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RISK OF CENTRAL NERVOUS SYSTEM DECOMPRESSION SICKNESS IN AIR DIVING TO NO-STOP LIMITS

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Current U.S. Navy Air and N_2-O_2 decompression procedures are calculated by using the Thalmann Algorithm with the VVal-18 or VVal-18M parameter sets. Recent man-testing at the Navy Experimental Diving Unit (NEDU) of the VVal-18 air no-stop limits at 130, 150 and 190 feet of sea water resulted in incidents of severe central nervous system decompression sickness (CNSDCS). A logistic model of the probability of CNSDCS (P_{CNSDCS}) in air no-stop dives from the recent NEDU man-testing and the USN primary N_2-O_2 data set was developed and used to produce a set of iso-risk air no-stop limits and estimated P_{CNSDCS} of various air no-stop limits. A new parameter set (VVal-76) for the Thalmann Algorithm that produces air no-stop limits with P_{CNSDCS} near 0.002 was developed. Similar air no-stop limits are obtained by using the unmodified Navy Special Warfare version of the Navy Dive Computer (NSW III). The NSW III is recommended for no-stop air diving.

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INTRODUCTION

The current U.S. Navy air and N_2-O_2 decompression procedures are calculated by using the Thalmann Algorithm with the VVal-18 or VVal-18M parameter sets.[1] The VVal-18M Thalmann Algorithm Air decompression tables require longer decompression times than the Standard Air decompression tables (USN57)[2] that they replaced in Revision 6 of the *U.S. Navy Diving Manual*.[3] However, the VVal-18M Thalmann Algorithm Air no-stop limits for dives to 90 feet of sea water (fsw) and deeper are longer than the corresponding USN57 no-stop limits. Recent man-testing at NEDU[4] found that these extended no-stop limits result in a low incidence of decompression sickness (DCS), but that the severity of the DCS was unacceptable, with all cases manifesting signs and symptoms of central nervous system involvement.

As an interim measure to avoid inclusion of excessively risky extended air diving no-stop limits in Revision 6 of the *U.S. Navy Diving Manual*, USN57 air no-stop limits, where they are shorter, were substituted for the VVal-18M Thalmann Algorithm Air no-stop limits. However, such executive substitutions are not possible in real-time applications of the Thalmann Algorithm such as in the diver-carried Navy Dive Computer (NDC). The NDCs operate with a version of the Thalmann Algorithm that is parameterized with VVal-18 and that consequently prescribes the same unacceptable no-stop limits for deep air dives as those prescribed by the Thalmann Algorithm with VVal-18M. On the other hand, the NSW III version of the NDC, which also operates with the VVal-18 Thalmann Algorithm, performs real-time decompression calculations assuming air breathing shallower than 78 fsw and constant 0.7 atmospheres (atm) PO_2–in–nitrogen breathing otherwise. The result is shorter no-stop limits for dives to depths of 78 fsw or deeper than the limits prescribed assuming air breathing only. Because the NSW III is already authorized for Navy use in Naval Special Warfare diving operations, its use to support air diving is a readily available means of fielding an NDC that will prescribe acceptable air no-stop limits.

This report examines the implications of using the NSW III for air diving and proposes a set of no-stop limits that incur acceptable risks of central nervous system DCS (CNSDCS).

METHODS

The general methodology was to compile no-stop decompression data from a variety of well-documented experimental man-trials and fit a simple logistic model of the probability of central nervous system DCS (P_{CNSDCS}) to these data. The resulting model was used to predict P_{CNSDCS} of various no-stop limits and to produce a set of iso-risk no-stop limits.

NO-STOP CALIBRATION DATA

The data for logistic model calibration comprised dive profiles and their outcomes from the recent NEDU no-stop trial and the USN primary N_2-O_2 data set. The USN primary N_2-O_2 data set comprises machine-readable data files that each describe depth/time/breathing gas history, number of divers, and decompression sickness outcome for a collection of dives completed as part of a given experimental man-trial. A description of many of these data files has been compiled along with narrative descriptions of the DCS cases.[5] Single no-stop air dives and accompanying DCS case descriptions were identified in this report. No-stop dives were identified by ascent rate (see below) and by cross-referencing with original reports.[6-12] The recent NEDU no-stop trial has been reported in brief[4] with further details to be provided in a forthcoming technical report.

A summary of each of the no-stop dive profiles was produced with an identifier of the man-trial or data file name, depth, bottom time (BT), ascent rate, descent rate, and DCS outcome. The resulting full data set, the contents of which are summarized in Appendix A, contains 329 dive profile summaries representing 1629 man-dives. Throughout this report depth is expressed in fsw and no-stop limit BTs are expressed in minutes.

Summary extraction and selection of no-stop dives

The Naval Medical Research Institute (NMRI) Standard format[13] used to encode individual dive profiles in the USN primary N_2-O_2 data set begins with two header lines, the second of which includes the number of divers and an indication of DCS outcome (DCS, marginal, or no DCS). Each of the following lines up to an end-of-dive profile identifier line give the depth, elapsed time from the beginning of the profile, and breathing gas for a node in the profile. Collectively, the nodes provide a detailed depth/time/breathing gas history for the profile. Each data file identified as containing single no-stop air dive profiles was machine-processed to extract the number of divers, the DCS outcome and the time and depth at leave surface (LS), reach bottom (RB), leave bottom (LB), and reach surface (RS) for each dive profile.

In most cases, LS and RS times were the times of leaving and reaching a depth of zero fsw. However, some dive profiles include shallow (≤ 7 fsw) isobaric segments immediately after leaving surface and/or immediately before reaching surface. These isobaric segments represent time divers spent submerged in the wet pot while the chamber complex was un-pressurized. For such dives, LS time was defined as the time at leaving this "wet pot depth" and RS time was defined as the time at returning to this wet pot depth. Details on the handling and implications of pre-LS and post-RS shallow isobaric segments are given on page 7 in the Holds, delays, and excursions section.

RB was taken from the first node no more than 3 fsw shallower than maximum depth. LB was taken from the node immediately preceding the first node both later and more than 3 fsw shallower than maximum depth.

The following were calculated from the LS, RB, LB, and RS nodes:
BT = LB time – LS time
Ascent time = RS time – LB time
Ascent rate = (LB depth – RS depth)/(RS time – LB time)
Descent time = RB time – LS time
Descent rate = (RB depth – LS depth)/(RB time – LS time)

In the recent NEDU no-stop trial chamber pressure was recorded every two seconds. These raw dive profiles have not been converted to NMRI Standard format. For these carefully controlled no-stop dives, depth and bottom time were assumed to be as planned. Ascent and descent rates in each profile were assumed to be the average values of random samples (n = 9) taken from the descent and ascent phases of the raw dive profile.

The target ascent rates given in the original reports[6-12] range from 25 to 60 fsw/minute. An ascent rate of at least 25 fsw/minute was the primary criterion for selecting no-stop dive profiles but each selected dive profile was also verified by inspection. Fourteen no-stop dive profiles were included with ascent rates ranging from 9 to 24 fsw/minute. These were all to depths of 44 fsw or less with total ascent times of 3 minutes or less. It is typically not possible to maintain a fast ascent rate at shallow depths where the pressure differential across the chamber exhaust system is small, and this is evident as a slower than target ascent rate as surface is approached in many dive profiles. The ascent rates in the no-stop data set ranged from 9 to 61 fsw/minute and were distributed with peaks at 15, 25, 29 and 57 fsw/minute (Figure 1).

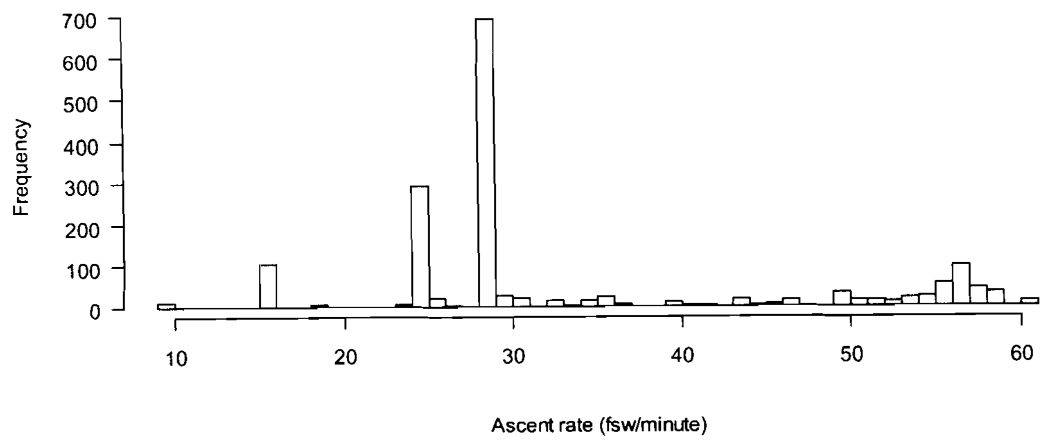

Figure 1. Ascent rates in no-stop calibration data, excluding any holds at wet pot depth before surfacing (see text).

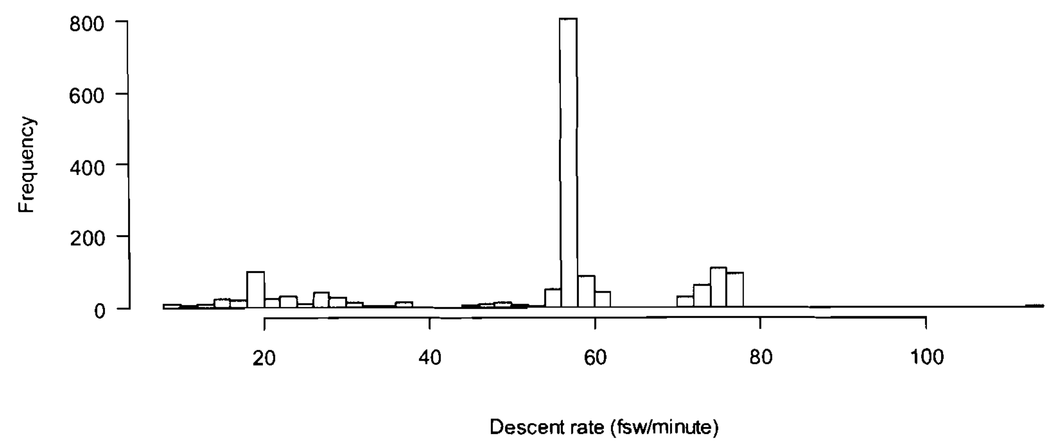

Figure 2. Descent rates in no-stop calibration data.

Holds, delays, and excursions

For logistic modeling, all dive profiles were idealized as having linear descent (notionally at 60 fsw/min), the remainder of BT spent at the maximum depth, and then linear no-stop ascent. Depth, BT and ascent rate were variables in the logistic models. Some dive profiles departed from ideal with brief upward excursions during the BT or delays in descent, the latter typically due to holds at various depths.

Depending on the extent of delays or excursions, dive profile summaries were either included in or excluded from the calibration data set. Decisions were based on the following assumptions. The body is considered to consist of a collection of compartments each with a different rate of gas uptake or washout characterized by a particular time constant τ. In classical decompression modeling, no-stop decompressions are scheduled so that the compartmental dissolved inert gas tension P_{tis} does not exceed a compartment-specific maximum permissible value (M_0) in any compartment on arrival at surface. Dives in the calibration are assumed to be testing, and therefore near, no-stop limits, so holds, delays, and excursions are relevant only to the extent they alter P_{tis} in the compartment closest to its M_0. This compartment of interest is assumed to have a τ approximately equal to the no-stop limit BT for the dive depth, an assumption that is addressed more specifically in Appendix B.

A rapid, model-free approximation of the difference in P_{tis} between the actual and idealized dive profiles was based on the following. Any portion of a dive profile can be considered to comprise n segments of duration t, each occurring after a step change in arterial nitrogen partial pressure P_a. At time T after a step-change in P_a at time T-t,

$$P_{tis_T} = P_{a_T} + \left(P_{tis_{T-t}} - P_{a_T}\right) \cdot e^{\frac{-t}{\tau}} \tag{1}$$

Similarly, for P_{tis} at time T-t,

$$P_{tis_{T-t}} = P_{a_{T-t}} + \left(P_{tis_{T-2t}} - P_{a_{T-t}}\right) \cdot e^{\frac{-t}{\tau}} \tag{2}$$

Substituting Equation 2 into Equation 1 and rearranging gives:

$$P_{tis_T} = P_{a_T} + P_{a_{T-t}} \cdot e^{\frac{-t}{\tau}} - P_{a_T} \cdot e^{\frac{-t}{\tau}} - P_{a_{T-t}} \cdot e^{\frac{-2t}{\tau}} + P_{tis_{T-2t}} \cdot e^{\frac{-2t}{\tau}} \tag{3}$$

Recursion back n steps gives:

$$P_{tis_T} = \sum_{i=1}^{n} \left(P_{a_{i \cdot t}} \cdot e^{\frac{-(n-i) \cdot t}{\tau}} - P_{a_{i \cdot t}} \cdot e^{\frac{-(n-i+1) \cdot t}{\tau}} \right) + P_{tis_0} \cdot e^{\frac{-n \cdot t}{\tau}} \tag{4}$$

Rearrangement gives:

$$P_{tis_T} = \left(1 - e^{\frac{-t}{\tau}} \right) \cdot \sum_{i=1}^{n} P_{a_{i \cdot t}} \cdot e^{\frac{-(n-i) \cdot t}{\tau}} + P_{tis_0} \cdot e^{\frac{-n \cdot t}{\tau}} \tag{5}$$

where P_a can vary at any step i. For $\overline{P}_{tis_T}$ equal to the value of P_{tis_T} obtained when P_a is assumed constant and equal to $\overline{P}_a$ (for instance an average or mode, as in the idealized dive profiles), it follows that

$$P_{tis_T} - \overline{P}_{tis_T} = \left(1 - e^{\frac{-t}{\tau}}\right) \cdot \sum_{i=1}^{n} \left(P_{a_{i,t}} - \overline{P}_a\right) \cdot e^{\frac{-(n-i) \cdot t}{\tau}} \tag{6}$$

A single excursion of P_a from $\overline{P}_a$ causes a greater $P_{tis_T} - \overline{P}_{tis_T}$ difference the closer the excursion occurs to time = T. For T = end of BT, we assume that t is small relative to BT and that $\tau \cong BT = n \cdot t$. Thus for a single excursion during the $i = 1$ time interval, $n\text{-}i = n\text{-}1 \cong \tau/t$, and Equation 6 becomes

$$P_{tis_T} - \overline{P}_{tis_T} = \left(1 - e^{\frac{-t}{BT}}\right) \cdot \left(P_{a_t} - \overline{P}_a\right) \cdot e^{-1} \tag{7}$$

For a single excursion near the middle of the dive profile, $n\text{-}i \cong n/2 \cong \tau/2t$, so Equation 6 becomes

$$P_{tis_T} - \overline{P}_{tis_T} = \left(1 - e^{\frac{-t}{BT}}\right) \cdot \left(P_{a_t} - \overline{P}_a\right) \cdot e^{\frac{1}{2}} \tag{8}$$

A dive profile was excluded from the calibration data set if it contained an excursion from depth of duration t during the first half of BT that caused $P_{tis_T} - \overline{P}_{tis_T} < -1$ fsw under Equation 8. For example, dive profile 15 of data file NMRNSW2 is a 61.5 fsw dive for BT = 102.2 minutes but has a 5.5 fsw upward excursion for 9.3 minutes during the first half of the BT. We consequently have t/BT $\cong$ 9.3/102.2 = 0.09 and $P_{a_t} - \overline{P}_a \cong 0.79 \times 5.5 = -4.35$, for which Equation 8 gives $P_{tis_T} - \overline{P}_{tis_T} = -0.23$ fsw. MRNSW2 profile 15 was retained in the calibration data because this upward excursion results in less than 1 fsw reduction in nitrogen tension in the compartment of interest from an ideal dive. No dive profiles had excursions during the second half of BT.

