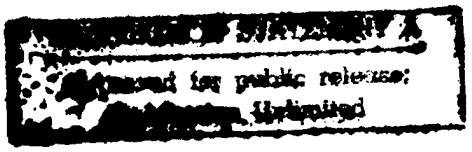
DCIEM TECHNICAL MEMORANDUM 98-TM-68

HeO_2 CUMA REPETITIVE DIVE TABLE TRIALS – SERIES 2 AND 3

1998

EXECUTIVE SUMMARY

The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen (HeO_2). Decompression tables for use with the CUMA include no-decompression, surface decompression with oxygen, and in-water oxygen decompression tables. DCIEM/EDU has been tasked to develop and test repetitive diving tables and procedures for CUMA. Although repetitive diving for MCM has not been a requirement in the past, MCM divers will be required to conduct repetitive dives to accomplish the mission. Currently, there are no adequate repetitive diving procedures or tables for diving with HeO_2 breathing mixtures such as used in the CUMA, and a surface interval of 18 hours is required before a diver is considered "clean" and can do a new dive. Repetitive diving procedures with reduced surface intervals will allow greater employment rates and turn-around times for small dive teams, both operationally and under training. Theoretical calculations based on the DCIEM decompression model used to develop the CUMA tables have suggested that this surface interval may be reduced to only 6 hours and that simple repetitive dive procedures for surface intervals from 3 to 6 hours can be devised. A limited EDU in-house pilot study was carried out in November 1997 to explore the feasibility and logistics of conducting repetitive dives on CUMA. The results, for short bottom time dive schedules (10 min at 45, 60, 69, and 81 msw) repeated after a 6 hour surface interval, suggested that the second dive could be considered a new dive rather than a repetitive dive. Following the completion of the pilot study, plans were made to start a full-scale testing program for CUMA repetitive diving. This technical memorandum describes the results of Series 2, using CF divers, and Series 3, with CF divers and international participants from the Royal Navy, US Navy, and Royal Australian Navy. The results of Series 2 and 3, with dives of 20 minute bottom times (at 45, 60, 69, and 81 msw), have confirmed the findings of the pilot series that a 6 hour surface interval appears to be sufficient to allow a second dive on the CUMA to be treated as a new dive. In addition, repetitive dives after a surface interval of 3 hours were tested for four 10 minute bottom time dives (at 45, 60, 69, and 81 msw) and one 20 minute bottom time dive (at 60 msw). These dives showed that the additional decompression requirements calculated from the decompression algorithm appear to be adequate. More testing still must be conducted on a wider range of bottom times and depths.



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3752B-P51CD/6.i.b.13(0010) (EDU)

27 Oct 1998

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REFERENCES:

A. Nishi, R.Y. and M.R. Warlow. Development of CUMA HeO_2 Decompression Tables: Final Report. DCIEM 97-R-68, December 1997.
B. Work Unit No. 6ib13. Repetitive CUMA Decompression Procedures Development
C. Nishi, R.Y. and M.L. Kessler. HeO_2 CUMA Repetitive Dive Table Trials – Pilot Series. DCIEM Technical Memorandum 98-TM-29, 3752B-P51CD/6.i.2(0010) (EDU), dated 24 Feb 1998.
D. Protocol # L-196 Determination Of Safe Surface Interval And Repetitive Dive Procedure Using The Canadian Underwater Mine Apparatus (CUMA) And CF Decompression Tables.

1. BACKGROUND

1.1 The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen (HeO_2). In 1996, the Experimental Diving Unit (EDU) at DCIEM successfully completed a five year program for the development and validation of HeO_2 decompression tables for use with CUMA (Ref. A). These tables included no-decompression, surface decompression with oxygen, and in-water oxygen decompression tables and have been approved for operational use by the CF.

1.2 Currently, there are no adequate repetitive diving procedures for diving with HeO_2 breathing mixtures. DCIEM/EDU was tasked to test repetitive diving procedures and develop repetitive diving tables for CUMA (Ref. B). A pilot study was conducted in November 1997 (Ref. C) to test whether or not repetitive diving, with surface intervals much less than the 18-24 hours presently used for HeO_2 diving, is possible with CUMA. This preliminary study was a limited EDU in-house trial to explore the feasibility and logistics of testing repetitive dives on CUMA and to obtain some evidence of whether a 6-hour surface interval, as indicated by theoretical calculations, was sufficient to allow divers to repeat the first dive without any additional decompression requirements. The tests suggested that CUMA dives could be considered a new dive rather than a repetitive dive after 6 hours and the same dive could be conducted with no decompression penalty. Only short duration dives with bottom times of 10 min to a maximum depth of 81 msw were tested. No symptoms of decompression illness (DCI) were encountered. This has considerable applications in operational and training diving such as allowing greater employment rates and turn around times for small dive teams.

1.3 Following the completion of the pilot study, plans were made to start a full-scale testing program for CUMA repetitive diving. This technical memorandum describes the results of Series 2, using CF divers, and Series 3, with international participation. Dives with 20 min bottom times were planned for surface intervals of 6 hours. In addition, surface intervals of 3 hours were examined for repetitive dives using 10 min bottom time dives.

2. PROCEDURES

2.1 The experimental dive program was approved by the DCIEM Human Ethics Committee (Ref. D). Table 1 shows the decompression schedules that were tested during Series 2 and 3. For surface intervals of 6 hours, dive subjects repeated the same dive that they had done earlier. For surface intervals of 3 hours, the second dive decompression was conducted according to the schedules listed in Table 1. These schedules are taken from the proposed CF Table 14, designed for use for all CUMA repetitive dives to be conducted for surface intervals between 3 and 6 hours.

Table 1. Repetitive Dive Schedules Tested during Series 2 and 3.

