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EVALUATION TESTING OF THE ADVANCED (SWINDELL) AIR DIVING HELMET

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Navy Experimental Diving Unit

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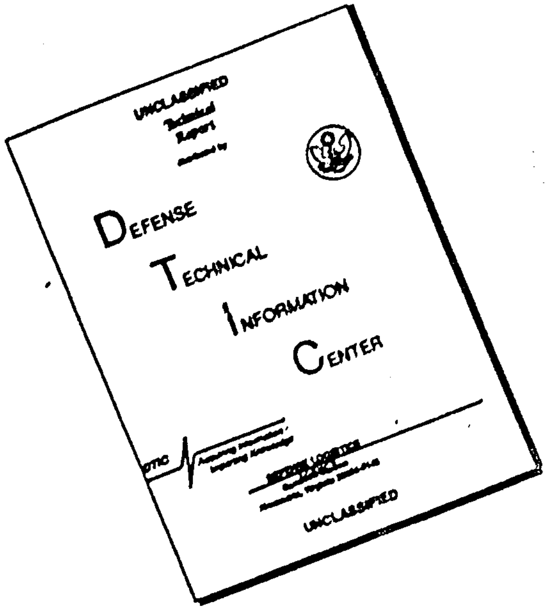

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13. ABSTRACT

The Advanced (formerly Swindell) Series 2000 Model Open-Circuit Air Diving Helmet manufactured and distributed by the Diver's Exhange, Inc. of Harvey, LA was subjected to evaluation testing at the Navy Experimental Diving Unit. The helmet was tested for sound levels and ventilation efficiency using specially built test manikins. It was tested for diver comfort in a series of 36 manned dives. Since many of the testing methods used were new, a discussion of the procedures used as well as the results obtained is presented. The sound levels existing in the helmet were found to be into the damage risk levels under all of the conditions tested, but not so far as to preclude its use provided appropriate precautions are taken. The ventilation efficiency of the helmet was found to be generally adequate provided the air supply pressure is maintained at sufficient levels. The helmet was found to be comfortable for work rates up to and including moderate work.

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I. INTRODUCTION

In 1970, the Navy Experimental Diving Unit began a program to develop a combination air and helium-oxygen diving helmet that would be an improvement over the traditional Mk V air and helium-oxygen helmets. Part of this program was a series of evaluations of commercially available helmets.

This report details the tests performed using the Advanced (formerly Swindell) Air Diving Helmet, Series 2000 Model.

Since many of the evaluation techniques used were new, a discussion of the techniques used is also included.

Appreciation is expressed to the Naval Medical Research Institute for their cooperation in the conduct of this evaluation.

II. EQUIPMENT TESTED

The "Advanced" Air Diving Helmet was initially developed and manufactured by Mr. George Swindell. He sold it as a central part of a general line of air diving equipment under the company name of Advanced Diving Equipment & Manufacturing, Inc. Today the helmet is commonly referred to by both the names "Swindell" and "Advanced". "Advanced" is the name used in this report.

Mr. Swindell sold his helmet business in 1971 to Beckman Instruments, Inc. Beckman in turn sold it in early 1973 to Diver's Exchange, Inc. (DIVEX) of 2245 Breaux Ave., Harvey, LA 70028. DIVEX is the company that manufactures and markets the "Advanced" helmet line at this time.

Figure 1 shows an exploded view of the 2000 Series helmet with a neckseal and jocking strap. Figure 2 shows it on a diver in conjunction with a Series 5549 Bouyancy/Breathing Bag. Figure 3 shows the 1000 Series helmet with neckseal on a diver. The 1000 and 2000 Series helmets are basically similar with the exceptions that the 2000 Series helmet has an upper viewport and recessed earphone sockets not present in the 1000 Series helmet. The 2000 Series helmet also uses a slightly different muffler in the air control valve assembly.

The helmet is constructed primarily of a moulded fiberglass shell with nickel and chrome plated brass fittings. The air control and exhaust assemblies are attached to the brass base piece and not to the fiberglass shell. The viewports are made of fracture-resistant polycarbonate. The exhaust valve assembly is very similar in construction and performance to that in the U.S. Navy Mark V Air Helmet. Muffling of the noise of the incoming air is effected by the use of a sintered metal silencer. The air control valve requires approximately 4 turns to go from the fully closed position to the fully open position. The exhaust valve requires approximately 3 turns. All working seals are effected by the use of "O" rings.

The main helmet tested was the Advanced Air Diving Helmet, Series 2000, Serial Number 419. It was tested using it with standard Advanced neckseals and also a lesser degree (manned tests only) using it with the Advanced 5549 Bouyancy/Breathing Bag. An older 1000 Series Advanced Air Diving Helmet was tested for sound levels only.

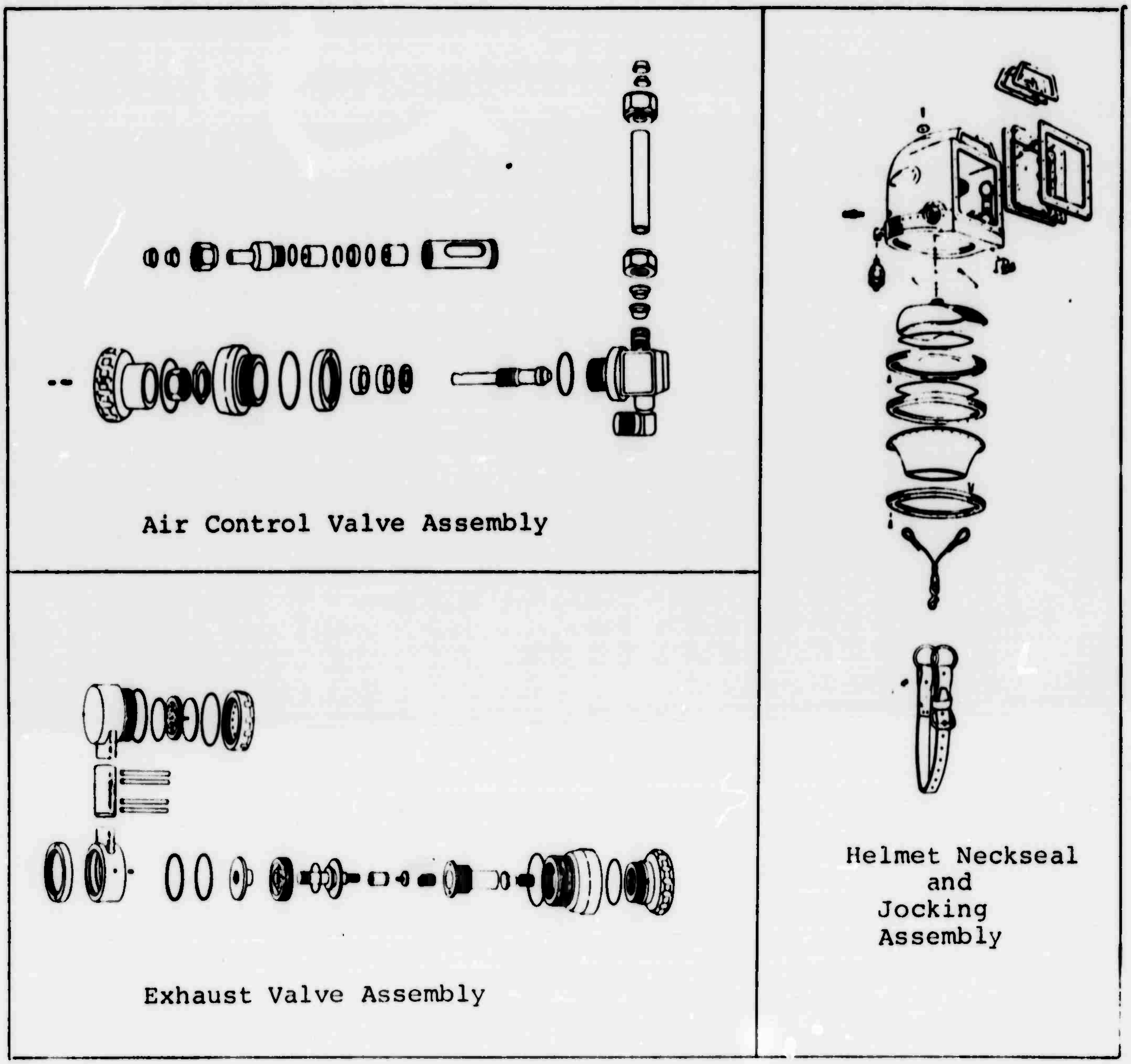

Figure 1

Advanced Series 2000 Air Diving Helmet

Exploded View

Figure 2

Air Diving Helmet, Series 2000

With Model 5549 Bouyancy/Breathing Bag.

Figure 3a
Front View

Figure 3b
Rear View

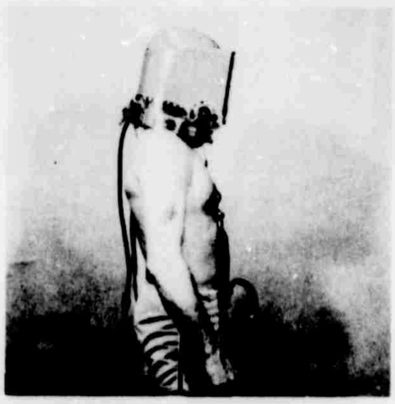

Figure 3c
Right Side View

Figure 3d
Left Side View

Figure 3
1000 Series Helmet and Neckseal

III. TEST PROCEDURES

A. Sound Level Tests

1. Apparatus

A test manikin consisting of a soft rubber head and a fiberglass torso was modified to accommodate a Bruel and Kjaer 1-inch condenser microphone and preamplifier at either the right or left ear position. The microphone head was recessed 1/4 inch from the surface of the manikin ear and was connected through appropriate wiring to a B&K sound level meter outside the chamber. Figure 4 shows a simplified schematic diagram of the complete experimental apparatus.

2. Procedure

Both helmets described in Section II were tested. Both were tested dry in NAVXDIVINGU's #5 recompression chamber.

The helmets were "jocked" (fastened to the test manikin) in a normal diving position. The junction between the helmet neckseal and the manikin's neck was sealed with tape to prevent leaks. Leaks, if present, tended to act as additional sound sources.

The exhaust valve was set at full open during all tests. For the newer 2000 Series helmet, sound level measurements were taken with the air control valve set at 1/4, 1/2 and fully open at depths of 0, 50, 100, 150 and 200 fsw. For the older 1000 Series helmet only surface runs were conducted. Both ear positions were tested for each helmet.

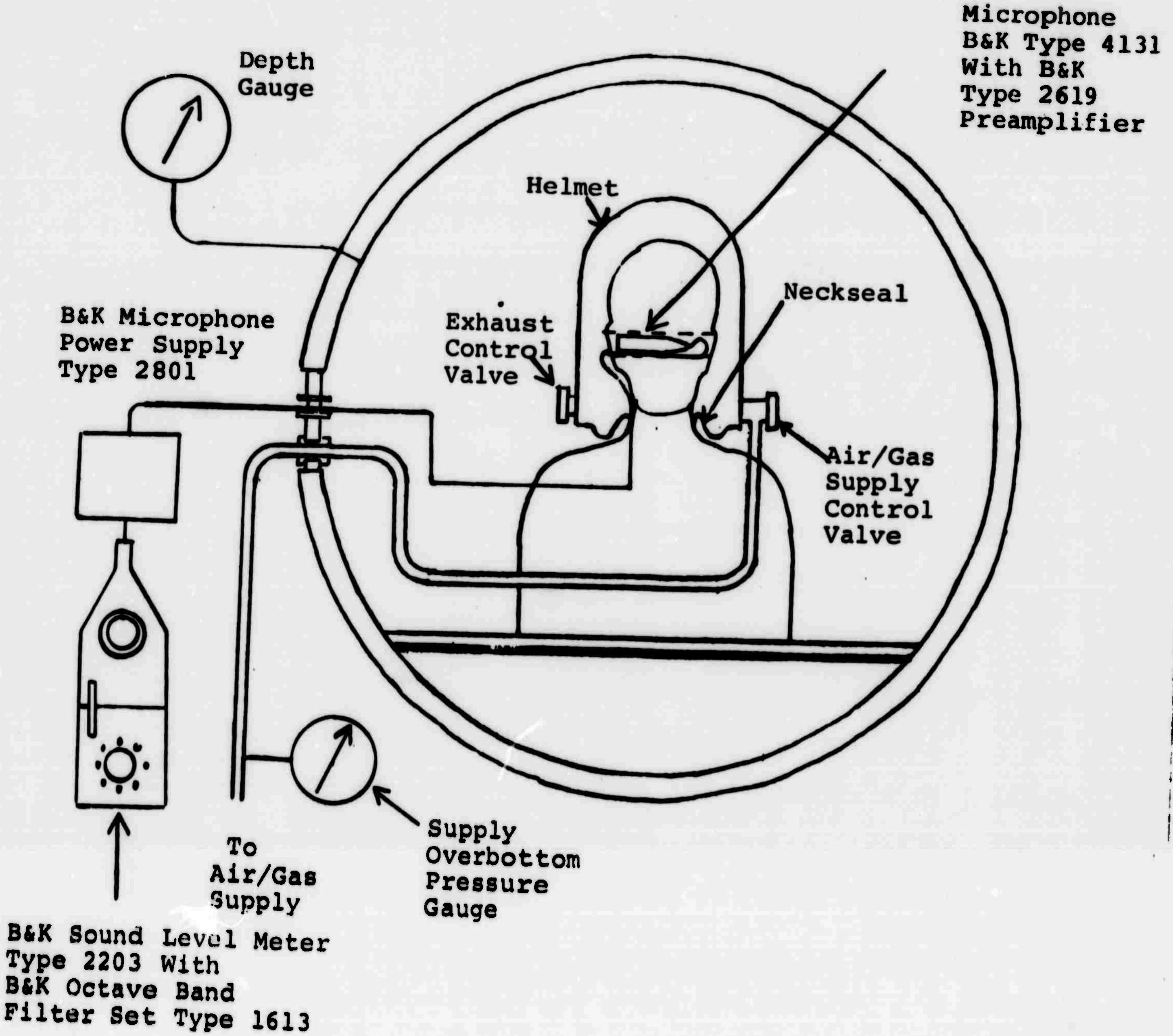

Figure 4

Test Set-Up for Measuring Sound Levels in Advanced Air Diving Helmet.

