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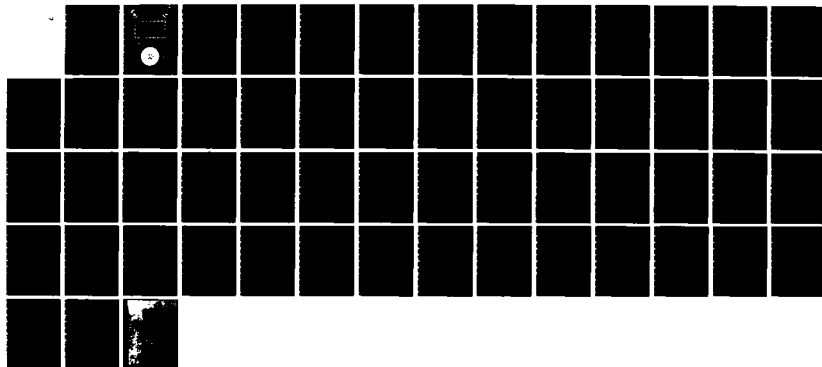
A PROCEDURE FOR DOING MULTIPLE LEVEL DIVES ON AIR USING REPETITIVE GROUPS(U) NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY FL E D THALMANN ET AL. SEP 83 NEDU-13-83

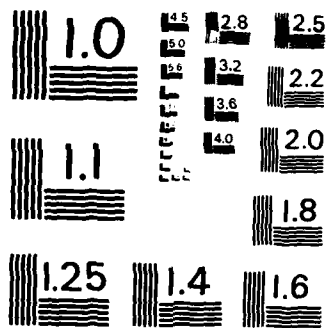
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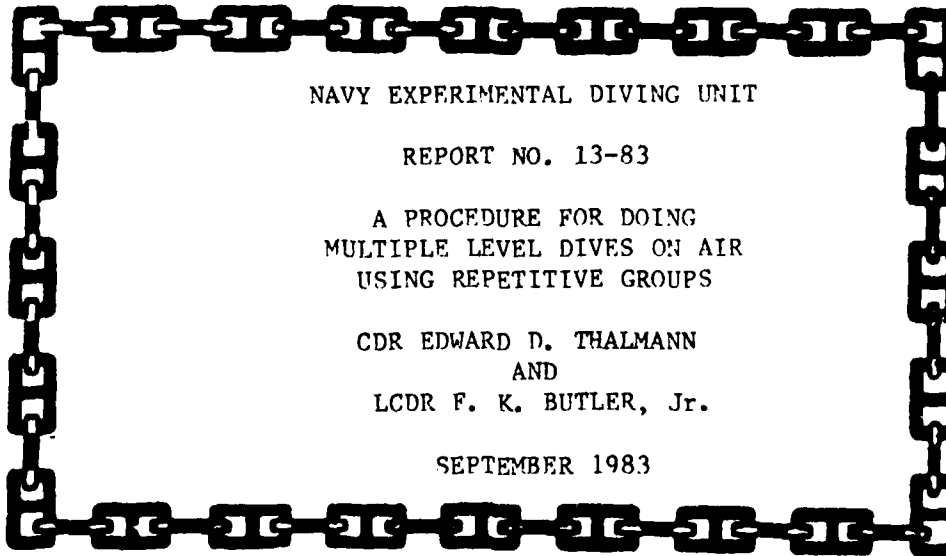




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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 13-83

A PROCEDURE FOR DOING
MULTIPLE LEVEL DIVES ON AIR
USING REPETITIVE GROUPS

CDR EDWARD D. THALMANN
AND
LCDR F. K. BUTLER, Jr.

SEPTEMBER 1983

NAVY EXPERIMENTAL DIVING UNIT



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DEPARTMENT OF THE NAVY
 NAVY EXPERIMENTAL DIVING UNIT
 PANAMA CITY, FLORIDA 32407

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CDR EDWARD D. THALMANN
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SEPTEMBER 1983

Approved for public release; distribution unlimited.

Submitted by:

E. D. Thalmann

E. D. THALMANN
 CDR, MC, USN
 Senior Medical Officer

F. K. Butler Jr.

F. K. BUTLER, Jr.
 LCDR, MC, USNR

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Approved by:

Frank E. Eissing

FRANK E. EISSING
 CDR, USN
 Commanding Officer

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Current Combat Swimmer missions involve multiple depth dives using air where long periods of time are spent at depths 30 FSW and shallower. Current dive procedure requires using the deepest depth for the total dive time unless at least 10 min intervals are taken at 1 ATA in which case repetitive dive procedures may be used. Also, current repetitive dive procedures only addresses times up to 350 min. This report first reviews the origin of the current Air Repetitive Diving Procedures and examines in detail how the		

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No-Decompression Repetitive Group Designations, the Residual Nitrogen Timetable, and the Surface Interval Credit Table were calculated. In addition, several errors and inconsistencies in these tables are pointed out and discussed. Then, a procedure is developed based on using Repetitive Air Diving techniques for doing multiple level dives where no surface interval is taken. Additions and/or changes in current repetitive diving procedure necessary to accomplish this include extension of the Residual Nitrogen Timetable to a depth of 30 FSW and extension of repetitive group designations at 30 FSW from Group L to Group O. This Combat Swimmer Multi-level Dive Procedure (CSMD Procedure) involves dividing the dive up into alternating intervals 30 FSW and shallower and deeper than 30 FSW. For each interval a repetitive group is calculated and used to find a residual nitrogen time for the next interval. The procedure limits are a depth of 120 FSW and total dive time of 12 hours. The procedure is designed as an interim measure until a computer algorithm and Air Underwater Decompression Calculator can be developed.



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A Procedure for Doing Multiple Level Dives on Air
Using Repetitive Groups

On Page 14, Equation (2):

Change the denominator of the fraction in [] to read:

(P_A-33)

This is a transcription and changes none of the calculations or conclusions of the report.

Submitted by:

E. D. THALMANN
CDR, MC, USN
Senior Medical Officer

Approved by:

FRANK E. EISSING
CDR, USN
Commanding Officer

Table of Contents

	<u>Page</u>
Abstract	vii
Forward	viii
PART I	
ORIGIN OF CURRENT AIR REPETITIVE DIVE PROCEDURES.....	1
Introduction.....	2
Repetitive Group Assignments.....	2
Residual Nitrogen Timetable.....	8
Surface Interval Credit Table.....	11
Summary.....	19
PART II	
BASIS FOR THE COMBAT SWIMMER MULTI-LEVEL DIVE (CSMD) PROCEDURE....	21
Introduction.....	22
Basic Premises.....	22
Repetitive Group Designations.....	25
Residual Nitrogen Times.....	25
Unplanned Excursion Decompression Table.....	26
Decompression and Shallow Interval.....	26
Normal Procedure.....	28
Emergency Procedures.....	28
Safety.....	29
Future Considerations.....	29
Conclusions.....	29
References.....	31
APPENDICES	
Appendix A Combat Swimmer Multi-Level Dive (CSMD) Procedure....	32
I The Ground Rules.....	33
II Planning The Dive.....	33
III Unplanned Excursions.....	40
IV Omitted Decompression.....	42
V Executing The Mission.....	43
Appendix A Enclosures.....	44
FIGURES	
Figure 1 Desaturation Curve for 120 min Exponential Halftime Tissue at 1 ATA.....	10
Figure 2 Combat Swimmer Dive Profile.....	23
Figure A-1 Sample Combat Swimmer Dive Profile.....	35

Table of Contents
(Continued)

TABLES

		<u>Page</u>
Table 1	Repetitive Groupings for Dives in NEDU Report 6-57....	4
Table 2	Repetitive Group Letter Designations for No-Decompression Dives (from Table 1).....	4
Table 3	Repetitive Groups for No-Decompression Dives from U.S. Navy Diving Manual.....	5
Table 4	No-Decompression Times for a Given Repetitive Group Designation Computed for the Maximum Tension in Each Group.....	7
Table 5	"Best Fit" to Table 3.....	7
Table 6	Computed Residual Nitrogen Times.....	9
Table 7	Residual Nitrogen Timetable from U.S. Navy Diving Manual.....	9
Table 8	Computed Surface Interval Credit Table.....	12
Table 9	Surface Interval Credit Table from NEDU Report 6-57...	12
Table 10	Time Differences Between Successive Repetitive Group Desaturation Times.....	15
Table 11	Depths and Tissue Tensions Used in Computing Minimum Surface Interval.....	15
Table 12	Surface Interval Credit Table from U.S. Navy Diving Manual.....	16
Table 13	Repetitive Group Designation After Decompression from Air Dives with Indicated Bottom Times.....	24
Table 14	Residual Nitrogen Times for Given Repetitive Groups and Depths.....	24
Table 15	Unplanned Excursion Decompression Schedule.....	27
Table A-1	Residual Nitrogen Times for Given Repetitive Groups and Depth.....	34
Table A-2	Repetitive Group Designation After Decompression From Air Dives with Indicated Bottom Times.....	34
Table A-3	Mission Dive Profile Worksheet.....	37

Table of Contents
(Continued)

		<u>Page</u>
Table A-4	CMSD Decompression Worksheet - Start Page.....	38
Table A-5	CMSD Decompression Worksheet - Continuation Page.....	39
Table A-6	Unplanned Excursion Decompression Procedure.....	41

ABSTRACT

Current Combat Swimmer missions involve multiple depth dives using air where long periods of time are spent at depths 30 FSW and shallower. Current dive procedure requires using the deepest depth for the total dive time unless at least 10 min intervals are taken at 1 ATA in which case repetitive dive procedures may be used. Also, current repetitive dive procedures only addresses times up to 350 min. This report first reviews the origin of the current Air Repetitive Diving Procedures and examines in detail how the No-Decompression Repetitive Group Designations, the Residual Nitrogen Timetable, and the Surface Interval Credit Table were calculated. In addition, several errors and inconsistencies in these tables are pointed out and discussed. Then, a procedure is developed based on using Repetitive Air Diving techniques for doing multiple level dives where no surface interval is taken. Additions and/or changes in current repetitive diving procedure necessary to accomplish this include extension of the Residual Nitrogen Timetable to a depth of 30 FSW and extension of repetitive group designations at 30 FSW from Group L to Group O. This Combat Swimmer Multi-level Dive Procedure (CSMD Procedure) involves dividing the dive up into alternating intervals 30 FSW and shallower and deeper than 30 FSW. For each interval a repetitive group is calculated and used to find a residual nitrogen time for the next interval. The procedure limits are a depth of 120 FSW and total dive time of 12 hours. The procedure is designed as an interim measure until a computer algorithm and Air Underwater Decompression Calculator can be developed.

KEY WORDS

Repetitive Diving
Multiple-Level Dives
Decompression
Combat Swimmer
Air Dives
Residual Nitrogen Times
Surface Interval Credit Table

FORWARD

Air diving as practiced in the U.S. Navy allows repetitive diving where a diver carries over any decompression obligation from a previous dive to the current dive by adding a Residual Nitrogen Time to the current bottom time. These procedures assume that between successive dives the diver leaves the water and spends his surface interval at 1 ATA. A Surface Interval Credit Table tells the diver how much of the decompression obligation from the previous dive he has discharged during the surface interval. This is reflected in the Residual Nitrogen Time decreasing with increasingly longer surface intervals. After a 12 hour surface interval the diver is assumed to have discharged his entire decompression obligation from any previous dives and the Residual Nitrogen time becomes 0.

While these procedures are useful when time is spent at the surface between dives, no procedure currently exists for tailoring decompression profiles when long periods of time are spent at shallow depths (30 FSW or less). A set of decompression tables for closed circuit Underwater Breathing Apparatus (UBA) providing a constant PO_2 of 0.7 ATA in a nitrogen diluent has been developed at NEDU, and the algorithm used to generate these tables published (1). The algorithms are intended to be programmed into a wrist-worn Underwater Decompression Calculator (UDC) which will tailor a decompression schedule exactly suited to a particular dive. This algorithm could be used to compute a set of tables which would allow planning of multiple depth dives where the UDC was unavailable. During these dives, the surface interval would not necessarily have to be at 1 ATA. Unfortunately, no such algorithm exists for air diving and the original repetitive dive tables do not appear to have been computed using a particular set of algorithms for all dives.

Current combat swimmer mission scenarios involve multiple depth air dives where long periods of time are spent at depths shallower than 30 FSW. Current U.S. Navy practice would obligate these swimmers to decompress on a schedule based on the maximum depth ever attained during the dive for the entire time of the dive. This can lead to considerable decompression time, most of which is probably unnecessary. Also, the maximum dive time at 30 FSW in the U.S. Navy Diving Manual (5) is currently 310 min, limiting maximum mission times to just over 6 hours.