Dive Series	Dive No.	Surface Interval between dives (h)	Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]										Surf. Int. (min)[2]	RCC[3]	Total Dec. Time (min)
					In-Water Stops												
					HeO_2									O_2			
					36	33	30	27	24	21	18	15	12	9	0	12	
2, 3	1		45	10	-	-	-	-	-	-	-	-	4	5	7	11	28
	2	3	45	10	-	-	-	-	-	-	-	-	4	5	7	17	34
2, 3	1		60	10	-	-	-	-	-	-	-	5	3	5	7	21	42
	2	3	60	10	-	-	-	-	-	-	4	3	3	5	7	27	50
2, 3	1		69	10	-	-	-	-	-	4	2	2	4	5	7	27	52
	2	3	69	10	-	-	-	-	-	5	2	3	4	6	7	30*	63
2	1		60	20	-	-	-	-	4	2	3	3	6	11	7	50*	92
	2	3	60	20	-	-	-	3	2	2	3	4	8	11	7	58*	104
2	1		81	10	-	-	-	-	5	2	2	3	3	7	7	32*	67
	2	6	81	10	-	-	-	-	5	2	2	3	3	7	7	32*	67
2	1		45	20	-	-	-	-	-	-	-	4	4	5	7	30	51
	2	6	45	20	-	-	-	-	-	-	-	4	4	5	7	30	51
2, 3	1		60	20	-	-	-	-	4	2	3	3	6	11	7	50*	92
	2	6	60	20	-	-	-	-	4	2	3	3	6	11	7	50*	92
2, 3	1		69	20	-	-	4	2	2	3	2	5	11	12	7	61**	120
	2	6	69	20	-	-	4	2	2	3	2	5	11	12	7	61**	120
2	1		81	20	4	2	2	2	3	3	5	10	13	16	7	75**	153
	2	6	81	20	4	2	2	2	3	3	5	10	13	16	7	75**	153

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min.
3. Asterisk (*) indicates number of 5 min air breaks required.

2.2 Dive subjects from the Fleet Diving Unit (Pacific) participated in Series 2. Dive subjects for Series 3 were from the Fleet Diving Unit (Atlantic), the Royal Australian Navy, the Royal Navy, and the US Navy. The minimum time between the start of successive dive pairs for any individual was 48 hours. Team leaders were drawn from the EDU diving pool and only dived once a day, with a new team leader participating in the second dive of the day.

2.3 All dives were carried out in the DCIEM Dive Research Facility (DRF). Each dive was planned for four divers -- two wet working divers, one standby diver (partially wet, resting) breathing from the CUMA, and one team leader (dry, lightly working). The wet divers and standby diver wore well-fitting neoprene dry suits, gloves and hood for each dive. The wet divers worked on a bicycle ergometer set at 50 watts and commenced pedaling (5 min work/5 min rest) on arrival at the depth of the dive. The water temperature was 6-8 degrees C. The standby diver remained in the intermediate area at the dive chamber barrier for most of the dive and was directed to move around frequently to avoid cramped muscles and to improve circulation. Inspired PO_2 and CO_2 were monitored for all subjects on CUMA from the time the subjects first put on the sets before the dive to the arrival at the surface. Team leaders were not counted as dive subjects. For the 45 msw dive, team leaders breathed air to the 9 msw O_2 stop. For the deeper dives, they breathed 80/20 HeO_2 from BIBS with a switch to air at the first stop and to oxygen at 9 msw.

2.4 The first dives were controlled by following the tables developed at Ref A. For surface intervals of 6 hours, the second dive of each repetitive dive pair was treated as a new dive, using the same schedule used for the first dive. For each dive, a printed minute-by-minute listing of elapsed time, depth and the calculated Safe Ascent Depth (SAD) for the planned schedule was available as a guide. In addition, a PC-based real-time dive computer was used on-line to display the elapsed time, depth, and the SAD. The planned descent rate and initial ascent rate to the surface were at 18 msw/min. In case of a delay in descent, the beginning of decompression was delayed until the calculated SAD, as displayed on the computer, reached the printed SAD for the planned schedule. For all other eventualities the printed tables were followed.

2.5 For surface intervals of 3 hours, the second dive of each repetitive dive pair was conducted by following the printed tabular schedules shown in Table 1. A printed minute-by-minute listing of elapsed time, depth and the calculated SAD was not available for the second dive. The dive computer was initialized as for a new dive to allow the SAD to be used to determine when decompression should be started in case of a delay during the initial descent to depth.

2.6 On arrival at the 12 msw, CUMA subjects switched the diluent off to allow the diluent level to decay, thus reducing the time required to reach 100% O_2 after the switch to oxygen at the 9 msw O_2 stop. On arrival at the O_2 stop, CUMA subjects flushed their counterlungs and all subjects began O_2 breathing. The timing of the O_2 stop was counted from two minutes after reaching 9 msw. On completion of the 9 msw stop, the chamber was brought to the surface.

2.7 On reaching the surface, both the wet and the standby divers were removed from the water and undressed. All divers, including the team leader proceeded into the Living Chamber. During this surface interval (SurD SI[1]), one wet diver and the standby diver were monitored for venous gas emboli (VGE) using the Doppler ultrasonic bubble monitor if time permitted. Six minutes after leaving the 9 msw "in-water" stop, all divers were placed back on O_2 and the Living Chamber was pressurized to 12 msw. (The SurD SI, the time from leaving the 9 msw stop to reaching the 12 msw stop, was 7 minutes). At the 12 msw chamber stop, 5-

[1] To avoid confusion between the surface interval between the first and second dives of the day and the surface interval between the in-water part of the dive and the subsequent surface decompression at 12 msw in the chamber, the latter will be referred to as "SurD SI".

minute air breaks were taken at 30 minute intervals. On completion of the 12 msw stop, the DRF was then depressurized to the surface.

2.8 All divers were monitored for VGE for a minimum of 2 hours post-dive. Bubbles were scored using the Kisman-Masurel (KM) Code. For surface intervals of 6 hours, the wet and standby divers were monitored for bubbles again at 5 hours after the end of the first dive. For this dive series, the decision was made that any subject having Grade 3 or 4 precordial bubbles at rest one hour before the start of the second dive would not dive the second dive. After the required surface interval of 6 or 3 hours, the divers began their second dive. Doppler monitoring was carried out at the SurD SI and for at least 2 hours post-dive.