In all cases the air supply pressure was regulated at 100 psi over bottom pressure. The plumbing between the pressure regulation point and the helmet air control valve was approximately equivalent to three 50' sections of standard diver's air hose.

Microphone calibration was checked before and after each test run with a B&K Sound Level Calibrater Type 4230. No changes in microphone calibration were found.

Chamber background noise levels were also tested and found to be insignificant when compared to the measured helmet sound levels.

3. Data Handling

Octave band sound pressure levels and A-weighted sound levels were taken for all test conditions.

The descriptive sound measurement most frequently used to determine noise risk in industry and in the Navy is the A-weighted sound level, dBA. This term also relates closely to the various noise-rating numbers used to describe interference with communications, annoyance and noise fatigue (3)(4)(5). Unfortunately, calibration curves for the A-weighted sound level measurement at increased ambient pressures as read directly from the sound level meter are not available. It was necessary to first correct the octave band sound pressure levels for increased pressure (6)(7) and then determine an equivalent A-weighted sound level (dBA) from the equivalent sound level contours shown in Figure 5.

It is worth noting that for the noise spectrums normally encountered in diving helmets (noise mostly in the 1000-4000 center frequency octave bands) the equivalent A-weighted

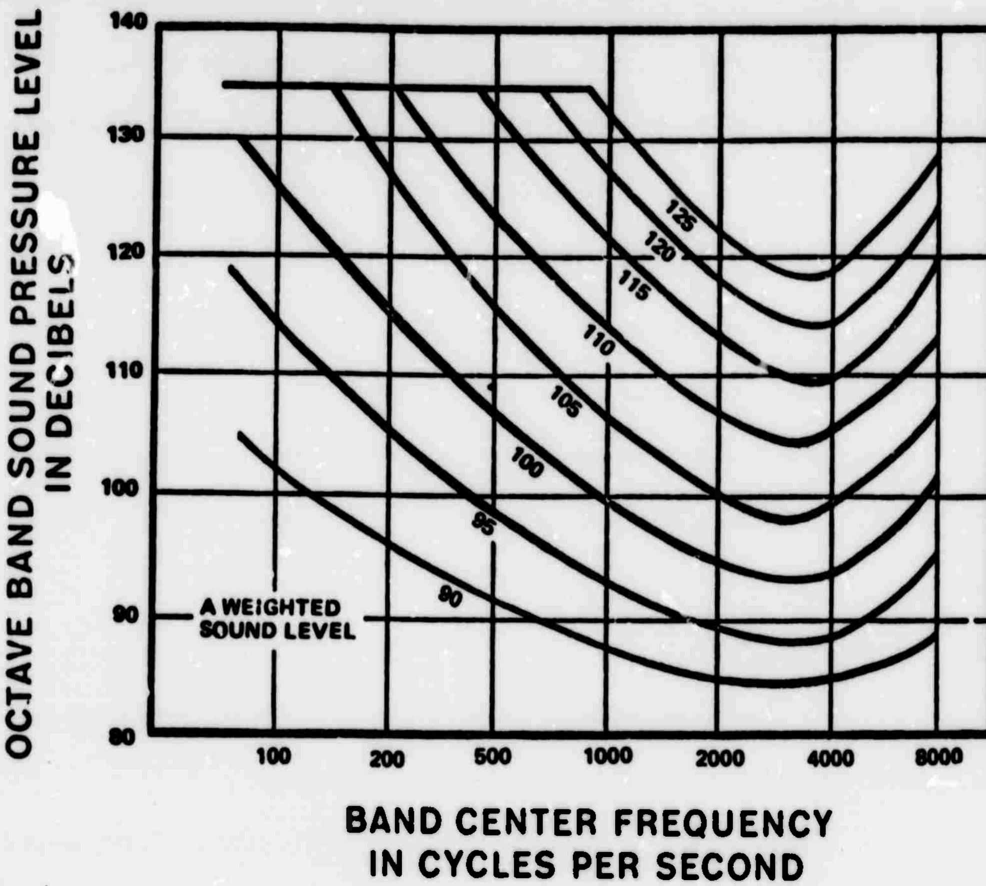

Fig. 5. Equivalent A-Weighted Sound Level Contours. Octave Band Sound Pressure Levels May Be Converted to the Equivalent A-Weighted Sound Level by Plotting Them on This Graph and Noting the A-Weighted Sound Level Corresponding to the Point of Highest Penetration into the Sound Level Contours (2).

sound levels calculated as above at the surface are usually 2-3 dB higher than the meter reading (dBA slow). This comparison, however, can be made, and is valid only at surface conditions.

B. Ventilation Tests

1. Apparatus

Figure 6 shows a schematic diagram of the test set-up used for these tests. Figure 7 shows a typical helmet arrangement in the test box.

The test manikin shown consisted of a head of ¼" soft rubber over a sawdust and epoxy resin core and a fiberglass torso. It contained internal tubing to allow it to breath like a working diver when connected to an external breathing machine as shown. The internal tubing was arranged such that the ratio of oral flow to nasal flow was approximately 2 to 1. The manikin also contained additional internal tubing to allow 4 gas samples and 1 pressure reference to be taken from inside the helmet without having to penetrate or disturb the helmet itself. The pressure reference point was in the center front of the manikin's chin. The gas sample openings were 2 below each ear, and they carried fittings to allow extension tubing or caps to be added as desired. This was done whenever a sample was desired from a location other than immediately below the manikin's ears. Two eyebolts fastened to the torso base front and rear were provided as anchor points for the various helmet "jocking" systems.

The test box was made of ½" acrylic plastic in the shape of a regular hexagonal cylinder 5' high by 33" internal diagonal. The main lid was removed only when changing helmets or working on equipment inside the box. A smaller armhole was used for helmet valve adjustments and minor internal repairs.

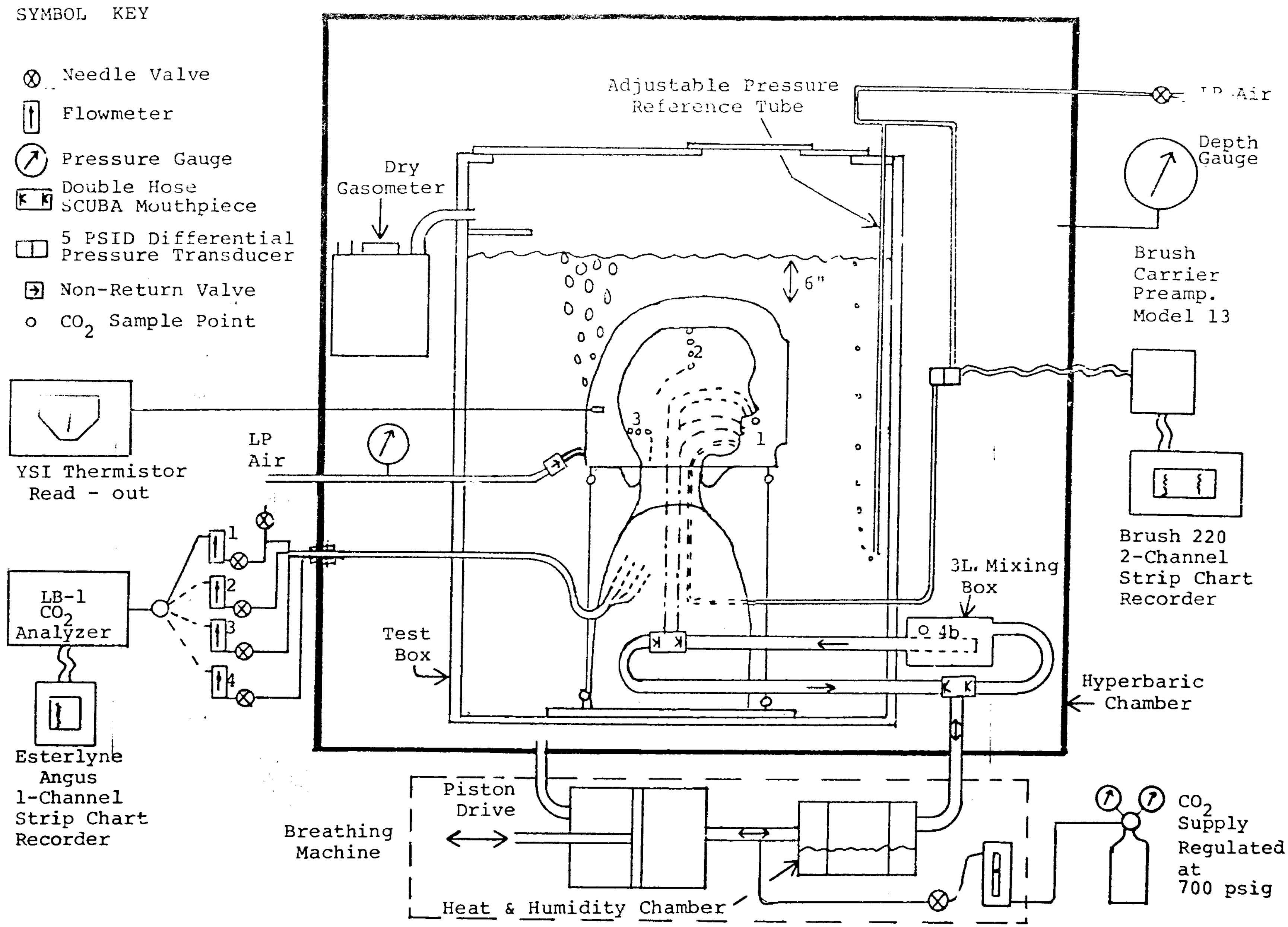

Figure 6 Schematic, Ventilation Efficiency Test Apparatus, 1970-1971
Numbers Refer to CO_2 Sample Lines

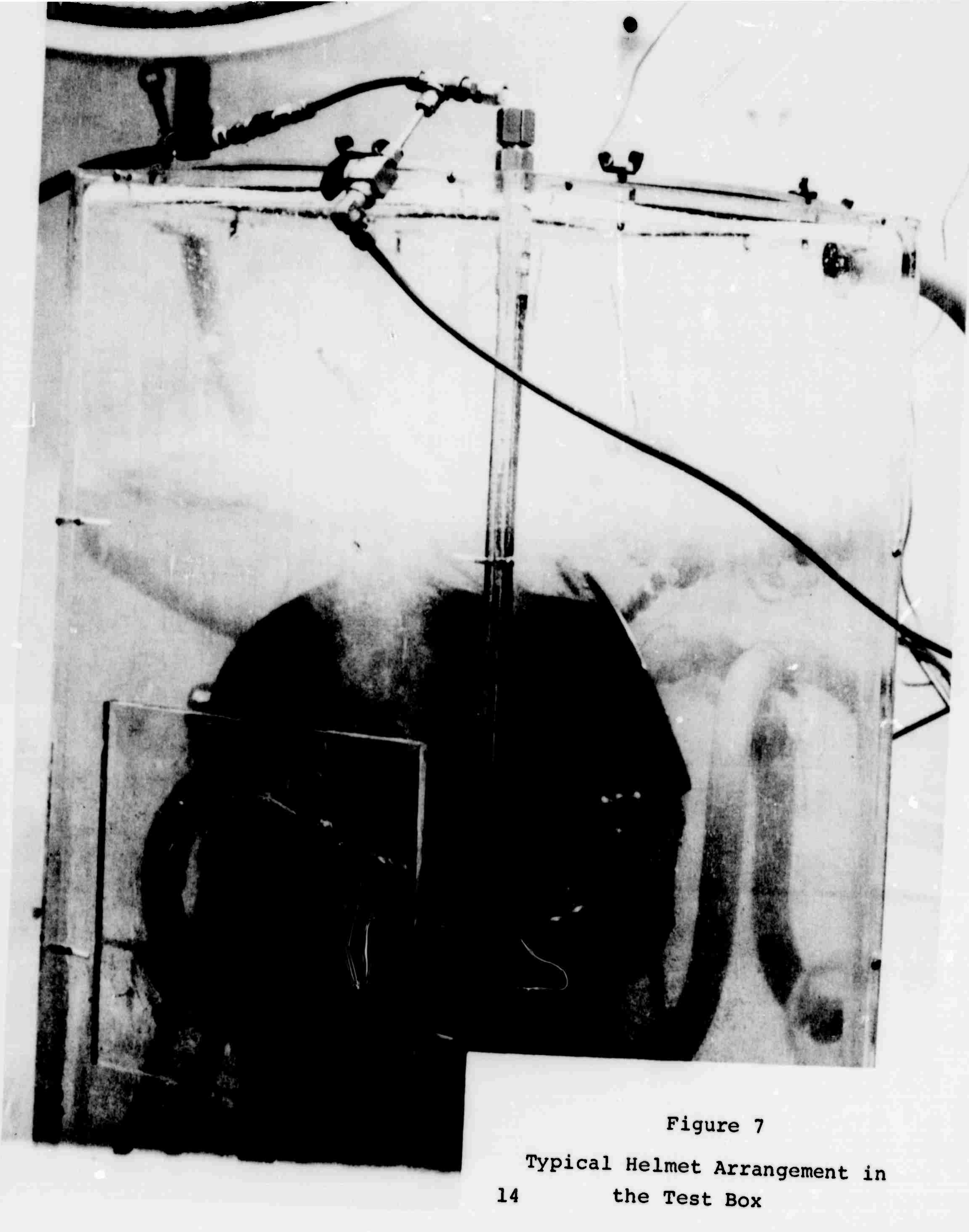

Figure 7

Typical Helmet Arrangement in the Test Box

The loop in the plumbing between the breathing machine and the manikin was used to obtain a more uniform CO_2 concentration in the manikin's exhaled breath. Without the loop the CO_2 had to move from its addition point at the breathing machine to the manikin's mouth by diffusing through an oscillating column of gas. This resulted in a heavy concentration of the expired CO_2 toward the end of the expiration cycle. This situation occured because the necessity (and convenience) of having the breathing machine outside the pressure boundary resulted in long hoses with an internal volume in excess of the 2 liter tidal volume provided by the breathing machine. With the arrangement shown the volume of the oscillating (net flow equal only to the CO_2 addition rate) gas column between the loop (uni-directional flow) and the manikin's mouth was reduced to approximately 140 cc. This was the volume of the breathing system tubing internal to the manikin. With the system shown the volume (or length) of the hoses used in the breathing loop and the volume of the plumbing between the breathing machine and the breathing loop have negligible effect on the expired CO_2 profile. They affect only the mechanical (hose stretch) and pneumatic (air compressability) compliance of the breathing system and its CO_2 concentration time constant (the length of time for CO_2 concentrations to reach equilibrium or steady state). Total breathing loop volume was approximately 5.5 liters.

