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EVALUATION OF THE DCIEM 1983 DECOMPRESSION MODEL FOR COMPRESSED AIR DIVING (SERIES L-Q)

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ABSTRACT

The Defence and Civil Institute of Environmental Medicine (DCIEM), Downsview, Ontario, has developed a new mathematical model for decompressing compressed air divers. This model, referred to as the **DCIEM 1983 DECOMPRESSION MODEL,** has been employed for real-time computer-controlled diving using the DCIEM XDC-2 decompression computer. **Standard Air, In-Water Oxygen,** and **Surface Oxygen** decompression procedures have been developed and examined for single and repetitive dives.

The effectiveness of the DCIEM 1983 Decompression Model has been assessed both subjectively (classical symptoms of decompression sickness) and by Doppler ultrasonic bubble detection method.

This report presents the results of 283 experimental dives (with the detailed "Doppler" data on 217 dives) decompressed with the new model using **Standard Air, In-Water Oxygen,** and **Surface Oxygen** decompression.

This report is a continuation of DCIEM Reports 84-R-72 and 84-R-73 which presented the results of 667 previous experimental dives decompressed on the DCIEM 1983 Decompression Model (Series A-F and G-K).

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INTRODUCTION

This report presents the results of experimental air dives decompressed in accordance with the **DCIEM 1983 Decompression Model** (1) and is a continuation of previous evaluations of that model (2,3).

The DCIEM 1983 Decompression Model is based on the pioneering decompression work done at DCIEM by Kidd and Stubbs (4,5) and continued by others (6,7). The culmination of these early efforts was the development of a microprocessor-based digital decompression computer programmed with the Kidd-Stubbs 1971 Decompression Model (KS-1971) - the XDC-2 (8). This instrument has since been used extensively for real-time computer controlled diving at DCIEM (9,10,11). In 1982, XDC-2 controlled Oxygen Decompression procedures were developed and evaluated (12).

DCIEM has been assessing the safety of decompression profiles for compressed air diving with the **Doppler ultrasonic bubble detector** since 1979. Analyses of a variety of dive data indicate that there is a correlation between the number of bubbles observed in the precordial region and the safety of the decompression procedure (13). Although Decompression Sickness (DCS) does not necessarily accompany high bubble grades (according to grading schemes such as the Kisman-Masurel (14) or Spencer (15) bubble codes), most of the cases of DCS reported were associated with high bubble grades (grades 3 or 4). Therefore, with decompression profiles which produce high bubble grades, there is a definite risk of DCS, and such profiles should be avoided. Conversely, if decompression profiles consistently result in no observable bubbles, they may be overly conservative.

The decompression schedules based on the DCIEM 1983 Decompression Model are considerably more conservative than those published in the United States Navy (USN) and the Royal Navy (RN) diving manuals (16, 17). However, the initial evaluations of the DCIEM model using Doppler ultrasonic bubble detection methods (2,3) have proven that this conservatism is justified and necessary. **Figure 1** provides a simple comparison of the total decompression times of the DCIEM 1983, USN, and RN Standard Air Decompression schedules.

During the initial evaluations of the DCIEM 1983 Decompression Model, **Standard Air, In-Water Oxygen,** a combination of **In-Water Oxygen**

plus **Surface Oxygen** and a more traditional **Surface Oxygen** (SurD O_2) procedure were examined for single and repetitive dives.

As a result of those experiments, Decompression Tables and Procedures based on the DCIEM 1983 Decompression Model were published (18). These tables provide **Standard Air, In-Water O_2,** and **SurD O_2** tables in both **feet of seawater** (fsw) and **metres of seawater** (msw) to **240 fsw** and **72 msw** respectively. Also provided are a **Repetitive Diving Table** and procedures and a **Depth Corrections for Diving at Altitudes Table** and procedures.

Further, simple, one-page **Short Standard Air** and **Short In-Water O_2** tables were developed. These short tables - Table 1S and Table 2S - contain a minor deviation from the DCIEM 1983 Decompression Model. They are slightly less conservative for short, shallow dives, and have a less conservative No-Decompression (No-D) limit than the model dictates. This modified No-D limit was evaluated in Series K (3).

The **Canadian Forces Air Decompression Tables** (19) based on the DCIEM 1983 Decompression Model (with the modifications for short, shallow dives incorporated) were approved for use by the Canadian Forces (CF) in Jan '85 and will become the standard decompression method for all Air Diving in the CF in the near future.

In this report, the results of additional dives decompressed by the **Standard Air, In-Water O_2,** and **SurD O_2** methods are presented. Selected profiles from the **Short Standard Air** and **Short In-Water O_2** tables were also examined.

EXPERIMENTAL METHODS

1. DECOMPRESSION PROCEDURES

The real-time computer-controlled decompression procedures used for these experiments were:

a. **Standard Air** Decompression

(1) The divers did a normal XDC-2 ascent at 18 msw/min (60 fsw/min) to the first stop which was the closest multiple of 3 msw deeper than the indicated Safe Ascent Depth (SAD);

(2) The divers remained at that stop until the SAD indicated the next shallower multiple of 3 msw and then ascended to that stop, and so on; and

(3) The divers surfaced from the 3 msw stop when the SAD reached "0".

b. **In-Water Oxygen** Decompression (In-Water O_2)

(1) The divers did a normal XDC-2 ascent (as for Standard Air) at 18 msw/min to 9 msw (30 fsw) and stopped;

(2) The divers' gas and the XDC-2 were switched to O_2. The divers remained at 9 msw until the SAD read "0"; and

(3) The divers then surfaced at 4.5 msw/min (Note 1).

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Note 1: Owing to vent rate limitations in the hyperbaric facility used for these experiments, almost 2 minutes were required to surface from 9 msw. Therefore, the decompression profiles presented in **Table 1** show a time of 2 minutes for ascent from the 9 msw water stop.

c. **Surface Oxygen** Decompression (SurD O_2)

(1) The divers did a normal XDC-2 ascent at 18 msw/min to 9 msw;

(2) The divers remained on air at 9 msw until the SAD read "6 msw" (Note 2)(Note 3); and

(3) The divers were then brought to the surface at 4.5 msw/min, undressed, and recompressed to 12 msw in the RCC on O_2. The XDC-2 was switched to "O_2" when the divers started breathing O_2. The SI was not to exceed 7 minutes; (Note 4)

(4) The divers remained on O_2 at 12 msw with 5-minute air breaks after each 30 minutes on O_2 (Note 5) until the XDC-2 SAD read "-1 msw" (Note 6); and

(5) The divers then surfaced at 6 msw/min on O_2.

