during descent of one minute or less at any depth was ignored.

At Depth

The depth at bottom included the OSF wet pot water offset (i.e. the OSF pressure plus the wet pot water offset).

As soon as possible after reaching bottom divers began working at their stations: R and G divers at the treadmill stations; Y and B divers at the weight lifting stations.

- Divers at the treadmill stations were instructed to walk at approximately 30-50 steps/min for the duration of the work period.
- Divers at the weight lifting stations completed a two-handed lift of a 62 lb (28.1 kg) kettlebell from the deck to the table stand, then returned the kettlebell to the deck. Each diver was instructed to perform 5 repetitions per minute, resting as necessary.

Treadmill walking rates and weight lifting cadences were not recorded by any Medical Deck instrumentation, but were monitored by Medical Deck personnel who provided the divers feedback about rates or cadences observed to deviate significantly from targets.

After 7 minutes of work the divers rested for 3 minutes. Divers repeated 7-minute work/3-minute rest periods throughout the time at bottom. Halfway through the time at bottom during a rest period, divers rotated work stations to perform the alternate exercise during the remaining time at bottom.

The Medical Deck obtained and recorded divers' self-assessed thermal status at the end of the bottom time and every 30 minutes during in-water decompression stops. Thermal status was reported according to the numeric discomfort scale in Table 3, adapted from the modified Borg scale for dyspnea.⁷ Scores were recorded as negative values for cold discomforts and positive for warm discomforts.

Table 3. Numeric Scale for Subject Thermal Status Self-Assessment

Score	Thermal Discomfort	Score	Thermal Discomfort
0	None		
1	Very slight	6	
2		7	Severe ²
3	Slight	8	
4		9	Very, very severe
5	Moderate ¹	10	Intolerably severe, Terminate

¹ Onset of shivering in cold reports or sweating in warm reports

² Uncontrollable continuous shivering in cold reports or profuse sweating in warm reports

Decompression

In-Water

Divers remained standing on the OSF wet pot low stand, often leaning against the wet pot wall, during the in-water decompression phase. Decompression to all in-water stops occurred at a rate as close as possible to 30 fsw/min. Decompression stops were completed as prescribed in Appendix A or B. Decompression stop times in dives conducted according to schedules in Appendix A included travel time to the stop except for the first decompression stop. Decompression stop times in dives conducted according to schedules in Appendix B included travel time to the stop except for the first decompression stop and all gas switching stops.

A 5-minute air breathing break was taken after each 30 minutes of O₂ breathing at the 30 and 20 fsw stops for the in-water decompression schedules.

For decompressions completed entirely in water, the wet pot was brought to the surface upon completion of the 20 fsw last in-water decompression stop with divers remaining on 100% O₂. Ascent was as fast as possible in the OSF, which was at a nonlinear rate averaging about 12 fsw/min, less than the constant 30 fsw/min prescribed for operational dives. Divers then completed their decompression from the wet pot water depth offset to surface pressure by making their way to the high stand while continuing to breathe from their MK 20 MOD 1 UBAs. With assistance of a tender, divers then climbed the ladder into the trunk, where they removed their MK 20 MOD 1 UBAs and exited the chamber for post dive monitoring.

SurDO₂

Scheduled SurDO₂ commenced upon completion of the 40 fsw last in-water decompression stop by bringing the wet pot to the surface as fast as possible with

divers continuing to breathe 50%-50% N₂-O₂. Ascent was as fast as possible in the OSF, which was at a nonlinear rate averaging about 19 fsw/min, less than the constant 40 fsw/min prescribed for operational dives. If a 40 fsw in-water stop was not required, an arbitrarily-inserted 5 min stop at 40 fsw was completed, which included the travel time from the 90 fsw gas switch or the last preceding stop, whichever was shallower, before SurDO₂ procedures were started.

Divers completed their decompression from the wet pot water depth offset to surface pressure by making their way to the high stand while continuing to breathe from their MK 20 MOD 1 UBAs. With assistance of a tender, divers then climbed the ladder into the trunk, where they removed their MK 20 MOD 1 UBAs, and moved into Bravo chamber as expeditiously as possible. A tender was not required to accompany divers during SurDO₂. Divers monitored each other and were video monitored by topside personnel for signs of DCS and central nervous system (CNS) O₂ toxicity.

Once all divers were in Bravo chamber with hearing protection and BIBS masks at hand, Bravo chamber was compressed on air to 50 fsw at a maximum rate of 100 fsw/min.

At the direction from the Control Room, the divers donned their BIBS masks and began the first oxygen-breathing period. This time was noted as On-Gas (oxygen) in the Control Room log, the Medical Deck Operations Checklist, and the Medical Deck DAS.

If the 50 fsw chamber stop was reached within 5 minutes of leaving the 40 fsw last in-water stop, Bravo chamber was decompressed to 40 fsw at 30 fsw/min after 15 minutes of oxygen breathing at 50 fsw. The remaining 15 minutes of the first oxygen-breathing period was completed at 40 fsw.

A 5-minute air break was taken after every 30 minutes of oxygen breathing. At direction of the Dive Watch Supervisor (DWS), all divers removed their BIBS and began breathing chamber air. At the end of the air-break, again at the direction of the DWS, all divers resumed oxygen breathing from BIBS. Chamber oxygen periods beyond the fourth, if required by the schedule, were completed at 30 fsw. In such cases, the chamber was decompressed from 40 to 30 fsw during the air break following the fourth oxygen period.

During air breaks the divers were queried for any CNS O₂ toxicity symptoms using the acronym VENTIDC (visual symptoms, ear symptoms, nausea or vomiting, twitching or tingling, irritability, dizziness, or convulsions). Responses were recorded by the Medical Deck on the Medical Deck Operations Checklist.

After completing the final oxygen period, the DWS directed divers to come off-gas and begin breathing chamber atmosphere. This time was noted as Off-Gas in the Control Room log, the Medical Deck Operations Checklist, and the Medical Deck DAS. The chamber was then decompressed to the surface at target rate of 30 fsw/min.

Surfacing

After completing each dive, divers exited the chamber and remained in the OSF Alpha chamber staging area for post-dive monitoring by the DWS and duty UMO. Once cleared by the DWS and interviewed by the duty UMO after 10 minutes, divers could participate in venous gas emboli (VGE) measurements by 2D-echocardiography during the remainder of a two-hour post dive monitoring period, as described below. Usually, divers were escorted to the NEDU Physiology Laboratory after the first 10-minute post dive period, where they completed the two-hour post dive monitoring period with VGE detection. During the first month of man-diving, these measurements were completed as all divers remained in the OSF Alpha chamber staging area, because construction work made access to the treatment chamber difficult from the Physiology Laboratory.

If divers needed to leave the Physiology Laboratory during the 2-hour post dive period, they were accompanied by another diver or corpsman at all times. Divers were instructed to use the elevator to avoid climbing stairs, were not allowed to shower, and not allowed to perform physical training or duties involving more than light activity during the 2-hour post dive period. The duty UMO cleared the divers to leave NEDU after a 2-hour post dive interview.

Divers remained within 60 minute travel time of NEDU for a period of 48 hours after the dive, and returned to NEDU (except on weekends, in which case the duty UMO contacted divers via phone call) for a medical interview at a time between 18 and 24 hours after surfacing.

Divers were instructed not to dive or fly, or otherwise be exposed to hyperbaric or hypobaric pressure, except as a diver under this protocol, for 72 hours after surfacing from a dive.

VGE DETECTION

During the two-hour post dive observation period, subjects were monitored at approximately 30-minute intervals for VGE. For each examination, the subject laid in the left lateral decubitus position while the heart was imaged (apical long-axis four-chamber view) by two-dimensional trans-thoracic echocardiography (General Electric LOGIQ e R7 with a 3SC-R7 1.7–4.0 MHz phased array cardiac probe). VGE in the right heart chambers (which appear as brightly echogenic spots) were graded according to an ordinal scale adapted from Eftedal and Brubbak,^{8, 9} and defined in Table 4. The division of grade 4 into 4a and 4b was adopted because it provides better alignment with the VGE grading scale previously used at NEDU.¹⁰

During each examination, VGE in the right heart chambers were graded three times: after the subject had been at rest for approximately one minute and then after forceful limb flexions around the right elbow and right knee. For the movement conditions, the grade was assigned to the highest signal sustained for four cardiac cycles (grades 1–3) or about 0.5 seconds (grades 4a–5). Usually this maximum grade was obvious, but in doubtful cases, a video buffer was reviewed. Grades were assigned at the time of measurement and video recording of the measurements were not saved.

Measurements were made by a trained cardiac sonographer throughout the study, one of the investigators (usually DJD, FGM, or DMS) attended all sessions, and the assigned grades were generally the consensus of the operator and investigator. For each man-dive, the peak grade of all resting examinations and the peak grade of all conditions (rest, arm flexure, and leg flexure) were used for analysis.

Table 4. VGE grading scale

<i>Grade</i>	<i>Definition</i>
0	No observable bubbles
1	Occasional bubbles
2	At least 1 bubble every 4 cardiac cycles
3	At least 1 bubble every cardiac cycle
4a	At least 1 bubble per cm ² in every image
4b	At least 3 bubbles per cm ² in every image
5	“white-out”, single bubbles cannot be discriminated

RESULTS

Two hundred and thirty-two man-dives were completed in the NEDU OSF by 56 divers (54 male, 2 female) on 20 different depth/time schedules selected from the two candidate replacement tables in Appendices A and B. Each diver participated in up to 13 experimental dives (median of 3).

PROTOCOL DEVIATIONS

During the course of man-diving, two notable deviations from the protocol’s prescribed dive conditions occurred. One pertained to the wet pot water temperature, while the other related to the wet pot water offset adjustment for diver depth.

Wet Pot Water Temperature

During the first month of diving starting on 30-June-2021, several divers reported a subjective feeling of being hot during the in-water phases of the dives. This was unexpected as the wet pot water temperature range chosen for the protocol, $86 \pm 4^{\circ}\text{F}$, had been used in a previous dive series without divers reporting feeling hot.⁶

During this time the OSF Control Room wet pot water temperature thermistor was indicating wet pot water temperatures within the $86 \pm 4^{\circ}\text{F}$ range specified in the protocol. However, Medical Deck readings of water temperature had been ranging from 87.6 to as high as 96.1 °F (See Figure 1).