A sample of the CO_2 profile leaving the mixing box with this system is contained in Appendix A. The time with this system was about 5 minutes. The errors introduced by the mechanical and pneumatic compliance of the breathing loop plumbing were small and could safely be neglected. These errors affected only the maximum and minimum breathing pressures produced in the helmet, and their effect was to reduce the peak pressures produced. The worst case peak reduction which occured at the surface (0 fsw) where the pneumatic compliance was greatest was estimated at less than 10%.

2. Procedure

The following were the controlled variables and the values at which they were controlled:

depth	0, 50, 100, 150, 200 fsw
breathing media	air
breathing machine	
tidal volume	2.0 liters per breath
breathing rate	15, 25 breaths per minute
CO_2 add rate	1.2 and 2.0 slpm respectively at breathing rates of 15 and 25 breaths per minute
waveform	modified sinusoid with exhalation to inhalation time ratio of 1.1 to 1.0
supply pressure	50 psi overbottom pressure at 0 and 50 fsw
	90 psi overbottom pressure at 100, 150, 200 fsw
	measured at the inlet to the non-return valve.

valve positions	
exhaust valve	½ open, fully open
air control valve	¼, ½, fully open
helmet position on manikin	normally jocked position with manikin head looking straight ahead.
exhaled gas	
humidity	saturated at room temp.
temperature	room temp. (approx 70°F)

The following were the measured variables:

helmet pressure relative to water pressure at the level of the manikin's suprasternal notch (20 cm. below the mouth center)

helmet flow rate

helmet internal temperature

CO_2 levels at the following locations

1. at center of manikin's mouth
2. over top of manikin's head
3. lower rear of manikin's head
4.a. inlet to helmet exhaust valve, runs 1,2,5 and 6
  b. outlet of exhalation mixing box, runs 3 and 4.

The procedure was to set the helmet air control and exhaust valves at given positions and then proceed through the depth and breathing rate conditions in the following order:

0 fsw	25 breaths per minute
50 "	25 " " "
100 "	15 " " "
100 "	25 " " "
150 "	25 " " "
200 "	15 " " "
200 "	25 " " "

The air supply pressure and the CO_2 addition rate were varied with depth and breathing rate as indicated above in the paragraph on controlled variables.

The order in which the various air control and exhaust valve positions were tested is given in Tables 4 and 5. For test runs 3 and 4 only, CO_2 sample line #4 was shifted from the inlet to the helmet exhaust valve to the outlet of the exhalation mixing box. This was done to obtain a check on the performance of the breathing machine and CO_2 addition system.

CO_2 samples 1 and 4 were taken by means of open ended 1/16" I.D. tubes. CO_2 samples 2 and 3 were taken by means of 6" sections of perforated 1/16"I.D. tubes closed at the ends. The locations of the various sample points (except the inlet to the helmet exhaust valve) are shown in Figure 6. Due to the time varying nature of CO_2 sample #1 and the lengths of the sample transmission lines (approx. 10' 1/32" I.D. tube), #1 sample line was equipped with a bleed to atmosphere just upstream of its flowmeter. This reduced the sample dwell time in the tubing and helped improve the CO_2 analyser response.

In order to prevent flooding of the helmet the seal between the neckseal and the manikin's neck was augmented with Band-Aid™ skin tape. This was done only after repeated flood-outs with several neck seal type helmets.

The water pressure reference tube for the differential pressure transducer was kept clear of water by adding air from an LP source sufficient to produce a steady, but tiny stream of bubbles from its open end as shown in Figure 6. This was monitored by visual observation.

All transducers, CO_2 analysers and recorders were calibrated daily and immediately prior to any major test. No significant changes in calibration were found to occur. The differential pressure transducer and its recorder were calibrated against a water manometer; the CO_2 analyser and its recorder against gases of known CO_2 concentrations. The dry gasometer and flowmeters were factory calibrated. The thermistor was calibrated against room temperature.

3. Data Handling

The values of the measured parameters are tabulated in Tables 5 and 6. The measured CO_2 values were also cross-checked for consistency and conservation of CO_2. The general results of these cross-checks are discussed in Section IV. B. The detailed results are contained in Appendix A, Tables A-1 and A-2.

C. Manned Tests

1. Apparatus and Procedure

These tests were all conducted in NAVXDIVINGU's #5 and #6 wetpots. The oxygen and carbon dioxide levels existing in the helmet were monitored by Beckman F-3 and IR 215 analysers respectively. The samples were taken at the inlet to the helmet exhaust and were transmitted to the analysers via 1/32" I.D. tubing approx. 20 feet in length.

The helmet was supplied with air from the air control board at 50 psi overbottom pressure for all depths down to 99 fsw and 100 psi overbottom thereafter. The piping between the pressure regulation point and the inlet to the helmet non-return valve consisted of 30 feet of 3/4" I.D. pipe, 3 3/4" CPV globe valves (all fully open) and 50' of standard divers air hose.

Water temperature for all dives was maintained at a level comfortable to the divers, usually about 80°F.

Normal U.S. Navy diving procedures were followed. While on the bottom the divers alternated between 10 minute periods of moderate work and 5 minute rest periods. The work the divers were asked to perform alternated between lifting a 70-pound weight (78 lbs dry) a distance of 2½ feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (20). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (16) or to swimming in SCUBA at a steady speed of approximately 0.8 knots (16)(20).

Thirty manned dives were conducted with the helmet (Series 2000, Serial Number 419) and a standard Swindell neckseal. Six were conducted using the helmet with the Advanced Model 5549 Bouyancy/Breathing Bag. Table 1 lists the depths and bottom times used. Sixteen different divers were used.

Depth/Time (fsw)/(minute)	Helmet with Neckseal	Helmet with Bouyancy/Breathing Bag
30/27	5	0
40/30	2	0
50/40	1	0
60/45	1	0
100/60	9	4
140/20	2	2
150/30	4	
190/20	6	
	30	6

Table 1

Depth-Time Breakdown for Manned Test Dives Conducted With the Advanced Air Diving Helmet.

2. Data Handling

Oxygen and carbon dioxide level readings were taken every 5 minutes during all manned dives. After each dive the divers were asked to complete a subjective analysis questionnaire on the helmet, a copy of which is found in Appendix B.

IV. RESULTS AND DISCUSSION

A. Sound Level Tests

Tables 2 and 3 list the octave band sound pressure levels and equivalent dBA sound levels obtained from the 2000 series helmet. Table 4 lists the same data obtained from the older 1000 series helmet. Also listed for comparison are the surface dBA slow readings directly from the sound level meter.

Figure 8 lists the currently accepted noise exposure limits.

Comparison of figure 8 with Tables 2, 3 and 4 indicates that the sound levels existing in the Advanced Air Diving Helmet are into the damage risk levels under all the conditions tested. The conditions tested are considered representative of most normal diving situations.

The tests described herein were all conducted with the helmet dry. However tests conducted on other Advanced (Swindell) Helmets of the same type at the Naval Coastal Systems Laboratory (NCSL) have indicated that there is no significant increase or decrease in the measured sound levels when the helmet is submerged. There are some increases in the low frequency sound pressure levels due to bubble noise, but they are not sufficient to affect the overall sound levels (10). The sound levels reported by NCSL (10) are comparable to the levels reported herein.

Subsequent experience has shown that reducing the supply overbottom pressure from 100 to 50 psi usually reduces the measured equivalent dBA levels by about 5 dB (8)(9)(11).

DEPTH FSW	SUPPLY VALVE SETTING	OCTAVE BAND SOUND PRESSURE LEVELS DB RE 0.0002 MICROBAR AT THE INDICATED CENTER FREQUENCIES IN HERTZ										dBA Equiv.	S.L. Meter dBA Slow
		31.5	63	125	250	500	1000	2000	4000	8000	16000		
SURFACE	1/8 OPEN												
	1/4 OPEN	90	86	81	76	81	80	87	88	82	84	95	92
	FULL OPEN	93	90	84	87	84	83	89	89	83	84	96	95
50 FEET	1/8 OPEN												
	1/4 OPEN	89	83	76	80	80	83	91	89	85	87	96	
	FULL OPEN	93	87	81	83	84	84	90	89	85	88	96	
100 FEET	1/8 OPEN												
	1/4 OPEN	88	80	76	81	80	82	91	91	90	85	98	
	FULL OPEN	93	87	83	86	87	86	92	91	88	87	98	
150 FEET	1/8 OPEN												
	1/4 OPEN	90	81	78	83	83	83	94	93	91	82	100	
	FULL OPEN	93	87	83	89	90	87	94	93	91	85	100	
200 FEET	1/8 OPEN												
	1/4 OPEN	89	80	78	83	85	85	96	94	86	79	101	
	FULL OPEN	92	86	85	91	92	89	96	94	93	82	101	

Table 2
Sound Levels, Advanced Air Diving Helmet, 2000 Series, Serial Number 419
Left Ear Position, Exhaust Valve Fully Open

Data Taken 13 April 1970

DEPTH FSW	SUPPLY VALVE SETTING	OCTAVE BAND SOUND PRESSURE LEVELS DB RE 0.0002 MICROBAR AT THE INDICATED CENTER FREQUENCIES IN HERTZ										dBA Equiv.	S.L. Meter dBA Slow
		31.5	63	125	250	500	1000	2000	4000	8000	16000		
SURFACE	1/8 OPEN												
	1/4 OPEN	88	82	77	76	81	81	88	88	83	84	95	93
	FULL OPEN	91	85	81	85	83	83	89	89	84	85	96	95
50 FEET	1/8 OPEN												
	1/4 OPEN	86	80	77	76	78	81	89	87	89	85	94	
	FULL OPEN	89	83	80	82	82	84	89	88	86	87	95	
100 FEET	1/8 OPEN												
	1/4 OPEN	87	84	77	76	80	84	91	90	90	84	97	
	FULL OPEN	90	84	81	86	87	87	91	91	88	86	98	
150 FEET	1/8 OPEN												
	1/4 OPEN	87	86	80	81	82	86	93	91	88	81	98	
	FULL OPEN	89	85	84	86	89	89	93	93	88	83	100	
200 FEET	1/8 OPEN												
	1/4 OPEN	85	88	81	82	83	87	95	93	88	79	100	
	FULL OPEN	88	82	84	88	90	90	95	95	89	80	102	

Table 3
Sound Levels, Advanced Air Diving Helmet, 2000 Series, Serial Number 419
Right Ear Position, Exhaust Valve Fully Open

Data Taken 13 April 1970

DEPTH FSW	SUPPLY VALVE SETTING	OCTAVE BAND SOUND PRESSURE LEVELS DB RE 0.0002 MICROBAR AT THE INDICATED CENTER FREQUENCIES IN HERTZ										dBA Equiv.	S.L. Meter dBA Slow
		31.5	63	125	250	500	1000	2000	4000	8000	16000		
						RIGHT	EAR						
SURFACE	1/4 Open	86	82	80	78	83	85	86	88	83	84	95	93
	1/2 Open	91	85	83	79	87	86	86	90	85	85	97	95
	3/4 Open	91	86	83	79	88	86	87	91	86	86	98	95
	Full Open	91	86	83	79	87	86	87	91	86	86	98	95
						LEFT	EAR						
SURFACE	1/4	92	90	85	82	84	82	85	88	84	82	95	93
	1/2	97	95	91	84	89	83	87	92	86	84	99	96
	3/4	97	96	91	84	89	84	87	92	87	84	99	96
	Full Open	97	96	91	84	91	84	88	93	87	84	100	97

Table 4

Sound Levels, Advanced Air Diving Helmet, 1000 Series, Serial Number Unknown, Exhaust Valve Fully Open
Data Taken 14 April, 1970