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Note 2: Experience had shown that a diver could be surfaced safely for recompression in a chamber after completing the required 9 msw in-water stop - i.e., when SAD equals 6 msw.

3: The decompression is exactly the same as for normal Standard Air decompression to the completion of the 9 msw stop.

4: The 7-minute SI was chosen to enhance the operability of the procedure and to reduce the chances for "omitted" decompression. The full 7-minute SI was used throughout these experiments.

5: The 5-minute air breaks after every 30 minutes on O_2 were introduced to reduce, or eliminate entirely, the possibility of O_2 toxicity problems and for diver comfort. (The XDC-2 is switched to "air" for these breaks.)

6: The diver remains on O_2 at 12 msw in the RCC until the indicated SAD = "-1 msw" to provide a compensatory decompression benefit for the time that he was in violation of the model during the SI. By using the computer SAD to define it, this benefit is always proportional to the severity of the dive.

The decompression procedures used with the "short" tables were:

a. **Short Standard Air** (Table 1S)

(1) The divers descended and ascended at 18 msw/min;

(2) The divers remained at the appropriate stop for the tabulated stop time **minus** the travel time to that stop at 18 msw/min. (Stop times include ascent time to the stop); and

(3) On completion of the 3 msw stop, the divers surfaced.

b. **Short In-Water O_2** (Table 2S)

(1) The divers descended and ascended at 18 msw/min;

(2) The divers were switched to O_2 after reaching the 9 msw stop and remained on O_2 for the full tabulated stop time. (O_2 stop time **does not** include ascent time to the stop); and

(3) On completion of the stop, the divers surfaced on O_2 at 4.5 msw/min.

Except for the Table 1S and Table 2S experiments, all dives presented in this report were controlled in real-time by the XDC-2 decompression computer.

This paper is a continuation of the DCIEM 1983 Decompression Model validation process and the following is a summation of the experiments previously reported (Series A-F,G-K), and those presented in this report - Series L-Q:

a. **Series A**

Standard Air Decompression 32 dives

b. **Series B**

Standard Air Decompression 31 dives

c. **Series C**

In-Water O_2 Decompression 93 dives

d.	**Series D**	
	In-Water O_2 + Surface O_2 Decompression	76 dives
e.	**Series E**	
	Standard Air Decompression for selected repetitive dive combinations	62 dive combinations
f.	**Series F**	
	In-Water O_2 + Surface O_2 Decompression for one repetitive dive combination	18 dive combinations
g.	**Series G**	
	In-Water O_2 + Surface O_2 Decompression for selected exceptional exposure profiles	63 dive combinations
h.	**Series H**	
	SurD O_2 Decompression for selected profiles including exceptional exposures	30 dives
i.	**Series I**	
	In-Water O_2 Decompression for one repetitive dive combination	15 dive combinations
j.	**Series J**	
	SurD O_2 Decompression for one repetitive dive combination	11 dive combinations
k.	**Series K**	
	Examination of the proposed **operational No-D limit** which is less conservative than the No-D limit predicted by the DCIEM 1983 Decompression Model.	132 dives

l. **Series L** (Note 7)

Standard Air Decompression for two selected profiles	35 dives (28 monitored)

m. **Series M**

In-Water O_2 Decompression for two selected profiles	20 dives (18 monitored)

n. **Series N**

SurD O_2 Decompression for six selected profiles	126 dives (98 monitored)

o. **Series O**

SurD O_2 Decompression (first dive) and **Standard Air** Decompression (second dive) for one repetitive dive combination	24 dive combinations (16 monitored)

p. **Series P**

Short Standard Air Decompression (table method) for two profiles	23 dives (16 monitored)

q. **Series Q**

Short In-Water O_2 Decompression (table method) for three profiles	31 dives (25 monitored)

Table 1 shows the dive/decompression profiles which were tested. For these decompression profiles, the stop times include the ascent time to the stops, except for the "short" **In-Water O_2** table.

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Note 7: In Series L to Q, not all subjects were monitored for bubbles because of personnel and time constraints.

2. DIVE SUBJECTS

Each dive (except for the "short" table dives) was planned to include a wet, working diver (on a bicycle ergometer) wearing a Viking dry suit with underwear and a Superlite SL-17B helmet; a wet, swimming diver (swimming against a barrier) and a standby diver wearing Viking dry suits with underwear and AGA Full Face Masks; at least two dry, resting subjects and a team leader all wearing coveralls. Heart rates were measured on both wet divers to control the work level as shown in **Table 2.** For the "short table" experiments, all subjects were dry, resting and wearing coveralls.

Team leaders were DCIEM Clearance Divers. The other subjects were divers from the DCIEM Ships Diver Roster and the Canadian Underwater Training Centre. The subjects who participated in this study were all male. Their age, weight, and heights (means and standard deviations) were 26 $\pm$ 4 yr, 77 $\pm$ 6 Kg, and 177 $\pm$ 0.05 m, respectively.

All dive subjects had a minimum of 36 hours between dives and were asked not to engage in strenuous physical exercise (which was not a part of normal daily routine) for 24 hours pre-dive and for 12 hours post-dive.

3. DOPPLER ULTRASONIC MONITORING PROCEDURES

The instrument used for monitoring bubbles was the model "DUG" Bubble Detector developed by the Institut National des Sciences Appliquées de Lyon for the Centre d'Etudes et de Recherches Techniques Sous-Marines in Toulon, France, and manufactured by Sodelec SA of Marseille, France.

Divers were monitored for bubbles at the precordial site (right ventricle and/or pulmonary artery) and the subclavian sites (both left and right shoulders.) Two conditions were used at each site; in the first condition, the diver stood at rest, and in the second, the diver performed a specific movement. For the precordial site, this movement was a deep knee-bend - squatting and returning to the standing position in a continuous, smooth motion. For the subclavian sites, the movement consisted simply of clenching the fist on the side being monitored.

