THE DCIEM/CANADIAN FORCES AIR DECOMPRESSION TABLES

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The DCIEM/Canadian Forces decompression tables were developed in 1983 as a replacement for the US Navy Standard Air Tables [1]. The problem with the USN tables is that the tables are rarely used as printed and corrections must be made for safe decompression. The objective in developing a new set of tables for the Canadian Forces was to produce tables which could be used directly as printed for hard-working dives in cold water. Although the decompression model underlying the new tables was developed in 1983, its history goes back over 20 years.

Decompression research was started in 1962 at the Defence Research Medical Laboratory and the Institute of Aviation Medicine (now DCIEM) by Kidd and Stubbs [2] who set out to develop an instrument which would 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 many repetitive dives in addition to standard dives to a fixed depth for a given bottom time. By 1967, they had developed a successful decompression computer based on about 5000 man-dives. The final configuration of the computer was a series arrangement of tissue compartments instead of the parallel arrangement of the Haldane model. In 1970, Stubbs modified the model again to make diving in the 200 to 300 ft range safer. The final model was known as the Kidd-Stubbs (KS) 1971 model.

Although the KS decompression computer was used extensively at DCIEM and for some dives in the ocean, it was recognized that there were some deficiencies in the model for operational use. The first was that the no-decompression limits were overly conservative. Figure 1 shows the no-decompression limits for the KS, Royal Navy (RN) [3] and USN tables. In some cases at the shallower depths, the No-D limit is only half that of the others.

The second problem was that the decompression stress increased with increasing bottom time. Figure 2 shows a comparison of total decompression times as a function of the bottom time for the KS, USN and RN tables at 45 metres of seawater (msw). Initially, because of the conservative No-D limits, the decompression times for short exposures are too conservative. As the bottom time increases, the decompression stress changes from being too conservative to not being conservative enough, and eventually, there is a large risk of decompression sickness. The three numbers define regions of constant decompression stress. Similar regions exist at the other depths. At 1, the decompression stress is mild to moderate; at 2, the stress is moderate to severe, and at 3, the stress is severe. These are limits for average divers. For above average divers, who are young, fit and well-acclimatized, limit 2 represents mild to moderate stress and limit 3 represents moderate to severe stress. An ideal decompression model should be equally safe no matter what the bottom time is.

A third problem with the KS model was the excessively long decompression times at long bottom times. The KS model consists of an arrangement of four compartments in series. The

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long decompression times are an "end effect" anomaly resulting from the model being limited to only four compartments. The result is a long "tail" to the decompression profile. For example, the decompression time for 45 msw for 50 min is more than twice that at 40 min. All this additional time is spent at the 3 msw stop.

To develop the new Canadian Forces decompression tables, it was decided to start with and modify the KS model since a large database of valuable decompression information already existed at DCIEM in a computer data bank [4]. All dives done at DCIEM since 1964 are recorded in this data bank. Developing a completely new model would have been prohibitive in terms of manpower and time.

To overcome the problems and anomalies existing in the KS model, the following objectives were set.

1. Increase the No-D limits.
2. Decrease the decompression requirements for moderate exposures (short bottom times) where the decompression times are known to be conservative.
3. Increase the decompression requirements for exposures in which the decompression stress is severe (region 3).
4. Remove the anomaly caused by the "end effect", that is, the excessively long decompression times for long bottom times.
5. Introduce oxygen decompression into the model.

The changes made to the KS model satisfied the objectives set and the modified model is known as the DCIEM 1983 decompression model. Figure 3 shows the new No-D limits. They have been increased but they are still more conservative than the USN and RN limits over most of the depth range. Since the changes to the model were kept simple, it was impossible to increase the limits any more without seriously affecting the decompression times for longer bottom times. As a result, the No-D limits have been extended in the new tables to allow more practical no-decompression dives. These limits are shown in Figure 3 by the solid line identified as "CF Operational".

Figure 4 shows the DCIEM 1983 decompression times compared with those of the KS times for 45 msw. It can be seen that the decompression times have been reduced for short bottom times and increased for bottom times where the decompression stress was severe. The long tail to the decompression has also been removed. Figure 5 shows a comparison of the total decompression times generated with the DCIEM 1983 model for 45 msw with the USN Standard Air and RN Table 11 decompression times. The DCIEM times are more conservative than the others for all bottom times. It should be noted that a true comparison should also consider the relative times spent at the different decompression stops. The DCIEM decompression profiles have deeper first stops than the USN profiles.