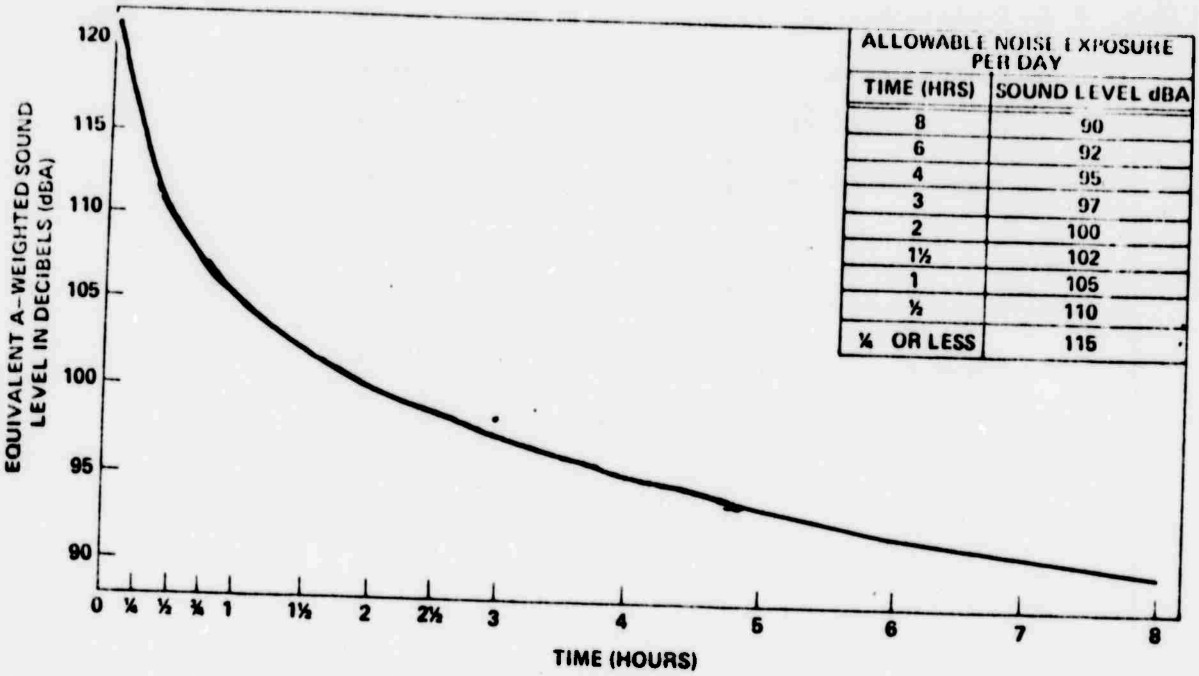

FIGURE 8

Currently Accepted Daily Noise Exposure Limits(2)(4)

Consequently the values presented in Tables 2 and 3 may be somewhat (approximately 5 dB) high for those applications where a 50 psi overbottom pressure may be used.

The tests conducted herein were all conducted with a 100 psi overbottom supply pressure measured at the inlet to a hose arrangement estimated to be equivalent to three 50 foot sections of standard diver's air hose. Consequently the pressure actually reaching the non-return and air control valves was not accurately known nor was the helmet flow rate. Both were known to be appropriate to a diving situation, because the helmet was set-up as it would have been in an actual working dive. However, the fact remains that they were not accurately known, and this makes the reproducibility of data subject to some small degree of uncertainty.

The reproducibility of the NCSL data is also subject to a similar small degree of uncertainty. The helmet flow rates used in producing that data are known, however, the air pressures actually reaching the non-return and control valves are not.

The damage risk levels (Figure 8) have been developed for exposures in 14.7 psia air, and their applicability under increased ambient pressures has not yet been substantiated. There is some reason to believe that the ear may tolerate higher noise levels at increased ambient pressures (1, 19). There are, however, at least three documented cases where maximum exposures (Figure 8) to damage risk level noise under conditions of high ambient pressures have produced significant temporary hearing impairments (1). This suggests that the damage risk criteria should be considered accurate for high ambient pressures until such time as they are either demonstrated inaccurate in that application or are replaced by a subsequent standard.

The variables affecting the sound levels listed in Tables 2, 3 and 4 are not known accurately enough to permit the establishment of maximum exposure times in the helmet based solely on the listed sound levels. Further, more carefully controlled testing would be required before that could be done. However until that time it is considered advisable not to exceed the maximum daily exposure times indicated by comparison of Tables 2, 3 and 4 to Figure 8. In general terms this means restricting a diver's time in the helmet to no more than two to three hours per day depending on the depth of the dive. This may have to be reduced further if the diver is exposed to high noise levels in his non-diving work as well.

If it is desired to compute the maximum allowable exposure to noise of varying levels, the following formula may be used (2)(4):

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots \frac{Cn}{Tn} \leq 1$$

where $C_1 \ldots Cn$ are the actual durations of exposure at the noise levels with duration limits $T_1 \ldots Tn$ as defined by Figure 8. Reference 2, BUMED INST. 6260.6B, Navy Dept., Hearing Conservation Program, should be consulted if it is found necessary to use this formula.

B. Ventilation Tests

Tables 5 and 6 present the complete data taken on the final set of tests. Data from an earlier set of runs with much lower flow rates is contained in Table A-3, Appendix A. Figures 9, 10 and 11 present the more important data contained in Tables 5 and 6 in graphic form. Figure 9 gives a plot of the helmet flow rate versus depth; Figure 10, a plot of the peak helmet pressures resulting from inspiration and expiration; and Figure 11, a plot of the indicated inspired PCO_2.

As can be seen from Tables 5 and 6 and Figure 9, the helmet allows ample air flow throughout most of the depths tested. It fell below the desired maximum flow of 4.5 acfm (17) only at 200 fsw, and then only to 3.6 acfm. Care must be exercised however in using these figures as the capability of many operational air supply systems to actually deliver air at 90 psi overbottom pressure to the helmet (measured at the inlet to the non-return valve) is highly doubtful.

Some leakage of the test box seals occurred at 200 fsw and below during later work using helium-oxygen mixtures. None however is believed to have occurred during these tests. However since seal leakage is a possibility that cannot be completely ruled out at the depths of 150 and 200 fsw the helmet flows for these depths are marked with the "greater than" symbol (>) in Tables 5 and 6.

VALVE POSITION (EXHAUST)	SUPPLY	1/4 OPEN					Run #	1/2 OPEN					Run #	FULL OPEN				
	DEPTH (fsw)	0	50	100	150	200		0	50	100	150	200		0	50	100	150	200
1/2 OPEN	Flow Rate (acfm)	9.5	4.6	3.6	> 2.9	> 2.5		14.1	7.1	6.4	> 5.6	> 3.5		14.8	7.1	6.4	> 4.2	> 3.6
	Peak Inhalation Pressure (cm H_2O)	-6	-18	-18	-20	-22		12	-12	0	-15	-20		16	-8	0	0	10
	Peak Exhalation Pressure (cm H_2O)	38	39	62	72	78		76	76	120	120	110		72	72	120	120	120
	Indicated Inhaled CO_2 Level (% S.E.)	.7	1.4	1.5	< 2.1	< 2.3		.5	.9	1.0	< 1.5	< 1.7		.4	1.1	1.2	< 1.3	< 1.7
	Top of Helmet CO_2 Level (% S.E.)	.65	1.3	1.1	1.4	1.5	1	.4	.7	.5	.5	.9	3	.3	.8	.6	.7	.9	5
	Helmet Lower Rear CO_2 Level (% S.E.)	.65	1.3	1.2	1.4	1.5		.3	.7	.5	.5	.9		.3	.8	.6	.9	.9
	Exhaust Gas/M. Box CO_2 Level (% S.E.)	.6-.8	1.3	1.3	> 1.5	> 1.6		* 4.8	* 4.5	* 4.2	* 4.6	* 4.7		.4-.6	1.0	.9	> .9	> 1.[illegible]
FULL OPEN	Flow Rate (acfm)	7.8	5.6	4.9	> 3.5	> 2.8		15.5	8.1	7.1	> 5.6	> 4.2		16.9	7.4	7.1	> 4.2	> 4.0
	Peak Inhalation Pressure (cm H_2O)	-20	-30	-25	-28	-30		0	-20	-14	-20	-24		4	-16	-4	-16	-20
	Peak Exhalation Pressure (cm H_2O)	28	30	56	64	70	2	58	60	100	96	96	4	60	55	110	90	110	6
	Inhaled CO_2 Level (% S.E.)	.7	1.5	1.5	< 1.9	< 2.3		.4	1.1	1.2	< 1.6	< 1.8		.4	1.0	1.2	< 1.7	< 1.8
	Top of Helmet CO_2 Level (% S.E.)	.6	1.3	1.1	1.2	1.5		.3	.3	.7	.8	.9		.3	.8	.6	.9	.9
	Helmet Lower Rear CO_2 Level (% S.E.)	.7	1.3	1.1	1.2	1.5		.3	.3	.7	.9	1.1		.3	.8	.7	1.0	1.1
	Exhaust Gas/M. Box CO_2 Level (% S.E.)	.6-.9	1.4	1.2	> 1.3	> 1.6		* 4.6	* 4.5	* 5.0	* 5.3	* 4.9		.4-.6	.9	.9	> 1.2	> 1.2

Table 5

Ventilation Tests, Advanced Air Helmet, Serial #419, 2000 Series
25 breaths per minute, 2.0 liters per breath. Overbottom pressures;
50 psi, 0 and 50 fsw; 90 psi, 100,150,200 fsw. CO_2 add rate 2.0 slpm.
Date 29 Jan- 2 Feb, 1971. *Exhalation Mixing Box

VALVE POSITION (EXHAUST)	SUPPLY	1/4 OPEN					Run #	1/2 OPEN					Run #	FULL OPEN				
	DEPTH (fsw)	0	50	100	150	200		0	50	100	150	200		0	50	100	150	200
1/2 OPEN	Flow Rate (acfm)			3.5		> 2.5				5.8		> 3.5				6.0		> 3.5
	Peak Inhalation Pressure (cm H_2O)			-8		-15				8		-12				16		0
	Peak Exhalation Pressure (cm H_2O)			41		48				90		88				88		88
	Indicated Inhaled CO_2 Level (%S.E.)			1.0		< 1.2				.6		< 1.0				.7		< 1.1
	Top of Helmet CO_2 Level (% S.E.)			.8		.7	1 3			.3		.5	5			.4		.5
	Helmet Lower Rear CO_2 Level (% S.E.)			.9		.7				.3		.5				.4		.5
	Exhaust Gas/M. Box CO_2 Level (% S.E.)			.9		> .8				* 4.0		* 4.5				.6		> .6
FULL OPEN	Flow Rate (acfm)			4.2		> 2.8				6.4		> 4.2				7.1		> 3.5
	Peak Inhalation Pressure (cm H_2O)			-20		-27	2 4			0		-16	6			6		-6
	Peak Exhalation Pressure (cm H_2O)			31		38				68		64				75		64
	Inhaled CO_2 Level (% S.E.)			1.1		< 1.4				.7		< 1.3				.7		< 1.1
	Top of Helmet CO_2 Level (% S.E.)			.7		.8				.4		.7				.3		.6
	Helmet Lower Rear CO_2 Level (% S.E.)			.8		.8				.4		.7				.3		.6
	Exhaust Gas/M. Box CO_2 Level (% S.E.)			.9		> 1.0				* 4.6		* 4.9				.6		> .9

Table 6

Ventilation Tests, Advanced Air Helmet, Serial #419, 2000 Series
90 psi overbottom pressure, 15 breaths per minute, 20 liters per breath.
CO_2 add rate, 1.2 slpm. 29 Jan-2 Feb 1971. *Exhalation Mixing Box.

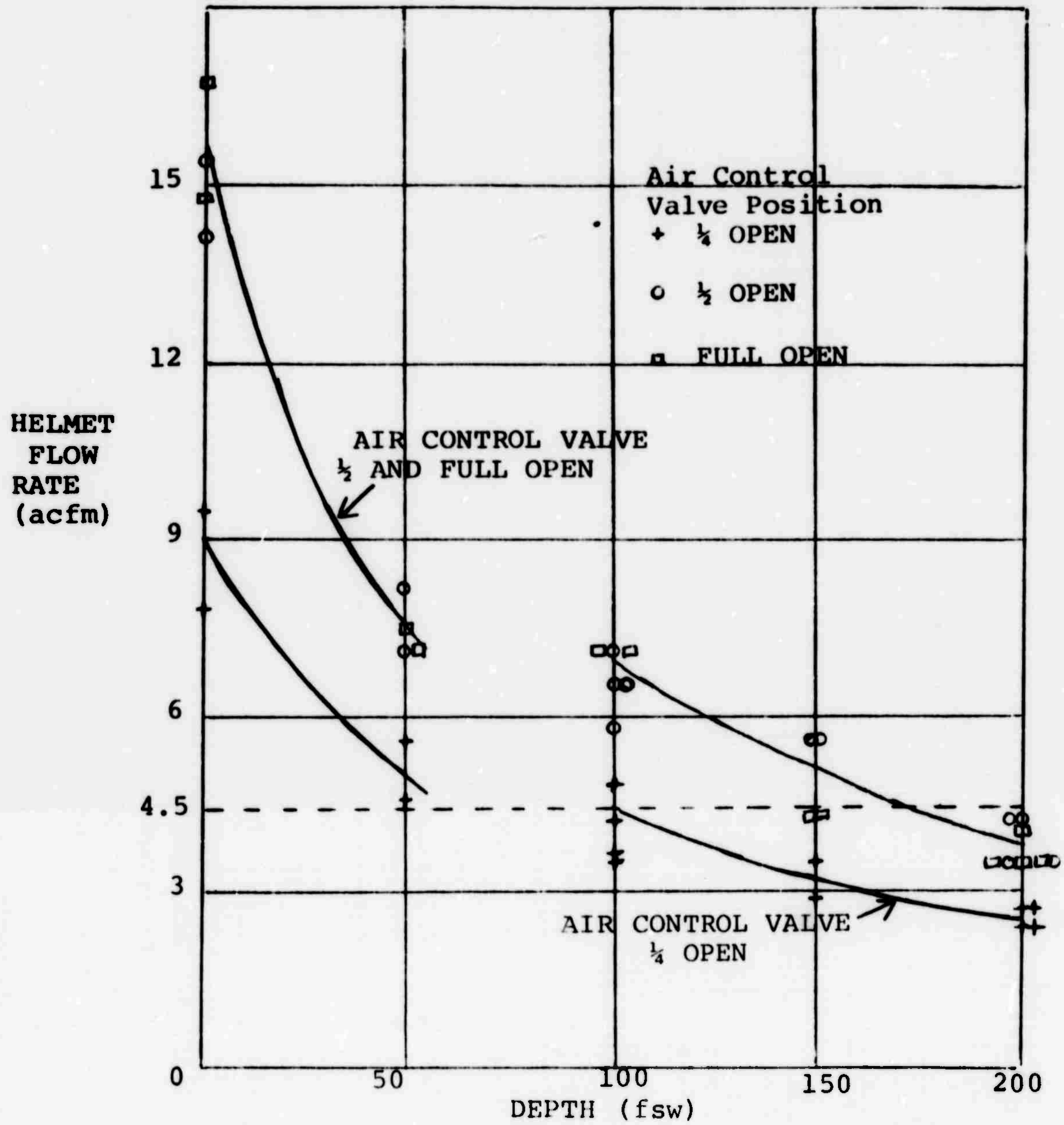

Figure 9

Helmet Flow Rate vs. Depth, Advanced Series 2000 Air Diving Helmet
Supply Pressure Reaching the Helmet Non-Return Valve was 50 psi Overbottom Pressure at 0 and 50 fsw; 90 psi Overbottom at 100, 150, 200 fsw