A more common departure from the ideal dive profile was a slower than 60 fsw/minute descent rate. Delay in descent was treated as a single upward excursion from maximum depth to half the maximum depth with duration t equal to the difference between the actual descent time and the time of a 60 fsw/minute descent. A dive profile was excluded from the calibration data set if $P_{tis_T} - \overline{P}_{tis_T} < -1$ fsw under Equation 7.

Table 1 lists dive profiles that were excluded from the calibration data because of a $P_{tis_T} - \bar{P}_{tis_T}$ < −1 fsw violation under either Equation 7 or 8. Each tabulated dive profile number (Profile #) is the number listed for the profile in NMRI TR 99-02.[5]

Table 1. Dive profiles excluded on the basis of $P_{tis_T} - \bar{P}_{tis_T}$ < −1 fsw

Data file	Profile #	fsw	BT	n	DCS
DC4D	110	98	10	2	0
DC4D	226	80	25	6	0
DC4D	229	100	15	6	0
DC4D	251	178	5	5	0
DC4D	252	130	8	5	0

Table 2 lists the data file name and dive profile number of dive profiles with $P_{tis_T} - \bar{P}_{tis_T}$ < −1 fsw that were included in the calibration data. These dives were scheduled with a real-time decompression algorithm so that BT was adjusted to account for the delays in descent.[9,11] These dive profiles were included in the calibration data with the BT adjusted to that planned for a 60 fsw/minute descent rate.

Table 2. Real-time algorithm dive profiles included with adjusted BT

Data file	Profile #	fsw	BT	n	DCS
EDU885a	29	100	30	10	0
EDU885a	32	150	14	10	0
EDU885a	33	150	14	10	0
EDU885a	46	190	10	10	0
EDU885a	50	190	10	9	0
EDU885a	51	120	24	9	0
EDU885a	53	120	24	10	0
EDU885a	75	100	30.5	1	1
PASA	24	101.5	31.8	1	0
PASA	25	101.5	30	2	0
PASA	26	101.5	30	2	0

Most dive profiles in data files DC4W and EDU885a included a hold at wet pot depth at the beginning of the dive. The effect of excluding these holds from BT on nitrogen tension in the compartment of interest was calculated using some of the same assumptions described on page 5. In data file EDU885a, this hold was at 7 fsw typically for 1.5 minutes. The increase in P_{tis} from equilibrium with air at surface after 1.5 minutes at 7 fsw was calculated using Equation 1 for a series of compartments with time constants increasing in one-minute increments from an initial value of one minute. The hold results in a greater than 1 fsw increase in P_{tis} for compartments with τ < 9 minutes. The shortest BT in EDU885a is 10 minutes so the hold at wet pot depth does not substantially influence any compartment of interest.

In data file DC4W, the initial hold was at 3 fsw typically for 6 minutes, which results in a greater than 1 fsw increase in P_{tis} for compartments with $\tau < 20$ minutes. The DC4W data file contains 29 no-stop dive profiles on which a total of 50 man-dives were completed with BTs less than 20 minutes (range 5 to 16). Although the corresponding P_{tis} increases in compartments with τ ranging from 5 to 16 minutes range from 2.66 fsw to 1.18 fsw, it was decided to retain these dives in the model calibration data because their effectively shorter BTs (which exclude holds at wet pot depth) cause underestimation of the decompression stresses of the dives and slightly conservative estimates of P_{CNSDCS} by a model fit to data that includes these dives.

Dive profiles in data file DC4W also had a hold, typically of 3 minutes duration, at 3 fsw just before surfacing. This hold was treated as a variation in ascent rate, which was tested as an independent variable in the logistic modeling. These slower ascent rates including the hold are shown in the calibration data set in Appendix A. These dive profiles were originally selected as no-stop dives because their ascent rates, excluding the hold before surfacing, were faster than 25 fsw/minute and it is these faster ascent rates that are illustrated in Figure 1.

Central Nervous System (CNS) DCS cases

Each dive was manually assigned an outcome of CNSDCS or no CNSDCS. The NEDU no-stop study resulted in one Type I DCS case on a 150 fsw/5 minute USN 57 no-stop schedule and six Type II DCS cases with symptoms of CNS involvement on the schedules listed in Table 3. Full narratives of the CNSDCS cases from the NEDU no-stop study are given in Appendix B. Narratives of the DCS cases from previous studies, which included thirteen cases with CNS involvement, are published elsewhere.[5] The list in Table 3 includes these thirteen cases with the data file name and dive profile number for each that corresponds to that listed in NMRI TR 99-02.[5]

Table 3 CNSDCS cases

Data file/Man-trial	profile	fsw	BT	CNS cases	Notes
DC4W	127	231	6.8	1	1
EDU849LT2	49	150	30	1	2
EDU849LT2	50	150	30	1	3
EDU849LT2	59	150	30	1	4
EDU849LT2	63	150	33	1	5
EDU849LT2	66	150	36	1	5
EDU849LT2	67	150	36	1	5
EDU849LT2	68	150	36	1	5
EDU849LT2	69	150	36	1	5
EDU849LT2	70	150	36	1	5, 6
NMR97NOD	6	40	200	1	7
NMR97NOD	9	41.2	200	1	8
NMRNSW2	28	61.5	82.3	1	9
NEDU2008SerA	1	130	20	2	10
NEDU2008SerA	2	150	15	1	10
NEDU2008SerA	3	190	11	1	10
NEDU2008SerB	2	150	12	1	10
NEDU2008SerB	3	190	9	1	10

1. Weak, faint, vertigo
2. Heavy legs, abnormal gait
3. Vertigo and cardiorespiratory symptoms
4. Bilateral numbness and paresthesia, nausea, faintness
5. Case narratives in the original NEDU logs and reproduced in NMRI TR 99-02[5] included the adjectives "dopey", "mentally groggy", or "mentally sluggish". Only those cases additionally classified as "mentally sluggish" as distinct from "fatigue" in Tables 16–19 of the original report,[6] were included.
6. Pain in both feet, paresthesia
7. Hearing deficit, anisocoria, nystagmus, confusion, emotionally labile, abnormal tandem gait
8. Scintillating scotoma, abnormal left foot dorsiflexion
9. Weakness, general left side paresthesia, numbness, abnormal gait
10. See Appendix C

LOGISTIC MODELING

Logistic models of the form

$$\ln\left(\frac{P_{CNSDCS}}{1-P_{CNSDCS}}\right) = \beta_0 + \beta_1 \cdot \ln(fsw) + \beta_2 \cdot \ln(BT) + \beta_3 \cdot \ln(BT)^2 + \beta_4 \cdot AscentRate \quad (9)$$

were fit to the data. Equation 9, including only the first four terms on the right-hand side, is the form that provided the best correlation between DCS incidences and no-stop dive profile properties in a previous analysis.[14] The final term on the right of Equation 9 was used to investigate any effect of ascent rate.

A reduced or nested model was obtained by omitting terms for which the Wald test statistic of the coefficient estimate, $W = \hat{\beta}/S.E.$, was not significant, P(Z > |W|) > 0.05. The log-likelihood of the nested model (LL_n) with p_n adjustable parameters and the log-likelihood of the full model (LL_f) with p_f adjustable parameters were then compared by using the likelihood ratio test with goodness-of-fit statistic $G = -2\cdot(LL_n - LL_f)$. The nested model was selected as the final model if the fit of the nested model was not significantly different from that of the full model; i.e., if $P(\chi^2 > G) > 0.05$, df = $p_f - p_n$.

Fit of the final selected model was assessed by examining group-specific and global Pearson χ^2 statistics[15], analogous to the Hosmer-Lemeshow test.[16] The calibration data were grouped, and a global goodness-of-fit statistic (C) was calculated as the sum of the squared Pearson residuals for the g groups:*

$$C = \sum_{k=1}^{g} (\text{Pearson residual}_k)^2 = \sum_{k=1}^{g} \frac{\left(o_k - n_k \cdot \bar{\pi}_k\right)^2}{n_k \cdot \bar{\pi}_k \cdot \left(1 - \bar{\pi}_k\right)} \tag{10}$$

where o_k is the number of observed CNSDCS cases, n_k is the number of man-dives, and $\bar{\pi}_k$ is the average model-estimated P_{CNSDCS} for the k^{th} group:

$$\bar{\pi}_k = \sum_{j=1}^{c_k} \frac{m_j \cdot \pi_j}{n_k} \tag{11}$$

In Equation 11 c_k is the number of dive profile summaries in the k^{th} group and m_j and π_j are the number of man-dives and the model-estimated P_{CNSDCS} for the j^{th} dive profile summary, respectively. The model was considered to fit the data groups equally well if $P(\chi^2 > C) > 0.05$, df = $g-2$.

Calibration data manipulation and logistic modeling were conducted using R: A language and environment for statistical computing (Version 2.5.1. R Development Core Team [2007]. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org).

* The squared Pearson residual was incorrectly termed the Pearson residual in an earlier review.[15]

RESULTS

LOGISTIC MODEL FIT

Logistic modeling results are given in Table 4. The fit of Model 2, a reduced version of Model 1 obtained by omitting $\ln(BT)^2$ and *AscentRate* terms, did not differ significantly from that of Model 1, while both Models 1 and 2 fit the data significantly better than the NULL model under which all no-stop dives have the same P_{CNSDCS}.

Table 4. Logistic model results

Model	Variables	Coefficients			Likelihood Ratio Test		
		estimate	S.E.	P(Z>|W|)	LL	df	$P(\chi^2>G)$
1	Intercept	−53.0	9.6	<0.0001	−58.5	2	0.6245*
	ln(fsw)	7.97	1.69	<0.0001			
	ln(BT)	3.32	1.62	0.0404			
	$\ln(BT)^2$	0.04	0.24	0.8488			
	Asc.rate	−0.03	0.04	0.3896			
2	Intercept	−56.0	9.1	<0.0001	−59.0	2	<0.0001†
	ln(fsw)	8.16	1.44	<0.0001			
	ln(BT)	3.81	0.67	<0.0001			
NULL	Intercept	−4.44	0.23	<0.0001	−78.5		

*Model 2−Model 1, †NULL−Model 2

Model 2 was accepted as the final model which allowed the full data set to be condensed into 177 dive profile summaries by neglecting ascent and descent rate fields and combining summaries with identical depth and BT from each man-trial. The condensed data was used for residual and graphical analysis of Model 2. Group specific Pearson χ^2 statistics for the calibration data grouped by dive trial are shown in Table 5. Corresponding observed and model-estimated CNSDCS incidences are shown graphically in Figure 3. Data file EDU849 was subdivided into post-dive work or rest, an experimental condition unique to this trial, and the recent NEDU trial was subdivided into the different phases that tested substantially different BTs. The group-specific Pearson χ^2 for trial NMRNOD97 is high but the global χ^2 is not significant. Because NMRNOD97 is a large trial of a 40 fsw for 200 minute no-stop limit, its high group-specific Pearson χ^2 motivated an examination of Model 2 performance on shallow dives. The calibration data were re-grouped by depth rounded to the nearest 10 fsw. Corresponding group-specific Pearson χ^2 statistics and observed and model-estimated CNSDCS incidences are shown in Table 6 and Figure 4. None of the group-specific Pearson χ^2 statistics are high, while the global statistic is not significant, which motivates retention of the hypothesis that Model 2 provides a valid summary of results from all the dive trials across all depths.

Table 5. Model 2 goodness-of-fit χ^2 statistic by dive trial groups

ID	n_k	CNSDCS observed	CNSDCS estimated	(Pearson residual)^2
DC4D	257	0	0.98	0.987
DC4W	69	1	0.58	0.31
EDU1351NL	143	0	0.95	0.953
EDU849LT2REST	71	4	4.97	0.203
EDU849LT2WORK	69	5	4.87	0.004
EDU885A	112	0	0.70	0.706
NEDU2008SERA	284	4	3.39	0.112
NEDU2008SERB	148	2	0.73	2.193
NEDU2008USN57	257	0	0.14	0.139
NMR97NOD	103	2	0.38	7.054
NMRNSW2	48	1	0.31	1.56
NSM6HR	57	0	0.93	0.944
PASA	5	0	0.03	0.027
RNPLX50	6	0	0.05	0.055
		Global		15.247
		$P(\chi^2>G)$, df=12		0.2282

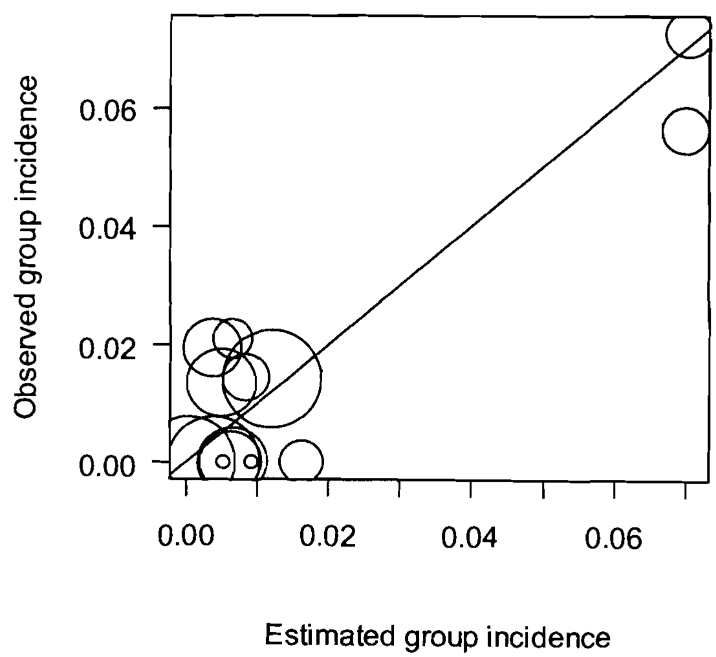

Figure 3. Observed and estimated P_{CNSDCS} for the dive trial groups in Table 5. Bubble area is proportional to the number of man-dives in each group.

Table 6. Model 2 goodness-of-fit χ^2 statistic by depth groups

fsw group	n_k	CNSDCS observed	CNSDCS estimated	(Pearson residual)^2
30	24	0	0.09	0.093
40	146	2	1.30	0.38
50	21	0	0.04	0.039
60	111	1	0.39	0.955
70	16	0	0.02	0.021
80	16	0	0.03	0.034
90	35	0	0.16	0.162
100	168	0	3.2	3.258
110	27	0	0.13	0.133
120	62	0	0.29	0.29
130	215	2	1.04	0.89
140	25	0	0.05	0.049
150	393	11	8.56	0.708
160	14	0	0.04	0.035
170	12	0	0.02	0.025
190	277	2	2.58	0.13
200	27	0	0.37	0.379
230	28	1	0.46	0.646
260	12	0	0.22	0.226
		Global		8.542
		$P(\chi^2>G)$, df=17		0.9559

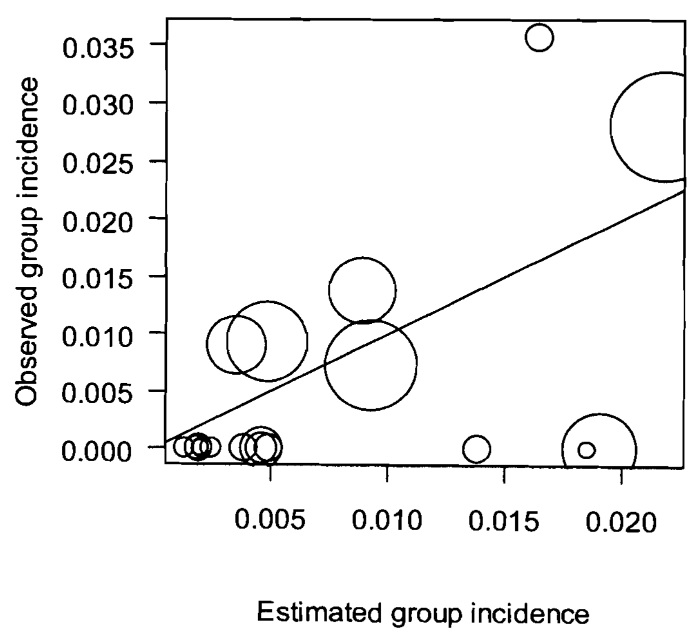

Figure 4. Observed and estimated P_{CNSDCS} for the depth groups in Table 6. Bubble area is proportional to the number of man-dives in each group.