In order to meet current operational needs, a method of computing decompression obligation for multiple depth dives is essential. This report describes such a procedure which will be known as the Combat Swimmer Multi-Level Dive (CSMD) Procedures. This report consists of 2 parts and an appendix. Part I discusses the origin of the current repetitive dive procedures for air diving as practiced by the U.S. Navy. A thorough review of these procedures was necessary because the CSMD Procedure is heavily based on them. Part I of this report is technically involved and requires some familiarity with decompression theory. Readers unfamiliar with the decompression theory used to compute the U.S. Navy Standard Air Decompression Tables will have to read the cited references. Part II of this report describes the CSMD Procedure and can be read without thoroughly understanding Part I, although some of the extrapolations and justifications may not be clear. Finally, Appendix A contains a detailed set of instructions for using the CSMD Procedure to actually compute the decompression obligation for a sample profile.

PART I
ORIGIN OF CURRENT AIR REPETITIVE
DIVING PROCEDURES

Introduction

A comprehensive method for computing air decompression schedules as well as repetitive dives was reported by Dwyer in 1955 (2). The decompression model used was not original but based on exponential gas uptake and offgassing in 6 theoretical tissues with halftimes ranging from 5 to 120 min. Decompression was accomplished by defining maximum values for tissue gas tensions at 10 feet of seawater (FSW)* depth increments and requiring a diver to stop at a given depth until all tissues had desaturated to this maximum value after which ascent to the next shallower stop was allowed. Dwyer systematized the calculations in such a way that the procedure could be programmed into a computer. He later gave further details of this method of calculation (3) which was eventually programmed into a UNIVAC Computer at the David Taylor Model Basin in Washington, D.C. A set of Standard Air Tables was tested by des Granges (4) in 1956 and this testing resulted in the Standard Air Tables as currently published in the U.S. Navy Diving Manual (5). The testing involved some 564 man-dives resulting in 26 cases of decompression sickness.

The problem of repetitive diving on air was addressed by des Granges (6) in 1957. While Dwyer (2) had worked out the theoretical aspects of calculating the tables no practical method which could be used operationally had yet been developed. When the initial set of Standard Air Tables were computed on the UNIVAC Computer (4), fourteen other sets of repetitive dive tables were also computed. These tables became known as the UNIVAC Tables. Each set of UNIVAC tables assumed the diver surfaced with each of his six tissues saturated with the maximum amount of gas allowed for surfacing (the so called surfacing tension). The amount of gas remaining in each tissue at the end of the fourteen surface intervals was computed and these tensions assumed as starting tissue tensions for the next dive. Surface intervals of 0, 10, 20, 30, 45, 60, 75, 90, 120, 150, 180, 240, 480 and 720 min were used. The initial tables which were tested by des Granges (4) and which were eventually modified to become the Standard Air Tables, were the 720 min UNIVAC Tables. Since after a 12 hour (720 min) surface interval it was assumed that all tissues had completely desaturated and there was no additional decompression obligation from previous dives these 720 min tables are also the dive tables for the initial dive (Residual Nitrogen Time = 0). It became obvious that the prospect of carrying around fourteen sets of tables would prove cumbersome and a more efficient method of calculating repetitive dives was developed.

Repetitive Group Assignments

The method chosen as described in NEDU Research Report 6-57 (6), was to group all of the standard air tables according to the tissue tension in the 120 min halftime tissue upon surfacing having followed the appropriate decompression profile. When these tissue tensions were computed it was

* Units of feet of seawater (FSW) are used for both depth and gas tensions. When used as a gas tension, 33 FSW = 1 ATA = 760 mmHg.

assumed that all breathing gas was composed of 100% inert gas to simplify the calculation. The grouping of tissue tensions was in 1 FSW increment beginning at 34 FSW up through 64.1 FSW. The value of 64.1 FSW is the surfacing tension of the 120 min tissue. Therefore, if the proper decompression stops are taken, no dive would surface with more than a 64.1 FSW tissue tension in the 120 min tissue.

Table 1 shows how dives were grouped based on depth and bottom time. Table 1 was constructed from data taken from Appendix B of NEDU Report 6-57 (6). The letter designation across the top of the table are the initial repetitive group designations. Each letter designator represented a 2 FSW increment in the 120 min tissue tension and the groups are subdivided into 2 increments of 1 FSW each. Along the top of the table at the line separating each letter group are the maximum 120 min tissue tensions allowed in the group immediately to the left. All tissue tensions were computed to the nearest 0.1 FSW so the minimum tension for the group to the immediate right is 0.1 FSW more than the indicated tension. For example, a tissue tension of 35.9 FSW was the maximum allowed in the 120 min tissue after decompression for a dive to be in group A. A tension of 36.0 FSW would have put the dive in group B. Similarly only dives with 120 min tissue tensions between 36.0 FSW and 37.9 FSW would be considered to be in group B. The only exception to this is group O and Z where the maximum 120 min tissue tensions were defined as 63.7 FSW and 64.1 FSW respectively. It was later decided to subdivide each repetitive group into 2 subdivisions labeled 1 and 2. Along the bottom of Table 1 are the maximum tissue tensions for each initial repetitive group subdivision. (The letter designators along the bottom will be explained shortly). Thus, for a dive to be in group A1 the 120 min tissue tension had to be 34.9 FSW or less. If the 120 min tissue tension was 35.0 FSW to 35.9 FSW, the dive would be in group A2 and if between 36.0 FSW and 36.9 FSW, in group B1 and so on. For group O, subgroup O1 included dives whose surfacing 120 min tissue tension was 62.0 FSW to 62.9 FSW and O2 included dives with 120 min tensions from 63.0 FSW to 63.7 FSW. Group Z included dives with 120 min tissue tensions from 63.8 FSW to 64.1 FSW.

Surfacing tissue tensions after appropriate decompression for all dives in the standard air tables were computed and the appropriate repetitive group assigned to each table. In Table 1 the bottom times for each depth have been placed in the column corresponding to its repetitive group. In some instances (i.e. 35 FSW for 200 min and 35 FSW for 210 min both of which are in group L2) more than one bottom time at a given depth are in the same repetitive group. The heavy line running through the body of the table indicates the division between no-decompression dives and those requiring decompression.

After grouping the dives according to the 120 min tissue tensions the repetitive grouping was changed. Subgroup A1 became group A and all other repetitive groups were shifted 1 FSW to the left. Subgroups A2 and B1 became group B, B2 and C1 became group C and so on. Group Z was now composed of subgroup O2 and the original group Z. The new group designators (which will be called the Final Repetitive Groups) are listed along the bottom of Table 1. At depths 35 FSW and deeper dives were computed in increments of 5 or 10 min. For dives 30 FSW and shallower bottom times were computed such that the 120 min tissue tension saturated to the minimum level in each repetitive subgroup.

TABLE 1
Repetitive Groupings For Dives in NEDU Report 6-57

Bottom Times (Min)

Tension(FSW)	35.9		37.9		39.9		41.9		43.9		45.9		47.9		49.9		51.9		53.9		55.9		57.9		59.9		61.9		63.7		64.1																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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Final Groups	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU	GV	GW	GX	GY	GZ	HA	HB	HC	HD	HE	HF	HG	HH	HI	HJ	HK	HL	HM	HN	HO	HP	HQ	HR	HS	HT	HU	HV	HW	HX	HY	HZ	IA	IB	IC	ID	IE	IF	IG	IH	II	IJ	IK	IL	IM	IN	IO	IP	IQ	IR	IS	IT	IU	IV	IW	IX	IY	IZ	JA	JB	JC	JD	JE	JF	JG	JH	JI	IJ	JK	KL	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	KA	KB	KC	KD	KE	KF	KG	KH	KI	KJ	KL	KM	KN	KO	KP	KQ	KR	KS	KT	KU	KV	KW	KX	KY	KZ	LA	LB	LC	LD	LE	LF	LG	LH	LI	LJ	LK	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	MA	MB	MC	MD	ME	MF	MG	MH	MI	MJ	MK	ML	MN	MO	MP	MQ	MR	MS	MT	MU	MV	MW	MX	MY	MZ	NA	NB	NC	ND	NE	NF	NG	NH	NI	NJ	NK	NL	NO	NP	NQ	NR	NS	NT	NU	NV	NW	NX	NY	NZ	OA	OB	OC	OD	OE	OF	OG	OH	OI	OJ	OK	OL	OM	ON	OO	OP	OQ	OR	OS	OT	OU	OV	OW	OX	OY	OZ	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL	PM	PN	PO	PP	PQ	PR	PS	PT	PU	PV	PW	PX	PY	PZ	QA	QB	QC	QD	QE	QF	QG	QH	QI	QJ	QK	QL	QM	QN	QO	QP	QQ	QR	QS	QT	QU	QV	QW	QX	QY	QZ	RA	RB	RC	RD	RE	RF	RG	RH	RI	RJ	RK	RL	RM	RN	RO	RP	RQ	RR	RS	RT	RU	RV	RW	RX	RY	RZ	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM	SN	SO	SP	SQ	SR	SS	ST	SU	SV	SW	SX	SY	SZ	TA	TB	TC	TD	TE	TF	TG	TH	TI	TJ	TK	TL	TM	TN	TO	TP	TQ	TR	TS	TU	TV	TW	TX	TY	TZ	UA	UB	UC	UD	UE	UF	UG	UH	UI	UJ	UK	UL	UM	UN	UO	UP	UQ	UR	US	UT	UU	UV	UW	UX	UY	UZ	VA	VB	VC	VD	VE	VF	VG	VH	VI	VJ	VK	VL	VM	VN	VO	VP	VQ	VR	VS	VT	VU	VV	VW	VX	VY	VZ	WA	WB	WC	WD	WE	WF	WG	WH	WI	WJ	WK	WL	WM	WN	WO	WP	WQ	WR	WS	WT	WU	WV	WW	WX	WY	WZ	XA	XB	XC	XD	XE	XF	XG	XH	XI	XJ	XK	XL	XM	XN	XO	XP	XQ	XR	XS	XT	XU	XV	XW	XX	XY	XZ	YA	YB	YC	YD	YE	YF	YG	YH	YI	YJ	YK	YL	YM	YN	YO	YP	YQ	YR	YS	YT	YU	YV	YW	YX	YZ	ZA	ZB	ZC	ZD	ZE	ZF	ZG	ZH	ZI	ZJ	ZK	ZL	ZM	ZN	ZO	ZP	ZQ	ZR	ZS	ZT	ZU	ZV	ZW	ZX	ZY	ZZ	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	

TABLE 3

Repetitive Groups for No-Decompression
Dives From U.S. Navy Diving Manual

**NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE
FOR NO-DECOMPRESSION AIR DIVES**

Depth (feet)	No-decom- pression limits (min)	Group Designation														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10		60	120	210	300											
15		35	70	110	160	225	350									
20		25	50	75	100	135	180	240	325							
25		20	35	55	75	100	125	160	195	245	315					
30		15	30	45	60	75	95	120	145	170	205	250	310			
35	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
50	100		10	15	25	30	40	50	60	70	80	90	100			
60	60		10	15	20	25	30	40	50	55	60					
70	50		5	10	15	20	30	35	40	45	50					
80	40		5	10	15	20	25	30	35	40						
90	30		5	10	12	15	20	25	30							
100	25		5	7	10	15	20	22	25							
110	20			5	10	13	15	20								
120	15			5	10	12	15									
130	10			5	8	10										
140	10			5	7	10										
150	5			5												
160	5				5											
170	5				5											
180	5				5											
190	5				5											

Table 2 presents the maximum times in each of the Final Repetitive Groups from Table 1 for no-decompression dives. Table 3 shows the no-decompression repetitive dive tables as currently published. Comparison of Table 2 and Table 3 shows one obvious discrepancy. For depths from 10 to 30 FSW all the times in Table 3 were shifted one group to the left compared to Table 2. The times listed in Table 2 under repetitive group A do not appear in Table 3. Why this discrepancy occurred is unknown. No mention of it is made in NEDU Report 6-57 (6). The most obvious explanation is that this portion of the table was tabulated separately from the rest of the table and before the shift in repetitive groups downward by 1 FSW was made. Since the times for depths 30 FSW and shallower were computed for the minimum tissue tension in each repetitive group, one could interpret these as the maximum tissue tension for the next lower repetitive group. So if one decided that the times required to be in a given repetitive group should reflect the time to reach the maximum tension in each group, one could reconstruct the times in Table 3 for depths down to 30 FSW by shifting the times in Table 2 one group to the left. The most likely reason for the shift was probably an error in transcribing times. The question is not so much why this shift occurred but rather whether it is reasonable.