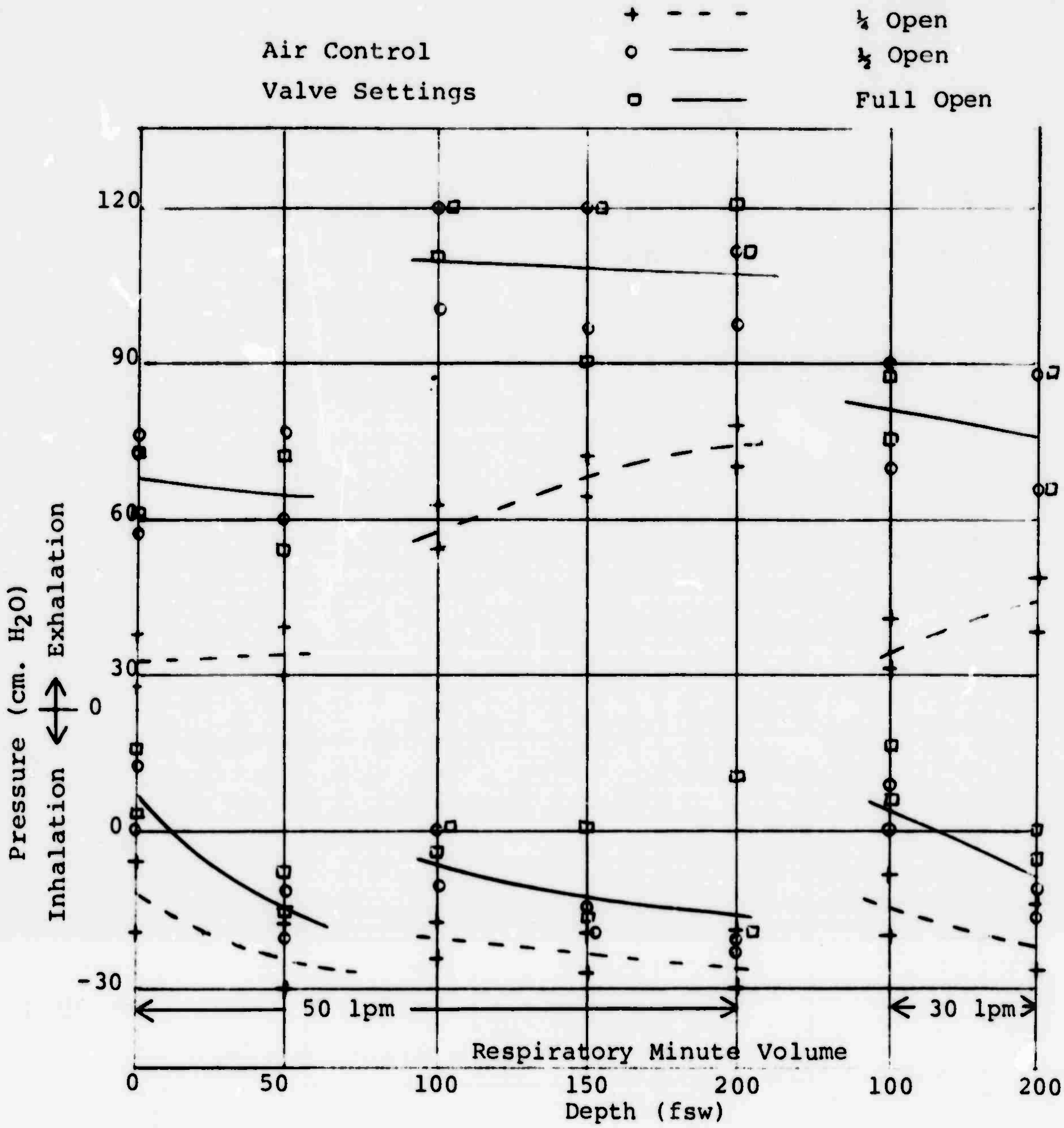

Figure 10

Peak Helmet Pressures on Inhalation and Exhalation Relative to the Suprasternal Notch Level of the Test Manikin (20 cm below mouth level)

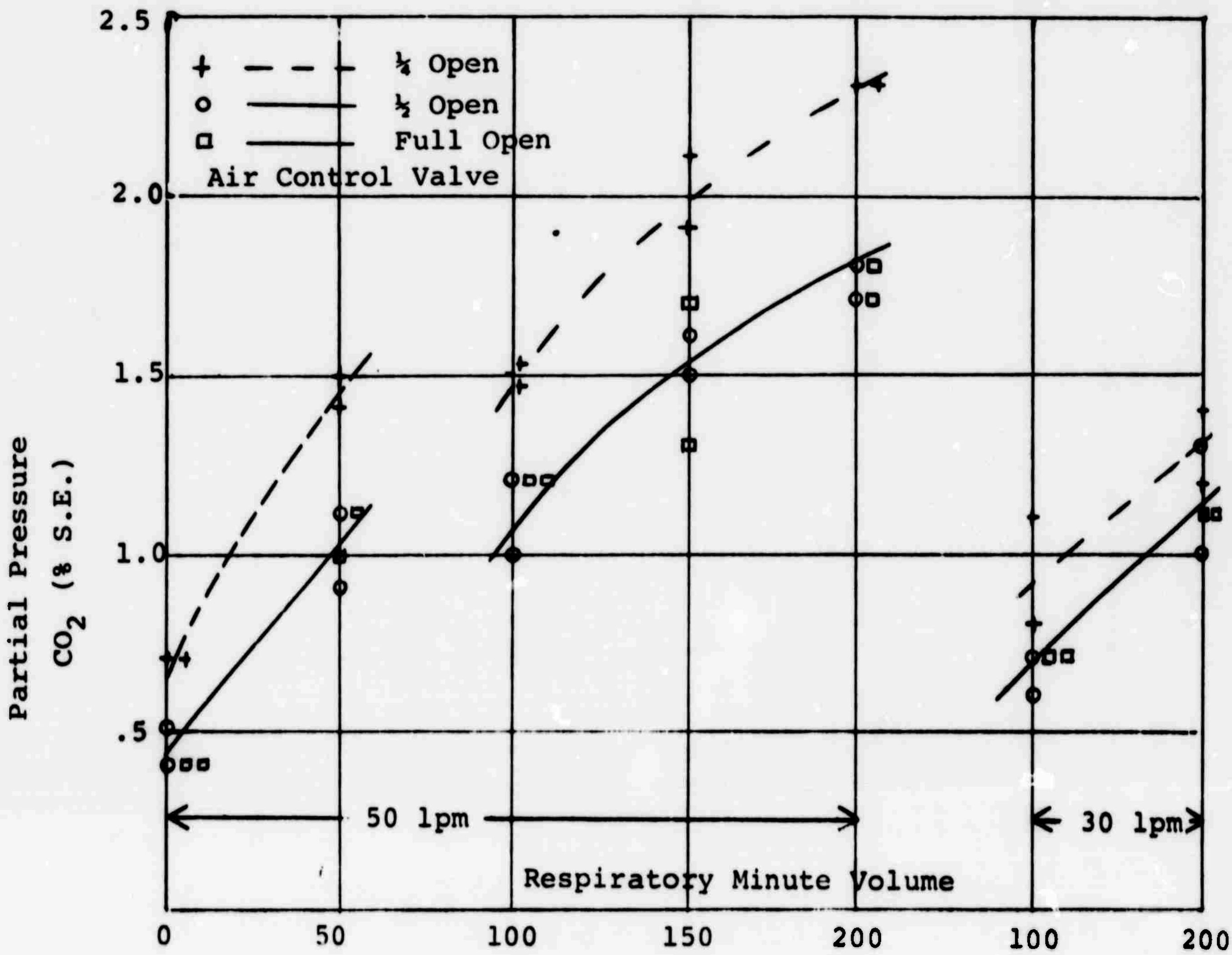

Figure 11

Inspired PCO_2 vs. Depth
Advanced Series 2000 Air Diving Helmet.

Supply Pressure Reaching the Helmet Non-Return Valve was 50 psi Overbottom Pressure at 0 and 50 fsw; 90 psi Overbottom Pressure at 100, 150 and 200 fsw.

The maximum and minimum pressures developed in the helmet during respiration (relative to the test manikin's suprasternal notch 20 cm below mouth center line) were huge! See Figure 10 and Tables 5 and 6. During the early tests (Table A-3 Appendix A) they were sufficient to repeatedly cause flooding of the helmet due to neckseal leakage.

The net air flow into a neckseal type helmet may be characterised as a steady flow equal to the air control valve flow with a sine wave flow equal to the diver's respiratory flow superimposed on top of it. At a respiratory minute volume of 50 lpm a diver is inhaling and exhaling air at peak flows of about 5 cfm. Thus if air is coming in the air control valve at 5 cfm, the net flow into the helmet is varying between 0 and 10 cfm. Since what goes in must come out unless it can somehow accumulate, the exhaust valve under these conditions sees not a steady flow, but rather an unsteady flow varying between nearly 0 and 10 cfm. The effect of neckseal displacement is to provide an accumulator effect that reduces the variations in exhaust valve flow. Allowing the helmet to bob up and down on the diver's shoulders in tune with his respiration has a similar effect. The ultimate in accumulators is a full dry suit or a breathing bag.

In these tests the helmet was securely jocked and could not bob up and down on the test manikin as it often does on a diver. Consequently the only variation in helmet volume available to provide an accumulator effect was neckseal displacement. The volume variation available from neckseal displacement was not measured, but it is estimated to have been no more than 1 liter, considerably less than the 2 liter tidal volume produced by the breathing machine. Thus the exhaust valve was in fact seeing a widely varying flow rate. The exhaust valve used in the Advanced Helmet is very similar in construction and performance to the exhaust valve used in the USN Mark V air helmet, and the Mk V air exhaust valve is known to have a considerable sensitivity to flow rate. At the same valve setting greater flow requires considerably greater pressure differential. Consequently, the wide pressure variations encountered in these tests are considered to represent normal performance by the equipment for the conditions tested. They are not considered to be the result of equipment malfunctions, misadjustment or the like.

They are however unreasonable as far as a diver is concerned. What inhalation and exhalation pressures are tolerable in a helmet are not known at this time. Tests have indicated that due to their short duration in neckseal helmets peak exhalation pressures of up to 60 cm water do not produce discomfort over short (15 minute) periods of time (12)(13). This is quite different from the situation existing with open circuit SCUBA regulators where the peak respiratory pressures and the average respiratory pressures tend to be very nearly equal. There peak pressures of over 20 cm water can become intolerable and even lower peak pressures are required for regulators approved for U.S. Navy use (14). More testing and experimentation will be required before this subject is fully understood. However 120 cm water (1.75 psi) peak exhalation pressure is considered too much. A working diver would either adjust his breathing pattern to shallower, faster breathing (thereby increasing his tendency to retain CO_2) or reduce his work rate. Consequently, the Advanced Air Diving Helmet when used with a neckseal is not considered suitable for heavy work.

The CO_2 levels found to exist in the helmet were almost all below the 2.0% S.E. considered to be the maximum safe level (17). Figure 11 presents a graph of the measured inspired PCO_2 levels versus depth. The CO_2 levels measured in the helmet (top and lower rear) and at the inlet to the helmet exhaust valve were even lower. See Tables 5 and 6.

The CO_2 levels indicated for the top and lower rear of the helmet are considered highly accurate.

The measured inspired CO_2 levels at 150 and 200 fsw may be slightly too high. These levels are marked with the "less than" symbol (<) in Tables 5 and 6. This possible error is due to the measuring technique used. The inhalation PCO_2 readings were taken from a tube in the center of the diver's mouth opening that was drawing a continuous sample. Thus it also drew in exhaled breath. At 150 and 200 fsw the difference between the CO_2 reading obtained for inhaled and exhaled breath dropped below the expected 4.0% S.E., indicating that the measured inhalation PCO_2 reading was too high or the measured exhalation PCO_2 reading was too low, or both. A detailed error analysis is contained in Appendix A.

