Undersea Biomedical Research, Vol. 5, No. 2, June 1978

Development of unlimited duration excursion tables and procedures for helium–oxygen saturation diving

W. H. SPAUR, E. D. THALMANN, E. T. FLYNN, J. L. ZUMRICK, T. W. REEDY, and J. M. RINGELBERG

U.S. Navy Experimental Diving Unit, Panama City, Florida 32407

Spaur, W. H., E. D. Thalmann, E. T. Flynn, J. L. Zumrick, T. W. Reedy, and J. M. Ringelberg. 1978. Development of unlimited duration excursion tables and procedures for helium–oxygen saturation diving. Undersea Biomed. Res. 5(2):159–177.—Excursion ascents were performed during a series of experimental helium–oxygen saturation dives ranging between 150 and 1000 fsw to study the limits of multiple and extended duration excursions both deeper and shallower than the saturation depth. The distance a diver can safely ascend without decompression following saturation was found to be a function of depth, increasing from 75 ft at a saturation depth of 225 fsw to 180 ft at 1000 fsw. Initiation of saturation decompression immediately after an excursion was found to be safe. This information is incorporated into new U.S. Navy Unlimited Duration Excursion Tables and Procedures for Saturation Diving.

decompression tables
excursion diving

The previous U.S. Navy Helium–Oxygen Saturation-Excursion Tables (U.S. Navy, 1973) were computed by Bornmann (1970, 1971) from Workman M values (Workman, 1965). The tables were tested by Summitt and his co-workers (1970a, b, c, d, e) at the Navy Experimental Diving Unit. In these validation studies, no decompression sickness was observed during or within one day after 1126 excursion dives from 50 to 150 ft deeper than saturation depths ranging from 150 to 600 fsw. Inspection of other successful dive profiles and the work of Barnard (1976) on stage decompression from saturation dives indicated that considerably greater excursions than those allowed by U.S. Navy tables might be safe.

Experiments were undertaken to determine whether the time and depth limits of excursions from saturation depths could be extended significantly. To develop new excursion tables and procedures for saturation diving, safe excursion distances and safe saturation decompression procedures after excursions had to be established.

This report describes the results of 245 excursion ascents from deeper depths ranging between 225 and 1000 fsw and the development of the tables and procedures.

METHODS

These studies were performed between February 1974 and June 1976 during 11 saturation dives at the U.S. Navy Experimental Diving Unit, located in Washington, D.C. during the first four dives of the series and at Panama City, Florida during the last seven dives of the series.

The studies began by incremental extension of the time of excursions between 300 and 400 fsw, as described by Bornmann (1970, 1971). The depth of subsequent excursions was chosen by estimation and then incrementally increased either in time or depth. Each experimental excursion distance attempted was selected on the basis of human diving experience. No theoretical model or hypothesis was considered. The studies were conducted in the general depth ranges from 150 to 230, 300 to 410, 350 to 456, 600 to 750, and 800 to 1000 fsw. In two of the 11 saturation dives performed, excursion ascents were studied in two depth ranges rather than a single one.

U.S. Navy divers assigned to the Navy Experimental Diving Unit served as subjects except for the 456 fsw dive, which included four divers of the Canadian Forces. Five subjects participated in each dive and all were exposed together to the pressure changes of the excursions. Seven of the 49 subjects participated in two of the dives in the series.

Before each dive, a thorough physical examination was conducted on each subject, which included chest X ray, air conduction audiogram, and vestibular function studies. The last studies included balance assessment, pendulum tracking, measurement of positional nystagmus, optokinetic nystagmus, and nystagmus induced by ice water irrigation of the external auditory meatus. Details of these tests and their significance have been discussed by Braithwaite, Berghage, and Crothers (1974). After each dive, a general medical history was obtained, a physical examination was conducted, and an audiogram performed.

On all dives, the chambers contained one atmosphere absolute (ATA) of air, and initial compression was made to a depth of 14 or 20 fsw in 1 min on a mixture of helium–oxygen or pure helium. Oxygen was then added as needed to reach a chamber oxygen partial pressure of 0.3 to 0.4 ATA, depending on the dive in the series. After a variable period long enough to stabilize the atmosphere and check the function of life support equipment, pure helium was used to compress to the first study depth. Compression rates to this initial depth varied during the dive series. Chamber oxygen partial pressure was maintained at 0.30 to 0.35 ATA at saturation depths and increased to 0.4 ATA at excursion depths in the first six dives of the series. During the subsequent five dives, the chamber oxygen partial pressure was maintained between 0.35 and 0.40 ATA at all times. Carbon dioxide partial pressure was maintained at less than 3.8 mmHg. Chamber humidity was maintained at 50% to 70% and the temperature was controlled at levels comfortable to the subjects.

Compressions associated with excursions were at 30 ft/min. The subjects were kept in the dry chamber during this phase.

At the deeper depth before excursion decompression ascents, the divers performed a variety of experiments. In most cases, one diver pedalled an underwater bicycle ergometer, in either a vertical or horizontal position, as part of the test and evaluation of underwater breathing apparatus, while another diver acted as standby diver in the water. The dive subjects rotated these positions. The depth of the divers in the wet chamber water was not considered in the excursion distances or in the listed deeper depths. This depth varied between 3 and 12 ft, depending on the position of the ergometer or test stands in the wet chambers. In the water, divers used the MK 10 or SLSS MK 1 closed-circuit underwater breathing apparatus, which maintained the oxygen partial pressure about a set point of 0.4 ATA, or they breathed from a USN MK 1 Diver's Mask supplied with a helium–oxygen mixture of 0.4 ATA oxygen partial

pressure. One of the three divers out of the water performed intermittent moderate work on a Monark cycle ergometer and the other two divers were employed as tenders or winch operators. During the first five of the saturation dive series, the water temperature in the wet pot was approximately 21°C. The water temperature during the last six of the dive series was maintained at 5.6°C. During this series, the divers wore open-circuit hot water thermal protective garments. When the duration of the stay at depth before excursion ascents was 24 h or longer, the divers performed a variety of experiments, including 2-to-3 h exposures in the dry chamber to helium–oxygen atmospheres of 20 or 25°C.

Excursion ascents were conducted with all subjects in the dry chamber. The subjects were at rest, warmly clad, and usually had electrodes in place for nystagmography before initiation of excursion ascent. All excursion ascents were performed at 60 ft/min, with the exception of the ascents from 230 or 225 to 150 fsw. These ascents were conducted at 32.5 ft/min, the maximum ascent rate of the chamber system at that depth.