The Doppler ultrasonic signals, which include contributions from blood flow, cardiac motion, and bubbles, were simultaneously recorded on audio magnetic tape and assessed aurally. In cases of doubt, the tape recording was replayed and compared with the pre-dive reference recording. The bubble signals were classified according to the Kisman-Masurel code (14) which uses three criteria (each on a scale from 0 to 4):

a. the number of bubbles per cardiac cycle;

b. the percentage of cardiac cycles with bubbles; and

c. the amplitude of the bubble signals relative to the background.

The resulting 3-digit code was used to obtain a global bubble grade from 0 to 4. This bubble grade scale is similar to the other commonly used bubble grade scale developed by Spencer (15).

Monitoring was performed by a team of experienced technicians. (owing to time and personnel constraints, not all subjects were monitored after each dive. However, all wet subjects were monitored.) A reference signal was recorded before each dive for all subjects, and selected subjects were monitored at half-hour intervals for at least 2 hours following the end of decompression. During this time, the divers were asked to rest in the immediate vicinity, and to refrain from excessive post-dive activity, since this is thought to contribute to decompression problems (9). If bubbles were detected, the subject was required to remain under observation until the bubbles diminished to insignificant numbers. For the repetitive diving experiments, the subjects were monitored between dives as well as after the second dive. The subjects were asked to report any pain or other symptoms of decompression sickness (DCS). The attending Diving Medical Officer considered subjective symptoms only, not bubble grades, in deciding whether to treat for DCS.

4. ANALYSIS PROCEDURES

The Doppler results, expressed as bubble grades, were used to assess the decompressions stress experienced by each subject for a given dive profile and decompression method. A high bubble grade was considered indicative of a stressful dive for that individual. If several of the divers had high bubble grades, then this pointed to a stressful profile. These results were qualitative.

A more detailed analysis of the results of these experiments will be published separately.

RESULTS

1. DIVE PROFILES

The left half of **Table 3** presents the actual dives carried out with the total number of subjects, the number of subjects monitored for bubbles and the number of wet, working divers (all monitored). The water temperature for wet divers was 10°C.

Series L consisted of a total of 35 man-dives using **Standard Air** Decompression. Series M consisted of 20 man-dives decompressed with the **In-Water O_2** method and Series N consisted of 126 man-dives (including 33 exceptional exposures) using the **SurD O_2** method.

Series O consisted of 24 repetitive man-dive combinations using **SurD O_2** decompression for the first dive (54 msw/30 min) and **Standard Air** decompression for the second dive (18 msw/30 min) with a Surface Interval of 3 hrs.

Series P and Q consisted of 23 and 31 man-dives decompressed using the **Short Standard Air Table 1S** and the **Short In-Water O_2 Table 2S,** respectively.

2. DOPPLER RESULTS

The right half of **Table 3** summarizes the peak bubble grades observed for all monitored dives grouped by dive profiles and decompression methods. A bubble grade of "0" represents no detectable bubbles. Increasing bubble grades indicate increasingly larger numbers of bubbles, with grade "1" representing only 1 or 2 bubbles per cardiac cycle, and grade "4" representing bubbles too numerous to count.

Table 4 provides the detailed Doppler results for selected dive profiles (36 msw/50 min and 45 msw/40 min) using different decompression methods. The results of similar dives performed in previous series are included for comparison. The Doppler scores "X/Y" represent "at rest/after movement". (The dives in Series D used the **In-Water O_2** plus **Surface O_2** method and are therefore slightly different than those in Series N which were decompressed with the traditional **SurD O_2** method.)

Table 5 presents a summary of the percentage of man-dives decompressed with the DCIEM 1983 Decompression Model (including similar dives from previous series) which resulted in no detectable bubbles, or only 1 or 2 bubbles per cardiac cycle (Doppler scores of "0" or "1").

3. DECOMPRESSION SICKNESS (DCS)

The number of incidents of DCS on each profile are shown in **Table 3** (last column). All cases of DCS were Type I and were treated using USN Treatment Tables (16).

a. **Standard Air** Decompression - Series L

Four incidents of DCS occurred in 35 man-dives using the Standard Air Decompression method.

(1) Subject 0131 reported some "itching" in the right shoulder immediately following a dive to 36 msw for 50 min as a dry, resting subject. He was placed on Surface O_2 while preparations for treatment were made. Prior to treatment commencement, all symptoms were relieved and the decision was taken not to treat. His maximum Doppler score was 3/3+ precordial.

Later that evening, Subject 0131 reported a mild pain in his right shoulder and elbow and was treated on Table 6 some 10 hrs post-dive. Most of the pain was relieved on reaching 60 fsw. A dull "ache" remained and was relieved gradually over the treatment period.

Further investigation showed that Subject 0131 performed very heavy exercises just prior to the dive and had little sleep the previous night.

(2) Subject 0122 reported pain in his right ankle some 5 hrs following a 45 msw/40 min dive as a dry, resting subject. His maximum Doppler score was 3/3, 3 hrs post-dive. Subject 0122 was treated on Table 6 and had complete relief after 48 min at 60 fsw. The subject reported "twisting" his right ankle the evening before the dive, but he had no pain pre-dive.

(3) Subject 0124 reported pain in his left shoulder 3.5 hrs after leaving the bottom following a 45 msw/40 min dive as a dry, resting subject. His Doppler score at that time was 3/3 (left shoulder). He was treated on Table 5 with complete relief attained on reaching 60 fsw.

(4) Subject 0127 reported pain his his right wrist immediately after surfacing from a 45 msw/40 min dive as a dry, resting subject. His Doppler score at that time was -3/4 (right shoulder) and -3/-4 (precordial). He was treated on Table 6 (treatment already in progress for another case) and attained complete relief after 10 min at 60 fsw.

b. **In-Water O_2** Decompression - Series M

Three incidents of DCS occurred in 20 man-dives with the In-Water O_2 Decompression method.

(1) Subject 0118 was a wet, working diver for a 45 msw/40 min dive. One hour post-dive, he reported a slight pain in both elbows. His Doppler score was minimal at this time. Although the pain disappeared prior to recompression, the subject was treated on a Table 5. He remained asymptomatic through the treatment.