3. RESULTS

3.1 Table 2A shows the number of dives and the number of wet-working and standby man-dives conducted in Series 2 (2-27 Feb 1998). Seventeen divers participated in Series 2 (FDU(P) - 9, EDU – 6 (TL)). Fourteen dive pairs (28 dives) were planned to test 8 dive schedules, with 13 being completed successfully. In one case, the bottom depth (69 msw) could not be attained in the second dive (DR1815R) and it was completed as a 45 msw/10 min in-water oxygen decompression dive. Of the 13 successful dive pairs, there was one case where a delay occurred in reaching the12 msw chamber stop after the SurD SI on the second dive (see Note 1, Table 2A). In a second case, there was a delay of 10 min in starting the second dive (Note 4).

Table 2A. Dives conducted during Series 2.

Date	Dive Prof. msw/min	First Dive				SI (h)	Second Dive				Notes
		Ser. No.	# Wet	# Stdby	# TL		Ser. No.	# Wet	# Stdby	# TL	
980205	45/20	DR1806A	2	1	1	6	DR1807R	2	1	1	
980206	45/10	DR1808A	2	1	1	3	DR1809R	2	1	1	
980209	60/20	DR1810A	2	1	1	6	DR1811R	2	1	1	Note 1.
980210	81/10	DR1812A	2	1	1	6	DR1813R	2	1	1	
980211	69/20	DR1814A	2*	1*	1	6	DR1815R	2*	1*	1*	Note 2.
980212	60/10	DR1816A	2	1	1	3	DR1817R	2	1	1	
980216	81/20	DR1818A	2	1	1	6	DR1819R	2	1	1	
980217	69/10	DR1820A	2	1	1	6	DR1821R	2	1	1	Note 3.
980218	60/20	DR1822A	2	1	1	3	DR1823R	2	1	1	
980219	60/10	DR1824A	2	1	1	3	DR1825R	2	1	1	
980223	81/20	DR1826A	2	1	1	6	DR1827R	2	1	1	
980224	60/20	DR1828A	2	1	1	6	DR1829R	2	1	1	
980225	60/20	DR1830A	2	1	1	3	DR1831R	2	1	1	Note 4.
980226	45/10	DR1832A	2	1	1	3	DR1833R	2	1	1	

Notes:

1. Delay in reaching 12 msw in the recompression chamber on the 2nd dive (DR1811R) required adding the delay time to the chamber stop. This provided approximately 9 minutes additional decompression in the chamber.
2. Problems in attaining bottom depth on the 2nd dive (DR1815R). Dive aborted and 2nd dive completed as 45 msw/10 min in-water oxygen decompression dive. This dive pair has been excluded from the dataset.
3. Wet and Standby divers changed roles for the second dive.
4. Delay in preparing for the 2nd dive. Actual surface interval was 3 hours, 10 minutes instead of 3 hours.

3.2 No cases of DCI were observed in Series 2. However, in DR1826A, the first dive of an 81 msw/20 min dive pair, the standby diver reported minor pain (3/10) 3 minutes into the SurD SI. The pain disappeared at 3 msw during recompression to 12 msw. In another dive, DR1818A (81 msw/20 min), a Team Leader reported mild niggles in the left clavicle during the SurD SI that disappeared at 12 msw. One wet diver on the second dive to 45 msw/20 min (DR1807A) reported pain (1/10) in his right wrist about 50 min post-dive. A trial of pressure approximately 3 hours post-dive resulted in no change and the conclusion was that it was a strain pain as a result of a tight wrist cuff.

3.3 Table 2B shows the number of dives and the number of wet-working and standby man-dives conducted in Series 3 (7 Apr – 1 May 1998). This was the first international series in the repetitive dive work unit. Eighteen divers (FDU(A) - 3, RAN - 2, RN - 4, USN – 1, DCIEM EDU – 8 (TL)) participated in this series. Thirteen dive pairs (26 dives) were planned and completed successfully to test 5 repetitive dive schedules.

Table 2B. Dives conducted during Series 3.

Date	Dive Prof. msw/min	First Dive				SI (h)	Second Dive				Notes
		Ser. No.	# Wet	# Stdby	# TL		Ser. No.	# Wet	# Stdby	# TL	
980414	45/10	DR1843A	2	1	1	3	DR1844R	2	1	1	
980415	60/10	DR1845A	2	1	1	3	DR1846R	2	1*	1	Note 1.
980416	69/20	DR1847A	2	1	1	6	DR1848R	2	1	1	
980417	45/10	DR1849A	2	1	1	3	DR1850R	2	1	1	
980420	60/20	DR1851A	2	1	1	6	DR1852R	2	1	1	
980421	60/20	DR1853A	2	1	1	6	DR1854R	2	1	1	
980422	69/10	DR1855A	2	1	1	3	DR1856R	2	1	1	
980423	69/10	DR1857A	2	1	1	3	DR1858R	2	1	1	
980424	69/10	DR1859A	2	1	1	3	DR1860R	2	1	1	
980427	69/20	DR1861A	2	1	1	6	DR1862R	2	1	1	
980428	69/20	DR1863A	2	1	1	6	DR1864R	2	1	1	
980429	69/20	DR1865A	2	1	1	6	DR1866R	2	1	1	
980430	60/10	DR1867A	2	1	1	3	DR1868R	2	1	1	

Notes: 1. Standby diver in 2nd dive not monitored for bubbles because of communications problems.

3.4 No cases of DCI were observed in Series 3. However, in dive DR1848R, the second dive of a 69 msw/20 min dive pair, one wet diver reported a niggle in his elbow during the SurD SI. This subject had Grade 3 and 4 precordial bubbles at rest and after movement, respectively, during the SurD SI. The standby diver on this dive also had a few niggles in his hand.