The subjects were monitored continuously for nystagmus for 15 min immediately after decompression. After this period, each diver performed a standing steadiness test and was given an air conduction audiogram. These procedures occupied the divers for one hour after the excursion ascent. An additional 15 min of nystagmographic monitoring was then performed. Careful clinical examinations complemented these objective studies and comprised the immediate monitoring system for detection of decompression sickness.

RESULTS

Two hundred forty-five man-excursion ascents were performed. Two cases of decompression sickness resulted directly from the excursions and two other cases occurred late in the saturation decompression.

75- and 80-ft ascents from 225 and 230 to 150 fsw

A total of 25 man-ascents were performed from 225 fsw to 150 fsw (Fig. 1). Fifteen of these man-ascents were made after 24 h at the deeper depth. In addition, five man-ascents were performed from 230 fsw to 150 fsw after a 24-h interval at the deeper depth.

One case of pain-only decompression sickness (knee pain) developed during saturation decompression 4½ h after an ascent from 225 to 150 fsw. The duration at the deeper depth had been 24 h. Saturation decompression at 5 ft/h had been started immediately after the excursion ascent. The pain developed at 138 fsw. The diver had complete relief within 20 min after 10-ft of recompression to 148 fsw and a period of high partial pressure oxygen breathing by mask. This diver had spent two of the three hours before the excursion ascent at a depth of 235 fsw, 10 ft deeper than the tabulated depth, in 20°C water performing heavy work.

100- and 110-ft ascents from 400 and 410 to 300 fsw

One hundred fifteen man-ascents were performed from depths of 400 or 410 fsw to 300 fsw (Fig. 2). Thirty of these man-ascents were made after intervals of 8 h or more at the deeper depth, and 20 were performed after intervals at the deeper depth of 24 or more hours. Five of the total were performed from 410 fsw to 300 fsw after an interval of 24 h at the deeper depth.

The series included four sequential excursions conducted on a profile which allotted 2 h at the deeper depth separated by 1-h intervals at the shallower depth, and three excursions were

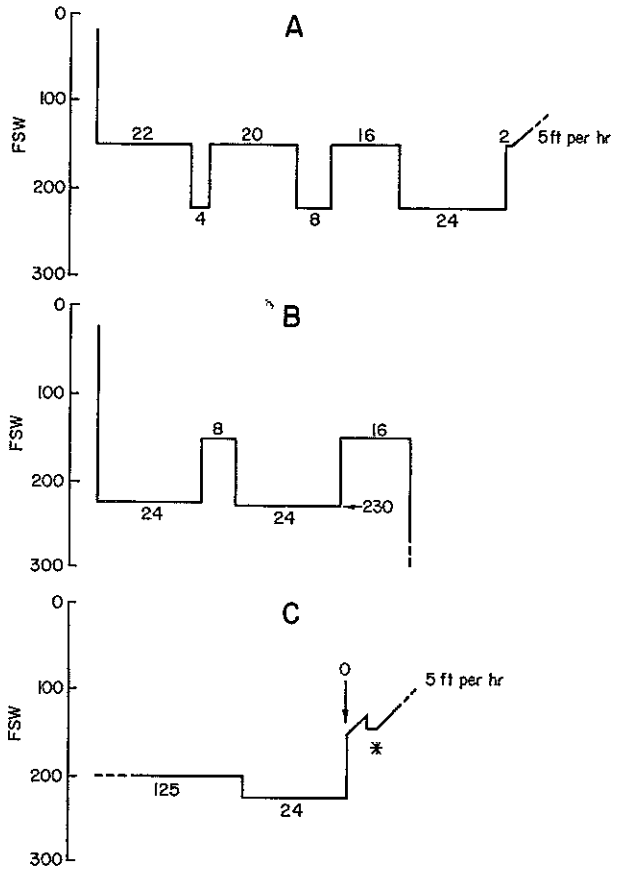


Fig. 1. Profiles of excursions, 75 ft from 225 to 150 fsw and 80 ft from 230 to 150 fsw, and initial hours of saturation decompression. Duration at each depth is indicated in hours on the profile. Initial rate of saturation decompression is indicated on 1A and 1C. *Indicates recompression treatment for pain-only decompression sickness.

conducted on a profile which allotted 4 h at the deeper depth, separated by 1-h intervals at the shallower depth.

After one of the excursion ascents from 400 to 300 fsw, one diver was found to have a 20 dB unilateral hearing loss in the 6000-Hz range. The diver could notice no hearing loss and had no other complaints. A trial of recompression and high partial pressure oxygen breathing caused no change (Fig. 2). On examination, the tympanum was slightly hyperemic. The hearing loss gradually reversed over 5 days and the final diagnosis was ear squeeze.

106-ft ascents from 456 to 350 fsw

Fifteen man-ascents were performed from 456 fsw to 350 fsw. Ten were made after 8-h intervals at the deeper depth and five after a 24-h interval at the deeper depth (Fig. 3).

One diver experienced knee pain during saturation decompression at a depth of 34 fsw. This case occurred 4 days after an excursion ascent and is described in the discussion of the saturation decompressions (DISCUSSION section).