When NEDU Report 6-57 was published, computer time was expensive and many of the computations were undoubtedly done by hand. At the present time, computers are readily available and one can easily compute the repetitive groups for various bottom times under a variety of assumptions. If Table 2 were being computed today, one would compute the time it would take the 120 min tissue to saturate to the maximum allowable tension in each repetitive group. Table 4 shows the results of this computation using the following formula:

$$(1) \quad T = (120/\text{Ln}2) \cdot \text{Ln} [(P_I - P_{\text{AMB}})/(P_{\text{FINAL}} - P_{\text{AMB}})]$$

where:

P_I = Initial tissue tension = 33 FSW

P_{AMB} = Ambient absolute pressure at depth of interest in FSW

P_{FINAL} = Final tissue tension
(34.9 FSW for group A, 36.9 FSW for Group B, etc.)

T = Time in min to saturate from P_I to P_{FINAL}

Equation 1 is simply the exponential saturation equation for the 120 min tissue:

$$P_{\text{FINAL}} = P_{\text{AMB}} - (P_{\text{AMB}} - P_I) e^{-(\text{Ln}2 \cdot T/120)}$$

solved for T . To be consistent with the definitions in NEDU Report 6-57 (6) all gas is assumed to be 100% nitrogen.

TABLE 4

No-Decompression Times for a Given Repetitive Group Designation
 Computed For the Maximum Tension in Each Group
 (Time rounded down to nearest minute)

Bottom Times (Min)

Depth (FSW)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	36	85	154	270	797										
15	23	52	96	129	186	272	452								
20	17	37	60	87	118	156	205	274	390	917					
25	13	29	46	65	87	111	140	174	217	275	361	540			
30	11	24	37	52	69	87	107	130	157	188	226	275	344	460	987
35	9	20	31	44	57	71	87	104	124	145	170	198	233	276	333
40	8	17	27	38	49	61	73	87	102	119	137	157	180	207	
50	6	14	21	29	38	47	56	66	76	87	99	112			
60	5	11	17	24	31	38	46	53	61	69					
70	4	9	15	20	26	32	38	44	51	57					
80	4	8	13	18	22	27	33	38	43						
90	3	7	11	15	20	24	29	33							
100	3	6	10	14	18	21	25								
110	3	6	9	12	16	19	23								
120	2	5	8	11	14	18									
130	2	5	8	10	13										
140	2	4	7	10	12										
150	2	4	6												
160	2	4	6	8											
170	1	4	6	8											
180	1	3	5	7											
190	1	3	5	7											
Tension (FSW)	34.9	36.9	38.9	40.9	42.9	44.9	46.9	48.9	50.9	52.9	54.9	56.9	58.9	60.9	62.9

TABLE 5

"Best Fit" to Table 3

Bottom Times (Min)

Depth (FSW)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	15	60	120	205(210)	395(300)										
15	10	35	70	105(110)	155(160)	225	345(350)								
20	5	25	45(50)	70(75)	100	135	180	240	325	515(-)					
25	5	20	35	55	75	100	125	155(160)	195	245	315	435(-)			
30	5	15	30	45	60	75	95	120	140(145)	170	205	250	310	395(-)	585(-)
35	5	15	25	35(40)	50	65(60)	80	95(100)	115(120)	135(140)	155(160)	185(190)	215(220)	255(250)	305(310)
40	-5(5)	10(15)	20(25)	30	40	55(50)	65(70)	80	95(100)	110	125(130)	145(150)	165(170)	190(200)	
50	-	10	15	25	30	40	50	60	70	80	90	100			
60	-	5(10)	15	20	25	35(30)	40	45(50)	55	65(60)					
70	-	5	10	15	20	25(30)	35	40	45	50					
80	-	5	10	15	20	25	30	35	40						
90	-	5	9(10)*	14(12)*	15	20	25	30							
100	-	5	8(7)	10	15	20	24(22)*	25							
110	-	-	5	10	14(13)*	15	20								
120	-	-	5	10	13(12)*	15									
130	-	-	5	9(8)*	10										
140	-	-	5	8(7)*	10										
150	-	-	5												
160	-	-	5(-)	7*(5)											
170	-	-	5(-)	7*(5)											
180	-	-	-	5											
190	-	-	-	5											
Tension (FSW)	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62

All times rounded down to nearest 5 min except * which were rounded down to nearest min.

Numbers in parenthesis are Table 3 times where they differ from times in this Table.

All times in Table 4 were rounded down to the nearest minute. One sees that all times (except those in Column A down to 35 FSW) in Table 4 are greater than or equal to times in Table 2. This means that for any bottom time at a given depth, Table 2 will result in the same or higher repetitive group than Table 4. So, Table 2 is on the average more conservative than Table 4. In Table 3, the no-decompression repetitive groupings from the U.S. Navy Diving Manual (5), the repetitive groups for a given bottom time also reflect the same or greater 120 min tissue tension than those from Table 4. However, at 30 FSW and shallower, Table 3 is much less conservative than Table 4 because of the shifting of all times one group to the left as previously mentioned.

If one were looking for a way to compute no-decompression repetitive group times for the best fit to Table 2, the time to reach the minimum 120 min tissue tensions for each of the original repetitive groups provides the closest agreement to Table 2. Thus, for group A find the time to reach 34 FSW, for group B the time to 36 FSW, etc. This has been done in Table 5 with all times rounded down to the next lower 5 minute increment. Deviations from Table 2 are noted, with Table 2 values shown in parenthesis.

In summary, the no-decompression repetitive group assignments 35 FSW and deeper as they appear in the U.S. Navy Diving Manual appear conservative when compared to tables computed according to the definitions outlined in NEDU Report 6-57. An error in assigning repetitive groups for depths 30 FSW and shallower appears to have been made where all times were shifted to the next lower repetitive group. Table 5 provides the best fit to the values currently in the U.S. Navy Diving Manual (Table 3) except for values 30 FSW and shallower, where an apparent shifting of times one group to the left was made.

Residual Nitrogen Timetable

The next table of interest is the Residual Nitrogen Timetable. Basically, this table gives the amount of time it would take the 120 min tissue to saturate from a tension of 1 ATA (33 FSW) to the tension of the various repetitive groups. To compute the times, equation 1 is used with the appropriate value for P_{FINAL} for each repetitive group. To be on the conservative side one would use values for P_{FINAL} which reflected the minimum 120 min tissue tension in the next higher group rather than the maximum for a given group. That is, to compute the Residual Nitrogen Time for group A, compute the time for the 120 min tissue to reach 35 FSW (the minimum tension to be in group B) rather than 34.9 FSW (the maximum tension in group A). This was done and the results are shown in Table 6. These times have all been rounded up to the next minute. If one compares these times to those in Table 4 one sees that the times are very similar, those in Table 6 being equal to or slightly greater. The similarity results from Table 6 and 4 having been computed from the same formula. However, since the times in Table 6 were computed for a P_{FINAL} 0.1 FSW greater than in Table 4 and were rounded up 1 min, they are all slightly longer. Table 7 is the Residual Nitrogen Time

TABLE 6
Computed Residual Nitrogen Times

DEPTH (FSW)	RESIDUAL NITROGEN TIMES (MIN.)															
	Z (64.2)	O (63.0)	N (61.0)	M (59.0)	L (57.0)	K (55.0)	J (53.0)	I (51.0)	H (49.0)	G (47.0)	F (45.0)	E (43.0)	D (41.0)	C (39.0)	B (37.0)	A (35.0)
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15240	279.0	159.0	80.0	39.0
20	0.0	0.0	0.0	0.0	0.0	0.0	15240	399.0	279.0	200.0	159.0	120.0	80.0	62.0	39.0	10.0
30	0.0	15240	469.0	349.0	279.0	229.0	190.0	159.0	132.0	109.0	80.0	70.0	54.0	39.0	25.0	12.0
40	262.0	240.0	208.0	182.0	159.0	130.0	120.0	103.0	80.0	75.0	62.0	50.0	39.0	26.0	10.0	9.0
50	169.0	159.0	142.0	127.0	113.0	100.0	80.0	77.0	67.0	57.0	48.0	39.0	36.0	22.0	10.0	7.0
60	127.0	120.0	109.0	98.0	88.0	79.0	70.0	62.0	54.0	46.0	39.0	32.0	25.0	16.0	12.0	6.0
70	102.0	97.0	88.0	80.0	73.0	65.0	58.0	51.0	45.0	39.0	33.0	27.0	21.0	16.0	10.0	5.0
80	86.0	81.0	75.0	68.0	62.0	56.0	50.0	44.0	39.0	33.0	29.0	23.0	19.0	13.0	9.0	4.0
90	74.0	70.0	65.0	59.0	54.0	49.0	44.0	39.0	34.0	29.0	25.0	20.0	16.0	12.0	9.0	4.0
100	65.0	62.0	57.0	52.0	48.0	43.0	39.0	34.0	30.0	26.0	22.0	18.0	14.0	11.0	7.0	3.0
110	58.0	55.0	51.0	47.0	43.0	39.0	35.0	31.0	27.0	24.0	20.0	17.0	13.0	10.0	6.0	3.0
120	52.0	50.0	46.0	42.0	39.0	35.0	32.0	28.0	25.0	21.0	18.0	15.0	12.0	9.0	6.0	3.0
130	48.0	45.0	42.0	39.0	35.0	32.0	29.0	26.0	23.0	20.0	17.0	14.0	11.0	8.0	5.0	3.0
140	44.0	42.0	39.0	36.0	33.0	30.0	27.0	24.0	21.0	18.0	16.0	13.0	10.0	8.0	5.0	2.0
150	40.0	39.0	36.0	33.0	30.0	27.0	25.0	22.0	20.0	17.0	14.0	12.0	9.0	7.0	5.0	2.0
160	38.0	36.0	33.0	31.0	28.0	26.0	23.0	21.0	18.0	16.0	13.0	11.0	9.0	7.0	4.0	2.0
170	35.0	34.0	31.0	29.0	26.0	24.0	22.0	19.0	17.0	15.0	13.0	10.0	8.0	6.0	4.0	2.0
180	33.0	32.0	29.0	27.0	25.0	23.0	20.0	18.0	16.0	14.0	12.0	10.0	8.0	6.0	4.0	2.0
190	31.0	30.0	28.0	25.0	23.0	21.0	19.0	17.0	15.0	13.0	11.0	9.0	7.0	6.0	4.0	2.0

Numbers in parenthesis are final tissue tensions used to compute times.

TABLE 7
Residual Nitrogen Timetable From U.S. Navy Diving Manual

REPETITIVE DIVE DEPTH	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
40	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
100	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	42	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2
150	40	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	35	34	31	29	26	24	22	19	17	15	13	10	8	6	4	2
180	32	31	29	27	25	22	20	18	16	14	12	10	8	6	4	2
190	31	30	28	26	24	21	19	17	15	13	11	10	8	6	4	2

RESIDUAL NITROGEN TIMES (MINUTES)