3.5 Tables 3A and 3B show the post-dive Doppler results with the number of wet (W) and standby (S) divers participating in each dive schedule tested in both Series 2 and 3. Table 3A shows the results for the schedules tested with a surface interval between the first and second dives of 3 hours, and Table 3B shows the results for a surface interval of 6 hours. The bubble scores observed in the precordial region at rest and the maximum scores observed from all sites (precordial and the two subclavian veins, under both rest and movement conditions) are presented as the number of subjects over the total number of subjects on that dive schedule having Bubble Grades > 0 (any bubbles) and Bubble Grades > 2 (Grades 3 and 4, many bubbles).

Table 3A: Doppler results for 1st and 2nd dives with 3 hour surface interval

Dive Series	Profile (msw/min)	Dive No.	Role	No. of Man-dives	Precordial Rest		All Sites Max.		DCI	SI Pain
					BG > 0	***BG > 2***	BG > 0	BG > 2		
2, 3	45/10	1	W	8	0/8	***0/8***	0/8	0/8	0	0
			S	4	0/4	***0/4***	0/4	0/4	0	0
	45/10 (3 hr)	2	W	8	0/8	***0/8***	0/8	0/8	0	0
			S	4	0/4	***0/4***	0/4	0/4	0	0
2, 3	60/10	1	W	8	2/8	***0/8***	3/8	0/8	0	0
			S	4	0/4	***0/4***	1/4	0/4	0	0
	60/10 (3 hr)	2	W	8	3/8	***0/8***	3/8	1/8	0	0
			S	4	0/4	***0/4***	1/4	0/4	0	0
2, 3	69/10	1	W	8	2/8	***0/8***	2/8	0/8	0	0
			S	4	0/4	***0/4***	1/4	0/4	0	0
	69/10 (3 hr)	2	W	8	1/8	***0/8***	4/8	0/8	0	0
			S	4	1/4	***0/4***	1/4	0/4	0	0
2	60/20	1	W	2	0/2	***0/2***	1/2	0/2	0	0
			S	1	0/1	***0/1***	1/1	0/1	0	0
	60/20 (3 hr)	2	W	2	1/2	***0/2***	1/1	0/1	0	0
			S	1	0/1	***0/1***	1/1	0/1	0	0

Table 3B: Doppler results for 1st and 2nd dives with 6 hour surface interval

Dive Series	Profile (msw/min)	Dive No.	Role	No. of Man-dives	Precordial Rest		All Sites Max.		DCI	SI Pain
					BG > 0	***BG > 2***	BG > 0	BG > 2		
2	81/10	1	W	2	0/2	***0/2***	0/2	0/2	0	0
			S	1	1/1	***0/1***	1/1	0/1	0	0
	81/10 (6 hr)	2	W	2	0/2	***0/2***	0/2	0/2	0	0
			S	1	0/1	***0/1***	1/1	0/1	0	0
2	45/20	1	W	2	2/2	***0/2***	2/2	0/2	0	0
			S	1	0/1	***0/1***	1/1	0/1	0	0
	45/20 (6 hr)	2	W	2	2/2	***1/2***	2/2	1/2	0	0
			S	1	0/1	***0/1***	0/1	0/1	0	0
2, 3	60/20	1	W	10	3/10	***2/10***	7/10	2/10	0	0
			S	5	3/5	***1/5***	3/5	2/5	0	0
	60/20 (6 hr)	2	W	10	6/10	***3/10***	7/10	4/10	0	0
			S	5	3/5	***2/5***	4/5	2/5	0	0
3	69/20	1	W	8	6/8	***4/8***	7/8	5/8	0	0
			S	4	2/4	***1/4***	2/4	2/4	0	0
	69/20 (6 hr)	2	W	8	6/8	***2/8***	7/8	3/8	0	0
			S	4	2/4	***1/4***	2/4	1/4	0	0
2	81/20	1	W	4	4/4	***0/4***	4/4	2/4	0	0
			S	2	1/2	***1/2***	1/2	1/2	0	1
	81/20 (6 hr)	2	W	4	3/4	***2/4***	4/4	3/4	0	0
			S	2	1/2	***1/2***	1/2	1/2	0	0

3.6 Figures 4A and 4B show the Doppler results obtained during the surface interval (SurD SI) prior to the surface decompression in the recompression chamber. In one dive to 60 msw/10 min during Series 3, the standby diver could not be monitored during the SurD SI because of communications problems with the Doppler station in the dive chamber. The results do not seem to show any significant differences between the first and second dives.

Table 4A. Doppler results at SI prior to SurD O_2 for 1st and 2nd dives with 3 hr surface intervals

Dive Series	Profile (msw/min)	Dive No.	Role	No. of Man-dives	Precordial Rest		All Sites Max.		DCI	SI Pain
					BG > 0	***BG > 2***	BG > 0	BG > 2		
2, 3	45/10	1	W	4	1/4	***0/4***	1/4	0/4	0	0
			S	4	0/4	***0/4***	0/4	0/4	0	0
	45/10 (3 hr)	2	W	4	1/4	***0/4***	1/4	0/4	0	0
			S	4	1/4	***0/4***	1/4	0/4	0	0
2, 3	60/10	1	W	4	0/4	***0/4***	0/4	0/4	0	0
			S	4	0/4	***0/4***	1/4	0/4	0	0
	60/10 (3 hr)	2	W	4	0/4	***0/4***	1/4	0/4	0	0
			S	3	0/3	***0/3***	1/3	0/3	0	0
2, 3	69/10	1	W	4	1/4	***0/4***	2/4	0/4	0	0
			S	4	0/4	***0/4***	0/4	0/4	0	0
	69/10 (3 hr)	2	W	4	1/4	***0/4***	3/4	1/4	0	0
			S	4	1/4	***0/4***	1/4	1/4	0	0
2	60/20	1	W	1	1/1	***1/1***	1/1	1/1	0	0
			S	1	0/1	***0/1***	1/1	0/1	0	0
	60/20 (3 hr)	2	W	1	0/1	***0/1***	0/1	0/1	0	0
			S	1	1/1	***0/1***	1/1	0/1	0	0

