Naval Medical Research Center
8901 Wisconsin Avenue
Bethesda, Maryland 20889-5607

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STATISTICALLY BASED DECOMPRESSION TABLES XI:
Manned Validation of the LE Probabilistic Model for Air and Nitrogen-Oxygen Diving

E. D. Thalmann
P. C. Kelleher
S. S. Survanshi
E. C. Parker
P. K. Weathersby

Bureau of Medicine and Surgery
(MED-02)
Department of the Navy
Washington, DC 20372-5120

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Institutes of Health .

This technical report has been reviewed by the NMRC scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

THOMAS J. CONTRERAS
CAPT, MSC, USN
Commanding Officer
Naval Medical Research Center

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Thalmann, E.D., P.C. Kelleher*, S.S. Survanshi, E.C. Parker, and P.K. Weathersby

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NAVAL MEDICAL RESEARCH CENTER
(CODE 00)
8901 WISCONSIN AVENUE
BETHESDA, MARYLAND 20889-5607

NAVY EXPERIMENTAL DIVING UNIT; COMMANDING OFFICER
321 BULLFINCH ROAD
PANAMA CITY, FL 32407-7015

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*COMSUBDEVRON 5, Medical Department, 137 Sylvester Road, San Diego, California 92106-3597

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13. ABSTRACT *(Maximum 200 words)*

This first-ever validation trial of a probabilistic decompression algorithm was conducted from 1991-92. A real time computer algorithm updated subjects' optimal decompression schedule within a numerical specification of the acceptable risk of decompression sickness (DCS). Long dives (majority over 6 hours) were chosen for testing because of operational needs and under-representation in the calibration data set: long repetitive air dives and multi-level dives - with air throughout, or with 0.7 ATA O_2 during shallow transits or during the final decompression. Non-acclimatized divers wearing wet suits were immersed, chilled, and performed moderate exercise on the bottom but rested during decompression. A total of 730 dives resulted in 36 DCS cases, and another 20 cases with marginal symptoms. A subset (158 dives) were performed with the Combat Swimmer Multi-level Dive procedure, demonstrating greater safety when shallow transits were taken at 15 than at 30 feet of seawater. Overall the model was a predictive success: on none of the profiles were observed DCS incidence outside statistical uncertainty, and optimal model parameters were not greatly changed by the addition of the trial data. The real time algorithm is reliable enough for general Navy use.

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The research protocol employing human subjects in this study has been reviewed and approved by the Naval Medical Research Institute's and the Navy Experimental Diving Unit's Committees for the Protection of Human Subjects.

NOTE: All dive profiles shown in Table 2 are available on floppy disk in the format described in reference 4. These profiles may be obtained by writing to the authors.

Preliminary data from Phases 1b, 2, and 3 have been previously documented and analyzed in NEDU Technical Memoranda TM92-08 (20) and TM92-11 (21). Inconsistencies between these two technical memoranda and this report reflect re-analysis and inclusion of profiles which were excluded in the preliminary analysis but later found suitable for inclusion.

INTRODUCTION

This report describes the results of a manned dive series done as part of the validation of a probabilistic decompression model developed at this laboratory. The decompression model chosen for this particular validation, the LE1 Model, was judged the best of several candidate models at describing the actual decompression sickness (DCS) outcomes in an earlier evaluation (1). The details of the decompression model are described in full elsewhere (1,2) and will only be summarized here. The model uses a risk function to compute the probability that DCS will occur as a result of a dive according to standard survival or time failure analysis techniques (3,4).

Model parameters were optimized before beginning the study described here using an existing dive data base of over 2300 man dives where the breathing gas was either air or nitrogen-oxygen mixtures and where the outcomes (DCS, no DCS) and dive profile were precisely known (5). In optimizing parameter values for risk functions used by the decompression model we included not only the number of DCS cases occurring, but also information on their time of occurrence. This allows the model to predict the time distribution of symptoms as well as their incidence (see References 1 and 6 for details).

While the data base used for optimization of the initial parameters for the LE1 Model was extensive, there were areas where it was felt there was insufficient experience to be able to accept the model predictions without further testing. In deciding what types of profiles to test consideration was given to how the LE1 Model would ultimately be used. The end users would be divers who would be doing the standard surface supplied bounce diving with repetitive dives as well combat swimmers whose missions involve very long multiple level dives. These combat swimmer profiles also involve switching between air and a constant 0.7 PO_2 in N_2 breathing gas so these types of profiles had to be considered as well.

The goal of the validation dive series described here was twofold. One was to verify that the LE1 Model could accurately determine the risk of DCS (P(DCS)) on combat swimmer profiles computed according to techniques already in use by fleet divers. The second was to verify that the LE1 Model could be used to compute safe decompression profiles in real time in those areas of operational importance underrepresented in the database available at the time. Upon completion of testing, the data from this series could be then added to the existing database to further optimize the parameter values.

Once validated, the LE1 Model could be used either to compute a set of printed decompression tables or could be programmed into a diver carried Underwater Decompression Computer (UDC) for real time use.

DECOMPRESSION PROFILE COMPUTATION

Decompression profiles for dives tested in this evaluation were computed in one of two ways, either in real time using the probabilistic LE1 decompression algorithm or according to procedures already in operational use.

Real Time Decompression

The basis of all the real time decompression was a computer algorithm incorporating the LE1 probabilistic decompression model (2,7). A MicroVax 3400 computer (Digital Equipment Corporation) received input from a digital pressure gauge (Heisegauge), which was connected to the chamber in which the dives were conducted. Depth accuracy was ±0.5 fsw. The computer was constantly provided with the chamber depth that was sampled every 5 s and a new decompression profile computed and displayed before the next depth was sampled. During the dives, divers would be in a water-filled wetpot which would increase their depth compared to the dry chamber depth as monitored by the depth gauge. While in the wetpot, divers either stood upright on the wetpot deck or rode a bicycle ergometer in the sitting position. While on the ergometer, the divers' head was approximately 6" higher than their standing height. When the diver left the surface of the wetpot and descended to the deck, a technician signaled the computer via a keyboard input and the computer then added a predetermined depth offset to the dry chamber depth so long as the divers were immersed. This depth offset was set as the depth from the water surface to a distance 6 fsw above the deck at the bottom of the wetpot. This meant that throughout the dive the depth used by the computer was the actual hydrostatic pressure at a distance of 6 fsw above the bottom of the wetpot deck on which the divers were standing. For most subjects this meant that the depth was somewhere between neck level to just above the head during the immersed portions of the dive. Thus, the diver was at a slightly greater depth compared to the depth which would have been sampled by a diver UDC worn on the arm. This was considered to be a worst case for decompression stress. During dives where breathing gas switches were done the type and time of gas switches were signaled to the computer via a keyboard entry[1].

Decompression information was displayed to chamber operators on a CRT monitor that showed the actual time, time since the computer algorithm was started (zero time), dry chamber depth, diver depth (dry depth plus offset) in the current breathing gas in use. In addition, various output values as computed by the LE1 Model were also displayed including the depth of the

[1] Upon completion of each dive, and before dive profile analysis or inclusion in the dive data base, 1.5 fsw was added to each in-water depth of the final profile which referenced the depth at a point close to mid-chest level. This is the convention adopted for all dives in the data base (5).

current decompression stop (safe ascent depth or SAD), the total stop time (TST)[2], and the no-decompression time or the time remaining at the current decompression stop. All decompression stops were calculated in 10-fsw stop depth increments and 5-minute stop time increments with the exception of a single profile (*see* below). No-decompression times were computed to the nearest 0.1 minute. Diver depth was never allowed to go shallower than the SAD and decompression was accomplished by matching diver depth to the SAD all the way to the surface. The only exception were profiles F1a and E1b, which were designed to test whether the last decompression stop could be taken at 20 fsw vice 10 fsw. For these profiles, the diver remained at 20 fsw until the LE1 algorithm showed the SAD to be 0 fsw, at which point the divers ascended directly to the surface.

In addition to the real time display, provisions were made whereby a set of printed decompression tables could be computed based on the dive profile history up to the actual time of computation. These profiles were computed once the final bottom depth was reached and during decompression if there had been a deviation from the original profile for any reason. These printed profiles could be used in the event of a computer failure and would reflect the exact real time decompression profile and would have the same validity as a real time profile. During the conduct of the trial, these printed tables never had to be used.

Parameter Sets and Target Risk

The basic decompression model remained the LE1 Model throughout the study (1,2), which was used either to compute only a P(DCS) for a particular profile where decompression was

[2] Total Stop Time (TST) is the sum of all decompression stop times and does not include the time taken to ascend between stops. This is in contrast to Total Decompression Time (TDT) which includes the sum of all stop times plus the ascent time between stops. TDT is the time usually shown in U.S. Navy decompression tables, and this should be kept in mind when comparing profiles reported here with those already published.

determined from current Fleet procedures, or to compute real-time decompression schedules. In implementing the LE1 Model to compute only the P(DCS) for a given dive profile it need only be supplied with a set of parameter values. When used to compute a decompression schedule, a Target Risk value must also be supplied.

Parameter Sets: There were 3 sets of parameter values used in this study and their values are given in Table 1. Two of these sets of parameters (*B* and *F*) were "best fit," meaning that all parameter values were optimized using the method of maximum likelihood without any constraints or conditions (see Parker et al. (1) for details). Best-fit parameter sets would produce the best available estimate of the true risk of DCS using the LE1 Model based on the dataset used for optimization. Table 2 shows the individual data file names for each dataset used. Parameter Set *B* gave the best estimate of true risk of DCS available before the trial started (2) and was computed using Dataset BIG191, which consisted of some 14 data files described by Weathersby et al. (5). The final parameter set, *F*, gave the best estimate of risk available after the trial was completed and was optimized using Dataset BIG292. This dataset included not only all the files from BIG191, but also the 5 datasets eventually resulting from this trial, as well as two other datasets (ASATARE (5) and NSM6HR (8)), not associated with this series, but which became available shortly after this trial was completed. Parameter Set *F* is used for all computations of P(DCS) in this paper.

The third set of parameter values, *C*, were designated as Compromise Parameters. The compromise parameters arose from the fact that the *B* parameters, while giving the best overall estimate of risk before beginning this dive series, tended to over estimate risk for shallow air saturation dives resulting in some undesirable outcomes when computing decompression profiles. For instance, the *B* parameter set predicted that about 8 cases of DCS should have resulted from the 90 air saturation dives at 20 and 24 fsw in the dataset, while only 1 DCS and 1 "niggle" were actually observed. Operationally, it was desirable to be able to compute decompression profiles with the last stop at 20 fsw since it is easier to hold that depth for the last stop than 10 fsw. Using the *B* parameters, dives with the last stop at 20 fsw were considerably longer than dives with the last stop at 10 fsw. This was a direct result of the overestimation of risk for the 20 fsw and 24 fsw air saturation dives. In an attempt to correct this problem, the *C* parameter set was developed. It arose by setting Parameter *Thr3* (Table 1) to the largest plausible value found in early exploratory work and then re-optimizing the remaining parameters values.

Using this method, *C* parameters were optimized to a local maximum, which resulted in a likelihood value only slightly less than that for the global maximum (Table 1). The compromise struck by the *C* parameters was a slightly degraded overall fit (*LL* 1013 vs 997 using *B* parameter set) in exchange for a DCS risk for a 20-fsw air saturation dive of 3.5% vice 7.0%. Because there were special constraints placed on the algorithm used to compute the *C* parameter set, it cannot be used to estimate the true P(DCS).

Target Risk: Target Risk is a variable that is used in combination with a parameter set by the LE1 Model to compute decompression schedules. Throughout the paper, the Parameter Set-Target Risk combinations will be specified as a letter-number combination. Thus, *C*(4) denotes Compromise Parameters at a Target Risk of 4% and *B*(2.5-7.0) denoted *B* parameters with the risk sliding from 2.5% to 7.0%.

In order to be able to compute decompression profiles in real time, the LE1 Model controls the future risk of DCS occurrence, so-called conditional probability (6,7), to the specified value of the Target Risk. This assumes that as long as no DCS has occurred up to the present, the diver is willing to assume the same risk of DCS occurring on future decompression profiles as he had for past dives. So, the risk of DCS on a second repetitive dive would be the same as the risk for the first. However, when analyzing dive profiles, what is of interest is the risk of DCS occurring in a large number of individuals. This "population risk" is the risk of DCS occurring taking the entire profile into account and is in fact the computed P(DCS). As will be seen below, the value of P(DCS) invariably exceeds that of the Target Risk used to compute the decompressions. P(DCS) is the best estimate of the true binomial probability of DCS occurrence and is used to calculate expected numbers of DCS assuming a binomial distribution.

Ideally, one would simply specify a value for Target Risk to be used for all decompression profiles. In trying to determine what Target Risk levels should be used for this trial, No-Decompression (ND) limits were considered first. Our analysis found that the current U.S. Navy ND limits (9) from 60 fsw to 110 fsw were of low risk and could be computed from the LE1 Model using *B* parameters and a Target Risk in the range 2.3% - 2.5%. We chose 2.5% as the no-decompression Target Risk. However, when this Target Risk was used to compute decompression schedules, the resulting profiles became impractically long. This problem was overcome by allowing the Target Risk to increase with increasing Total Stop Time (TST) up to some maximum value. The Target Risk was kept at 2.5% in this dive series, as long as the TST did not exceed 20 min. For all but one profile, as the TST increased from 20 min to 60 min the Target Risk increased linearly from 2.5% to a 5.0% maximum where it remained for further TST increases. The one exception was Profile A2 where the maximum risk was allowed to go to 7.0%. Using a sliding risk decreased the TST considerably for the most operationally relevant decompression dives. Information on how choices from maximum risk was chosen is given in the Results. Target risk implementation is described in detail in Survanshi et al. (7).

Decompression Using Existing Multi-level Procedures

In addition to profiles computed in real time using the LE1 Model, several profiles were computed using the Combat Swimmer Multi-level Dive (CSMD) procedure currently in use by the Navy Combat Swimmer community (10). This procedure uses the current U.S. Navy Standard Air Tables and repetitive dive procedures (9). Dives are divided up into segments deeper and shallower than 30 fsw, which allows for the conduct of multi-level diving without having to use the "deepest depth for the entire time" rule. In this study CSMD profiles were done to simulate a submarine lockout at 60 or 80 fsw with a long transit at 30 fsw or 15 fsw followed by a descent back to 60 or 80 fsw to lock back into the submarine followed by decompression to the surface. Decompression profiles were computed directly from the operational procedures and the real-time system was used only to record the profile.

PROFILES

Dives were conducted in 4 distinct phases during the period from 27 Feb 91 through 12 Feb 92. Phase 1a was done at the Naval Medical Research Institute (NMRI) and Phases 1b, 2, and 3 at the Navy Experimental Diving Unit (NEDU). Profiles are designated by a one- or two-letter code followed by the phase during which they were conducted. Thus, C1a indicates Profile C from Phase 1a, A3 Profile A from Phase 3 and Ca1b Profile Ca from Phase 1b. Where the profile as actually conducted differed significantly from the planned profile, the profile designation is followed by a lower case roman numeral in parentheses (see below). Table 3 summarizes the series by phase and profile arranged in chronological order, with two exceptions. Profiles C1a(i) and C1a(ii) were done on the same day, but after testing Profile E1a was completed (Table B-1, 18 March) and the final set of dives on Profile Cc1b were done after testing on Profile E1b was started (Table B-2, 5 Sept). More profiles were planned than actually tested, which accounts for the absence of A and B profiles in Phase 1a.

Individual profiles were grouped into 5 dive types (I, II, III, IV, V) whose descriptions are shown in Table 4. All profiles were recorded in real time for later inclusion in a Dive Database. A total of 5 data files were eventually constructed, with each file containing dives of single type (Table 2).

Phase 1 was considered exploratory to allow development of experimental techniques and software. As such, it was decided that only a maximum of 30 trials would be done on each profile. During Phase 1, a set of rejection criteria was put in place that would stop testing before the 30-trial maximum was reached if the incidence of DCS exceeded the lower 95% binomial confidence interval for a true incidence of 5%. Testing was stopped if there were 3 cases of DCS in the first 12 man-dives or 4 cases if DCS occurred in the first 24 man-dives assuming all cases were Type 1. Testing was also stopped if there were 2 cases of Type 2 DCS at any time. See Results for definitions of Type 1 and Type 2 DCS symptoms.

During Phases 1b, 2, and 3 a different approach was used. A specific set of trial rules was implemented to control how many divers were exposed on each profile. This approach is called sequential design (11,12) and seeks to economize over fixed replication rules by stopping replication of a profile if early results appear either "much safer" or "much less safe" than desired. Sequential rules can be as complex as desired, and their choice is essentially arbitrary after a number of alternatives are considered. We chose to "Accept" a profile following 0 DCS in 30 man-dives, or with 1 DCS case in 40 dives, or 2 in 50 dives; and to "Reject" following a 3rd DCS case at any point. The "accept/reject" terminology is more appropriate to hypothesis testing. We used it here only to make day-to-day decisions during the trial. "Acceptance" for this trial -

unlike prior tests of non-probabilistic models - was a broader concept of statistical predictability discussed below. The "power" (statistical properties) of the chosen sequential rules are shown in Figure 1.