However, is the model too conservative? The DCIEM tables are designed for hard work in cold water. In the USN manual, it states that for hard work in cold water, the next bottom time should be used. Figure 6 shows that if the DCIEM 1983 decompression times are compared with the USN decompression times for the next bottom time (USN+1) at 45 msw, the decompression times are similar. This holds true for all depths. For extreme bottom times, the DCIEM times become conservative compared to the USN+1 times. 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.

The model has been used to generate a complete set of tables including standard air decompression, in-water oxygen decompression, surface decompression with oxygen, repetitive dive procedures, and corrections for diving at altitude. Of interest to the scientific diver are four tables:

Table 1S. Short Standard Air.

Table 5. Depth Corrections for Diving at Altitude.

Table 4A. Repetitive Dive Factors.

Table 4B. Allowable No-Decompression Limits for Repetitive Dives.

The Short Standard Air Decompression Table (Table 1S) is a simplified version of the complete Standard Air Table. It consists of two sections - a **no-decompression (No-D)** section on the left of the double vertical lines and a **decompression-required** section to the right of the lines. Each entry in the table gives a bottom time and a **Repetitive Group (RG)**. (*Note that these repetitive groups are different from and thus incompatible with the repetitive dive groups of the US Navy tables.*) Where bottom times appear without an RG, repetitive diving is not recommended. The bottom time is defined as the time from leaving the surface to leaving bottom. A descent rate of 18 msw/min was used for the profile calculations.

In the No-D region, 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. For repetitive No-D dives, more conservative limits are required. These are given in Table 4B.

For bottom times in the "decompression-required" section of Table 1S, the decompression stop times and stop depths are specified at the bottom of the table. The stop times include the ascent time to the stops. The ascent rate and travel rate between stops are 18 $\pm$ 3 msw/min.

Tables 4A and 4B are used for calculating the decompression requirements for repetitive dives. Table 4A gives **Repetitive Factors (RF)** for each repetitive dive group for surface intervals to 18 hours. The RF is used to determine the **Effective Bottom Time (EBT)** of the repetitive dive, this EBT being the combined total of the actual bottom time and the time that must be considered to have been already spent at that depth because of the residual nitrogen remaining in the body from the previous dive. Table 4B gives the allowable No-D limits at different depths for second and subsequent dives as a function of the repetitive factors. These No-D limits are actual bottom times, not EBT's. (The **maximum** RG for the times given at each depth is shown at the right of the table and is given to assist in planning a third dive, if intended.)

The general procedure for calculating a repetitive dive is to determine the RG of the first dive from Table 1S and the RF for that group from Table 4A for the surface interval between the first and second dive. Table 4B should then be consulted to determine whether the planned dive can be done as a No-D dive or whether decompression will be required.

For a No-D repetitive dive (i.e, the planned (or actual) bottom time is less than or equal to the repetitive No-D limit of Table 4B), no further calculations are necessary if a third dive is not intended. If a third dive is intended, and the actual bottom time of the second dive is equal to the repetitive No-D limit, the RG for the second dive can be obtained from the right-hand column of Table 4B. However, if a third dive is intended and the bottom time of the second dive is less than the repetitive No-D limit from Table 4B, the RG for the second dive is found by multiplying the actual bottom time of the second dive by the RF to obtain the EBT. The RG for second dive is equal to the RG for the EBT in Table 1S.

If the repetitive dive requires decompression (i.e., the planned (or actual) bottom time is greater than the repetitive No-D limit), then the bottom time of the second dive is multiplied by the RF to obtain the EBT. The depth of the second dive and the EBT are used to determine the decompression requirements (from Table 1S) for the second dive. The RG for the second dive is also determined from the depth and EBT of the second dive if a third dive is desired.

If the planned bottom time exceeds the allowable No-D bottom time in Table 4B but with the EBT less than the No-D limit in Table 1S, a 5-minute decompression stop is mandatory. The reason for this is that the No-D limits for repetitive dives have been assumed to be close to the conservative limits predicted by the DCIEM 1983 model whereas the No-D limits in Table 1S are greater than those of the model and are for first dives only.