Table 4B. Doppler results at SI prior to SurD O_2 for 1st and 2nd dives with 6 hr surface intervals

Dive Series	Profile (msw/min)	Dive No.	Role	No. of Man-dives	Precordial Rest		All Sites Max.		DCI	SI Pain
					BG > 0	***BG > 2***	BG > 0	BG > 2		
2	81/10	1	W	1	0/1	***0/1***	0/1	0/1	0	0
			S	1	0/1	***0/1***	0/1	0/1	0	0
	81/10 (6 hr)	2	W	1	0/1	***0/1***	0/1	0/1	0	0
			S	1	0/1	***0/1***	0/1	0/1	0	0
2	45/20	1	W	1	1/1	***1/1***	1/1	1/1	0	0
			S	1	0/1	***0/1***	0/1	0/1	0	0
	45/20 (6 hr)	2	W	1	1/1	***0/1***	1/1	1/1	0	0
			S	1	0/1	***0/1***	0/1	0/1	0	0
2, 3	60/20	1	W	5	2/5	***0/5***	3/5	0/5	0	0
			S	5	2/5	***0/5***	4/5	0/5	0	0
	60/20 (6 hr)	2	W	5	0/5	***0/5***	2/5	1/5	0	0
			S	5	2/5	***0/5***	3/5	0/5	0	0
3	69/20	1	W	4	2/4	***1/4***	2/4	2/4	0	0
			S	4	2/4	***0/4***	3/4	0/4	0	0
	69/20 (6 hr)	2	W	4	2/4	***2/4***	3/4	2/4	0	0
			S	4	0/4	***0/4***	2/4	0/4	0	0
2	81/20	1	W	2	1/2	***0/2***	2/2	1/2	0	0
			S	2	1/2	***0/2***	1/2	1/2	0	1
	81/20 (6 hr)	2	W	2	1/2	***0/2***	1/2	1/2	0	0
			S	2	1/2	***1/2***	1/2	1/2	0	0

3.7 Another way of looking at the Doppler results is to look at the difference in bubble scores between the first and second dives for each individual subject. These differences can then be grouped into individuals whose bubble scores changed by up to one, two, three or four bubble grades greater or lesser than the bubble scores during the first dive. The results (precordial at rest and after movement) are shown in Figure 1 for post-dive bubbles and

Figure 2 for bubbles during the SurD SI. All divers, except for the two divers who changed roles (wet divers – standby divers) between the first and second dives (DR1820A and DR1821R), are shown. These include divers who had no bubbles at all in both dives at any site.

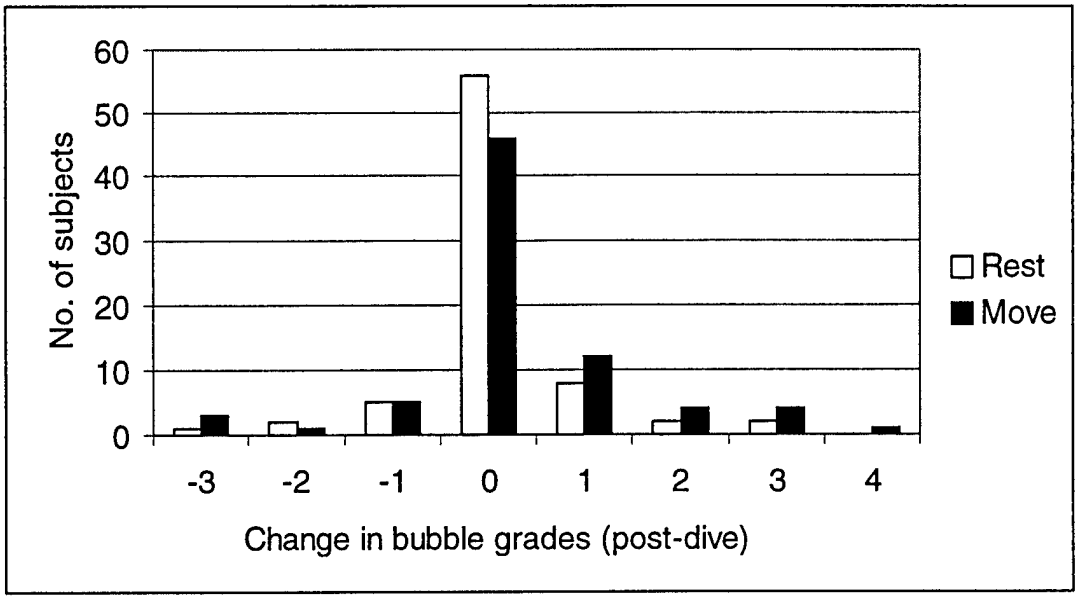

Figure 1. Change in post-dive bubble scores, precordial at rest and after movement, between the first and second dives (surface intervals of 3 and 6 hours). The results for 0 change in bubble grades include 28 subjects who had no observable bubbles in both dives at any site post-dive or during the SurD SI (if monitored at that time).