Later investigation showed that the subject was wet and cold (both arms to elbows) during the dive.

(2) Subject 0117 was a wet, working subject for a 45 msw/40 min dive. He reported a slight pain in his right elbow 10 min post-dive. His Doppler score (right shoulder) was 2/3 at that time. Subject reported cold discomfort during dive and further investigation revealed he had virtually no food for two days prior to the dive.

The subject was treated on Table 5 with total relief of symptoms on descent to 60 fsw.

(3) Subject 0119 was a dry, resting subject for a 45 msw/40 min dive. He reported pain in his upper left arm 1.5 hrs post-dive. His Doppler score was 0/0 at this time and the pain disappeared prior to recompression. He was, however, treated on Table 5 and the "pain" re-appeared on descent. He was again totally asymptomatic on reaching 60 fsw.

c. **SurD O_2** Decompression - Series N

One incident of DCS occurred in 126 dives using the SurD O_2 decompression method.

(1) Subject 0137 was a wet, working diver for a 36 msw/50 min dive. Two hrs post-dive, the subject reported pain in his left forearm near the elbow. His Doppler score at that time was 2/3 (precordial). He was diagnosed as having Type I DCS but was treated on Table 6 with another diver. Total relief was attained after 9 min at 60 fsw.

d. **Repetitive Dives** - Series O

One incident of DCS occurred in 24 repetitive combinations consisting of a 54 msw/30 min dive decompressed with **SurD O_2** followed after 3 hrs by a 18 msw/30 min dive decompressed with **Standard Air.**

(1) Subject 0136 was a wet, working diver for the above dive combination. He reported a slight pain in his right shoulder during the Surface Interval prior to the RCC O_2 stop (SurD O_2). On reaching the 12 msw RCC stop, the pain was relieved and he successfully completed the decompression.

During the Surface Interval between dives, his maximum Doppler score was 3/-3 in the right shoulder.

After completing the second dive, he was totally asymptomatic. His maximum Doppler score was 3-/3 (precordial) and 3-/2 (right shoulder).

6 hours post-dive, subject 0136 reported severe pain in the right shoulder and elbow. He was treated on Table 6 with pain reduced significantly after 60 min and complete relief on ascent to 30 fsw.

e. **Short Standard Air** Decompression Table - Series P

No incidents of DCS occurred in 23 man-dives decompressed on the Short Standard Air table.

f. **Short In-Water O_2** Decompression Table - Series Q

No incidents of DCS occurred in 31 man-dives decompressed on the Short In-Water O_2 table.

DISCUSSION

Subjectively, nine confirmed or probable incidents of DCS occurred in 283 man-dives which were decompressed with the DCIEM 1983 Decompression Model in series L-Q. This is an overall incidence of DCS of 3.2%, which is consistent with the 3.5% and 3.3% incidence rate previously observed in Series A-F and Series G-K, respectively (2,3).

Out of the nine cases of DCS, seven victims had Doppler scores of "3-" or greater. In the remaining two cases (subjects 0118 and 0119, In-Water O_2 decompression), the Doppler scores were minimal and the symptoms (mild pain) were, in fact, totally relieved before treatment commenced.

The application of different decompression methods to the first and second dives of a repetitive dive combination (Series O) works as predicted and provides greater flexibility for multi-exposure diving.

The one-page **Short Standard Air** and **Short In-Water O_2** tables based on the DCIEM 1983 Decompression Model are simple to apply and result in minimal decompression stress (Series P,Q).

All DCIEM 1983 Decompression Model evaluation dives which required decompression (except for Series P and Q) were decompressed by real-time computer control. Therefore, the decompression applied was always precisely in accordance with the mathematical model. As the Decompression Tables based on the DCIEM 1983 Decompression Model (18,19) are "rounded up" versions of the mathematical model, they are always more conservative than the real-time computer calculations. This additional conservatism in the tables is most pronounced in the Repetitive Diving procedures which have to account for the "worst case" situation (a "severe" first dive leaving maximum "residual nitrogen" followed by a second dive requiring little or no decompression).

In view of the above and the results of all the model evaluation dives (Series A-Q), it can be stated that the DCIEM 1983 Decompression Model (2) and the Decompression Tables and Procedures based on that model (18,19) provide a flexible, attractive and conservative alternative to existing decompression tables and procedures for diving within the Canadian Forces Air Diving Limits shown in Figure 2.

The validation process for the DCIEM 1983 Decompression Model for Air Diving is now considered to have been successfully completed.