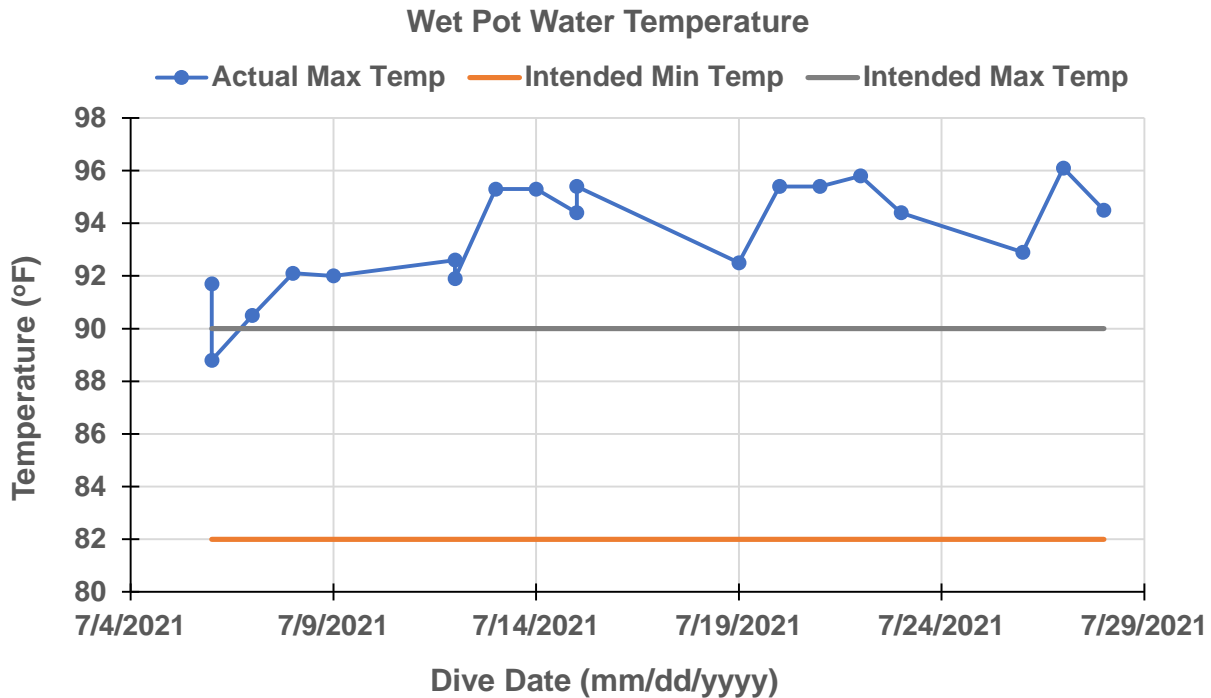


Figure 1. Wet pot water temperatures as recorded from Medical Deck thermistor before increasing the wet pot water recirculation pump rate.

The Control Room temperature readings are used to actively control the wet pot water temperature and the Medical Deck temperatures are recorded as data. Discrepancies between Control Room and Medical Deck wet pot water temperature readings were not unusual, but the Control Room readings were those kept within the temperature range specified in the protocol.

On the evening of 27-July-2021, in response to continued diver reports of feeling hot, a concerted effort to identify the cause of the discrepancies was undertaken. The investigators requested that the NEDU Engineering Department add additional thermal monitoring instrumentation to the OSF wet pot. It was determined that the different readings from the different Control Room and Medical Deck temperature sensors were correct. The causes for the difference were as follows:

- Channeling of thermal control recirculating water between wet pot input and wet pot output.
- Control Room and Medical Deck thermistors at different locations within the wet pot water volume.
- Inadequate mixing of the wet pot water volume, causing temperature sensors to register different location-dependent readings.

The problem was corrected on 29-July-2021 by increasing the wet pot water recirculation pump rate, which increased mixing throughout the wet pot water volume. Thereafter, the Control Room and Medical Deck instruments registered the same water

temperature within 1°F, regardless of thermistor location in the wet pot. Medical Deck readings of water temperature then averaged 85.4°F and ranged from 84.8 to 87.8°F (See Figure 2).

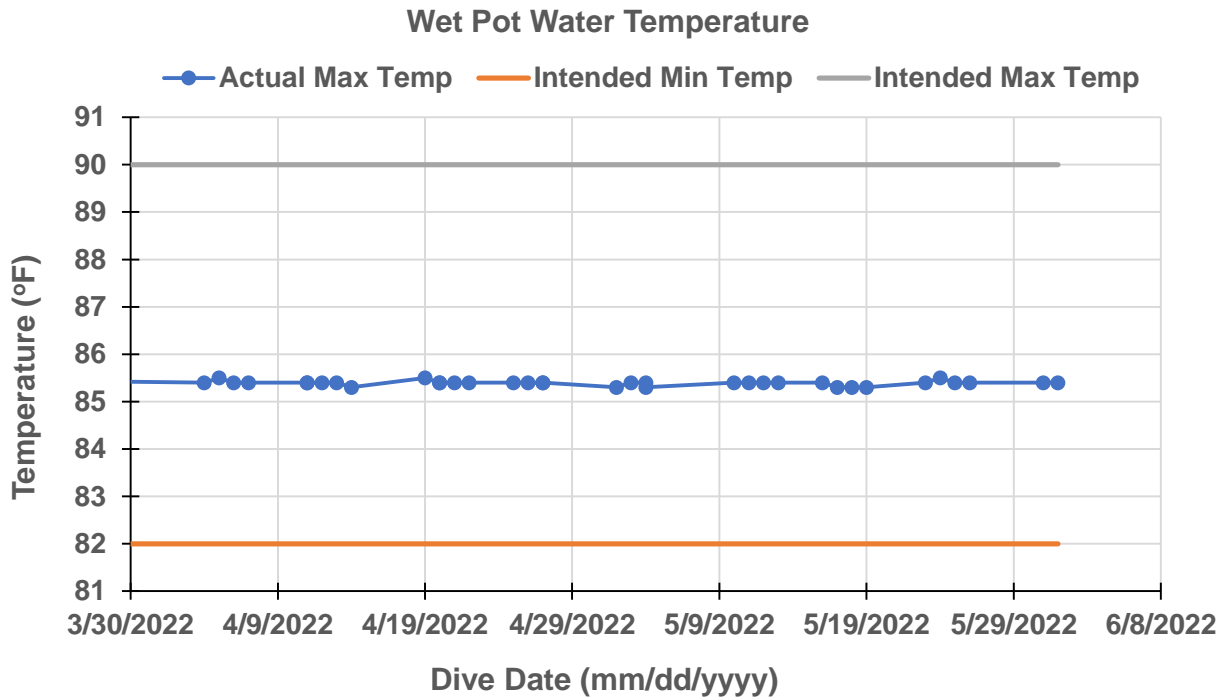


Figure 2. Wet pot water temperatures as recorded from Medical Deck thermistor after increasing the wet pot water recirculation pump rate.

Diver self-reported thermal scores were compared prior to correcting the wet pot water temperature and after the correction was made. Cold and hot discomfort were both graded on a scale of 0 (none) to 10 (maximally severe), with negative values for cold and positive values for hot.

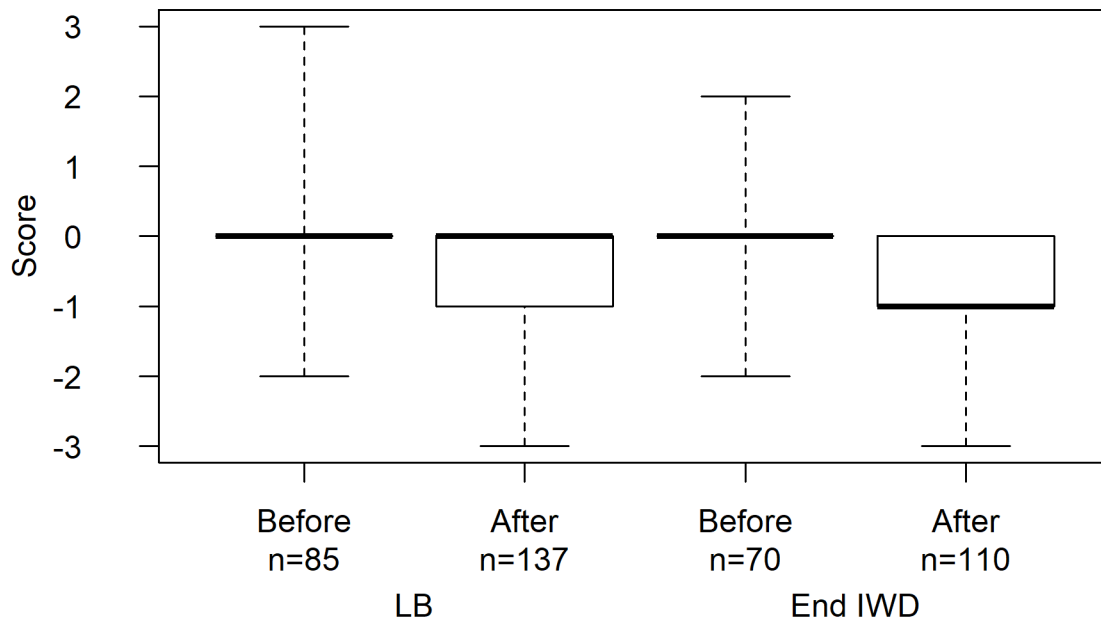


Figure 3. Diver thermal comfort scores before and after increasing the wet pot water recirculation pump rate. Scores are those reported just prior to leaving bottom (LB) and at the end of the last in-water decompression stop (End IWD). Box and whisker plots indicate median, interquartile range, and range.

By inspection of Figure 3, there is no difference in the median thermal scores before the divers left bottom and there is approximately a 1 grade difference in the medians at the end of IWD. A difference of 1 is of little practical significance, being the difference between none and very slight thermal discomfort.

Water Offset

On completion of the 57th surface-supplied He-O₂ dive on Monday, July 19, 2021, it was determined that the 10 fsw water offset depth used to this date was greater than the actual water offset of 7 fsw. The wet pot water offset is added to the chamber air pressure to account for the depth of water in the wet pot for setting in-water diver depths. As a result, in-water diver depths in the 57 man-dives completed with the erroneous water offset were actually 3 fsw shallower than intended. The impact of this error on the estimated P_{DCS} for the test schedules in the protocol is illustrated in Figure 4. The estimated P_{DCS} of the 57 schedules as dived under the protocol through 19 July were about 0.2% lower than had the dives been completed with the correct water offset depth. The water offset error was corrected for all dives undertaken on and after 20 July 2021.