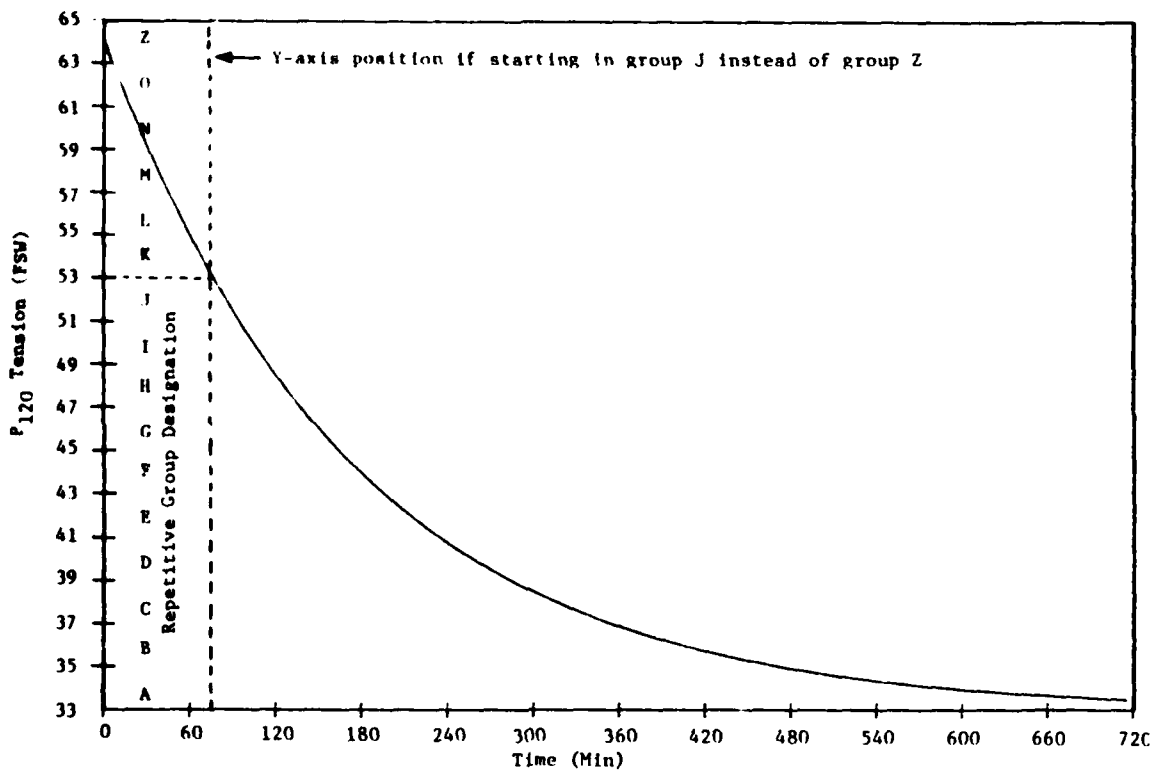


FIGURE 1. DESATURATION CURVE FOR 120 MINUTE EXPONENTIAL HALFTIME TISSUE AT 1 ATA

Table as presented in NEDU Report 6-57 and currently in the U.S. Navy Diving Manual. The first difference between Table 6 and 7 is that Residual Nitrogen Times at depths shallower than 40 FSW do not appear in Table 7. No reason was given for this omission in NEDU Report 6-57. Comparison of times in Table 6 and 7 will show there are only 5 times in Table 6 shorter than in Table 7 (40-group 0 240 min, 1 min shorter; 40-N 208 min, 3 min shorter; 40-M 182 min, 5 min shorter, 40-L 159 min, 2 min shorter; 50-0 159 min, 1 min shorter). All other times in Table 6 are equal to or greater than those in Table 7 with only 10 times being more than 2 min greater. Since the original tables were probably calculated by hand, 1 or 2 min discrepancies between Table 6 and 7 would not be unexpected. Why the vast majority of times in Table 6 are longer but 5 are shorter is a puzzle. When Table 6 was calculated it was done with the object of having all times slightly greater than in Table 7. It appears some computational or rounding errors were made in computing the 5 times under question. In general, Table 6 is a remarkably good fit to Table 7 and overall is more conservative.

Surface Interval Credit Table

The final table needed to determine repetitive dive decompression schedules is a table which gives the diver credit for time spent at 1 ATA. This is basically a 120 min exponential decay curve which gives the amount of time needed for the 120 minute tissue to decrease its tissue tension by 2 FSW, while at an ambient pressure of 1 ATA. This is graphically illustrated in Figure 1. Figure 1 is presented in tabular form in Table 8. Each row in Table 8 represents a shift in the x-axis of Figure 1 such that time 0 begins at the top of the repetitive group whose letter appears in the left most column. Then each time entry in that row is the amount of time it takes for the tissue tension to fall an additional 2 FSW (except for group Z where the tension falls only 1.4 FSW). This time represents the time at which the tissue tension enters the next lower repetitive group. For example, if the values in row labeled Z were plotted, Figure 1 would result. The first time in row Z is 7 min (note times are hrs.min) and this represents the amount of time it took for the tissue tension to fall from 64.1 FSW (the top of group Z) to 62.9 FSW (the bottom of group Z). The next entry is 19 min which is the amount of time it takes to fall the next 2 FSW to 60.9 FSW, the largest tension in group 0. If one started a group J, then one would enter Table 1 in row "J". The first entry in this row is 18 min which is the amount of time a tissue starting at the top of group J would take to fall to the bottom. The numbers in this row can be gotten from Figure 1 by sliding the y-axis to the right until the y-axis intersects the curve at a value of 53 FSW (dotted line). One thing about Table 1 soon becomes obvious, the difference between any two times in adjacent columns represents the time for the 120 min tissue to decay 2 FSW from the same initial to the same final value and should all be the same. For instance, the difference between all times in columns H and G represent the time for the 120 min tissue tension to fall from 46.9 FSW to 44.9 FSW and this takes 17 min.

Table 8 was constructed assuming that the tissues start out with the highest tension of one repetitive group and falls to the highest in the next. One problem is to choose where to consider a tissue completely desaturated.

TABLE 8
Computed Surface Interval Credit Table

SURFACE INTERVAL CREDIT TABLE
(MPS. III)

START	FINISH															
	Z (62.9)	O (60.9)	N (58.9)	M (56.9)	L (54.9)	K (52.9)	J (50.9)	I (48.9)	H (46.9)	G (44.9)	F (42.9)	E (40.9)	D (38.9)	C (36.9)	B (34.9)	A (33.1)
AK(34.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
BC(36.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	10.34
CD(38.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	3.16	11.46
DE(40.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.51	2.02	4.07	12.36
EF(42.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.39	1.30	2.41	4.46	13.16
FG(44.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.32	1.11	2.01	3.13	5.18	13.47
GH(46.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.27	.59	1.38	2.28	3.40	5.45	14.14
HI(48.9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.23	.50	1.22	2.01	2.52	4.03	6.08	14.38	
IJ(50.9)	0.00	0.00	0.00	0.00	0.00	0.00	.21	.44	1.11	1.47	2.22	3.12	4.24	6.28	14.58	
JK(52.9)	0.00	0.00	0.00	0.00	0.00	.18	.39	1.02	1.29	2.01	2.40	3.30	4.42	6.47	15.16	
KL(54.9)	0.00	0.00	0.00	0.00	.17	.35	.55	1.19	1.46	2.17	2.57	3.47	4.59	7.03	15.33	
LM(56.9)	0.00	0.00	0.00	.15	.32	.50	1.11	1.34	2.01	2.33	3.12	4.02	5.14	7.18	15.49	
MN(58.9)	0.00	0.00	.14	.29	.46	1.04	1.24	1.48	2.15	2.46	3.26	4.16	5.28	7.32	16.02	
NO(60.9)	0.00	.13	.27	.42	.58	1.17	1.37	2.01	2.28	2.59	3.38	4.29	5.41	7.45	16.19	
OP(62.9)	0.00	.12	.25	.39	.54	1.10	1.29	1.49	2.13	2.40	3.11	3.50	4.41	5.53	7.57	16.27
ZQ(64.1)	.07	.19	.32	.46	1.01	1.17	1.36	1.56	2.19	2.46	3.18	3.57	4.48	5.59	8.04	16.34

Numbers in parenthesis represent starting and finishing tensions in FSW.

TABLE 9

Surface Interval Credit Table From NEDU Report 6-57

REPETITIVE GROUP DESIGNATION AT THE END OF THE SURFACE INTERVAL

	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
Z	0-10	0-22	0-34	0-46	1-02	1-18	1-36	1-55	2-17	2-42	3-10	3-45	4-29	5-27	6-56	10-05
O	0-10	0-23	0-35	0-51	1-07	1-24	1-43	2-04	2-29	2-59	3-33	4-17	5-16	6-44	9-54	
N		0-10	0-24	0-39	0-54	1-11	1-30	1-53	2-19	2-47	3-22	4-04	5-03	6-32	9-43	
M			0-10	0-25	0-42	0-59	1-18	1-39	2-05	2-34	3-08	3-52	4-49	6-18	9-28	
L				0-10	0-26	0-45	1-04	1-25	1-49	2-19	2-53	3-36	4-35	6-02	9-12	
K					0-10	0-28	0-49	1-11	1-35	2-03	2-38	3-21	4-19	5-48	8-59	
J						0-10	0-31	0-54	1-19	1-47	2-20	3-04	4-02	5-40	8-49	
I							0-10	0-33	0-59	1-29	2-02	2-44	3-43	5-12	8-21	
H								0-10	0-36	1-06	1-41	2-23	3-20	4-49	7-59	
G									0-10	0-40	1-15	1-59	2-58	4-25	7-35	
F										0-10	0-45	1-29	2-28	3-57	7-05	
E											0-10	0-54	1-57	3-22*	6-30*	
D												0-10	1-09	2-38	5-48	
C													0-10	1-39	2-49*	
B														0-10	2-10*	
A															0-10	

*Times which are internally inconsistent with other times in table (see text)

Original Time	"Correct" Time
2-10	3-20
2-49	4-49
3-22	3-24
6-32	6-34
8-40	8-50

USE THE STANDARD AIR DECOMPRESSION TABLE AS IS AFTER SURFACE INTERVAL OF TWELVE (12) HOURS OR MORE

REPETITIVE GROUP DESIGNATION FROM THE PREVIOUS DIVE

If one used the 100% inert gas tension at 1 ATA (33 FSW) the time required would be infinitely long. Table 8 uses a value of 33.1 FSW and one can see from the last column in the table it would take over 16 1/2 hours to achieve this value if one had started out in group Z.

Table 9 is the Surface Credit Interval Table as originally published in NEDU Report 6-57 (6) and currently in use. Compare the row labeled Z in Table 8 with that of Table 9. There is very good agreement up to Column E, and differences could be attributed to roundoff errors in Table 9 which was probably computed by hand. Even the 19 and 32 min difference in D and C are reasonable considering the long surface intervals required to reach these groups but the 68 min difference in row B is not. The differences in the last column are due to differences in defining complete desaturation. As previously mentioned, Table 8 uses a value of 33.1 FSW as the 120 min tissue tension for complete desaturation. Table 9 used a value of 33.9 FSW and the desaturation time was defined as 12 hours. If one compares all the times in Table 8 and 9 many discrepancies appear, the largest of which are in rows B and A. Ferreting out the reasons for these discrepancies is not easy because NEDU Report 6-57 gives no mention of exactly how Table 9 was computed. In sorting out these discrepancies one can first find several internal discrepancies in Table 9. As previously mentioned, the difference between any two repetitive group columns' times should be the same for all rows. If one subtracts the times in adjacent columns of Table 9, most of the differences between adjacent columns time vary by only 1 to 2 min. There are 4 differences which fall outside of this variation. In row E of Table 9, the difference between the times in columns C and B is 1 hr 25 min, all other differences between times in these two columns are 1 hr 27 min to 1 hr 29 min. The differences in times between row B and A are all 3 hr 09 min to 3 hr 11 min except for three: in row J the difference is 3 hrs, in row C the difference is 1 hr 10 min, and in row B the difference is 2 hr 10 min. Thus, to make Table 9 internally consistent, the time in row J column A should be increased from 8 hrs 40 min to 8 hrs 50 min; the time in row C column A should be increased from 2 hr 49 min to 4 hr 49 min and the time in row B column A should be increased from 2 hr 10 min to 3 hr 20 min. In addition, the times in row E column B and A should be increased by 2 min. These discrepancies are indicated in Table 9 with an asterisk. Even if these inconsistencies are corrected, complete reconciliation of the differences between Tables 8 and 9 cannot be achieved. Table 10 shows the differences between times in successive columns from Table 8 and 9 (inconsistencies in Table 9 having first been corrected). Agreement is very good up to the differences in values between columns G and E. At that point, the differences between the values from Tables 8 and 9 become quite large. The large discrepancies between the A-B and B-C differences of Tables 8 and 9 can only be accounted for by some sort of systematic error in computing or transcribing Table 9.

The question is how was Table 9 arrived at. Not having ready access to a computer one would assume the times for row Z were computed, the differences between times of adjacent columns computed and these differences used to get the times in successive rows. Then, once initial starting times for each row were determined, the differences would be added to the time in one column to get the time in the next column to the right. In Table 9 the first time in each row was defined as 10 min (the reason for this will be discussed later)

and the computed differences between successive columns (Table 10) added to the time of the previous column. Except for the 4 obvious errors noted previously, Table 9 can be derived this way with variations not exceeding 2 min. If one now compares times in Tables 8 and 9 one notes times in Table 8 generally are longer except for the Z row. The reason is that in Table 8 the minimum 10 min surface interval was not used in the table, rather the first non-zero entry in each row is the time it takes the tissue to desaturate to the bottom of the designated repetitive group. It takes 7 min for a tissue starting at the top of group Z to desaturate to the top of the next lower group at which time it would be considered in group 0. The only initial time less than 10 min is in row Z, all the others are greater. All successive entries in a particular row are for the most part greater than or less than the corresponding entry in Table 8 by the difference between the initial time in the row and 10 min. The initial value in row Z of Table 8 is 7 min which is 3 min shorter than 10 min and all succeeding entries are 3 min shorter than those in Table 9. In row 0, the first entry is 2 min longer so all successive times are 2 min longer (or so) than those in Table 9. This applies up to the last 5 columns where larger differences occur because of errors in computing Table 9 as previously described.