The CO_2 levels reported for the helmet exhaust at 150 and 200 fsw may be slightly too low. These levels are indicated with the "greater than" symbol (>) in Tables 5 and 6. The flow through the exhaust valve is unsteady as discussed above and it also has a time varying CO_2 concentration that is highest when the flow is highest (manikin exhaling). Thus a sample taken by an open ended tube drawing a steady flow just inside the exhaust valve may represent a true time average of the exhaust gas CO_2 level but not necessarily a true volume average, and the volume average is the important average in this case. This effect becomes more pronounced at the deeper depths where the ratio of peak respiratory flows to helmet flows often exceeds unity and helmet exhaust flow stops althogether during the period of peak inspiratory flow. The accuracy of the measured exhaust CO_2 level can be checked by performing a simple CO_2 balance. Exhaust flow times exhaust PCO_2 should equal the CO_2 addition rate. This balance was performed during the error analysis and the results are listed in the row labelled "CO_2 Exhaust Rate #1" in Table A-2 of Appendix A. Only at the 150 and 200 fsw depths did the calculated exhaust rates fall significantly below the CO_2 addition rates.

The second helmet CO_2'exhaust'rate calculated in Table A-2, inspired PCO_2 times helmet flow rate, yielded CO_2 exhaust rates nearly equal in all cases to the addition rate.

During Runs 3 and 4 the CO_2 level in the outlet of exhalation mixing box was monitored. These levels are marked with an asterisk in Tables 5 and 6. These readings provided a check on the CO_2 addition system and are used in the error analysis in Appendix A. The CO_2 addition system worked well throughout the test series.

Overall the CO_2 levels measured during these tests of the Advanced Air Diving Helmet indicate that the helmet is safe from a CO_2 point of view for all the conditions tested provided:

1. That the air control valve is at least ½ open.
2. That the overbottom pressures measured at the inlet to the helmet non-return valve under the condition of a fully opened air control valve are at least 50 psi for diving in the depth range 0-90 fsw and 90 psi for diving in the depth range 91 to 200 fsw.

The conditions tested are considered to be representative of moderate (30 lpm RMV) and heavy (50 lpm RMV) work.

Due to the possible inaccuracies discussed above in the measured inspired and helmet exhaust PCO_2 levels, no attempt was made to calculate a "helmet mixing effectiveness factor". The "helmet mixing effectiveness factor" is defined as the ratio of average CO_2 level of the inspired air to the average CO_2 level measured in the helmet exhaust gas (15). Other work has indicated a range of "mixing effectiveness factors" for this helmet of from 0.6 to 1.4 (18).

The helmet internal temperature was between 59°F and 69° F for all the tests reported in Tables 5 and 6. It was between 72°F and 89°F for all the tests reported in Table A-3.

C. Manned Tests

CO_2 level readings were obtained for 20 of the 30 dives conducted with the helmet and neckseal and for 4 of the 6 dives conducted with the helmet and bouyancy/ breathing bag. Tables 7 and 8 contain the results. CO_2 values are given only for the bottom times since the decompression CO_2 levels were nearly always low.

The CO_2 levels measured when using the buoyancy/ breathing bag were slightly higher than when using only the neckseal. This probably occurs due to the "accumulator" effect of the bouyancy/breathing bag. The bag smoothes out the exhaust flow and thereby eliminates some of the preferential CO_2 exhaust effect that occurs when the exhaust flow follows closely the sum of helmet flow plus diver's respiratory flow as described in the previous section. The CO_2 levels at moderate diver work rates measured when the bouyancy/breathing bag was used were still below the 2.0% S.E. level recognized as desireable (17).

The average working CO_2 levels measured for the 6 100 foot for 60 minute dives conducted with the helmet and neckseal combination (Table 7) compare very favorably with the helmet CO_2 levels measured on the test manikin when a respiratory minute volume (RMV) 30 lpm was used (Table 6). An RMV of 30 lpm corresponds closely to the moderate work levels the divers were asked to perform (16). The helmet CO_2 levels measured with the helmet on the test manikin at 100 fsw and 30 lpm RMV ranged from .3 to .9% S.E. with

MEASURED CO_2 LEVELS								
Depth/Time	REST				WORK			
(fsw)/(Min.)	N	Avg.	Std. Dev.	Max.	N	Avg.	Std. Dev.	Max.
100/60	5	.61	.33	1.16	8	.75	.36	1.32
100/60	6	.28	.18	.55	5	.55	.40	1.16
100/60	5	.35	.10	.45	8	.53	.19	.76
100/60	6	.09	.07	.22	7	.19	.07	.29
100/60	4	.70	.45	1.35	8	.92	.24	1.26
100/60	6	.46	.05	.53	6	.61	.14	.84
100/60	4	.36	.07	.45	8	.37	.08	.45
100/60	4	.86	.65	1.78	8	1.65	.43	>2.01
Averages 100/60	-	.44	-	-	-	.72	-	-
30/27	5	.25	.09	.41	-	-	-	-
30/27	4	.58	.20	.84	1	.74	.00	.74
50/40	4	.82	.33	1.22	5	.67	.13	.84
60/45	4	.31	.11	.46	6	.27	.09	.38
140/20	3	.65	.08	.74	2	.90	.51	1.26
150/30	3	.94	.22	1.10	3	2.02	.57	2.61
150/30	6	.42	.10	.60	1	.60	.00	.60
150/30	2	.61	.08	.67	4	.59	.14	.75
190/20	2	.48	.09	.54	3	.42	.00	.42
190/20	2	.41	.00	.41	3	.44	.15	.60
190/20	1	1.40	.00	1.40	3	1.06	.16	1.20
190/20	2	.61	.00	.61	2	.75	.19	.88
Averages 190/20	-	.63	-	-	-	.66	-	-

N= Number of Measurements Taken
Avg.= Average Co_2 Level (% S.E.)
Std. Dev.= Standard Deviation of the Average
Max.= Maximum Recorded CO_2 Level (% S.E.)

Table 7

CO_2 Levels Measured in the Advanced Air Diving Helmet in 13 Dives with the Divers Performing Moderate Work and Using a Neckseal.

MEASURED CO_2 LEVELS								
Depth/Time	Rest				Work			
(fsw)/(Min.)	N	Avg.	Std. Dev.	Max.	N	Avg.	Std. Dev.	Max.
100/60	5	.58	.17	.82	8	.56	.18	.8
100/60	6	1.03	.38	1.78	5	.79	.33	1.35
100/60	6	.75	.24	1.23	7	.98	.16	1.12
Averages 100/60	-	.91	-	-	-	.83	-	-
140/20	3	.59	.08	.68	2	.76	.31	.98

N = Number of Measurments Taken
Avg. = Average CO_2 Level (% S.E.)
Std. Dev. = Standard Deviation of the Average
Max. = Maximum Recorded CO_2 Level (% S.E.)

Table 8

CO_2 Levels Measured in the Advanced Air Diving Helmet in 4 Dives with the Divers Performing Moderate Work and Using a Bouyancy/Breathing Bag.

an average of .5% S.E. Except for one dive the helmet CO_2 levels measured during work periods at 100 fsw ranged from .2 to 1.3% S.E. with an average at .6% S.E. That one dive had unusually high CO_2 levels and brought the overall 100 fsw average level up to .7% S.E.

All 36 test dives were conducted with no complaints of tinnitus (ringing ears) or muffled hearing subsequent to a dive. Spot audiometer checks of the divers' hearing acuity pre-and post-dive failed to turn up any temporary hearing decrements. All test dives represented noise exposures less than the recommended maximum exposures.

The diver's personal evaluations of the helmet were generally quite favorable. The characteristics most liked were its light weight in and out of the water, its ease of donning and doffing and its maneuverability in and out of the water. The characteristic that most frequently evoked unfavorable comment was jock strap discomfort. There were also some complaints that the exhaust valve was too small causing the helmet to want to bob up and down on the diver's shoulders and also causing neckseal blow-by at large supply valve openings. It is worth noting here also that below 100 feet none of the test divers used exhaust valve settings other than full open. See Appendix B for more details.

The exhaust valve comments compare well with the test data obtained with the helmet on the test manikin. At a 30 lpm RMV the peak exhalation pressures measured there (Table 6 and Figure 10) were 30 to 90 cm H_2O. As mentioned in Section IV. B, peak exhalation pressures of this magnitude in neckseal helmets are not necessarily intolerable (12)(13). They are however sufficiently high to cause some discomfort and therefore some diver complaints.

Overall the divers liked the helmet and neckseal combination at the light to moderate work rates they were asked to perform. No attempts were made to perform heavy work (RMV's of 40 to 60 lpm). However based on the results reported in Section IV. B and the exhaust valve comments reported herein at moderate work, it is felt that the divers would not have found the helmet-neckseal combination suitable for heavy work.

Comments concerning the helmet-bouyancy/breathing bag combination were uniformly unfavorable. The bag tended to over-inflate and squeeze the diver's chest. Its bouyancy and its tendency to bulge outward at the bottom also increased jock strap discomfort. The bag was wearable and useable, but only with an unpleasant degree of discomfort.

The over-inflation problem is probably related to the exhaust valve problems discussed previously. The tendency of the bags to go straight like boards on inflation could be eliminated by better bag design.

The idea of a bouyancy/breathing bag has a lot of merit. It gives the diver some degree of bouyancy control if he wants it, and it provides an "accumulator" effect that reduces greatly the peak respiratory pressures produced in the helmet. The particular bag tested was simply a poor execution of an otherwise reasonable idea.

V. CONCLUSIONS

The conclusions given below are strictly valid only for the helmet tested, Advanced Air Diving Helmet, Series 2000, Serial Number 419 which was in factory condition at the time it was tested. Their applicability to other helmets of the same type is dependent on the quality control exercised by the manufacturer. At this time there is no reason to suspect that other helmets of the same type will not possess essentially similar characteristics since they are manufactured by modern small assembly line techniques. However, if there is doubt regarding a specific helmet, particularly with reference to its sound level characteristics, it should be tested.

A. The sound levels existing in the helmet were into damage risk levels under all of the conditions tested. The conditions tested are considered representative of most normal air diving situations.

B. With proper precautions the helmet may be used without risking damage to the diver's hearing.

C. The maximum flow rates of which the helmet is capable fall below the recommended maximum of 4.5 acfm only at depths deeper than approximately 170 fsw provided that the air pressure reaching the inlet to the helmet non-return valve under the condition of a fully open air control valve is at least 50 psi overbottom pressure in the depth range 0 to 90 fsw and 90 psi overbottom pressure in the depth range 91 to 200 fsw.

D. The CO_2 levels existing in the helmet at diver work rates appropriate to respiratory minute volumes of up to 50 lpm will be within recognized safe limits (less than 2.0% S.E.) in the depth range 0 to 200 fsw provided that:

1. The conditions identified in C above are met.
2. Reasonable prudence is exercised on the part of the diver in his manipulation of the air control valve.
3. The helmet is supplied with air containing no more CO_2 than is found in normally clean atmospheric air.
4. The helmet is assembled as recommended by the manufacturer and is in normal good working order.
5. The helmet is used with a neckseal.

E. The CO_2 levels in the helmet when it is used with a bouyancy/breathing bag are slightly higher than when it is used with a neckseal.

F. When the helmet is used with a neckseal, the pressure variations in the helmet caused by respiration rates appropriate to moderate work are sufficient to cause some diver discomfort. The pressure variations caused by respiration rates appropriate to heavy work are high enough to cause considerable diver distress.

G. The agents primarily responsible for the wide pressure variations found in the helmet-neckseal combination at high diver RMV's are:

1. Insufficient variable volume in the helmet-neckseal combination.

2. Insufficient exhaust valve capability and too much exhaust valve sensitivity to exhaust flow rate.

H. The helmet and neckseal combination is considered reasonably comfortable by the divers for work rates up to and including moderate work.

I. The bouyancy/breathing bag is uncomfortable.

V. RECOMMENDATIONS

A. No significant USN use of this helmet is presently contemplated. However, prior to any significant USN use, more thoroughly instrumented sound level testing should be conducted to augment the data contained herein.

B. If the helmet is to be used prior to the completion of A above, it is recommended that the daily exposure times in the helmet be controlled such that noise exposure limits based on the data contained herein are not exceeded. Basically, this means limiting a diver's time in the helmet to 2 to 3 hours per day depending on the depth of the dive and the level of noise the diver is exposed to when he is not diving.

C. For future work it is recommended that instrumentation improvements be implemented to remove the measurement uncertainties expressed in Section IV. B. It is also recommended that instruments be obtained to permit the monitoring and measurement of helmet flow rates and pressures during manned test dives.

D. It is recommended that efforts be initiated to develop meaningful guidelines for acceptable helmet pressure variations resulting from the diver's respiration. These guidelines would most likely be in the form of maximum external work of respiration rather than in the form of pressure limitations.

REFERENCES

1. Summitt, J. K. and Reimers, S. D. "Noise, A Hazard to Divers and Hyperbaric Chamber Personnel", Aerospace Medicine, Vol. 42, No. 11, Nov 1970 also available as NAVXDIVINGU Research Report 5-71.

2. Navy Department: Hearing Conservation Program. Bureau of Medicine and Surgery Instruction 6260.6B, 5 March 1970

3. Bruel and Kjaer Corporation, "Precision Sound Level Meter Type 2203, Instructions and Applications", Copenhagen, 1968

4. "Criteria for a Recommended Standard, Occupational Exposure to Noise", U.S. Department of Health, Education, and Welfare, 1972

5. Botsford, J. H., "Using Sound Levels to Gauge Human Response to Noise", Sound and Vibration 3(10); 16-28, 1969

6. Bruel and Kjaer Corporation, "One-Inch Condenser Microphones, Instructions and Applications". Copenhagen, 1968

7. Thomas, W. G., Preslar, M. J. and Farmer, J. C., "Calibration of Condenser Microphones under Increased Atmospheric Pressures", Journal of the Acoustical Society of America, Vol. 51, Number 1 (Part 1), 1972 pp 6-14

8. Reimers, S. D. and Summitt, J. K., "Sound Level Testing of the Standard USN MK V Air and Helium Oxygen Diving Helmets". Navy Experimental Diving Unit Report 4-73, 8 June 1973

9. Lauderdale, C.L., "Measurement of Noise Levels in the General Electric and Navy MK V Diving Helmets", Navy Coastal Systems Laboratory Technical Report, February 1973.