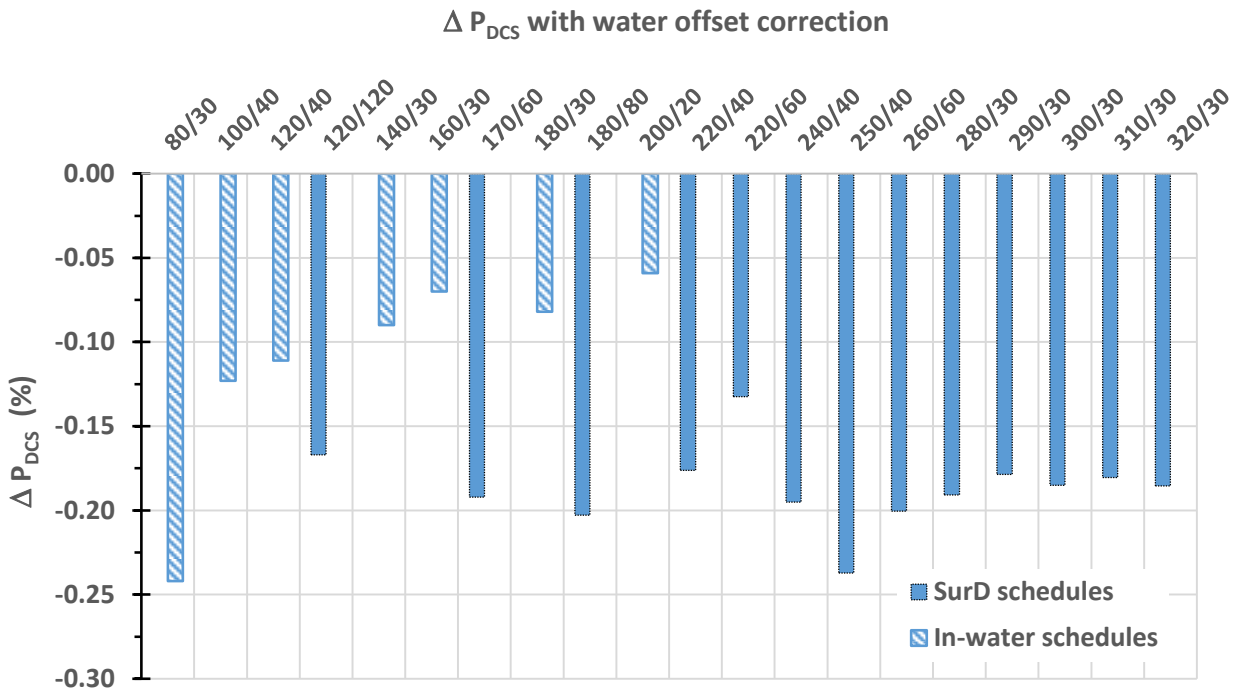


Figure 4. Changes in the estimated P_{DCS} of test schedules listed in Appendix A with correction of the water offset depth to 7 fsw. Estimates for the SurDO₂ schedules are conditional risks computed given that subjects completed the surface interval free of DCS. The negative deltas indicate that the water offset correction reduced the estimated risk of DCS for test dives completed with the erroneous 10 fsw water offset.

DIVES COMPLETED AND DCS

As a result of the above protocol deviations and testing of schedules from two candidate tables, man-dives in this trial were completed in the four groups of dive conditions shown in Table 5. A summary of dives completed by specific subjects with abbreviated descriptions of adverse outcomes is given in Table 6.

Table 5. Dive Condition Groups

Group	Schedules	# Man-Dives	Water Offset	Water Temp
A	Initial	57	Erroneous	Erroneous
B	Initial	28	Corrected	Erroneous
C	Final	141	Corrected	Corrected
D	Initial	6	Corrected	Corrected

Table 6. Test Dives Completed Summary

Schedule	Diver ID												# Dives/Sched
	4	5 ^c	7	15	20	22	12	28	47	53			
80/30 No-stop	4	5 ^c	7	15	20	22	12	28	47	53			10
100/40 IWD	3	3	10	12	13	34	38	11	44	39	12		11
120/40 IWD	21	10	20	49	40	51	11	15	46	51	44		11
120/120 SurDO ₂	3	8	11	12	19	19	34	39	15	46	40	44	12
140/30 IWD	14 ^f	20	22	23	17	37	42	44	51	6	46	52	12
160/30 IWD	19	38	6	49	49	6	38	2	11	56	57	41	12
170/60 SurDO ₂	4	11	15	25	15	20	46	37	44	60	46		11
180/30 IWD	6	10	13	17	2	55	56	57	45	28	19	12	12
180/80 SurDO ₂	9	11	20	28	19	30 ^g	6	13	7	12	30	11	12
200/20 IWD	18	2	29	25	7	46	32	20	19	54	28	13	12
220/40 SurDO ₂	2	7	14	16	12	55	13	11	12	28	20	59	12
220/60 SurDO ₂	2	8	16	27	13	20	28	45	11	35	60	45	12
240/40 [aborted]	1 ^b	5 ^a	9	11	---	---	---	---	---	---	---	---	4
240/40 SurDO ₂	4	6	8	15	7	57	56	19	7	52	38	57 ^h	12
250/40 SurDO ₂	23	13	29	33	25	30	29	6	7	55	15		11
260/40 SurDO ₂	6	13	17	22	7	41	43	45	45	59	30	12	12
280/30 SurDO ₂	7	18	20	21	26	36	37	19	32	54	11		11
290/30 SurDO ₂	7	58	38	60 ⁱ	11	51	59	20	41	42	47	19	12
300/30 SurDO ₂	2	7	10 ^d	16	18	19	21	26	7	20	45	49	12
310/30 SurDO ₂	9	11	21	28 ^e	17	37	51	52	59	57	56	40	12
320/30 SurDO ₂	7	13	17	23	52	57	47	44	12	38	51	45	12
Total:												237	
Aborted or disqualified:												-5	
Adjusted total:												232	

Note: Shaded divers completed schedules that lacked consideration of a $\pm 0.5\%$ gas mixing error allowed in the *U.S. Navy Diving Manual*.

- a, b Ear squeezes on initial descent: Dive aborted
- c Delayed presentation: Diagnosed mechanical injury after multiple recompression treatments failed to resolve complaint.
- d DCS II: Required multiple recompression treatments
- e SurDO₂ surface interval pain: Spontaneously resolved by time of arrival at the 50 fsw first SurDO₂ stop
- f Delayed report of probable mild DCS II four weeks after spontaneous resolution: No treatment required
- g Protocol deviation: Diver violated 72 post-dive prohibition of further hyperbaric exposure by serving as a tender in a hyperbaric treatment. Man-dive disqualified.
- h Marginal DCS: Transient DCS symptoms not requiring recompression
- i SurDO₂ surface interval pain: Spontaneously resolved by time of arrival at the 50 fsw first SurDO₂ stop

85 man-dives were completed on the initial schedules computed without accommodation of the $\pm 0.5\%$ gas mixing error allowed in the *U.S. Navy Diving Manual* and with an erroneous wet pot water temperature. 57 of the dives on the initial schedules were completed with an erroneous water offset and 28 were completed after correction of the water offset. 6 man-dives were completed on the initial schedules with a corrected water offset and corrected wet pot water temp. The remaining 141 man-dives were completed with the correct water offset and wet pot water temperature on schedules computed to accommodate the $\pm 0.5\%$ allowed gas mixing error.

In the 57 man-dives completed on the initial schedules in Appendix A with an erroneous water offset and wet pot water temperature, one delayed report of presumptive Type II DCS occurred. In the 28 man-dives completed on the initial schedules with an erroneous wet pot water temperature and correct water offset, one case of Type II DCS occurred and one case of surface interval pain occurred that resolved by the time of arrival at the 50 fsw first surface decompression chamber stop. In the 141 man-dives completed on the modified schedules in Appendix B, one case of marginal DCS occurred and one case of surface interval pain occurred that resolved by the time of arrival at the 50 fsw surface decompression chamber stop. Medical incidents are detailed in Appendix H.

DCS incidences from the A, B, and C dive condition groups are summarized in a 2x3 contingency table for a Fisher's exact test of independence (Table 7). DCS counts not in parentheses do not include surface interval pain that resolved before or on arrival to the 50 fsw first chamber SurDO₂ stop. DCS counts in parentheses include surface interval pain resolved before or on arrival at the 50 fsw first chamber SurDO₂ stop.

Table 7. Contingency Table for Evaluation of Dive Condition Independence

	Dive Condition Group			row totals
	A	B	C	
DCS	1	1(2)	1(2)	3(5)
No DCS	56	27(26)	140(139)	223(221)
column totals	57	28	141	226

P=0.317(0.157) by Fisher's exact test

Results failed to support a significant difference in DCS outcomes between any of the groups at $P < 0.05$, regardless of whether surface interval pain is counted as DCS. The 6 man-dives in condition group D completed with no incidents of DCS on the initial schedules with corrected wet pot water offset and corrected water temperature were not included in this test because a 2x4 table test is not supported for cases with a zero entry in any cell. However, results from all 232 completed man-dives were pooled as a 2x2 test failed to support a significant difference between pooled results of the 226 group A through group C man-dives and the 0/6 group D dives. Omitting cases of surface interval pain as per provisions in the protocol, DCS incidence in this trial was 1.3% (3/232), from which it can be inferred at 95% binomial confidence that the actual DCS risk of the schedules is less than 3.3%. If the cases of surface interval pain are included in the pooled results, DCS incidence in the trial was 2.2% (5/232), from which it can be

inferred at 95% binomial confidence that the actual DCS risk of the schedules is less than 4.5%. Either result fails to satisfy the provisions for rejection of the candidate schedules outlined in the protocol, which require the rejection of schedules if there is evidence of an actual DCS risk exceeding 5%.

VGE

Peak VGE grades during the two-hour post-dive monitoring period are shown in Figure 5. This figure includes VGE grades for the 180-fsw/80-minute man-dive omitted from the denominator for DCS incidence count (see note g for Table 6). This diver was included in the VGE results but not in the DCS results because he undertook a prohibited hyperbaric exposure after the VGE monitoring period but before the end of the DCS monitoring period. Figure 5 also includes VGE data from a man-dive that resulted in DCS with onset and recompression before the fourth and final VGE measurement. This diver had grade zero VGE for all preceding measurements and it is distinctly unusual in this circumstance to get a substantive increase in VGE grade for the last measurement.

A Kruskal Wallis test on the four groups was significant for both resting and movement VGE grades ($p < 0.0001$), indicating not all groups are the same. In the resting condition, there were differences between all pairs of groups (two-sided Wilcoxon signed-rank test, $p < 0.05$), but we focused on the peak of both resting and movement (“Movement”) measurements since these are generally considered to have a better association with DCS than resting grades.¹¹ In the movement condition, there were no differences between VGE grades for the initial table IWD and SurDO₂ dives and the final table IWD dives. However, the final table SurDO₂ schedules resulted in significantly lower VGE grades than the other groups (two-sided Wilcoxon signed-rank test, $p < 0.05$) indicating that VGE incidence with movement was more effectively mitigated by the final SurDO₂ schedules than other schedules tested. The lower VGE scores in final SurDO₂ schedules than the other groups is consistent with the final SurDO₂ schedules having the longest decompression times. By this rationale, however, it is unclear why the initial IWD schedules, which had the shortest decompression times, were not different from the initial SurDO₂ and final IWD schedules, but this may simply be because of the relatively small number of initial IWD dives.