Detailed dive profile descriptions are shown in Tables 5-8. These descriptions are idealized and represent planned profiles as computed by the LE1 Model using the specified parameter set/ target risk combinations and ascent/descent rates. The Time column indicates Bottom Time, that is, it includes the descent time from the surface or shallow transit depth. Integer Bottom Times were pre-planned before the dive. Decimal Bottom Times were no-decompression times as computed by the LE1 Model. With the exception of the dives that used the CSMD procedure, all decompressions stop times were computed by the LE1 Model in 5-minute increments. CSMD profiles had stop times computed according to current USN procedures (10). The values for P(DCS) were computed for the profile as given in the table using the *F* parameter set. In several instances, actual profiles varied from these planned idealized profiles as discussed below.

Type I Profiles (Table 5)

These are repetitive air dives. Profiles C1a and D1a are two decompression bounce dives with fixed bottom times and a 90-minute surface interval. The remaining 4 profiles involved three ND dives in succession with either 140-minute or 200-minute surface intervals. The first two dives in Profiles G1a and H1a were done at fixed bottom times slightly less than the ND limit. These fixed bottom times are denoted by integers. The last dive of Profiles G1a and H1a and all three dives of Profiles A1b and D1b had the maximum ND time computed by the LE1 Model in real time. These times are shown as decimal values. All of the Type I profiles were computed using the Compromise parameter set and a Target Risk of 3% or 4%. Divers exited the water and remained resting in the chamber building during the surface intervals. There were 3 unplanned profiles that occurred in this group. Unplanned profiles are serious deviations from the protocol arising for a variety of reasons. They are fully reported here, and included in specific tabulations as appropriate.

Type II Profiles (Table 6)

These were single-bounce decompression dives breathing air. Three of the Phase 1a profiles were planned and computed using the Compromise Parameter set and a Target Risk of 3% or 4%. One unplanned profile from Phase 1a (D1b(ii)) was also placed in this group because only a single dive in a planned repetitive dive was completed. On Profile F1a, the last stop was taken at 20 fsw (see Conduct of Dives below).

Type III Profiles (Table 7)

These were all multi-level air dives. The first 4 done during Phases 1b were computed according to the Combat Swimmer Multi-level Dive (CSMD) procedure (10). This procedure requires stopping a minimum of 30 min at 20 fsw (even if there is no decompression stop required at 20 fsw) before being allowed to descend to 30 fsw for completion of the Shallow Transit phase. If the transit was shallower than 20 fsw, direct ascent to that depth is allowed provided there is no decompression stop required. Profile E1b was computed using the *C* parameter set and a 5% Target Risk and the last stop was taken at 20 fsw (see Conduct of Dives below). Profile A3 was computed using the *B* parameter set and a sliding Target Risk of 2.5 % to 5.0 %. Two unplanned profiles occurred in this group.

Type IV Profiles (Table 8)

These dives were designed to simulate a combat swimmer profile where the final decompression would be carried out breathing from a MK-16 UBA, which supplies a constant PO_2 of 0.7 ata in a nitrogen diluent. They were all multi-level dives with long periods at 30 fsw or 15 fsw to simulate SDV transits. Bottom times at both excursion depths and at the transit depth were chosen beforehand. All ascents followed the decompression stops and times as computed in real time by the LE1 algorithm. While the MK-16 was not used in the trial, the 48% O_2 gas mix breathed during decompression provided a PO_2 of 0.77 ata at the 20-fsw stop and 0.63 ata at the 10-fsw stop. These PO_2 levels were close enough to 0.7 ata such that it was felt the algorithm performance would be the same over the range of PO_2 levels used. All profiles were computed using the *B* parameter set and a sliding Target Risk of 2.5 % to 5.0 %.

Type V Profiles (Table 9)

These were multi-level profiles involving long periods of time at 30 or 15 fsw breathing a high FO_2 gas to simulate Swimmer Delivery Vehicle transits. Bottom times at both excursion depths and at the transit depth were chosen beforehand. All ascents followed the decompression stops and times as computed in real time by the LE1 algorithm. During transits a high O_2 fraction breathing gas was breathed to simulate the 0.7 ata constant PO_2 that would be supplied by a MK-16 UBA. The 37% O_2 at 30 fsw provided a PO_2 of 0.71 ata and the 48% O_2 mix at 15 fsw provided a .70 ata PO_2. All profiles were computed using the *B* parameter set and a sliding Target Risk of 2.5 % to 5.0 %. One unscheduled profile occurred in this group.

DIVER-SUBJECTS

There were 148 diver-subjects who participated in this validation study. Diver 149 participated as a tender only and is included only to provide information on the DCS he developed while tending. Protocols for all studies described in this report were reviewed and approved by the Committees for the Protection of Human Subjects at each institution. Diver physical characteristics are shown in Annex A. In addition, the total number of dives done by each subject in each phase is shown. Some subjects also participated as dive tenders and these dives are noted by the "T" suffix. None of these tender dives was used for parameter optimization. Also shown in the "U" column are the number of Unplanned Profiles included in the total. Some of these were profiles where the subject had to be removed from the chamber early because of ear squeezes during descent or where one or more repetitive dives were not completed for various reasons, including DCS occurrence during a surface interval. Of the 34 unplanned dives 13 were excluded (denoted in the "x" column) which means they were not included in data resulting from this trial. However, 21 unplanned dives were considered of sufficient quality that they could be used for parameter optimization but in some cases recategorization was necessary (see Profile Variations below).

The "DCS" column shows the total number of definite cases of DCS for each subject while in the "m" column the number of marginal symptoms are recorded (*see* RESULTS for definition). The last row of Table A-1 shows the numbers of dives and DCS cases actually used for parameter optimization.

Annex B shows the days on which each individual subject performed a dive. Usually there was a minimum of 60 hours between dives. There are 4 Tables in Annex B, one each for Phases 1a, 1b, 2, and 3. Each cell entry represents a single dive. An asterisk (*) denotes a planned dive not resulting in DCS. Cell containing a "D" denotes definite DCS and those containing "m" a marginal symptom. Unplanned dives are denoted with a "u" and dives as tenders as "t". Excluded dives not used for parameter optimization have an "x" as the last cell entry.

CONDUCT OF DIVES

Dives were all conducted with fully submerged subjects breathing through an open circuit underwater breathing apparatus (UBA) using either a hard helmet (Superlite 17) or a full face mask (AGA). The NMRI chamber wetpot was only able to accommodate a maximum of 4 divers at a time while the NEDU wetpot was able to accommodate up to 10 divers at once. Besides the diver-subjects, there were additional personnel acting as tenders in the dry chambers who assisted the divers in dressing and entering and exiting the water. The chambers were all compressed to depth using air. Divers breathed either air or high FO_2 mixes as required by the profile being tested through their UBA connected to a gas supply outside of the chamber by an umbilical. Tenders breathed an enriched O_2 in N_2 mixture throughout the dive and 100% O_2 during decompression stops and were not included in the study.

Divers wore full 1/4″ neoprene wet suits including "Farmer John" overalls, jacket, hood, gloves, and boots. The water was chilled (±2 °F) according to single-dive in-water time as follows: 90 min or less, 55°F (12.8 °C); 91-200 min, 60 °F (15.6 °F); 201-300 min, 65 °F (18.3 °C); 301-480 min, 70 °F (21.1 °C); greater than 480 min, 75 °F (23.9 °C). Most subjects were visibly chilled and reported being uncomfortably cold during the dives. While at depth, divers performed exercise on an electrically braked bicycle ergometer (Warren G. Collins) with cases specifically built for underwater use (13). Divers exercised for 10 min and rested for 10 min during the entire time at depth. Where bottom times did not allow all exercise periods to be a full 10 min, the last work/rest cycle was shortened so that each diver exercised for approximately half of the total time at depth. Based on previous experience, O_2 consumption during exercise was

1.6-1.8 l/min and during rest .48 l/min (14). Divers rested in an upright position during decompression stops, transits, and during depth changes.

After donning their wet suits outside of the chamber, divers entered the chamber, donned their UBAs and then entered the water where they initially remained at the surface. After all divers had entered the water, the real-time algorithm was started and on a signal from the Dive Supervisor all subjects descended to the wetpot deck in unison as the computer technician entered the appropriate depth offset via a keyboard. This depth offset was added to the chamber depth gauge reading so that the monitored diver depth was the actual hydrostatic pressure at a distance of 6 fsw above the bottom of the wetpot (see footnote 1). Descent rates were 30-40 fsw/min. Occasional delays occurred because of Eustachian tube blockage requiring stops necessitating brief occasional ascents so the diver could clear the blockage. When diving profiles with decompressions computed in real time, the computer algorithm took these delays into account when calculating decompression stops. When dives were done according to the CSMD procedure, the decompression obligation remained unchanged despite delays in descent. However, the delays were brief and considered insignificant over the course of a 6-8 hour dive. Ascent rates were 60 fsw/min to a depth of 20 fsw where chamber ventilation plumbing slowed ascents to 30 fsw/min from 20 to 10 fsw and 15 fsw/min from 10 fsw to the surface.

Once in the water, divers breathed from their UBA continuously. When breathing gas changes were finished, switches were made at a manifold close to the chamber hull and divers purged their UBA so that the change was completed in 30 s or less. All breathing gas changes were made in unison as the computer technician entered the change into the computer by keyboard.

During surface intervals between repetitive dives, divers exited the chamber and were evaluated by a Diving Medical Officer (DMO) or signs of DCS. For other profiles, divers remained in the water throughout but could talk to a DMO through chamber communications, if necessary. After completion of the dive, all subjects reported for examination by DMO immediately after exiting the chamber. If no symptoms of DCS were found, the divers undressed, took a hot shower and were re-examined 2 h after surfacing. If still DCS-free, divers were allowed to leave but had to remain within 1 h travel of the chamber facility and be in the company of someone who would recognize symptoms of DCS for the next 24 h. All divers were seen again by a DMO the morning after their dive and, after that, only if symptoms of DCS developed.

The only criteria used to evaluate profile outcome was the occurrence of clinical DCS. All examinations and diagnosis were made by U.S. Navy Diving Medical Officers experienced in the recognition and treatment of DCS. All DCS was treated and divers allowed to return to diving in accordance with procedures found in Revision 2 of the U.S. Navy Diving Manual (9). Doppler monitoring was not performed.

RESULTS

Numbers of dives and outcomes by Phase and Profile are summarized in Table 3. Dives done as tenders are not included in this Table. Table 4 summarizes the series according to the Type of Dive. Most of the dives (236) were Type III Multi-level Air and the fewest (72) Type II Single Air. The remaining three dive types had approximately the same number of exposures (137) for Type I, 136 for Type IV, and 149 for Type V.

Of the 730 man-dives completed, a total of 717 were used for parameter optimization after excluding the 13 unsuitable Unplanned Profiles (*see* Diver-Subjects above). There were a total of 36 cases of definite DCS and 20 marginal symptoms. Marginal symptoms were transient fleeting aches lasting a few seconds or minutes, commonly known as niggles, which were felt to be related to the decompression but were not considered serious enough to warrant treatment. In keeping with the convention established in earlier reports (1,2) marginal symptoms were considered as having an outcome value of 0.1 when computing overall incidence.

Descriptions of DCS symptoms and marginal symptoms are found in Annex C grouped by phase. Detailed descriptions are given only for definite DCS symptoms. Only the location and times are given for marginal symptoms. The DCS symptoms involving the musculoskeletal system (usually joint pain) were classified as Type 1, DCS symptoms involving the neurological system were classified as Type 2. There were no cardiovascular or pulmonary symptoms in this study. Note that by the symptom classification used here, a diver could have both Type 1 and Type 2 symptoms present. Each individual DCS symptom in Annex C is preceded by either a (1) or (2) denoting whether is was counted as a Type 1 or Type 2 symptom, respectively. Individual marginal symptoms are labeled as niggles with the symptom location(s) following.

The time shown in the "Last Well" column (T1) is the closest time relative to surfacing at which the diver was definitely known to be symptom-free. Some of these entries are negative, which indicate that the symptom occurred during the dive before surfacing for the last time. In most cases this "Last Well" time is shown as 2 h after surfacing, which was the time that subject was last seen by a DMO before being allowed to go home. Other earlier times record where accurate diver recall or DMO examinations were able to verify that symptoms were not present. Times shown in the "Time Onset" column (T2) denote the time at which the diagnosis of DCS was definitely made. This was usually the time that the subject reported for treatment or the time at which the Diving Medical Officer was certain the symptom was definitely due to DCS. Long intervals between T1 and T2 are either times during which no symptoms were present, or during which the symptom could not definitely be ascribed to DCS. In the former case, the diver may not notice symptoms for some time, because symptoms may have taken time to evolve to an intensity where treatment was sought, or a diver may have gone to sleep symptom-free and awoke the next morning with symptoms. Problems ascribing symptoms to DCS would arise if a diver sustained some sort of musculoskeletal injury during the dive (such as pulling a muscle), which resulted in pain on surfacing. In these cases, only after observing the diver long enough to ascertain that the pain was increasing with time could a definite diagnosis of DCS be made. The "Time to Treat" column shows the elapsed time after surfacing when recompression treatment was started.

Annex D shows every symptom and every anatomical location (site) for DCS occurring during this study including those occurring in tenders. Since some divers had DCS symptoms at multiple sites, the number of sites will exceed the number of cases. For niggles and Type 1 symptoms the affected area is noted without regard for symmetry. That is, bilateral symptoms affecting the same area are counted the same as a single symptom occurring on only one side. The Table is divided up into 4 horizontal sections. The top section shows niggles (20 cases, 27 sites) where they were the only type of symptom although at multiple sites in some cases. The next section shows all Type 1 symptoms where they were the only type present (23 cases, 26 sites). The third section shows DCS cases where both Type 1 and Type 2 symptoms occurred concurrently (11 cases, 31 sites: 18 Type 1, 13 Type 2) in the same individual and the fourth section shows cases where the only type of symptoms were Type 2 (5 cases, 9 sites). These data are summarized in Table 10. Counting the 3 definite DCS in the tenders, 39 cases of DCS resulted in a total of 66 individual definite symptoms, 44 Type 1 (All Type 1 column), and 22 Type 2 (All Type 2 column).

Referring to Table 10 and considering only definite Type 1 DCS (not niggles), the upper extremity was affected more than 3 times as frequently as the lower (31 vs. 9), with the shoulder joint being affected most frequently. The upper arm, elbow joint, and wrist joints were also affected but at a lower prevalence. In the lower extremity the knee joint was the only joint in which Type 1 DCS symptoms occurred. Looking only at niggles, the upper extremity was affected almost twice as frequently as the lower (17 vs. 10). Taking niggles and Type 1 symptoms together the upper extremity was affected about 2.5 times as frequently as the lower. The shoulder joint was affected the most frequently (24) followed by the knee (15), elbow (12), upper arm (7), wrist (3) and hands (2). Only single symptoms occurred in other locations and there were 4 Type 1 symptoms occurring in areas other than the extremities.

Type 2 symptoms referable to the extremities (presumably spinal cord lesions) were classified as either weakness or changes in sensation. Symptoms occurred in the upper extremity almost twice as frequently as the lower (13 vs. 6) and sensory changes occurred almost twice as frequently as weakness (12 vs. 7). There were 3 neurological symptoms referable to CNS structures above the spinal cord.

DISCUSSION

Test Evolution

Development of decompression procedures using probabilistic models requires determination of an acceptable level of risk and balancing a reduction in risk against an increase in decompression time. At the beginning of this series, no final decision had been made as to exactly what Target Risk level was appropriate for operational dives. All profiles used during Phases 1a and 1b used either the *C* parameter set or the CSMD procedure (see Tables 3, 5,6, and

7). The *B* parameter set put the current USN no-decompression limits for 60-110 fsw in the 2.3-2.5 % P(DCS) range, but decompression profiles computed at these Target Risk levels were exceptionally long. For example, Profile C1a computed using the *B* parameter set with a 2.5% Target Risk had a 365 min TST for the first dive and 845 min for the second, a total TST of 1210 min. Similarly, for profile D1a the TSTs were 595 min and 740 min, a total TST of 1335 min. These times were judged too long for use in operational diving.

As noted above, the *C* parameter set was computed to give lower calculated risk values for 20-fsw air no-decompression saturation dives and it was thought that this parameter set might provide decompression profiles with shorter TSTs. Indeed, using the *C* parameter set and a 2.5% Target Risk the TSTs for profile C1a were 195 min, 300 min, total 495 min. For Profile D1a they were: 215, 250, total 465. While an improvement over the *B* parameter set profiles, these were still felt to be longer than necessary. In an earlier study (15), a repetitive dive combination essentially identical to Profile C1a (#35 in (15)) had a TST of 250 min with 3 cases of DCS in 9 dives. While that earlier DCS incidence was clearly unacceptable, another doubling of the stop time seemed excessive. A profile identical to Profile D1a (#36 in (15)) had a TST of 295 min and there were 2 cases of DCS in 16 man-dives. Again, this DCS incidence was unsatisfactory but an almost 3-hour increase in TST seemed excessive at the time. For the start of the present trial it was decided to use the *C* parameter set initially but with Target Risk levels above 2.5% to make the TSTs not so conservative.

