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THE DCIEM DECOMPRESSION TABLES AND PROCEDURES FOR AIR DIVING

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NIS / 1986

Introduction

New decompression tables for compressed air diving have been developed by DCIEM for use by the Canadian Forces (1). The objective in developing new tables was to produce a set of tables which could be used directly as printed for hard-working dives in cold water. Previously, the authorized tables for air diving in the Canadian Forces were the US Navy Standard Air Tables. The new tables include those for standard air dives, dives with in-water oxygen decompression, and dives using surface decompression with oxygen. Repetitive dive procedures and depth corrections for diving at altitude are also included.

Although the new tables were developed in 1983, the history of the decompression model used goes back over 20 years. Decompression research started in 1962 at the Defence Research Medical Laboratory and the Institute of Aviation Medicine (now DCIEM) by Kidd and Stubbs (2). Their objective was to develop a decompression computer to monitor the diver's depth-time history and provide instantaneous decompression information when complicated dive profiles and wide variations in gas mixtures would make the traditional tabular approach to decompression inadequate. They initially based their decompression computer on the traditional Haldane model to duplicate the US Navy 1958 standard air tables and then modified and changed parameters in the model as necessary until they attained a low incidence of decompression sickness. The type of dives tested consisted of random depth dives and repetitive dives in addition to standard dives to a fixed depth for a given bottom time.

By 1967, Kidd and Stubbs had developed a successful pneumatic analogue decompression computer. The final configuration of the computer model was a series arrangement of four tissue compartments (3) instead of the parallel arrangement of the Haldane model. In 1971, Stubbs modified the model again to make diving in the 200 to 300 ft range safer. This computer model was used extensively for real-time monitoring and control of experimental and training dives at DCIEM and for some operational dives in the ocean.

Development of the New DCIEM Tables

The Kidd-Stubbs (KS) model is essentially an empirical model, having been experimentally derived from approximately 5000 man-dives during the original development period. (The mathematical model, however, can be shown to be an approximation of a bulk-diffusion model (4)). Although the model was successful in providing safe decompression, an analysis showed that there were some deficiencies and anomalies which had to be corrected. A detailed study in 1979 of selected profiles using the Doppler ultrasonic bubble detector also identified operational limits for safe diving (5). For the new air diving tables, it was decided to modify the KS model rather than to devise an entirely new model because of the large database of well-documented dive data which existed on this model.

The supersaturation or surfacing criteria for the different compartments were modified to achieve the desired objectives of increasing the decompression times in regions where there was a high risk of decompression sickness (DCS) and decreasing the decompression times where the model was known to be very conservative. This modified model is known as the DCIEM 1983 model. Tables were developed to a depth of 72 metres of seawater (msw) using standard air decompression, in-water O_2 decompression, and surface decompression with O_2 (SurD O_2). The bottom times allowed at each depth were defined by a normal air diving limit and an exceptional exposure limit. Figure 1 shows these depth and bottom time limits.

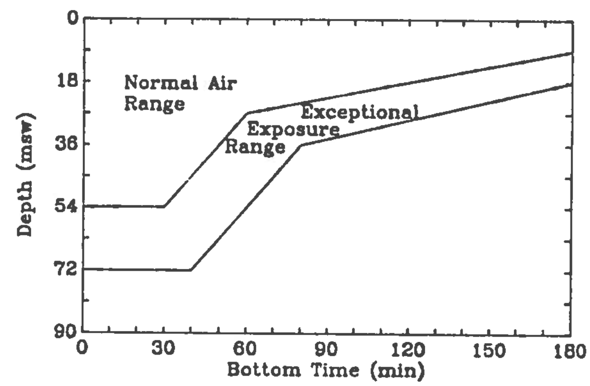

Figure 1. Air Diving Limits

Validation of the new tables was done by testing selected profiles. About 900 man-dives, both dry-resting and wet-working, were conducted using the Doppler ultrasonic bubble detector and clinical symptoms of decompression sickness as criteria for determining the decompression stress and the safety of the new model. The Doppler results were divided into two groups: Group A - subjects with no observable bubbles or Grade 1 bubbles in the precordial region at rest (low decompression stress), and Group B - subjects with bubbles greater than Grade 1 (moderate to severe decompression stress). Bubbles were graded according to the Kisman-Masurel code (6). Dive profiles in which the majority of subjects were in Group A were considered acceptable. Not all subjects were monitored.