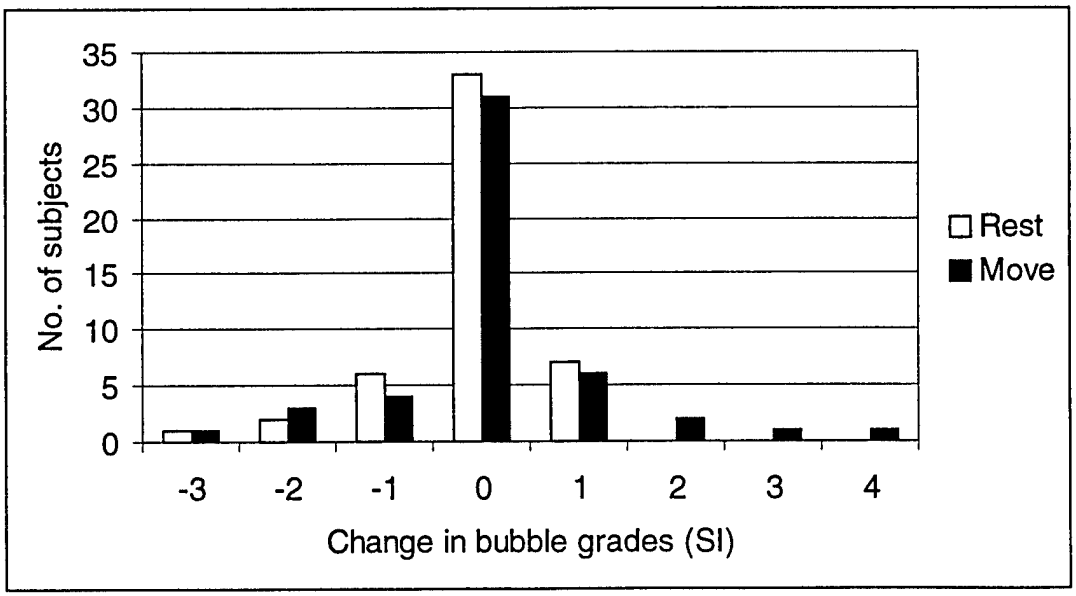

Figure 2. Change in SurD SI bubble grades, precordial at rest and after movement, between the first and second dives (surface intervals of 3 and 6 hours) for all subjects monitored during the SurD SI. The results for 0 change in bubble grades include 17 subjects who had no observable bubbles in both dives at any site post-dive or during the SurD SI.

3.8 Table 5 shows the Doppler results for team leaders who breathed either air or 20/80 HeO_2 on the bottom. Team Leaders only participated in one dive each day. For the second dive of the day, a new Team Leader was used. A comparison and analysis of CUMA dive schedules with those from CF Tables 2 and 3 (for those breathing air) or CF Tables 7 and 8 (for those breathing HeO_2) for the same depth and bottom times showed that team leaders would be getting more decompression than required. Although CF Tables 7 and 8 are designed for 84/16 HeO_2, team leaders were put on 80/20 HeO_2 to obtain a greater margin of safety. Team leaders were not monitored during the 7-minute surface interval.

Table 5. Doppler results for Team Leaders (single dives)

Dive Series	Profile (msw/min)	Dive Schedule	Role	No. of Man-dives	Precordial Rest		All Sites Max.		DCI	SI Pain
					BG > 0	BG > 2	BG > 0	BG > 2		
2,3	45/10	New	TL	4	0/4	0/4	0/4	0/4	0	0
2,3	60/10	New	TL	4	0/4	0/4	1/4	0/4	0	0
2,3	69/10	New	TL	4	0/4	0/4	2/4	0/4	0	0
2	81/10	New	TL	2	0/2	0/2	0/2	0/2	0	0
2	45/20	New	TL	2	0/2	0/2	2/2	0/2	0	0
2,3	60/20	New	TL	11	3/11	2/11	7/11	3/11	0	0
2,3	69/20	New	TL	9	3/9	1/9	4/9	3/9	0	0
2	81/20	New	TL	4	2/4	0/4	3/4	2/4	0	0
2,3	45/10	Repet	TL	4	0/4	0/4	0/4	0/4	0	0
2,3	60/10	Repet	TL	4	0/4	0/4	1/4	0/4	0	0
2,3	69/10	Repet	TL	4	0/4	0/4	2/4	0/4	0	0
2	60/20	Repet	TL	1	1/1	0/1	1/1	1/1	0	0
2	not counted		TL	1						

4. DISCUSSION

4.1 Although the number of subjects involved to date is low, the Doppler results from Series 2 and 3 shown in Tables 3 and 4 indicate that there appears to be little difference between the bubble scores on the first and second dives. This appears to be true for all decompression stress levels identified previously (Ref. A) – low (45 msw/10 min, 60/10, 69/10, 45/20), moderate (81/10, 60/20) and high (69/20, 81/20). The pilot study (Ref. C) showed that for bottom times of 10 minutes, a 6 hour surface interval was adequate to allow the second dive to be conducted as a new dive instead of as a repetitive dive. The results of these two dive series suggest that 20 minute bottom time dives can also be conducted as new dives instead of as repetitive dives.

4.2 For surface intervals of 3 hours, the results suggest that the calculated decompression requirements for the second dive are adequate for the 10 minute bottom time dives. One dive with a 20 min bottom time (60 msw/20 min, moderate decompression stress level) was tested and showed favourable results. However, a greater range of depths with 20 min bottom times will have to be tested to verify that the calculated decompression requirements will be adequate or if more decompression time may have to be added for the high

decompression stress range. One other aspect that could be examined is the actual decompression requirement as calculated for the 3 hour surface interval dives. To evaluate this, the dive computer should be left on between the first and second dives.

4.3 The results shown in Figures 1 and 2 indicate that most subjects have similar responses for the first and second dives, and that subjects who had bubbles could equally have lower bubble scores as higher bubble scores on the second dive. Hence there appears to be no clear trend that the second dive is more stressful than the first.

4.4 A possible concern may be oxygen toxicity. For the deep longer dives, the total amount of oxygen being breathed may be quite high for the two dives combined. Although the CUMA decompression tables have been designed for a time-weighted average (TWA) PO_2 of 1.0 ATA, the actual TWA PO_2 could be higher since the CUMA is a semi-closed circuit breathing apparatus and the PO_2 varies with the activity of the diver. Table 6 shows the TWA PO_2 during the bottom time, during the decompression until arriving at the 9 msw O_2 stop, and from the beginning of the dive until the 9 msw O_2 stop (i.e., bottom time and decompression stops combined). Since the standby divers are not working during the bottom time, their TWA PO_2 is higher than that of the wet divers. The TWA PO_2 during decompression is generally lower than that for the bottom time because of the initial drop in PO_2 at the beginning of decompression. However, for the longer decompression times and deeper depths, the TWA PO_2 could be higher, partly as a result of the diluent being turned off on arrival at 12 msw. As a result, the TWA PO_2 from the start of the dive until the 9 msw O_2 stop for the longer dives may be higher than that for the shorter dives at the same depth.