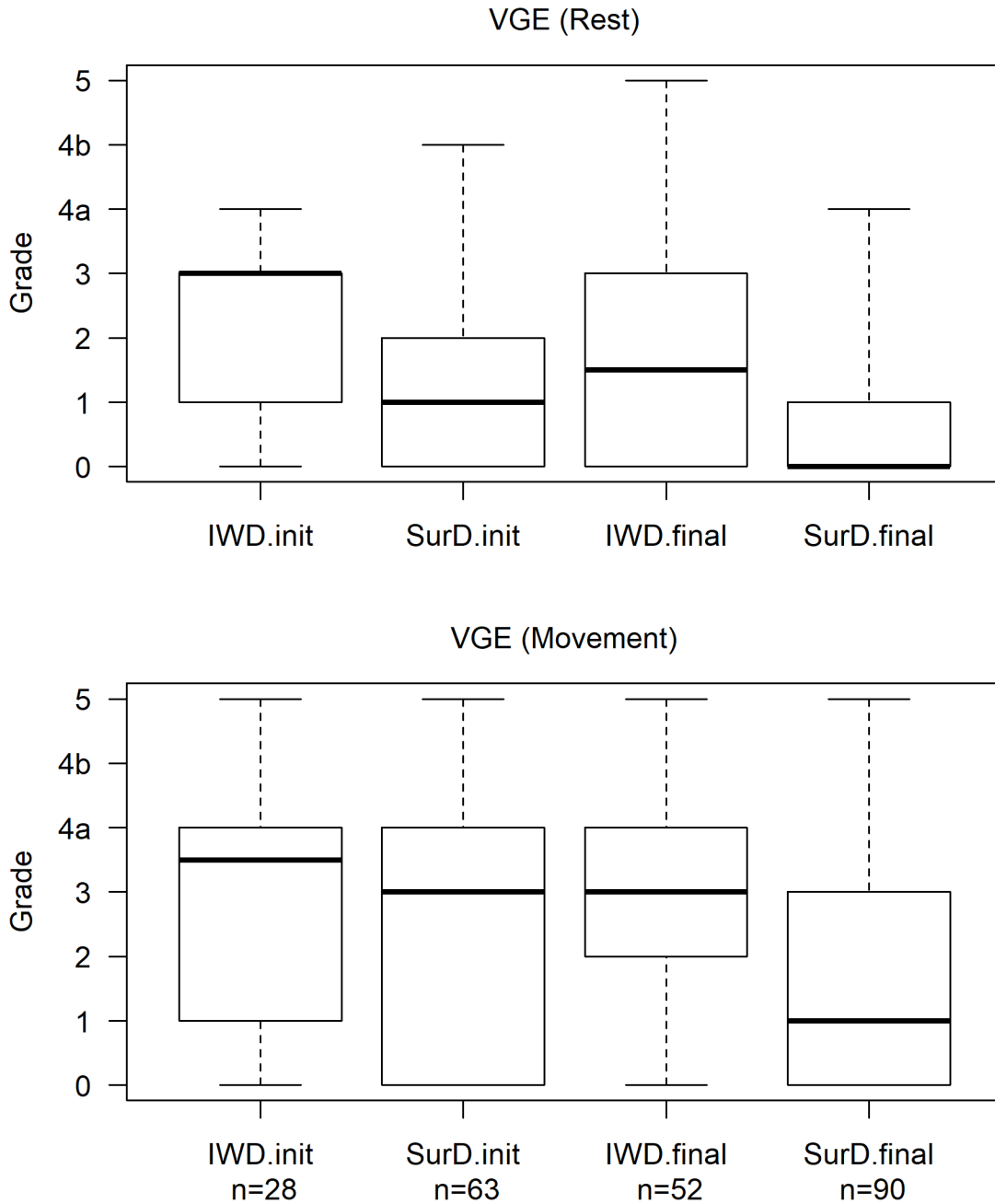


Figure 5. Peak post-dive VGE grades. Peak VGE grade during the two-hour post-dive observation period for resting condition examinations (top panel) and under any condition (resting or limb flexion [movement], bottom panel). Groups are the initial table in-water decompression and SurDO₂ schedules (IWD.init and SurDO₂.init, respectively) and the final table in-water decompression and SurDO₂ schedules (IWD final and SurDO₂ final, respectively). Box and whisker plots indicate median, interquartile range, and range.

DISCUSSION

This report describes a man-dive series completed in the Navy Experimental Diving Unit Ocean Simulation Facility to test a Surface-Supplied Helium-Oxygen Decompression table to replace the table in the current *U.S. Navy Diving Manual*. DCS incidences on completed candidate replacement schedules did not differ significantly between dives completed on initial and modified candidate schedules or under different unanticipated deviations from planned conditions (wet pot water temperature and depth offset), motivating pooling of results from all completed dives. These pooled results indicate that tested schedules incur risks of DCS less than an acceptable 5%. Because the final candidate schedules in Appendix B are more conservative than the initial schedules, the table in Appendix B is recommended for replacement of the Supplied Helium-Oxygen Decompression Table in the current *U.S. Navy Diving Manual*.

Failure of DCS incidences to differ significantly between dives on initial and modified schedules is not inconsistent with the significant difference in VGE scores for SurDO₂ dives on the two sets of schedules. A much larger number of dives would be required to resolve differences between the low DCS incidences in the two sets of dives.

Limited availability of qualified divers to volunteer for this study required allowing any given diver to participate in multiple experimental dives. To fill the dive bill from the 57-diver volunteer pool with a minimum of three divers per scheduled dive, the number of dives an individual could complete in the study was ultimately increased from 10 to 17. A maximum number of 13 dives was completed by each of two subjects. Allowing a given diver to complete multiple dives challenged the presumption in all present statistical analyses that each man-dive was independent, see Appendix D. The U.S. Navy has conducted several large-scale dive trials in which the same-diver subject repeatedly dived the same dive profile but with different DCS outcomes,¹²⁻¹⁴ which is conclusive evidence of a day-to-day (intra-subject) variability in susceptibility to DCS. On the other hand, whereas it is assumed that there is inter-subject variability in the susceptibility to DCS, the magnitude of such variability has not been conclusively established.

CONCLUSIONS

1. The candidate SS He-O₂ decompression schedules in Appendix B have acceptable risks of DCS.
2. The candidate table of schedules in Appendix B is recommended to replace the Surface-Supplied Helium-Oxygen Decompression Table in the current *U.S. Navy Diving Manual*.

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APPENDIX A INITIAL CANDIDATE REPLACEMENT SURFACE-SUPPLIED HELIUM-OXYGEN DECOMPRESSION TABLE

Schedules in Table A-1 were computed to incur an estimated risk of DCS no higher than 2.3% assuming divers breathe the minimum bottom gas O₂ fraction given for each dive depth group in the table.

Maximum descent and ascent rates are 75 fpm and 30 fpm, respectively.

Times at all stops except the first include travel time to the stop.

Tabulated in-water stop times at 30 and 20 fsw do not include a recommended 5-minute air-breathing break after each 30 minutes of O₂ breathing. The air break after the last O₂ period is omitted to surface the diver on air. Each SurDO₂ chamber O₂ period except the last consists of 30 minutes O₂ breathing followed by 5 minutes chamber air breathing. As with in-water decompression, the air break after the last O₂ period is omitted to surface the diver on air.

A double line in a dive depth group separates normal exposure dives above the line from exceptional exposure dives below the line as given for the group in the current U.S. Navy Surface-Supplied Helium-Oxygen Decompression Table.

TABLE A-1. INITIAL CANDIDATE REPLACEMENT SURFACE-SUPPLIED HELIUM-OXYGEN DECOMPRESSION TABLE

Depth (fsw) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																	TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN)																			
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40			30
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)			
60	10																			0	
Max O ₂ = 40.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																			0	
	60																	2		2	1
	80																		17	17	1
	100																		37	37	2
	120																		54	54	2
70	10																			0	
Max O ₂ = 40.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																			0	
	60																	7		7	1
	80																		33	33	2
	100																		55	55	2
	120																		74	74	3
80	10																			0	
Max O ₂ = 38.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																	3		3	1
	60																	1	20	21	1
	80																	2	47	49	2
	100																	2	71	73	3
	120																	2	91	93	4

A-2

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																	TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN)																			
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40			30
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)		
90	10																			0	
Max O ₂ = 34.9%	20																			0	
Min O ₂ = 21.0%	30																	3		3	1
	40																	4		4	1
	60																	3	31	34	2
	80																	3	61	64	3
	100											1						3	85	89	3
	120											1						12	98	111	4
100	10																			0	
Max O ₂ = 32.3%	20																			0	
Min O ₂ = 21.0%	30																	4		4	1
	40											1						8		9	1
	60											1						5	42	48	2
	80											1						6	73	80	3
	100											1						8	98	107	4
	120											1						31	98	130	5
110	10																			0	
Max O ₂ = 30%	20																	4		4	1
Min O ₂ = 21.0%	30											1						6		7	1
	40											1						6	12	19	1
	60											1						7	52	60	2
	80											1						7	86	94	4
	100											1						23	98	122	5
	120											1						47	99	147	5

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																	TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN)																			
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40			30
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)			
120	10																			0	
Max O ₂ = 28%	20																	4		4	1
Min O ₂ = 21.0%	30											1						8		9	1
	40											1						7	21	29	1
	60											1						8	64	73	3
	80											1						8	99	108	4
	100														2			36	99	137	5
	120														2			61	99	162	6
130	10																			0	
Max O ₂ = 26.3%	20											1						6		7	1
Min O ₂ = 21.0%	30											1						11		12	1
	40											1						8	30	39	2
	60											1						9	76	86	3
	80											1						20	101	122	5
	100													1	3			49	99	152	5
	120													1	3			74	101	179	6
140	10																			0	
Max O ₂ = 24.8%	20											1						6		7	1
Min O ₂ = 21.0%	30											1						19		20	1
	40											1	1					10	38	50	2
	60													2	2			10	83	97	4
	80												1	2	3	2		30	98	136	5
	100												1	1	3	3	3	58	98	167	6
	120													2	3	2	5	84	100	196	7

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																	TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods			
		STOP TIMES (MIN)															20	10					
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60					50	40	
BOTTOM MIX															(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)	
210	10																	6	7	1			
Max O ₂ = 17.7%	20																	10	28	42	2		
Min O ₂ = 16.0%	30												5	3	1	3	2	8	15	60	97	3	
	40												8	2	2	10	11	9	14	94	150	4	
	60												14	12	11	10	10	9	58	102	226	6	
	80							3	4	3	1		18	12	11	10	9	9	103	107	290	8	
	100							4	6	2	3	3	18	12	11	9	19		139	114	340	9	
	120							4	5	6		7	18	11	11	20	8		164	129	383	10	
220	10																	8	9	1			
Max O ₂ = 17.0%	20													3	2	2			9	33	49	2	
Min O ₂ = 16.0%	30													7	2	2	2	7	9	15	66	3	
	40													9	2	8	11	11	9	14	101	4	
	60							1	3	3	1			18	12	11	10	9	9	72	102	6	
	80							6	3	4	4	6		18	12	11	10	9	9	118	109	319	8
	100							9	4	6	4	7		19	11	10	10	18		150	124	372	10
	120							5	4	4	10	12		18	12	11	28			175	136	415	11
230	10																	8	9	1			
Max O ₂ = 16.3%	20														4	3			13	37	57	2	
Min O ₂ = 16.0%	30														8	2	3	3	10	10	15	72	3
	40														10	6	12	11	9	9	21	103	5
	60							5	4	3	3	2		19	12	11	9	10	8	87	103	276	7
	80							5	3	5	3	7	12	18	12	11	10	18		131	113	348	9
	100							8	5	3	6	8	12	19	11	10	17	11		162	130	402	10
	120							5	3	4	9	14	12	17	12	13	27			186	145	447	12