LOGISTIC MODEL ESTIMATES

Model 2 was used to estimate the P_{CNSDCS} of the USN57 no-stop limits[17], the VVal-18 Air no-stop limits[1], and the nominal no-stop limits of the NSW III version of the NDC. The latter were calculated with the Thalmann Algorithm Navy Dive Planner (version 3.03. [2007]. Navy Experimental Diving Unit, Panama City, FL) as would obtain for idealized square dives with 60 fsw/minute descent and 30 fsw/minute ascent rates. Results are shown in Table 7. Also shown are P_{CNSDCS} = 0.002 iso-risk no-stop limits computed with Model 2. A P_{CNSDCS} = 0.002 isopleth is plotted over the condensed calibration data set in Figure 5. Figure 6 and Figure 7 compare the P_{CNSDCS} = 0.002 isopleth to the USN57, VVal-18 Air, and NSW III no-stop limits. Note the good match of the P_{CNSDCS} = 0.002 isopleth and the NSW III no-stop limits.

Table 7. No-stop limits and Model 2 P_{CNSDCS}

fsw	USN57		VVal-18		NSW III		Iso-risk BT
	BT	P_{CNSDCS}	BT	P_{CNSDCS}	BT	P_{CNSDCS}	P_{CNSDCS} = 0.002
30	NA	NA	371	0.0036	371	0.0036	319
40	200	0.0035	163	0.0016	164	0.0017	172
50	100	0.0016	92	0.0011	92	0.0011	107
60	60	0.0010	63	0.0012	63	0.0012	72
70	50	0.0017	48	0.0015	48	0.0015	52
80	40	0.0022	39	0.0020	39	0.0020	39
90	30	0.0019	33	0.0027	32	0.0024	30
100	25	0.0023	29	0.0040	27	0.0030	24
110	20	0.0021	25	0.0049	23	0.0036	20
120	15	0.0014	22	0.0061	19	0.0035	16
130	10	0.0006	19	0.0067	16	0.0035	14
140	10	0.0011	17	0.0080	13	0.0029	12
150	5	0.0001	15	0.0087	11	0.0027	10
160	5	0.0002	13	0.0086	9	0.0021	9
170	5	0.0004	11	0.0075	8	0.0022	8
180	5	0.0006	10	0.0083	7	0.0021	7
190	5	0.0009	9	0.0086	6	0.0018	6
mean		0.0013		0.0050		0.0024	
SD		0.0009		0.0029		0.0008	

Dashed boxes indicates U.S. Navy Diving Manual, Revision 6 air no-stop limits and risks

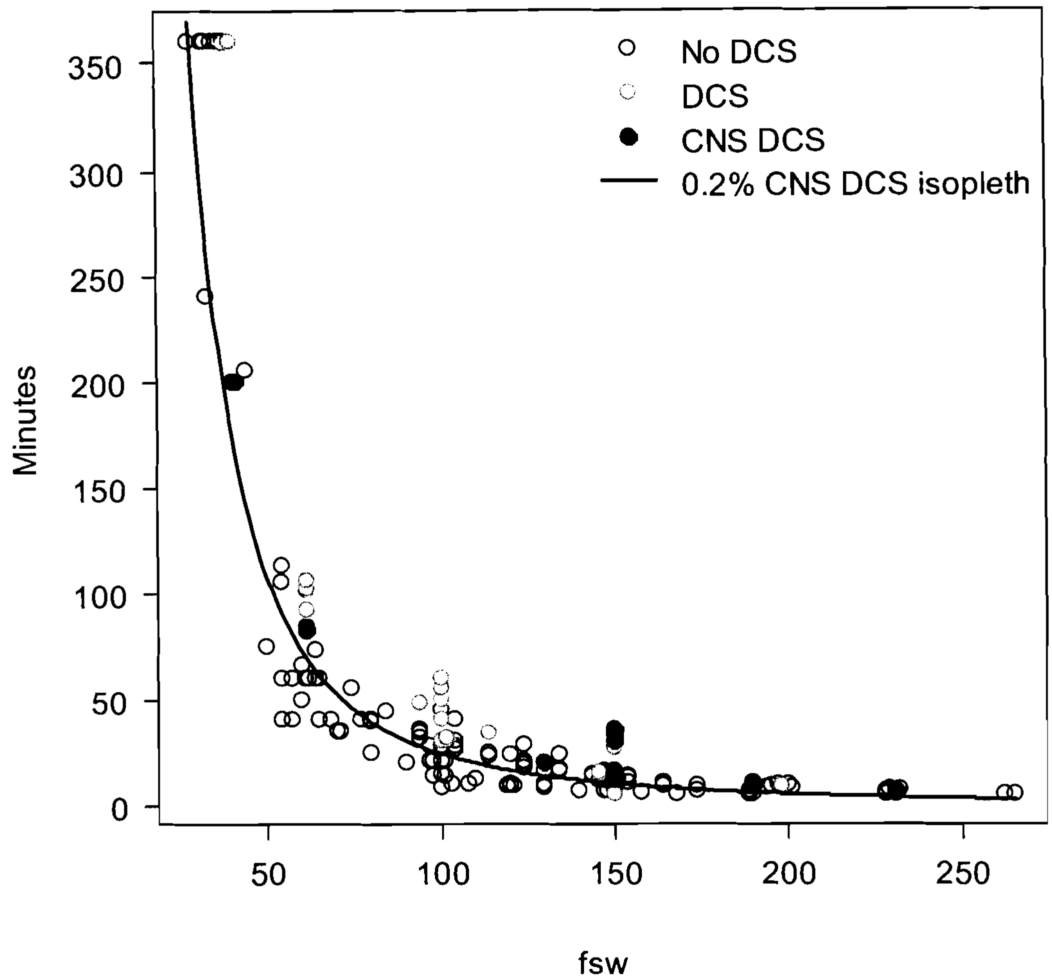

Figure 5. Fit of the 0.2% P_{CNSDCS} isopleth to the condensed calibration data set. Each circle represents a dive profile summary. The median number of man-dive represented by open circles (No DCS) is 4 (range 1–102). Black circles represent a median of 1 (range 1–3) cases of CNSDCS out of a median of 16 (range 2–100) man dive. Grey circles represent a median of 1 (range 1–4) cases of DCS not involving the CNS out of a median of 4 (range 1–102) man dives.

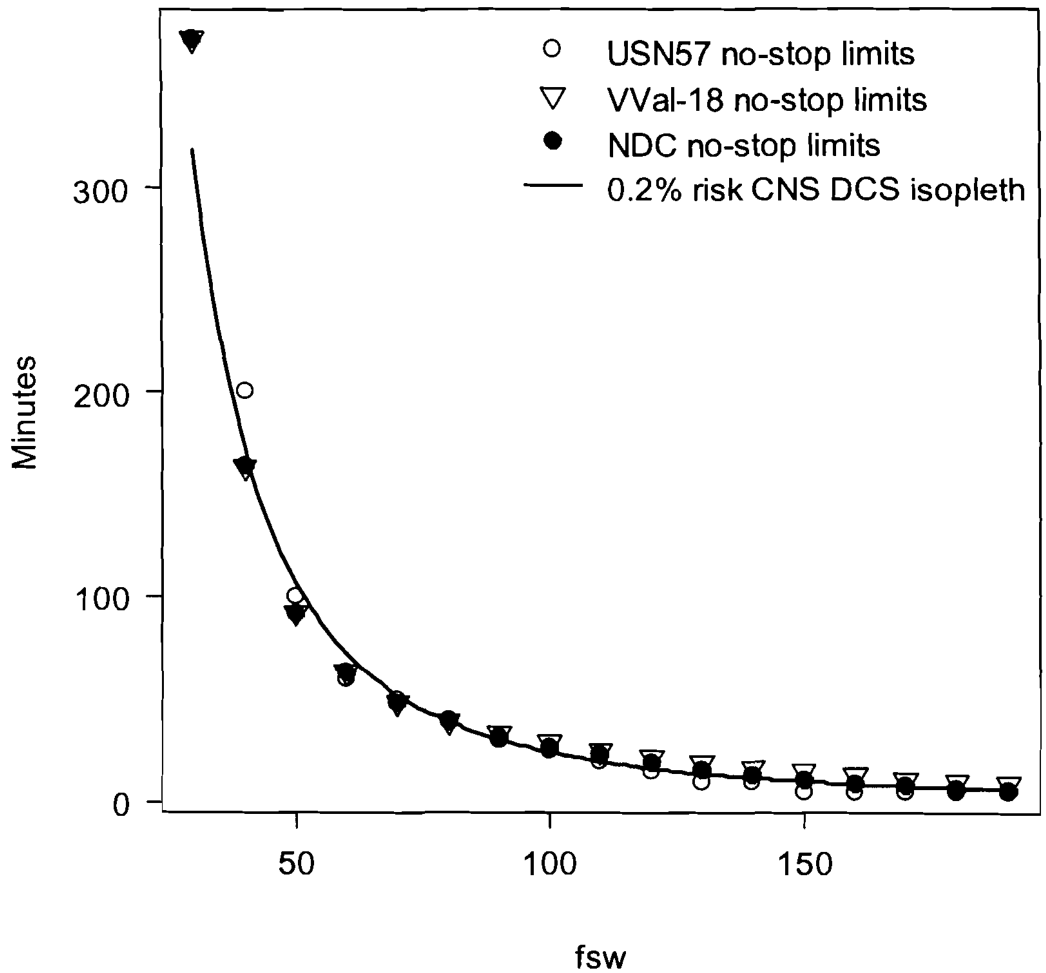

Figure 6. Comparison of the 0.2% P_{CNSDCS} isopleths to no-stop limits

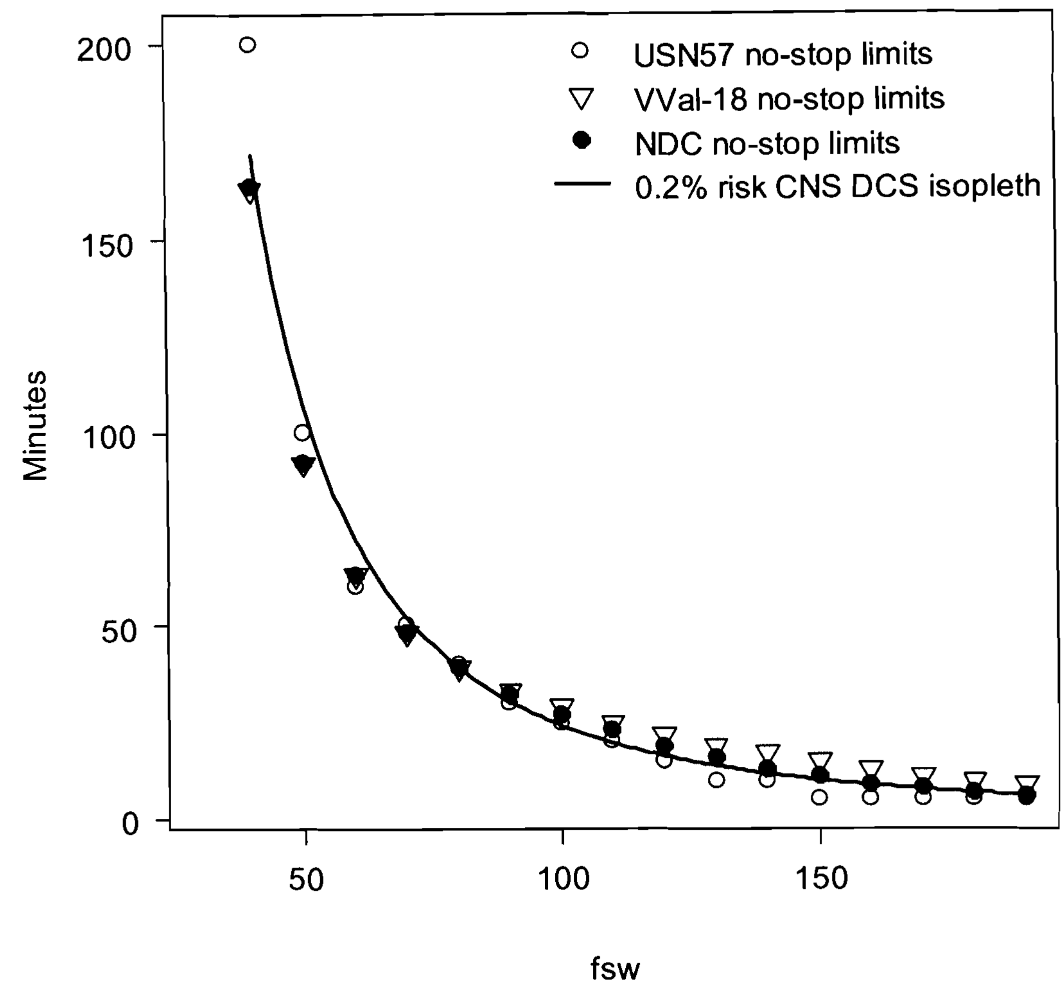

Figure 7. Expanded scale comparison of the 0.2% P_{CNSDCS} isopleths to no-stop limits

SHORTER NO-STOP LIMITS AND AIR DECOMPRESSION TIMES

Any calculation method that shortens Thalmann Algorithm no-stop limits will also lengthen decompression times for some schedules. One method to shorten no-stop limits is to develop a new parameter set for the Thalmann Algorithm. Such a parameter set (VVal-76) has been developed (see Appendix D) and used to compute a set of VVal-76 Air Decompression tables given in Appendix E. VVal-76 is a modification of VVal-18M but prescribes no-stop limits with P_{CNSDCS} near 0.002 and, consequently, longer decompression schedules for deep, short BT dives. VVal-76 air decompression schedules for 80 fsw to 190 fsw dives have up to 10 minutes more total decompression stop time (TST) than the corresponding VVal-18M air decompression schedules.

Another strategy is to adopt the NSW III for air scuba diving. However, since the NSW III assumes air breathing shallower than 78 fsw and constant 0.7 atm PO_2 in nitrogen otherwise, the NSW III prescribes longer decompression times for all dives to depths of 78 fsw or deeper than if the calculations were based on air throughout. Figure 8 shows the increase in TST for calculating decompression by using constant 0.7 atm PO_2 in nitrogen instead of air for dives deeper than 78 fsw. The increase in TST becomes substantial for deep, long dives but since NSW III is not intended for decompression diving, the increase in TST is of little consequence.