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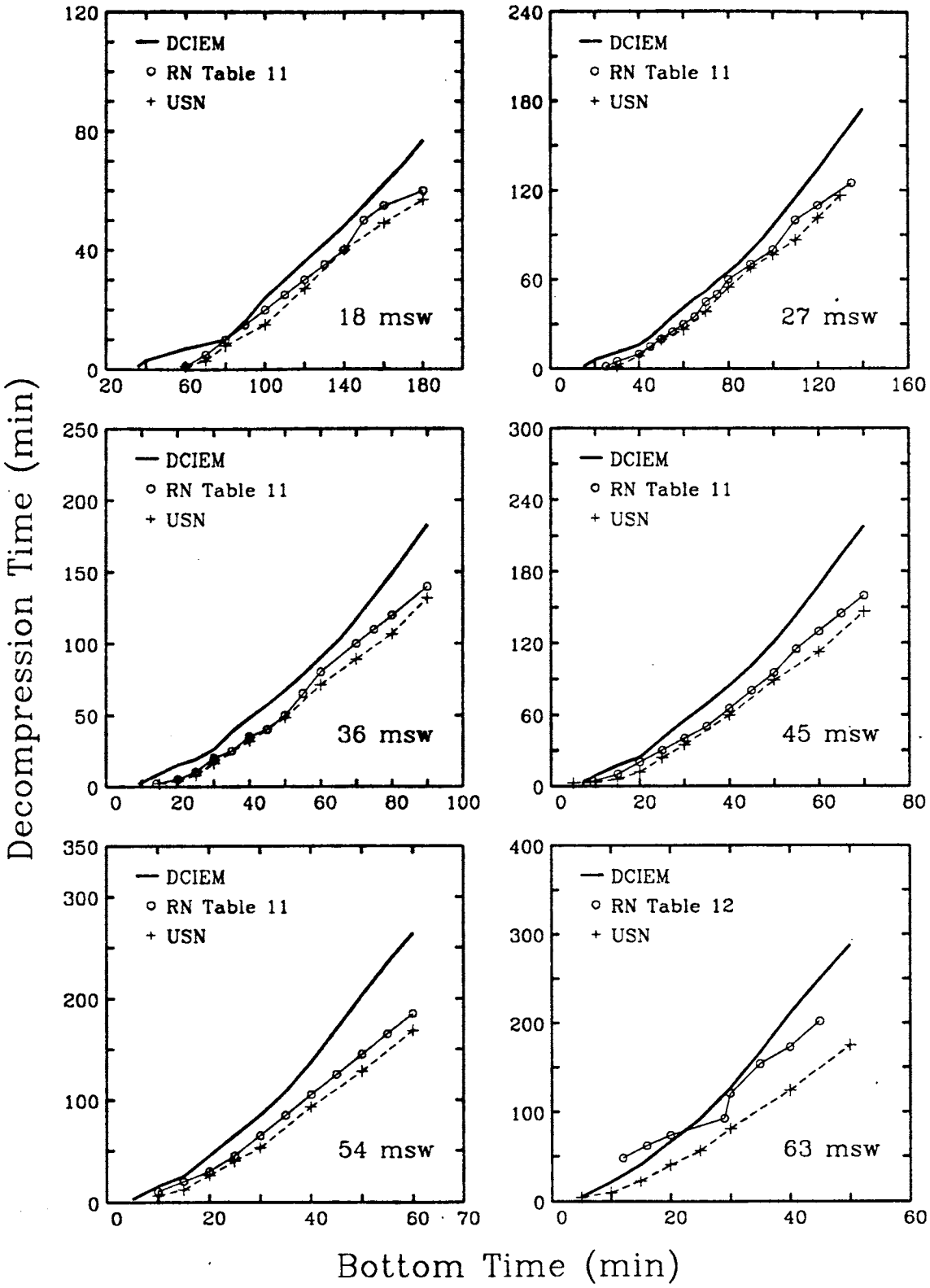

FIGURE 1

COMPARISON OF THE DCIEM 1983 DECOMPRESSION TIMES FOR "STANDARD AIR" DECOMPRESSION WITH THOSE OF THE US NAVY STANDARD AIR TABLE AND ROYAL NAVY TABLES 11-12.

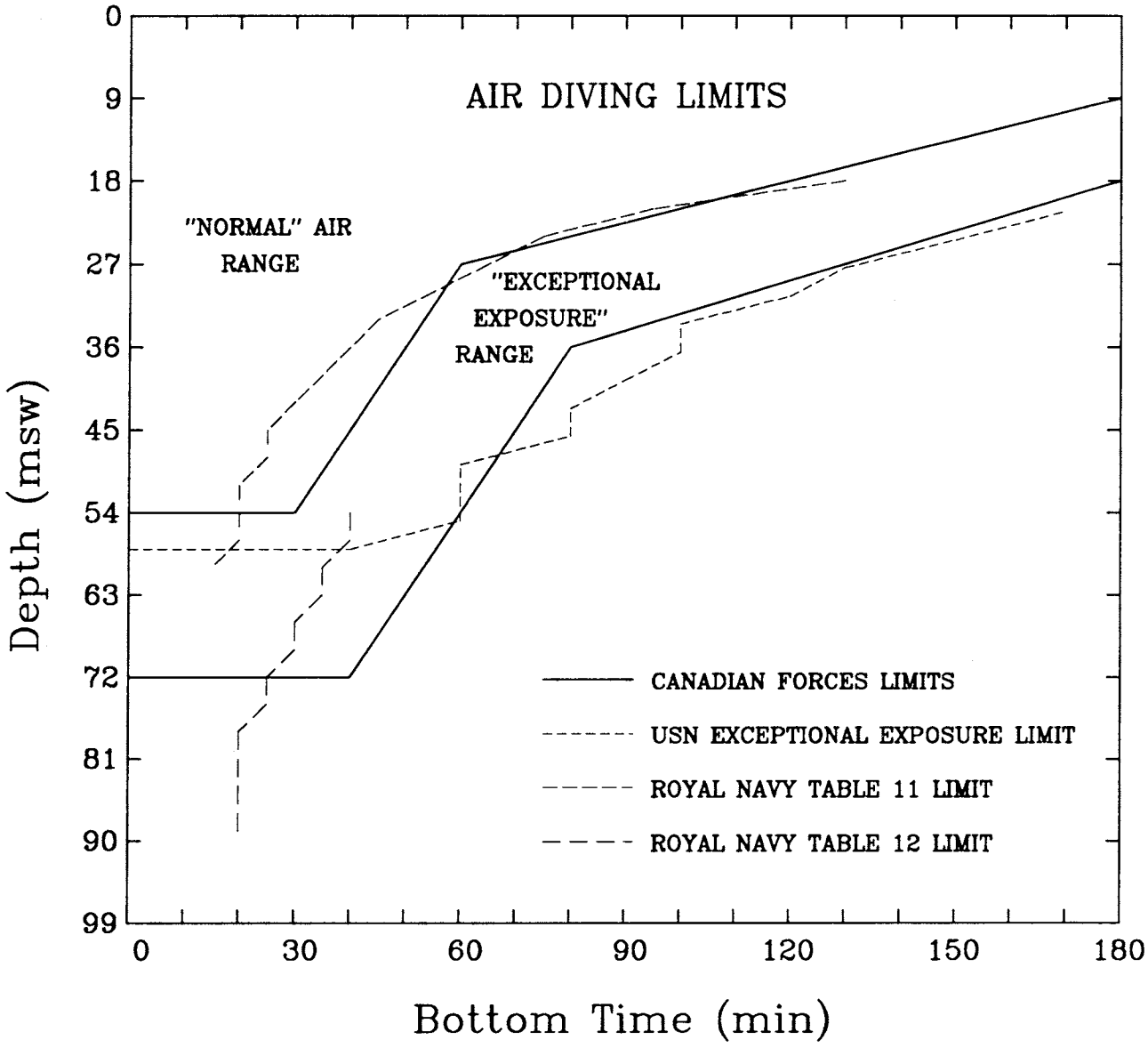

FIGURE 2

CANADIAN FORCES AIR DIVING LIMIT

LIST OF TABLES

TABLE 1

DECOMPRESSION PROFILES TESTED

SERIES L. STANDARD AIR

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)						Decom. Time (min)
		18	15	12	9	6	3	
36	50	-	-	4	7	10	46	67
45	40	-	4	6	7	15	52	84