When the Surface Interval Credit Table was constructed, the authors realized that a minimum surface interval at 1 ATA would be necessary for the procedure to work. The reason is that by keeping track of only the 120 min tissue tension one cannot always be assured that the tissue tensions in the 5 slower tissues will always be correctly estimated at all depths for repetitive dives. The entire repetitive dive procedure is based on breaking the actual dive profile into a series of equivalent single depth dives all starting at 1 ATA. The initial dive of course does start at 1 ATA and after a period of time at a given depth the tissues will all have saturated to a particular gas tension. If instantaneous descent and ascent are assumed as they were in NEDU Report 6-57 (6), then the tensions in all the tissues are related and given the tension in the 120 min tissue all other tensions can be computed from the formula:

$$(2) \quad P_{T_{1/2}} = P_A + (33 - P_A) \left[\frac{(P_A - P_{120})}{(33 - P_A)} \right]^{(120/T_{1/2})}$$

where:

- $P_{T_{1/2}}$ = Tension in tissue with half-time $T_{1/2}$
- P_A = Ambient pressure
- 33 = Starting Tissue Tension at 1 ATA
- P_{120} = Given Tissue Tension in the 120 min Tissue
- $T_{1/2}$ = half-time of Tissue of interest
- 120 = half-time of the 120 min Tissue

TABLE 10

Time Differences Between Successive Repetitive Group
Desaturation Times (Min)

Repetitive Groups (Start → Finish)

	Z + O	O + N	N + M	M + L	L + K	K + J	J + I	I + H	H + G	G + F	F + E	E + D	D + C	C + B	B + A (33.9)
Table 8	12	13	14	15	16	19	20	25	27	32	39	51	71	125	129*
Table 7															
max	12	13	14	15	17	19	21	23	26	30	35	44	59	89	191
min	12	12	13	14	16	18	19	21	25	28	32	42	57	87#	189#
Δ															
max	0	0	0	0	+1	0	+1	+2	-1	-2	-4	-7	-12	-36	+62
min		-1	-1	-1	-1	-1	-1	-2	-2	-4	-6	-9	-14	-38	+60

* Times in Column A of Table 8 computed based on a final tension of 33.1 FSW. This time was computed based on a final tension of 33.9 FSW which was the value used in Table 7.

Some time differences in Table 7 are lower than these because of internal inconsistencies in Table 7. These times represent the lowest differences between adjacent columns after these inconsistencies have been corrected.

TABLE 11

Depths and Tissue Tensions Used In
Computing Minimum Surface Interval

Tissue Halftime (Min)	5	10	20	40	80	120
Maximum Surfacing Tension (FSW)	130.7	112.9	92.4	74.2	66.3	64.1
P ₁₂₀ Control Tension (FSW)	44	47	50	52	64	---
Schedule (FSW/Min)	60/110	150/15	340/10	210/15	50/140	---
Calculated Minimum Control Tension (FSW)	125.4	105.1	84.9	68.1	66.1	---
Time (Min) Required to Desaturate From Surfacing Tension to Minimum Control Tension at 1 ATA.	0.40	1.48	3.90	9.25	0.70	---

In equation 2, once an ambient pressure and 120 min tissue tension are specified, the tension in any other halftime tissue can be calculated by substituting the appropriate value for the tissue halftime as $T_{1/2}$. Since a given repetitive group specifies the 120 min tissue tension only, the values of all other tissue tensions for a dive in a particular repetitive group will be depth dependent. For a given value of P_{120} , as P_A increases, the calculated value of $P_{T_{1/2}}$ will increase.

After leaving 1 ATA and descending to some depth for a period of time, the 6 tissues will all have reached certain tensions all interrelated by equation 2. Now, suppose a repetitive dive is done where the surface interval is 0 min. Since ascents and descents are assumed instantaneous, this simply corresponds to a depth change. Since the repetitive dive procedure keeps track of only the 120 min tissue tension, all other tissue tensions must be estimated from this value. That is, using only the value of P_{120} all tissue tensions which existed at the initial depth (D_1) must be approximated at the instant after ascent or descent to D_2 . Since ascent or descent is instantaneous, all tissue tensions the instant of arrival at D_2 will actually be the same as those present the instant before leaving D_1 . If D_2 is deeper than D_1 , and equation 2 is used to predict all other tissue tensions given only a value for P_{120} and P_A , all other tissue tensions will be computed to a higher value than those which actually existed upon leaving D_1 . Thus, the residual nitrogen time at D_2 computed from the P_{120} at the end of the stay at D_1 will simulate a dive from the surface to D_2 for a time where the tension in the 120 min tissue will be the same as it was at D_1 but all other tissue tensions will be greater. Thus, the decompression obligation for this simulated dive will be equal to or greater than that actually required by the actual tensions which exist at the completion of the stay at D_1 . As an example, Table 7 gives the residual nitrogen time for Repetitive Group H at 60 FSW as 52 min which is well within no-decompression limits. At 120 FSW, however, the residual nitrogen time for repetitive Group H is 25 min. A 120 FSW for 25 min decompression schedule requires a 6 min stop at 10 FSW (5). At 190 FSW, a Group H would predict a 15 min residual nitrogen time and a 190 FSW for 15 min schedule requires 11 minutes of decompression stops. What this means is that if the repetitive dive is to a deeper depth than the initial dive, the repetitive dive procedure can be used to compute a residual nitrogen time at the deeper depth even if no surface interval is taken. The resulting residual nitrogen time will be conservative and the decompression obligation resulting from adding this residual nitrogen time to the actual bottom time at the new depth will be the same or longer than if the decompression model were used to compute an exact profile taking the depth change into account.

If D_2 is less than D_1 , using the repetitive dive procedure to find a residual nitrogen time from D_1 to add to the bottom time at D_2 will result in an equivalent time at D_2 which will predict lower tissue tensions for all tissues faster than the 120 min tissue. Thus, the decompression obligation will be shorter and the procedure may eliminate decompression stops. For example, a dive to 190 FSW for 10 min would put the diver in repetitive group G and require 7 min of decompression. At 60 FSW, the residual nitrogen time

for group G is 44 min so if one ascended from 190 to 60 FSW and stayed at 60 FSW for 1 min, the repetitive dive procedure (using a 0 min surface interval) would have him decompress on a 60 FSW for 45 min schedule which is a no-decompression dive, whereas a 190 FSW for 10 min schedule requires a 1 min stop at 20 FSW and 3 min at 10 FSW.

In order to circumvent this difficulty, it was realized that a certain minimum time would have to be spent at 1 ATA to allow sufficient tissue desaturation so that required decompression time would not be missed when the repetitive dive depth was shallower than the initial dive depth. By requiring ascent to 1 ATA, the first thing that happens is that a maximum value is put on all tissue tensions. This results from the decompression model which requires that all tissue tensions be at or below their surfacing tissue tension before leaving the 10 FSW stop for the surface. A tissue cannot "control" any stop unless it saturates to a tension greater than its surfacing tension and so as long as the dive is to a depth less than its surfacing tension, it cannot control any decompression stop. In NEDU Report 6-57 (6) the surfacing values of all tissue tensions for all air dives were computed. These dives were then grouped by the 120 min tissue tension into the various repetitive groups. One can peruse these groupings to find the lowest repetitive group for which a given tissue just surfaces at its surfacing tension (e.g. it controlled the 10 FSW stop). This would give the smallest value of P_{120} for which the tissue would control a stop. As P_{120} increased, longer tissues would control stops and the actual surfacing tension of the shorter tissue in question would actually decrease. At lower values of P_{120} , the tissue would not saturate to a level sufficient to ever control a stop. Now once these "minimum P_{120} control tensions" have been established, one can calculate the tension to which the tissue in question would saturate using equation 2 with P_A exactly equal to the surfacing tension of the tissue and P_{120} equal to the "minimum P_{120} control tension". This will be called the "minimum control tension". For repetitive dives shallower than P_A , the tissue can never saturate enough to control a stop. So, if sufficient time were spent at 1 ATA for the tissue in question to desaturate from its maximum surfacing tension to its minimum control tension, there would never be a repetitive dive where decompression obligation would be less than required if the decompression model were used to compute the exact decompression profile. Although dives to shallower depths would have the tissue tensions underestimated, it wouldn't matter because the tissue in question could never saturate to a level where it would control a stop. The calculation of the minimum surface interval is summarized in Table 11. The surfacing tensions were not explicitly given in NEDU Report 6-57 and had to be estimated from values given in Appendix F of NEDU Report 5-57 (4). In Table 11, the " P_{120} Control Tension" is the minimum tension in the 120 min tissue where the maximum tension in the halftime tissue occurs as determined from Appendix B of NEDU Report 6-57 (6). The "Schedule" line shows on which dive schedule this maximum tension occurred. The Calculated Minimum Control Tensions are the calculated tissue tensions using equation 2 for a P_A exactly equal to the Maximum Surfacing Tension given the value of P_{120} in the second row of Table 11. Finally, the time for the tissue to desaturate from its maximum tension to the Calculated Minimum Control Tension is given. The longest time is for the 40 min tissue and a 10 min surface interval would be sufficient for all tissues to decay to their Calculated Minimum Control Tension.

Having decided a minimum of 10 min was required at 1 ATA to ensure the repetitive dive procedure would be theoretically valid under all circumstances, Table 9 was constructed as previously described. Overall, Table 9, which is the one eventually published, is less conservative than Table 8 which was computed using the rules set down in NEDU Report 6-57 (6). In addition, there are several rather large errors in Table 9 which seem to have been made during transcription as previously discussed.

Overall, it would appear that a sufficient number of errors were made in Table 9 to make it unsafe. However, the instructions for using Table 9 reinterpreted the time values so as to negate the effect of almost all the errors. As originally computed, the times in both Tables 8 and 9 represent the time at which the tissue enters the next lower repetitive group. When the instructions for Table 9 were written, these times were redefined as the minimum surface interval necessary to enter the repetitive group in that column. As an example, suppose one surfaced in group J. Using the definitions used when Table 9 was originally computed, if one started out in group J, one would have had a sufficient surface interval after 1 hr and 19 min to leave group G and enter group F. However, the final instructions say that one must have a surface interval of at least 1 hr 19 min to enter group G and cannot enter group F until a surface interval of 1 hr 47 min has been taken. This is made plain by looking at the table as currently published in the U.S. Navy Diving Manual. This is reproduced in Table 12. In this table, the surface interval must fall between the two times shown for the new repetitive group to be in the group indicated by the designators along the bottom of the table. This would correspond to shifting the group designators in the column heading of Table 8 one to the left.

The instructions for Table 12 as written will generally produce a higher repetitive group for a given surface interval using Table 12 than if one uses Table 8. Thus, Table 12 is more conservative than Table 8 with a few exceptions. These exceptions are the result of the large errors made in the repetitive group B column as previously noted in discussing Table 9 and are noted in Table 12 with a "#".

Summary

Repetitive air diving, as currently practiced in the U.S. Navy, is based on grouping dives according to the nitrogen tension in the 120 min halftime tissue at the surface after taking all decompression stops. These groupings are given letter designators called repetitive groups. The Surface Interval Credit Table (Table 9) was originally published to determine how much a repetitive group would decrease during a surface interval. Table 9 was eventually upgraded to Table 12 which is what appears in the current edition of the U.S. Navy Diving Manual (5). The Residual Nitrogen Timetable (Table 7) is used to find the residual nitrogen time for a given repetitive group and depth. Tables 7 and 9 could not be exactly reproduced by a computer algorithm using the rules and concepts set down in NEDU Report 6-57 (6). Table 6 and Table 8 are two attempts to reproduce Table 7 and Table 9 respectively. There

not only appears to have been some transcribing errors in Table 9 but the complete desaturation tension of 33.9 FSW leads to shorter complete desaturation time than in Table 8 which uses a tension of 33.1 FSW. Also, a change in definition of times in Table 9 would require shifting all times in Table 8 one column to the left to make it conform to the same rules as finally written for Table 9.

Table 3 was constructed to provide repetitive group designations for no-decompression dives. Table 4 was the attempt to reproduce it. The agreement between Table 4 and 3 is not good especially at 30 FSW and shallower because of an apparent shift of all times one column to the left in constructing Table 3. However, the times in Table 3 are more conservative than Table 4 except for depths 30 FSW and shallower.

The repetitive dive procedure using Tables 3, 7 and 9 was tested on 61 repetitive dive combinations by des Granges (6). During testing, 122 man-dives were done resulting in 3 cases of decompression sickness.