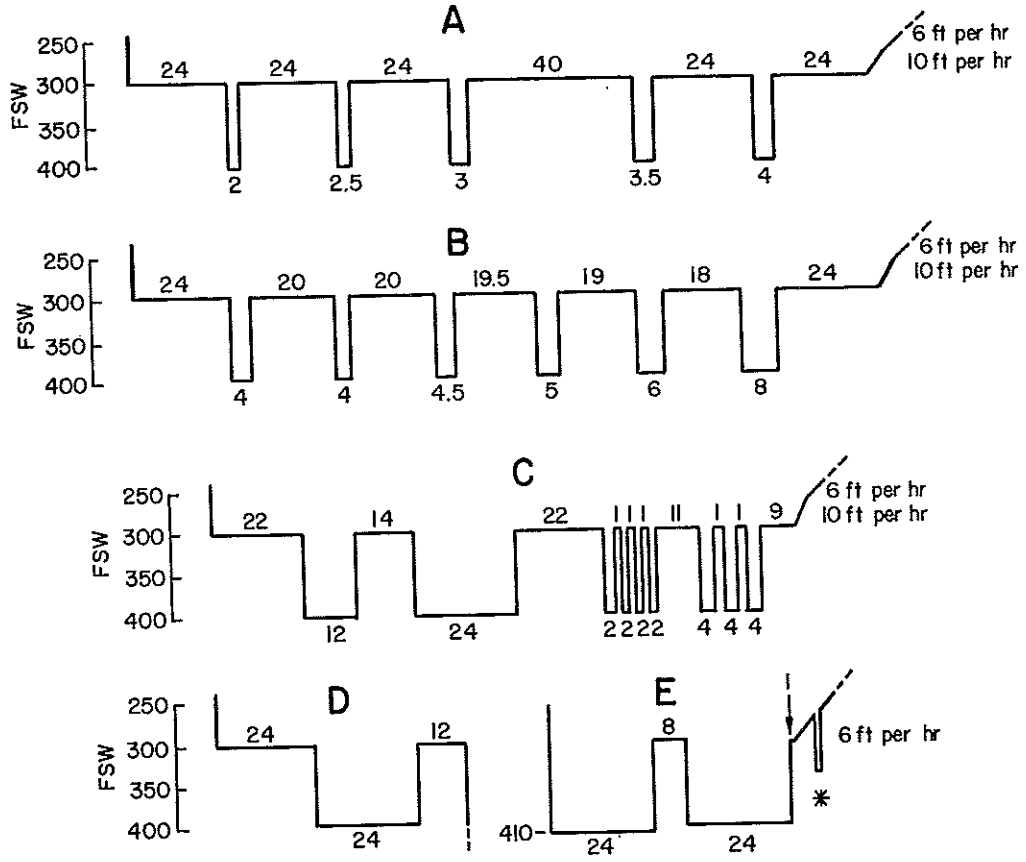


Fig. 2. Profiles of excursions, 100 ft from 400 to 300 fsw and 110 ft from 410 to 300 fsw, and initial hours of saturation decompression. Figure 2E is a continuation of Fig. 1B profile. Duration at each depth is indicated in hours on the profile. *Indicates a trial of recompression for hearing loss secondary to squeeze.

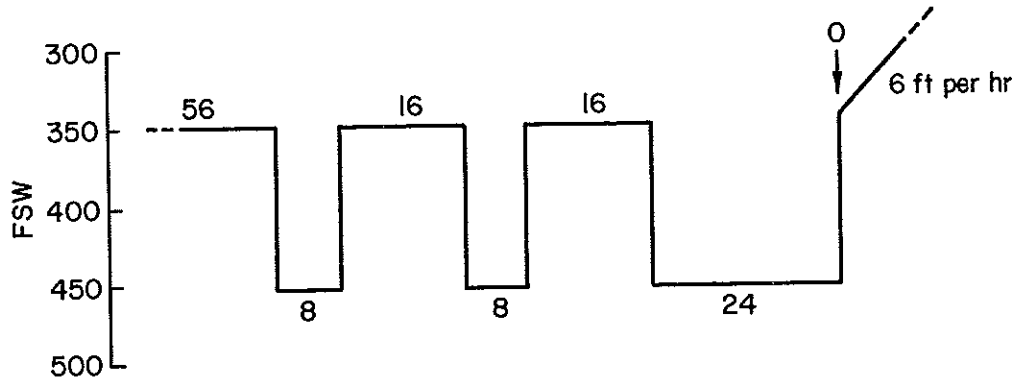


Fig. 3. Profiles of excursions, 106 ft from 456 to 350 fsw, and initial hours of saturation decompression. Duration at each depth is indicated in hours on the profile.

150-ft ascents from 750 to 600 fsw

Thirty-five man-ascents from 750 fsw to 600 fsw were performed (Fig. 4). Twenty of these were made after intervals of 24 h or greater at the deeper depth. Three excursions of two-hours' duration with 1-h intervals at the shallower depth between the excursions were also performed.

One diver experienced discomfort in both knees 15 min after the first excursion from 750 to 600 fsw. The duration at the deeper depth had been 24 h. The discomfort was mild and the diver attributed it to arthralgias which he often experienced from running and bicycle exercise. Recompressing 30 ft combined with a period of high oxygen partial pressure breathing caused no change, nor was the discomfort altered by compression to 750 fsw the following day. The mild discomfort remained unchanged through the next excursion ascent, compression to 1000 fsw, and the saturation decompression. The diagnosis was thought to be arthralgia secondary to pedalling rather than decompression sickness.

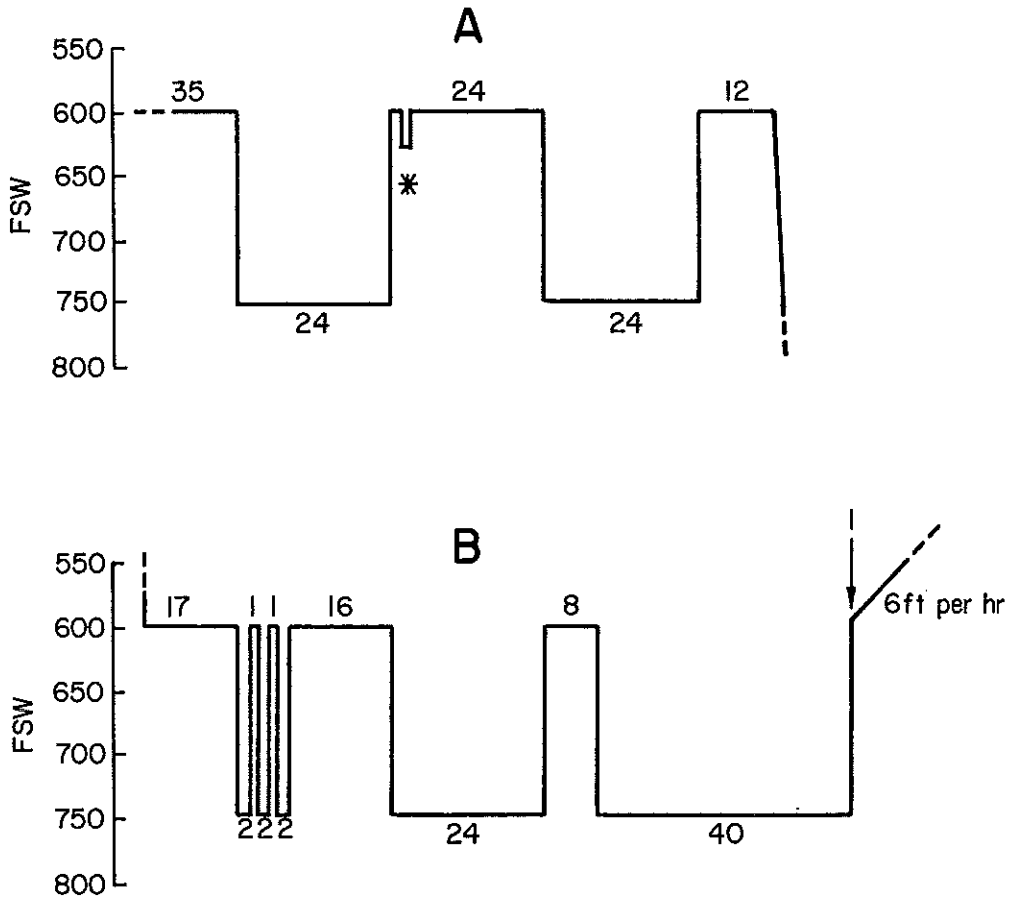


Fig. 4. Profiles of excursions, 150 ft from 750 to 600 fsw, and initial hours of saturation decompression. Figure 4A is a continuation of Fig. 2D profile. Duration at each depth is indicated in hours on the profile. *Indicates a trial of recompression for arthralgia secondary to ergometer pedalling.