SERIES M. IN-WATER O_2 DECOMPRESSION

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)					Decom. Time (min)
		Air			O_2		
		18	15	12	9	Asc	
36	50	-	-	4	37	2	43
45	40	-	4	6	42	2	54

SERIES N. SURFACE O_2 DECOMPRESSION (Sur D O_2)

Depth (msw)	Bottom Time (min)	Stop times (min) at Different Depths (msw)													Decom Time* (min)
		In-water Stops								Surface			Chamber		
		Air								Air		O_2	O_2		
		30	27	24	21	18	15	12	9	Asc	SI	Des	12	Asc	
27	60	-	-	-	-	-	-	-	2	2	4	1	30	2	46
36	50	-	-	-	-	-	-	4	7	2	4	1	42	2	67
45	40	-	-	-	-	-	4	6	7	2	4	1	48	2	79
45	70	-	-	-	-	5	5	8	20	2	4	1	95	2	157
54	30	-	-	-	-	3	4	6	7	2	4	1	47	2	81
63	30	-	-	-	5	4	4	7	8	2	4	1	60	2	107
72	40	3	3	3	4	6	6	13	28	2	4	1	114	2	204

SERIES O. REPETITIVE - SURFACE O_2 DECOMPRESSION plus STANDARD AIR

Dive No.	Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)									Decom. Time* (min)
			In-Water Stops				Surface			Chamber		
			Air				Air		O_2	O_2		
			18	15	12	9	Asc	SI	Des	12	Asc	
1	54	30	3	4	6	7	2	4	1	47	2	81

Dive No.	Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)						Decom. Time (min)
			18	15	12	9	6	3	
2	18	30(40)†	-	-	-	-	-	3	7

* Decompression time includes 5 min air breaks after every 30 min on O_2 in the chamber.
† Time shown in () is Effective Bottom Time for second dive

TABLE 1 (continued)

DECOMPRESSION PROFILES TESTED

SERIES P. SHORT STANDARD AIR TABLE

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)						Decom. Time (min)
		18	15	12	9	6	3	
24	30	-	-	-	-	-	5	5
33	15	-	-	-	-	-	5	5

SERIES Q. SHORT IN-WATER O_2 TABLE

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)					Decom. Time‡ (min)
		Air			O_2		
		18	15	12	9	Asc	
18	80	-	-	-	5	2	8
24	34	-	-	-	5	2	8.5
30	21	-	-	-	5	2	9

‡ O_2 stop at 9 msw stop does not include ascent time to the stop

TABLE 2

WORKLOAD FOR WET DIVERS

Bottom Time (min)	Workload	Percentage of Max. Heart Rate At Surface	Work/Rest Cycle
over 60 min	1	50%	Continuous
31 to 60 min	2	65%	10 min/10 min
21 to 30 min	3	70%	5 min/ 5 min
10 to 20 min	4	75%	3 min/ 2 min

TABLE 3

MAXIMUM BUBBLE GRADES OBSERVED IN THE PRECORDIAL REGION AT REST AND FOLLOWING MOVEMENT FOR ALL DIVES

SERIES L. STANDARD AIR

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
36	50	11	8(2)	5	1	0	2	0	5	0	0	2	1	1
45	40	24	20(4)	8	2	2	8	0	8	2	1	8	1	3
TOTALS		35	28(6)	13	3	2	10	0	13	2	1	10	2	4

SERIES M. IN-WATER O_2 DECOMPRESSION

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
36	50	7	7(2)	3	1	2	1	0	2	0	2	3	0	0
45	40	13	11(2)	7	2	1	1	0	5	2	2	2	0	3
TOTALS		20	18(4)	10	3	3	2	0	7	2	4	5	0	3

SERIES N. SURFACE O2 DECOMPRESSION (SurD O_2)

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
27	60	20	16(4)	14	1	1	0	0	13	0	1	2	0	0
36	50	24	18(4)	16	1	1	0	0	15	0	0	3	0	1
45	40	12	9(2)	8	1	0	0	0	8	1	0	0	0	0
45	70	10	8(0)	8	0	0	0	0	8	0	0	0	0	0
54	30‡	37	26(6)	19	1	3	3	0	16	2	3	5	0	0
63	30	12	10(2)	5	0	3	2	0	5	0	0	5	0	0
72	40	11	11(2)	8	0	2	1	0	8	0	0	3	0	0
TOTALS		126	98(20)	78	4	11	6	0	73	3	4	18	0	1

† Numbers in () indicate number of wet divers.

‡ Includes a dive to 54 msw for 45 min (13 man-dives, 9 monitored) in which 20 min was taken to reach 54 msw. Post-dive analysis showed that the decompression for this dive, controlled in real-time by the XDC-2 computer, was equivalent to that for a dive to 54 msw for 30 min.

TABLE 3 (continued)

MAXIMUM BUBBLE GRADES OBSERVED IN THE PRECORDIAL REGION AT REST AND FOLLOWING MOVEMENT FOR ALL DIVES

SERIES O. REPETITIVE - SurD O_2 + STANDARD AIR

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
54	30	24	16(4)	11	3	1	1	0	10	1	1	4	0	0
18	30	24	16(4)	14	1	0	1	0	12	3	0	1	0	1
TOTALS		48	32(8)	25	4	1	2	0	22	4	1	5	0	1

SERIES P. SHORT STANDARD AIR TABLE

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
24	30	12	8(0)	8	0	0	0	0	8	0	0	0	0	0
33	15	11	8(0)	8	0	0	0	0	8	0	0	0	0	0
TOTALS		23	16(0)	16	0	0	0	0	16	0	0	0	0	0

SERIES Q. SHORT IN-WATER O_2 TABLE

Depth (msw)	Bottom Time (min)	No. of Man Dives	No. Man Dives Monitored†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
18	80	10	9(0)	7	1	1	0	0	7	0	1	1	0	0
24	34	10	8(0)	8	0	0	0	0	8	0	0	0	0	0
30	21	11	8(0)	8	0	0	0	0	8	0	0	0	0	0
TOTALS		31	25(0)	23	1	1	0	0	23	0	1	1	0	0

† Numbers in () indicate number of wet divers.