During Phase 1a, the *C* parameter set was initially used with a Target Risk of 4.0% resulting in Profiles C1a, D1a (Table 5), and E1a (Table 6). Note that Profile E1a is equivalent to the first dive of Profile C1a. Upon completion of these first three profiles of this validation series it became clear that the number of observed DCS (7 DCS in 51 man dives) was excessive and that a reduction in risk level was called for. At this point, the Target Risk was reduced to 3.0% and Phase 1a was completed with only 2 additional cases of DCS in 88 man-dives (Profiles F1a, G1a, H1a, I1a (Table 3)).

As noted above, profiles essentially identical to C1a and D1a had been tested in an earlier dive series with unsatisfactory results (15). The results of testing here indicated that a further lengthening of an already long decompression time was necessary. Given the already long decompression times, combined with the fact that these types of deep long repetitive dives would be rarely done by Fleet divers and never by the Combat Swimmer community, it was decided to forego further testing and concentrate on profiles more likely to be encountered during operational diving.

In starting Phase 1b, profiles computed using the *C*(3) parameter set/target risk were used and Profile A1b conducted 30 times with no DCS. The next profile (B1b) was a multi-level air dive computed using the CSMD procedure with the transit taken at the deep edge of the allowed CSMD range (30 fsw), and the 4 cases of DCS in 38 man-dives (Table 3) met the rejection criteria. The next profile (D1b) was a triple repetitive no-decompression profile similar to H1a computed using the *C*(3) parameter set/target risk combination. However, for Profile D1b the bottom times were at the no-decompression limit computed by the LE1 Model, which were longer than those used in Profile H1a. Profile D1b was rejected with 3 cases of DCS in 40 dives but it should be noted that all cases of DCS occurred after the first or second dive (see the Discussion section).

At this point, a series of three multi-level dives computed according to the CSMD procedure were done (Table 7). Profile Ca1b was accepted while the second profile (Cb1b) met the rejection criteria. Profile Cc1c was constructed by combining the 30-minute 20-fsw stop time with the 150-minute 30-fsw transit time from Cc1b into a single 180-minute transit time at 15 fsw. The idea was to see if simply raising the maximum transit depth floor to 15 fsw would result in an acceptable DCS outcome and the profile was accepted with 1 case of DCS is 42 man-dives.

Since the results of the multi-level dives suggested the model reliably predicted DCS in CSMD dives, the next step was to conduct similar multi-level air profiles, but calculate decompression in real time according to a specified risk rather than using the CSMD procedure. Profile E1b (Table 7) was designed to be similar to Profile B1b, except that instead of spending 47 min at 20 fsw (as required by the CSMD) and the remainder of the 120-minute shallow interval at 30 fsw, the entire 120 min was spent at 30 fsw. The last stop was forced to be 20 fsw, which was accomplished by remaining at 20 fsw, even when the model allowed ascent to 10 fsw, until the model allowed ascent to the surface. Profiles were computed with the *C* parameter set using Target Risks of 3%, 4%, and 5% to see how much the TST would be increased over that of Profile B1b. It was decided to test the profile computed initially using the 5% Target Risk because the more than 25% (104 min) increase in Total Dive Time compared to Profile B1b seemed adequate to reduce the high observed DCS incidence on that profile[3]. This proved not to be the case and Profile E1b was eventually rejected with 3 DCS in 47 man-dives.

In analyzing the preliminary data from Phase 1a and Phase 1b it appeared that profiles with a P(DCS) of 7% or less (as computed using the *B* parameter set) would be acceptable. At this time, a method for varying the risk based on the total stop time had also been devised (see *Target Risk*

[3] Table 7 shows that Profile E1b has a TST 58 min longer than Profile B1b and yet the Total Dive Time was increased by 104 min. in spite of both profiles having the same bottom times. The reason is that the 47 min required stop at 20 fsw in Profile B1b was counted as a decompression stop and only the 73 min at 30 fsw counted as transit time but one could argue that these two times could be combined into a single 120-minute transit time, the same as for Profile E1b. If one considers only the final decompression, profile E1b requires an additional 105 min of decompression. The remaining 1 min discrepancy is due to the additional 1 min of travel time required to get to and from the 20-fsw stop on the first dive of Profile B1b.

above) and this method was felt superior to using a constant risk for any dive or "constrained" parameters such as the *C* parameter set. The first profile of Phase 2 was A2 (Table 9), computed using the *B*(2.5-7.0) parameter set, and rejection because of 5 cases of DCS in 30 dives caused the maximum risk level to be lowered to 5.0%. The remainder of the validation trial was completed using the *B* parameter set with the risk increasing from 2.5% to 5.0% as the TST increased from 20 min to 60 min.

The purpose of Phases 2 and 3 was to test very long profiles where high PO_2 breathing gas similar to the 0.7 ata gas supplied by the MK-16 UBA was used either during transits or during decompression. This would not only reduce the TST but would also test the ability of the model to handle high O_2 breathing gases. The four remaining profiles tested during Phase 2 (Table 8) simulated the case where a switch to the high O_2 breathing gas was made during the final decompression. Of these four, only Profile B2 was rejected with 3 DCS in 20 dives.

Phase 3 profiles (Table 9) retained the *B*(2.5-5.0) parameter set for computing decompressions and simulated dives where the MK-16 UBA would be used during shallow transits but air would be breathed at all other times. All dives in Phase 3 were completed with no DCS cases occurring.

Model Performance

The first indication of model performance is the log likelihood (LL) value given in Table 1. Using the results of this dive series, the *B* parameter set was updated to the *F* parameter set. Note that Parameter Sets *B* and *F* are quite similar, actually differing by less than one standard error of the estimated parameter itself. The similarity is reinforced by the LL of the pre-trial parameter set being within 1 LL unit of the post-trial optimal parameters (set F) when applied to the post-trial combined data. This indicated that the *B* parameter set was already predicting accurate estimates of P(DCS) for the dives in this series prospectively. However, the LL of the *C* parameter set degraded an additional 6 points compared to the *B* parameters when the data from this dive series was combined with the previously available data. Overall, the indication was that there was little change in relative model performance in using the *F* parameters vice the *B* parameters.

Given that there was little change in relative model performance as a result of this dive series, the next question is just how well is it performing on an absolute basis? Observed and predicted outcomes can be compared directly. However, uncertainties in each weaken the ability to detect an actual significant difference. Uncertainty in prediction follows from parameter uncertainty and correlation in fitting to data. This predictive uncertainty can be propagated into prediction of DCS incidence on a given profile using standard statistical methods (16). Uncertainty on observed incidence arises from the random binomial nature of DCS. Uncertainty in observation decreases as the number of replicate dives on a profile increases

Profile Variations

Before comparison can be made using the binomial distribution, it must be verified that grouped profiles are actually replicates of each other. As was alluded to above, not all profiles where executed exactly as planned. As noted earlier, 13 of 34 unplanned dives were excluded from this study altogether. Annex E addresses discrepancies between the remaining 21 unplanned profiles included in this study and the planned profiles. Each individual recorded dive profile included as data in this series along with its P(DCS), as computed from the actual profile, are listed in Tables E-2 through E-6. Profiles showing discrepancies are marked with an asterisk.

Profile names reflect the convention used for computer file names and are letter/number combinations, with the last 2 digits indicating the dive sequence for that particular dive. For example, in Table E-2 the first dive, PAA1A01, denotes the first dive using Profile A in Phase 1b (see key at beginning of Annex). PAA1A02 is the second, and PAA1A03 the third[4]. Note that the P(DCS) values for all three of these dives are similar meaning that there are no discrepancies. The dives numbered 4-10 in Table E-2 show the 4 individual dives done on Profile D in Phase 1a. On some dives where DCS occurred, an individual profile was constructed for the affected diver and an "AD" follows the profile name. If the dive was not completed as planned, the profile name is followed by an "AB". So dive PAA1D01AD is the profile for the diver who suffered DCS while PAA1D01 is the profile for the unaffected divers.

Discrepancies were identified in one of two ways. In the first significant differences in P(DCS) were identified. For example, the sixth profile in Table E-2, PAA1D02, was actually conducted as planned and the P(DCS) of 7.24% calculated from the actual profile is close to the 7.3% calculated for the idealized profile (D1b in Table 5). Three other dives done with D1b as the planned profile had significantly different P(DCS) values ranging from 2.70% to 5.14% meaning that the planned profile was not followed. Profile Dive PAA1D03 was considered a discrepancy based on a second consideration, namely that a review of the dive records showed that it differed in some details from other dives in the group. In this case there was a slow descent on the first dive.

Each dive marked with an asterisk in Tables E-2 through E-6 is included in Table E-1. This table shows the profile that was actually planned as the "Parent Profile," the computer dive file name, the number of divers on that dive, the number of DCS occurring as a result of that dive, and the Group File (dive Type) of that dive. Notice that some dives (PAA1D03AB and

[4] Individual dives in Tables E-2 through E-6 are easily keyed to the dates shown in the Annex B tables. Along the bottom of Tables B-1 through B-4 are letters indicating the profile names. Thus, the first occurrence of D in the table showing dives done during Phase 1a (Table B-1) indicates the first D profile in that phase. The profile name is

PAA1D04AB) that were planned as repetitive dives (parent Profile D1b) were eventually classified as single-bounce dives (Group file PASA) because the diver aborted the dive after completing only the first dive. The fifth column in Table E-1 shows the "Reason" that the profile was originally identified as a discrepancy. The sixth column shows the "Disposition" of the profile, which was either to consider the profile the same as the planned Parent Profile or to consider it as a separate profile. This decision was made based on comparing the P(DCS) of the dive under question to that of those done as planned. If the absolute relative risk ([risk as actually conducted - risk as planned]/risk as planned) was greater than 10%, the dive remained as unplanned and was given a new profile name (last 2 columns of Table E-1). This new name was the parent profile name followed by lower case roman numerals in parenthesis. If the absolute relative risk was less than 10%, the dive was treated as a planned profile. There was one exception to this rule. Dive PAAIIC02AD was the profile followed by the single diver who displayed symptoms of DCS before surfacing from Profile C2 during Phase 2. This diver was locked into the treatment chamber before surfacing and taken to 60 fsw. The low risk resulted when recompression truncated all further risk, but since the DCS occurred as a result of the parent profile, this DCS was considered as resulting from a planned profile. All dives in Table E-1 were included in the data used to optimize the *F* parameter set.

Comparison with Binomial Predictions

Table 11 summarizes the two methods of comparing observed outcome with predicted using the binomial distribution as discussed above. The profiles are ordered according to the P(DCS) for the Idealized profiles (Table11, column 10) computed using the *F* parameter set as shown in

D1a and that particular dive is found in the computer file PAA0D01 (see Annex E for file naming convention). The second D in the table indicates computer file name PAA0D02 and the third PAA0D03.

Tables 5-9. Column 11 shows the computed risks using the actual recorded profile and the agreement with the idealized profiles is excellent, verifying that after recategorization, remaining variations were insignificant.

The first several columns show the total number of dives in the trial, the number of unplanned dives included in that total, and the number excluded. Using the Net Dives (Total - Excluded) as the profile trial size and the number of DCS cases observed, upper and lower 95% binomial confidence limits on the "true" DCS incidence were computed (columns 12 & 13). In no case did the P(DCS) as computed using the *F* parameter set fall outside of these limits. Therefore, point estimates of the model for each profile all are within trial uncertainty of the observed outcome. The point estimate uncertainty is presented as model-propagated upper and lower 95% confidence limits (columns 14 and 15).

The last column of Table 11 shows whether or not the profile met the acceptance or rejection criteria set up before beginning the studies. As the study progressed it became obvious that the required minimum 30 dives to formally meet the acceptance criteria could not be done for all profiles in the allotted time. Therefore, it was decided to lower the acceptance criteria to 0 DCS in at least 26 dives. There were 13 profiles that never accumulated sufficient numbers to formally meet either the acceptance or rejection criteria set for this study. Of these, 7 were unplanned profiles and two (C1a, D1a) had further testing purposely stopped for reasons discussed above. In these cases a dash appears in the last column. Of the four remaining profiles (F1a, I1a, G1a, H1a), all had at least 20 man-dives done and only two, G1a and I1, each had single cases of DCS (Table C-1). The G1a DCS was Type 1 and the I1a DCS knee pain with associated paresthesias over the involved joint. Criteria used in earlier manned validation dive trials (15,17-19) would have allowed acceptance of these profiles so they were considered as accepted here.

Two of the 6 profiles meeting the rejection criteria had a calculated P(DCS) between 4.6% and 5.2% (B2 and E1a). These two profiles came close to meeting the criteria for underprediction of outcomes as described above, indicating that the P(DCS) as computed by the model may have been too low. Profile E1a was a 100-fsw for 60 min single-bounce dive with almost three times the decompression time found in the current U.S. Navy air decompression tables (115 min vs 39 min). Profile B2 was a multi-level dive where a 0.7 ata PO_2 gas was breathed for the final decompression and there is no current procedure to which it can be compared. The other 4 rejected profiles had risks of 7.5% or greater.

Although meeting the revised acceptance criteria, Profile D1b presents a bit of a problem. While no DCS occurred on the 26 man-dives where all three repetitive dives were completed, two cases occurred out of 9 divers after completing only the first two dives (D1b(ii)) and one case occurred in the 5 divers after completing only the first dive (D1b(i)). If the planned and unplanned dives on Profile D1b are combined then there were a total of 50 man-dives with 3 DCS, which meet the rejection criteria. If each profile is considered individually, Profile D1b would be accepted (26 dives, 0 DCS), while the much less risky unplanned profiles are indeterminate because there were too few DCS cases to reject them (3 cases needed) and too few dives to accept them (50 needed for D1b(ii), 40 needed for Dib(i)

So after making all plausible data combinations to find definite evidence of model prediction failures, none were found. The final column demonstrates a greater tendency for profile Rejection on profiles with higher predicted risk, but as the experimental power calculations show (Figure 1), total segregation into Accept and Reject groups would be unlikely. As a final note, the pre-trial parameters (Set *B* in Table 1) produce a slight over prediction of total trial DCS: 46

cases predicted vs. 36 DCS and 20 marginals observed.

Specific Implications for the CSMD

One surprising aspect of Phase 1b was the performance of the CSMD procedure. Discussion of this procedure with Fleet units using it revealed there has been almost no DCS incidents reported. Two of the profiles (B1b and Cb1b) were rejected outright, but there were still 3 cases of DCS in the remaining two (Ca1b, Cc1b). The CSMD procedure was derived from procedures found in the Standard Air Tables, but was never subjected to formal man testing (10). The 60- and 80-fsw excursion depths are extreme compared to typical fleet profiles where 30 or 40 fsw would be more typical. In addition, transits are rarely taken at exactly 30 fsw, but would be in the 15-20 fsw range. As shown by Profile Cc1b, a 15-fsw transit markedly reduces risk and observed DCS compared to a deeper transit. Finally, the MK-16 UBA, which delivers a 0.7 ata constant PO_2 in N_2, is breathed during the transits of many operational dives giving an added safety margin to a procedure that assumes air is breathed throughout. Overall, it appears that if performed to the foot and minute, and if transits are taken at exactly 30 fsw, then the CSMD would probably result in significantly more DCS than currently experienced in operational use. This is typical of tabular procedures, which are rarely used at their exact limits. However, there seems little reason to modify the procedure at present, given that as actually used in the fleet there are few problems. The only significant improvement over the current CSMD would be a diver carried decompression computer working in real time and optimizing the decompression to the actual dive profile.

CONCLUSIONS

This trial was successful in both of its objectives. First, the real-time algorithm containing a probabilistic model ran smoothly. No software problems were encountered, and no unpleasantly surprising displays were produced. The algorithm itself is recommended as ready for U.S. Navy use.

Second, the LE1 probabilistic model itself was subjected to a prospective "clinical trial". It's predictions proved quite accurate, despite being used outside the main depth-time region of the pre-trial calibration data. Any trial with individual profiles replicated less than 50 times each has limited power to reveal predictive failures, but none were found in this study. And with the nature of a probabilistic model, the trial data regardless of outcome is immediately available to recalibrate the model's parameters. In this case, that proved hardly necessary. The model itself is recommended as ready for Navy use within the bounds of the expanded dataset (Table 1) now available.

What are the apparent bounds on the model's "verified" performance? The trial success was notable on long dives (about 500 were over 6 h total duration) and on a selection of the essentially infinite depth/time sequences of multi-level diving. Since multi-level dives and gas switches are of direct interest to combat swimmers, it is reasonable to expect reliable predictions with "similar" profiles. The algorithm is specifically recommended for use by Navy Special Warfare divers.

The written procedure already used by that community, the CSMD, was tested to a limited extent under this trial. Results strongly suggest that "shallow" transits are more safely performed at 15 rather than 30 fsw deep, despite the CSMD's treatment of them as equivalent.

Another dimension of the model's range is the safety level of the calibration dives. In this trial, most dives were in the 3-10% DCS range. Choice of an "acceptable risk" for Navy diving is largely a policy issue outside the scope of this trial. However, indications imply that routine dives should stay below 3% DCS, and so data from this trial is not directly applicable for choosing those limits. (Of course, a successful model can extrapolate down to that range.) Dives over 5% DCS might only be acceptable when long decompression times pose a greater hazard. The long repetitive air dives tested here clearly fall in that category. Despite doubling or tripling Total Decompression Time from the current U.S. Navy Air Tables (9), a low DCS incidence is still not achieved. The present model is well suited for supporting the risk management of those dives as well.