Table 6. Time-Weighted Average PO_2 During Dives (Mean ± Std. Dev.)

Dive (msw/min)	Wet Divers				Standby Divers			
	No.	From start of dive to leaving bottom	From start of decompression to 9 msw O_2 stop	From start of dive to 9 msw O2 stop	No.	From start of dive to leaving bottom	From start of decompression to 9 msw O_2 stop	From start of dive to 9 msw O2 stop
45/10	16	1.18 ± 0.04	0.91 ± 0.05	1.10 ± 0.03	8	1.25 ± 0.13	0.97 ± 0.04	1.17 ± 0.09
45/20	4	1.13 ± 0.04	1.09 ± 0.06	1.12 ± 0.05	2	1.43 ± 0.03	1.12 ± 0.03	1.34 ± 0.01
60/10	16	1.30 ± 0.11	1.06 ± 0.06	1.19 ± 0.08	8	1.44 ± 0.20	1.07 ± 0.07	1.26 ± 0.11
60/20	24	1.27 ± 0.09	1.25 ± 0.06	1.26 ± 0.06	12	1.45 ± 0.13	1.24 ± 0.04	1.35 ± 0.07
69/10	16	1.44 ± 0.07	1.15 ± 0.07	1.27 ± 0.06	8	1.53 ± 0.14	1.14 ± 0.08	1.31 ± 0.09
69/20	18	1.33 ± 0.07	1.41 ± 0.05	1.38 ± 0.05	9	1.53 ± 0.07	1.38 ± 0.06	1.44 ± 0.06
81/10	4	1.49 ± 0.04	1.16 ± 0.06	1.29 ± 0.04	2	1.36 ± 0.01	1.05 ± 0.01	1.17 ± 0.01
81/20	8	1.34 ± 0.07	1.43 ± 0.03	1.40 ± 0.03	4	1.56 ± 0.04	1.43 ± 0.04	1.47 ± 0.03

4.5 Table 7 shows the oxygen tolerance units (OTU) (mean ± standard deviations) calculated from the inspired PO_2 for the dives that were tested. The OTU is calculated from

$$OTU = \Delta t((PO_2 - 0.5)/0.5)^{0.83},$$

where Δt is the time of exposure in minutes and PO_2 is the partial pressure of oxygen in atm. Also shown are the OTU's calculated for the CUMA decompression schedules shown in Table 1. The actual observed OTU's for the wet and standby divers are approximately 14% and 16% higher, respectively, than those calculated for the printed schedules. For the longest dive pair, 81 msw/20 min, the total OTU for the combined dives is nearing the recommended single day whole body OTU limit of 850[2]. Daily exposures should be varied to stay within recommended limits for multiday diving. For example, an average daily exposure of 460 OTU's would allow five consecutive days of diving.

Table 7. Comparison of Actual OTU's (Mean ± Std. Dev.) and Theoretical Calculations based on Inspired PO_2 of 1 ATA (N is the number of divers)

1st and 2nd Dives	Wet Divers				Standby Divers				Calculated from Model		
Surface Interval	N	1st dive	2nd dive	Total	N	1st dive	2nd dive	Total	1st dive	2nd dive	Total
45/10 + 3 h + 45/10	8	68.1	85.6	153.7	4	69.5	86.5	156.1	*58.7*	*75.2*	*133.9*
		±1.6	±1.4	±2.6		±2.3	±2.7	±4.5			
60/10 + 3 h +60/10	8	104.2	122.4	226.5	4	106.3	124.7	231.0	*90.3*	*108.8*	*199.1*
		±2.7	±3.5	±6.0		±3.8	±4.4	±8.1			
69/10 + 3 h +69/10	8	130.2	137.5	267.7	4	130.9	138.6	269.5	*110.8*	*123.4*	*234.2*
		±3.1	±3.5	±6.2		±3.8	±6.6	±10.0			
60/20 + 3 h + 60/20	2	230.8	263.6	494.3	1	233.0	261.8	494.8	*204.1*	*230.1*	*434.2*
		±3.7	±2.5	±6.2							
81/10 + 6 h + 81/10	2	151.7	151.9	303.6	1	147.3	145.0	292.3	*132.2*	*132.2*	*264.4*
		±1.2	±3.3	±4.5							
45/20 + 6 h + 45/20	2	138.2	140.1	278.3	1	147.5	149.6	297.1	*125.0*	*125.0*	*250.0*
		±2.3	±4.5	±6.8							
60/20 + 6 h + 60/20	8	228.3	228.7	457.0	4	234.5	232.9	467.4	*204.1*	*204.1*	*408.2*
		±4.2	±4.3	±8.3		±8.3	±1.3	±9.5			
69/20 + 6 h + 69/20	8	289.2	288.6	577.7	4	292.5	292.3	584.8	*247.7*	*247.7*	*495.4*
		±5.1	±2.8	±6.8		±5.3	±6.6	±11.4			
81/20 + 6 h + 81/20	4	358.7	361.1	719.8	2	366.3	367.8	734.1	*310.6*	*310.6*	*621.2*
		±2.4	±1.3	±1.9		±2.5	±2.5	±5.0			

[2] Hamilton, RW 1989. Tolerating exposure to high oxygen levels: Repex and other methods. Marine Tech Soc J 23(4): 19-25.