TABLE 4

MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
Series B	0023	WW	3/4	207	2/3-	116	2/2	207	
36/50	0023	DR	3/3	170	3/3+	140	0	-	
Std Air	0024	WW	3-/3	80	0/2	80	0	-	
	0024	DR	2/3	212	0	-	0	-	
	0025	DR	0	-	3/3-	93	0	-	
	0025	WW	2/3	142	3-/3-	175	3/3	77	
	0011	DR	3+/3	100	NM	-	NM	-	Type 1
	0029	L	2/3	199	2/1	140	0	-	
	0029	L	2/3	150	0	-	2/1	189	
	0007	S	2/1	87	3/2	87	3-/1	87	
	0007	S	2/2	85	1/1	95	2/2	95	Type 1
Series L	0120	DR	0	-	0	-	0	-	
36/50	0106	S	0	-	0	-	0	-	
Std Air	0111	DR	3+/4	202	3+/4	144	2/3-	144	
	0112	WW	0	-	0	-	0	-	
	0131	DR	3/3+	81	2/3-	81	2/2	81	Type 1
	0128	DR	0	-	0	-	0	-	
	0117	DR	0	-	0/1	137	1/1	94	
	0119	WW	1+/3-	109	1/1	109	1+/1	156	
Series L	0120	WW	0	-	0/1	-	0	-	
45/40	0123	DR	3/3	204	2/2	204	2/2	240	
Std Air	0092	L	3/3+	157	0	-	0	-	
	0122	DR	3/3	276	1/1	166	3/3	166	Type 1
	0124	DR	3-/2	241	3/3	183	0	-	Type 1
	0109	S	1/1	197	1/1	160	0	-	
	0125	DR	2/3-	252	1/0	139	2/2	139	
	0127	DR	3-/4-	137	0	-	3-/4	137	Type 1
	0126	DR	3/3+	279	0	-	2/2+	124	
	0128	DR	0	-	0	-	0	-	
	0129	DR	0	-	0	-	0	-	
	0121	WW	2/3-	261	0	-	0	-	
	0120	WW	0	-	0/1	-	0	-	
	0106	S	0	-	0	-	0/1	118	
	0111	DR	3-/3-	168	1/1	111	0/1	168	
	0113	WW	3/3	102	0/2	215	3/3+	102	
	0131	DR	1/1	106	2/2	106	0/1	154	
	0117	WW	0	-	2/2	225	0	-	
	0119	DR	0	-	0	-	0	-	
	0129	DR	0	-	0	-	0	-	

Explanation of Symbols

Role
- WW - wet-working diver
- DR - dry-resting subject
- S - standby diver
- L - team leader, dry

Code
- P - precordial site
- LS - left shoulder
- RS - right shoulder
- a/b a bubble grade, rest; b bubble grade, movement

Code
- T - time from start of decompression
- NM - not monitored

TABLE 4 (continued)

MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
Series C	0005	DR	0	-	0	-	0	-	
36/50	0033	WW	3/4	175	2/2	235	2/2	113	
In-Water	0033	DR	0/3	111	0	-	0	-	
O_2	0037	DR	0/2	180	0	-	2+/3	210	
	0037	WW	1/3+	290	0	-	0	-	
	0044	WW	1/1	85	0	-	3/2	115	
	0045	WW	0	-	0	-	0	-	
	0045	DR	0	-	0	-	0	-	
	0047	DR	0	-	0	-	0	-	
	0048	WW	0	-	0	-	0	-	
	0048	DR	0	-	0	-	0	-	
	0052	DR	3/4	131	0	-	0	-	
	0052	WW	2/3	120	0	-	0	-	
	0057	DR	0	-	0/1	92	0	-	
	0057	WW	0	-	0	-	0	-	
	0009	WW	3/3+	154	0	-	0	-	
	0009	DR	3/3+	94	0	-	0	-	
	0009	L	2+/3+	74	0	-	0	-	
	0002	L	3/4	122	2/2	179	3/3-	238	
	0002	L	3/4	120	1/1	215	3-/3	215	
	0030	S	0/3	186	0	-	0	-	
	0030	S	2/3	308	1/1	68	2/2	170	
	0014	S	2/3+	126	0	-	0	-	
	0014	S	0	-	0	-	0	-	
Series M	0123	DR	2/3-	180	0	-	0	-	
36/50	0131	DR	2/2+	125	1/1	93	1/1	93	
In-Water	0125	DR	3-/3-	103	0	-	2/2	103	
O_2	0009	L	1/3-	62	0	-	0	-	
	0128	DR	0/2	198	2/2	151	2/2	198	
	0129	DR	0	-	0	-	0	-	
	0121	DR	0	-	0	-	0	-	

TABLE 4 (continued)

MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
Series C 45/40 In-Water O_2	0032	DR	0	-	0	-	0	-	
	0035	DR	0	-	0	-	0	-	
	0043	WW	0	-	0	-	0	-	
	0043	DR	0	-	0	-	0	-	
	0046	WW	0	-	3-/2+	131	2/2	71	
	0046	DR	2/3	95	2/2+	124	3/2	154	Type 2
	0049	WW	0	-	0	-	0	-	
	0049	DR	0	-	0	-	0	-	
	0050	DR	3-/3+	95	0	-	0	-	
	0050	DR	0/1	119	0	-	0	-	
	0055	DR	0	-	0	-	0	-	
	0055	WW	0	-	0	-	0	-	
	0061	DR	0	-	0	-	0	-	
	0061	WW	0	-	0	-	0	-	
	0016	L	0	-	0	-	2/3-	130	
	0016	L	0	-	0/1	90	0	-	
	0007	L	0	-	3-/3	107	1/0	77	
	0007	L	0	-	2/1	160	0	-	
	0021	S	0	-	0	-	0	-	
	0021	S	0	-	0	-	0	-	
	0087	S	3-/3	134	0/2	105	2/1	225	
	0087	S	0	-	0	-	0/1	95	
Series M 45/40 In-Water O_2	0110	DR	0	-	0	-	0	-	
	0111	DR	1/3-	187	0	-	0	-	
	0112	DR	0	-	0	-	0	-	
	0118	WW	0/1	117	1/1	117	1/2	117	Type 1
	0113	DR	0	-	1/2	118	1/1	118	
	0114	DR	0	-	2/1	144	0	-	
	0130	DR	3/3	131	0	-	0	-	
	0116	DR	1/2	136	1/1	136	1/2	136	
	0117	WW	0/2	120	0	-	2/3	120	Type 1
	0137	S	2/1	216	0	-	0	-	
	0119	DR	0	-	0	-	0	-	Type 1