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Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN)																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)				
300	10											3	2	2				8	23	38	2	
Max O ₂ = 12.9%	20											13	2	2	12	10	9	15	84	147	4	
Min O ₂ = 12.0%	30				7	6	4	4	2			21	13	10	10	10	9	70	104	270	6	
	40		11	10	2	2	15	9			3	12	20	12	11	11	17		138	117	390	9
	60	14	8	22	7	8	5	13	12	3		17	19	12	51	25			187	146	549	12
	80	24	23	1	11	15	7	9		6	19	17	36	53	58	26			187	147	639	12
	100	43	17	3			3	9	16	18	18	18	72	53	59	36			183	149	697	12
	120	29	5	14	11		9	16	17	17	35		102	54	59	40			179	152	739	12
310	10												4	2	2				8	28	44	2
Max O ₂ = 12.5%	20												14	2	7	11	11	9	14	91	159	4
Min O ₂ = 12.0%	30				13	4	4	4	4	2			22	12	11	10	10	8	84	106	294	7
	40	8	7	1	8	10	14	1	1	3	8	16	20	12	10	10	18		148	122	417	10
	60	16	26	6	12	3	13		5	5	19	17	18	19	59	27			186	147	578	12
	80	31	9	12	27				13	18	19	18	44	53	61	34			185	143	667	11
	100	17	19	15	3	18	9	10	17	18	19	18	78	54	59	38			180	152	724	12
	120	40		6	10	19	5	15	17	18	36		114	55	60	51			172	160	778	12
320	10												4	4					10	32	50	2
Max O ₂ = 12.2%	20												15	2	12	11	10	9	15	97	171	4
Min O ₂ = 12.0%	30			9	7	4	4	5	3	4	4	3	21	12	10	10	10	9	98	107	320	7
	40	11	4	4	5	9	30		1		6	16	20	11	11	17	11		159	130	445	10
	60	32	18	1		17	11	9		11	17	17	18	37	59	34			182	146	609	11
	80	23	42	9	1	8		9	17	12	18	18	65	54	62	35			183	142	698	11
	100	66	3	4	11	1		11	17	18	35	1	108	55	62	68			164	162	786	11
	120	51	1	6	7	12	14	15	18	50			146	57	64	72	81		117	173	884	10

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods		
		STOP TIMES (MIN)																					
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20	
BOTTOM MIX												(50)	(50)	(50)	(50)	(50)	(50)	(90)	(90)				
370	10											8	2	3	2	3	4	16	46	84	3		
Max O ₂ = 10.6%	20				5	16					2	22	12	11	10	9	9	60	112	268	6		
	30	21	3	14	7	6	9	15	3		9	7	21	11	10	29			169	137	471	11	
	40	46	17	8	1		2	3	11	21	22	17	18	23	59	39			179	153	619	12	
380	10												10	2	2	2	3	8	16	51	94	3	
Max O ₂ = 10.4%	20				15	9	5	4	2				22	13	10	10	10	9	84	111	304	7	
	30	30	2	6	12	10		5		18	22	19	20	11	11	34			181	149	530	12	
	40	56	38	3	1	9				10	14	17	21	36	53	60	44			176	154	692	12

APPENDIX B FINAL CANDIDATE REPLACEMENT SURFACE-SUPPLIED HELIUM-OXYGEN DECOMPRESSION TABLE

Schedules in Table B-2 were computed to incur an estimated risk of DCS no higher than 2.3% assuming divers breathe the minimum bottom gas O₂ fraction given for each dive depth group less 0.5% to accommodate the U.S. Navy allowed gas mixing error.^a

Descent and ascent rates of 75 and 30 fsw/min, respectively, were assumed. Any schedule may be used operationally with a slower descent rate without penalty.

Times at all decompression stops except the first and those with a gas switch include travel time to stop.

Breathing gas is switched during ascent from bottom mix to 50% N₂/50% O₂ at 90 fsw and to 100% O₂ at 30 fsw for in-water decompression. In-water stop times on 100% O₂ at 30 and 20 fsw do not include a 5-minute air-breathing break recommended after each 30 minutes of O₂ breathing.

SurDO₂ is conducted in accordance with guidance in the *U.S. Navy Diving Manual*, Revision 7 Change A, with the following provisions: To commence SurDO₂ in schedules with no 40 fsw in-water stop, a 5 min stop at 40 fsw, including travel time from the 90 fsw gas switch or the last preceding stop, whichever is shallower, shall be arbitrarily inserted before no-stop ascent to surface. Each chamber O₂ period except the last consists of 30 minutes O₂ breathing followed by 5 minutes chamber air breathing. The air break after the last O₂ period is omitted.

A double line in a dive depth group separates normal exposure dives above the line from exceptional exposure dives below the line as given for the group in the current U.S. Navy Surface-Supplied Helium-Oxygen Decompression Table.

^a The maximum bottom gas O₂ fraction for each dive depth group is as specified in the current *U.S. Navy Diving Manual* to avoid exceeding a 1.3 atm inspired oxygen partial pressure. Accommodation for the ±0.5% gas mixing error allowed in the *U.S. Navy Diving Manual* has been made in the computed schedules, not in these tabulated specifications.

TABLE B-2. FINAL CANDIDATE REPLACEMENT SURFACE-SUPPLIED HELIUM-OXYGEN DECOMPRESSION TABLE

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																			
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)			
60	10																			0	
Max O ₂ = 40.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																			0	
	60																	2		2	1
	80																		18	18	1
	100																		38	38	2
	120																		56	56	2
70	10																			0	
Max O ₂ = 40.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																			0	
	60																		8	8	1
	80																		34	34	2
	100																		56	56	2
	120																		76	76	3
80	10																			0	
Max O ₂ = 38.0%	20																			0	
Min O ₂ = 21.0%	30																			0	
	40																		3	3	1
	60																		1 21	22	1

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Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																			TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
	80																	2	48	50	2	
	100																	2	72	74	3	
	120																	2	92	94	4	
90	10																				0	
Max O ₂ = 34.9%	20																				0	
Min O ₂ = 21.0%	30																	3		3	1	
	40																	5		5	1	
	60																	3	32	35	2	
	80											1						2	62	65	3	
	100											1						2	87	90	3	
	120											1						13	98	112	4	
100	10																				0	
Max O ₂ = 32.3%	20																				0	
Min O ₂ = 21.0%	30											1						3		4	1	
	40											1						7		8	1	
	60											1						3	43	47	2	
	80											1						4	74	79	3	
	100											1						8	97	106	4	
	120											1						30	98	129	5	
110	10																				0	
Max O ₂ = 30.0%	20																	4		4	1	
Min O ₂ = 21.0%	30											1						4		5	1	
	40											1						4	13	18	1	

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																			TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
	60											1						5	54	60	2	
	80											1						5	87	93	4	
	100											1						22	99	122	5	
	120											1						46	99	146	5	
120	10																			0		
Max O ₂ = 28.0%	20											1						3		4	1	
Min O ₂ = 21.0%	30											1						6		7	1	
	40											1						5	22	28	1	
	60											1						6	65	72	3	
	80											1						7	99	107	4	
	100														2			36	100	138	5	
	120														2			61	100	163	6	
130	10																			0		
Max O ₂ = 26.3%	20											1						4		5	1	
Min O ₂ = 21.0%	30											1						9		10	1	
	40											1						6	31	38	2	
	60													2				7	76	85	3	
	80													2				19	101	122	5	
	100													3				49	100	152	5	
	120													2	2			74	101	179	6	
140	10																			0		
Max O ₂ = 24.8%	20											1						4		5	1	
Min O ₂ = 21.0%	30											1						17		18	1	

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
	40											1						8	40	49	2	
	60												1	3				11	82	97	4	
	80												1	2	2	3		30	98	136	5	
	100												1	2	2	3	3	60	98	169	6	
	120												1	2	2	2	6	85	100	198	7	
150	10																			0		
Max O ₂ = 23.4%	20											1						5		6	1	
Min O ₂ = 21.0%	30											1						7	19	27	1	
	40												2					8	49	59	2	
	60											1	1	2	6			15	86	111	4	
	80												2	2	2	3	8	38	99	154	5	
	100												2	2	3	4	10	68	98	187	6	
	120												2	2	3	6	9	93	102	217	7	
160	10																			0		
Max O ₂ = 22.2%	20											1						7		8	1	
Min O ₂ = 21.0%	30											2						8	26	36	2	
	40											1	1	3				9	55	69	3	
	60											1	2	2	2	3	9	15	93	127	4	
	80											1	2	3	2	10	9	46	98	171	5	
	100											1	3	3	4	10	10	76	99	206	6	
	120											1	2	3	7	11	9	101	103	237	7	
170	10											1						4		5	1	
Max O ₂ = 21.2%	20											1						11		12	1	

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																			
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)			
Min O ₂ = 16.0%	30											4						8	44	56	2
	40											3	2	2	3			16	66	92	3
	60											4	2	2	3	9	10	29	98	157	5
	80											5	2	2	11	10	10	66	99	205	6
	100											5	2	6	11	10	10	96	103	243	7
	120											5	2	8	11	15	5	122	110	278	8
180	10											1						4		5	1
Max O ₂ = 20.1%	20											2						17	1	20	1
Min O ₂ = 16.0%	30											2	3	2				7	51	65	2
	40											4	3	1	3	2	6	15	72	106	3
	60											5	3	2	9	11	9	36	100	175	5
	80											6	2	11	11	10	9	73	101	223	6
	100											6	7	11	11	10	9	104	105	263	7
	120											6	9	11	11	19		129	114	299	9
190	10											1						4		5	1
Max O ₂ = 19.2%	20											2						8	17	27	1
Min O ₂ = 16.0%	30											4	4					15	51	74	3
	40											5	2	2	3	5	9	15	80	121	4
	60											7	2	9	11	10	9	44	100	192	5
	80											7	11	12	10	10	9	81	103	243	7
	100											11	13	11	10	10	8	112	109	284	8
	120											14	13	10	10	19		137	118	321	9
200	10											1						4		5	1

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods			
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																						
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)						
Max O ₂ = 18.4%	20											1	3					8	26	38	2			
Min O ₂ = 16.0%	30											4	2	2	3	3	3	15	57	89	3			
	40											7	2	3	3	12	9	15	88	139	4			
	60											8	9	12	10	10	9	52	102	212	6			
	80								1			17	12	11	10	9	9	91	105	265	7			
	100								3	5		17	12	11	9	19		126	111	313	8			
	120								4	3	4	17	12	10	11	18		151	124	354	10			
210	10											1						6		7	1			
Max O ₂ = 17.7%	20											2	3					8	32	45	2			
Min O ₂ = 16.0%	30											6	2	2	2	3	9	15	63	102	3			
	40											8	2	2	11	11	9	15	96	154	4			
	60											15	13	11	10	9	9	60	103	230	6			
	80								3	3	4	3	18	13	10	9	10	9	107	106	295	8		
	100								4	6	2	3	5	18	12	10	10	18	139	117	344	9		
	120								4	6	1	4	9	17	12	10	29		166	129	387	10		
220	10											1						6		7	1			
Max O ₂ = 17.0%	20											4	3					8	37	52	2			
Min O ₂ = 16.0%	30											7	2	2	3	7	10	16	68	115	3			
	40											9	3	9	11	10	9	17	102	170	4			
	60								5	3		18	12	11	10	9	9	75	103	255	6			
	80								3	3	4	3	6	6	18	12	11	10	11	7	120	111	325	8
	100								5	5		4	6	13	18	12	10	10	18	152	124	377	10	
	120								5	5		9	5	12	18	12	10	28		177	139	420	11	