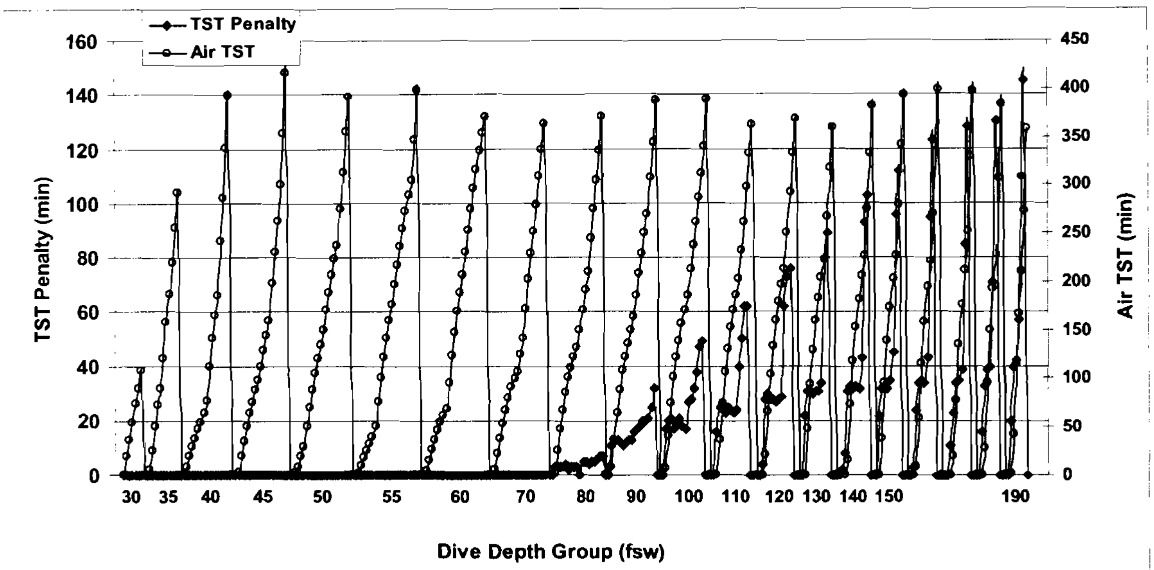

Figure 8. Decompression time penalty using NSW III for air diving. Total decompression stop time (TST) for VVal-18 Air decompression schedules (Air TST) and the corresponding increase in TST for the same schedules calculated using constant 0.7 atm PO_2 in nitrogen 78 fsw and deeper (TST Penalty). TST calculated with a 10 fsw last stop.

DISCUSSION

The no stop limits of the USN57 Standard Air Decompression tables[2,18] introduced in the 1959 *U.S. Navy Diving Manual*[19] were considerably longer than the no-stop limits of the Standard Decompression tables[20,21] they replaced — limits which in turn were longer than the limits in the previous Construction and Repair tables[22] based on the original tables of Haldane and colleagues.[23] The USN57 no-stop limits have a long history of successful application in table-based decompression planning. However, with the transition to computer-based, real-time decompression guidance, which lacks the safety margins introduced by depth and BT round-ups in table-based decompression planning, it is important to re-evaluate no-stop limits. During development of the USN57 tables, the no-stop limits were accepted after four DCS-free dives on eight of the schedules and two DCS-free dives on one other schedule. Later, additional extensive testing indicated potential problems with the USN57 40 fsw no-stop limit[12] but the recent NEDU test of the 130, 150, and 190 fsw USN57 no-stop limits resulted in only one Type I DCS case in 257 man-dives. In Revision 6 of the *U.S. Navy Diving Manual*[3] the air no-stop limits are those prescribed by the VVal-18M Thalmann Algorithm for dives shallower than 90 fsw, which are shorter than the corresponding USN57 no-stop limits. For 90 fsw or deeper dives the shorter USN57 no-stop limits were substituted for the VVal-18M no-stop limits. The resulting set of no-stop limits fall close to the Model 2 P_{CNSDCS} = 0.002 isopleth (see Figure 6 and Figure 7) but range from 0.0001 to 0.0036 (see Table 7). The USN57 schedules were originally calculated for five-minute or 10-minute BT increments,[18] and the deep no-stop limits are relatively coarse, being rounded down to the nearest five minutes, and therefore some are excessively conservative. The Model 2 P_{CNSDCS} = 0.002 iso-risk no-stop limits, rounded down to the nearest minute, provide more no-stop bottom time deeper than 110 fsw and still maintain P_{CNSDCS} at or near 0.002.

The major problem with any approach that entails arbitrary substitution of algorithmically-prescribed no-stop limits is the difficulty making computer-based decompression applications prescribe no-stop limits consistent with the substituted table. One strategy for avoiding this problem in computer-based no-stop air diving is to adopt the NSW III. The nominal NSW III no-stop limits are close to the *U.S. Navy Diving Manual, Revision 6* air no-stop limits and the Model 2 P_{CNSDCS} = 0.002 iso-risk no-stop limits. NSW III no-stop limits from 100 fsw to 130 fsw are two to three minutes longer than corresponding points on the 0.002 CNSDCS isopleth and have estimated P_{CNSDCS} between 0.003 and 0.0036, but there is no direct evidence indicating these will be problematic. The model calibration data includes 452 man-dives to depths from 100 to 139 fsw of which 324 man-dives were for BTs equaling or exceeding the nominal NSW III no-stop limits. The two CNSDCS in this depth range both occurred on the 130 fsw for 20 minute schedule tested in the NEDU no-stop study. The nominal NSW III no-stop limit for 130 fsw is 16 minutes, a schedule that was dived 57 times with no DCS in the NEDU no-stop study. The other depth that has been extensively tested is to100 fsw (range 100–104 fsw) with 129 man-dives at or longer than the nominal NSW III no-stop limit of 27 minutes with no cases of CNSDCS. In fact, the shortest BT with any manifestation of DCS at 100 fsw is five minutes longer than the nominal NSW III no-stop limit. Conducting air decompression dives deeper than 78 fsw following the guidance of the NSW III will result in increased decompression time compared to that using a real-time air algorithm. Since the NSW III is not intended for decompression diving, the impact of this increased decompression time is of little operational significance.

Ultimately, the ideal method for producing computer-based no-stop limits and decompression schedules with acceptable risks of DCS is to develop an entirely new decompression algorithm. An interim solution is to adopt a new parameter set for the Thalmann Algorithm. Pending further analysis, VVal-76 might be a useful parameter set for some Thalmann Algorithm applications but its incorporation into an NDC would entail unnecessary expense since the NSW III, which prescribes air no-stop limits with acceptably low risks of CNSDCS, is already developed, tested, and authorized for Navy use. Designated the AIR III, a yellow-case version (signifying its use for air diving) of the NSW III is already available.

RECOMMENDATIONS

The AIR III should be adopted for air scuba diving.

The P_{CNSDCS} = 0.002 iso-risk no-stop limits in this report could replace the present air no-stop limits for 90 fsw and deeper in Revision 6 of the *U.S. Navy Diving Manual.*

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APPENDIX A. NO-STOP MODEL CALIBRATION DATA