10. Freeman, E. and Mullen, W., Unpublished Data, Project SF27523, Task 13306, Naval Coastal Systems Laboratory, 1970.

11. Reimers, S.D., "Sound Level Testing of the DESCO Prototype Helium-Oxygen Diving Helmet" Navy Experimental Diving Unit Report 5-73, 15 June 1973.

12. Reimers, S.D., "Advanced HeO_2 Diving Helmet" Navy Experimental Diving Unit, Unpublished Data.

13. Reimers, S.D. "Aquadyne HeO_2 Diving Helmet" Navy Experimental Diving Unit, Unpublished Data.

14. "Regulator, Air, Demand, Single Hose, Nonmagnetic, Diver's", Military Specification MIL-R-24169A, 22 March 1967.

15. Henkener, J.A., "Low-Pressure Compressed Air Breathing Systems Study. Part II. Mark V Helmet Ventilation Studies". Battelle Memorial Institute, Sept. 22, 1970.

16. U.S. Navy Diving Gas Manual, Research Report Number 3-69, U.S. Navy Supervisor of Diving, Naval Ship Systems Command, Oct. 1, 1969.

17. U.S. Navy Diving Manual, NAVSHIPS 0994-001-9010, March 1970.

18. Henkener, J.A. "Preliminary Results on Swindell Helmet", Battelle Memorial Institute, Unpublished Data, January 25, 1971.

19. Fluur, E. and Adolfson, J., "Hearing in Hyperbaric Air". Aerospace Medicine, Vol. 37, No. 8, 1966, pp. 783-785.

20. Lanphier, E.H., Dwyer, J.V. and Walkowski, A.J., "A Trapeze Ergometer", Navy Experimental Diving Unit Formal Report 1-55, 18 March 1955.

Appendix A.

1. Error Analysis of Final Ventilation Tests, Tables A-1 and A-2.
2. Results of Initial Ventilation Tests, Table A-3.
3. Samples of Recorder Outputs from Final Ventilation Tests, Figures A-1 to A-3.

DEPTH (fsw)	0	50	100	150	200		100	200
Respiratory Minute Volume (alpm)	50	50	50	50	50		30	30
CO_2 Addition Rate (slpm)	2.0	2.0	2.0	2.0	2.0		1.2	1.2
RUN 3								
Exhalation Mixing Box PCO_2 (% S.E.)	4.8	4.5	4.2	4.6	4.7		4.0	4.5
Indicated Exhaled PCO_2 (% S.E.)	4.7	4.5	4.2	4.0	3.5		4.0	4.0
Indicated Inhaled PCO_2 (% S.E.)	.5	.9	1.0	< 1.5	< 2.3		.6	< 1.0
PCO_2 Difference M. Box - Ind. Inh. (% S.E.)	4.2	3.6	3.2	3.1	3.0		3.4	3.5
PCO_2 Difference M. box - Helmet PCO_2 (% S.E)	4.4	3.8	3.7	4.1	3.8		3.7	4.0
RUN 4								
Exhalation Mixing Box PCO_2 (% S.E.)	4.6	4.5	5.0	5.3	4.9		4.6	4.9
Indicated Exhaled PCO_2 (% S.E.)	4.3	4.7	5.0	4.7	4.2		4.6	4.9
Indicated Inhaled PCO_2 (% S.E.)	.4	1.1	1.2	< 1.6	< 1.3		.7	< 1.3
PCO_2 Difference M. Box - Ind. Inh. (% S.E.)	3.9	3.4	3.8	3.7	3.6		3.9	3.6
PCO_2 Difference M. Box - Helmet PCO_2 (% S.E.)	4.3	4.2	4.3	4.5	4.0		4.2	4.2
AVERAGES, RUNS 3 AND 4								
PCO_2 Difference #1 M. Box - Exh PCO_2 (% S.E.)	.2	-.1	.0	.6	.8		.0	.3
PCO_2 Difference #2 M. Box - Inh PCO_2 (% S.E.)	4.1	3.5	3.5	3.4	3.3		3.7	3.6
PCO_2 Difference #3 M. Box-Helmet PCO_2 (% S.E.)	4.4	4.0	4.0	4.3	3.9		4.0	4.1
PCO_2 Difference #3 Minus Pred. Diff of 4.0% S.E.	.4	.0	.0	.3	-.1		.0	.1

Table A-1
Advanced Air Helmet Tests, Error Analysis Runs 3 & 4 < Indicates Actual Value May Have Been Slightly Lower Than Value Indicated.

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DEPTH (fsw)	0	50	100	150	200		100	200
Resp. Minute Volume (alpm)	50	40	50	50	50		30	30
CO_2 Addition Rate (slpm)	2.0	2.0	2.0	2.0	2.0		1.2	1.2
	RUN 1							
Indicated CO_2 Exhaust Rate (slpm)	1.5	1.7	1.3	1.2	1.1		.9	.6
Indicated Exhaled PCO_2 (% S.E.)	5.0	4.7	4.2	4.7	4.6		5.8	4.7
Indicated Inhaled PCO_2 (% S.E.)	.7	1.4	1.5	<2.1	<2.3		1.0	<1.2
Indicated PCO_2 Difference Exhale-Inhale (% S.E.)	4.3	3.3	2.7	2.6	2.3		4.8	3.5
	RUN 2							
Indicated CO_2 Exhaust Rate (slpm)	2.0	2.2	1.7	1.3	1.3		1.1	.8
Indicated Exhaled PCO_2 (% S.E.)	4.3	5.3	4.5	4.2	4.6		5.2	5.1
Indicated Inhaled PCO_2 (% S.E.)	.7	1.5	1.5	<1.9	<2.3		1.1	<1.4
Indicated PCO_2 Difference Exhale-Inhale (% S.E.)	3.6	3.8	3.0	2.3	2.3		4.1	3.7
	RUN 5							
Indicated CO_2 Exhaust Rate (slpm)	2.1	2.0	1.6	1.1	1.0		1.0	.6
Indicated Exhaled PCO_2 (% S.E.)	4.4	4.5	4.2	3.6	3.5		4.4	4.0
Indicated Inhaled PCO_2 (% S.E.)	.4	1.1	1.2	<1.3	<1.7		.7	<1.1
Indicated PCO_2 Difference Exhale-Inhale (% S.E.)	4.0	2.4	3.0	2.3	1.8		3.7	2.9
	RUN 6							
Indicated CO_2 Exhaust Rate (slpm)	2.4	1.9	1.8	1.4	1.3		1.2	.9
Indicated Exhaled PCO_2 (% S.E.)	4.6	4.7	4.8	4.7	4.0		4.6	4.5
Indicated Inhaled PCO_2 (% S.E.)	.4	1.0	1.2	<1.7	<1.8		.7	<1.1
Indicated PCO_2 Difference Exhale-Inhale (% S.E.)	4.2	3.7	3.6	3.0	2.2		3.9	3.4

Table A-2

Advanced Air Diving Helmet, Error Analysis Runs 1, 2, 5 & 6

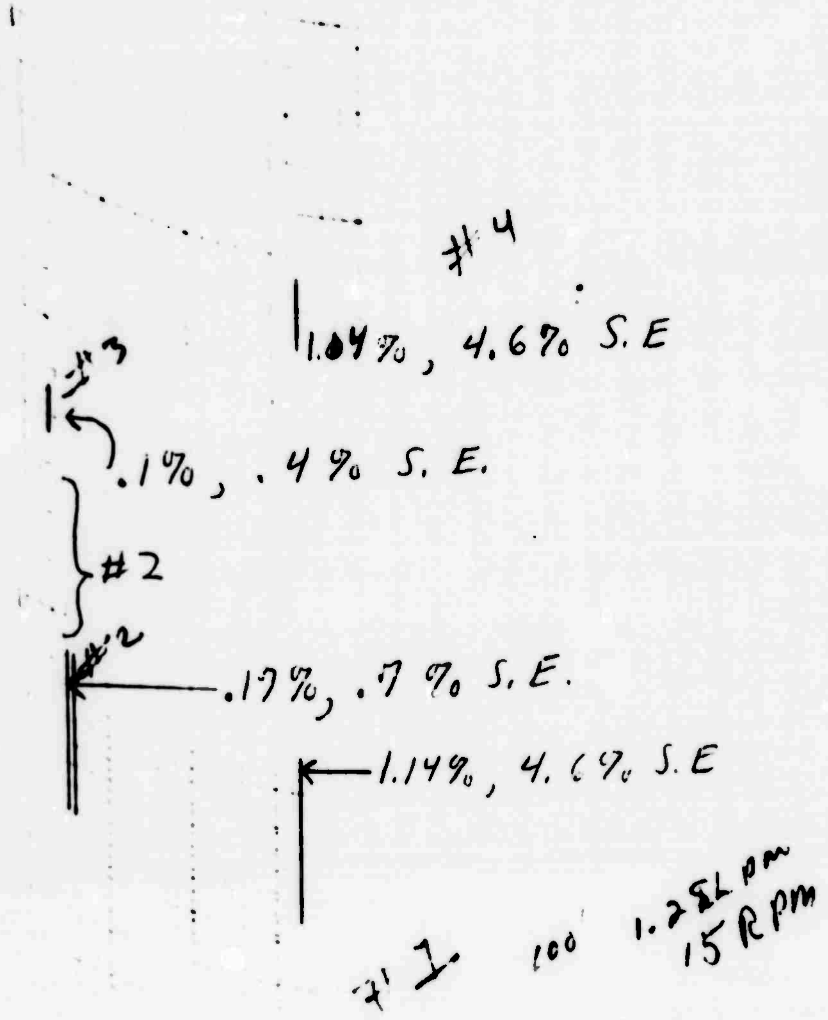
DEPTH (fsw)	0	50	100	150	200		100	200
Respiratory Minute Volume (alpm)	50	50	50	50	50		30	30
CO_2 Addition Rate (slpm)	2.0	2.0	2.0	2.0	2.0		1.2	1.2
	AVERAGES , RUNS 1, 2, 5 and 6							
Indicated CO_2 Exhaust Rate (slpm)	2.0	2.0	1.6	1.3	1.2		1.1	.7
Standard Deviation of CO_2 Exhaust Rate	.37	.20	.22	.13	.15		.13	.15
Indicated Helmet PCO_2 (% S.E.)	.5	1.1	.9	1.1	1.2		.6	.7
Indicated Exhaust Gas PCO_2 (% S.E.)	.8	1.2	1.0	1.2	1.4		.8	.8
	AVERAGES, RUNS 1-6							
Indicated Exhaled PCO_2 (% S.E.)	4.6	4.7	4.5	4.3	4.1		4.4	4.5
Indicated Inhaled PCO_2 (% S.E.)	.5	1.2	1.3	1.7	1.9		.8	1.2
Indicated PCO_2 Difference Exhale - Inhale	4.0	3.6	3.2	2.6	2.4		4.0	3.4
Standard Deviation of Indicated PCO_2 Difference	.26	.19	.41	.30	.34		.47	.28
AVERAGE CO_2 PRODUCTION AND EXHAUST RATES								
CO_2 Production (slpm) (PCO_2 Diff #2) x RMV	2.1	1.8	1.8	1.7	1.7		1.1	1.1
CO_2 Production (slpm) (PCO_2 Diff #3) x RMV	2.2	2.0	2.0	2.2	2.0		1.2	1.2
CO_2 Exhaust Rate #1 (slpm) Exhaust PCO_2 x Flow Rate	2.0	2.0	1.6	1.3	1.2		1.1	.7
CO_2 Exhaust Rate #2 (slpm) Inhaled PCO_2 x Flow Rate*	1.8	2.1	2.1	2.0	1.9		1.2	1.1

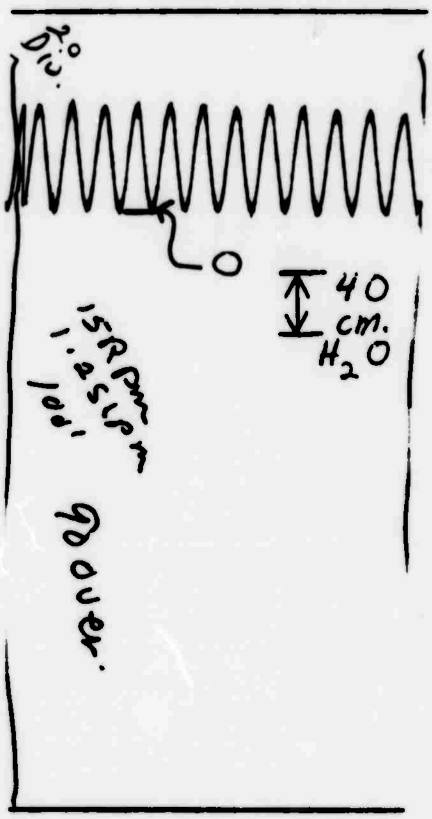
Table A-2 (Cont)

* Not necessarily a true exhaust rate.