Because the model is a continuous model and because of the large database of safe and unsafe dives done on the original model existing in the CANDID (Canadian Diving Data) decompression data bank (7), it was not necessary to try and test a very large number of combinations of depths and bottom times. All dive profiles tested were controlled by a microprocessor-controlled real-time on-line decompression computer which took into account the actual time-pressure profile. Hence, the mathematical model was always being tested instead of the printed tables derived from the model. Repetitive dive procedures were tested with all three decompression procedures. Corrections for diving at altitude were not tested.

Standard Air Table

The Standard Air Table is available in two formats. The first is the traditional tabular format of depth, bottom-time, stop-times, and total decompression time. Stop-times are represented in the Royal Navy (RN) format with ascent times to the stops included in the stop-times. Stop depths are at 3 msw intervals, and the ascent rate is 18 ± 3 msw/min. The bottom time includes the descent time to the depth at 18 msw/min. Each depth segment in the table is divided into two sections by a line corresponding to the normal air diving limit. Bottom times beyond this line are considered to be exceptional exposures. Repetitive dive groups are shown for dives only within the normal air diving limit and are not recommended beyond this limit. (Repetitive dive procedures will not be discussed in this presentation).

The second format for the standard air table is a simplified one-page version called the "Short Standard Air Table" (Table 1). Each entry in the table gives a bottom time and a Repetitive Group (RG). Where bottom times appear without an RG, repetitive diving is not recommended. In the "No-Decompression" (No-D) section, several bottom times are given for each depth. These are for the purposes of calculating repetitive dives. The No-D limits in Table 1S are for first dives only and are more conservative than most existing No-D limits. For repetitive No-D dives, even more conservative limits are used. For bottom times in the "Decompression Required" section of Table 1S, the decompression stop depths and stop times, in multiples of 5 min, are specified at the bottom of the table.

Depth (msw)	No-Decompression Bottom Times (min)			Decompression Required Bottom Times (min)			
9	30 A 60 C	90 D 120 F	180 H 400				
12	30 B 60 D	90 G 120 H	150 J 175 L	190	200	206	213
15	20 A 30 C	40 D 50 E	60 F 75 G	100 I	120 K	126 K	132 L
18	20 B	30 D	50 F	60 G	80 I	87 J	91 J
21	15 B	25 D	35 E	40 F	53 H	65 I	68 J
24	10 A	20 D	25 E	30 F	37 G	50 H	54 I
27	10 A	15 C	20 D	24 E	28 F	38 H	44 I
30	5 A	10 B	15 D	18 D	22 F	30 G	37 H
33	5 A	10 B	12 C	15 D	18 D	24 G	31 H
36		5 A	10 C	12 D	15 D	19 F	25 G
39		5 A	8 B	10 C	13 D	17 F	21 G
42		5 A	7 B	9 C	12 D	14 F	18 G
45			7 D	8 C	10 D	13 F	16 G
Decompression Time (min)		6 msw		-	-	5	10
		3 msw		5	10	10	10

Table 1. Canadian Forces Table 1S Short Standard Air

The standard air decompression table, in general, is more conservative than other published standard air tables. Figure 2 shows that the total decompression times of the DCIEM model are more conservative than those of the USN Standard Air Decompression Table (8) and the RN Table 11 Air Table (9) for all bottom times at a sample depth of 45 msw. It should be noted that a true comparison should also consider the relative times spent at the different decompression stops. Table 2 shows that the DCIEM profiles at 45 msw have deeper first stop depths than the USN and RN standard air tables.