For a dive at altitude, the reduced atmospheric pressure at the surface makes the dive equivalent to a deeper dive at sea level. The depth corrections given in Table 5 are added to the actual depth of the dive to determine the dive profile to be used for decompression purposes. Table 5 also gives the actual stop depths to be used for the standard decompression stops. (Divers are cautioned that most commonly used depth gauges will not read "actual" water depth at altitude, unless the gauge has been specifically calibrated for that altitude. Shot lines are

recommended.)

The corrections shown in Table 5 apply only for divers who have been acclimated at the altitude of the dive site, i.e., for those who have spent at least 12 to 24 hours at that altitude. Corrections to the depth would be greater for those who have not been acclimated.

The tables have been tested extensively using the Doppler ultrasonic bubble detector and bends incidence as safety criteria. (The depth corrections for diving at altitude have not been experimentally validated by DCIEM. However, they are similar to those which have been published for recreational divers [5].) About 900 man-dives were performed during the validation dive series over a two year period. These tables were tested in a hyperbaric chamber with wet-working divers in cold water at 10 ° Celsius as well as with dry-resting divers. All dives were done using a real-time on-line decompression computer [6] following the exact decompression profile as specified by the DCIEM 1983 decompression model. No realistic decompression procedures can totally eliminate the occurrence of decompression sickness. However, these tables are believed to be safer than most existing tables.

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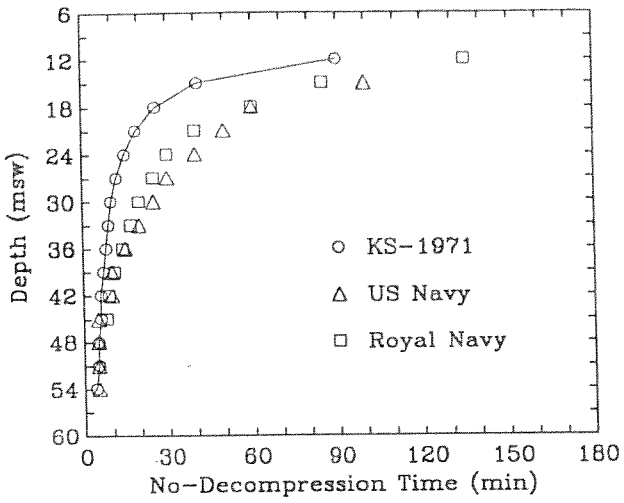
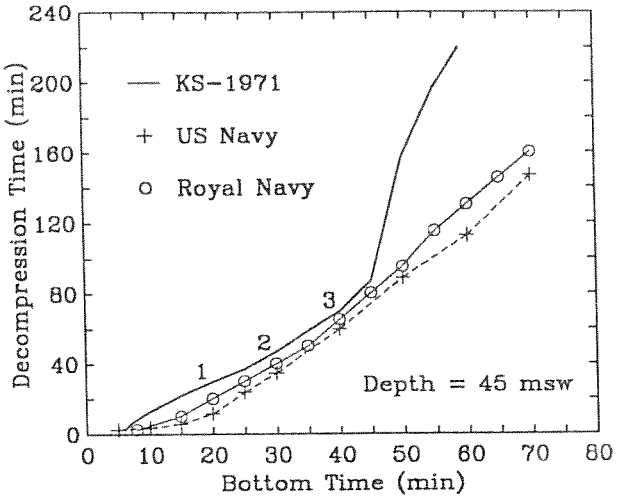


Figure 1



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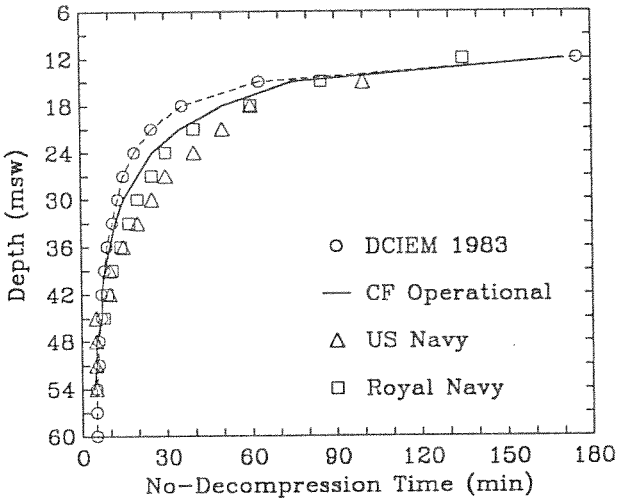