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
230	10											1						9		10	1	
Max O ₂ = 16.3%	20											6	3					14	45	68	2	
Min O ₂ = 12.0%	30											10	3	2	4	12	9	16	84	140	4	
	40											13	7	12	11	10	9	30	107	199	5	
	60				8	4	4	5	3	4		21	12	10	11	10	7	109	111	319	8	
	80				12	18	1	1		5	14	20	12	10	11	17		157	129	407	10	
	100				14	1	2	5	10	18	17	18	12	12	28			185	145	467	12	
	120				8	3	5	5	15	20	17	18	12	53	27			185	148	516	12	
240	10											1						10		11	1	
Max O ₂ = 15.7%	20											6	2	5				16	48	77	3	
Min O ₂ = 12.0%	30											11	2	3	10	11	9	15	93	154	4	
	40											15	14	11	10	10	9	37	109	215	5	
	60				8	5	3	6	3	5	3	10	20	12	11	10	18		125	114	353	8
	80				15	11	5	3	2		13	16	20	12	11	27			170	137	442	11
	100				7	8	4	1	16	8	20	17	19	11	35	25			186	149	506	12
	120				12		3	5	16	13	20	18	18	30	59	25			186	148	553	12
250	10											1						11		12	1	
Max O ₂ = 15.2%	20											7	2	3	2	3	3	16	51	87	3	
Min O ₂ = 12.0%	30											13	2	7	11	10	10	15	100	168	4	
	40				6							20	13	11	10	9	9	54	109	241	6	
	60			8	10	4	8	11	1	1	9	20	12	11	11	17		143	123	389	9	
	80			8	7		4	6	4	19	20	17	19	12	11	28			180	143	478	11
	100			11	7	8		6	7	18	20	18	18	13	58	26			186	147	543	12
	120			9	6	8	5		17	18	20	17	18	51	59	26			186	149	589	12

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																			TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
	120	15	10	24			10	12	8	18	21	18	78	53	59	35			182	148	691	12
290	10												3	3					23	2	31	1
Max O ₂ = 13.3%	20												12	2	2	6	10	10	14	77	133	4
Min O ₂ = 12.0%	30					11							20	14	10	10	11	7	51	109	243	6
	40		4	11	2	4	4	8	6		18		20	12	11	11	17		124	113	365	8
	60	18	7		4	6	2	18	4	14	36		19	12	25	25			186	148	524	12
	80	13	9	19	15	2			32	37			22	53	60	26			186	146	620	12
	100	12	16	20	2	3	6	12	17	20	19	19	54	54	59	32			183	149	677	12
	120	13	9	9	9	7	16	16	18	18	21	17	86	53	60	38			179	152	721	12
300	10												3	2	2				8	21	36	1
Max O ₂ = 12.9%	20												13	2	2	10	11	9	15	83	145	4
Min O ₂ = 12.0%	30				5	10	4	2					21	12	11	10	10	8	69	107	269	6
	40		12	13	8	1	1	7	8		14		20	12	11	11	17		139	120	394	9
	60	15	14	22	4			9	11	7	18	18	18	13	52	23			187	146	557	12
	80	16	23	18	17		7	7		14	20	18	39	53	58	30			184	146	650	12
	100	29	12		7	4	16	16	17	20	20	18	68	53	59	35			181	151	706	12
	120	28	15	7	8	4	10	16	17	19	37		105	54	60	40			178	153	751	12
310	10												4	2	2				7	26	41	2
Max O ₂ = 12.5%	20												14	2	6	11	11	9	14	90	157	4
Min O ₂ = 12.0%	30			1	12	4	5	4	7				20	12	11	10	10	8	85	107	296	7
	40	8	11	17	5	3		4	5	6	15		20	12	10	11	17		153	126	423	10
	60	23	3	19	4	14	21			7	20	18	18	21	58	31			184	148	589	12
	80	34	17	2	15	8	8	57					70	54	59	35			181	147	687	11

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																			TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20		
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
	100	20	19	11	12	22	1	10	17	20	20	17	85	54	59	40			178	153	738	12
	120	19	12	12	14	16	14	16	18	19	37		116	54	61	53			171	159	791	12
320	10												5	2	3				8	33	51	2
Max O ₂ = 12.2%	20												16	3	10	11	10	9	14	103	176	4
Min O ₂ = 10.0%	30			10	15	6	3	5	5	3	5		22	12	11	9	19		117	116	358	8
	40	22	16		1	10	3	7	8	1	43		20	12	11	29			180	148	511	11
	60	47	9	25	1	7	9	8		22	23	22	45	53	59	38			178	149	695	11
	80	42	27	12	5	2	11	21	20	23	28	18	90	53	61	43			175	157	788	12
	100	47	17	10	8	15	19	19	21	28	41		134	56	63	70	52		133	167	900	11
	120	82				18	19	20	229	482	420		115	60	67	77	88	100	63	174	2014	8
330	10												6	4					9	38	57	2
Max O ₂ = 11.8%	20												18	6	11	11	10	9	13	111	189	5
Min O ₂ = 10.0%	30		3	17	14	4	5	2	3	5	12		23	11	11	9	18		129	125	391	9
	40	23	18	7	20				7	7	22	19	19	12	32	32			182	147	547	11
	60	59	26	11	4	2	2	1	15	18	44		63	54	61	42			179	149	730	11
	80	60	27	10	8		5	20	21	25	44		116	55	63	70	36		145	160	865	11
340	10												7	4					12	40	63	2
Max O ₂ = 11.5%	20												19	11	11	10	10	9	14	118	202	5
Min O ₂ = 10.0%	30		14	17	15			9	5		6	11	22	11	10	10	18		146	128	422	10
	40	30	3	6	16	14	15	7			26	20	19	12	47	37			179	150	581	11
	60	54	25	1	14	8		22	23	49			85	55	60	44			176	149	765	11
350	10												8	2	3				15	41	69	2

Depth (fswg) FO ₂ %	Bottom Time (min)	DECOMPRESSION STOPS (FSW)																		TOTAL IWD STOP TIME (min)	Chamber O ₂ Periods	
		STOP TIMES (MIN). All except first and those with a gas switch include travel time to stop																				
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30			20
BOTTOM MIX											(50)	(50)	(50)	(50)	(50)	(50)	(100)	(100)				
Max O ₂ = 11.2%	20					1						22	13	11	10	10	9	20	125	221	5	
Min O ₂ = 10.0%	30	7	16	7	4	5	12	10	2	5	6	18	22	11	11	10	17		155	135	453	10
	40	40	6	8	25				12	13	43		19	21	59	40			179	151	616	12
	60	64	40	10	1		4	16	11	19	45		94	56	63	72			162	160	817	11
360	10												8	3	2	4			16	44	77	3
Max O ₂ = 10.9%	20					12							22	13	11	10	10	8	45	121	252	6
Min O ₂ = 10.0%	30	17	15	17	17	1	6		3	17			21	11	11	28			174	146	484	11
	40	40	13	19	9		5	6	7	17	25	20	19	38	59	39			178	152	646	12

B-12

370	10												9	3	1	3	3	3	15	48	85	3
Max O ₂ = 10.6%	20				3	20							22	12	11	10	10	8	66	118	280	7
Min O ₂ = 10.0%	30	24	18	1	6	7	12		8	6	13	19	20	11	11	29			179	149	513	11
	40	49	34	8	2	4	1	1	13	11	44		23	54	60	45			176	154	679	12
380	10												10	2	2	3	2	7	17	50	93	3
Max O ₂ = 10.4%	20				14	12	5	2					22	12	11	10	11	7	83	116	305	7
Min O ₂ = 10.0%	30	29	7	15	7	14	6	3		11	12	20	20	11	24	40			178	152	549	12
	40	59	16		8	8	8	7	18	56			43	54	61	47			174	152	711	11

APPENDIX C TEST DIVE PROFILES*

- 1) 80/30 no-stop
- 2) 100/40 In-water
- 3) 120/40 In-water
- 4) 120/120 SurDO₂
- 5) 140/30 In-water
- 6) 160/30 In-water
- 7) 170/60 SurDO₂
- 8) 180/30 In-water
- 9) 180/80 SurDO₂
- 10) 200/20 In-water
- 11) 220/40 SurDO₂
- 12) 220/60 SurDO₂
- 13) 240/40 SurDO₂
- 14) 250/40 SurDO₂
- 15) 260/40 SurDO₂
- 16) 280/30 SurDO₂
- 17) 290/30 SurDO₂
- 18) 300/30 SurDO₂
- 19) 310/30 SurDO₂
- 20) 320/30 SurDO₂

*Dive Depth (fsw)/Bottom Time (min)

APPENDIX D EXPERIMENTAL DESIGN

The objective of this study was to validate new surface-supplied heliox decompression tables given in Appendices A and B by man-testing representative decompression schedules selected from the tables. Occurrence of DCS or not after each man-dive was the experimental endpoint. Criteria for assessment of dive outcomes are given in Appendix E. The DCS or No-DCS outcomes from all decompression schedules were pooled under the expectation that all schedules have the same risk of DCS.

The cumulative incidence of DCS in this study was expected to be less than 5%. With a rare binary outcome, it is not practicable to conduct enough man-dives to establish with any confidence that the P_{DCS} is less than some small value. As is usual for validation of decompression algorithms, the study was designed to reject the decompression algorithm with a high cumulative incidence of DCS, but otherwise accept the decompression algorithm. In this case the null hypothesis (H_0) was that these surface-supplied He-O₂ dives would result in a cumulative incidence of DCS not higher than 5% with 85% confidence.

The proposed 240 man-dive sample size was chosen as a number that could achieve a statistically significant result within constraints of cost and scheduling. To limit diver exposure to unnecessary risk, the dives were conducted in a group sequential design. The trial was to stop, and the new decompression schedules rejected in full if the incidence of DCS indicated P_{DCS} greater than 5% with 85% confidence, according to the stopping rules in Table D-1. The minimum number of DCS to trigger a stop was four to avoid stopping due to a cluster of DCS cases early in the trial. Man-dives accrued in groups of three or four and could cross boundaries in Table D-1. To avoid ambiguity in applying stopping rules, man-dives were assumed to accrue in order of divers' color designations (Red, Green, Yellow, Blue). For instance, if a group of four divers were to complete man-dives 39–42, Blue diver was to be considered to have completed the 42nd man-dive, and if Blue diver became the fourth case of DCS, the trial would not be stopped.