PART II

BASIS FOR THE COMBAT SWIMMER
MULTI-LEVEL DIVE (CSMD) PROCEDURE

Introduction

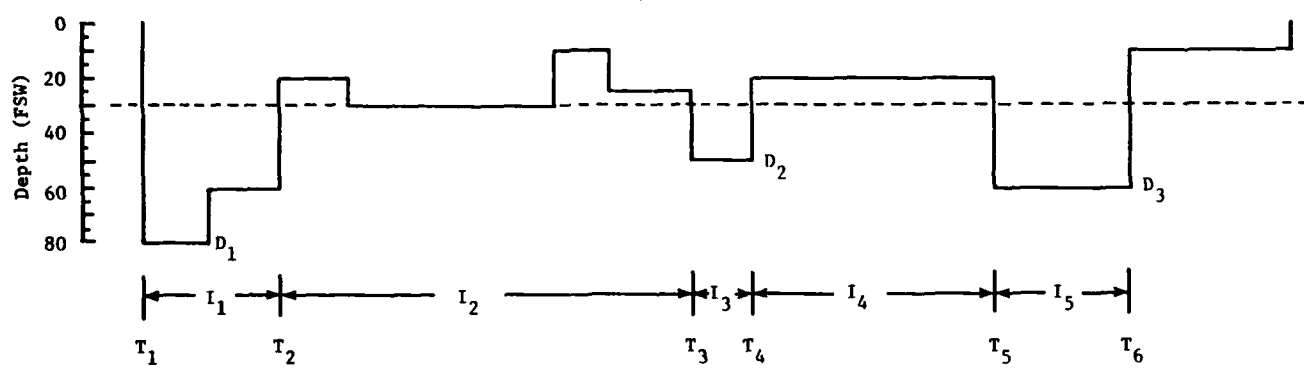
Current combat swimmer mission scenarios involve long transits at 30 FSW or shallower with deeper excursions interspersed throughout the profile. If no surface interval at 1 ATA is taken, current rules would obligate decompression at the end of the mission to the deepest depth ever attained for the total mission time. This is obviously restrictive. In addition, there are currently no residual nitrogen times for depths shallower than 40 FSW and the maximum bottom time at 30 FSW for which a repetitive group is available is 310 min.

The approach used to develop a procedure which would be less restrictive was to divide the dive profile up into segments; those deeper than 30 FSW and those 30 FSW or shallower. For segments deeper than 30 FSW, decompression obligation is computed for the deepest depth ever attained during that segment for the entire time deeper than 30 FSW. For segments shallower than 30 FSW, the decompression obligation is computed assuming the diver is always at 30 FSW for the entire segment. Note that this approach requires alternating profile segments deeper than 30 FSW with segments 30 FSW or shallower. Figure 2 shows a typical dive profile divided up into alternating segments above and below 30 FSW. Each segment below 30 FSW is represented by a dive of a single depth for the entire segment. In the CSMD Procedure, repetitive dive procedures currently in use are used to carry the decompression obligation incurred in one segment of the dive forward to the next segment, and a residual nitrogen time is added to each succeeding segment time interval based on this repetitive group.

Basic Premises

Because transits are 30 FSW and shallower, it was desirable to always allow divers to ascend directly to 30 FSW without taking any decompression stops. This, along with other considerations, resulted in a maximum depth of 120 FSW being chosen. Next, it was desirable to extend the total dive time out to 12 hours. The absolute pressure at 30 FSW is a tension of 63 FSW which would just put the diver at the very minimum tension in group Z if he were saturated at 30 FSW. This was felt too restrictive and since some time will be spent shallower than 30 FSW the maximum tension which could be attained at 30 FSW was defined as being at the top of repetitive group 0. Decompression dives are allowed at any time during the dive but excursions cannot be planned which would put the diver in repetitive group Z except for the very last excursion. This is to prevent the possible acquisition of stops deeper than 30 FSW during the mission. After the last excursion, stops deeper than 30 FSW have little impact upon the mission. No surface interval is required and no reduction in repetitive group is allowed even if a considerable amount of time is spent very shallow. Finally, required decompression stops at 10 FSW are allowed to be taken at a depth between 10 and 20 FSW to prevent having to venture close to the surface and having to contend with wave action during decompression.

Dive profile shows how dive is broken up into alternating intervals
30 FSW and shallower and deeper than 30 FSW



Interval	Depth	Time
I ₁	D ₁	T ₂ -T ₁
I ₂	≤30 FSW	T ₃ -T ₂
I ₃	D ₂	T ₄ -T ₃
I ₄	≤30 FSW	T ₅ -T ₄
I ₅	D ₃	T ₆ -T ₅

FIGURE 2. COMBAT SWIMMER DIVE PROFILE

TABLE 13

Repetitive Group Designation
After Decompression From Air
Dives with Indicated Bottom Times

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Z
30 FSW and Shallower	5	15	30	45	60	75	95	120	145	170	205	250	310	395	-	
40	5	15	25	30	40	50	70	80	100	110	130	150	170	200	250	300
50	-	10	15	25	30	40	50	60	70	80	90	100	120	160	180	220
60	-	10	15	20	25	30	40	50	55	60	70	80	100	120	140	160
70	-	5	10	15	20	30	35	40	45	50	60	70	80	90	110	140
80	-	5	10	15	20	25	30	35	40	-	50	60	70	80	100	120
90	-	5	10	12	15	20	25	30	-	40	-	50	60	70	90	100
100	-	5	7	10	15	20	22	25	30	-	40	50	-	60	70	90
110	-	-	5	10	13	15	20	25	-	30	-	40	50	60	70	80
120	-	-	5	10	12	15	-	20	25	30	-	40	-	50	60	80
130	-	-	5	8	10	15	-	20	-	25	-	-	30	40	50	60
140	-	-	5	7	10	-	15	-	20	25	30	-	-	40	50	60

No Decompression | Decompression

Note: Decompression repetitive groups assume all required stops have been taken.

TABLE 14

RESIDUAL NITROGEN TIMES FOR GIVEN REPETITIVE GROUPS AND DEPTHS

Repetitive Dive Depth	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
30	-	469	349	279	229	190	159	132	109	88	71	54	39	25	12	
40	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	73	70	64	58	53	47	43	38	32	29	24	20	16	11	7	3
100	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3

There are three new tables required for the CSMD Procedure; Repetitive Group Designation After Decompression From Air Dives (Table 13), a Residual Nitrogen Timetable (Table 14), and, finally, an Unplanned Excursion Decompression Table (Table 15). In addition, a set of Emergency Procedures is required to handle unforeseen circumstances.

Repetitive Group Designations

Table 13 is used to find the appropriate repetitive group for a given bottom time and depth. This table was constructed from Table 3 with the addition of bottom times for decompression dives. The repetitive group designations for the decompression dives were taken from the Standard Air Tables and assume that all required decompression stops have been taken. As mentioned in the first section of this report, it appeared that all bottom times for depths 30 FSW and shallower in Table 3 were shifted one repetitive group to the left. To be conservative, the bottom times for the 30 FSW and shallower row of Table 13 were taken directly from Table 5 and times in repetitive groups B through M will be shifted one to the right when compared to Table 3. Three new times had to be added to Table 13 which do not appear in Table 3; 5 min in the group A column, 395 for group N and an infinite time for group O. Note that in Table 5 a time of 585 min is in the group O column. Remember Table 5 was a "best fit" Table and the group O time computed to a P_{120} of 62 FSW. As previously mentioned, group O is defined as the highest group which can be reached by an tissue at 30 FSW which is a tension of 63 FSW. Therefore, it will take an infinite time to leave group O. Thus, the infinite time in column O in Table 13 was defined and not a result of the same algorithm used to compute the other times in the 30 FSW row.

To use Table 13, one goes to the exact or next greater depth and bottom time. Where no entry appears in a particular column for a repetitive group, one goes to the next higher repetitive group.

Residual Nitrogen Times

Table 14 is the same as Table 7, the Residual Nitrogen Timetable which appears in the U.S. Navy Diving Manual (5), with the addition of residual nitrogen times for 30 FSW and shallower. As already mentioned, Table 6 is the best fit which can be generated to Table 7 and the 30 FSW residual nitrogen times were taken from this Table 6. In Table 6, the 15240 entries signify an infinite time. The residual nitrogen times in Table 14 are felt to be conservative compared to the repetitive group assignments in Table 13. For example, a 250 min dive to 30 FSW will put the diver in group L according to Table 13, but the residual nitrogen time for group L in Table 14 is 20 min longer.

Unplanned Excursion Decompression Table

The final table needed for the CSMD Procedure is Table 15. During transits, unplanned excursions below 30 FSW may occur. Since the diver may not know what his decompression obligation is, a worst-case set of decompression profiles had to be constructed. It was assumed that the diver was saturated at 30 FSW, and therefore in group 0, and the excursions to the indicated depths would be limited to 20 min. Twenty minutes was added to the group 0 residual nitrogen times at the indicated depths and the decompression profiles taken from the Standard Air Tables. These schedules will keep the diver in repetitive group 0 except for the 100 FSW schedule. The residual nitrogen time for group 0 at 100 FSW is 62 min giving an equivalent dive time of 82 min for a 20 min excursion. A 100 FSW for 90 min schedule will put the diver in repetitive group Z. This means that only a single unplanned excursion to 100 FSW may be made. If a second unplanned excursion is made to any depth after an unplanned excursion was made to 100 FSW or deeper (no matter what the shallow interval) the divers are considered to have omitted decompression (see Emergency Procedures below).

Decompression and Shallow Interval

In the CSMD Procedure, decompression dives are allowed at any time. By limiting the maximum depth of the dive to 120 FSW, the first decompression stop will never be deeper than 30 FSW. Thirty and 20 FSW stops are taken at the appropriate depth but the 10 FSW stop can be taken at any depth between 20 and 10 FSW. While the decompression model used to compute the Standard Air Tables predicts a decreased rate of offgassing with increasing depth, there is experimental evidence to show that on air the rate of inert gas elimination actually increases with depth down to about 50 FSW (7). Also, in testing a series of fixed PO₂ SCUBA tables at NEDU, a series of man dives was done where the 10 and 20 FSW stop times were combined and the combined stop taken at 20 FSW. This procedure proved safe. Therefore, allowing the 10 FSW stop to be taken as deep as 20 FSW should, if anything, improve offgassing.

As mentioned in the first section of this report, a minimum 10 min surface interval was mandatory in order to theoretically ensure the repetitive dive procedure would work. In the CSMD Procedure, a surface interval is not essential but a "shallow interval" at a depth of 20 FSW or less must be taken between dive segments. The length of this "shallow interval" was computed by finding the tension at 1 ATA after 10 min of desaturation from each of the maximum surfacing tensions for each tissue and computing the time at 20 FSW required for desaturation to the same tension. The longest desaturation time was for the 120 min tissue and was approximately 30 min. Therefore, it is required to spend a minimum of 30 min at 20 FSW or shallower after all required decompression has taken place.

TABLE 15

Unplanned Excursion Decompression Schedule

(Stop Times in Min)

Excursion Depth (FSW)	STOPS (FSW)		
	30	20	10
40			15
60			39
80		11	46
100	3	23	57
120	9	23	55

Normal Procedure

Using the Standard Air Tables in conjunction with Tables 13, 14 and 15, one can now plan any dive. The detailed procedure is given in Appendix A. In essence, the dive is divided into intervals which begin and end when a depth of 30 FSW is reached. The depth and bottom time of one interval is used to get the appropriate repetitive group from Table 13 and using this repetitive group a residual nitrogen time for the depth of the following interval is obtained from Table 14. This residual nitrogen time is added to the actual time spent in that dive interval to get an equivalent bottom time. This equivalent bottom time is used to select the appropriate decompression schedule and the new repetitive group is selected from Table 13 so a residual nitrogen time for the next dive segment can be computed. This procedure can be carried out ad infinitum until (a) a total dive time of 720 min is reached, or (b) the diver ends up in repetitive group Z. If either of these conditions occur, the dive must be replanned or terminated.

The CSMD Procedure is used to plan a dive and is not intended to compute decompression obligation during the dive. Once planned, the plan must be followed closely or the dive aborted. Table 15 allows certain unplanned excursions to be made without having to abort the dive but deep excursions to depths of 100 or 120 FSW could easily put the diver into repetitive group Z and therefore are cause to terminate the dive.

Emergency Procedures

The only emergency which need be provided for is omitted decompression. This would occur if at any time the divers exceed a depth of 120 FSW or lose track of their dive profile. The divers are considered to have omitted decompression if an unplanned excursion deeper than 120 FSW is made, if any unplanned excursion exceeds 20 min, if any required decompression stops are missed, or if an excursion is made to a depth deeper than 30 FSW before the required 30 min shallow interval has been taken. Also, divers are considered to have omitted decompression if a second unplanned excursion below 30 FSW follows an unplanned excursion below 80 FSW. In all these cases, the divers are directed to transit at 30 FSW to ensure they are well below any required first stop, decompress according to a 40 FSW for 720 min schedule (if ascent to 1 ATA is required to get to a decompression chamber) and be treated on a Treatment Table 5, 1A, 6 or 2A unless reconstruction of the actual dive profile is possible and it is determined that adequate decompression has been taken.