150-, 180-, 190-, and 200-ft ascents from 1000 to 850, 820, 810, and 800 fsw

Figure 5 shows the profile of the excursions. The first 5 man-ascents were from 1000 to 850 fsw. These were followed by 35 man-ascents from 1000 to 820 fsw after durations at the deeper depth of 24 h on three occasions, and 40 h on one occasion. Also, three 2-h excursions with 1-h intervals between excursions were performed. These ascents were without evidence of decompression sickness.

Five divers then safely performed an excursion ascent of 190 ft from 1000 to 810 fsw after a duration of 25 h at the deeper depth.

Next, five divers performed an excursion ascent from 1000 to 800 fsw after 24 h at the deeper depth. During the postexcursion electronystagmography, one diver displayed brief and intermittent nystagmus. The diver denied all symptoms and had normal standing steadiness, past pointing maneuvers, and audiogram. Pendulum tracking revealed jerky ocular motions not confined to lateral gaze. Recompression to 1000 fsw and high oxygen partial pressure

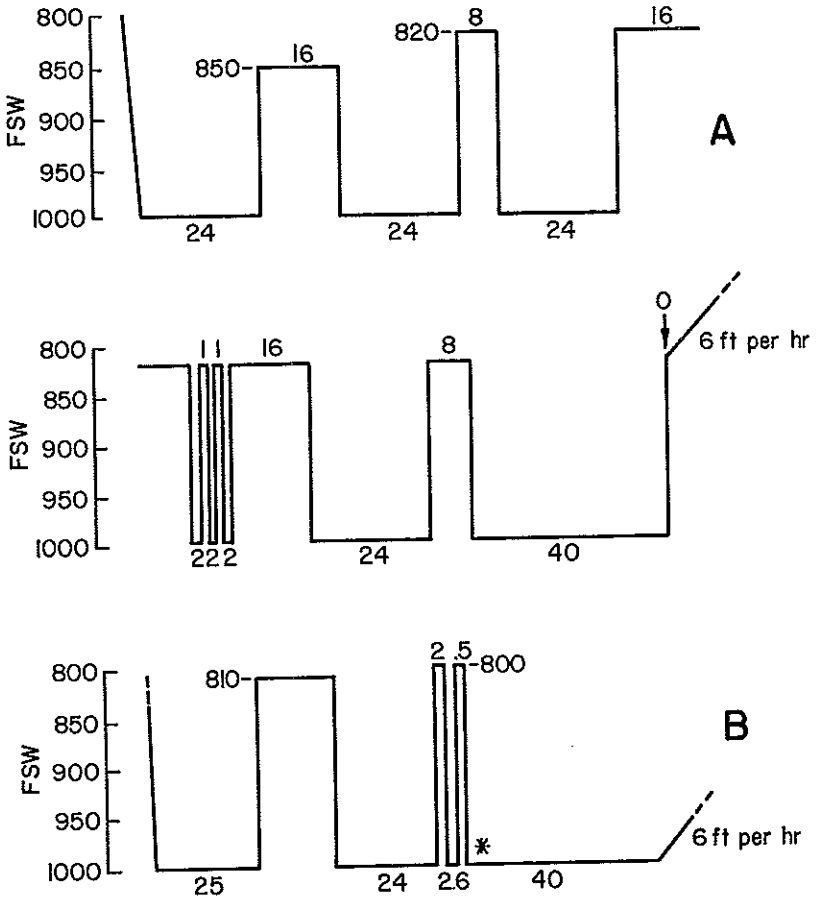


Fig. 5. Profiles of excursions, 150 ft from 1000 to 850 fsw, 180 ft from 1000 to 820 fsw, 190 ft from 1000 to 810 fsw, and 200 ft from 1000 to 800 fsw. Profile A is in 2 parts. Duration at each depth is indicated in hours on the profile. *Indicates recompression treatment for serious decompression sickness.

breathing did not alter these findings. Review of predive base-line records revealed similar findings. The diver responded in both ears to cold caloric stimulation at 1000 fsw as he had before the dive. The conclusion was that the diver had chronic intermittent spontaneous nystagmus and that the decompressions and recompressions had not altered these findings. Findings remained unchanged on repeated studies performed during decompression and 5 days postdive.

The divers then made a second excursion ascent to 800 fsw. Twenty-seven minutes later, another diver developed spinal decompression sickness, manifested as chest pain, profound weakness of the right lower extremity, and numbness and paresthesia of the right ankle and foot. Recompression to 1000 fsw and the first 20-min period of high oxygen partial pressure breathing resulted in complete return to normal of all objective signs, and the diver felt fully recovered except for a slight change in the quality of light touch sensation. At the end of the second 20-min period of treatment gas by mask, all subjective changes had reversed and the diver felt fully recovered.

The studies of these depths indicated that 24 h at 1000 fsw followed by a 60 ft/min ascent to 800 fsw caused serious decompression sickness. Lesser ascents from 1000 fsw to depths of 850, 820, and 810 were without untoward effects.

Saturation decompression following excursions

Nine final excursion ascents were followed by the Navy Standard Saturation Decompression (Table 1, Figs. 1A, 1C, 2A, 2B, 2C, 2E, 3, 4B, 5A). Three cases of decompression sickness occurred during the saturation decompression after excursion ascents. Only the incident on the profile depicted in Fig. 1C was attributable to an excursion ascent. Three divers suffered knee pain which was relieved completely by recompressing 10 to 26 ft and periods of high oxygen partial pressure treatment gas breathing.