Table D-1. Stop-high (reject) rules

Stop with 85% confidence > 5% P _{DCS}	
# DCS (or more)	in # man-dives (or fewer)
4	41
5	56
6	71
7	87
8	104
9	120
10	137
11	153
12	170
13	188
14	205
15	222
16	240

The null hypothesis was to be rejected if the trial was ended with a stop-high outcome. Monte Carlo simulation of possible trial outcomes¹⁵ indicated that the probability of rejecting the hypothesis if the real P_{DCS} is less than 5% (equivalent to significance) was 7.9% and the probability of failing to reject the hypothesis if the real P_{DCS} is higher than 5% (equivalent to 1-power) was 1.2%. This latter error was calculated assuming the real P_{DCS} of the schedules being tested could be any value up to 100%. The error is larger (and the power lower) if a more credible upper limit of real P_{DCS} is used. For instance, using 25% as the upper limit for real P_{DCS} results in an estimate of 1-power of 5.6%.

Although testing was to be based on pooled results of all schedules, it was recognized that the incidence of DCS on one or more individual schedules might indicate that schedules in a particular depth/bottom time domain incur unacceptable risks. Testing of any schedule was to be terminated on occurrence of two or more DCS cases of inordinately high severity (life or limb threatening). The NEDU Senior Medical Officer or their designee, with concurrence of the NEDU Commanding Officer, were to determine if this criterion was met and that testing must cease.

All dives deeper than 300 fsw were considered exceptional exposure. Limited testing of schedules for dives to depths deeper than 300 fsw was planned but outcomes of these dives were not planned to contribute to the sequential trial hypothesis testing. Testing of these exceptional exposure schedules was to be terminated on the occurrence of any DCS.

APPENDIX E CRITERIA FOR DCS AS AN EXPERIMENTAL OUTCOME

No gold standard criteria or generally accepted case definition for DCS exists. For consistency with assessments of DCS outcomes in past work, the outcome of each man-dive was categorized according to the Weathersby, et al.,^a standard criteria reprinted in Appendix A of Temple, et al,¹⁶ and reproduced again following. The duty Undersea Medical Officer was responsible for all outcome assignments.

A1: DCS requiring recompression

- Joint pain persisting at least as long as tabulated below (whether recompressed or not)

Severity	One joint	Multiple joints
Mild	60 min	30 min
Moderate	30 min	15 min
Severe	15 min	8 min

- Skin rash or mottling in combination with joint pain of any duration
- Dyspnea, unless clearly from barotrauma or anxiety hyperventilation syndrome
- Any spinal neurological symptoms supported by signs
- Any brain symptoms^b
- Any inner ear symptoms,^c unless clearly from barotrauma
- Any suspicious symptom leading to and relieved by recompression

A2: Marginal DCS (DCS not requiring recompression)^d

- Joint pain not persisting as long as tabulated above
- Moderate or severe fatigue
- Skin itch in water-immersed divers breathing air or N₂-O₂
- Skin rash or mottling as only symptom
- Symptoms reported as “DCS not requiring recompression” not fitting other criteria

B: Unknown outcome (data should not be used)

- Headache, typical and common for this diver
- Vague abdominal or chest pain, not related to trauma or barotrauma
- Vague symptoms of any kind not responding to recompression or oxygen therapy attempted <18 hours after dive^e

C: Not DCS

- No signs or symptoms reported
- Signs or symptoms reported 24 hours after surfacing

^a Weathersby et al. 1988 criteria²³; language reflects development for retrospective data review; not used for treatment decisions

^be.g., visual blurring, “mental sluggishness”

^c e.g., unsteadiness, vertigo, hearing loss

^d Based on perception that lack of treatment will not result in morbidity

^e Diver may have gone on to develop DCS if not treated

- Mild joint pain or fatigue consistent with recent exercise
- Sharp pain consistent with joint sprain or impact injury
- Vague symptoms similar to Marginal DCS not responding to recompression therapy attempted >18 hours after dive

Surface Interval Pain

Mild musculoskeletal pain and associated symptoms occurred in rare instances while divers were at surface between completing in-water stops and recompression for SurDO₂. Surface interval pain is defined as any Type I DCS symptom (limb pain, rash, itch, or lymphatic symptoms) or cutaneous sensory symptoms with patchy or non-dermatomal distribution that resolve during the first 15 minutes of chamber oxygen at the first SurDO₂ chamber stop. Such transient mild manifestations of DCS are considered to have no long-term health effects. One tally of DCS outcomes in present work did not include such incidents as DCS and another included them. Final recommendation for adoption of a replacement table was to be based on the tally that did not include cases of surface interval pain.

APPENDIX F DIVER CHARACTERISTICS

Diver ID	Age (yr)	Height (in)	Height (m)	Weight (lbs)	Weight (kg)	Waist (in)	Waist (m)	Neck (in)	Neck (m)	BMI	Body Fat (%)
1 ^F											
2	36	71	1.8	200	90.7	37	0.94	16	0.41	28	20
3 ^F	30	69	1.75	156	70.8	28	0.71	12.5	0.32	23	10
4	37	70	1.78	190	86.2	34	0.86	15	0.38	27	17
5	45	71	1.8	199	90.3	37	0.94	16	0.41	28	20
6	43	65	1.65	198	89.8	40	1.02	16	0.41	33	28
7	36	71	1.8	178	80.7	31	0.79	14.5	0.37	25	12
8	34	73	1.85	215	97.5	38	0.97	16.5	0.42	28	21
9	34	75	1.9	245	111.1	34	0.86	17	0.43	31	11
10	35	71	1.8	205	93	40	1.02	15.5	0.39	29	27
11	27	70	1.78	172	78	34	0.86	15	0.38	25	17
12	26	69	1.75	165	74.8	33	0.84	15.5	0.39	24	15
13	34	69	1.75	207	93.9	39	0.99	16	0.41	31	25
14	33	69	1.75	175	79.4	32	0.81	14.5	0.37	26	14
15	31	70	1.78	206	93.4	37	0.94	15.5	0.39	29	22
16	34	69	1.75	175	79.4	34	0.86	14	0.36	26	19
17	29	72	1.83	180	81.6	35	0.89	15.5	0.39	24	18
18	33	70	1.78	230	104.3	42	1.07	16	0.41	33	29
19	44	65	1.65	185	83.9	37	0.94	16.5	0.42	31	22
20	35	70	1.78	193	87.5	36	0.91	16	0.41	28	19
21	46	75	1.9	220	99.8	36	0.91	15.5	0.39	28	18
22	31	69	1.75	183	83	36	0.91	14.5	0.37	27	22
23	31	72	1.83	205	93	35	0.89	15.5	0.39	28	18
25	34	66	1.68	165	74.8	34	0.86	15	0.38	27	19
26	31	71	1.8	198	89.8	32	0.81	14.5	0.37	28	14
27	38	72	1.83	205	93	37	0.94	13.5	0.34	28	25
28	37	69	1.75	196	88.9	37	0.94	14	0.36	29	25
29	32	72	1.83	135	61.2	31	0.79	14	0.36	18	12
30	37	69	1.75	202	91.6	34	0.86	16.5	0.42	30	14
32	49	68	1.73	210	95.3	38	0.97	17.5	0.44	32	22
33	39	70	1.78	218	98.9	38	0.97	17	0.43	31	21
34	38	65	1.65	223	101.2	36	0.91	16.5	0.42	37	20
35	30	74	1.88	184	83.5	31	0.79	14	0.36	24	12
36	34	76	1.93	251	113.9	39	0.99	16	0.41	31	22
37	35	69	1.75	206	93.4	38	0.97	14.5	0.37	30	26
38	33	67	1.7	166	75.3	34	0.86	14	0.36	26	20
39 ^F	30	65	1.65	138	62.6	28	0.71	12.5	0.32	23	12
40	32	70	1.78	237	107.5	38	0.97	15	0.38	34	25
41	26	68	1.73	205	93	40	1.02	16	0.41	31	27
42	33	66	1.68	186	84.4	36	0.91	16.25	0.41	30	20
43	35	70	1.78	176	79.8	32	0.81	15	0.38	25	13
44	36	72	1.83	269	122	45	1.14	18	0.46	36	29
45	33	71	1.8	191	86.6	38	0.97	15	0.38	27	24
46	27	72	1.83	204	92.5	37	0.94	16	0.41	28	20
47	23	74	1.88	199	90.3	32	0.81	15.5	0.39	26	11
49	33	68	1.73	184	83.5	36	0.91	16	0.41	28	19
51	41	72	1.83	218	98.9	42	1.07	17	0.43	30	27
52	39	74	1.88	225	102.1	37	0.94	15.5	0.39	29	20
53	32	70	1.78	175	79.4	35	0.89	16	0.41	25	17
54	39	72	1.83	260	117.9	44	1.12	18	0.46	35	28

F Female; (Others Male)

Diver ID	Age (yr)	Height (in)	Height (m)	Weight (lbs)	Weight (kg)	Waist (in)	Waist (m)	Neck (in)	Neck (m)	BMI	Body Fat (%)
55	43	69	1.75	190	86.2	38	0.97	16.5	0.42	28	23
56	34	71	1.8	186	84.4	37	0.94	15	0.38	26	22
57	39	70	1.78	225	102.1	43	1.09	15	0.38	32	32
58	38	73	1.85	209	94.8	39	0.99	16.5	0.42	28	22
59	31	70	1.78	210	95.3	38	0.97	15.5	0.39	30	24
60	31	73	1.85	228	103.4	42	1.07	16	0.41	30	28

APPENDIX G DIVING INTENSITY

Diver ID	Dive Date (mm/dd/yy)																				
	6/25/2021	6/30/2021	7/1/2021	7/6/2021	7/7/2021	7/8/2021	7/9/2021	7/12/2021	7/13/2021	7/14/2021	7/15/2021	7/19/2021	7/20/2021	7/21/2021	7/22/2021	7/23/2021	7/26/2021	7/27/2021	7/28/2021	7/29/2021	7/30/2021
1	W																				
2	W		X				X			X						X					
3	W		X								W					W	X				X
4	W	X		X				X													
5	W					W					X										
6	W	X			X						X	X									
7	W		X	X			X		X					X							
8	W	X				X				X											
9	W										W				X					X	
10	W		X	X							X		X*								
11	W		W			X		X							X					X	
12	W		X			X															
13	W		X		X						X			X					X		
14	W		X			W		X*													
15	W	X		X				X													
16	W		X				X			X											
17			W		X						X			X							
18			W				X		X							X					
19			W			X					W		X				X				
20			W	X				X			X				X						X
21			W	X					X				X							X	
22			W		X			X			X										
23						W		X						X					X		
25						W		X				X				X					
26						W			X				X								
27										X											
28											W				X					X ^p	
29											W	X				X			X		
30											W	X									
31											W										
32											W										
33																W			X		
34																W	X				X
35																W					
36																W				X	
37																W				X	
38																W					X
39																W	X				