VALVE POSITION (EXHAUST)	SUPPLY	1/4 OPEN					1/2 OPEN					FULL OPEN				
	DEPTH (fsw)	0	50	100	150	200	0	50	100	150	200	0	50	100	150	200
1/2 OPEN	Flow Rate (acfm)	4.6	2.1	1.6	1.2	.9	5.0	2.8	1.9	1.4	1.1	4.4	4.3	2.9	2.3	1.3
	Peak Inhalation Pressure (cm H_2O)	-46	-50	-68	-78	-70	-40	-42	-60	-60	-60	-10	-12	-14	-12	-12
	Peak Exhalation Pressure (cm H_2O)	2	30	44	49	47	100	102	100	100	100	20	30	30	32	32
	Indicated Inhaled CO_2 Level (%S.E.)															
	Top of Helmet CO_2 Level (% S.E.)	.4	1.1	2.1	3.2	4.0	.2	.8	1.6	2.1	2.6	.7	1.0	1.3	1.7	2.2
	Helmet Lower Rear CO_2 Level (% S.E.)	.5	1.4	2.3	3.8	4.6	.2	.9	1.8	2.2	2.9	.8	1.1	1.5	1.8	2.6
	Exhaust Gas/M. Box CO_2 Level (% S.E.)															
FULL OPEN	Flow Rate (acfm)	2.8	1.9	1.3	1.0	.8	3.1	2.3	2.1	2.0	1.0	3.5	3.7	2.1	1.7	1.6
	Peak Inhalation Pressure (cm H_2O)	-50	-58	-60	-68	-84	-30	-34	-30	-34	-44	-20	-20	-20	-20	-20
	Peak Exhalation Pressure (cm H_2O)	14	52	60	38	44	4	30	42	40	02	4	16	16	22	34
	Inhaled CO_2 Level (% S.E.)					Flood out										
	Top of Helmet CO_2 Level (% S.E.)	1.5	1.8	2.6	3.2		.8	1.5	2.3	3.2	4.3	.7	1.0	1.5	1.7	2.1
	Helmet Lower Rear CO_2 Level (% S.E.)	1.5	2.0	2.8	3.6		.9	1.4	2.3	3.3	3.4	.8	1.1	1.6	2.1	2.3
	Exhaust Gas/M. Box CO_2 Level (% S.E.)															

Table A-3
Results of Initial Tests With Advanced Air Diving Helmet. The overbottom Pressure Reaching the Air Control Valve was Unknown and Very Low Due to a Restriction in the Supply Hose. Data Taken 14-16 December 1970.





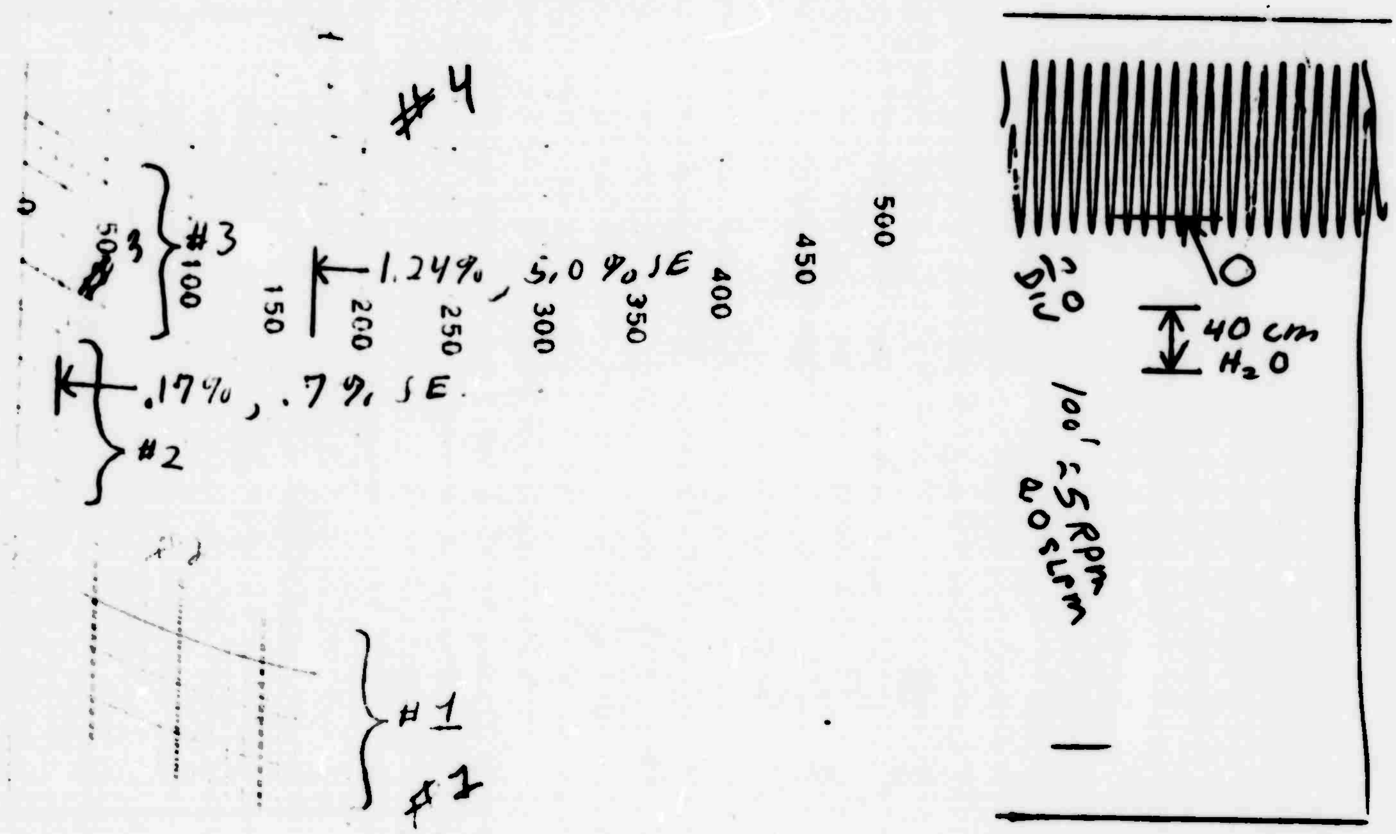
Helmet Pressure

Measured CO_2 Levels

#1 is mouth
#2 is top of helmet
#3 is lower rear of helmet
#4 is outlet of mixing box

Figure A-1

Recorder Outputs, Run 4 at 100 fsw and an RMV of 30 lpm.



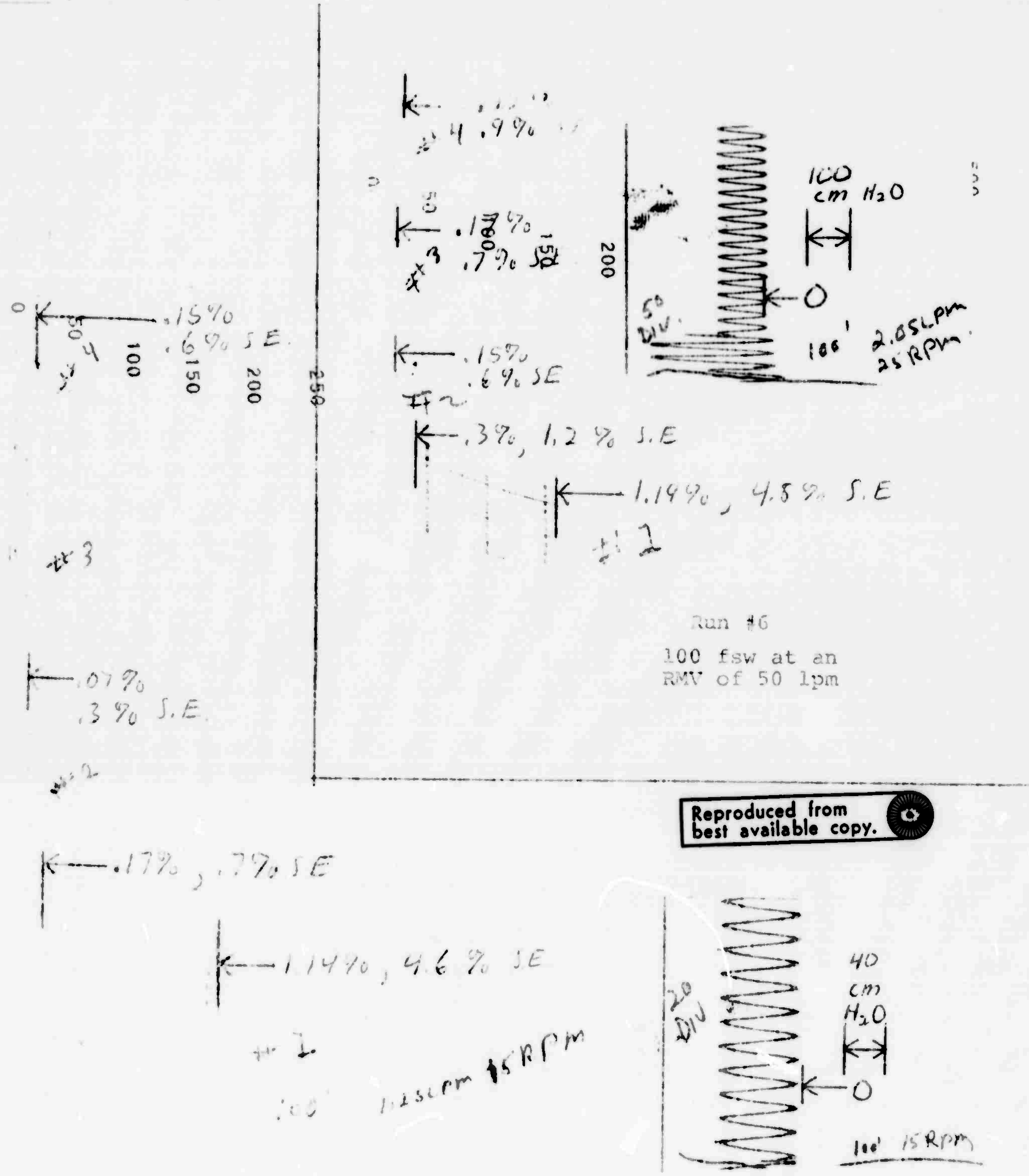
Helmet Pressure

Measured CO_2 Levels

#1 is mouth
#2 is top of helmet
#3 is lower rear of helmet
#4 is outlet of mixing box

Figure A-2

Recorder Outputs, Run 4 at 100 fsw and an RMV of 50 lpm.



Measured CO_2 Levels

Helmet ...ure

#1 is mouth
#2 is top of helmet
#3 is lower rear of helmet
#4 is inlet to helmet exhaust valve

Run 6 at 100 fsw and an RMV of 30 lpm

Figure A-3 Recorder Outputs, Run 6 at 100 fsw.

Appendix B

Summary of Diver's Subjective Comments Regarding The "Advanced" Series 2000 Air Diving Helmet When Used With a Neckseal

SUBJECTIVE ANALYSIS OPEN CIRCUIT
AIR DIVING HELMET

Manufacturer DIVEX, formerly Advanced Diving Equipment Co.

Model Series 2000

Date February to May 1970

Subject - 8 different divers -

1. Can the helmet with all its accessories be donned by the diver without assistance?

   Yes 4 No 4

   Comment on any feature of the helmet and/or accessories that make donning the helmet easy or difficult.

   "Like neoprene neckseal"
   "Earphone wires get under seal"
   "Bayonet fitting difficult for 1 man to line up"

2. Comment on the out-of-the-water comfort and fit of the helmet.

   Generally good- comments ranged from "excellent, can walk around easily" to "slightly heavy, okay for short periods.

   Would you rate it as:

   Excellent 2 , Good 5 , Fair 1, or Poor 0

3. Comment on the in-the-water comfort of the helmet. Include comments on the helmet buoyancy.

   "Especially comfortable in water. Buoyancy no problem with tight jock"
   "Comfort easily adjusted by jock strap"
   "Poor exhaust, too slow, makes helmet rise up and jock uncomfortable"
   "Chin button hard to reach"

   Would you rate it as:
   Excellent 3 , Good 3 , Fair 2 , or Poor 0

4. Comment on the arrangement of internal fittings and any special features.

   Generally liked by the divers.

5. Comment on the noise level in the helmet from air inlet and exhaust.

   "Inlet makes buzzing noise at 3/4 turn open"
   "Not as noisy as standard MK5 helmet"
   "No problem with exhaust noise, inlet noise noticeable only when communicating"

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Does it interfere with communications?

No 6 Yes 2

"Slightly, but can still hear OK"
"Inlet only. Communications were lousy"
"Com very bad; have to turn air off to hear"

6. Are the helmet air inlet and exhaust valves easily accessible and operable?

Yes 8 No 0

Are the valves easy to operate even with gloves?

Yes - No -

If any answers are no, please comment.

7. Comment on the visibility from the helmet.

"Straight ahead was good"
"Side ports were missed. However ease of moving head and shoulders overcame this"

Would you rate it as:
Excellent 3, Good 5, Fair 1, or Poor 0

8. Can the helmet be easily cleared of water?

Yes 8 No 0

Comment:

"Can be easily cleared, and it does not flood out easily in loss of air".

9. List and discuss any features of the helmet especially liked.

weight
ease of donning
maneuverability

10. List and discuss any features of the helmet especially disliked.

"Jock strap uncomfortable"
"Control valve came off at 190 ft."
"Hard to swim"

11. What is your overall evaluation of the helmet?

Would you rate it as:
Excellent 1, Good 6, Fair 1, or Poor 0

12. What inlet and exhaust settings did you find comfortable when at work and when standing at rest? Express valve settings as number of turns open or closed (example: inlet 2¼ turns open). Record the CO_2 level in the helmet under the same conditions.

	Inlet*	Exhaust*	CO_2 Level
At work:	1 - 2½	Full Open	-
Standing at rest:	½ - 1½	Full Open	-

Type of work ____________________

Comments:

*All dives recorded here were 100-190 feet.

" To keep CO_2 level down while at work had exhaust open completely and air all way open, blowing out around neck seal" (150 & 190 ft. test dives).