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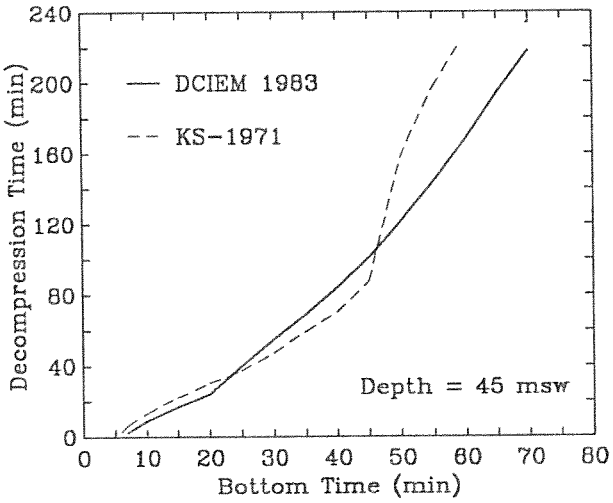

Figure 4

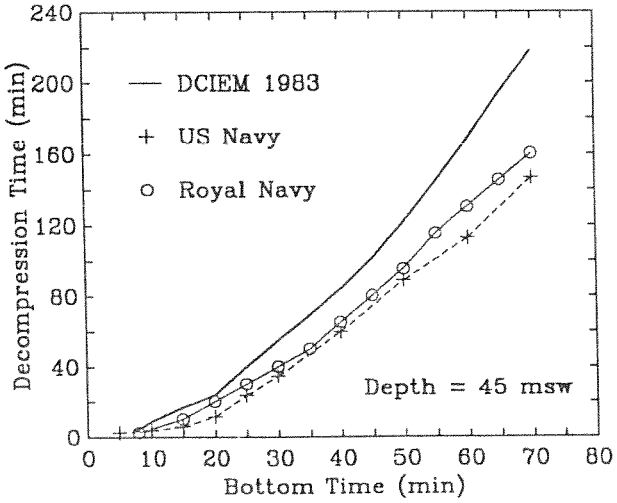

Figure 5

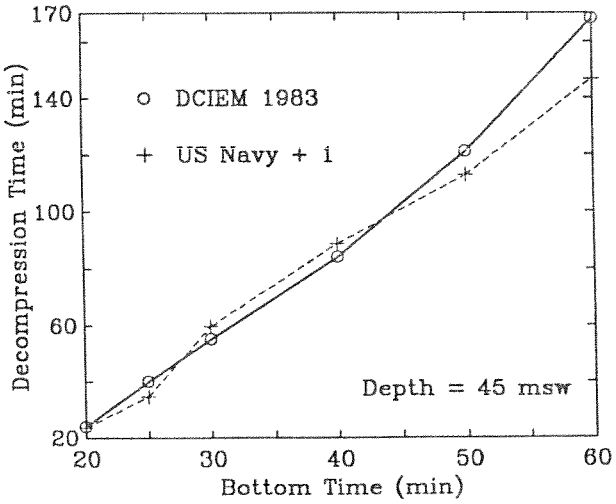

Figure 6

CANADIAN FORCES AIR DIVING TABLE 1S (FEET)
SHORT STANDARD AIR

Depth (fsw)	No-Decompression Bottom Times (min)			Decompression Required Bottom Times (min)			
30	30 A 60 C	90 D 120 F	180 H 380				
40	30 B 60 D	90 G 120 H	150 J 175 L	185	190	199	206
50	20 A 30 C	40 D 50 E	60 F 75 G	95 I	115 K	122 K	127 L
60	20 B	30 D	50 F	60 G	80 I	84 J	88 J
70	15 B	25 D	35 E	40 F	50 G	63 I	66 J
80	10 A	20 D	25 E	29 F	35 G	48 H	52 I
90	10 A	15 C	20 D	23 E	27 F	36 H	43 I
100	5 A	10 B	15 D	18 D	21 E	29 G	36 H
110	5 A	10 B	12 C	15 D	18 D	23 F	30 H
120		5 A	10 C	12 D	15 D	19 F	25 G
130		5 A	8 B	10 C	13 D	16 F	21 G
140		5 A	7 B	9 C	11 D	14 F	18 G
150			6 B	8 C	10 D	12 E	15 F
Decompression Time (minutes)			20 fsw	-	-	5	10
			10 fsw	5	10	10	10

