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DEPARTMENT OF THE NAVY SEA SYSTEMS COMMAND

DEPARTMENT OF THE NAVY EXPERIMENTAL DIVING UNIT

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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 9-83

EVALUATION OF DIVEX AGA COMMERCIAL MASK

JAMES R. MIDDLETON
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M. G. JANTZEN
R. C. MAULBECK

JUNE 1983

NAVY EXPERIMENTAL DIVING UNIT

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NAVY EXPERIMENTAL DIVING UNIT
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breathing resistance	open-circuit demand
umbilical supplied	unmanned

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Between September 1982 and January 1983, an open circuit demand full-face mask (FFM) was evaluated in both manned and unmanned modes on air in accordance with NAVSEA Task No. 81-3. The mask, designed for use with open circuit (O/C) SCUBA, is produced by AGA SPIRO of Lindingo, Sweden and modified for the umbilical supplied use by Divers Exchange (DIVEX) of Harvey, Lousiana. The purpose of the task was to provide unmanned performance data and open water operational data to aid in the selection of a new FFM to replace the current U.S. Navy Lightweight Mask (Jack Browne).

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Unmanned breathing resistance, respiratory work and umbilical pressure drop studies were conducted using a hyperbaric breathing simulator at depths up to 198 feet-of-seawater (FSW) at simulated work rates ranging from light to extreme. The tests were conducted using the two umbilical sizes currently found in the fleet.

In addition, open water manned testing was conducted on board an operational submarine tender where human and operational factor considerations were evaluated.

Results of unmanned testing revealed the DIVEX AGA commercial mask to perform adequately for shallow water diving operations not exceeding 66 FSW with either 3/8 or 1/2 inch inside diameter (ID) umbilicals in both 200 and 300 ft. lengths tested. Breathing resistance and breathing work values were within the performance goals specified at depths up to 60 FSW.

Manned testing showed the AGA mask to be a lightweight, easy to use and maintain underwater breathing apparatus (UBA). The DIVEX AGA commercial mask requires human factors modifications to the purge button, the communications electrical connector, and to a device aiding valsalva and subsequent NEDU testing before it could be considered an adequate replacement for the current USN Jack Browne FFM. In addition, topside overbottom pressure control is require when using the DIVEX AGA mask which will require operating procedures and possibly equipment currently not used with the Jack Brown mask.

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Glossary

BPM	breaths per minute
cmH_2O	centimeters of water pressure
DIVEX	Diver's Exchange of Harvey, LA
EDF	Experimental Diving Facility Hyperbaric Chamber Complex
FFM	full-face mask
FSW	feet-of-seawater
FT	foot
HP	high pressure
ID	inside diameter
in	inches
kg·m/l	kilogram-meters per liter (respiratory work)
TV	the liter-tidal volume of air breathed in and out of the lungs during normal respiration
lpm	liters per minute (flow rate)
MOD	modified
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
O/B	over bottom
O/C	open-circuit
ΔP	pressure differential
psid	pounds per square inch differential
psig	pounds per square inch gauge
RMV	respiratory-minute-volume in liters-per-minute
SCUBA	self-contained underwater breathing apparatus
SEV	surface equivalent value
SI	System International (units of measure)
TEMP	temperature

Glossary (continued)

UBA	underwater breathing apparatus
U/W	underwater

SI Unit Conversion Table

To Convert From	To	Multiply By
kg•m/l	joule per liter (J/L)	9.807
psi	kilopascal (kPa)	6.895
feet	meters	0.305
FSW	meters of seawater (MSW)	0.305
FSW	kilopascal (kPa)	3.065

Abstract

Between September 1982 and January 1983, an open circuit demand full-face mask (FFM) was evaluated in both manned and unmanned modes on air in accordance with NAVSEA Task No. 81-3. The mask, designed for use with open circuit (O/C) SCUBA, is produced by AGA SPIRO of Lindingo, Sweden and modified for the umbilical supplied use by Divers Exchange (DIVEX) of Harvey, Lousiana. The purpose of the task was to provide unmanned performance data and open water operational data to aid in the selection of a new FFM to replace the current U.S. Navy Lightweight Mask (Jack Browne).

Unmanned breathing resistance, respiratory work and umbilical pressure drop studies were conducted using a hyperbaric breathing simulator at depths up to 198 feet-of-seawater (FSW) at simulated work rates ranging from light to extreme. The tests were conducted using the two umbilical sizes currently found in the fleet.

In addition, open water manned testing was conducted on board an operational submarine tender where human and operational factor considerations were evaluated.

Results of unmanned testing revealed the DIVEX AGA commercial mask to perform adequately for shallow water diving operations not exceeding 66 FSW with either 3/8 or 1/2 inch inside diameter (ID) umbilicals in both 200 and 300 ft. lengths tested. Breathing resistance and breathing work values were within the performance goals specified at depths up to 60 FSW.

Manned testing showed the AGA mask to be a lightweight, easy to use and maintain underwater breathing apparatus (UBA). The DIVEX AGA commercial mask requires human factors modifications to the purge button, the communications electrical connector, and to a device aiding valsalva and subsequent NEDU testing before it could be considered an adequate replacement for the current USN Jack Browne FFM. In addition, topside overbottom pressure control is required when using the DIVEX AGA mask which will require operating procedures and possibly equipment currently not used with the Jack Brown mask.

PART I - UNMANNED

I. INTRODUCTION

During September 1982 NEDU performed unmanned testing on the DIVEX AGA Commercial Mask Model 9800 in accordance with NAVSEA Task Number 81-3. This underwater breathing apparatus (UBA) is an O/C demand/free flow FFM used in umbilical supplied diving operations. The purpose of testing was to evaluate performance to aid in the selection of a lightweight FFM to replace the current U.S. Navy Jack Browne mask. (APPENDIX A contains manufacturer addresses.)