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Annex A

Diver-Subject Characteristics and Diving Summary

Table A-1

Diver Subject Characteristics and Diving Summary

(see key at end of Table for Headings)

Physical Characteristics				Phase 1a					Phase 1b					Phase 2					Phase 3					Subject Totals				
subj	age	ht	wt	Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms		
#	(yrs)	(cm)	(kg)	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	D	m	x	Total	U	DCS	m	x
1	24	183	78.9						5															5				
2	39	183	89.8						2		1													2		1		
3	31	178	76.2						5		1			2										7		1		
4	31	165	78						2															2				
5	35	173	83.9						4	1	1													4	1	1		
6	40	175	92.5						5		1			2					2					9		1		
7	32	168	67.6						3	1				1										4	1			
8	26	165	67.1						2															2				
9	40	178	88.5						1															1				
10	40	178	75.8						8	2			1	1					2					11	2			1
11	27	180	72.6						4															4				
12	41	175	92.1						4		2													4		2		
13	37	175	69.4						3										3			1		6			1	
14	34	180	82.1						3															3				
15	37	191	89.8	1		1			8			1												9		1	1	
16	29	183	95.3						4	1	1													4	1	1		
17	40	183	79.4	1					5	1									1					7	1			
18	31	183	73.9	2					3			1												5			1	
19	30	170	72.6	5		1			3			1												8		1	1	
20	26	180	81.6	1					3															4				
21	33	170	70.8						4	1														4	1			
22	24	175	65.3						4	1														4	1			
23	34	175	90.7						6	1	1													6	1	1		
24	35	188	82.6						5															5				
25	34	175	92.1						4															4				
26	32	180	91.6	6		1	2		4			1							3					13		1	3	
27	30	178	79.4	7		1			9			2							4			2		20		1	4	
28	31	178	77.1	2	1				2					1										5	1			
29	36	183	81.6	4					6			2		1,1T		1T		1T						11,1T		1T	2	1T
30	28	185	97.5						3															3				
31	24	183	80.3	2		1			4	1		1												6	1	1	1	
32	27	178	71.2						1															1				
33	31	180	74.8						8					3					3					14				
34	31	178	78						5					2					1					8				
35	32	191	86.2	4	1				3															7	1			
36	31	185	75.8						2	1				2		1								4	1	1		
37	27	178	66.7						6															6				
38	37	185	82.6						1															1				
39	44	163	72.6						1															1				
40	39	178	86.2						1															1				

Table A-1 (con't)

Diver Subject Characteristics and Diving Summary

(see key at end of Table for Headings)

Physical Characteristics				Phase 1a					Phase 1b					Phase 2					Phase 3					Subject Totals				
subj	age	ht	wt	Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms		
#	(yrs)	(cm)	(kg)	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	D	m	x	Total	U	DCS	m	x
41	43	170	77.1						1															1				
42	45	170	74.8						1															1				
43	30	183	86.2	3					8															11				
44	33	178	80.7						4		2			3										7		2		
45	30	188	87.1						8		2			3	1			1	2					13	1	2		1
46	35	175	92.1						4	1														4	1			
47	33	185	81.6						2	1														2	1			
48	35	183	77.1						9					1										10				
49	35	170	72.6						1			1		1	1			1						2	1		1	1
50	31	185	99.8						1															1				
51	36	183	99.8	3					11					3		1								17		1		
52	30	185	95.3						5	1	2			2					2					9	1	2		
53	35	183	97.5						5															5				
54	29	175	83.9						2															2				
55	31	178	71.7						5										2					7				
56	37	178	86.2						6	1		1												6	1		1	
57	34	173	80.3						3															3				
58	34	180	80.7						8					2	1			1	1					11	1			1
59	21	180	78.5						4										4					8				
60	27	175	73.5						1															1				
61	35	180	88.9						2,1T		1T		1T	1		1								3,1T		1,1T		1T
62	34	183	78.5						7	1				2					2					11	1			
63	39	170	69.4						6	1	1	1		1					1					8	1	1	1	
64	37	178	86.2						5															5				
65	40	180	111.1						3		1			1					2					6		1		
66	28	183	79.8						9					3					2					14				
67	21	180	83.9											5		1								5		1		
68	24	170	66.7											4										4				
69	29	170	73.5																2					2				
70	35	170	77.1											4					1					5				
71	27	183	77.1											3					1					4				
72	28	180	81.2											3					2					5				
73	26	180	89.8																6	2			2	6	2			2
74	33	178	69.9											1		1								1		1		
75	21	178	81.6																6					6				
76	31	178	80.3																3					3				
77	31	183	86.2											1					1					2				
78	26	178	76.2											8										8				
79	19	178	80.3											8										8				
80	22	168	69.9																5	1			1	5	1			1

Table A-1 (con't)

Diver Subject Characteristics and Diving Summary

(see key at end of Table for Headings)

Physical Characteristics				Phase 1a					Phase 1b					Phase 2					Phase 3					Subject Totals				
subj	age	ht	wt	Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms		
#	(yrs)	(cm)	(kg)	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	D	m	x	Total	U	DCS	m	x
81	21	170	71.7																7					7				
82	28	175	95.3																7					7				
83	30	178	83											4					2					6				
84	23	178	73.5																5	2			2	5	2			2
85	21	170	78.5																4					4				
86	20	185	76.7											7										7				
87	21	178	84.8																4					4				
88	36	175	88.5	3										1										4				
89	32	178	81.6																1					1				
90	21	168	68											8										8				
91	27	183	79.4	7										7		1								14		1		
92	22	168	73																6					6				
93	24	175	83											8										8				
94	29	170	69.4											4					2					6				
95	24	183	79.4																5					5				
96	33	170	68.5											1		1								1		1		
97	26	180	88.9											3										3				
98	26	173	85.7																6					6				
99	25	178	73.5											4		1								4		1		
100	35	178	83											6										6				
101	35	188	82.6																1					1				
102	31	178	88.9											2		1								2		1		
103	21	170	66.2											8										8				
104	26	175	65.8	5										1		1								6		1		
105	32	168	79.4																4					4				
106	30	175	93.9											2		1			2					4		1		
107	28	180	79.4																6					6				
108	31	175	80.7											2					1					3				
109	34	191	88.9											4					2					6				
110	22	147	70.3											4										4				
111	25	191	83.9											7	1			1	5	1			1	12	2			2
112	30	183	87.1											6										6				
113	22	185	77.6																5					5				
114	29	173	70.3																4	2			1	4	2			1
115	20	175	69.4																5					5				
116	30	175	72.1											2										2				
117	29	173	82.6	4																				4				
118	28	191	90.7	2			1																	2			1	
119	37	183	72.6	1																				1				
120	30	183	79.4	2																				2				

Table A-1 (con't)

Diver Subject Characteristics and Diving Summary

(see key at end of Table for Headings)

Physical Characteristics				Phase 1a					Phase 1b					Phase 2					Phase 3					Subject Totals				
subj	age	ht	wt	Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms			Dives		Symptoms		
#	(yrs)	(cm)	(kg)	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	DCS	m	x	Total	U	D	m	x	Total	U	DCS	m	x
121	25	173	81.6	2																				2				
122	21	173	74.8	3																				3				
123	39	160	59	1	1			1																1	1			1
124	31	183	78.9	1																				1				
125	35	178	80.7	1																				1				
126	24	173	70.3	3		1																		3		1		
127	39	165	73.5	2			1																	2			1	
128	32	183	79.4	4																				4				
129	33	180	76.2	3																				3				
130	38	188	88.5	1																				1				
131	27	183	81.6	5																				5				
132	32	188	93	2	1																			2	1			
133	36	178	90.7	1																				1				
134	32	170	79.4	3																				3				
135	24	178	74.8	5																				5				
136	40	183	88.5	1																				1				
137	29	183	83.9	2																				2				
138	36	170	74.8	2	1	1																		2	1	1		
139	24	180	72.6	2																				2				
140	34	180	88	5																				5				
141	37	175	68	6																				6				
142	30	163	81.6	2		1																		2		1		
143	38	173	79.4	5			1																	5			1	
144	31	178	77.1	1																				1				
145	31	173	68	2		1																		2		1		
146	29	170	74.8	1																				1				
147	26	178	63.5	6																				6				
148	23	170	77.1	2																				2				
149	28	188	100.7						1T		1T		1T											1T		1T		1T
mean	30.5	177.5	80.1																									
stdev	5.72	6.78	8.71																									
min	19	147	59																									
max	45	191	111.1																									
Total for Series				139	5	9	5	1	277,2T	17	16,2T	12	1,2T	166,1T	4	11,1T	0	4,1T	148	8	0	3	7	730,3T	34	36,3T	20	13,3T
Used for Parameter Optimization				138	4	9	5		276	16	16	12		162	0	11	0		140	1	0	3		717	21	36	20	

Table A-1 Heading Key

Total - Total profiles of all types (Includes planned and unplanned profiles)
U- Unplanned profiles included in total dives.
DCS-decompression sickness
m- marginal symptoms
x- excluded dive (Dives not used for parameter optimization)
T- acting as tender (not used for parameter optimization)

Annex B

Individual Diving Intensity

Table B-1

Individual Diving Intensity Phase 1a

Subject	Feb-91		Mar-91									May-91															Jun-91			Subject
#	27	28	4	5	6	7	8	11	12	14	18	6	7	8	9	13	14	15	16	20	21	22	23	28	29	30	3	4	5	Totals
15			D																											1
17										*																				1
18																									*		*			2
19					*			D						*							*						*			5
20		*																												1
26								m		D				*							*					m		*		6
27		*					*	D				*			*					*									*	7
28										*	u																			2
29			*			*		*		*																				4
31																									*		D			2
35							*		*		u		*																	4
43																					*					*			*	3
51		*			*			*																						3
88			*															*										*		3
91			*			*		*		*												*		*				*		7
104														*			*					*		*			*			5
117												*			*							*							*	4
118	*			m																										2
119																								*						1
120																								*				*		2
121																										*	*			2
122													*					*			*									3
123		ux																												1
124	*																													1
125				*																										1
126													*				D					*								3
127						m								*																2
128													*				*			*			*							4
129						*								*														*		3
130									*																					1
131													*			*			*	*			*							5
132										*	u																			2
133	*																													1
134													*			*			*											3
135													*			*			*	*			*							5
136														*																1
137														*				*												2
138										*	Du																			2
139																									*		*			2
Profile	D	D	D	C	C	E	E	E	E	E	C	F	F	F	G	G	G	G	G	G	G	H	H	H	H	H	I	I	I	Profile

Table B-1 (con't)

Individual Diving Intensity Phase 1a

Subject	Feb-91		Mar-91									May-91															Jun-91			Subject
#	27	28	4	5	6	7	8	11	12	14	18	6	7	8	9	13	14	15	16	20	21	22	23	28	29	30	3	4	5	Totals
140				*			*									*							*				*			5
141					*			*				*			*				*									*		6
142					D																							*		2
143									*			*			*			m										*		5
144													*																	1
145	*			D																										2
146																	*													1
147							*	*		*				*											*				*	6
148																										*	*			2
n=48																														
Profile	D	D	D	C	C	E	E	E	E	E	C	F	F	F	G	G	G	G	G	G	G	H	H	H	H	H	I	I	I	Profile

* - planned dive
u - unplanned dive
x - dive not used for parameter optimization
t - dive done as tender
D - decompression sickness
m - marginal symptom

Table B-2

Individual Diving Intensity Phase 1b

Subject	Jul-91											Aug-91												Sept-91						Subject
#	16	17	18	19	22	23	24	26	29	30	31	1	2	5	6	7	8	12	13	14	15	27	29	3	5	9	11	12	17	Totals
1									*			*		*			*			*										5
2														D								*								2
3	*				*			*				*		D																5
4						*						*																		2
5				*				*			Du								*											4
6			*				D															*					*		*	5
7				*							u												*							3
8																*							*							2
9																			*											1
10		ux								u						*			*			*		*		*		*		8
11										*			*		*			*												4
12			*				D																	*		D				4
13															*			*			*									3
14								*								*					*									3
15	*			m		*		*		*			*		*				*											8
16	*			*				*	Du																					4
17											u					*				*			*			*				5
18		*			*											m														3
19															*			*			*									3
20													*		m				*											3
21											u			*			*					*								4
22			*					*			u								*											4
23					*			Du								*				*		*						*		6
24		*																*			*						*		*	5
25																							*	*		*		*		4
26	*			m	*				*																					4
27	*			*	m			*	*			*		m			*			*										9
28																									*			*		2
29			*		*							*			m			m						*						6
30									*					*													*			3
31		*			*						u					m														4
32						*																								1
33			*				*			*			*									*		*		*			*	8
34										*					*								*			*		*		5
35	*			*		*																								3
36																								*		u				2
37							*		*			*		*			*			*										6
38																					*									1
39																					*									1
40																		*												1
Profile	A	A	A	B	B	B	B	D	D	D	D	Ca	Ca	Ca	Ca	Cb	Cb	Cb	Ca	Cc	Cc	Cc	Cc	E	Cc	E	E	E	E	Profiles

Table B-2 (con't)

Individual Diving Intensity Phase 1b

Subject	Jul-91											Aug-91												Sept-91						Subject
#	16	17	18	19	22	23	24	26	29	3	31	1	2	5	6	7	8	12	13	14	15	27	29	3	5	9	11	12	17	Totals
41													*																	1
42										*																				1
43	*			*			*			*			*		*			*			*									8
44																	D					*					*		D	4
45	*			D								*			*			*			*			*			D			8
46			*		*					*										u										4
47						*				u																				2
48		*				*							*	*						*		*			*		*		*	9
49				m																										1
50																*														1
51			*				*			*			*				*		*				*		*	*		*	*	11
52	*										u					D					*	D								5
53		*							*								*		*							*				5
54						*						*																		2
55	*				*							*						*										*		5
56			*				*				u						m						*				*			6
57			*			*																			*					3
58		*				*							*			*					*			*		*		*		8
59												*		*			*			*										4
60									*																					1
61		*							*										Dtx											3
62					*			*			u												*		*		*		*	7
63			*								u				m			D									*		*	6
64								*											*				*	*			*			5
65		*				D																							*	3
66		*					*		*				*	*			*					*		*				*		9
149																		Dtx												1
n=67																														279
Profiles	A	A	A	B	B	B	B	D	D	D	D	Ca	Ca	Ca	Ca	Cb	Cb	Cb	Ca	Cc	Cc	Cc	Cc	E	Cc	E	E	E	E	Profiles

* - planned dive
u - unplanned dive
x - dive not used for parameter optimization
t - dive done as tender
D - decompression sickness
m - marginal symptom

Table B-3

Individual Diving Intensity Phase 2

Subject	Nov-91							Dec-91										Subject
#	15	18	19	21	22	25	26	2	3	5	6	9	10	12	17	18	20	Totals
3									*			*						2
6								*						*				2
7						*												1
10										*								1
28																*		1
29										*			Dtx					2
33						*		*			*							3
34		*															*	2
36				D													*	2
44			*			*					*							3
45	ux			*											*			3
48				*														1
49				ux														1
51		*			*		D											3
52					*						*							2
58	ux						*											2
61			D															1
62							*								*			2
63												*						1
65																*		1
66				*			*					*						3
67					D				*		*		*			*		5
68									*		*		*			*		4
70			*			*									*		*	4
71						*								*		*		3
72						*				*			*					3
74			D															1
77																	*	1
78	*		*		*		*		*		*		*			*		8
79		*		*		*		*		*		*		*	*			8
83	*								*					*			*	4
86	*		*		*			*		*			*		*			7
88		*																1
90		*		*		*		*		*		*		*	*			8
91	*		D					*		*		*		*	*			7
93	*		*		*		*		*		*		*			*		8
94								*					*		*		*	4
96		D																1
97	*	*		*														3
99					*		*		*		D							4
100			*			*		*		*		*		*				6
102	*				D													2
103	*		*		*		*		*		*		*		*			8
104		D																1
106							*					D						2
108														*		*		2
109					*				*				*			*		4
110									*		*		*			*		4
111		*		*		*		*		*		*		ux				7
112							*	*		*		*		*	*			6
116		*		*														2
n=53																		167
Profile	A	A	A	B	B	C	C	C	C	D	D	D	D	D	E	E	E	Profile

* - planned dive
u - unplanned dive
x - dive not used for parameter optimization
t - dive done as tender
D - decompression sickness
m - marginal symptom

Table B-4

Individual Diving Intensity Phase 3

Subject	Jan-92								Feb-92							Subject
#	14	15	16	21	27	28	30	31	3	4	6	7	10	11	12	Totals
6	*								*							2
10							*								*	2
13							*					m	*			3
17														*		1
26							*		*		*					3
27							*			*		m		m		4
33					*			*							*	3
34															*	1
45	*			*												2
52					*						*					2
55						*									*	2
58	*															1
59						*			*			*	*			4
62	*											*				2
63										*						1
65	*														*	2
66	*											*				2
69									*					*		2
70							*									1
71															*	1
72	*			*												2
73		*		*		ux			*		*			ux		6
75			*		*		*		*		*		*			6
76	*			*		*										3
77			*													1
80			*		*				*		ux			*		5
81		*		*		*		*		*		*		*		7
82		*		*		*		*		*		*		*		7
83		*										*				2
84			*		ux				*		*			ux		5
85			*	*			*						*			4
87		*				*		*		*						4
89															*	1
92		*		*		*		*		*			*			6
94			*				*									2
95			*		*			*			*		*			5
98		*		*		*		*		*		*				6
101															*	1
105							*		*		*		*			4
106	*												*			2
107			*		*		*		*		*		*			6
108															*	1
109		*													*	2
111		*		*		*		*		ux						5
113			*		*			*		*			*			5
114	*				*					u				ux		4
115			*		*			*			*			*		5
n=47																148
Profile	**A**	**A**	**A**	**B**	**B**	**B**	**C**	**C**	**C**	**D**	**D**	**D**	**E**	**E**	**E**	**Profile**