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
DC4D	137	108	10	1	0	0	0	33	49	FALSE
DC4D	150	100	8	2	0	0	0	37	59	FALSE
DC4D	154	147	7	1	0	0	0	37	73	FALSE
DC4D	155	54	40	1	0	0	0	45	22	FALSE
DC4D	156	148	12	1	0	0	0	59	62	FALSE
DC4D	160	198	8	1	0	0	0	56	60	FALSE
DC4D	161	228	5	1	0	0	0	58	58	FALSE
DC4D	162	228	6	1	0	0	0	57	114	FALSE
DC4D	163	228	5.9	1	0	0	0	58	60	FALSE
DC4D	164	98	14	4	0	0	0	58	60	FALSE
DC4D	165	194	8	8	0	0	0	57	59	FALSE
DC4D	166	195	9	5	0	0	0	57	59	FALSE
DC4D	167	98	21	4	0	0	0	58	58	FALSE
DC4D	168	97	21	4	0	0	0	57	57	FALSE
DC4D	169	97	28	4	0	0	0	57	61	FALSE
DC4D	170	97	28	4	0	0	0	57	57	FALSE
DC4D	171	146	11.3	4	0	0	0	58	61	FALSE
DC4D	172	147	11.3	4	0	0	0	57	58	FALSE
DC4D	173	147	15.5	4	0	0	0	59	61	FALSE
DC4D	174	147	15.5	4	0	0	0	57	58	FALSE
DC4D	175	197	10	4	0	0	0	56	60	FALSE
DC4D	176	197	10	4	0	0	0	58	59	FALSE
DC4D	177	65	40	4	0	0	0	59	58	FALSE
DC4D	178	54	60	4	0	0	0	54	59	FALSE
DC4D	179	77	40	4	0	0	0	59	59	FALSE
DC4D	180	62	60	4	0	0	0	56	55	FALSE
DC4D	181	61	60	4	0	0	0	55	61	FALSE
DC4D	182	229	7.5	4	0	0	0	56	60	FALSE
DC4D	183	229	7.5	4	0	0	0	57	58	FALSE
DC4D	184	229	7.5	4	0	0	0	56	58	FALSE
DC4D	185	262	5.5	4	0	0	0	57	59	FALSE
DC4D	186	262	5.5	4	0	0	0	57	60	FALSE
DC4D	187	147	16	2	0	0	0	59	61	FALSE
DC4D	189	147	16	2	0	0	0	61	61	FALSE
DC4D	190	146	15.5	2	0	0	0	58	58	FALSE
DC4D	191	146	15.5	1	0	1	0	58	58	FALSE
DC4D	192	146	15.5	1	0	0	0	58	58	FALSE
DC4D	193	147	14.2	2	0	0	0	59	61	FALSE
DC4D	194	195	9	2	0	0	0	59	61	FALSE
DC4D	195	195	9	2	0	0	0	56	59	FALSE
DC4D	196	228	6.8	2	0	0	0	58	57	FALSE
DC4D	210	119	9	1	0	0	0	52	54	FALSE
DC4D	211	119	9	1	0	0	0	57	52	FALSE
DC4D	212	119	9	3	0	0	0	57	57	FALSE
DC4D	213	119	9	2	0	0	0	54	57	FALSE
DC4D	214	119	9	1	0	0	0	50	57	FALSE
DC4D	215	119	9	2	0	0	0	54	52	FALSE
DC4D	216	120	9	1	0	0	0	55	55	FALSE
DC4D	217	119	9	1	0	0	0	50	57	FALSE
DC4D	218	119	9	1	0	0	0	54	52	FALSE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
DC4D	219	120	9	1	0	0	0	57	57	FALSE
DC4D	220	120	9	1	0	0	0	52	57	FALSE
DC4D	221	120	9	1	0	0	0	55	60	FALSE
DC4D	222	121	9	1	0	0	0	58	58	FALSE
DC4D	223	120	9	2	0	0	0	57	60	FALSE
DC4D	225	70	35	6	0	0	0	50	47	FALSE
DC4D	227	90	20	6	0	0	0	50	56	FALSE
DC4D	228	60	50	6	0	0	0	55	46	FALSE
DC4D	230	110	12	6	0	0	0	50	50	FALSE
DC4D	231	50	75	4	0	0	0	50	56	FALSE
DC4D	232	120	10	6	0	0	0	57	55	FALSE
DC4D	233	130	8	5	0	0	0	57	57	FALSE
DC4D	234	71	35	4	0	0	0	55	55	FALSE
DC4D	235	80	25	5	0	0	0	50	57	FALSE
DC4D	236	90	20	5	0	0	0	53	60	FALSE
DC4D	237	60	50	5	0	0	0	46	50	FALSE
DC4D	238	100	15	5	0	0	0	53	48	FALSE
DC4D	239	120	10	5	0	0	0	55	57	FALSE
DC4D	240	50	75	4	0	0	0	50	56	FALSE
DC4D	241	110	12	6	0	0	0	52	58	FALSE
DC4D	242	130	8	4	0	0	0	54	57	FALSE
DC4D	243	140	7	6	0	0	0	56	58	FALSE
DC4D	244	140	7	6	0	0	0	56	56	FALSE
DC4D	245	140	7	5	0	0	0	52	56	FALSE
DC4D	248	148	7	6	0	0	0	57	57	FALSE
DC4D	249	158	6	6	0	0	0	61	56	FALSE
DC4D	250	168	5	4	0	0	0	54	60	FALSE
DC4W	81	108	10	2	0	0	0	33	49	TRUE
DC4W	87	150	7	1	0	0	0	21	73	TRUE
DC4W	88	57	40	1	0	0	0	13	22	TRUE
DC4W	89	151	12	1	0	0	0	27	62	TRUE
DC4W	93	201	8	1	0	0	0	30	60	TRUE
DC4W	94	231	5	1	0	0	0	33	58	TRUE
DC4W	95	231	6	1	0	0	0	33	114	TRUE
DC4W	96	231	5.9	1	0	0	0	33	60	TRUE
DC4W	97	101	14	2	0	0	0	21	60	TRUE
DC4W	98	101	21	2	0	0	0	21	58	TRUE
DC4W	99	100	21	2	0	0	0	21	57	TRUE
DC4W	100	100	28	2	0	0	0	21	61	TRUE
DC4W	101	100	28	2	0	0	0	21	57	TRUE
DC4W	102	149	11.3	2	0	0	0	27	61	TRUE
DC4W	103	150	11.3	2	0	0	0	26	58	TRUE
DC4W	104	150	15.5	2	0	0	0	27	61	TRUE
DC4W	105	150	15.5	2	0	0	0	26	58	TRUE
DC4W	106	200	10	2	0	0	0	30	60	TRUE
DC4W	107	200	10	2	0	0	0	31	59	TRUE
DC4W	108	68	40	2	0	0	0	16	58	TRUE
DC4W	109	57	60	1	1	0	0	14	59	TRUE
DC4W	110	57	60	1	0	0	0	14	59	TRUE
DC4W	111	80	40	2	0	0	0	18	59	TRUE
DC4W	112	65	60	1	1	0	0	15	55	TRUE
DC4W	113	65	60	1	0	0	0	15	55	TRUE
DC4W	114	64	60	2	0	0	0	15	61	TRUE
DC4W	115	232	7.5	2	0	0	0	32	60	TRUE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
DC4W	116	232	7.5	2	0	0	0	33	58	TRUE
DC4W	117	232	7.5	2	0	0	0	32	58	TRUE
DC4W	118	265	5.5	2	0	0	0	34	59	TRUE
DC4W	119	265	5.5	2	0	0	0	34	60	TRUE
DC4W	120	150	16	2	0	0	0	27	61	TRUE
DC4W	121	150	16	2	0	0	0	27	61	TRUE
DC4W	122	149	15.5	4	0	0	0	27	58	TRUE
DC4W	123	150	14.2	2	0	0	0	27	61	TRUE
DC4W	124	198	9	1	0	1	0	31	61	TRUE
DC4W	125	198	9	1	0	0	0	31	61	TRUE
DC4W	126	198	9	2	0	0	0	30	59	TRUE
DC4W	127	231	6.8	1	0	1	1	33	57	TRUE
DC4W	128	231	6.8	1	0	1	0	33	57	TRUE
DC4W	138	103	10	2	0	0	0	17	53	TRUE
EDU1351NL	1	44	205	4	0	0	0	24	73	TRUE
EDU1351NL	2	54	105	4	0	0	0	25	77	TRUE
EDU1351NL	3	54	113	4	0	0	0	25	77	TRUE
EDU1351NL	4	64	73	4	0	0	0	25	71	TRUE
EDU1351NL	5	74	55	4	0	0	0	25	74	TRUE
EDU1351NL	6	84	44	4	0	0	0	25	76	TRUE
EDU1351NL	7	94	32	4	0	0	0	25	72	TRUE
EDU1351NL	8	94	34	2	0	0	0	25	72	TRUE
EDU1351NL	9	94	34	2	2	0	0	25	72	TRUE
EDU1351NL	10	94	35	6	0	0	0	25	72	TRUE
EDU1351NL	11	94	35	2	2	0	0	25	72	TRUE
EDU1351NL	12	94	36	4	0	0	0	25	72	TRUE
EDU1351NL	13	94	48	3	0	0	0	25	72	TRUE
EDU1351NL	14	94	48	1	0	1	0	25	72	TRUE
EDU1351NL	15	104	26	4	0	0	0	25	74	TRUE
EDU1351NL	16	104	28	4	0	0	0	25	74	TRUE
EDU1351NL	17	104	30	4	0	0	0	25	74	TRUE
EDU1351NL	18	104	40	4	0	0	0	25	74	TRUE
EDU1351NL	19	114	23	4	0	0	0	25	76	TRUE
EDU1351NL	20	114	25	4	0	0	0	25	76	TRUE
EDU1351NL	21	114	34	2	0	0	0	25	76	TRUE
EDU1351NL	22	114	34	1	1	0	0	25	76	TRUE
EDU1351NL	23	114	34	1	0	1	0	25	76	TRUE
EDU1351NL	24	124	18	2	0	0	0	25	73	TRUE
EDU1351NL	25	124	19	4	0	0	0	25	73	TRUE
EDU1351NL	26	124	21	4	0	0	0	25	73	TRUE
EDU1351NL	27	124	29	3	0	0	0	25	73	TRUE
EDU1351NL	28	134	16	4	0	0	0	25	74	TRUE
EDU1351NL	29	134	17	4	0	0	0	25	74	TRUE
EDU1351NL	30	134	24	4	0	0	0	25	74	TRUE
EDU1351NL	31	144	14	4	0	0	0	25	76	TRUE
EDU1351NL	32	144	15	4	0	0	0	25	76	TRUE
EDU1351NL	33	154	11	4	0	0	0	25	73	TRUE
EDU1351NL	34	154	13	4	0	0	0	25	73	TRUE
EDU1351NL	35	154	14	2	0	0	0	25	73	TRUE
EDU1351NL	36	164	9	4	0	0	0	25	75	TRUE
EDU1351NL	37	164	11	4	0	0	0	25	75	TRUE
EDU1351NL	38	174	7	4	0	0	0	25	76	TRUE
EDU1351NL	39	174	9	3	0	0	0	25	76	TRUE
EDU1351NL	40	174	9	1	1	0	0	25	76	TRUE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
EDU1351NL	41	189	5	4	0	0	0	25	76	TRUE
EDU1351NL	42	189	7	3	0	0	0	25	76	TRUE
EDU1351NL	43	189	7	1	1	0	0	25	76	TRUE
EDU849LT2rest	1	100	40	13	0	0	0	25	77	FALSE
EDU849LT2work	1	100	40	8	0	0	0	25	77	FALSE
EDU849LT2rest	2	100	40	1	1	0	0	25	77	FALSE
EDU849LT2work	3	100	40	1	1	0	0	25	77	FALSE
EDU849LT2work	4	100	40	1	1	0	0	25	77	FALSE
EDU849LT2work	5	100	40	1	1	0	0	25	77	FALSE
EDU849LT2work	6	100	40	1	0	1	0	25	77	FALSE
EDU849LT2rest	7	100	45	4	0	0	0	25	77	FALSE
EDU849LT2work	7	100	45	1	0	0	0	25	77	FALSE
EDU849LT2work	8	100	45	1	1	0	0	25	77	FALSE
EDU849LT2work	9	100	45	1	1	0	0	25	77	FALSE
EDU849LT2work	10	100	45	1	1	0	0	25	77	FALSE
EDU849LT2rest	11	100	50	5	0	0	0	25	77	FALSE
EDU849LT2work	11	100	50	3	0	0	0	25	77	FALSE
EDU849LT2work	12	100	50	1	1	0	0	25	77	FALSE
EDU849LT2work	13	100	50	1	1	0	0	25	77	FALSE
EDU849LT2rest	14	100	50	1	1	0	0	25	77	FALSE
EDU849LT2work	15	100	50	1	0	1	0	25	77	FALSE
EDU849LT2rest	16	100	55	8	0	0	0	25	77	FALSE
EDU849LT2work	16	100	55	2	0	0	0	25	77	FALSE
EDU849LT2work	17	100	55	1	1	0	0	25	77	FALSE
EDU849LT2work	18	100	55	1	1	0	0	25	77	FALSE
EDU849LT2work	19	100	55	1	1	0	0	25	77	FALSE
EDU849LT2work	20	100	55	1	0	1	0	25	77	FALSE
EDU849LT2work	21	100	55	1	0	1	0	25	77	FALSE
EDU849LT2rest	22	100	55	1	0	1	0	25	77	FALSE
EDU849LT2work	23	100	55	1	0	1	0	25	77	FALSE
EDU849LT2work	24	100	55	1	0	1	0	25	77	FALSE
EDU849LT2rest	25	100	60	9	0	0	0	25	77	FALSE
EDU849LT2work	25	100	60	5	0	0	0	25	77	FALSE
EDU849LT2rest	26	100	60	1	1	0	0	25	77	FALSE
EDU849LT2work	27	100	60	1	0	1	0	25	77	FALSE
EDU849LT2work	28	100	60	1	0	1	0	25	77	FALSE
EDU849LT2work	29	100	60	1	1	0	0	25	77	FALSE
EDU849LT2work	30	100	60	1	1	0	0	25	77	FALSE
EDU849LT2work	31	100	60	1	1	0	0	25	75	FALSE
EDU849LT2work	32	150	27	2	0	0	0	25	75	FALSE
EDU849LT2rest	33	150	27	1	1	0	0	25	75	FALSE
EDU849LT2work	34	150	27	1	1	0	0	25	75	FALSE
EDU849LT2rest	35	150	27	1	1	0	0	25	75	FALSE
EDU849LT2rest	36	150	27	1	0	1	0	25	75	FALSE
EDU849LT2rest	37	150	27	1	0	1	0	25	75	FALSE
EDU849LT2work	38	150	27	1	1	0	0	25	75	FALSE
EDU849LT2work	39	150	27	1	1	0	0	25	75	FALSE
EDU849LT2rest	40	150	30	8	0	0	0	25	75	FALSE
EDU849LT2work	40	150	30	3	0	0	0	25	75	FALSE
EDU849LT2rest	41	150	30	1	1	0	0	25	75	FALSE
EDU849LT2rest	42	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	43	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	44	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	45	150	30	1	1	0	0	25	75	FALSE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
EDU849LT2work	46	150	30	1	1	0	0	25	75	FALSE
EDU849LT2rest	47	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	48	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	49	150	30	1	0	1	1	25	75	FALSE
EDU849LT2work	50	150	30	1	0	1	1	25	75	FALSE
EDU849LT2rest	51	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	52	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	53	150	30	1	0	1	0	25	75	FALSE
EDU849LT2work	54	150	30	1	0	1	0	25	75	FALSE
EDU849LT2rest	55	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	56	150	30	1	0	1	0	25	75	FALSE
EDU849LT2rest	57	150	30	1	1	0	0	25	75	FALSE
EDU849LT2work	58	150	30	1	0	1	0	25	75	FALSE
EDU849LT2rest	59	150	30	1	0	1	1	25	75	FALSE
EDU849LT2work	60	150	30	1	0	1	0	25	75	FALSE
EDU849LT2rest	61	150	30	1	1	0	0	25	75	FALSE
EDU849LT2rest	62	150	33	3	0	0	0	25	75	FALSE
EDU849LT2work	63	150	33	1	0	1	1	25	75	FALSE
EDU849LT2work	64	150	33	1	1	0	0	25	75	FALSE
EDU849LT2rest	65	150	36	1	0	0	0	25	75	FALSE
EDU849LT2rest	66	150	36	1	0	1	1	25	75	FALSE
EDU849LT2rest	67	150	36	1	0	1	1	25	75	FALSE
EDU849LT2rest	68	150	36	1	0	1	1	25	75	FALSE
EDU849LT2work	69	150	36	1	0	1	1	25	75	FALSE
EDU849LT2work	70	150	36	1	0	1	1	25	75	FALSE
EDU849LT2work	71	150	36	1	1	0	0	25	75	FALSE
EDU849LT2rest	72	150	36	1	0	1	0	25	75	FALSE
EDU849LT2work	73	150	36	1	1	0	0	25	75	FALSE
EDU849LT2work	74	150	36	1	0	0	0	25	75	FALSE
EDU885A	29	100	30	10	0	0	0	36	16	TRUE
EDU885A	30	100	31.5	10	0	0	0	31	28	TRUE
EDU885A	32	150	14	10	0	0	0	36	26	TRUE
EDU885A	33	150	14	10	0	0	0	44	17	TRUE
EDU885A	37	60	66.9	9	0	0	0	26	24	TRUE
EDU885A	40	60	66.6	10	0	0	0	30	29	TRUE
EDU885A	41	60	66.7	10	0	0	0	35	28	TRUE
EDU885A	46	190	10	10	0	0	0	30	27	TRUE
EDU885A	50	190	10	9	0	0	0	33	23	TRUE
EDU885A	51	120	24	9	0	0	0	40	21	TRUE
EDU885A	53	120	24	10	0	0	0	31	23	TRUE
EDU885A	75	100	30.5	1	0	1	0	27	20	TRUE
EDU885A	77	100	30.1	1	0	1	0	25	31	TRUE
EDU885A	78	100	30.1	1	0	1	0	25	31	TRUE
EDU885A	79	100	30.1	1	0	1	0	25	31	TRUE
EDU885A	82	80	39.7	1	0	0	0	40	27	TRUE
NMR97NOD	1	40	200	86	0	0	0	16	20	TRUE
NMR97NOD	2	40	200	1	1	0	0	16	20	TRUE
NMR97NOD	3	40	200	1	1	0	0	16	20	TRUE
NMR97NOD	4	40	200	1	1	0	0	16	20	TRUE
NMR97NOD	5	40	200	1	0	1	0	16	20	TRUE
NMR97NOD	6	40	200	1	0	1	1	16	20	TRUE
NMR97NOD	7	41.2	200	10	0	0	0	16	21	TRUE
NMR97NOD	8	41.2	200	1	1	0	0	16	21	TRUE
NMR97NOD	9	41.2	200	1	0	1	1	16	21	TRUE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
NMRNSW2	1	61.5	81.5	3	0	0	0	36	34	TRUE
NMRNSW2	2	61.5	83.6	3	0	0	0	47	15	TRUE
NMRNSW2	3	61.5	82.3	2	0	0	0	56	19	TRUE
NMRNSW2	4	61.5	82.3	1	1	0	0	56	19	TRUE
NMRNSW2	5	61.5	92.2	1	0	0	0	41	22	TRUE
NMRNSW2	6	61.5	92.3	3	0	0	0	51	28	TRUE
NMRNSW2	7	61.5	91.9	2	0	0	0	51	32	TRUE
NMRNSW2	8	61.5	91.9	1	0	1	0	51	32	TRUE
NMRNSW2	9	61.5	92.1	2	0	0	0	56	31	TRUE
NMRNSW2	10	61.5	92.2	3	0	0	0	44	29	TRUE
NMRNSW2	11	61.5	92.1	2	0	0	0	44	31	TRUE
NMRNSW2	12	61.5	92.2	2	0	0	0	51	29	TRUE
NMRNSW2	13	61.5	91.9	2	0	0	0	56	36	TRUE
NMRNSW2	14	61.5	102.2	2	0	0	0	47	29	TRUE
NMRNSW2	15	61.5	102.2	1	1	0	0	47	29	TRUE
NMRNSW2	16	61.5	102.4	1	0	0	0	56	27	TRUE
NMRNSW2	17	61.5	102.4	1	1	0	0	56	27	TRUE
NMRNSW2	18	61.5	106.1	2	0	0	0	47	9	TRUE
NMRNSW2	19	61.5	106.1	1	0	1	0	47	9	TRUE
NMRNSW2	20	61.5	101.6	2	0	0	0	47	38	TRUE
NMRNSW2	21	61.5	102.1	1	0	0	0	51	31	TRUE
NMRNSW2	22	61.5	102.1	1	1	0	0	51	31	TRUE
NMRNSW2	23	61.5	102.1	1	0	1	0	51	31	TRUE
NMRNSW2	24	61.5	92.3	2	0	0	0	51	29	TRUE
NMRNSW2	25	61.5	92.3	1	0	1	0	51	29	TRUE
NMRNSW2	26	61.5	84.2	3	0	0	0	56	15	TRUE
NMRNSW2	27	61.5	82.3	1	0	0	0	56	24	TRUE
NMRNSW2	28	61.5	82.3	1	0	1	1	56	24	TRUE
NSM6HR	1	28	360	3	0	0	0	9	28	FALSE
NSM6HR	2	28	360	3	0	0	0	9	14	FALSE
NSM6HR	3	28	360	4	0	0	0	9	28	FALSE
NSM6HR	4	32	360	6	0	0	0	25	16	FALSE
NSM6HR	5	32	360	5	0	0	0	25	11	FALSE
NSM6HR	6	36	360	4	0	0	0	26	9	FALSE
NSM6HR	7	36	360	3	0	0	0	26	18	FALSE
NSM6HR	8	36	360	4	0	0	0	19	18	FALSE
NSM6HR	9	38	360	3	0	0	0	57	38	FALSE
NSM6HR	10	38	360	1	1	0	0	57	38	FALSE
NSM6HR	11	38	360	3	0	0	0	35	38	FALSE
NSM6HR	12	38	359	2	0	0	0	47	38	FALSE
NSM6HR	13	38	359	1	0	1	0	47	38	FALSE
NSM6HR	14	40	360	4	0	0	0	26	20	FALSE
NSM6HR	15	40	360	2	0	0	0	44	18	FALSE
NSM6HR	16	40	360	1	0	1	0	44	18	FALSE
NSM6HR	17	40	360	6	0	0	0	57	13	FALSE
NSM6HR	18	40	360	1	0	1	0	57	13	FALSE
NSM6HR	19	40	360	1	1	0	0	57	13	FALSE
PASA	24	101.5	31.8	1	0	1	0	33	18	TRUE
PASA	25	101.5	30	2	0	0	0	42	8	TRUE
PASA	26	101.5	30	2	0	0	0	30	12	TRUE
RNPLX50	5	33	360	2	0	0	0	30	30	FALSE
RNPLX50	6	33	240	1	0	0	0	30	30	FALSE
RNPLX50	10	35	360	2	0	0	0	30	30	FALSE
RNPLX50	13	37	360	1	0	0	0	30	30	FALSE

Data file/Man-trial	Profile #	fsw	BT	n	marginal	DCS	CNS	Asc. rate	Desc. rate	Wet
NEDU2008SerA	1	130	20	84	0	2	2	29	58	TRUE
NEDU2008SerA	2	150	15	100	0	1	1	29	58	TRUE
NEDU2008SerA	3	190	11	100	0	1	1	29	58	TRUE
NEDU2008SerB	1	130	16	57	0	0	0	29	58	TRUE
NEDU2008SerB	2	150	12	51	0	1	1	29	58	TRUE
NEDU2008SerB	3	190	9	40	0	1	1	29	58	TRUE
NEDU2008USN57	1	130	10	53	0	0	0	29	58	TRUE
NEDU2008USN57	2	150	5	102	0	1	0	29	58	TRUE
NEDU2008USN57	3	190	5	102	0	0	0	29	58	TRUE

Profile # corresponds to the dive profile numbers listed in NMRI TR 99-02[5] except for NEDU2008 trials

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APPENDIX B. NO-STOP LIMIT COMPARTMENT OF INTEREST

Dive profile summaries for the no-stop logistic model calibration data set were selected based on the assumption that the gas exchange compartment of interest for determining any no-stop limit has a time constant (τ) approximately equal to the no-stop BT for that depth. In the classical Haldanean approach, the M_0 values for modeled compartments are specified to limit compartmental dissolved gas loads to maximum levels achieved over an empirically established set of no-stop limits. Figure B-1 illustrates the relationship between Model 2 P_{CNSDCS} = 0.002 iso-risk no-stop limits and the time constants τ of the compartment(s) that achieve their maximum inert gas tensions at those limits. Clearly, the no-stop limit at each depth governs the M_0 value for only a limited range of compartmental τ values that are nearly equal to the no-stop limit itself.