TABLE 1
SATURATION DECOMPRESSION AFTER EXCURSION ASCENTS

Final Excursion Ascent				Figure No.	Saturation Decompression		
Duration At Deeper Depth, h	Deeper Depth, fsw	Shallower Depth, fsw	Distance, ft		Saturation Decompression Delayed, h	Depth of Knee Pain, fsw	Hours of Decompression Before Pain
24	225	150	75	1A	2	None	—
24	225*	150	75	1C	0	138	4.5
4	400	300	100	2A	24	None	—
8	400	300	100	2B	24	None	—
4 h × 3	400	300	100	2C	9	None	—
24	400	300	100	2E	1	None	—
24	456	350	106	3	0	34	93
40	750	600	150	4B	1	None	—
40	1000	820	180	5A	0	100	180

*Diver was at 235 fsw in the wet chamber 2 of the last 3 h before excursion ascent.

Construction of the excursion tables

The goal of the experimental dives was to extend the duration of excursions for depths between 150 and 1000 fsw. Results indicated that excursions of unlimited duration or number, either ascents or descents, were feasible for depths between 150 and 1000 fsw provided the distance of vertical excursion did not exceed limits which were a function of depth. Table 2 is a summary of the excursion ascents tested, the instances of decompression sickness, and the chosen table limits.

The limiting excursion distances for the development of the excursion tables are graphically depicted in Fig. 6. The excursion limits chosen to construct the graph were a 75-ft excursion ascent from 225 to 150 fsw and a 180-ft excursion ascent from 1000 to 820 fsw, indicated by the arrows in Fig. 6.

The 75-ft excursion was chosen even though knee pain had developed in one diver during saturation decompression. Because the diver had been an additional 10 ft deeper, the discomfort had been mild, the pain had responded immediately to only 10 ft of recompression, and the 80-ft ascent had been tested successfully, the 75-ft distance was accepted.

The 180-ft excursion was chosen because an excursion ascent from 1000 to 820 fsw followed by saturation decompression and an excursion ascent from 1000 to 810 fsw were both apparently safe.

The tables and procedures developed and published in the U.S. Navy Diving Manual, Volume 2, Mixed-Gas Diving (1977) are presented with abbreviated instructions in Appendix A.

DISCUSSION

Despite many mathematical models describing the biophysical events occurring during decompression or excursions, the development of operationally useful diving tables and proce-

TABLE 2
EXCURSION ASCENTS TESTED, DECOMPRESSION SICKNESS, AND LIMITS SELECTED FOR THE TABLES

Excursion Ascent Tested			Unlimited Duration Excursion Table Limits, ft	Number of Man-Ascents			Decompression Sickness
Deeper Depth, fsw	Shallower Depth, fsw	Distance, ft		≥ 24 h	8–12 h	2–7 h	
225	150	75	75	15	5	5	Pain-only
230	150	80	75	5	—	—	—
400	300	100	99	15	10	85	—
410	300	110	99	5	—	—	—
456	350	106	106	5	10	—	—
750	600	150	146	20	—	15	—
1000	850	150	180	5	—	—	—
1000	820	180	180	20	—	15	—
1000	810	190	180	5	—	—	—
1000	800	200	180	5	—	—	Serious

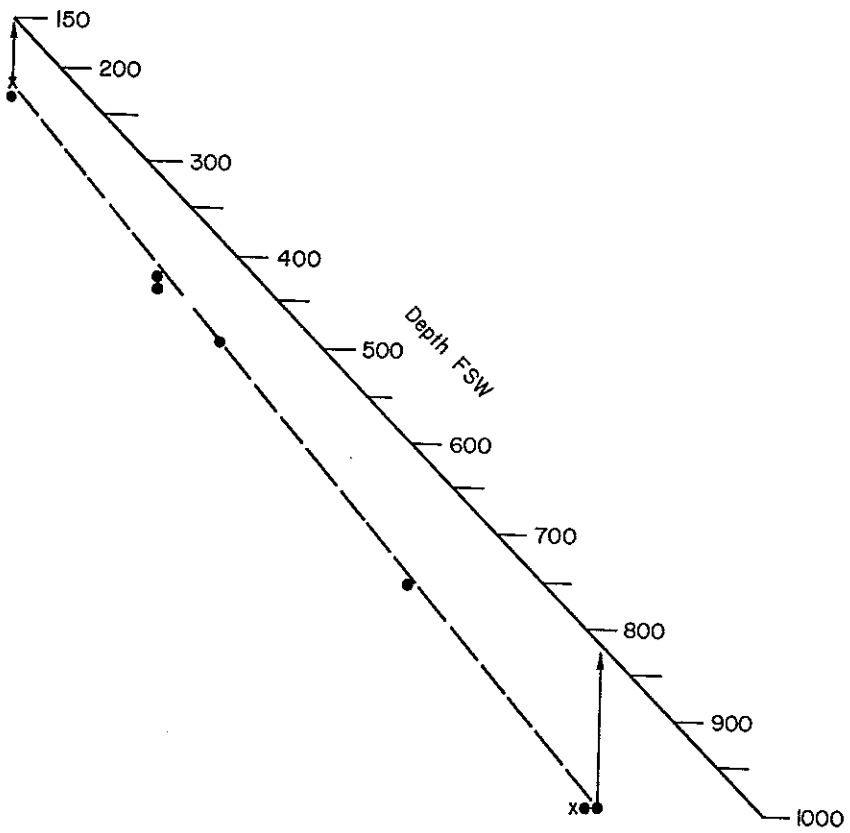


Fig. 6. Deeper and shallower depths shown in Table 2 are graphed together. Slanted solid line represents shallower depth, and vertical distance between solid line and deeper depth points is excursion distance. Broken line was fitted to excursions indicated by arrows. Vertical distances between solid and broken lines were then used to construct table. X = excursions in which decompression sickness occurred as a result of the excursion ascent; ● = excursions which were decompression-sickness-free.

dures depends upon human testing, estimation, and repeated trials. Since all the dives in this study were performed under comparable conditions and with a reasonably systematic method, the results should provide data for those interested in decompression modelling.

Results of the saturation excursion experimental dives graphed in Fig. 6 indicate a linear relationship between the excursion distance and the depth from which the excursion originated. The two excursions at the shallowest and deepest limits of the table (225 to 150 fsw and 1000 to 820 fsw) are probably very close to the maximum permissible excursions at these depths. This is evidenced by the development of serious decompression sickness when the upward excursion from 1000 fsw was increased by only 20 fsw, and the occurrence of knee pain in one of two divers who were 10 fsw deeper than the others during the ascent from 225 fsw. The intermediate points were all decompression-sickness-free; whether or not greater excursions would have been possible was not tested. However, a 150-fsw downward excursion from 300 fsw done at this facility by Flynn and Spaur (1976) produced decompression sickness in one diver after only 3 h at the deeper depth. These dat . indicate that the intermediate points are probably also near the maximum limits.