* - planned dive
u - unplanned dive
x - dive not used for parameter optimization
t - dive done as tender
D - decompression sickness
m - marginal symptom

Annex C

Decompression Symptom Descriptions

Table C-1

Decompression Symptom Descriptions Phase Ia

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
15	4-Mar-91	D1a	I	1		(1): R. shoulder pain.	2:00	17:00	26:00	Pain first noted upon awakening day after dive. Pain persisted and diver reported for examination. Neuro exam normal. Complete relief on descent to 60 fsw. TT5 completed.
118	5-Mar-91	C1a	I		1	Niggle: R. knee.	2:00	6:00		
145	5-Mar-91	C1a	I	1		(1): R. knee pain. (2): R. knee ext. weak.	2:00	13:00	15:00	Pain first noted upon awakening day after dive. Upon examination weakness also noted. Obtained 50% relief during first O2 period at 60 fsw, complete relief after 2nd O2 period. Completed TT6 with 2 extensions at 60 fsw.
142	6-Mar-91	C1a	I	1		(1): L. forearm pain.	2:00	12:00	14:00	Pain reduced after 3 min at 60 fsw and occurred only with wrist movement. This resolved after completion of the TT6.
127	7-Mar-91	E1a	II		1	Niggle: bilateral hip / bilateral finger joints.	1:00	2:00		
26	11-Mar-91	E1a	II		1	Niggle: R. arm / R. hand.	2:00	4:00		
19	11-Mar-91	E1a	II	1		(2): L. arm parenthesis.	2:00	12:00	14:00	Diver had pins and needles sensation distributed from L axilla down posterior part of arm and index fingers and lateral aspect of middle finger. Neuro exam showed only decreased sensation to lateral aspect of L. ring finger. Sensation returned to normal during 1st O2 period at 60 fsw and the pain in L arm and wrist was noted. Pain resolved during 2nd extension at 60 fsw. Completed 2 extensions at 60 fsw. During ascent to 30 fsw abnormal sensation in arm recurred but resolved during 1st O2 period at 30 fsw. Completed TT6 with 2 extensions at 60 and 30 fsw.
27	11-Mar-91	E1a	II	1		(1): L. Knee pain.	1:00	16:00	22:00	Also noted L. ankle Niggles 1 hr post dive lasting 10 sec. TT5 completed.
26	14-Mar-91	E1a	II	1		(1): R. elbow pain. (2): R. arm paresthesias. (2): R. hand paresthesias.	2:00	10:30	12:30	First symptom noted was pain which progressed to include decreased sensation of the right arm and hand in a glove distribution distal to the right elbow. Neuro exam showed only decreased sensation as noted. Complete relief at 23 fsw during compression to 60 fsw. TT6 completed.
138	18-Mar-91	C1a	I	1		(2): L. leg paresthesias. (2): cerebral signs. (2): cerebellar signs.	-4:41	1:30	1:45	First symptom was paresthesia over small area of left anterior tibial region of L leg just after surfacing. Neuro exam showed easy confusion and poor memory recall. Rapid alternating movements slow and awkward and positive Romberg bilaterally. After 2 O2 periods at 60 fsw mental status was normal, there where sensory deficits to pin prick and light touch in and L5/S1 distribution, slight motor weakness in L & R biceps femoris and L quadriceps, slightly decreased but symmetric patellar reflexes, and sustained clonus of the L & R ankles. Crossed adductor reflexes present, Babinski equivocal, and diver fell backward during Romberg. Over third O2 period sensory symptoms improved but motor symptoms remained same. After 5 O2 periods at 60 fsw sensory symptoms improved but persistent, motor strength normal, only one beat of ankle clonus and normal reflexes. Diver remained at 60 fsw 12 hrs and was decompressed following TT7. Approximately half way through treatment diver said he felt normal. Neuro exam on surfacing was normal, MRI was normal.

Table C-1

Decompression Symptom Descriptions Phase Ia (con't)

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
126	14-May-91	G1a	I	1		(1): R. upper arm pain,	2:00	5:00	7:00	Complete relief after 10-15 min after compression to 60 fsw. Completed TT6.
143	15-May-91	G1a	I		1	Niggle: R. clavicle, shoulder / R. hand,	2:00	5:00		
26	30-May-91	H1a	I		1	Niggle: bilateral shoulder,	2:00	16:00		
31	3-Jun-91	I1a	II	1		(1): L. Knee pain. (2): L. patellar paresthesias.	2:00	>72		Diver had some transient left knee pains during the 2 hr post dive period which resolved and were not treated. . Diver remained asymptomatic until he began an airplane flight 72 hrs. after surfacing. During the flight he developed L knee pain which persisted after the flight landed. About 96 hrs post dive he was examined and found to have numbness over the L patellar region in addition to the pain. Symptoms resolved completely during a TT6 with 2 extensions at 60 fsw and one at 30 fsw.
	Phase 1a Totals			9	5					

Notes : For Dive Type see Table 4.
For Profile descriptions see Tables 5-8 .

Table C-2

Decompression Symptom Descriptions Phase 1b

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
15	19-Jul-91	B1b	III		1	Niggle: R. foot, 2nd digit.	2:00	7:30		
26	19-Jul-91	B1b	III		1	Niggle: bilateral elbow / bilateral knee / bilateral ankle	2:00	4:00		
49	19-Jul-91	B1b	III		1	Niggle: R. Thigh.	2:00	9:00		
45	19-Jul-91	B1b	III	1		(1): bilateral upper arm pain.	-1:10	8:30	9:00	About 20 min post dive noted fluctuating pains which resolved spontaneously only to recur several hours later. Complete relief just after 10 min at 60 fsw. TT6 completed.
27	22-Jul-91	B1b	III		1	Niggle: L. Knee.	-1:36	-1:10		
65	23-Jul-91	B1b	III	1		(1): R. shoulder pain. (2): R. triceps weakness.	2:00	3:00	6:00	Complete relief after 2nd O2 period at 60 fsw with only mild residual soreness. TT6 completed. Asymptomatic 6 hrs post treatment but 32 hrs later noted to have 4/5 R triceps weakness. Complete relief after 2nd O2 period on repeat TT6.
6	24-Jul-91	B1b	III	1		(1): L. shoulder pain. (1): L. arm pain. (1): Rash on mid L. back. (2): L. triceps. weakness.	2:00	2:30	3:30	Initial symptom was pain followed by purpuric rash below L scapula. Complete relief after 3rd O2 period at 60 Fsw. Completed TT6. Noted recurrence of L upper arm and shoulder pain 8 hrs post treatment. L triceps weakness noted on Neuro exam. Complete relief after 2nd O2 period on repeat TT6.
12	24-Jul-91	B1b	III	1		(1): L. shoulder pain. (1): L. arm pain. (2): L. arm weakness (2): L. arm sensory changes.	2:00	4:20	7:50	Progressive L shoulder and upper arm pain associated with L triceps and deltoid weakness. Decreased pin prick and light touch in L. arm. Complete relief after 2 O2 periods at 60 fsw. Completed TT6 with 2 extensions at 60 and 30 fsw.
23	26-Jul-91	D1b(ii)	I	1		(1): L. shoulder pain (1st dive)	-0:03	0:12	1:20	Complete relief on descent to 60 fsw. TT6 completed. <Times related to surfacing from 1st dive of repetitive series.
16	29-Jul-91	D1b(i)	I	1		(1): R. sacroiliac joint pain	-3:47	0:05	0:15	A 5 min episode of sacroiliac joint pain 10 min after first of three planned repetitive dives resolved spontaneously. Joint pain recurred 5 min after 2nd dive. Complete relief after 9 min at 60 fsw. TT6 completed.
5	31-Jul-91	D1b	I	1		(1): R. shoulder pain	-0:03	0:10	0:40	Initially intermittent pain progressed to constant pain after the second dive of planned three. Complete relief after 15 min at 60 fsw. TT6 completed.
27	5-Aug-91	Ca1b	III		1	Niggle: R. shoulder	2:00	7:00		
3	5-Aug-91	Ca1b	III	1		(2): L. leg sensation. (2): L. leg weakness	2:00	30:00	164	Onset intermittent L. gluteal paresthesias 30 hrs post dive. Progressed to constant paresthesias radiating down L. leg after 2 days. On the 3rd day post dive noted mild l. leg weakness. Diver did not report symptoms until 7 days post dive. Neuro exam revealed decreased sensation to pin prick over posterior L. leg, and 4/5 weakness of L leg flexors and extensors. Complete relief after 4th O2 period at 60 fsw. TT6 with 2 extensions at 60 and 30 fsw completed.
2	5-Aug-91	Ca1b	III	1		(1): R. shoulder pain	2:00	5:30	8:00	Complete relief 5 min into 3rd O2 period at 60 fsw. Completed TT6 with 1 extension at 60 and 30 fsw.

Table C-2

Decompression Symptom Descriptions Phase 1b (con't)

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
20	6-Aug-91	Ca1b	III		1	Niggle: L. shoulder.	-0:50	0:00		
29	6-Aug-91	Ca1b	III		1	Niggle: L. elbow.	-0:50	0:00		
63	6-Aug-91	Ca1b	III		1	Niggle: L. shoulder.	-0:50	0:00		
18	7-Aug-91	Cb1b	III		1	Niggle: R. shoulder.	0:15	1:10		
31	7-Aug-91	Cb1b	III		1	Niggle: L. Knee.	2:00	7:00		
52	7-Aug-91	Cb1b	III	1		(1): L. shoulder pain.	0:30	1:10	1:30	Complete relief 7 min into 1st O2 period at 60 fsw. completed TT6.
56	8-Aug-91	Cb1b	III		1	Niggle: L. wrist / L. elbow.	2:00	4:00		
44	8-Aug-91	Cb1b	III	1		(1): R. elbow pain. (1): R. shoulder pain.	2:00	2:10	4:00	Complete relief 5 min into 2nd O2 period at 60 fsw. Completed TT6.
29	12-Aug-91	Cb1b	III		1	Niggle: Bilateral. elbow / bilateral shoulder.	2:00	9:00		
63	12-Aug-91	Cb1b	III	1		(1): L. shoulder pain.	0:20	1:00	1:20	Complete relief in compression to 60 fsw. Completed TT6.
149	12-Aug-91	Cb1b(T)	III(T)	1T		(1): L. cervical lymph node pain.	2:00	3:00	15:00	Diver acting as tender. Noted R. cervical lymph node tenderness and enlargement. Significant relief at end of 3rd O2 period at 60 fsw. Completed TT6.
61	13-Aug-91	Ca1b(T)	III(T)	1T		(1): L. shoulder pain. (1): L. knee pain. (2): L. leg weakness.				Diver acting as trunk tender. In addition to pain had L forearm paresthesias. Complete relief 8 min into 1st O2 period at 60 fsw. Completed TT6.
52	27-Aug-91	Cc1b	III	1		(1): L. shoulder pain.	2:00	4:00	5:30	Significant improvement after 5 O2 periods at 60 fsw. Complete relief after 1st O2 period at 30 fsw. Completed TT6 with 2 extensions at 60 and 30 fsw. Suffered DCS in same area on 7 Aug.
12	9-Sep-91	E1b	III	1		(1): R. shoulder pain.	2:00	3:00	5:00	Significant relief after 3rd O2 period at 60 fsw. Completed TT6 with 1 extension at 60 and 30 fsw. Minimal residual discomfort resolved within 1 week post treatment. Suffered DCS earlier on 24 July.
45	11-Sep-91	E1b	III	1		(1): R. elbow pain.	2:00	16:00	18:30	Transient 2 min episode of pain 2 hr after surfacing which resolved. Recurred next morning. Complete relief after 2 O2 periods at 60 fsw. Completed TT6. Previous DCS on 19 July.
44	17-Sep-91	E1b	III	1		(1): R. elbow pain. (1): L. knee pain	2:00	2:15	4:00	Complete relief 2 min into 2nd O2 period at 60 fsw. Completed TT6. Previous DCS on 6 Aug.
	Phase 1b Totals			16,2T	12					The two tender DCS (2T) not used in maximum liklehood parameter estimation.

Notes : For Dive Type see Table 4.
For Profile descriptions see Tables 5-8 .

Table C-3

Decompression Symptom Descriptions Phase 2

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
96	18-Nov-91	A2	V	1		(2): R. forearm paresthesias.	-5:47	-4:40	6:10	First noted paresthesias approximately 60 min into 120 min transit at 30 fsw(4:40 prior to surfacing). Intermittent symptoms persisted after surfacing described as 3 focal areas of tingling on the right forearm. No objective sensory changes noted. At the end of the third O2 period at 60 fsw symptoms where 50% resolved. Complete resolution occurred 47 min into 1st O2 period at 30 fsw. TT6 with 2 extensions at 60 fsw and 30 fsw completed.
104	18-Nov-91	A2	V	1		(1): bilateral knee pain.	2:00	5:00	6:10	Awoke from sleep without symptoms but on weight bearing noted burning in both knees. Progressed to a constant dull ache, in knee, L>R. Substantial relief 10 min into 1st O2 period at 60 fsw leaving only mild residual discomfort in L. Knee. TT6 with 2 extensions at 60 and 30 fsw (extensions done for diver # 96 treated concurrently) completed. Residual discomfort resolved spontaneously in 3 days.
61	19-Nov-91	A2	V	1		(1): L. shoulder pain. (1): R. inguinal pain. (2): lightheadedness.	0:13	2:00	2:30	Initially noted L. shoulder pain and bilateral lumbar tenderness. Later developed R. inguinal pain, progressive shoulder pain, and lightheadedness. Neuro exam normal. Complete resolution of symptoms 10 min into 1st O2 period at 60 fsw. Persistent mild bilateral lumbar discomfort was felt to be musculoskeletal in origin. TT6 completed.
74	19-Nov-91	A2	V	1		(1): L. elbow pain. (1): L. wrist pain.	2:00	2:10	2:30	Complete resolution 6 min into 1st O2 period at 60 fsw. TT6 (required by diver # 61 treated concurrently) completed.
91	19-Nov-91	A2	V	1		(1): R. shoulder pain.	2:00	2:30	4:45	Complete resolution 10 min into 2nd O2 period at 60 fsw. TT6 completed.
36	21-Nov-91	B2	IV	1		(1): R. shoulder pain. (2): L arm paresthesias.	2:00	12:00	16:10	Noted R. arm numbness when going to sleep. Awoke several hours later with R. shoulder pain and R. arm and forearm paresthesias described as tingling. Neuro exam normal. Complete resolution by end of 3rd O2 period at 60 fsw except for mild residual discomfort with movement of shoulder. TT6 with 1 extension at 60 and 30 fsw completed. Intermittent R. shoulder discomfort resolved spontaneously after several days.
67	22-Nov-91	B2	IV	1		(1): L. shoulder pain.	0:14	0:44	1:15	Complete resolution 5 min into 1st O2 period at 60 fsw. TT6 completed.
102	22-Nov-91	B2	IV	1		(1): L. elbow pain. (1): L. upper arm pain. (2): L. arm paresthesias.	0:15	2:50	3:10	Fleeting (<1 min) L. elbow pain 2 hrs post dive. Recurred and persisted 2:50 post dive with associated upper arm pain and paresthesias. Neuro exam revealed decreased sensation to pin prick in L. upper arm. Complete resolution 10 min into 1st O2 period at 60 fsw. TT6 completed.
51	26-Nov-91	C2	IV	1		(1): Bilateral elbow pain. (1): R. knee pain. (2): R. hand sensory changes	-0:86	-0:46	-0:21	Noted onset of bilateral elbow and R. knee burning pain and R. hypothenar eminence numbness 10 min into the 55 min decompression stop at 10 fsw after the final excursion. No other neurological symptoms. Diver removed from water and recompressed directly to 60 fsw after spending a total of 35 min at 10 fsw. TT6 completed.

Table C-3

Decompression Symptom Descriptions Phase 2 (con't)

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
99	6-Dec-91	D2	IV	1		(1): R. knee pain.	2:00	4:30	6:30	Pain was initially mild but progressed to deep severe pain over the next 1.5 hrs. Significant relief 5 min into 1st O2 period at 60 fsw. Complete relief occurred 15 min later. TT6 completed.
106	9-Dec-91	D2	IV	1		(1): R. knee pain.	2:00	12:10	12:55	Awoke morning after dive without symptoms. Upon weight bearing noted pain which progressed to throbbing medial R. knee pain. Gradual resolution during 5 O2 periods at 60 fsw. Complete resolution after 3rd O2 period at 30 fsw. TT6 with 2 extensions at 60 and 30 fsw completed.
29	10-Dec-91	D2(T)	IV(T)	1T		(2): R. hand paresthesias. (2): R. forearm paresthesias.	2:00	12:50	16:50	Diver acting as tender noted mild hyperesthesia over ulnar aspect of R. distal forearm and hand associated with sensation of tingling. Neuro exam normal. Gradual improvement at 60 fsw on TT6. complete resolution at end of 2nd O2 period at 60 fsw. TT6 completed.
	Phase 2 Totals			11,1T	0					Tender DCS (1T) not used in maximum liklehood parameter estimation.