TABLE 4 (continued)

MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
Series D	0033	DR	2/3	124	0	-	0	-	
36/50	0033	WW	0/3-	122	0/1	92	3-/3-	122	
In-Water O_2	0037	WW	0/2	101	0/1	71	0/1	130	
+	0037	DR	0	-	0/1	129	0	-	
Surface O_2	0044	DR	0	-	0	-	0	-	
	0044	WW	0/1	92	1/1	151	0/1	151	
	0045	DR	0/3-	130	0	-	0	-	
	0047	WW	0	-	0	-	0	-	
	0047	DR	0	-	0	-	0	-	
	0048	WW	0	-	0	-	0	-	
	0048	DR	0	-	0	-	0	-	
	0057	DR	0	-	0	-	0	-	
	0057	WW	0	-	0	-	0	-	
	0002	L	3+/4	132	0	-	0	-	
	0002	L	2/1	95	0/1	95	1/0	185	
	0009	L	3-/3	64	0	-	0	-	
	0009	L	1/2	70	0	-	0	-	
	0014	S	0	-	0	-	0	-	
	0014	S	0	-	0	-	0	-	
	0030	S	2/3	124	2/1+	185	0	-	
	0030	S	0	-	0	-	0	-	
Series N	0110	WW	0	-	0	-	0	-	
36/50	0111	DR	0	-	0	-	0	-	
Sur D O_2	0112	DR	0	-	1+/1+	93	0	-	
	0118	DR	0	-	0	-	1/1	99	
	0095	S	0	-	0	-	0	-	
	0114	DR	0	-	0/1	89	0	-	
	0116	DR	0	-	1/1	123	1+/1+	155	
	0117	DR	0/3+	106	0	-	0	-	
	0119	DR	0	-	0	-	0	-	
	0137	WW	2/3-	180	1/2	81	0	-	Type 1
	0111	DR	1/3-	145	0	-	0	-	
	0112	WW	0	-	0	-	0	-	
	0118	DR	0	-	0	-	0	-	
	0114	DR	0	-	0/1	97	2/2	139	
	0119	WW	0	-	0	-	0	-	
	0113	DR	0	-	2/2	140	0	-	
	0109	S	0	-	0	-	0	-	
	0014	L	0	-	0	-	0	-	

TABLE 4 (continued)

MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
Series D	0009	WW	3-/3-	144	0	-	0	-	
45/40	0032	DR	0	-	0	-	0/1	167	
In-Water O_2	0032	WW	NM	-	NM	-	NM	-	Type 1
+	0035	WW	0	-	0	-	0	-	
Surface O_2	0041	DR	0	-	0/1	76	0/1	136	
	0043	WW	0	-	0	-	0	-	
	0043	DR	0	-	0	-	0	-	
	0049	WW	0	-	0	-	0	-	
	0049	DR	0	-	0	-	0	-	
	0050	WW	0	-	0	-	0	-	
	0055	WW	0	-	0	-	0	-	
	0055	WW	0	-	0	-	1/0	172	
	0061	DR	0	-	0	-	0	-	
	0061	WW	2/3-	191	0	-	0	-	
	0016	L	0	-	0	-	0/1+	134	
	0016	L	0	-	0	-	0	-	
	0007	L	0	-	0/1	131	0	-	
	0007	L	0	-	1/1	76	0	-	Type 1
	0021	S	0	-	2/1	161	0	-	
	0021	S	0	-	1/1	100	0	-	
	0087	S	0	-	0	-	0	-	
	0087	S	0	-	0	-	0	-	
Series N	0120	WW	0	-	0	-	0	-	
45/40	0106	S	0	-	1/1	133	0	-	
Sur D O_2	0111	DR	0	-	0	-	0	-	
	0118	DR	0	-	0	-	2/2	139	
	0113	DR	1/1	155	2/1	120	1/2	155	
	0131	DR	0	-	1/1	109	1/1	145	
	0128	WW	0	-	0	-	0	-	
	0117	DR	0	-	0	-	0/1	195	
	0129	DR	0	-	0	-	0	-	

TABLE 5

COMPARISON OF DIVES USING THE DCIEM 1983 DECOMPRESSION MODEL WHICH RESULTED IN "MINIMAL" DOPPLER SCORES (GRADES "0" OR "1", PRECORDIAL, AFTER MOVEMENT)

Profile (msw/min)	Percentage of Man-Dives with Minimal Doppler Scores			
	Standard Air	In-Water O_2	In-Water O_2 + Surface O_2	Sur D O_2
27/60	-	83%(23C)*	89%(19D)*	81%(16N)*
36/50	18%(11B)*	42 (24C)	62 (21D)	74 (23H,N)
36/60	-	-	70 (10G)	-
45/30	58 (31B,E†)	53 (15I†)	94 (18F†)	55 (11J†)
45/40	50 (20L)	79 (33C,M)	86 (22D)	100 (9N)
45/70	-	-	54 (13G)	100 (8P)
54/30	71 (21E†)	79 (24C)	79 (14D)	66 (46H,N,O†)
54/45	-	-	82 (11G)	-
63/30	-	-	50 (12G)	52 (21H,N)
72/40	-	-	71 (17G)	52 (21H,N)
45/30+45/20‡	85 (20E)	73 (15I)	100 (18F)	100 (11J)

* Figures and letters in () are number of man-dives and dive series
† Includes first dives of repetitive dives
‡ After second dive of repetitive dives