The 40 FSW for 720 min schedule is used only to get the divers out of the water and into the chamber until the actual profile can be reconstructed. It is felt to provide adequate decompression for most anticipated dive profiles with total mission times less than 720 min. The next 720 min schedule is at 60 FSW and is felt to be too long for this application.

Safety

The CSMD Procedure as presented above is felt to be as safe as the standard air repetitive dive procedures on which it is based. During air workup dives for saturation dives done at NEDU, times approaching 12 hours have been spent at 30 FSW and decompression directly to the surface has been accomplished without incident. Thus, the maximum time of 12 hours at 30 FSW on air is reasonable. Allowing 10 FSW stops to be taken at 20 FSW has been tested as already described and is safe. Taking a 30 min shallow interval at 20 FSW instead of a 10 min surface interval at 1 ATA is theoretically equivalent based on the decompression model used to compute the Standard Air Tables. Also, evidence presented above (7) establishes that offgassing at a depth of 20 FSW will be equal to or more rapid than at 1 ATA breathing air.

Based on the above considerations, the CSMD Procedure should expose the diver to no more risk than would be encountered doing repetitive dives on air using established technique. Thus, it is felt that this procedure can be put to immediate use operationally.

FUTURE CONSIDERATIONS:

The CSMD Procedure was developed to fill an interim operational need. It is conservative and restrictive but additional flexibility cannot be added without making the procedure extremely complex and it cannot be made less conservative without man-testing. However, the ultimate flexibility would be gained through development of an algorithm which would safely compute air decompression schedules for dive profiles of any level of complexity. This algorithm could then be programmed into a wrist-worn Underwater Decompression Calculator (UDC) which would keep track of each diver's exact dive profile and compute a decompression profile exactly suited to a particular dive profile. Dives of unlimited complexity could then be done and any combination of unplanned excursions could be made to any depth for any time without the divers losing track of their decompression obligation and having to abort a mission prematurely.

While development of an air algorithm for inclusion into a UDC provides the ultimate degree of flexibility, the CSMD Procedure would still retain usefulness as a basis for emergency procedures which could be used in the event of a UDC failure.

CONCLUSIONS:

1. The repetitive dive procedures, as published in the U.S. Navy Diving Manual, contain several apparent errors and internal inconsistencies, but are conservative overall.

2. The repetitive dive procedures can be adapted to do multi-level diving where alternating dive intervals deeper and shallower than 30 FSW are considered.
3. The Combat Swimmer Multi-Level Dive Procedure outlined in Appendix A is conservative and subjects the diver to no more risk than would be encountered in doing repetitive diving using established procedures.
4. The ultimate in combat swimmer mission flexibility will be provided through the development of an air decompression algorithm for inclusion in a diver-carried Underwater Decompression Calculator.

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2. Dwyer, J.V; Calculation of Air Decompression Tables. U.S. Navy Experimental Diving Unit Report 4-56, November 1955.
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APPENDIX A

COMBAT SWIMMER MULTI-LEVEL DIVE
(CSMD) PROCEDURE

Combat Swimmer Multi-Level Dive Procedure

I. The Ground Rules

- (A) Maximum depth at any time is 120 FSW.
Maximum mission time is 720 min.
- (B) All dives start at 0 FSW at time 0. Dives are divided into sections 30 FSW and shallower, and deeper than 30 FSW. When deeper than 30 FSW, the maximum depth ever attained during that time is used to compute the decompression obligation. When shallower than 30 FSW, repetitive groups are computed assuming all time was spent at 30 FSW. All times are rounded up to the next minute.
- (C) Dives requiring in-water decompression stops are permitted. No dives will be planned which require any decompression stops deeper than 30 FSW or which exceed repetitive Group 0 prior to the last excursion. 30 FSW stops are taken at a constant depth of 30 FSW. 20 FSW stops are taken at a constant depth of 20 FSW. 10 FSW stops may be taken at any depth between 10 and 20 FSW.
- (D) No surface intervals are required during the dive. If surface intervals are taken, no decrease in repetitive group is allowed. After each excursion deeper than 30 FSW, a "Shallow Interval" is required. This "Shallow Interval" consists of 30 minutes spent at a depth of 20 FSW or shallower and allows for sufficient reduction in the body's nitrogen load that a surface interval is not required before making a subsequent downward excursion.
- (E) Surfacing is allowed at any time during the dive except after excursions deeper than 30 FSW which require decompression stops prior to surfacing.

II. Planning The Dive

Table A1 (Residual Nitrogen Time Table) and A2 (Repetitive Group Designation) are used along with the Mission Dive Profile Worksheet (Enclosure A-1) and the CSMD Decompression Worksheet (Enclosure A-2) and Continuation Page (Enclosure A-3). A sample dive profile is shown in Figure A-1 and the completed Mission Dive Profile Sheet and CSMD Decompression Worksheet and Continuation Page are shown in Table A-3, A-4 and A-5 respectively. Using the profile in Figure A-1, the decompression schedule is computed as follows:

- (A) All times at which a depth of 30 FSW is arrived at or crossed are identified. These times are entered on the Mission Dive Profile Worksheet. In Figure A-1, all ascents and descents are 60 FSW/min. After leaving the surface at time 0 and spending 60 min at 80 FSW, ascent is begun and crosses 30 FSW at time 60:50. Note the ascent

TABLE A-1
RESIDUAL NITROGEN TIMES FOR GIVEN REPETITIVE GROUPS AND DEPTHS

Repetitive Dive Depth	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
30		∞	469	349	279	229	190	159	132	109	88	71	54	39	25	12
40	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	73	70	64	58	53	47	43	38	32	29	24	20	16	11	7	3
100	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3

TABLE A-2
Repetitive Group Designation
After Decompression From Air
Dives with Indicated Bottom Times

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Z
30 FSW and Shallower	5	15	30	45	60	75	95	120	145	170	205	250	310	395	∞	
40	5	15	25	30	40	50	70	80	100	110	130	150	170	200	250	300
50	-	10	15	25	30	40	50	60	70	80	90	100	120	160	180	220
60	-	10	15	20	25	30	40	50	55	60	70	80	100	120	140	160
70	-	5	10	15	20	30	35	40	45	50	60	70	80	90	110	140
80	-	5	10	15	20	25	30	35	40	--	50	60	70	80	100	120
90	-	5	10	12	15	20	25	30	--	40	--	50	60	70	90	100
100	-	5	7	10	15	20	22	25	30	--	40	50	--	60	70	90
110	-	-	5	10	13	15	20	25	--	30	--	40	50	60	70	80
120	-	-	5	10	12	15	--	20	25	30	--	40	--	50	60	80
130	-	-	5	8	10	15	--	20	--	25	--	--	30	40	50	60
140	-	-	5	7	10	--	15	--	20	25	30	--	--	40	50	60

Note: Decompression repetitive groups assume all required stops have been taken.

Planned profile - actual profile times and depths may be slightly different

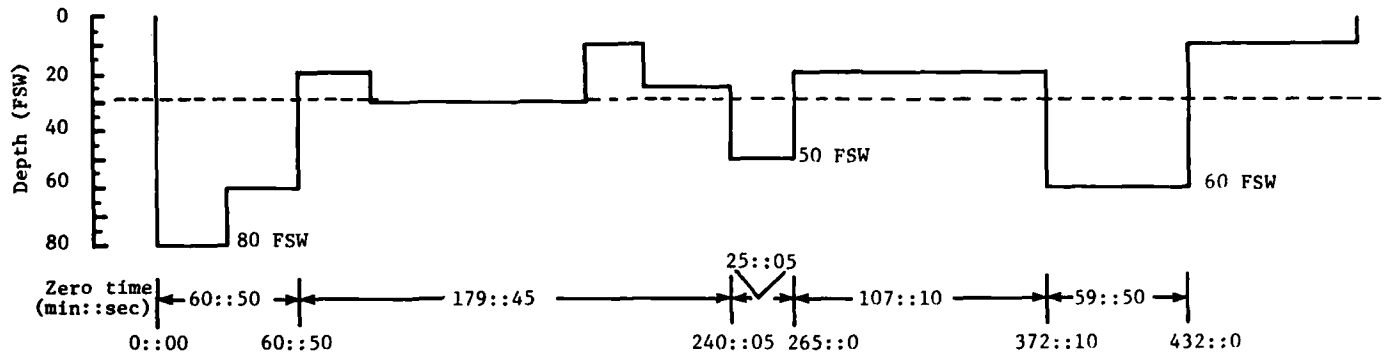


FIGURE A1. Sample Combat Swimmer Dive Profile

to 20 FSW is planned and can be done because the first stop for an 80 FSW/60 min schedule is at 10 FSW. The profile makes several upward and downward excursions but never below 30 FSW. The 30 FSW mark is crossed at time 240:05 and 25 min is spent at 50 FSW. This time and depth are entered on the 3rd line of Table A-3. Ascent from 50 FSW crosses 30 FSW at 265 min and the mission stays shallower than 30 FSW until zero time 372:10. These are the next 2 entries in Table A-3. After spending 60 min at 60 FSW, the mission is completed and decompression to the surface begun at time 432.

- (B) The depths and times from the Mission Dive Profile Worksheet are transferred to the CSMD Decompression Worksheet. The first time is rounded up to 61 min and is the first and second time entry in Table A-4. The maximum depth attained was 80 FSW, so decompression on an 80 FSW/61 min schedule is required. There is a 23 min stop at 10 FSW but the rules allow this stop to be taken at any depth 20 FSW or shallower. After the 23 min stop, depth may be anywhere between 0 FSW and 30 FSW but an additional 30 min shallow interval must be taken for a total shallow interval of 53 min. The dive plan calls for 29 min at 20 FSW and an additional 149 min above 30 FSW, more than satisfying these requirements. Using Table A-2, it is determined that the diver will be in Repetitive Group M after the 80 FSW excursion.
- (C) The third time entry in the Mission Dive Profile Worksheet is 240:05 which is rounded up to 241 min. (Note: All times are rounded up to the nearest minute) and the total time shallower than 30 FSW computed. From Table A-1, a 349 min residual nitrogen time is found giving an equivalent time 30 FSW and shallower of 529 min. From Table A-1, it is determined that the diver is now in Repetitive Group 0. (Note that once a time of 395 min was exceeded the diver will remain in Group 0 no matter what his duration 30 FSW or shallower).
- (D) The 50 FSW maximum depth and the time at which 30 FSW was crossed from the 4th entry in the Mission Dive Profile Worksheet are entered in the next segment of Table A-4. The residual nitrogen time for Group 0 is found to be 160 min at 50 FSW from Table A-1 giving an equivalent bottom time of 185 min. Decompression must be done on a 50 FSW/200 min schedule which requires a 35 min stop at 10 FSW and an additional 30 min shallower than 30 FSW. The dive plan calls for 117 min to be spent at 20 FSW satisfying these requirements. Note that if a planned excursion to 60 FSW was desired this could not be done because the resulting decompression dive would put the diver in repetitive Group Z. A Group 0 would give the diver 117 min residual nitrogen time at 60 FSW and after only 23 min at 60 FSW a 60 FSW/160 schedule would have been needed resulting in the diver being in a Group Z.
- (E) The next time entry from the Mission Dive Profile Worksheet is entered and a time of 107 min computed for the 30 FSW shallow interval. Since the diver starts out in Group 0 he will stay in

TABLE A-3
MISSION DIVE PROFILE WORKSHEET

<u>EVENT</u>	<u>MAX DEPTH</u>	<u>TIME</u>
START MISSION	<u>80 FSW</u>	<u>0::00</u>
ARRIVE 30 FSW	30 FSW	<u>60::50</u>
START EXCURSION 1	<u>50 FSW</u>	<u>240::05</u>
ARRIVE 30 FSW	30 FSW	<u>265::00</u>
START EXCURSION 2	<u>60 FSW</u>	<u>372::10</u>
ARRIVE 30 FSW	30 FSW	<u>432::00</u>
<hr/>		
START EXCURSION 3	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 4	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 5	_____	_____

*Finish
Leave Bottom*

TABLE A-4

CMSD DECOMPRESSION WORKSHEET

Starting Repet Group —

START PAGE

Leave Surface a 0 min
 Arrive 30 FSW ascending b 61 min
 Total time below 30 FSW b-a 61 min
 RNT + 0 min
 Equivalent Dive Time 61 min
 Max depth attained between times a and b 80 FSW
 Decompression Schedule 80 FSW 70 min