X = experimental dive, W = work-up dive, *DCS, ^p Surface Interval Pain

Diver ID	4/1/2022	4/4/2022	4/5/2022	4/6/2022	4/7/2022	4/8/2022	4/11/2022	4/12/2022	4/13/2022	4/14/2022	4/19/2022	4/20/2022	4/21/2022	4/22/2022	4/25/2022	4/26/2022	4/27/2022	4/29/2022	5/2/2022	5/3/2022	5/4/2022
1						W															
2										W			X				X				
6	W				X					X				X			X				
7	W			X					X			X				X			X		
11	W	X						X				X			X						X
12	W						X					X			X					X	
13	W				X									W	X						X
15	W		X											W			X		X		
17	W						X				X										
19	W				X			X						X		X					X
20	W		X						X			X									
28	W						X											W			X
30	W				X													W		X	
31	W																				
32						W		X				X									
37	W		X				X				X										
38										W				X			X				
39										W		X									
40	W	X																			
41	W			X														W			X
42	W						X														
43	W			X											W						
44	W						X					X					X				
45	W			X					X									W		X	
46	W		X							X		X					X				
47	W						X														
49	W	X							X						X		X				
51	W	X								X	X						X				
52						W				X	X										
53						W	X								W						
54						W		X										W			X
55										W			X		X				X		
56										W			X			X					X
57										W			X			X					X
58														W							
59																		W		X	

X = experimental dive, W = work-up dive

Diver ID	5/5/2022	5/9/2022	5/10/2022	5/11/2022	5/12/2022	5/13/2022	5/16/2022	5/17/2022	5/18/2022	5/19/2022	5/20/2022	5/23/2022	5/24/2022	5/25/2022	5/26/2022	5/31/2022	6/1/2022
7				X			X					X					
11				X					X					X			
12				X				X							X		X
13					X										W		
15						W				X							
17	W																
19											W				X	X	
20	W				X			X						X			
28					X			X							X		
29																	
30				X							W						
35						W		X									
38						W	X					X					X
40	W		X							X							
41															W	X	
42															W	X	
44		W				X				X			X				
45					X				X						X		X
46		W				X				X							
47											W		X			X	
51											W			X			X
52						W	X						X				
56			X														
57			X				X*						X				
58											W	X					
59			X					X						X			
60		W				X			X			X ^P					

X = experimental dive, W = work-up dive, *DCS, ^P Surface Interval Pain

APPENDIX H MEDICAL INCIDENTS

DCS: DIVER ID 14, 12 JUL 2021, 140/30 IN-WATER SCHEDULE

In the afternoon of 09 August 2021, a diver who had participated in an experimental 140 fsw/30 min heliox in-water decompression dive on 12 July 2021 presented to a UMO's office to report that during the dive, somewhere between the 90 fsw and 30 fsw in-water stops, he noticed a "pins and needles" sensation in the lateral aspect of his left foot. He noted that this resolved shortly after breathing 100% O₂ at 30 fsw, and that the rest of the dive and ascent to surface was uneventful. The diver did not report any issues during the 10-minute and 2-hour post-dive interviews. The diver continued recounting that later in the evening of the dive, around 2330, he woke up with his right elbow feeling swollen and painful. The pain was constant and did not change with movement. In addition to the right elbow symptoms, his whole right leg (from hip to toes) felt like "pins and needles." He thought that he might have been sleeping on his right side awkwardly. He was able to walk and use the restroom without issue and remained awake for approximately 20 minutes before falling back asleep. During that time both sensations remained constant and unchanged. When he awoke the following morning, both his elbow and leg were back to normal. During his 18-24 hour post dive interview the next morning (0915) he only reported feeling tired and needing a nap when he got home after the dive with no sensory or pain symptoms since surfacing. In the 09 August 2021 report, the diver stated that he did not report the elbow and leg symptoms earlier because they had resolved and he didn't want people to worry. Another UMO examined the diver on 10 August and found him doing well without any residual symptoms, subjective abnormalities, or objective findings on neurologic exam. He felt that his symptoms were mild/moderate, about a 4-5/10 in severity, although he noted that he could not recall specifically since it was so long ago. They were significant enough that he did not immediately chalk it up to nothing, and was concerned he was bent at the time. Had the symptoms been persistent in the morning after the dive, he had intended to disclose his issues. He additionally reported fatigue that lasted about one week after the dive, noting that he did not feel up to completing his daily exercise during that time.

MECHANICAL INJURY: DIVER ID 5, 15 JUL 2021, 80/30 NO STOP SCHEDULE

The subject presented on 18 July, approximately 72 hours after surfacing. Due to the delayed presentation of possible DCS Type II, administration of a Treatment Table 6 with two extensions at 60 fsw was chosen to maximize therapeutic benefit while limiting oxygen exposure. The hyperbaric oxygen therapy provided partial relief of symptoms. After re-examination the following morning and findings of persistent symptoms, the diver was administered a Treatment Table 5. Symptoms were partially relieved at 60 fsw but returned to morning baseline levels at 38 fsw and persisted on return to surface. The diver was administered a Treatment Table 9 on the next day (20 July) and his symptoms remained stable from the previous day. He then underwent a Treatment Table 6 with two extensions at 60 fsw on 21 July. Of note, A Treatment Table 6 instead of a Treatment Table 9 was selected since another individual who required a more aggressive treatment was also being treated at that time. Following this treatment, the subject's symptoms again remained stable and consisted of a small region of diminished sensation over his knee and slight burning with flexion, both of which had improved from initial presentation. The treating physician felt

that this individual's symptoms were most likely due to mechanical injury, rather than DCS. Given the subject's mild symptoms, and stable clinical course without continued improvement with hyperbaric treatments, the subject continued non-hyperbaric medical care and evaluation. He was cleared to go on a scheduled vacation and as of 07/26/2021 he reported stable symptoms to his physician during a phone check-in. He returned for a follow-up visit with a physician upon his return and reported full functional recovery.

DCS: DIVER ID 10, 20 JUL 2021, 300/30 SURDO₂ SCHEDULE

On 20 July 2021, a diver that had participated in an experimental 300 fsw/30 min heliox SurDO₂ decompression dive complained of a swelling sensation in both feet and altered tactile sensation on one toe of the left foot during the two-hour post dive monitoring period. Upon completion of a post-dive physical examination by a UMO, the diver was administered a Treatment Table 6 with two extensions at 60 fsw. The diver noted complete relief of symptoms, confirmed by in-chamber examination by an inside tender, within the first eight minutes of the first oxygen period at 60 fsw and remained symptom-free thereafter. The diver was re-examined the following morning reporting 5/10 headache upon waking, improving to 1/10 during examination. Mild cognitive dysfunction was noted with slight left arm pronator drift in Rhomberg test. Diver was administered a Treatment Table 6 with two extensions at 60 fsw and one half-extension (30 minutes) at 30 fsw. The treating UMO had planned two extensions (60 minutes each) at 30 fsw but the diver complained of increasing respiratory discomfort and requested that we discontinue the extensions. All symptoms were reported resolved by the end of the 2nd oxygen period at 30 fsw. During follow-up examination on 23 July, diver reported "feeling off" and fullness feeling with some burning and paresthesia in fingertips of both hands. Diver was administered a Treatment Table 5, after which minor cognitive and sensory issues in fingertips persisted. Diver was administered a Treatment Table 9 on 24 July. On follow-up examination 26 July, UMO could not identify any cognitive deficiencies, though the diver reported stable 90-95% cognitive function. Diver was found to have decreased sensation in thumbs, and large toes, some paresthesias in second toes of both feet, and decreased sensation on abdomen. Rhomberg and pronator drift were normal but heel-to-toe walk seemed off. The diver was administered a Treatment Table 9 with resolution of Rhomberg and pronator drift issues but only incremental improvement of other symptoms. The diver was administered a Treatment Table 9 during mornings of the subsequent two days with continued incremental but incomplete improvement of remaining symptoms. At this time the diver had mild pulmonary and whole-body oxygen toxicity symptoms and therefore a rest period was prescribed before initiating further hyperbaric oxygen treatments. After a four-day hiatus with no hyperbaric treatments, the diver was examined on the morning of 2 August with findings of complete resolution of finger-tip sensory deficits but persistent subjective sensory deficit on the abdomen in an area extending bilaterally from the navel and minor sensory deficits in the toe-tips of both feet. The diver was administered a Treatment Table 9 with complete resolution of all remaining symptoms. No abnormalities were found on follow-up physical examination on 4 August, although some subjective mood/affect issues were noted. The latter were expected to resolve as the diver resumed normal daily routines.

SURFACE INTERVAL PAIN: DIVER ID 28, 28 JUL 2021, 310/30 SURDO₂ SCHEDULE

On 28 July 2021, a diver participating in an experimental 310 fsw/30 min heliox

SurDO₂ decompression dive noticed a warm sensation in his left elbow upon leaving the last 40 fsw in-water stop to commence the SurDO₂ procedure. The sensation changed to pain deep in the left elbow increasing in severity to a 5-6/10 level upon reaching surface. The diver followed the prescribed SurDO₂ procedure accompanying the other three divers as they transferred from the wet pot to Bravo chamber for surface decompression. The diver reported complete relief of symptoms on arrival at the 50 fsw first chamber stop before starting oxygen breathing and denied any subsequent complaints as the SurDO₂ was completed.

As per protocol, with complete relief of surface interval symptoms within the first 15 minutes of reaching the first SurDO₂ chamber stop, no modifications of the SurDO₂ schedule were imposed. A DMT was locked in to the chamber and completed two neurological examinations; one during the first oxygen period and another during the rest period after the second oxygen period; with no abnormal findings. The diver surfaced after SurDO₂ with no complaints and was examined by a UMO 10 minutes and two hours after final surfacing with no abnormal findings. The diver complained only of slight upper left forearm muscle pain – different from the initial SI complaint - during UMO interview the following morning (29-July). This was not considered residual SI pain, but a likely consequence of the kettle bell exercise performed during the previous day's dive.

DCS: DIVER ID 57, 16 MAY 2022, 240/40 SURDO₂ SCHEDULE

Diver reported to the duty UMO at the 10-minute post-dive interview recurrent, transient left elbow pain, 2/10 at its maximum that occurred during the 240/40 SurDO₂ dive on 16MAY2022. He denies any previous injuries to the elbow, no issues with the elbow while on bottom or during the in-water decompression stops. He reports pain first noticed during the SurDO₂ portion while waiting to climb the ladder out of the wet pot, located “deep” in his left elbow, lasted approximately 1 minute. He had pain in the left elbow again while traveling from the 40fsw to 30 fsw while breathing air during the SurDO₂, which resolved on its own within a minute. And finally, pain in left elbow while traveling from 30fsw to the surface on air, again resolving on its own without any intervention within about 1min. Complete neurologic exam after 10min interview was without abnormalities and no reported recurrence of the pain at the 2-hour and 18-24-hour post-dive interviews.

SURFACE INTERVAL PAIN: DIVER ID 60, 23 MAY 2022, 290/30 SURDO₂ SCHEDULE

On the 23MAY2022, 290/30 SurDO₂ schedule the diver reported to the duty UMO at the 10 min post-dive interview that they experienced right shoulder pain, described as a deep ache, 2/10 pain severity, during the SurDO₂ undress period. The pain resolved upon compression to 50 fsw and did not recur during the rest of decompression nor after final surfacing.