The linear relationship between excursion distance and depth has been analyzed on a theoretical basis by Hennessy and Hempleman (1977). Berghage, Gomez, Roa, and Everson (1976) have compared the data from these dives with other human and animal data, and they discuss the various linear relationships between excursion distance and depth. A thorough discussion of the significance of these linear relationships is beyond the scope of this paper; the interested reader is referred to the cited references.

The cause and effect relationship of excursions at depth and the pain-only decompression sickness manifested as knee pain with onset at 100 fsw or shallower during decompressions using U.S. Navy Standard Saturation Decompression are difficult to analyze. The incidence of pain-only decompression sickness at the Experimental Diving Unit is estimated at approximately 10 percent. Because all dive subjects are recompressed when any diver complains, the actual incidence may be higher. Except for the dive depicted in Fig. 1C, the effects of the excursions on subsequent saturation decompression cannot be discerned.

Spaur, W. H.., E. D. Thalmann, E. T. Flynn, J. L. Zumrick, T. W. Reedy, and J. M. Ringelberg. 1978. Developpement de tables de décompression pour des excursions de durée indéfinie, et de procédés pour des plongées à saturation en hélium–oxygène. Undersea Biomed. Res. 5(2):159–177.—Pour établir les limites d'excursions multiples et de durée étendue, nous avons entrepris des excursions d'ascente au cours d'une série de plongées à saturation en hélium–oxygène entre 150 et 1000 fsw. La distance qu'un plongeur peut monter sans décompression après avoir atteint la saturation est une fonction de la profondeur, et varie de 75 pieds à une profondeur de saturation de 225 fsw, jusqu'à 180 pieds à 1000 fsw. Le commencement de la décompression à la suite d'une excursion n'entraine aucun inconvenient. Ces résultats ont été incorporés dans les nouvelles tables de décompression de la Marine americaine, U.S. Navy Unlimited Duration Excursion Tables and Procedures for Saturation Diving.

tables de décompression
plongée avec excursion

APPENDIX A

The unlimited duration excursion tables and procedures for saturation diving (Change 1 (1977) to U.S. Navy Diving Manual) (designated Fig. A1 in this paper) were developed to allow the diver a wide vertical range of working depths during a saturation dive. Within the depth limits of the tables, a diver may ascend or descend without regard to the number or duration of these excursions. The tables have no time limits, only depth limits.

The tables and procedures are for use with saturation diving depths between 150 and 1000 fsw. Excursions shallower than 150 ft have not been investigated, and possess a risk of decompression sickness.

Two tables are provided for unlimited duration excursions. The first (designated Table 1A in this paper) lists the limits for excursions deeper than a chosen depth, fsw and msw (U.S. Navy 1977). The first column lists the diver's initial depth. The middle column lists the corresponding deepest excursion distance the diver may descend from that initial depth. The third column is the sum of the initial depth plus the deepest excursion distance and is the deepest excursion depth permitted. To determine the deepest excursion distances for depths which lie between the initial depths listed, the initial depth which corresponds to the shorter deepest excursion distance and the shallower deepest excursion depth should be used.

The second table (designated Table 1B in this paper) lists the limits for excursions shallower than the deepest depth of the dive in fsw and msw (U.S. Navy, 1977). The first column lists depths between 150 and 1000 fsw defined as the deepest depth attained at any time during the dive. The middle column lists the corresponding shallowest excursion distance the diver may ascend from the deepest depth of the dive. The third column is the deepest depth of the dive minus the shallowest excursion distance and is the shallowest excursion depth permitted. To determine the shallowest excursion depth for depths which lie between the deepest depths listed, the deepest depth which corresponds to the deeper shallowest excursion depth should be used.

Standard saturation decompression may commence without delay following any excursion deeper or shallower within the limits of the excursion tables. Additionally, saturation decompression may be initiated by an ascent within the limits for excursions shallower than the deepest depth of the dive. For example, if the deepest depth attained by any diver during the course of a saturation dive were 1000 ft, saturation decompression may be initiated by an ascent to 820 ft at a rate not to exceed 60 ft per min. Following an excursion shallower than the deepest depth of the dive, standard saturation decompression rates and schedules govern the remainder of the decompression.

During use of the tables, the atmosphere in the hyperbaric chamber and personnel transfer capsules should be maintained at an oxygen partial pressure between 0.35 and 0.40 ATA. Additional instructions and examples for use of the tables are in the U.S. Navy Diving Manual (1977).—*Manuscript received for publication September 1977. Revision received April 1978.*

TABLE 1A, fsw

UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions DEEPER than a Chosen Depth

Initial Depth (FSW)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (FSW)	Initial Depth (FSW)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (FSW)
150	75	225	490	128	618
160	77	237	500	130	630
170	78	248	510	131	641
180	80	260	520	133	653
190	81	271	530	135	665
200	83	283	540	136	676
210	84	294	550	138	688
220	86	306	560	139	699
230	88	318	570	141	711
240	89	329	580	142	722
250	91	341	590	144	734
260	92	352	600	146	746
270	94	364	610	147	757
280	95	375	620	149	769
290	97	387	630	150	780
300	99	399	640	152	792
310	100	410	650	153	803
320	102	422	660	155	815
330	103	433	670	156	826
340	105	445	680	158	838
350	106	456	690	160	850
360	108	468	700	161	861
370	109	479	710	163	873
380	111	491	720	164	884
390	113	503	730	166	896
400	114	514	740	167	907
410	116	526	750	169	919
420	117	537	760	171	931
430	119	549	770	172	942
440	120	560	780	174	954
450	122	572	790	175	965
460	124	584	800	177	977
470	125	595	810	178	988
480	127	607	820	180	1000

TABLE 1A, msw

UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions DEEPER than a Chosen Depth

Initial Depth (MSW)	Deepest Excursion Distance (M)	Excursion Depth (MSW)	Initial Depth (MSW)	Deepest Excursion Distance (M)	Excursion Depth (MSW)
46	23	69	122	35	157
48	23	71	124	35	159
50	24	74	126	35	161
52	24	76	128	36	164
54	24	78	130	36	166
56	24	80	132	36	168
58	25	83	134	37	171
60	25	85	136	37	173
62	25	87	138	37	175
64	26	90	140	38	178
66	26	92	142	38	180
68	26	94	144	38	182
70	27	97	146	39	185
72	27	99	148	39	187
74	27	101	150	39	189
76	28	104	152	40	192
78	28	106	154	40	194
80	28	108	156	40	196
82	29	111	158	40	198
84	29	113	160	41	201
86	29	115	162	41	203
88	29	117	164	41	205
90	30	120	166	42	208
92	30	122	168	42	210
94	30	124	170	42	212
96	31	127	172	43	215
98	31	129	174	43	217
100	31	131	176	43	219
102	32	134	178	44	222
104	32	136	180	44	224
106	32	138	182	44	226
108	33	141	184	45	229
110	33	143	186	45	231
112	33	145	188	45	233
114	34	148	190	45	235
116	34	150	192	46	238
118	34	152	194	46	240
120	35	155	196	46	242

TABLE 1A, msw (cont'd.)

UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions DEEPER than a Chosen Depth

Initial Depth (MSW)	Deepest Excursion Distance (M)	Excursion Depth (MSW)	Initial Depth (MSW)	Deepest Excursion Distance (M)	Excursion Depth (MSW)
198	47	245	226	51	277
200	47	247	228	51	279
202	47	249	230	52	282
204	48	252	232	52	284
206	48	254	234	52	286
208	48	256	236	53	289
210	49	259	238	53	291
212	49	261	240	53	293
214	49	263	242	54	296
216	50	266	244	54	298
218	50	268	246	54	300
220	50	270	248	55	303
222	50	272	250	55	305
224	51	275			

TABLE 1B, fsw

UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions SHALLOWER than the Deepest Depth of the Dive

Deepest Depth (FSW)	Shallowest Excursion Distance (ft)	Shallowest Excursion Depth (FSW)	Deepest Depth (FSW)	Shallowest Excursion Distance (ft)	Shallowest Excursion Depth (FSW)
150	0	150	580	123	457
160	10	150	590	124	466
170	20	150	600	126	474
180	30	150	610	127	483
190	40	150	620	129	491
200	50	150	630	130	500
210	60	150	640	131	509
220	70	150	650	133	517
230	76	154	660	134	526
240	77	163	670	135	535
250	78	172	680	137	543
260	80	180	690	138	552
270	81	189	700	139	561
280	82	198	710	141	569
290	84	206	720	142	578
300	85	215	730	143	587
310	87	223	740	145	595
320	88	232	750	146	604
330	89	241	760	147	613
340	91	249	770	149	621
350	92	258	780	150	630
360	93	267	790	152	638
370	95	275	800	153	647
380	96	284	810	154	656
390	97	293	820	156	664
400	99	301	830	157	673
410	100	310	840	158	682
420	101	319	850	160	690
430	103	327	860	161	699
440	104	336	870	162	708
450	105	345	880	164	716
460	107	353	890	165	725
470	108	362	900	166	734
480	110	370	910	168	742
490	111	379	920	169	751
500	112	388	930	171	759
510	114	396	940	172	768
520	115	405	950	173	777
530	116	414	960	175	785
540	118	422	970	176	794
550	119	431	980	177	803
560	120	440	990	179	811
570	122	448	1000	180	820

TABLE 1B, msw

UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions SHALLOWER than the Deepest Depth of the Dive

Deepest Depth (MSW)	Shallowest Excursion Distance (M)	Shallowest Excursion Depth (MSW)	Deepest Depth (MSW)	Shallowest Excursion Distance (M)	Shallowest Excursion Depth (MSW)
46	0	46	122	30	92
48	2	46	124	30	94
50	4	46	126	31	95
52	6	46	128	31	97
54	8	46	130	31	99
56	10	46	132	31	101
58	12	46	134	32	102
60	14	46	136	32	104
62	16	46	138	32	106
64	18	46	140	33	107
66	20	46	142	33	109
68	22	46	144	33	111
70	23	47	146	33	113
72	23	49	148	34	114
74	24	50	150	34	116
76	24	52	152	34	118
78	24	54	154	34	120
80	24	56	156	35	121
82	25	57	158	35	123
84	25	59	160	35	125
86	25	61	162	36	126
88	25	63	164	36	128
90	26	64	166	36	130
92	26	66	168	36	132
94	26	68	170	37	133
96	27	69	172	37	135
98	27	71	174	37	137
100	27	73	176	37	139
102	27	73	178	38	140
104	28	76	180	38	142
106	28	78	182	38	144
108	28	80	184	38	146
110	28	82	186	39	147
112	29	83	188	39	149
114	29	85	190	39	151
116	29	87	192	40	152
118	30	88	194	40	154
120	30	90	196	40	156

TABLE 1B, msw (cont'd.)