STOPS
 30' —
 20' —
 10' 23
 SI 53

Repet Group M

Arrive 30 FSW ascending b 61 min
 Arrive 30 FSW descending c 241 min
 Total time 30 FSW or shallower c-b 180 min
 RNT from previous excursion + 349 min
 Equivalent time 30 FSW and shallower 529 min

Repet Group O

Arrive 30 FSW descending c 240 min
 Arrive 30 FSW ascending (or leave bottom) d 265 min
 Total time deeper than 30 FSW d-c 25 min
 Max depth attained between times c and d 50 FSW
 RNT from previous excursion + 160 min
 Equivalent Dive Time 185 min
 Decompression schedule 50 FSW 200 min

STOPS
 30' —
 20' —
 10' 35
 SI 65

Repet Group O

Arrive 30 FSW ascending d 265 min
 Arrive 30 FSW descending e 373 min
 Total time 30 FSW or shallower e-d 107 min
 RNT from previous excursion + X min
 Equivalent time 30 FSW and shallower X min

Repet Group O

Record in Time
 a Next Page

TABLE A-5

CMSD DECOMPRESSION WORKSHEET
CONTINUATION PAGE

<p>Arrive 30 FSW descending a <u>373</u> min</p> <p>Arrive 30 FSW ascending (or leave bottom) b <u>432</u> min</p> <p>Total time deeper than 30 FSW b-a <u>59</u> min</p> <p>Max depth attained between times a and b <u>60</u> FSW</p> <p>→ RNT from previous excursion + <u>117</u> min</p> <p>Equivalent Dive Time <u>176</u> min</p> <p>Decompression schedule <u>60</u> FSW <u>180</u> min</p> <p>Repet Group _____</p> <hr style="border-top: 1px dashed black;"/> <p>Arrive 30 FSW ascending b _____ min</p> <p>Arrive 30 FSW descending c _____ min</p> <p>Total time 30 FSW or shallower c-b _____ min</p> <p>→ RNT from previous excursion + _____ min</p> <p>Equivalent time 30 FSW and shallower _____ min</p> <p>Repet Group _____</p> <hr style="border-top: 1px solid black;"/> <p>Arrive 30 FSW descending c _____ min</p> <p>Arrive 30 FSW ascending (or leave bottom) d _____ min</p> <p>Total time deeper than 30 FSW d-c _____ min</p> <p>Max depth attained between times c and d _____ FSW</p> <p>→ RNT from previous excursion + _____ min</p> <p>Equivalent Dive Time _____ min</p> <p>Decompression schedule _____ FSW _____ min</p> <p>Repet Group _____</p> <hr style="border-top: 1px dashed black;"/> <p>Arrive 30 FSW ascending d _____ min</p> <p>Arrive 30 FSW descending e _____ min</p> <p>Total time 30 FSW or shallower e-d _____ min</p> <p>→ RNT from previous excursion + _____ min</p> <p>Equivalent time 30 FSW and shallower _____ min</p> <p>Repet Group _____</p>	<p><u>STOPS</u></p> <p>30' <u>—</u></p> <p>20' <u>—</u></p> <p>10' <u>56</u></p> <p>SI <u>Done</u></p> <p><u>STOPS</u></p> <p>30' <u>—</u></p> <p>20' <u>—</u></p> <p>10' <u>—</u></p> <p>SI <u>—</u></p>
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Record in Time a Next Page

Group 0 no matter how long he remains shallower than 30 FSW. The resulting equivalent dive time is infinite. This repetitive Group 0 gives a 117 min residual nitrogen time at 60 FSW and as the first segment on the Continuation Page (Table A-5) shows, the resultant equivalent dive time is 178 min committing the diver to a 60 FSW/180 min decompression schedule. The required stops are noted on the right and again the 10 FSW stop may be taken anywhere between 20 and 10 FSW. The diver surfaces in Group Z and at this point the Surface Interval Credit Table in the U.S. Navy Diving Manual may be used to compute a starting repetitive group if another mission is planned before 12 hours have elapsed. Note that while exceptional exposure air tables may be used for the final decompression, no more missions can be done with these divers for 12 hours.

III. Unplanned Excursions

- (A) All excursions in Figure A-1 were planned. If they are not taken, the plan can still be followed. Operational contingencies may require an unplanned excursion below 30 FSW. These excursions may be safely accomplished as long as the provisions below are observed.
- (B) As long as depth is 120 FSW or less and the limits of the Standard Navy Air Tables are not exceeded, a diver is never required to take a decompression stop deeper than 30 feet. If an unplanned downward excursion below 30 FSW takes place during the dive, ascent should be made to 30 FSW and the stops shown in Table A-6 taken (based on a repetitive group of "0" and a maximum excursion time of 20 minutes).
- (C) If the divers make an unplanned downward excursion during the dive, one of the following conditions will apply:
- (1) EXCURSION TO 80 FSW (OR LESS) FOR 20 MINUTES OR LESS -
- Divers remain in Repetitive Group "0" and are allowed to make additional downward excursions for 20 minutes or less as long as they observe the decompression stops and Shallow Intervals as shown in Table A-3.
- (2) EXCURSION TO A DEPTH GREATER THAN 80 FSW BUT LESS THAN 120 FSW FOR 20 MINUTES OR LESS -
- Divers are considered adequately decompressed after taking stops in Table A-3 and may complete the operation but no additional downward excursions are allowed except as the last downward excursion before decompression to 1 ATA.

TABLE A-6

Unplanned Excursion Decompression Procedure

<u>Max Excursion Depth</u>	<u>STOPS</u>			<u>Shallow Interval</u>
	<u>30 FSW</u>	<u>20 FSW</u>	<u>10 FSW</u>	<u>20 FSW or Less</u>
40	0	0	15	30
60	0	0	39	30
80	0	11	46	30
100	3	23	57	*
120	9	23	55	*

*No further excursions below 30 FSW allowed.

The 30 FSW stops should be taken at a depth of 30 FSW.

The 20 FSW stops should be taken at a depth of 20 FSW.

The 10 FSW stops may be taken at any depth between 10 and 20 FSW.

The Shallow Interval may be taken at any depth 20 FSW or shallower; this interval is not required for safe surfacing, but is required before another excursion below 30 FSW can be made.

- (3) EXCURSION TO A DEPTH GREATER THAN 120 FSW OR FOR LONGER THAN 20 MINUTES -

Divers are considered to have Omitted Decompression. They should abort the mission at once staying at a depth of 30 FSW until final decompression to the surface can be done. No surfacing should be done during the return transit. Final decompression is done in accordance with Section IV (C).

IV. Omitted Decompression

- (A) "Omitted Decompression" refers to any situation in which the divers are known to have definitely or possibly missed required decompression stops. This situation requires the immediate discontinuation of the mission in progress.
- (B) Divers may achieve an Omitted Decompression status in the following ways:
- (1) Exceeding the no-decompression depth/time limits during an excursion for which decompression stops are not planned.
 - (2) Surfacing before the required decompression stops have been completed following any excursion deeper than 30 FSW.
 - (3) Making an additional excursion below 30 FSW prior to completing the required decompression stops and/or Shallow Interval from a previous excursion.
 - (4) Making an unplanned downward excursion greater than 120 FSW.
 - (5) Making an unplanned excursion below 30 FSW for more than 20 minutes.
 - (6) Uncertainty regarding the depths or times in the dive profile.
 - (7) Making an additional excursion below 30 FSW after a previous unplanned excursion to deeper than 80 FSW.
- (C) If omitted decompression occurs the mission should be aborted. If a transit is required to return to the place where decompression will be done it should be done at 30 FSW. If a 1 ATA surface interval is required before access to a hyperbaric chamber is possible, decompress according to the 40 FSW/720 min Air Table. (This schedule is only to get the divers out of the water into a chamber. It is felt to provide what is probably the maximum decompression necessary for most missions less than 720 min. The next 720 min schedule is 60 FSW and is felt to be too long for the application).

If upon surfacing reconstruction of the dive profile is not possible, or if after reconstruction it is found that a schedule deeper than 40 FSW should have been used, treat the divers according to how much decompression time was missed. If less than 30 min was missed, treat divers on a Treatment Table 5 or 1A, if more than 30 min was missed treat on a Table 6 or 2A. Tables 1A and 2A are acceptable for treating asymptomatic omitted decompression even if oxygen is available. If symptoms occur these are treated using standard procedures as a recurrence of symptoms. In this case, use of Oxygen Treatment Tables is mandatory if oxygen is available.

V. Executing The Mission

Once the mission is planned, Enclosure A-1 is taken along to record the actual times and depths of the dive profile. If an excursion was planned below 30 FSW it may be omitted or taken at a shallower depth without having to abort the mission. If a planned excursion time is 20 min or greater and this time is exceeded, then the mission must be aborted. Therefore, all planned excursions should be made for the longest anticipated excursion time or several alternate dive profile plans should be available.

If unplanned excursions are made which exceed the limits in Table A-3 but the depths and times are known, the profile may be reconstructed on Enclosure A-2 and A-3. In this case, dives putting the diver in repetitive group Z are acceptable and the final no-decompression obligation computed as outlined in Section II. However, if in reconstructing the profile the divers would end up on an Exceptional Exposure Air Table before the final excursion, they must be treated for omitted decompression. If reconstruction of the dive profile shows that an Exceptional Exposure Air Table is required only for the final excursion of the mission, the appropriate Exceptional Exposure Air Table may be used for decompression.

MISSION DIVE PROFILE WORKSHEET

<u>EVENT</u>	<u>MAX DEPTH</u>	<u>TIME</u>
START MISSION	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 1	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 2	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 3	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 4	_____	_____
ARRIVE 30 FSW	30 FSW	_____
START EXCURSION 5	_____	_____

CMSD DECOMPRESSION WORKSHEET

Starting Repet Group _____

START PAGE

Leave Surface a 0 min
 Arrive 30 FSW ascending b _____ min
 Total time below 30 FSW b-a _____ min
 RNT + _____ min
 Equivalent Dive Time _____ min
 Max depth attained between times a and b _____ FSW

STOPS
 30' _____
 20' _____
 10' _____
 SI _____

Decompression Schedule _____ FSW _____ min

Repet Group _____

Arrive 30 FSW ascending b _____ min
 Arrive 30 FSW descending c _____ min
 Total time 30 FSW or shallower c-b _____ min
 RNT from previous excursion + _____ min
 Equivalent time 30 FSW and shallower _____ min

Repet Group _____

Arrive 30 FSW descending c _____ min
 Arrive 30 FSW ascending (or leave bottom) d _____ min
 Total time deeper than 30 FSW d-c _____ min
 Max depth attained between times c and d _____ FSW
 RNT from previous excursion + _____ min
 Equivalent Dive Time _____ min
 Decompression schedule _____ FSW _____ min

STOPS
 30' _____
 20' _____
 10' _____
 SI _____

Repet Group _____

Arrive 30 FSW ascending d _____ min
 Arrive 30 FSW descending e _____ min
 Total time 30 FSW or shallower e-d _____ min
 RNT from previous excursion + _____ min
 Equivalent time 30 FSW and shallower _____ min

Repet Group _____

Record in Time a Next Page

CMSD DECOMPRESSION WORKSHEET
CONTINUATION PAGE

Y	Arrive 30 FSW descending	a	_____ min	
	Arrive 30 FSW ascending (or leave bottom)	b	_____ min	<u>STOPS</u>
	Total time deeper than 30 FSW b-a		_____ min	30' _____
	Max depth attained between times a and b _____ FSW			20' _____
→	RNT from previous excursion	+	_____ min	10' _____
	Equivalent Dive Time		_____ min	SI _____
	Decompression schedule _____ FSW _____ min		_____ min	
	Repet Group _____			

	Arrive 30 FSW ascending	b	_____ min	
	Arrive 30 FSW descending	c	_____ min	
	Total time 30 FSW or shallower c-b		_____ min	
→	RNT from previous excursion	+	_____ min	
	Equivalent time 30 FSW and shallower		_____ min	
	Repet Group _____			

	Arrive 30 FSW descending	c	_____ min	
	Arrive 30 FSW ascending (or leave bottom)	d	_____ min	<u>STOPS</u>
	Total time deeper than 30 FSW d-c		_____ min	30' _____
	Max depth attained between times c and d _____ FSW			20' _____
→	RNT from previous excursion	+	_____ min	10' _____
	Equivalent Dive Time		_____ min	SI _____
	Decompression schedule _____ FSW _____ min		_____ min	
	Repet Group _____			

	Arrive 30 FSW ascending	d	_____ min	
	Arrive 30 FSW descending	e	_____ min	
	Total time 30 FSW or shallower e-d		_____ min	
→	RNT from previous excursion	+	_____ min	
	Equivalent time 30 FSW and shallower		_____ min	
	Repet Group _____			
			_____ min	

Record in Time a Next Page

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