Notes : For Dive Type see Table 4.
For Profile descriptions see Tables 5-8 .

Table C-4

Decompression Symptom Descriptions Phase 3

Subj #	DATE	Profile	Dive Type	DCS	Marg	DCS Type and Location	Last Well (T1)	Time Onset (T2)	Time to treat	Comments
13	7-Feb-92	D3a	V		1	Niggle: L. Knee.	2:00	5:00		
27	7-Feb-92	D3a	V		1	Niggle: L. knee.	2:00	5:00		
27	11-Feb-92	E3a	V		1	Niggle: R. elbow.	0:15	2:00		
	Phase 3a Totals			0	3					
Study Grand Total				36,3T	20					The three tender DCS (3T) not used in maximum liklehood parameter estimation.
Used for Parameter Estimation				36	20					

Notes : For Dive Type see Table 4.
For Profile descriptions see Tables 5-8 .

Annex D

Decompression Symptom Locations

Table D-1

Subj #	DATE	Profile	Dive Type	DCS Type	Sites	Niggles and Type 1 Symptoms	Sh	UA	El	FA	Wr	Hn	Hp	Th	Kn	Ak	Ft	Oth	Tot	Type 2 Symptoms	Uw	Us	Lw	Ls	CNS	Tot
26	30-May-91	H1a	I	Niggle	2	Niggle: bilateral shoulder.	1												1							
118	5-Mar-91	C1a	I	Niggle	1	Niggle: R. knee.									1				1							
143	15-May-91	G1a	I	Niggle	2	Niggle: R. clavicle, shoulder / R. hand.	1					1							2							
26	11-Mar-91	E1a	II	Niggle	1	Niggle: R. arm / R. hand.		1				1							2							
127	7-Mar-91	E1a	II	Niggle	2	Niggle: bilateral hip / bilateral finger joints.					1		1						2							
15	19-Jul-91	B1b	III	Niggle	1	Niggle: R. foot, 2nd digit.											1		1							
18	7-Aug-91	Cb1b	III	Niggle	1	Niggle: R. shoulder.	1												1							
20	6-Aug-91	Ca1b	III	Niggle	1	Niggle: L. shoulder.	1												1							
26	19-Jul-91	B1b	III	Niggle	3	Niggle: bilateral elbow / bilateral knee / bilateral ankle.			1						1	1			3							
27	22-Jul-91	B1b	III	Niggle	1	Niggle: L. Knee.									1				1							
27	5-Aug-91	Ca1b	III	Niggle	1	Niggle: R. shoulder.	1												1							
29	6-Aug-91	Ca1b	III	Niggle	1	Niggle: L. elbow.			1										1							
29	12-Aug-91	Cb1b	III	Niggle	2	Niggle: bilateral. elbow / bilateral shoulder.	1		1										2							
31	7-Aug-91	Cb1b	III	Niggle	1	Niggle: L. Knee.									1				1							
49	19-Jul-91	B1b	III	Niggle	1	Niggle: R. Thigh.								1					1							
56	8-Aug-91	Cb1b	III	Niggle	2	Niggle: L. wrist / L. elbow.			1		1								2							
63	6-Aug-91	Ca1b	III	Niggle	1	Niggle: L. shoulder.	1												1							
13	7-Feb-92	D3a	V	Niggle	1	Niggle: L. Knee.									1				1							
27	7-Feb-92	D3a	V	Niggle	1	Niggle: L. knee.									1				1							
27	11-Feb-92	E3a	V	Niggle	1	Niggle: R. elbow.			1										1							
	Total cases Niggles >			20	27	< Total Sites of Niggles	7	1	5		2	2	1	1	6	1	1		27	< Location Totals for Niggles						
5	31-Jul-91	D1b	I	1 only	1	(1): R. shoulder pain.	1												1							
15	4-Mar-91	D1a	I	1 only	1	(1): R. shoulder pain.	1												1							
16	29-Jul-91	D1b	I	1 only	1	(1): R. sacroiliac joint pain.												1	1							
126	14-May-91	G1a	I	1 only	1	(1): R. upper arm pain.		1											1							
142	6-Mar-91	C1a	I	1 only	1	(1): L. forearm pain.		1											1							
23	26-Jul-91	D1b	II	1 only	1	(1): L. shoulder pain.	1												1							
27	11-Mar-91	E1a	II	1 only	1	(1): L. Knee pain.									1				1							
2	5-Aug-91	Ca1b	III	1 only	1	(1): R. shoulder pain.	1												1							
12	9-Sep-91	E1b	III	1 only	1	(1): R. shoulder pain.	1												1							
44	8-Aug-91	Cb1b	III	1 only	2	(1): R. elbow pain, (1): R. shoulder pain.	1		1										2							
44	17-Sep-91	E1b	III	1 only	2	(1): R. elbow pain, (1): L. knee pain.			1						1				2							
45	19-Jul-91	B1b	III	1 only	1	(1): bilateral upper arm pain.		1											1							
45	11-Sep-91	E1b	III	1 only	1	(1): R. elbow pain.			1										1							
52	7-Aug-91	Cb1b	III	1 only	1	(1): L. shoulder pain.	1												1							
52	27-Aug-91	Cc1b	III	1 only	1	(1): L. shoulder pain.	1												1							
63	12-Aug-91	Cb1b	III	1 only	1	(1): L. shoulder pain.	1												1							
149	12-Aug-91	Cb1b(T)	III(T)	1 only	1	(1): L. cervical lymph node pain.												1	1							
67	22-Nov-91	B2	IV	1 only	1	(1): L. shoulder pain.	1												1							
99	6-Dec-91	D2	IV	1 only	1	(1): R. knee pain.									1				1							
106	9-Dec-91	D2	IV	1 only	1	(1): R. knee pain.									1				1							
74	19-Nov-91	A2	V	1 only	2	(1): L. elbow pain. (1): L. wrist pain.			1		1								2							
91	19-Nov-91	A2	V	1 only	1	(1): R. shoulder pain.	1												1							
104	18-Nov-91	A2	V	1 only	1	(1): bilateral knee pain.									1				1							
	Total Cases Type 1 only >			23	26	< Total Sites Type 1 only	11	3	4		1				5			2	26	< Location Totals for Type 1 only						
145	5-Mar-91	C1a	I	1 and 2	2	(1): R. knee pain.									1				1	(2): R. knee ext. weak.			1			1
26	14-Mar-91	E1a	II	1 and 2	3	(1): R. elbow pain.			1										1	(2): R. arm paresthesias, (2): R. hand paresthesias.		2				2
31	3-Jun-91	I1a	II	1 and 2	2	(1): L. Knee pain.									1				1	(2): L. patellar paresthesias.				1		1
6	24-Jul-91	B1b	III	1 and 2	4	(1): L. shoulder pain, (1): L. arm pain, (1): Rash mid L. back.	1	1										1	3	(2): L. triceps. weakness.	1					1
12	24-Jul-91	B1b	III	1 and 2	4	(1): L. shoulder pain, (1): L. arm pain.	1	1											2	(2): L. arm weakness, (2): L. arm sensory changes.	1	1				2
65	23-Jul-91	B1b	III	1 and 2	2	(1): R. shoulder pain.	1												1	(2): R. triceps weakness.	1					1
61	13-Aug-91	Ca1b(T)	III(T)	1 and 2	3	(1): L. shoulder pain, (1): L. knee pain.	1								1				2	(2): L. leg weakness.			1			1
36	21-Nov-91	B2	IV	1 and 2	2	(1): R. shoulder pain.	1												1	(2): L arm paresthesias.		1				1
51	26-Nov-91	C2	IV	1 and 2	3	(1): bilateral elbow pain, (1): R. knee pain.			1						1				2	(2): R. hand sensory changes		1				1
102	22-Nov-91	B2	IV	1 and 2	3	(1): L. elbow pain, (1): L. upper arm pain.		1	1										2	(2): L. arm paresthesias.		1				1
61	19-Nov-91	A2	V	1 and 2	3	(1): L. shoulder pain, (1): R. inguinal pain.	1											1	2	(2): lightheadedness.					1	1
	Total Cases Type 1 and 2 >			11	31	< Total Sites for Type 1 and Type 2	6	3	3						4			2	18	< Location Totals for Type 1 with concurrent Type 2 >	3	6	2	1	1	13
138	18-Mar-91	C1a	I	2 only	3	All Type 1 Location Totals>	24	7	12	0	3	2	1	1	15	1	1	4	71	(2): L. leg paresthesias, (2): cerebral signs, (2): cerebellar signs.			1		2	3
19	11-Mar-91	E1a	II	2 only	1															(2): L. arm parenthesis.		1				1
3	5-Aug-91	Ca1b	III	2 only	2	Total all Type 1 in Upper Extremity>	48													(2): L. leg sensation, (2): L. leg weakness			1	1		2
29	10-Dec-91	D2(T)	IV(T)	2 only	2	Total all Type 1 in Lower extremity>	19													(2): R. hand paresthesias, (2): R. forearm paresthesias.		2				2
96	18-Nov-91	A2	V	2 only	1															(2): R. forearm paresthesias.		1				1
	Total Cases Type 2 only >			5	9	< Total Sites Type 2 only														Location Totals for Type 2 only >		4	2	1	2	9
																				All Type 2 Location Totals>	3	10	4	2	3	22
																				Total all Type 2 in Upper Extremity>	13					
																				Total all Type 2 in Lower Extremity>	6					

Cases refer to the total number of divers affected.

Sites refer to the anatomical location of each symptom. Since some divers had multiple symptoms the number of sites is greater than the number of cases.

Symptom Location Key:

Type 1 symptoms: Sh-shoulder UA-upper arm El-elbow FA-forearm Wr-wrist Hn-hand Hp-hip Th-thigh Kn-knee Ak-ankle Ft-foot Oth-other Tot-total

Type 2 symptoms: Uw-upper extremity weakness Us-upper extremity sensory change Lw-lower extremity weakness Ls-lower extremity sensory change CNS-central nervous system symptom

Symptoms were classified in one of several ways:

Type 1 only: Only Type 1 symptoms occurred in that diver.
Type 2 only: Only Type 2 symptoms occurred in that diver.
Type 1 with concurrent Type 2: Diver diplayed both Type 1 and Type 2 symptoms.

All Type 1: All Type 1 symptoms whether occurring alone or with concurrent Type 2
All Type 2: All Type 2 symptoms whether occurring alone or with concurrent Type 1

Annex E

Disposition of Dives Different from Other Profiles of Same Name

Disposition of the dive profiles in question is given in Table E-1. The computed risks, P(DCS), for each of the profiles as actually dove is given in Tables E-2 through E-6 with the upper (HIGH) and lower (LOW) 95% confidence limits. Profiles denoted with an * are those whose disposition is described in Table E-1.

Dive profile names coded as PAAwxy(z)

w - phase	0-Phase 1a; 1- Phase 1b; II- Phase 2; III- Phase 3
x - profile	Single letter or letter/number combination:C1=Ca; C2=Cb; C3=Cc
y - sequence	Two digits signifying position in series, 01 is first set, 02 second etc.
(z) - optional	AB - aborted profile; AD - decompression sickness before completing profile.

Note: Some profile names appear more than once. These indicates that divers having symptoms were placed in separate data files from the others in that group. However, all divers made exactly the same dive at the same time up until DCS was diagnosed ion the affected diver..

All profiles are available on floppy disks, see reference section of main text.

Table E-1
Disposition of Dives Different from Other Profiles of Same Name
(all dives used for parameter estimation)

Parent Profile Name	Dive File	# Divers	DCS	Group File	Reason (risks computed from actual profiles using *F* parameter set)	Disposition u = designate as unscheduled		New Profile Name
D1b	PAA1D01AD	1	1		DCS after 1st dive of scheduled D1b profile. Risk 2.7% vice (7.2-7.4%)	Relative risk change >10%, present as new profile.	u	D1b(i)
	PAA1D02AD	1	1		DCS after 2nd dive of scheduled D1b profile. Risk 5.2% vice (7.2-7.4%)	Relative risk change >10%, present as new profile.	u	D1b(ii)
	PAA1D03	8	0		Slow descent on first dive. Risk 7.4% vice (7.2%)	Relative risk change <10%, keep as scheduled		
	PAA1D04	8	1	**PARA**	DCS after 2nd dive of scheduled D1b profile. Risk 5.09% vice (7.24-7.39 %)	Relative risk change >10%, present as new profile.	u	D1b(ii)
C1a	PAA0C03	3	1	(Table E-2)	Stops different than C1a: 5/85/**75**; 5/55/150/**70** vice (Risk 10.58%) 5/80/**25**; 5/70/150/**20** (Risk 11.69-11.71%)	Relative risk change > 10%, present as new profile.	u	C1a(i)
	PAA0C03AB	1	0		Diver removed after 1st dive. Risk 4.30% vice (10.58-11.71 %.)	Relative risk change >10%, present as new profile.	u	C1a(ii)
D1b	PAA1D03AB	2	0	**PASA**	Only 1 dive done on D1b. Risk 2.77% vice (7.24-7.39%)	Relative risk change >10%, present as new profile.	u	D1b(i)
	PAA1D04AB	2	0	(Table E-3)	Only 1 dive done on D1b. Risk 2.68% vice (7.24-7.39%)	Relative risk change >10%, present as new profile.	u	D1b(i)
B1b	PAA1B03	10	1	**PAMLA**	5 min stop at 20 fsw during descent subtracted from time at 80 fsw. Risk 9.66% vice (10.13-10.22%.)	Relative risk change <10%, keep as scheduled		
Cc1b	PAA1C301AB	1	0		Aborted from 15 fsw. Risk 0.7% vice (5.44-5.46%.)	Relative risk change >10%, present as new profile.	u	Cc1b(i)
E1b	PAA1E02AB	1	0	(Table E-4)	Aborted from 30 fsw. Risk 2.49% vice (9.69-9.79%.)	Relative risk change >10%, present as new profile.	u	E1b(i)
C2	PAAIIC02AD	1	1	**PAMLAOD** (Table E-5)	DCS on schedule C2 during 10 fsw stop. Risk 3.8% vice (5.5-5.6%)	Low risk because treatment truncated dive, keep as scheduled.		
A2	PAAIIA01	8	0		Stops different than A2 on second dive, 100 min at 10 fsw stop vice 140 min. Risk 7.43% vice (7.35%-7.83%.)	Relative risk change <10%, keep as scheduled.		
B3	PAAIIIB02	9	0	**PAMLAOS**	Part of 15 fsw transit taken at 20 fsw . Risk 3.4% vice (3.1-3.2%)	Relative risk change <10%, keep as scheduled		
C3	PAAIIIC01AB	1	0		Diver breathed 1 min air during 2nd 15 fsw transit	No change in risk, keep as scheduled		
D3	PAAIIID01	8	0	(Table E-6)	Slow 7 min descent time to 60 fsw subtracted from bottom time. Risk 4.4% vice (4.5-4.6%)	Relative risk change <10%, keep as scheduled		
	PAAIIID01AB	1	0		Removed during descent on 2nd excursion. Risk 0.30% vice (4.30-4.56%)	Relative risk change >10%, present as new profile.	u	D3(i)
Totals		66	6					
Total unscheduled		21	3					

Note: Risk ranges in parenthesis are those computed from the recorded profiles for dives which followed the scheduled parent profile.