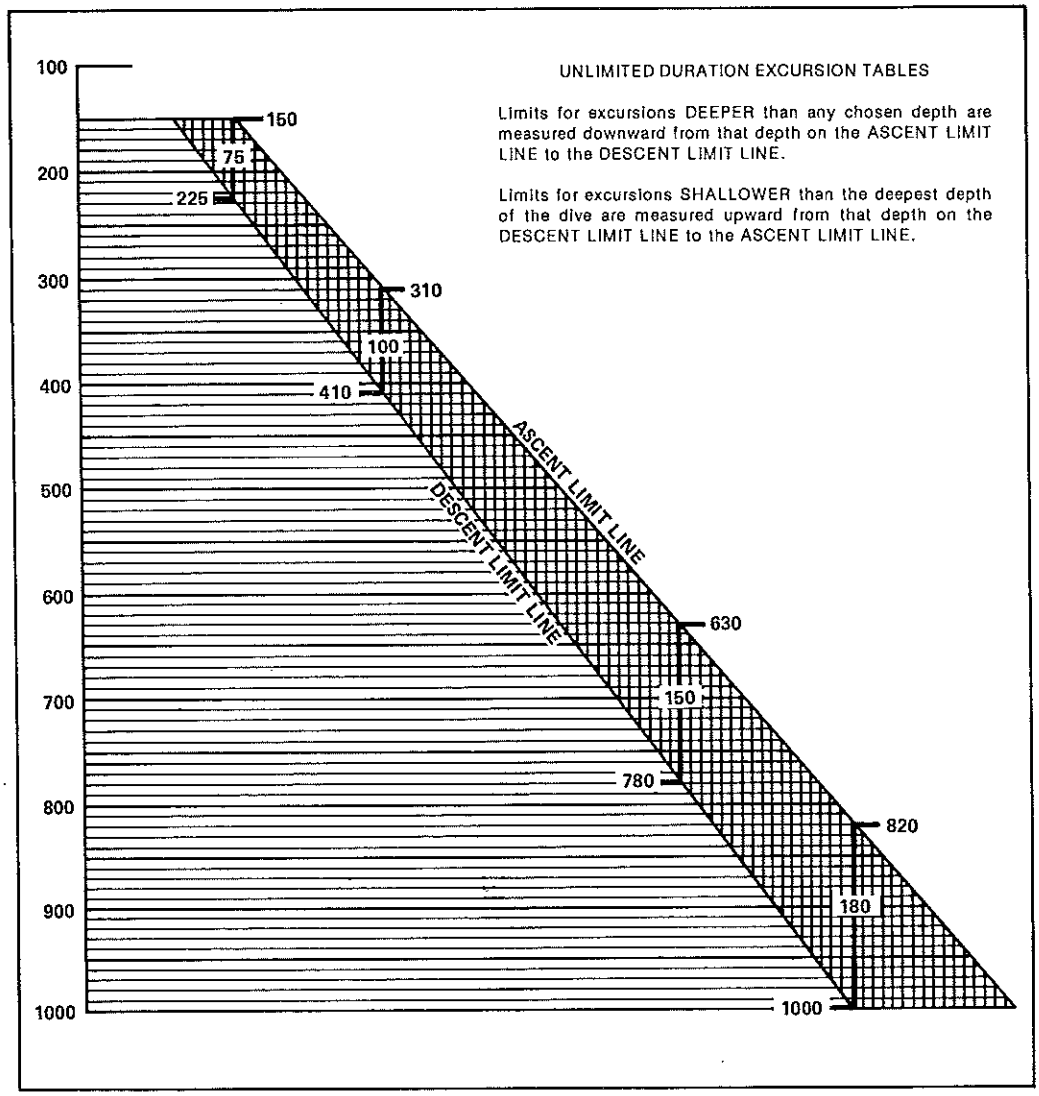
UNLIMITED DURATION EXCURSION TABLE

Limits for Excursions SHALLOWER than the Deepest Depth of the Dive

Deepest Depth (MSW)	Shallowest Excursion Distance (M)	Shallowest Excursion Depth (MSW)	Deepest Depth (MSW)	Shallowest Excursion Distance (M)	Shallowest Excursion Depth (MSW)
198	40	158	252	48	204
200	41	159	254	48	206
202	41	161	256	48	208
204	41	163	258	49	209
206	41	165	260	49	211
208	42	166	262	49	213
210	42	168	264	49	215
212	42	170	266	50	216
214	43	171	268	50	218
216	43	173	270	50	220
218	43	175	272	50	222
220	43	177	274	51	223
222	44	178	276	51	225
224	44	180	278	51	227
226	44	182	280	52	228
228	44	184	282	52	230
230	45	185	284	52	232
232	45	187	286	52	234
234	45	189	288	53	235
236	46	190	290	53	237
238	46	192	292	53	239
240	46	194	294	53	241
242	46	196	296	54	242
244	47	197	298	54	244
246	47	199	300	54	246
248	47	201	302	54	248
250	47	203	304	55	249

Fig. A1

UNLIMITED DURATION EXCURSION TABLES



REFERENCES

Barnard, E. E. P. 1976. Fundamental studies in decompression from steady-state exposures. Pages 263–271, *in* C. J. Lambertsen, Ed. Underwater physiology V. Proceedings of the fifth symposium on underwater physiology. Federation of American Societies for Experimental Biology, Bethesda, Md.

Berghage, T. E., J. A. Gomez, C. E. Roa, and T. R. Everson. 1976. Pressure-reduction limits for rats following steady-state exposures between 6 and 60 ATA. Undersea Biomed. Res. 3(3): 261–271.

Bornmann, R. C. 1970. Decompression schedule development for repetitive saturation excursion helium–oxygen diving. U.S. Navy Deep Submergence Systems Project Research Report 1–70.

Bornmann, R. C. 1971. Helium–oxygen saturation-excursion diving for U.S. Navy. Pages 529–536, *in* C. J. Lambertsen, Ed. Underwater physiology. Proceedings of the fourth symposium on underwater physiology. Academic Press, N.Y.

Braithwaite, W. R., T. E. Berghage, and J. C. Crothers. 1974. Postural equilibrium and vestibular response at 49.5 ATA. Undersea Biomed. Res. 1: 309–323.

Flynn, E. T., and W. H. Spaur. 1976. Recent U.S. Navy experiments in saturation-excursion diving. *In* R. W. Hamilton, Jr., Ed. Development of decompression procedures for depths in excess of 400 feet. Undersea Medical Society, Bethesda, Md. (WS 2–28–76).

Hennessy, T. R., and H. V. Hempleman. 1977. An examination of the critical released gas volume concept in decompression sickness. Proc. R. Soc. Lond. B. 197: 299–313.

Summitt, J. K., J. M. Herron, and E. T. Flynn. 1970a. Repetitive excursion dives from saturated depths on helium–oxygen mixtures. Nav. Exp. Diving Unit Research Report 2–70.

Summitt, J. K., J. M. Alexander, E. T. Flynn, and J. M. Herron. 1970b. Repetitive excursion dives from saturated depths on helium–oxygen mixtures, phase II-saturation depth 200 feet-saturation depth 150 feet. Nav. Exp. Diving Unit Research Report 6–70.

Summitt, J. K., J. M. Alexander, and E. T. Flynn. 1970c. Repetitive excursion dives from saturated depths on helium–oxygen mixtures, phase III-saturation depth 300 feet. Nav. Exp. Diving Unit Research Report 7–70.

Summitt, J. K., J. M. Alexander, and E. T. Flynn. 1970d. Repetitive excursion dives from saturated depths on helium–oxygen mixtures, phase IV-saturation depth 500 feet-saturation depth 600 feet. Nav. Exp. Diving Unit Research Report 8–70.

Summitt, J. K., and J. W. Julig. 1970e. Saturation dives, with excursions, for the development of a decompression schedule for use during SEALAB III. Nav. Exp. Diving Unit Research Report 9–70.

U.S. Navy Diving Manual, Volume 2. Mixed-Gas Diving. NAVSHIPS 0994–001–9010. Sept. 1973. Navy Department, Washington, D.C.

U.S. Navy Diving Manual, Volume 2. Mixed-Gas Diving. Change 1, January 1977.

Workman, R. D. 1965. Calculation of decompression schedules for nitrogen–oxygen and helium–oxygen dives. Nav. Exp. Diving Unit Research Report 6–65.

Blank Page: 178