SUMMARY

4.6 The results of Series 2 and 3 have confirmed the findings of the initial pilot series held in November 1997 that a 6 hour surface interval appears to be sufficient to allow a second dive on the CUMA to be treated as a new dive rather than a repetitive dive. In addition, repetitive dives with additional decompression can be conducted after a surface interval of 3 hours. More testing still has to be conducted on a wider range of bottom times and depths.

4.7 Future dive series are planned for November/December 1998 (Series 4), January/February 1999 (Series 5), May 1999 (Series 6), and November/December 1999 (Series 7).

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DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Establishment sponsoring a contractor's report, or tasking agency, are entered in section 12.)
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Ave. West, P.O. Box 2000, Toronto, ON M3M 3B9

2. DOCUMENT SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)
UNCLASSIFIED

3. DOCUMENT TITLE (the complete document title as indicated on the title page. Its classification should be indicated be the appropriate abbreviation (S,C,R or U) in parentheses after the title.)
HeO2 CUMA REPETITIVE DIVE TABLE TRIALS – SERIES 2 AND 3

4. DESCRIPTIVE NOTES (the category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
Technical Memorandum

5. AUTHOR(S) (Last name, first name, middle initial. If military, show rank, e.g. Burns, Maj. Frank E.)
Nishi, Ronald Y.
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6. DOCUMENT DATE (month and year of publication of document)	7.a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)	7.b. NO. OF REFS. (total cited in document)
October 1998	12	5

8.a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)	8.b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)
6IB13	

9.a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)	9.b. OTHER DOCUMENT NO.(S) (any other numbers which may be assigned this document either by the originator or by the sponsor.)
DCIEM 98-TM-68	

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The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen (HeO2). Decompression tables for use with the CUMA include no-decompression, surface decompression with oxygen, and in-water oxygen decompression tables. DCIEM/EDU has been tasked to develop and test repetitive diving tables and procedures for CUMA. Although repetitive diving for MCM has not been a requirement in the past, MCM divers will be required to conduct repetitive dives to accomplish the mission. Currently, there are no adequate repetitive diving procedures or tables for diving with HeO2 breathing mixtures such as used in the CUMA, and a surface interval of 18 hours is required before a diver is considered "clean" and can do a new dive. Repetitive diving procedures with reduced surface intervals will allow greater employment rates and turn-around times for small dive teams, both operationally and under training. Theoretical calculations based on the DCIEM decompression model used to develop the CUMA tables have suggested that this surface interval may be reduced to only 6 hours and that simple repetitive dive procedures for surface intervals from 3 to 6 hours can be devised. A limited EDU in-house pilot study was carried out in November 1997 to explore the feasibility and logistics of conducting repetitive dives on CUMA. The results, for short bottom time dive schedules (10 min at 45, 60, 69, and 81 msw) repeated after a 6 hour surface interval, suggested that the second dive could be considered a new dive rather than a repetitive dive. Following the completion of the pilot study, plans were made to start a full-scale testing program for CUMA repetitive diving. This technical memorandum describes the results of Series 2, using CF divers, and Series 3, with CF divers and international participants from the Royal Navy, US Navy, and Royal Australian Navy. The results of Series 2 and 3, with dives of 20 minute bottom times (at 45, 60, 69, and 81 msw), have confirmed the findings of the pilot series that a 6 hour surface interval appears to be sufficient to allow a second dive on the CUMA to be treated as a new dive. In addition, repetitive dives after a surface interval of 3 hours were tested for four 10 minute bottom time dives (at 45, 60, 69, and 81 msw) and one 20 minute bottom time dive (at 60 msw). These dives showed that the additional decompression requirements calculated from the decompression algorithm appear to be adequate. More testing still must be conducted on a wider range of bottom times and depths.

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Mine countermeasures
Decompression
Diving Tables
Repetitive Diving
Doppler Bubble Detection

DCIEM TECHNICAL MEMORANDUM 98-TM-68

HeO_2 CUMA REPETITIVE DIVE TABLE TRIALS – SERIES 2 AND 3

EXECUTIVE SUMMARY

The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen (HeO_2). Decompression tables for use with the CUMA include no-decompression, surface decompression with oxygen, and in-water oxygen decompression tables. DCIEM/EDU has been tasked to develop and test repetitive diving tables and procedures for CUMA. Although repetitive diving for MCM has not been a requirement in the past, MCM divers will be required to conduct repetitive dives to accomplish the mission. Currently, there are no adequate repetitive diving procedures or tables for diving with HeO_2 breathing mixtures such as used in the CUMA, and a surface interval of 18 hours is required before a diver is considered "clean" and can do a new dive. Repetitive diving procedures with reduced surface intervals will allow greater employment rates and turn-around times for small dive teams, both operationally and under training. Theoretical calculations based on the DCIEM decompression model used to develop the CUMA tables have suggested that this surface interval may be reduced to only 6 hours and that simple repetitive dive procedures for surface intervals from 3 to 6 hours can be devised. A limited EDU in-house pilot study was carried out in November 1997 to explore the feasibility and logistics of conducting repetitive dives on CUMA. The results, for short bottom time dive schedules (10 min at 45, 60, 69, and 81 msw) repeated after a 6 hour surface interval, suggested that the second dive could be considered a new dive rather than a repetitive dive. Following the completion of the pilot study, plans were made to start a full-scale testing program for CUMA repetitive diving. This technical memorandum describes the results of Series 2, using CF divers, and Series 3, with CF divers and international participants from the Royal Navy, US Navy, and Royal Australian Navy. The results of Series 2 and 3, with dives of 20 minute bottom times (at 45, 60, 69, and 81 msw), have confirmed the findings of the pilot series that a 6 hour surface interval appears to be sufficient to allow a second dive on the CUMA to be treated as a new dive. In addition, repetitive dives after a surface interval of 3 hours were tested for four 10 minute bottom time dives (at 45, 60, 69, and 81 msw) and one 20 minute bottom time dive (at 60 msw). These dives showed that the additional decompression requirements calculated from the decompression algorithm appear to be adequate. More testing still must be conducted on a wider range of bottom times and depths.