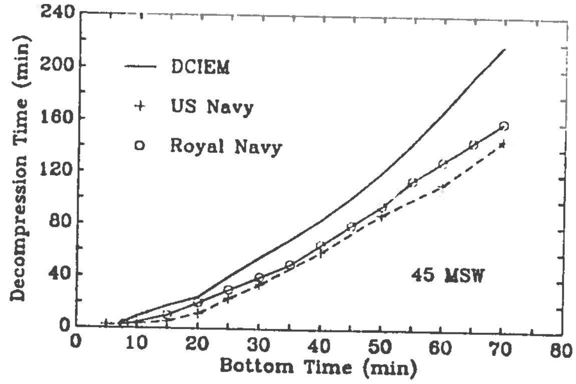

Figure 2. Comparison of Decompression Times

Depth (msw)	Bottom Time (min)	First Stop Depth (msw)		
		DCIEM	USN	RN
45	10	3	3	3
	15	6	3	6
	20	9	6	6
	30	12	6	9
	40	15	9	12
	60	18	12	15
	70	18	12	18
	80	18	15	21

Table 2. Comparison of first stop depths

However, is the model too conservative? The DCIEM tables are designed for hard work in cold water. The USN manual states that for these conditions the next bottom time should be used. Figure 3 shows that if the DCIEM decompression times at 45 msw are compared with those of the USN for the next bottom time (USN+1), the times are similar except for long bottom times where the DCIEM times become conservative again. However, in this range, a common practice is to go two bottom times beyond the actual bottom time or to go to the next depth as well as the next bottom time. In these cases, the results become comparable again. This holds true for all depths.

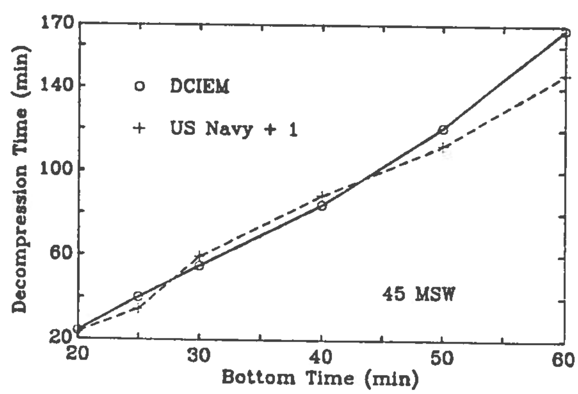

Figure 3. Comparison of Decompression Times

The standard air table was validated by manned dives to the limit of the normal air diving range only. A total of 267 man-dives were conducted. Of these, 55 had decompression times less than 30 min (90% of the subjects in Doppler Group A) and 84 were No-D dives (no observable bubbles). None resulted in DCS. The remaining 128 man-dives (66 single dives and 62 repetitive dive pairs) were near or at the normal air diving limit with decompression times between 48 and 88 min; 8 incidents of DCS were observed after the single dives and 4 were observed after the second dive of the repetitive pairs. However, some of these incidents were thought to have other contributing causes and may not have been attributable to the dive profiles alone. Dives near or at the normal air limit including first dives of repetitive pairs resulted in 64% of the subjects monitored in Doppler Group A. After the second dive of repetitive pairs, 93% were in Group A.

In-Water Oxygen Table

The use of O_2 in the water during decompression is useful for reducing the in-water exposure time. In the In-Water O_2 Table, 100% O_2 is applied at a depth of 9 msw until the decompression requirements are met. Ascent is then made to the surface directly. In-water decompression stops on air to and including the 12 msw stop are identical to those for the Standard Air Table. In calculating the safe depth during O_2 breathing, decompression was assumed to be only 80% effective. This allows for possible leakage of air around the face mask. (Leakage would not occur with a full face mask or in a surface-supplied diving helmet; however, the tables must also permit dives in a recompression chamber (RCC).) Although O_2 is applied at a relatively conservative depth, the possibility of O_2 toxicity problems still exist. Hence, the following conditions must be met for the use of the in-water O_2 table - the diver on O_2 must be accompanied (i.e., two divers on O_2, or one diver on O_2 and one on air as the standby diver); and an RCC must be within 1 h travelling time.