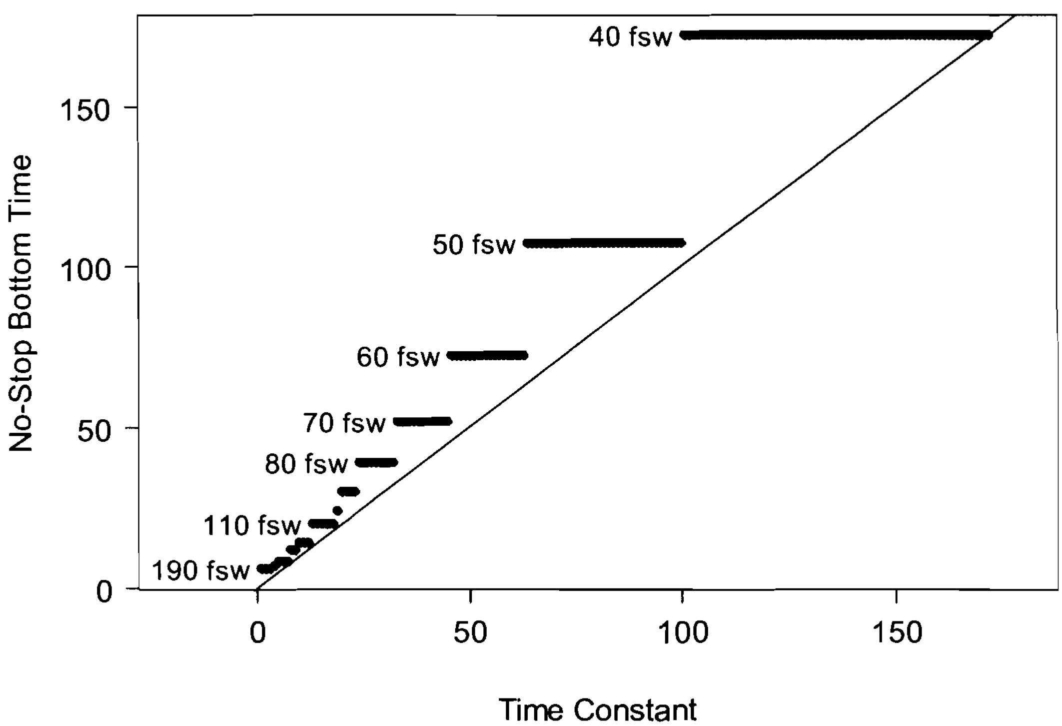

Figure B-1. P_{CNSDCS}=0.002 no-stop limit bottom time at various depths versus the time constants of compartments in which a dive to the limit produces the highest inert gas tensions in the compartments achieved at any no-stop depth and bottom time. Depths for some of the no stop limits are indicated.

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APPENDIX C. NEDU NO-STOP TRIAL DCS CASE NARRATIVES

190/11, 20041130

41-year-old active-duty male diver reached surface at 09:07::42 on 30NOV04 from an experimental 190/11 no-decompression dive in 55 °F water under moderate exercise and full rubber wetsuit conditions. Approximately 40 minutes after surfacing, the diver noted that his right thigh felt "heavy and fatigued" and his right hand was getting numb. The diver was examined at the NEDU sick bay at 09:55 and an abbreviated neurological exam was conducted. Cranial nerves II-XII, motor, and sensory systems were all objectively within normal limits, but the patient reported a progression of symptoms with the development of a "tight, squeezing" pain on his left abdominal region and a progression of the right thigh heaviness both down the right leg and across the lower back and into the left thigh. The diver was placed in the NEDU treatment hyperbaric chamber at 10:03 and brought to 60 fsw (reached bottom at 10:06). The diver reported that the abdominal pain completely resolved on descent and that the right arm and thigh heaviness had partially resolved on descent. The patient was placed on 100% oxygen by BIBS mask. A repeat neurological examination continued within normal limits and the patient reported a 50% reduction in right arm and leg "fatigue" within the first minute on oxygen. The patient reported a new "tingling" sensation in the toes of his right foot. After being on oxygen at 60 fsw for 5 minutes, the patient reported a complete resolution of all symptoms except for the right leg heaviness that continued as a 1/10 until just before the first air-break. All symptoms were completely resolved by the start of the first air-break. The remainder of the U.S.N. Treatment Table 6 treatment was completed without further incident or extensions. Post-treatment neurological examination was within normal limits. Diagnosis: rapidly progressing neurological Type II DCS. Possible contributing factors: 1) omitted decompression (per current U.S. Navy Standard Air Decompression Table) on experimental protocol, 2) cold water (55 °F), and 3) fatigue (diver reported <4 hours of sleep the previous evening).

150/15, 20041201

43-year-old, active-duty male diver presents approximately 25 minutes after surfacing from a dive complaining of a left visual field disturbance. Patient had completed an IRB-approved experimental dive testing no-decompression limits. His profile was 150 fsw for 15 minutes using surface-supplied MK 20 decompressed to the surface at 30 fsw/minute. Water temperature was 55 °F and while on bottom patient pedaled a cycle ergometer set at 50 watts. The patient reported a visual field deficit on the lower half of his left eye while completing a computerized neuropsychiatric test. He denied any other symptoms and otherwise felt well. He also denied any symptoms on the bottom or upon surfacing. On exam, patient's visual acuity in the left eye was decreased to 20/100 (normal for him is 20/20) and he demonstrated a clear visual field deficit of the lower half of the left eye. The right eye was normal and the remainder of his neurological exam was normal. During the course of the exam the patient noted that he felt his vision improving although this could not be confirmed objectively. He was compressed to 60 fsw in the treatment chamber and placed on oxygen. Within 4 minutes of starting oxygen he noted his vision improving which was confirmed on exam and his vision returned to normal after 14 minutes on oxygen. The rest of his neurological exam remained normal. He completed a standard U.S.N. Treatment Table 6 without extensions and had no recurrence of symptoms. Post-treatment the patient felt well and his physical exam was normal. Final diagnosis: Type II DCS.

130/20, 20041207

43-year-old active-duty male diver acting as a diver test subject on a 130 fsw for 20 minute no-stop dive using surface-supplied MK 20, decompressed to the surface at 30 fsw/minute. Water temperature was 55 °F and while on bottom patient pedaled a cycle ergometer set at 50 watts. He denied any other symptoms and otherwise felt well. He also denied any symptoms on the bottom or upon surfacing. On exam, he had weakness of the right lower extremity and difficulty with balance. The remainder of his neurological examination was normal. He was compressed to 60 fsw in the treatment chamber and placed on oxygen. He noted improvement in weakness during the first oxygen period and had complete relief of all symptoms after 1 hour and 50 minutes. The rest of his neurological examination remained normal. He completed a standard U.S.N. Treatment Table 6 with two extensions at 60 fsw. Post-treatment the patient felt well and his physical exam was normal. Approximately six hours after the initial treatment, patient awoke from sleep and noticed new sensory symptoms, described as tingling, heat or thick feeling, over the right side of his trunk and over the medial aspect of both legs. Exam revealed no objective sensory or motor deficit, but a presumptive diagnosis of recurrence of neurological symptoms of Type II DCS was made and patient was again recompressed and treated on U.S.N. Treatment Table 6 with no extensions. He noted minimal improvement with recompression. Symptoms gradually improved over the next 24 hours, but did not resolve completely and he was treated on U.S.N. Treatment Table 9 daily, during which he noted gradual improvement. On follow-up at 14 days, patient notes continuing gradual improvement. Final diagnosis: Type II DCS.

130/20, 20050127

Test subject is a 49-year-old white male USN diver who had never been bent in his career. Subject arrived at NEDU the morning of the dive complaining of upper respiratory congestion with productive cough and fatigue. Because of the fatigue, he drank an unusually large amount of coffee (two 32oz. mugs) and three 12oz glasses of water.

Subject's dive profile was a 130/20 experimental no-stop air dive in 55 °F water dressed in full 7 mm wet suit. Exercise on bottom was moderate (50 Watts cycling at 60 rpm on underwater ergometer). Subject was immersed for the compression to 130 fsw and reports that he felt completely normal from leaving surface until reaching bottom. Shortly after reaching bottom he began his underwater exercise period and within a couple minutes began to feel nauseated and felt "acid burping up." Subject states that he then vomited a few ounces of liquid into the oronasal mask of his MK 20 UBA. He tried to evacuate the vomit using the purge button but was unsuccessful. He therefore began forcefully exhaling through his mouth (5 or more times) until his oronasal mask was clear. Subject states that the last 14 minutes of BT were uneventful.

Ascent was normal and divers reached surface at 1051 on 27Jan05. Ten-minute clean time was unremarkable. Subject then gathered his "gear" together and left the third deck via the elevator on his way to shower in the diver's locker room located on the second deck at the far opposite end of the NEDU complex. Subject climbed flights of stairs to the test pool area and then walked back to the locker room only to find that he had forgotten his backpack in the control room. So he walked back down the flights and then up two flights to the control room to get his bag. He then walked back down the two flights and started back up the flights of stairs adjacent to the test pool, where he encountered his first symptom (approximately 18 minutes after surfacing). Subject states that his legs suddenly felt "very heavy" while climbing those stairs but he was able to reach the top and made his way back to the locker room.

Upon reaching the locker room, subject states that he "began to feel dizzy" so he sat down on the bench. After a few moments, he tried but was unable to stand. He states that his "legs felt like jello". He then began to feel "pins and needles" ascending to his trunk and arms bilaterally and rapidly progressive heaviness of both legs. At this point the diver used his cellular phone to call the NEDU Quarter Deck. The Duty Medical Officer was notified at 1130 and directly observed the diver's condition as it rapidly worsened with increased bilateral weakness of the lower extremities and progression to weakness in both shoulders. The patient was taken to the recompression chamber by which time he could not move either leg. The diver was placed on 100% oxygen by BIBS and pressed to 60 fsw. A compete neurological examination was performed upon reaching 60 fsw in the chamber and the diver was observed moving both legs. The diver reported complete resolution of all symptoms within 4 minutes of reaching 60 fsw. A U.S.N. Treatment Table 6 without extensions was performed and the diver reported continued relief of symptoms. Immediately prior to leaving the second oxygen period at 30 fsw for ascent to surface, the diver reported that he had 0.5/10 tingling of all fingertips of his left hand for the previous 60 minutes. The decision was made to bring the diver to surface for evaluation and observation.

Post-treatment neurological examination was completely within normal limits except for a small unsteadiness while the diver attempted heel-to-toe walking, a modest overshoot with the left fingertip during coordination testing, and continued 0.5/10 tingling over the palm and fingertips of the left hand. These findings were attributed to fatigue and hyperoxic exposure. The diver was observed overnight by a fellow diver and was to be re-evaluated the following morning.

The diver notified the duty DMO at 0600 on Day 2 (post-dive day 1) that "he was much worse." Prompt neurological examination demonstrated extreme unsteadiness and dis-coordination on finger-to-nose touch, rapid hand flipping, and the patient could not heel-to-toe walk without falling down. Similarly, the patient failed the Romberg test due to falling over when closing his eyes. A U.S.N. Treatment Table 6 was immediately initiated. The diver improved in steadiness throughout his 60 fsw stops, with 2 oxygen period extensions at 60 fsw, but failed to improve significantly during the 30 fsw stops (no extensions). Post-treatment neurological exam demonstrated continued, but reduced, cerebellar impairment and patchy paresthesias on the fingertips of the left hand, left palm, both feet in a stocking distribution, and the groin and perineal region. The patient reported that it "felt like he was wearing a diaper". Daily U.S.N. Treatment Table 6's with full extensions in oxygen periods at 60 fsw and no extensions at 30 fsw were initiated, with a total of five U.S.N. Treatment Table 6s being delivered over five days. The patient continued to improve during 60 fsw stops and then symptom resolution reached a plateau during the 30 fsw stops and the inter-treatment period. No relapses were noted. No signs or symptoms of pulmonary oxygen toxicity were observed until the final oxygen period at 60 fsw on the final U.S.N. Treatment Table 6 day, and the presenting symptom was mild substernal burning on inhalation.

The patient was given a day off of HBO and then initiated on daily U.S.N. Treatment Table 9s with a plan of continuing this daily routine until complete resolution of all symptoms was achieved or symptoms showed no improvement for two consecutive treatments. The patient received three U.S.N. Treatment Table 9s before achieving the second termination criterion. At the time the hyperbaric treatments were stopped, all cerebellar symptoms had resolved, but the diver was left with .5/10 patchy paraesthesias over the left hand, toes of both feet, and the perineum. These symptoms continue ten days past the last treatment (i.e., at the time of this report). Additionally, the diver has missed eight workdays subsequent to treatment cessation due to post-oxygen exposure fatigue and shortness of breath. He experienced significant myopic shift, thought to be hyperoxic myopia, for at least ten days after the final hyperbaric treatment but has not started to resolve his visual changes. Auto-refraction and Snellen visual acuity tests were performed daily.

Diagnosis: Central neurological Type II DCS

190/9, 20061026

47-year-old male, active-duty diver complained of onset of 2/10 right hip pain without radiation approximately 10 minutes after reaching surface from a 190/:09 experimental no-stop dive.. Patient began dressing and noticed gradual onset of left flank pain described as "gas pain". Patient reported general alteration of mental status. Patient also complained of right visual field changes approximately 20 min after reaching surface. Patient denied numbness or other sensory changes. On exam, patient had altered mental status with decreased calculation ability, right hip flexor 4/5 weakness, positive Romberg, and unsteady heel-to-toe gait. Patient recompressed to 60fsw with resolution of symptoms almost immediately upon reaching depth. Patient treated with U.S.N. Treatment Table 6 with two extensions at 60 fsw. Patient experienced slight cough immediately after treatment, but was at baseline by the next morning. Final diagnosis: Type II DCS.

150/12, 20061206

Diver complained of nausea, fatigue, and dizziness 17 minutes after reaching surface and was assisted to sick bay. At DMO arrival during move to sick bay, patient was alert, oriented, but unable to clearly localize what he felt was wrong. Halfway to sick bay, patient could still bear weight, but was unable to coordinate his leg movements to walk unassisted, so was carried remainder of distance. At chamber, his mental condition deteriorated with inability to process verbal instructions and he also reported loss of vision. Diver was compressed and upon arrival at 60 fsw, prior to oxygen administration, he reported full return of vision, significantly improved alertness, and no weakness or sensory changes. DMO exam found slowing of calculations, no motor or sensory deficits, normal vital signs, and otherwise normal physical exam. At the end of the first oxygen period, patient had near-complete restoration of mental function (rapid and accurate calculation and 1/10 "fogginess" improved from 4/10). He reported complete relief of symptoms just prior to the ascent to 30 fsw, after two extensions at 60 fsw. Completed U.S.N. Treatment Table 6 (without extensions at 30fsw), after which he reported no symptoms and had a normal physical/neurological exam except for some pre-existing, post-surgical sensory deficits. His follow-up exam the next day was notable for very mild and non-specific back discomfort that appeared consistent with prolonged limited mobility during the treatment. His exam remained normal.