CANADIAN FORCES AIR DIVING TABLE 4A
REPETITIVE DIVE FACTORS (RF)

Repetitive Group (RG)	RF for Surface Intervals (SI) in hr:min								
	0:30 →0:59	1:00 →1:29	1:30 →1:59	2:00 →2:59	3:00 →3:59	4:00 →5:59	6:00 →8:59	9:00 →11:59	12:00 →18:00
A	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0
B	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0
C	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0
D	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
E	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1
F	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1
G	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
H	-	1.9	1.7	1.6	1.5	1.4	1.3	1.1	1.1
I	-	2.0	1.8	1.7	1.5	1.4	1.3	1.1	1.1
J	-	-	1.9	1.8	1.6	1.5	1.3	1.2	1.1
K	-	-	2.0	1.9	1.7	1.5	1.3	1.2	1.1
L	-	-	-	2.0	1.7	1.6	1.4	1.2	1.1
M	-	-	-	-	1.8	1.6	1.4	1.2	1.1
N	-	-	-	-	1.9	1.7	1.4	1.2	1.1
O	-	-	-	-	2.0	1.7	1.4	1.2	1.1

CANADIAN FORCES AIR DIVING TABLE 5 (FEET)
DEPTH CORRECTIONS FOR DIVING AT ALTITUDE (EXCERPT)

Actual Depth (fsw)	Depth Correction (fsw) at Altitude (feet)								
	300 →999	1000 →1999	2000 →2999	3000 →3999	4000 →4999	5000 →5999	6000 →6999	7000 →7999	8000 →10000
30	+0	+10	+10	+10	+10	+10	+10	+20	+20
40	+0	+10	+10	+10	+10	+10	+20	+20	+20
50	+0	+10	+10	+10	+10	+20	+20	+20	+20
60	+0	+10	+10	+10	+20	+20	+20	+20	+30
70	+0	+10	+10	+10	+20	+20	+20	+30	+30
80	+0	+10	+10	+20	+20	+20	+30	+30	+40
90	+0	+10	+10	+20	+20	+20	+30	+30	+40
100	+0	+10	+10	+20	+20	+30	+30	+30	+40
110	+0	+10	+20	+20	+20	+30	+30	+40	
120	+0	+10	+20	+20	+30	+30	+30		
130	+0	+10	+20	+20					
140	+0	+10							

Sea Level Stop Depth (fsw)	Actual Stop Depth (fsw) at Altitude (feet)								
	300 →999	1000 →1999	2000 →2999	3000 →3999	4000 →4999	5000 →5999	6000 →6999	7000 →7999	8000 →10000
10	10	10	10	9	9	9	8	8	8
20	20	20	19	18	18	17	16	16	15
30	30	29	28	27	26	25	24	24	23

CANADIAN FORCES AIR DIVING TABLE 4B (FEET)
ALLOWABLE NO-DECOMPRESSION LIMITS FOR REPETITIVE DIVES

Depth (fsw)	Allowable No-D Limit (min) for Repetitive Factors (RF)										Repet. Gr. (RG)
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	
40	160	145	135	125	115	105	96	90	85	80	L
50	60	55	50	45	41	38	35	33	31	30	G
60	40	35	30	28	26	24	23	22	21	20	F
70	30	25	21	19	18	17	16	15	14	13	E
80	20	17	15	14	13	12	11	11	10	10	E
90	16	14	12	11	10	10	9	8	8	8	D
100	13	11	10	9	9	8	7	7	6	6	D
110	10	9	8	7	7	6	6	6	5	5	C
120	8	7	6	6	6	5	5	5	4	4	C
130	7	6	6	5	5	5	4	4	4	4	B
140	6	5	5	5	4	4	4	3	3	3	B
150	5	5	4	4	4	3	3	3	3	3	B