Table 3 compares decompression times with those of other in-water O_2 tables. The DCIEM column shows the decompression time with O_2 at 9 msw. The RNPL Metric Air Diving Tables (10) use stop depths at 5 msw intervals with O_2 at 10 and 5 msw; the RN Table 13 Deep Air-Oxygen Table (9) uses O_2 from 18 msw to the surface in 3 msw intervals; and the French Ministry of Labor Tables (11) use O_2 at 6 and 3 msw.

Depth (msw)	Bottom Time (min)	Decompression Time (min)			
		DCIEM	RNPL	RN	FR
30	50	27	40		21
	90	54	75		50
45	25	27	30		20
	40	53	60		42
60	20	42	35	29	27
	30	67	75	49	53

Table 3. Comparison of in-water O_2 decompression times.

The In-Water O_2 Table was validated by manned dives to the normal air diving limit only, with 114 single dives at the normal air diving limit (decompression times from 28 to 56 min) resulting in 6 incidents of DCS (5.2%), and 31 short dives (5-min O_2 stop only) with no DCS (96% in Doppler Group A). Fourteen repetitive dives to 45 msw/30 min followed by a dive to 45 msw/20 min after 2 h were done with no problems. All dives at the normal air diving limit, including first dives of repetitive pairs, resulted in 78% in Doppler Group A. After the second dive of the repetitive pairs, 86% were in Group A.

The In-Water O_2 Decompression Table is also available in two formats - in the traditional tabular format of depth, bottom time, stop-times, and total decompression time; and in a simplified one-page version similar to that of the "Short Standard Air Table".

Surface Decompression with O_2

The most effective way of reducing the in-water exposure time is to use surface decompression. The SurD O_2 procedure requires in-water decompression to the end of the 9 msw stop, direct ascent to the surface followed by a return to 12 msw in an RCC to complete the decompression requirements on O_2. The development of the DCIEM SurD O_2 Table relied partly on the work of Arntzen and Eidsvik (12) who studied how commercial diving companies in the North Sea had modified the USN SurD O_2 Table (8) to obtain safer dives. Arntzen and Eidsvik (A&E) devised their own SurD O_2 tables which were considerably more conservative than the USN Table. They included 5-min air breaks after every 20 min on O_2 and also introduced additional O_2 decompression by taking 12 min (at 1 msw/min) to return to the surface from the RCC stop. Preliminary calculations showed that the DCIEM model gave decompression times similar to those of A&E, and that it was feasible to use the model for SurD O_2.

The DCIEM SurD O_2 procedure is different from that of A&E or the USN. The in-water decompression procedure and stops to and including the 9-msw stop are identical to those of the Standard Air Table, with the ascent rate at 18 ± 3 msw/min. A surface interval (SI) of 7 min is allowed from leaving 9 msw in the water until reaching 12 msw in the RCC. (This SI was chosen to enhance the operability of the procedure and to reduce the chances of "omitted decompression".) In the RCC, a 5-min air break is taken after each 30-min period on O_2. (As in the In-Water O_2 Decompression Table, O_2 decompression has been assumed to be only 80% effective.) In calculating the stop times in the RCC, additional decompression has been included to compensate for the violation of the decompression model during the surface interval and any possible reduction in inert gas elimination resulting from gas phase separation. This has been done by taking the surfacing criterion to be when the safe depth reaches "-1 msw" instead of the normal end-point of "0 msw". Surfacing at "-1 msw" gives about 10-12 min additional decompression on O_2 for moderate bottom times. similar to the 12 min slow ascent used by A&E.