Table E-2

Risks for Type I Profiles as Recorded During Actual Diving

INPUT FILE **PARA .DAT** OUTPUT FILE PARA .EST

RISK COMPUTED USING PARAMETER FILE LE1EX7.OUT AND PROGRAM RISKNMRI

1.780	60.32	515.8	.0000	.0000
5.740	9.072	6.838	1.000	.1000
999.0	.9766	999.0	.0000	.0000
2.259				

	PROFILE	P(DCS)	LOW	HIGH
1	PAA1A01	5.7098	4.2942	7.1045
2	PAA1A02	5.7603	4.3302	7.1690
3	PAA1A03	5.8347	4.3974	7.2504
4	PAA1D01	7.2165	5.3852	9.0123
5	* PAA1D01AD	* 2.7017	1.9005	3.4963
6	PAA1D02	7.2361	5.3872	9.0488
7	* PAA1D02AD	* 5.1465	3.7358	6.5365
8	* PAA1D03	* 7.3852	5.4884	9.2438
9	* PAA1D04	* 5.0922	3.6916	6.4724
10	* PAA1D04	* 5.0922	3.6916	6.4724
11	PAA0D01	12.1094	10.1150	14.0595
12	PAA0D02	12.1191	10.0970	14.0956
13	PAA0D03	12.0087	9.9952	13.9771
14	PAA0D03	12.0087	9.9952	13.9771
15	PAA0C01	11.7050	9.7182	13.6480
16	PAA0C01	11.7050	9.7182	13.6480
17	PAA0C01	11.7050	9.7182	13.6480
18	PAA0C02	11.6879	9.7040	13.6283
19	PAA0C02	11.6879	9.7040	13.6283
20	* PAA0C03	* 10.5762	8.7230	12.3917
21	* PAA0C03	* 10.5762	8.7230	12.3917
22	* PAA0C03AB	* 4.2950	3.3102	5.2698
23	PAA0G01	5.7582	4.3103	7.1843
24	PAA0G02	5.7573	4.3129	7.1800
25	PAA0G03	5.7562	4.3122	7.1784
26	PAA0G03	5.7562	4.3122	7.1784
27	PAA0G04	5.7703	4.3275	7.1913
28	PAA0G04	5.7703	4.3275	7.1913
29	PAA0G05	5.7350	4.2999	7.1485
30	PAA0G06	5.7657	4.3164	7.1930
31	PAA0G07	5.7604	4.3158	7.1832
32	PAA0H01	6.7105	4.8158	8.5675
33	PAA0H02	6.6531	4.7791	8.4902
34	PAA0H03	6.7008	4.7971	8.5663
35	PAA0H04	6.6688	4.7846	8.5156
36	PAA0H05	6.6832	4.7962	8.5328
37	PAA0H05	6.6832	4.7962	8.5328

* Profile included in Table E-1

Table E-3

Risks for Type II Profiles as Recorded During Actual Diving

INPUT FILE **PASA .DAT** OUTPUT FILE PASA .EST

RISK COMPUTED USING PARAMETER FILE LE1EX7.OUT AND PROGRAM RISKNMRI

1.780	60.32	515.8	.0000	.0000
5.740	9.072	6.838	1.000	.1000
999.0	.9766	999.0	.0000	.0000
2.259				

	PROFILE	P(DCS)	LOW	HIGH
1	PAA0E01	4.6183	3.6285	5.5980
2	PAA0E02	4.6885	3.6957	5.6711
3	PAA0E02	4.6885	3.6957	5.6711
4	PAA0E03	4.6281	3.6390	5.6071
5	PAA0E04	4.6048	3.6165	5.5829
6	PAA0E04	4.6048	3.6165	5.5829
7	PAA0E04	4.6048	3.6165	5.5829
8	PAA0E04	4.6048	3.6165	5.5829
9	PAA0E05	4.6288	3.6392	5.6083
10	PAA0E06	4.6294	3.6393	5.6094
11	PAA0E06	4.6294	3.6393	5.6094
12	PAA0E07	4.6142	3.6246	5.5936
13	PAA0F01	2.9718	1.7135	4.2139
14	PAA0F02	2.9284	1.6644	4.1762
15	PAA0F03	2.9424	1.6815	4.1872
16	PAA0F04	2.9576	1.6923	4.2066
17	PAA0F05	2.9312	1.6688	4.1773
18	PAA0I01	3.4362	2.3725	4.4883
19	PAA0I02	3.4178	2.3559	4.4681
20	PAA0I02	3.4178	2.3559	4.4681
21	PAA0I03	3.4217	2.3591	4.4728
22	PAA0I04	3.4224	2.3595	4.4736
23	PAA0I05	3.4834	2.4074	4.5474
24	* PAA1D03AB	* 2.7615	1.9497	3.5666
25	* PAA1D04AB	* 2.6775	1.8798	3.4687

* Profile included in Table E-1

Table E-4

Risks for Type III Profiles as Recorded During Actual Diving

INPUT FILE **PAMLA .DAT** OUTPUT FILE PAMLA .EST

RISK COMPUTED USING PARAMETER FILE LE1EX7.OUT AND PROGRAM RISKNMRI

1.780	60.32	515.8	.0000	.0000
5.740	9.072	6.838	1.000	.1000
999.0	.9766	999.0	.0000	.0000
2.259				

	PROFILE	P(DCS)	LOW	HIGH
1	PAA1B01	10.1296	8.4468	11.7814
2	PAA1B01	10.1296	8.4468	11.7814
3	PAA1B01	10.1296	8.4468	11.7814
4	PAA1B01	10.1296	8.4468	11.7814
5	PAA1B01	10.1296	8.4468	11.7814
6	PAA1B02	10.2239	8.5075	11.9082
7	PAA1B02	10.2239	8.5075	11.9082
8	* PAA1B03	* 9.6642	8.0689	11.2317
9	* PAA1B03	* 9.6642	8.0689	11.2317
10	PAA1B04	10.1301	8.4514	11.7780
11	PAA1B04	10.1301	8.4514	11.7780
12	PAA1B04	10.1301	8.4514	11.7780
13	PAA1C101	6.9813	5.7131	8.2325
14	PAA1C102	7.0162	5.7456	8.2698
15	PAA1C103	6.9716	5.7053	8.2209
16	PAA1C103	6.9716	5.7053	8.2209
17	PAA1C103	6.9716	5.7053	8.2209
18	PAA1C103	6.9716	5.7053	8.2209
19	PAA1C104	7.0288	5.7570	8.2833
20	PAA1C104	7.0288	5.7570	8.2833
21	PAA1C105	7.0104	5.7390	8.2647
22	PAA1C201	8.0841	6.6932	9.4543
23	PAA1C201	8.0841	6.6932	9.4543
24	PAA1C201	8.0841	6.6932	9.4543
25	PAA1C201	8.0841	6.6932	9.4543
26	PAA1C202	8.1225	6.7279	9.4961
27	PAA1C202	8.1225	6.7279	9.4961
28	PAA1C202	8.1225	6.7279	9.4961
29	PAA1C203	8.1201	6.7257	9.4936
30	PAA1C203	8.1201	6.7257	9.4936
31	PAA1C203	8.1201	6.7257	9.4936
32	PAA1C301	5.4553	4.3652	6.5330
33	* PAA1C301AB	* .6928	.3914	.9933
34	PAA1C302	5.5194	4.4210	6.6051
35	PAA1C303	5.4356	4.3476	6.5113
36	PAA1C303	5.4356	4.3476	6.5113
37	PAA1C304	5.4452	4.3556	6.5224
38	PAA1C305	5.4441	4.3547	6.5212
39	PAA1E01	9.7302	7.6988	11.7169
40	PAA1E02	9.6897	7.6614	11.6734
41	* PAA1E02AB	* 2.3917	1.7496	3.0295
42	PAA1E02	9.6897	7.6614	11.6734
43	PAA1E03	9.7797	7.7172	11.7961
44	PAA1E03	9.7797	7.7172	11.7961
45	PAA1E04	9.7440	7.7123	11.7309
46	PAA1E05	9.7882	7.7354	11.7954
47	PAA1E05	9.7882	7.7354	11.7954
48	PAAIIIA01	3.7974	2.7040	4.8784
49	PAAIIIA02	3.7466	2.6588	4.8222
50	PAAIIIA03	3.7166	2.6338	4.7874

* Profile included in Table E-1

Table E-5

Risks for Type IV Profiles as Recorded During Actual Diving

INPUT FILE **PAMLAOD .DAT** OUTPUT FILE PAMLAOD .EST

RISK COMPUTED USING PARAMETER FILE LE1EX7.OUT AND PROGRAM RISKNMRI

1.780	60.32	515.8	.0000	.0000
5.740	9.072	6.838	1.000	.1000
999.0	.9766	999.0	.0000	.0000
2.259				

	PROFILE	P(DCS)	LOW	HIGH
1	PAAIIB01	5.2018	3.7549	6.6269
2	PAAIIB01	5.2018	3.7549	6.6269
3	PAAIIB02	5.1689	3.7513	6.5655
4	PAAIIB02	5.1689	3.7513	6.5655
5	PAAIIB02	5.1689	3.7513	6.5655
6	PAAIIC01	5.6463	4.2877	6.9855
7	PAAIIC02	5.5987	4.2325	6.9453
8	* PAAIIC02AD	* 3.7766	2.7646	4.7781
9	PAAIIC03	5.6056	4.2043	6.9864
10	PAAIIC04	5.5307	4.1507	6.8908
11	PAAIID01	5.6143	4.2153	6.9929
12	PAAIID02	5.6168	4.1848	7.0275
13	PAAIID02	5.6168	4.1848	7.0275
14	PAAIID03	5.6806	4.2565	7.0835
15	PAAIID03	5.6806	4.2565	7.0835
16	PAAIID04	5.6620	4.2174	7.0847
17	PAAIID05	5.6878	4.2700	7.0845
18	PAAIIE01	5.2252	3.5512	6.8701
19	PAAIIE02	5.2533	3.5755	6.9019
20	PAAIIE03	5.3370	3.6328	7.0110

* Profile included in Table E-1

Table E-6
Risks for Type V Profiles as Recorded During Actual Diving

INPUT FILE **PAMLAOS .DAT** OUTPUT FILE PAMLAOS .EST

RISK COMPUTED USING PARAMETER FILE LE1EX7.OUT AND PROGRAM RISKNMRI

1.780	60.32	515.8	.0000	.0000
5.740	9.072	6.838	1.000	.1000
999.0	.9766	999.0	.0000	.0000
2.259				

	PROFILE	P(DCS)	LOW	HIGH
1	* PAAIIA01	* 7.4263	6.1349	8.6999
2	PAAIIA02	7.3826	6.1149	8.6331
3	PAAIIA02	7.3826	6.1149	8.6331
4	PAAIIA02	7.3826	6.1149	8.6331
5	PAAIIA03	7.3541	6.0913	8.5998
6	PAAIIA03	7.3541	6.0913	8.5998
7	PAAIIA03	7.3541	6.0913	8.5998
8	PAAIIA03	7.3541	6.0913	8.5998
9	PAAIIIB01	3.2279	2.1706	4.2737
10	* PAAIIIB02	* 3.3715	2.2815	4.4493
11	PAAIIIB03	3.1220	2.0685	4.1643
12	PAAIIIC01	3.3978	2.3206	4.4631
13	* PAAIIIC01AB	* 3.4092	2.3307	4.4759
14	PAAIIIC02	3.3579	2.2826	4.4214
15	PAAIIIC03	3.3773	2.3000	4.4427
16	* PAAIIID01	* 4.2956	3.2864	5.2942
17	* PAAIIID01AB	* .3044	.1049	.5034
18	PAAIIID02	4.4618	3.4215	5.4909
19	PAAIIID03	4.5558	3.4888	5.6110
20	PAAIIID03	4.5558	3.4888	5.6110
21	PAAIIIE01	2.9496	1.9783	3.9113
22	PAAIIIE02	2.9935	2.0409	3.9368
23	PAAIIIE02	2.9935	2.0409	3.9368
24	PAAIIIE03	2.9199	1.9802	3.8507

* Profile included in Table E-1

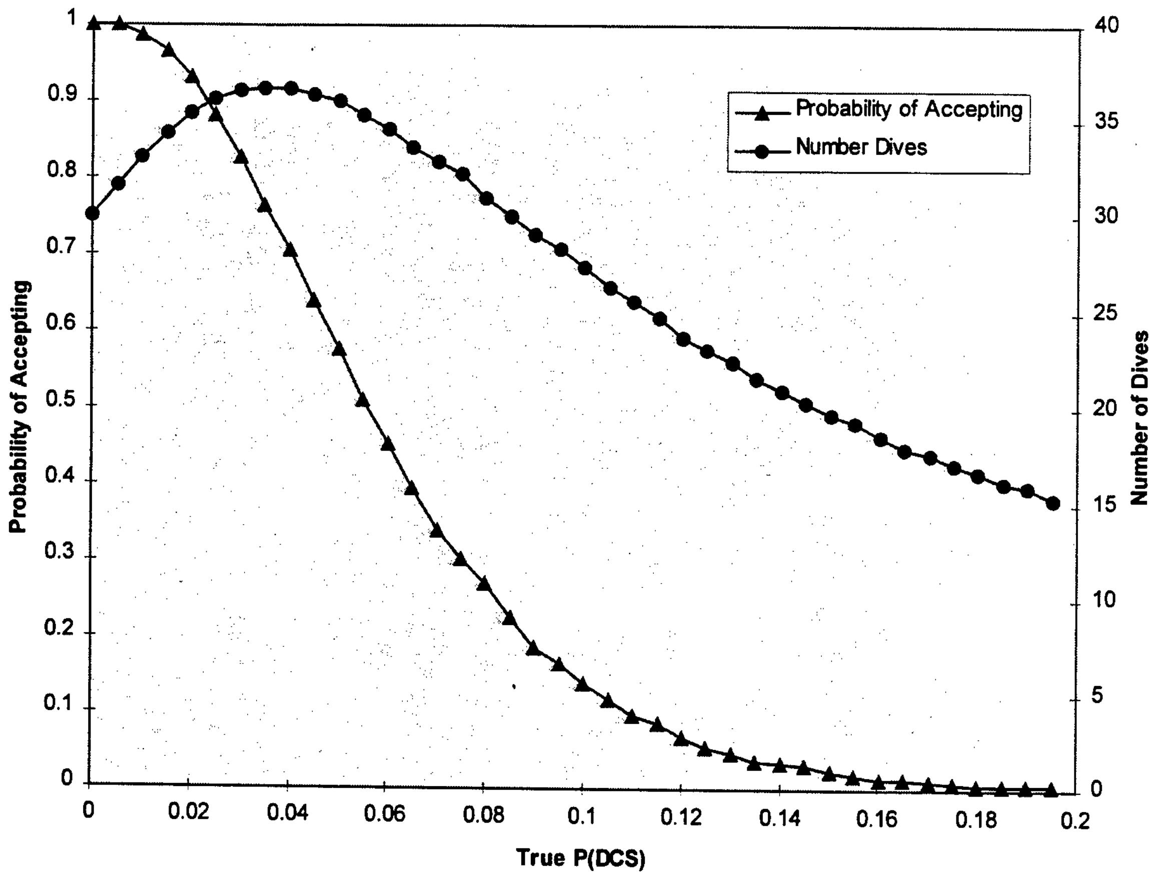

Figure 1: Power Curve for Dive Trial. Dive trial is designed for a maximum of 50 dives. A profile is accepted if the following occurs: 0 DCS in 30 man-dives, no more than 1 DCS in 40 man-dives, no more than 2 DCS in 50 man dives. A profile is rejected if 3 cases of DCS occurs at any time. The triangles show the power curve for the trial. For this trial design there is approximately an 80% chance of accepting a profile with a true P(DCS) of 3.2% and a 20 % chance of accepting a profile with a true P(DCS) as high as 8.7%. The circles show the number of dives expected in order to either accept or reject a profile. For the profile with a true P(DCS) of 3.2%, it would take on the average 36 dives while for a profile with a true P(DCS) of 8.7%, it would take on the average 30 dives. A dive with a high true P(DCS) incidence of 20% has almost no chance of being accepted and yet it would take on the average 15 dives to exceed the acceptance criteria. Also the maximum number of dives needed before either accepting or rejecting a profile will be 37 on average.

Table 1

Parameter Values

Parameters	Compromise (C parameter set)	Best Pre-series (B parameter set)	Final Post-series (F parameter set)
time constants (min)			
τ_1	1.32	1.47	1.7797
τ_2	139.87	50.80	60.319
τ_3	992.81	487.60	515.770
gains			
Gn_1	$4.060 \cdot 10^{-3}$	$4.30 \cdot 10^{-3}$	$3.2160 \cdot 10^{-3}$
Gn_2	$3.990 \cdot 10^{-4}$	$1.10 \cdot 10^{-4}$	$1.1487 \cdot 10^{-4}$
Gn_3	$5.910 \cdot 10^{-4}$	$1.00 \cdot 10^{-3}$	$1.0719 \cdot 10^{-3}$
crossover (fsw)			
PXO_1	24.20	∞	∞
PXO_2	3.06	1.06	0.9766
PXO_3	43.49	∞	∞
threshold (fsw)			
Thr_1	0	0	0
Thr_2	0	0	0
Thr_3	9.0 (fixed)	1.75	2.2591
LL Value using BIG 191 data set	707	697	697
LL Value using BIG 292 data set	1013	997	996

Table 2

Data Files Used for Parameter Estimation

Data Filename	Archive	Data Set (Used for Parameter Estimation)	
EDU885A	NMRI 92-85	⇑	⇑
DC4W	NMRI 92-85		
EDU885AR	NMRI 92-85		
DC4WR	NMRI 92-85		
SUBX87	NMRI 92-85		
NMRNSW	NMRI 92-85		
NMR8697	NMRI 92-85	BIG191	
EDU885M	NMRI 92-85		
EDU885S	NMRI 92-85		
EDU184	NMRI 92-85		BIG292
EDU1180S	NMRI 92-85		
ASATEDU	NMRI 92-85		
ASATNSM	NMRI 92-85		
ASATNMR	NMRI 92-85	⇓	
PARA	TRIAL (Type I)		
PASA	TRIAL (Type II)		
PAMLA	TRIAL (Type III)		
PAMLAOD	TRIAL (Type IV)		
PAMLAOS	TRIAL (Type V)		
ASATARE	NMRI 92-85		
NSM6HR	OTHER		⇓

Archive:	NMRI 92-85	Data files described in NMRI Report 92-85.
	TRIAL	Data files for dives described in this report.
	OTHER	Data files for other dives {#19}
Data Set:	BIG191	Pre-trial data used for parameter estimation, includes first 14 files only. (Used to optimize *B* parameter set in Table 1)
	BIG292	Post-trial data used for parameter estimation, includes all files. (Used to optimize *F* parameter set in Table 1)

Table 3

Dive Summary by Phase and Profile
(chronological order)

Phase	Profile	Parameters (Target Risk)	P(DCS)# %	Dive Type	Dives Total	Dives Unplanned	Symptoms DCS	Symptoms Marginal	Excluded
1a	D1a	C(4)	12.1	I	12	1	1	0	1
	C1a	C(4)	11.9	I	8	0	2	1	0
	C1a(i)	u	10.6	I	3	3	1	0	0
	C1a(ii)	u	4.3	I	1	1	0	0	0
	E1a	C(4)	4.6	II	27	0	3	2	0
	F1a	C(3)	3.0	II	20	0	0	0	0
	G1a	C(3)	5.7	I	28	0	1	1	0
	H1a	C(3)	6.6	I	20	0	0	1	0
	I1a	C(3)	3.5	II	20	0	1	0	0
Phase 1a Totals					139	5	9	5	1
1b	A1b	C(3)	5.8	I	30	1	0	0	1
	B1b	CSMD	10.3	III	38	0	4	4	0
	D1b	C(3)	7.3	I	26	0	0	0	0
	D1b(i)	u	5.2	II	5	5	1	0	0
	D1b(ii)	u	2.7	I	9	9	2	0	0
	Ca1b	CSMD	7.1	III	49	0	2	4	0
	Cb1b	CSMD	8.2	III	30	0	3	4	0
	Cc1b	CSMD	5.5	III	41	0	1	0	0
	Cc1b(i)	u	0.8	III	1	1	0	0	0
	E1b	C(5)	9.9	III	47	0	3	0	0
	E1b(i)	u	2.3	III	1	1	0	0	0
Phase 1b Totals					277	17	16	12	1
2	A2	B(2.5-7.0)	7.5	V	30	2	5	0	2
	B2	B(2.5-5.0)	5.2	IV	20	1	3	0	1
	C2	B(2.5-5.0)	5.6	IV	40	0	1	0	0
	D2	B(2.5-5.0)	5.7	IV	50	1	2	0	1
	E2	B(2.5-5.0)	5.3	IV	26	0	0	0	0
Phase 2 Totals					166	4	11	0	4
3	A3	B(2.5-5.0)	3.8	III	29	0	0	0	0
	B3	B(2.5-5.0)	3.3	V	30	2	0	0	2
	C3	B(2.5-5.0)	3.4	V	30	0	0	0	0
	D3	B(2.5-5.0)	4.6	V	28	2	0	2	2
	D3(i)	u	0.4	V	1	1	0	0	0
	E3	B(2.5-5.0)	3.1	V	30	3	0	1	3
Phase 3 Totals					148	8	0	3	7
Grand Total					730	34	36	20	13
Total used for parameter estimation					717	21	36	20	

- P(DCS) values are for Idealized profiles as shown in Tables 5-9.
u - unplanned profile

For Profile Descriptions see Tables 5-9.
For Dive Types see Table 4.