APPENDIX D. THALMANN ALGORITHM VVAL-76 PARAMETERS

TABLE C.1. TABLE OF VVAL-76 MAXIMUM PERMISSIBLE TISSUE TENSIONS

(DEPTHS AND PRESSURES IN FSW; SURFACE AT 1 ATA = 33 FSW)

$T_{1/2}$	5	10	20	40	80	120	160	200	240
SDR	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
DEPTH									
10	106.7	86.7	70.3	56	48.5	45.5	44.5	44	43.5
20	130	108	88	66	58.5	55.5	54.5	54	53.5
30	140	118	98	76	68.5	65.5	64.5	64	63.5
40	150	128	108	86	78.5	75.5	74.5	74	73.5
50	160	138	118	96	88.5	85.5	84.5	84	83.5
60	170	148	128	106	98.5	95.5	94.5	94	93.5
70	180	158	138	116	108.5	105.5	104.5	104	103.5
80	190	168	148	126	118.5	115.5	114.5	114	113.5
90	200	178	158	136	128.5	125.5	124.5	124	123.5
100	210	188	168	146	138.5	135.5	134.5	134	133.5
110	220	198	178	156	148.5	145.5	144.5	144	143.5
120	230	208	188	166	158.5	155.5	154.5	154	153.5
130	240	218	198	176	168.5	165.5	164.5	164	163.5
140	250	228	208	186	178.5	175.5	174.5	174	173.5
150	260	238	218	196	188.5	185.5	184.5	184	183.5
160	270	248	228	206	198.5	195.5	194.5	194	193.5
170	280	258	238	216	208.5	205.5	204.5	204	203.5
180	290	268	248	226	218.5	215.5	214.5	214	213.5
190	300	278	258	236	228.5	225.5	224.5	224	223.5
200	310	288	268	246	238.5	235.5	234.5	234	233.5
210	320	298	278	256	248.5	245.5	244.5	244	243.5
220	330	308	288	266	258.5	255.5	254.5	254	253.5
230	340	318	298	276	268.5	265.5	264.5	264	263.5
240	350	328	308	286	278.5	275.5	274.5	274	273.5
250	360	338	318	296	288.5	285.5	284.5	284	283.5
260	370	348	328	306	298.5	295.5	294.5	294	293.5
270	380	358	338	316	308.5	305.5	304.5	304	303.5
280	390	368	348	326	318.5	315.5	314.5	314	313.5
290	400	378	358	336	328.5	325.5	324.5	324	323.5
300	410	388	368	346	338.5	335.5	334.5	334	333.5

Table C.2. Table of VVal-76 Global Parameters

PARAMETER	VALUE	UNITS
PACO2	1.5	FSW
PH2O	0.0	FSW
PVCO2	2.3	FSW
PVO2	2.0	FSW
AMBAO2	0.0	FSW
PBOVP	10.0	FSW
sPBOVP	0.0	FSW
O2TIME	30.0	MIN
AIRTIME	5.0	MIN
CNDSDR_FO2	0.8	*
O2TIME_FO2	0.8	*
GSWLAT	0.0	MIN
AB_DEAD	TRUE	

*dimensionless

APPENDIX E. VVAL-76 AIR DECOMPRESSION TABLES

The following Air Decompression tables are calculated with the Thalmann Algorithm parameterized with the VVal-76 parameter set. The VVal-76 Tables have shorter no-stop limits and longer decompression times for some schedules than the VVal-18M Thalmann Algorithm Tables. These tables have not been evaluated for risk of decompression sickness or for the impact of parameter changes on repetitive diving.

DCA parameters:

TTIS	T	RE_MODE	2
RGD_SPRSS	2	RNDUPD	T
SRF_CNTRL_MODE	0	LST_DOMode	1

Descent Rate 75 fsw/minute; Ascent Rate 30 fsw/minute
Travel Time in stops except first stop on gas mix