Table 4 shows that the DCIEM SurD O_2 decompression times are similar to those of A&E for moderate bottom times. For longer bottom times, the DCIEM model gives longer decompression times for depths less than 45 msw, and shorter times for depths greater than 45 msw. A comparison with the US Navy SurD O_2 Table shows that, in many instances, two or even three bottom times longer are required to give the same decompression times as the DCIEM table.

The SurD O_2 method is the preferred method for all compressed air diving requiring significant decompression and is the only method recommended for exceptional exposure diving. During the validation dives, 295 single man-dives were conducted. Of these, 178 were at or near the normal air limit with decompression times between 40 and 80 min resulting in 4 incidents of DCS (2.2%). The remainder, 117 dives, were in the exceptional exposure range or at the exceptional expo-

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)						Decom. Time (min)
		In-Water Stops				S.I.	Chamber	
		Air					O_2	
		18	15	12	9		12	
36	30	-	-	-	4	7	22	33 D
	30	-	-	-	4	5	24	33 A
36	90	-	3	7	13	7	88••	128 D
	90	-	-	11	17	5	71••	114 A
45	20	-	-	-	6	7	18	31 D
	20	-	-	-	5	5	24	34 A
45	40	-	4	6	7	7	49•	78 D
	40	-	6	6	9	5	48•	79 A
54	30	-	5	5	7	7	43•	72 D
	30	9	5	9	6	5	46•	85 A

Table 4. Comparison between DCIEM (D) and Arntzen and Eidsvik (A) decompression stop times for surface decompression with oxygen. The asterisks (•) in the "Chamber" column indicate the number of 5-min air breaks to be added to the stop time.

sure limit with decompression times from 73 to 204 min, with 4 incidents of DGS (3.4%). Repetitive dives using SurD O_2 included 29 dives to 45 msw/30 min followed by 45 msw/20 min after 2 h with no DCS and 24 dives to 54 msw/30 min followed by a Standard Air dive to 18 msw/30 min after 3 h with one case of DCS. Dives at the normal air limit, including first dives of repetitive pairs, resulted in 88% in Doppler Group A, and dives in the exceptional exposure range resulted in 65% in Group A. After the second dives of repetitive pairs, only one subject was in Group B.

The DCIEM SurD O_2 Table is being used by several commercial diving companies. One company reported 300 dives with only one incident of DCS. Divers were reported as feeling physically better and ready to go back to work after the decompression, whereas on the USN tables, they felt extremely fatigued. A second company reported 200 dives for a total of 222 h bottom time (60% of the dives to 18 msw, 30% between 36 and 45 msw, 10% between 48 and 57 msw) with no problems, using the tables as printed. Divers also reported feeling better physically after the dives.

Summary

The DCIEM decompression tables described here have been developed based on over 20 years of decompression research at DCIEM. Although no realistic decompression procedures can totally eliminate the occurrence of DCS, the DCIEM tables, because of their conservative nature, are believed to be safer than most available tables. For Standard Air Dives at or near the normal air diving limit, there is still a high risk of DCS. For dives in the exceptional exposure range, the preferred method is surface decompression with oxygen. All validation dives were controlled by a decompression computer based on the actual time-depth profile, thus the decompression times used were slightly less than if the corresponding printed tables had been used. This was particularly true of the repetitive dive combinations examined, where the decompression times were considerably shorter than those resulting from the repetitive dive tables developed. The DCIEM Tables are now the official tables used by the Canadian Forces.

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Acknowledgements
The author would like to acknowledge the valuable contributions made by G.R. Lauckner, B.C. Eatock and LCdr. B.A. Hobson in the development of these tables. Special appreciation is due to the DCIEM diving team and the medical, technical, and operational support personnel for their efforts during the lengthy validation process and to the experimental dive subjects from the Canadian Forces Fleet Diving Units, the Canadian Underwater Training Centre, the Royal Navy, the French Navy, and the US Navy.

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