Table 4

Dive Summary by Type of Dive

Dive Type	Description	Dives		Symptoms		Excluded
		Total	Unplanned	DCS	Marginal	
I	**Repetitive Air**	137	15	8	3	2
II	**Single Air**	72	5	4	2	0
III	**Multi-level Air**	236	2	13	12	0
IV	**Multi-level/O_2 Decompression**	136	2	6	0	2
V	**Multi-level/O_2 Transit**	149	10	5	3	9
Grand Total		730	34	36	20	13
Used for parameter estimation		717	21	36	20	

Table 5

Type I Profile Descriptions (Repetitive Air)

Profile	Dive 1					Surface Interval	Dive 2						Surface Interval	Dive 3		Total Dive	Total Stop	P(DCS)[2]	Param.
	Depth	Time	Stop Time (min)			Time	Depth	Time	Stops Time (min)				Time	Depth	Time	Time	Time[1]	%	Set [3]
	(fsw)	(min)	30 fsw	20 fsw	10 fsw	(min)	(fsw)	(min)	40 fsw	30 fsw	20 fsw	10 fsw	(min)	(fsw)	(min)	(min)	(min)		
C1a	100	60	5	80	25	90	100	60	5	70	150	20				568	355	11.9	C(4)
C1a(i)	100	60	5	85	75	90	100	60	5	55	150	70				658	445	10.6	u
C1a(ii)	100	60	5	85	75	90	45-35 fsw for about 8 min then ascent to surface 10 fsw/min									334	174	4.3	u
D1a	150	40	5	100	25	90	150	30	5	40	150	25				515	350	12.1	C(4)
G1a	60	60	no stops			140	60	30	no stops				140	60	29.0	402	0	5.7	C(3)
H1a	100	25				200	100	15					140	100	23.1	408	0	6.6	C(3)
A1b	60	63.7				140	60	28.0					140	60	28.2	403	0	5.8	C(3)
D1b	100	31.8				200	100	20.1					140	100	14.8	412	0	7.3	C(3)
D1b(i)	100	31.8				200	100	20.1								255	0	5.2	u

All dives done breathing air throughout.
Descent rate 30 fsw/min.
Ascent rate 60 fsw/min.
Time entries include descent time, Stop Time entries show actual time at stop depth.
Decimal times are approximate no-decompression times. Actual times where computed in real time during dives.
"u" designates unplanned profile.

1- Includes sum of all stop times from Dive 1, Dive 2, and Dive 3.
2- All PDCS computed after adding 1.5 fsw to all depths (see text).
3- Shows parameter set/target risk used to compute decompression schedule.

Table 6
Type II Profile Descriptions
(Single Air)

Profile	Dive							Total Dive Time (min)	Total Stop Time (min)	P(DCS)[1] %	Param Set[2]
	Depth (fsw)	Time (min)	Stop Time (min) 40 fsw	30 fsw	20 fsw	10 fsw					
D1b(ii)	100	30	no stops					34	0	2.7	u
E1a	100	60		5	85	25		177	115	4.6	C(4)
F1a	150	30		5	123	0		161	128	3.0	C(3)
I1a	150	30		5	5	70		113	80	3.5	C(3)

All dives done breathing air throughout.
Descent rate 30 fsw/min.
Ascent rate 60 fsw/min.
Time entries include descent time, Stop Time entries show actual time at stop depth.
"u" designates unplanned profile.

1- All PDCS computed after adding 1.5 fsw to all depths (see text).
2- Shows parameter set/target risk used to compute decompression schedule.

Table 7

Type III Profile Descriptions (Multi-level Air)

Profile	First Deep Excursion		20 fsw Stop	Shallow Transit		Second Deep Excursion					Total Dive	Total Stop	P(DCS)[2]	Param. Set[3]
	Depth	Time	Time	Depth	Time	Depth	Time	Stop Time (min)			Time	Time[1]	%	
	(fsw)	(min)	(min)	(fsw)	(min)	(fsw)	(fsw)	30 fsw	20 fsw	10 fsw	(min)	(min)		
B1b	80	60	47	30	73	80	60		26	69	338	142	10.3	CSMD
Ca1b	60	60	30	30	90	60	60		0	48	290	78	7.1	CSMD
Cb1b	60	60	30	30	150	60	60		0	56	358	86	8.2	CSMD
Cc1b	60	60	0	15	180	60	60		0	56	358	56	5.5	CSMD
Cc1b(i)	60	60	0	15	125	direct ascent from 15 fsw				7	196	7	0.8	u
E1b	80	60	0	30	120	80	60	65	135	0	442	200	9.9	C(5)
E1b(i)	80	55	0	30	33	ascend from 30 fsw			13#	17	119	40	2.3	u
A3	50	45	0	15	360	50	45		5	25	482	30	3.8	B(2.5-5.0)

Dives with parameter set CSMD done according to the Combat Swimmer Multi-level Dive Procedure {6}. This procedure will sometimes require ascent to 20 fsw after the first excursion for a decompression stop before allowing descent to a 30 fsw transit depth.

All dives done breathing air throughout.
Descent rate 30 fsw/min.
Ascent rate 60 fsw/min.
Time entries include descent time, Stop Time entries show actual time at stop depth.
"u" designates unplanned profile.

#- stop actually taken at 22 fsw.
1- Includes sum of all stop times from both first and second deep excursions.
2- All PDCS computed after adding 1.5 fsw to all depths (see text).
3- Shows parameter set/target risk used to compute decompression schedule.

Table 8

Type IV Profile Descriptions
(Multi-level/O_2 Decompression)

Profile	First Deep Excursion						Shallow Transit		Second Deep Excursion						Total Dive Time (min)	Total Stop Time[1] (min)	P(DCS)[2] %	Param. Set[3]
	Depth (fsw)	Time (min)	Stop Time (min)				Depth (fsw)	Time (min)	Depth (fsw)	Time (min)	Stop Time (min)							
			40 fsw	30 fsw	20 fsw	10 fsw					40 fsw	30 fsw	20 fsw (48% O_2)	10fsw (48% O_2)				
B2	80	60	5				30	115	80	60	5	5	30	85	368	130	5.2	B(2.5-5.0)
C2	80	60	5	10	10		15	220	80	60	5	5	30	55	462	120	5.6	B(2.5-5.0)
D2	60	90		5	10		15	345	60	90		5	10	80	637	110	5.7	B(2.5-5.0)
E2	80	60	5				30	235	80	60	5	5	55	120	547	190	5.3	B(2.5-5.0)

All dives done breathing air throughout.
Descent rate 30 fsw/min.
Ascent rate 60 fsw/min.
Time entries include descent time, Stop Time entries show actual time at stop depth.

1- Includes sum of all stop times from both first and second deep excursions.
2- All PDCS computed after adding 1.5 fsw to all depths (see text).
3- Shows parameter set/target risk used to compute decompression schedule.

Table 9

Type V Profile Descriptions (Multi-level/O_2 Transit)

Profile	First Deep Excursion					Shallow Transit (0.7 ata PO_2) #		Second Deep Excursion						Shallow Transit (0.7 ata PO_2) #		Third Deep Excursion					Total Dive	Total Stop	PDCS[2]	Param.
	Depth	Time	Stop Time (min)			Depth	Time	Depth	Time	Stop Time (min)				Depth	Time	Depth	Time	Stop Time (min)			Time	Time[1]	%	Set[3]
	(fsw)	(min)	40 fsw	30 fsw	30 fsw	(fsw)	(min)	(fsw)	(min)	40 fsw	30 fsw	20 fsw	10 fsw	(fsw)	(min)	(fsw)	(min)	30 fsw	20 fsw	10 fsw	(min)	(min)		
A2	80	60	5			30	115	80	60	5	5	5	140								397	160	7.5	B(2.5-7.0)
B3	80	30				15	180	60	60			5		15	175	80	30		5	5	494	15	3.3	B(2.5-5.0)
C3	60	45				15	180	60	60		5	5		15	170	60	45		5	15	535	30	3.4	B(2.5-5.0)
D3	80	30				15	240	60	60			5		15	235	80	45	5	5	20	648	35	4.6	B(2.5-5.0)
D3(i)	80	30				15	240	40	7				10	direct ascent to surface							269	10	0.4	u
E3	60	45				15	240	60	60			5		15	235	60	45		5		638	10	3.1	B(2.5-5.0)

- 0.7 ata PO_2 approximated by breathing 37% O_2 during 30 fsw transits or 48% O_2 during 15 fsw transits. Diver switched to air 10 min before completing transit.

Descent rate 30 fsw/min.
Ascent rate 60 fsw/min.
Time entries include descent time, Stop Time entries show actual time at stop depth.
"u" designates unplanned profile.

1- Includes sum of all stop times from both first and second deep excursions.
2- All PDCS computed after adding 1.5 fsw to all depths (see text).
3- Shows parameter set/target risk used to compute decompression schedule.

Table 10

Symptom Frequency and Location

Type 1 DCS Symptoms and Niggles

Site Affected		Niggles	Number of definite symptoms: Type 1 with no concurrent Type 2	Type 1 with concurrent Type 2	All Type1	All Type 1 plus Niggles
Upper Extremity	Shoulder Joint	7	11	6	17	24
	Upper Arm	1	3	3	6	7
	Elbow Joint	5	4	3	7	12
	Forearm					
	Wrist Joint	2	1		1	3
	Hand Joints	2				2
	Total Upper Extremity	17	19	12	31	48
Lower Extremity	Hip Joint	1				1
	Thigh	1				1
	Knee Joint	6	5	4	9	15
	Lower Leg					
	Ankle Joint	1				1
	Foot	1				1
	Total Lower Extremity	10	5	4	9	19
Other	Cervical Lymph Node		1		1	1
	Rash L. Upper Back			1	1	1
	R. Inguinal area			1	1	1
	Sacroiliac Joint		1		1	1
	Total Other		2	2	4	4
	Grand Totals	27	26	18	44	71

Type 2 DCS Symptoms

Site Affected	Symptom	Number of definite symptoms: Type 2 with no concurrent Type 1	Type 2 with concurrent Type 1	All Type 2
Upper extremity	Weakness		3	3
	Sensory Changes	4	6	10
	Total Upper Extremity	4	9	13
Lower extremity	Weakness	2	2	4
	Sensory Changes	1	1	2
	Total Lower Extremity	3	3	6
Other	Cerebral	1		1
	Cerebellar	1		1
	Lightheadedness		1	1
	Total Other	2	1	3
	Grand Totals	9	13	22

Table 11

Observed and Calculated DCS Incidence with Confidence Limits

(Profiles ordered according to Idealized Calculated P(DCS))

Profile	Type	Total Dives	Unplanned	Number Excluded	Net Dives	DCS	Marginal	Observed DCS %	Idealized Calculated P(DCS) %	As Dove Calculated P(DCS) %	95% Binomial Confidence Limits on Incidence, %[a] Trial High	Trial Low	Model High	Model Low	Accept/ Reject ?
D3(i)	V	1	1	0	1	0	0	0.0	0.4	0.3	NA	NA	NA	NA	-
Cc1b(i)	III	1	1	0	1	0	0	0.0	0.8	0.7	NA	NA	NA	NA	-
E1b(i)	III	1	1	0	1	0	0	0.0	2.3	2.4	NA	NA	NA	NA	-
D1b(i)	II	5	5	0	5	1	0	20.0	2.7	2.7-2.8	71.6	0.5	1	0	-
F1a	II	20	0	0	20	0	0	0.0	3.0	2.9-3.0	16.8	0.0	2	0	A@
E3	V	30	3	3	27	0	1	0.0	3.1	2.9-3.0	12.8	0.0	3	0	A
B3	V	30	2	2	28	0	0	0.0	3.3	3.1-3.4	12.3	0.0	3	0	A
C3	V	30	0	0	30	0	0	0.0	3.4	3.3-3.4	11.6	0.0	3	0	A
I1a	II	20	0	0	20	1	0	5.0	3.5	3.4-3.5	24.9	0.1	3	0	A@
A3	III	29	0	0	29	0	0	0.0	3.8	3.7-3.8	11.9	0.0	3	0	A
C1b(ii)	I	1	1	0	1	0	0	0.0	4.3	4.3	NA	NA	NA	NA	-
D3	V	28	2	2	26	0	2	0.0	4.6	4.3-4.6	13.2	0.0	4	0	A
E1a	II	27	0	0	27	3	2	11.1	4.6	4.6-4.7	29.2	2.4	4	0	R
D1b(ii)	I	9	9	0	9	2	0	22.2	5.2	5.1-5.2	60.0	2.8	2	0	-
B2	IV	20	1	1	19	3	0	15.8	5.2	5.2	39.6	3.4	3	0	R
E2	IV	26	0	0	26	0	0	0.0	5.3	5.2-5.3	13.2	0.0	4	0	A
Cc1b	III	41	0	0	41	1	0	2.4	5.5	5.4-5.5	12.9	0.1	5	0	A
C2	IV	40	0	0	40	1	0	2.5	5.6	5.5-5.6	13.2	0.1	5	0	A
D2	IV	50	1	1	49	2	0	4.1	5.7	5.6-5.7	14.0	0.5	6	0	A
G1a	I	28	0	0	28	1	1	3.6	5.7	5.7-5.8	18.4	0.1	4	0	A@
A1b	I	30	1	1	29	0	0	0.0	5.8	5.7-5.8	11.9	0.0	4	0	A
H1a	I	20	0	0	20	0	1	0.0	6.6	6.7	16.8	0.0	4	0	A@
Ca1b	III	49	0	0	49	2	4	4.1	7.1	7.17	14.0	0.5	7	0	A
D1b	I	26	0	0	26	0	0	0.0	7.3	7.2-7.4	13.2	0.0	5	0	A
A2	V	30	2	2	28	5	0	17.9	7.5	7.3-7.4	36.9	6.1	5	0	R
Cb1b	III	30	0	0	30	3	4	10.0	8.2	8.1	26.5	2.1	6	0	R
E1b	III	47	0	0	47	3	0	6.4	9.9	9.7-9.8	17.5	1.3	9	1	R
B1b	III	38	0	0	38	4	4	10.5	10.3	9.7-10.2	24.8	3.0	8	1	R
C1a(i)	I	3	3	0	3	1	0	33.3	10.6	10.6	90.6	0.8	2	0	-
C1a	I	8	0	0	8	2	1	25.0	11.9	11.7	65.1	3.2	3	0	-
D1a	I	12	1	1	11	1	0	9.1	12.1	12.0-12.1	41.3	0.2	4	0	-
Totals		730	34	13	717	36	20	mean 5.3%[b]							

a - Exact binomial confidence limits for DCS% [using Net Dives and DCS] and for DCS [using Net Dives and Idealized Calculated P(DCS)%].
b- mean incidence =[(DCS +0.1*Marginal)/Net Dives] * 100
@- Accepted by criteria from an earlier study, see text.