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
30	371	1:00	AIR						0	1:00	0	Z
			AIR/O_2						0	1:00		
30	420	0:20	AIR						22	23:00	0.5	Z
			AIR/O_2						5	6:00		
30	480	0:20	AIR						42	43:00	0.5	
			AIR/O_2						9	10:00		
30	540	0:20	AIR						71	72:00	1	
			AIR/O_2						14	15:00		
30	600	0:20	AIR						92	93:00	1	
			AIR/O_2						19	20:00		
30	660	0:20	AIR						120	121:00	1	
			AIR/O_2						22	23:00		
30	720	0:20	AIR						158	159:00	1	
			AIR/O_2						27	28:00		
40	163	1:20	AIR						0	1:20	0	O
			AIR/O_2						0	1:20		
40	170	0:40	AIR						6	7:20	0.5	O
			AIR/O_2						2	3:20		
40	180	0:40	AIR						14	15:20	0.5	Z
			AIR/O_2						5	6:20		
40	190	0:40	AIR						21	22:20	0.5	Z
			AIR/O_2						7	8:20		
40	200	0:40	AIR						27	28:20	0.5	Z
			AIR/O_2						9	10:20		
40	210	0:40	AIR						39	40:20	0.5	Z
			AIR/O_2						11	12:20		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
				DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time								
40	220	0:40	AIR						52	53:20	0.5	Z
			AIR/O_2						12	13:20		
40	230	0:40	AIR						64	65:20	1	
			AIR/O_2						16	17:20		
40	240	0:40	AIR						75	76:20	1	
			AIR/O_2						19	20:20		
40	270	0:40	AIR						101	102:20	1	
			AIR/O_2						26	27:20		
40	300	0:40	AIR						128	129:20	1.5	
			AIR/O_2						33	34:20		
40	330	0:40	AIR						160	161:20	1.5	
			AIR/O_2						38	44:20		
40	360	0:40	AIR						184	185:20	2	
			AIR/O_2						44	50:20		
40	420	0:40	AIR						248	249:20	2.5	
			AIR/O_2						56	62:20		
40	480	0:40	AIR						321	322:20	2.5	
			AIR/O_2						68	79:20		
40	540	0:40	AIR						372	373:20	3	
			AIR/O_2						80	91:20		
50	92	1:40	AIR						0	1:40	0	M
			AIR/O_2						0	1:40		
50	95	1:00	AIR						2	3:40	0.5	M
			AIR/O_2						1	2:40		
50	100	1:00	AIR						4	5:40	0.5	N
			AIR/O_2						2	3:40		
50	110	1:00	AIR						8	9:40	0.5	O
			AIR/O_2						4	5:40		
50	120	1:00	AIR						21	22:40	0.5	O
			AIR/O_2						7	8:40		
50	130	1:00	AIR						34	35:40	0.5	Z
			AIR/O_2						12	13:40		
50	140	1:00	AIR						45	46:40	1	Z
			AIR/O_2						16	17:40		
50	150	1:00	AIR						56	57:40	1	Z
			AIR/O_2						19	20:40		
50	160	1:00	AIR						78	79:40	1	Z
			AIR/O_2						23	24:40		
50	170	1:00	AIR						96	97:40	1	
			AIR/O_2						26	27:40		
50	180	1:00	AIR						111	112:40	1.5	
			AIR/O_2						30	31:40		
50	190	1:00	AIR						125	126:40	1.5	
			AIR/O_2						35	36:40		
50	200	1:00	AIR						136	137:40	1.5	
			AIR/O_2						39	45:40		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
50	210	1:00	AIR						147	148:40	2	
			AIR/O_2						43	49:40		
50	220	1:00	AIR						166	167:40	2	
			AIR/O_2						47	53:40		
50	230	1:00	AIR						183	184:40	2	
			AIR/O_2						50	56:40		
50	240	1:00	AIR						198	199:40	2	
			AIR/O_2						53	59:40		
50	270	1:00	AIR						236	237:40	2.5	
			AIR/O_2						62	68:40		
50	300	1:00	AIR						285	286:40	3	
			AIR/O_2						74	85:40		
50	330	1:00	AIR						345	346:40	3.5	
			AIR/O_2						83	94:40		
50	360	1:00	AIR						393	394:40	3.5	
			AIR/O_2						92	103:40		
60	63	2:00	AIR						0	2:00	0	K
			AIR/O_2						0	2:00		
60	65	1:20	AIR						2	4:00	0.5	L
			AIR/O_2						1	3:00		
60	70	1:20	AIR						7	9:00	0.5	L
			AIR/O_2						4	6:00		
60	75	1:20	AIR						10	12:00	0.5	M
			AIR/O_2						5	7:00		
60	80	1:20	AIR						14	16:00	0.5	N
			AIR/O_2						7	9:00		
60	85	1:20	AIR						17	19:00	0.5	N
			AIR/O_2						9	11:00		
60	90	1:20	AIR						23	25:00	0.5	O
			AIR/O_2						10	12:00		
60	95	1:20	AIR						33	35:00	0.5	O
			AIR/O_2						12	14:00		
60	100	1:20	AIR						42	44:00	1	Z
			AIR/O_2						15	17:00		
60	110	1:20	AIR						57	59:00	1	Z
			AIR/O_2						21	23:00		
60	120	1:20	AIR						75	77:00	1	Z
			AIR/O_2						26	28:00		
60	130	1:20	AIR						102	104:00	1.5	
			AIR/O_2						31	33:00		
60	140	1:20	AIR						124	126:00	1.5	
			AIR/O_2						35	37:00		
60	150	1:20	AIR						143	145:00	2	
			AIR/O_2						41	48:00		
60	160	1:20	AIR						158	160:00	2	
			AIR/O_2						48	55:00		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
60	170	1:20	AIR						178	180:00	2	
			AIR/O_2						53	60:00		
60	180	1:20	AIR						201	203:00	2.5	
			AIR/O_2						59	66:00		
60	190	1:20	AIR						222	224:00	2.5	
			AIR/O_2						64	71:00		
60	200	1:20	AIR						240	242:00	2.5	
			AIR/O_2						68	80:00		
60	210	1:20	AIR						256	258:00	3	
			AIR/O_2						73	85:00		
60	220	1:20	AIR						278	280:00	3	
			AIR/O_2						77	89:00		
60	230	1:20	AIR						300	302:00	3.5	
			AIR/O_2						82	94:00		
60	240	1:20	AIR						321	323:00	3.5	
			AIR/O_2						88	100:00		
60	270	1:20	AIR						398	400:00	4	
			AIR/O_2						102	119:00		
70	48	2:20	AIR						0	2:20	0	K
			AIR/O_2						0	2:20		
70	50	1:40	AIR						2	4:20	0.5	K
			AIR/O_2						1	3:20		
70	55	1:40	AIR						9	11:20	0.5	L
			AIR/O_2						5	7:20		
70	60	1:40	AIR						14	16:20	0.5	M
			AIR/O_2						8	10:20		
70	65	1:40	AIR						19	21:20	0.5	N
			AIR/O_2						10	12:20		
70	70	1:40	AIR						24	26:20	0.5	N
			AIR/O_2						13	15:20		
70	75	1:40	AIR						32	34:20	1	O
			AIR/O_2						15	17:20		
70	80	1:40	AIR						44	46:20	1	O
			AIR/O_2						17	19:20		
70	85	1:40	AIR						55	57:20	1	Z
			AIR/O_2						20	22:20		
70	90	1:40	AIR						64	66:20	1	Z
			AIR/O_2						24	26:20		
70	95	1:40	AIR						73	75:20	1.5	Z
			AIR/O_2						28	30:20		
70	100	1:40	AIR						88	90:20	1.5	Z
			AIR/O_2						31	33:20		
70	110	1:40	AIR						120	122:20	1.5	
			AIR/O_2						38	45:20		
70	120	1:40	AIR						145	147:20	2	
			AIR/O_2						44	51:20		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
				DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time								
70	130	1:40	AIR						167	169:20	2	
			AIR/O_2						51	58:20		
70	140	1:40	AIR						189	191:20	2.5	
			AIR/O_2						59	66:20		
70	150	1:40	AIR						219	221:20	2.5	
			AIR/O_2						66	78:20		
70	160	1:20	AIR					1	244	247:00	3	
			AIR/O_2					1	72	85:00		
70	170	1:20	AIR					2	265	269:00	3	
			AIR/O_2					1	78	91:00		
70	180	1:20	AIR					4	289	295:00	3.5	
			AIR/O_2					2	83	97:00		
70	190	1:20	AIR					5	316	323:00	3.5	
			AIR/O_2					3	88	103:00		
70	200	1:20	AIR					9	345	356:00	4	
			AIR/O_2					5	93	115:00		
70	210	1:20	AIR					13	378	393:00	4	
			AIR/O_2					7	98	122:00		
80	38	2:40	AIR						0	2:40	0	J
			AIR/O_2						0	2:40		
80	40	2:00	AIR						2	4:40	0.5	J
			AIR/O_2						1	3:40		
80	45	2:00	AIR						10	12:40	0.5	K
			AIR/O_2						5	7:40		
80	50	2:00	AIR						17	19:40	0.5	M
			AIR/O_2						9	11:40		
80	55	2:00	AIR						24	26:40	0.5	M
			AIR/O_2						13	15:40		
80	60	2:00	AIR						30	32:40	1	N
			AIR/O_2						16	18:40		
80	65	2:00	AIR						40	42:40	1	O
			AIR/O_2						19	21:40		
80	70	2:00	AIR						54	56:40	1	O
			AIR/O_2						22	24:40		
80	75	2:00	AIR						67	69:40	1	Z
			AIR/O_2						25	27:40		
80	80	2:00	AIR						77	79:40	1.5	Z
			AIR/O_2						30	32:40		
80	85	2:00	AIR						93	95:40	1.5	Z
			AIR/O_2						34	36:40		
80	90	2:00	AIR						114	116:40	1.5	
			AIR/O_2						39	46:40		
80	95	2:00	AIR						131	133:40	2	
			AIR/O_2						43	50:40		
80	100	1:40	AIR					1	147	150:20	2	
			AIR/O_2					1	46	54:20		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
80	110	1:40	AIR					6	171	179:20	2	
			AIR/O_2					3	51	61:20		
80	120	1:40	AIR					10	200	212:20	2.5	
			AIR/O_2					5	59	71:20		
80	130	1:40	AIR					14	232	248:20	3	
			AIR/O_2					7	67	86:20		
80	140	1:40	AIR					17	258	277:20	3.5	
			AIR/O_2					9	73	94:20		
80	150	1:40	AIR					19	285	306:20	3.5	
			AIR/O_2					10	80	102:20		
80	160	1:40	AIR					21	318	341:20	4	
			AIR/O_2					11	86	114:20		
80	170	1:40	AIR					27	354	383:20	4	
			AIR/O_2					14	90	121:20		
90	30	3:00	AIR						0	3:00	0	I
			AIR/O_2						0	3:00		
90	35	2:20	AIR						6	9:00	0.5	J
			AIR/O_2						3	6:00		
90	40	2:20	AIR						14	17:00	0.5	L
			AIR/O_2						7	10:00		
90	45	2:20	AIR						23	26:00	0.5	M
			AIR/O_2						12	15:00		
90	50	2:20	AIR						31	34:00	1	N
			AIR/O_2						17	20:00		
90	55	2:20	AIR						39	42:00	1	O
			AIR/O_2						21	24:00		
90	60	2:20	AIR						56	59:00	1	O
			AIR/O_2						24	27:00		
90	65	2:20	AIR						70	73:00	1.5	Z
			AIR/O_2						28	31:00		
90	70	2:20	AIR						83	86:00	1.5	Z
			AIR/O_2						32	35:00		
90	75	2:20	AIR						103	106:00	1.5	Z
			AIR/O_2						38	46:00		
90	80	2:00	AIR					5	125	132:40	2	
			AIR/O_2					3	40	50:40		
90	85	2:00	AIR					9	143	154:40	2	
			AIR/O_2					5	43	55:40		
90	90	2:00	AIR					13	158	173:40	2	
			AIR/O_2					7	46	60:40		
90	95	2:00	AIR					16	171	189:40	2.5	
			AIR/O_2					8	49	64:40		
90	100	2:00	AIR					19	185	206:40	2.5	
			AIR/O_2					10	53	70:40		
90	110	2:00	AIR					25	224	251:40	3	
			AIR/O_2					13	61	86:40		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
90	120	1:40	AIR				2	28	256	288:20	3.5	
			AIR/O_2				2	14	70	98:40		
90	130	1:40	AIR				5	28	291	326:20	3.5	
			AIR/O_2				5	14	79	110:40		
90	140	1:40	AIR				8	28	330	368:20	4	
			AIR/O_2				8	14	87	126:40		
100	24	3:20	AIR						0	3:20	0	H
			AIR/O_2						0	3:20		
100	25	2:40	AIR						1	4:20	0.5	H
			AIR/O_2						1	4:20		
100	30	2:40	AIR						8	11:20	0.5	J
			AIR/O_2						4	7:20		
100	35	2:40	AIR						15	18:20	0.5	L
			AIR/O_2						8	11:20		
100	40	2:40	AIR						26	29:20	1	M
			AIR/O_2						14	17:20		
100	45	2:40	AIR						36	39:20	1	N
			AIR/O_2						19	22:20		
100	50	2:40	AIR						47	50:20	1	O
			AIR/O_2						24	27:20		
100	55	2:40	AIR						65	68:20	1.5	Z
			AIR/O_2						29	32:20		
100	60	2:40	AIR						81	84:20	1.5	Z
			AIR/O_2						33	36:20		
100	65	2:20	AIR					5	99	107:00	1.5	Z
			AIR/O_2					3	36	47:00		
100	70	2:20	AIR					11	124	138:00	2	
			AIR/O_2					6	39	53:00		
100	75	2:20	AIR					16	144	163:00	2	
			AIR/O_2					9	42	59:00		
100	80	2:20	AIR					21	160	184:00	2.5	
			AIR/O_2					11	45	64:00		
100	85	2:20	AIR					26	174	203:00	2.5	
			AIR/O_2					13	48	69:00		
100	90	2:00	AIR				2	28	196	228:40	2.5	
			AIR/O_2				2	14	53	82:00		
100	95	2:00	AIR				5	29	220	256:40	3	
			AIR/O_2				5	15	59	92:00		
100	100	2:00	AIR				9	28	241	280:40	3	
			AIR/O_2				9	14	66	102:00		
100	110	2:00	AIR				14	28	278	322:40	3.5	
			AIR/O_2				14	14	76	117:00		
100	120	2:00	AIR				19	28	324	373:40	4	
			AIR/O_2				19	14	85	136:00		
110	19	3:40	AIR						0	3:40	0	G
			AIR/O_2						0	3:40		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
110	20	3:00	AIR						1	4:40	0.5	H
			AIR/O_2						1	4:40		
110	25	3:00	AIR						7	10:40	0.5	I
			AIR/O_2						4	7:40		
110	30	3:00	AIR						15	18:40	0.5	K
			AIR/O_2						8	11:40		
110	35	3:00	AIR						27	30:40	1	M
			AIR/O_2						14	17:40		
110	40	3:00	AIR						39	42:40	1	N
			AIR/O_2						20	23:40		
110	45	3:00	AIR						50	53:40	1	O
			AIR/O_2						26	29:40		
110	50	3:00	AIR						71	74:40	1.5	Z
			AIR/O_2						32	35:40		
110	55	2:40	AIR					5	85	93:20	1.5	Z
			AIR/O_2					3	33	44:20		
110	60	2:40	AIR					13	111	127:20	2	
			AIR/O_2					7	36	51:20		
110	65	2:40	AIR					20	135	158:20	2	
			AIR/O_2					10	40	58:20		
110	70	2:40	AIR					26	155	184:20	2.5	
			AIR/O_2					14	42	64:20		
110	75	2:20	AIR				4	28	173	208:00	2.5	
			AIR/O_2				4	14	47	73:20		
110	80	2:20	AIR				9	28	200	240:00	2.5	
			AIR/O_2				9	14	54	90:20		
110	85	2:20	AIR				13	29	226	271:00	3	
			AIR/O_2				13	15	60	101:20		
110	90	2:20	AIR				18	28	249	298:00	3.5	
			AIR/O_2				18	14	68	113:20		
110	95	2:20	AIR				21	29	268	321:00	3.5	
			AIR/O_2				21	15	73	122:20		
110	100	2:20	AIR				25	28	295	351:00	3.5	
			AIR/O_2				25	14	79	131:20		
110	110	2:00	AIR			5	26	28	353	414:40	4	
			AIR/O_2			5	26	14	91	154:00		
120	16	4:00	AIR						0	4:00	0	G
			AIR/O_2						0	4:00		
120	20	3:20	AIR						5	9:00	0.5	H
			AIR/O_2						3	7:00		
120	25	3:20	AIR						14	18:00	0.5	J
			AIR/O_2						7	11:00		
120	30	3:20	AIR						24	28:00	0.5	L
			AIR/O_2						13	17:00		
120	35	3:20	AIR						38	42:00	1	N
			AIR/O_2						20	24:00		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
120	40	3:20	AIR						51	55:00	1	O
			AIR/O_2						27	31:00		
120	45	3:20	AIR						72	76:00	1.5	Z
			AIR/O_2						33	37:00		
120	50	3:00	AIR					10	85	98:40	1.5	Z
			AIR/O_2					5	33	46:40		
120	55	3:00	AIR					19	116	138:40	2	
			AIR/O_2					10	35	53:40		
120	60	3:00	AIR					27	142	172:40	2	
			AIR/O_2					14	39	61:40		
120	65	2:40	AIR				6	28	164	201:20	2.5	
			AIR/O_2				6	14	45	73:40		
120	70	2:40	AIR				13	28	190	234:20	2.5	
			AIR/O_2				13	14	51	86:40		
120	75	2:40	AIR				18	29	220	270:20	3	
			AIR/O_2				18	15	59	105:40		
120	80	2:40	AIR				24	28	246	301:20	3	
			AIR/O_2				24	14	67	118:40		
120	85	2:20	AIR			3	26	28	269	329:00	3.5	
			AIR/O_2			3	26	14	74	130:20		
120	90	2:20	AIR			7	26	28	303	367:00	3.5	
			AIR/O_2			7	26	14	80	140:20		
130	14	4:20	AIR						0	4:20	0	G
			AIR/O_2						0	4:20		
130	15	3:40	AIR						2	6:20	0.5	G
			AIR/O_2						1	5:20		
130	20	3:40	AIR						9	13:20	0.5	I
			AIR/O_2						5	9:20		
130	25	3:40	AIR						21	25:20	0.5	K
			AIR/O_2						11	15:20		
130	30	3:40	AIR						34	38:20	1	M
			AIR/O_2						18	22:20		
130	35	3:40	AIR						49	53:20	1	N
			AIR/O_2						26	30:20		
130	40	3:20	AIR					3	67	74:00	1.5	Z
			AIR/O_2					2	31	37:00		
130	45	3:20	AIR					12	84	100:00	1.5	Z
			AIR/O_2					6	33	48:00		
130	50	3:20	AIR					22	116	142:00	2	
			AIR/O_2					12	34	55:00		
130	55	3:00	AIR				4	28	145	180:40	2	
			AIR/O_2				4	14	40	67:00		
130	60	3:00	AIR				12	28	170	213:40	2.5	
			AIR/O_2				12	14	46	81:00		
130	65	3:00	AIR				20	28	203	254:40	2.5	
			AIR/O_2				20	14	54	102:00		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
130	70	2:40	AIR			1	26	28	235	293:20	3	
			AIR/O_2			1	26	14	63	117:40		
130	75	2:40	AIR			7	25	29	262	326:20	3.5	
			AIR/O_2			7	25	15	71	131:40		
130	80	2:40	AIR			12	26	28	297	366:20	3.5	
			AIR/O_2			12	26	14	79	144:40		
140	12	4:40	AIR						0	4:40	0	F
			AIR/O_2						0	4:40		
140	15	4:00	AIR						5	9:40	0.5	H
			AIR/O_2						3	7:40		
140	20	4:00	AIR						15	19:40	0.5	J
			AIR/O_2						8	12:40		
140	25	4:00	AIR						28	32:40	1	L
			AIR/O_2						15	19:40		
140	30	4:00	AIR						44	48:40	1	N
			AIR/O_2						23	27:40		
140	35	3:40	AIR					4	59	67:20	1.5	O
			AIR/O_2					2	30	36:20		
140	40	3:40	AIR					11	80	95:20	1.5	Z
			AIR/O_2					6	33	48:20		
140	45	3:20	AIR				3	21	113	141:00	2	
			AIR/O_2				3	11	34	57:20		
140	50	3:20	AIR				8	27	145	184:00	2	
			AIR/O_2				8	14	39	71:20		
140	55	3:20	AIR				16	28	171	219:00	2.5	
			AIR/O_2				16	14	46	85:20		
140	60	3:00	AIR			2	23	28	209	265:40	3	
			AIR/O_2			2	23	14	56	109:00		
140	65	3:00	AIR			7	26	28	245	309:40	3	
			AIR/O_2			7	26	14	66	127:00		
140	70	3:00	AIR			14	25	29	276	347:40	3.5	
			AIR/O_2			14	25	15	74	142:00		
140	75	3:00	AIR			20	26	28	316	393:40	4	
			AIR/O_2			20	26	14	83	162:00		
150	10	5:00	AIR						0	5:00	0	F
			AIR/O_2						0	5:00		
150	15	4:20	AIR						9	14:00	0.5	H
			AIR/O_2						5	10:00		
150	20	4:20	AIR						21	26:00	0.5	K
			AIR/O_2						11	16:00		
150	25	4:20	AIR						35	40:00	1	M
			AIR/O_2						19	24:00		
150	30	4:00	AIR					4	50	58:40	1.5	O
			AIR/O_2					2	26	32:40		
150	35	4:00	AIR					12	72	88:40	1.5	Z
			AIR/O_2					6	31	46:40		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
150	40	3:40	AIR				5	17	102	128:20	2	Z
			AIR/O_2				5	9	33	56:40		
150	45	3:40	AIR				11	24	141	180:20	2	
			AIR/O_2				11	12	39	71:40		
150	50	3:20	AIR			3	15	28	170	220:00	2.5	
			AIR/O_2			3	15	14	46	87:20		
150	55	3:20	AIR			7	21	28	212	272:00	3	
			AIR/O_2			7	21	14	57	113:20		
150	60	3:20	AIR			11	26	28	248	317:00	3	
			AIR/O_2			11	26	14	67	132:20		
150	65	3:00	AIR		1	18	26	28	286	362:40	3.5	
			AIR/O_2		1	18	26	14	77	150:00		
160	9	5:20	AIR						0	5:20	0	F
			AIR/O_2						0	5:20		
160	10	4:40	AIR						1	6:20	0.5	F
			AIR/O_2						1	6:20		
160	15	4:40	AIR						13	18:20	0.5	I
			AIR/O_2						7	12:20		
160	20	4:40	AIR						27	32:20	1	L
			AIR/O_2						15	20:20		
160	25	4:20	AIR					4	40	49:00	1	N
			AIR/O_2					2	21	28:00		
160	30	4:00	AIR				1	9	59	73:40	1.5	O
			AIR/O_2				1	5	28	39:00		
160	35	4:00	AIR				5	14	84	107:40	1.5	Z
			AIR/O_2				5	7	33	55:00		
160	40	4:00	AIR				12	20	130	166:40	2	
			AIR/O_2				12	10	38	70:00		
160	45	3:40	AIR			5	13	28	164	214:20	2.5	
			AIR/O_2			5	13	14	44	85:40		
160	50	3:40	AIR			10	19	28	207	268:20	3	
			AIR/O_2			10	19	14	55	112:40		
160	55	3:20	AIR		2	12	26	28	248	320:00	3	
			AIR/O_2		2	12	26	14	67	135:20		
160	60	3:20	AIR		6	17	25	29	291	372:00	3.5	
			AIR/O_2		6	17	25	15	77	154:20		
170	8	5:40	AIR						0	5:40	0	E
			AIR/O_2						0	5:40		
170	10	5:00	AIR						3	8:40	0.5	G
			AIR/O_2						2	7:40		
170	15	5:00	AIR						16	21:40	0.5	J
			AIR/O_2						9	14:40		
170	20	4:40	AIR					2	31	38:20	1	L
			AIR/O_2					1	17	23:20		
170	25	4:20	AIR				1	7	45	58:00	1	N
			AIR/O_2				1	4	23	33:20		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time						Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
				70	60	50	40	30	20			
170	30	4:20	AIR				5	11	72	93:00	1.5	Z
			AIR/O_2				5	6	29	45:20		
170	35	4:00	AIR			2	10	16	113	145:40	2	
			AIR/O_2			2	10	8	36	66:00		
170	40	4:00	AIR			6	13	23	155	201:40	2.5	
			AIR/O_2			6	13	12	43	84:00		
170	45	3:40	AIR		1	11	16	28	194	254:20	2.5	
			AIR/O_2		1	11	16	14	52	108:40		
170	50	3:40	AIR		5	12	23	28	243	315:20	3	
			AIR/O_2		5	12	23	14	66	134:40		
170	55	3:40	AIR		9	16	25	28	287	369:20	3.5	
			AIR/O_2		9	16	25	14	77	155:40		
180	7	6:00	AIR						0	6:00	0	E
			AIR/O_2						0	6:00		
180	10	5:20	AIR						6	12:00	0.5	G
			AIR/O_2						4	10:00		
180	15	5:20	AIR						20	26:00	0.5	J
			AIR/O_2						11	17:00		
180	20	5:00	AIR					5	34	44:40	1	M
			AIR/O_2					3	18	26:40		
180	25	4:40	AIR				5	7	54	71:20	1.5	O
			AIR/O_2				5	3	27	40:40		
180	30	4:20	AIR			3	6	14	84	112:00	1.5	Z
			AIR/O_2			3	6	7	32	58:20		
180	35	4:20	AIR			6	12	18	139	180:00	2	
			AIR/O_2			6	12	9	41	78:20		
180	40	4:00	AIR		2	11	13	27	175	232:40	2.5	
			AIR/O_2		2	11	13	14	47	97:00		
180	45	4:00	AIR		7	12	19	28	232	302:40	3	
			AIR/O_2		7	12	19	14	62	129:00		
180	50	3:40	AIR	1	11	13	25	28	276	358:20	3.5	
			AIR/O_2	1	11	13	25	14	75	153:40		
180	55	3:40	AIR	5	11	19	26	28	336	429:20	4	
			AIR/O_2	5	11	19	26	14	87	181:40		
190	6	6:20	AIR						0	6:20	0	E
			AIR/O_2						0	6:20		
190	10	5:40	AIR						9	15:20	0.5	H
			AIR/O_2						5	11:20		
190	15	5:40	AIR						25	31:20	1	K
			AIR/O_2						14	20:20		
190	20	5:00	AIR				2	7	37	51:40	1	N
			AIR/O_2				2	4	19	31:00		
190	25	4:40	AIR			2	6	9	67	89:20	1.5	Z
			AIR/O_2			2	6	5	28	46:40		
190	30	4:20	AIR		1	6	8	14	112	146:00	2	
			AIR/O_2		1	6	8	7	36	68:20		

Depth (fsw)	Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (fsw) Stop Times (min) include travel time 70	60	50	40	30	20	Total Ascent Time (M:S)	Chamb. O_2 Periods	RG
190	35	4:20	AIR		3	9	12	22	161	212:00	2.5	
			AIR/O_2		3	9	12	11	45	90:20		
190	40	4:20	AIR		7	12	14	29	210	277:00	3	
			AIR/O_2		7	12	14	15	56	119:20		
190	45	4:00	AIR	3	10	12	23	28	262	342:40	3.5	
			AIR/O_2	3	10	12	23	14	72	149:00		
190	50	4:00	AIR	8	10	16	26	28	322	414:40	4	
			AIR/O_2	8	10	16	26	14	84	178:00		