Unmanned testing was conducted in the NEDU Experimental Diving Facility (EDF). The UBA's were evaluated with respect to breathing work, breathing resistance and umbilical pressure drop at simulated diver work rates ranging from light to extreme. Four umbilical combinations were tested using 1/2 inch and 3/8 inch ID umbilicals in 200 and 300 foot (FT) lengths.

The mask, an AGA Divator 324, is produced by AGA Spiro of Sweden and modified for umbilical supplied use by DIVEX of Harvey, LA. The AGA Divator mask was originally designed for use with O/C SCUBA and the AGA modification makes the mask compatible with umbilical supplied diving operations.

II. FUNCTIONAL DESCRIPTION

A. The DIVEX AGA Commercial Mask (Model 9800) (Figures 1 through 3) is a lightweight umbilical supplied FFM. It consists of the basic AGA Divator FFM normally used for SCUBA diving which has been modified for umbilical supplied use by DIVEX of Harvey, LA. Essentially, three design changes were incorporated:

1. Modification of regulator demand valve to allow constant free flow operation.

2. A 90° swivel elbow with non-return valve was incorporated in the inlet to the demand regulator.

3. A provision for communications was added to the mask via microphone in the oronasal cup, a bone conductor earphone attached to the five point head harness and two post terminals for the communication umbilical attachment.

The DIVEX free flow modification is accomplished by a knob mounted to the demand regulator in the area of the diaphragm. This knob can be rotated clockwise to depress the demand valve in a manner similar to the operation of a SCUBA regulator purge button to provide a continuous and variable flow of gas to the diver. It has a rotational travel of five full turns which allows the amount of free flow to be adjusted for diver comfort. This is not a 'dial-a-breath' type mechanism as is found on the USN MK 1 MOD 0 mask for controlling variable overbottom (O/B) supply pressures. It simply allows the diver the choice in the rate of free-flow at the set O/B pressure.

FIGURE 1

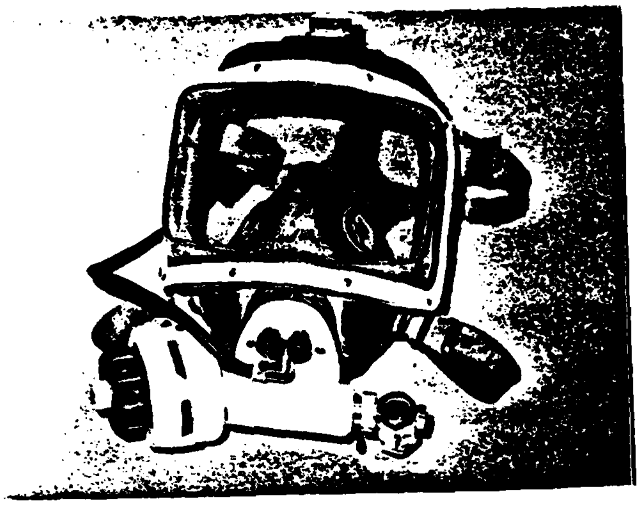


FIGURE 2

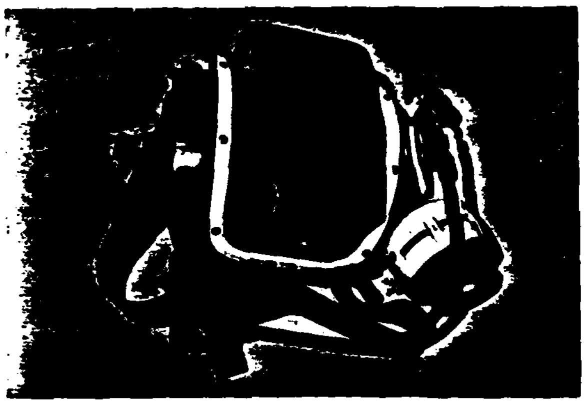


FIGURE 3

As with all AGA Divator masks, the DIVEX Model 9800 has an over pressure feature which, when activated, maintains approximately 5 cmH_2O pressure over ambient inside the mask cavity. This feature aids in maintaining an effective face seal, helps prevent water leakage and increases mask comfort.

Another unique feature of the AGA mask is the flow path which the incoming breathing gas follows through the mask. Rather than flowing directly into the oronasal cavity, the diver's inhaled gas is diverted through two ducts, directed across the face plate to help prevent fogging, and then into the oronasal cavity via two mushroom valves.

III. UNMANNED TEST PROCEDURE

A. Test Plan. The test equipment set-up is illustrated in reference 1. APPENDIX B provides the complete test plan and the test equipment used is listed in APPENDIX C. A breathing machine and hyperbaric chamber simulated diver inhalation and exhalation at various depths and diver work rates. The tank in which the UBA was submerged simulated open water diving conditions. A total of five respiratory minute volumes (RMV) were tested at all normal operating depths to simulate light through extreme diver work rates. Breathing resistance was measured using a pressure transducer located in the oronasal cavity of the FFM and another pressure transducer measured pressure drop across the various air supply umbilicals tested.

B. Controlled Parameters

1. Standardized NEDU breathing rates, tidal volume, exhalation/inhalation time ratio and breathing waveform were controlled as set forth in NEDU Report 3-81 (reference 1).

2. UBA breathing gas: air

3. Depths: 0 to 198 FSW in 33 FSW increments

4. Air supply pressure: 135 psig overbottom

5. Umbilical ID: 3/8 in. and 1/2 in.

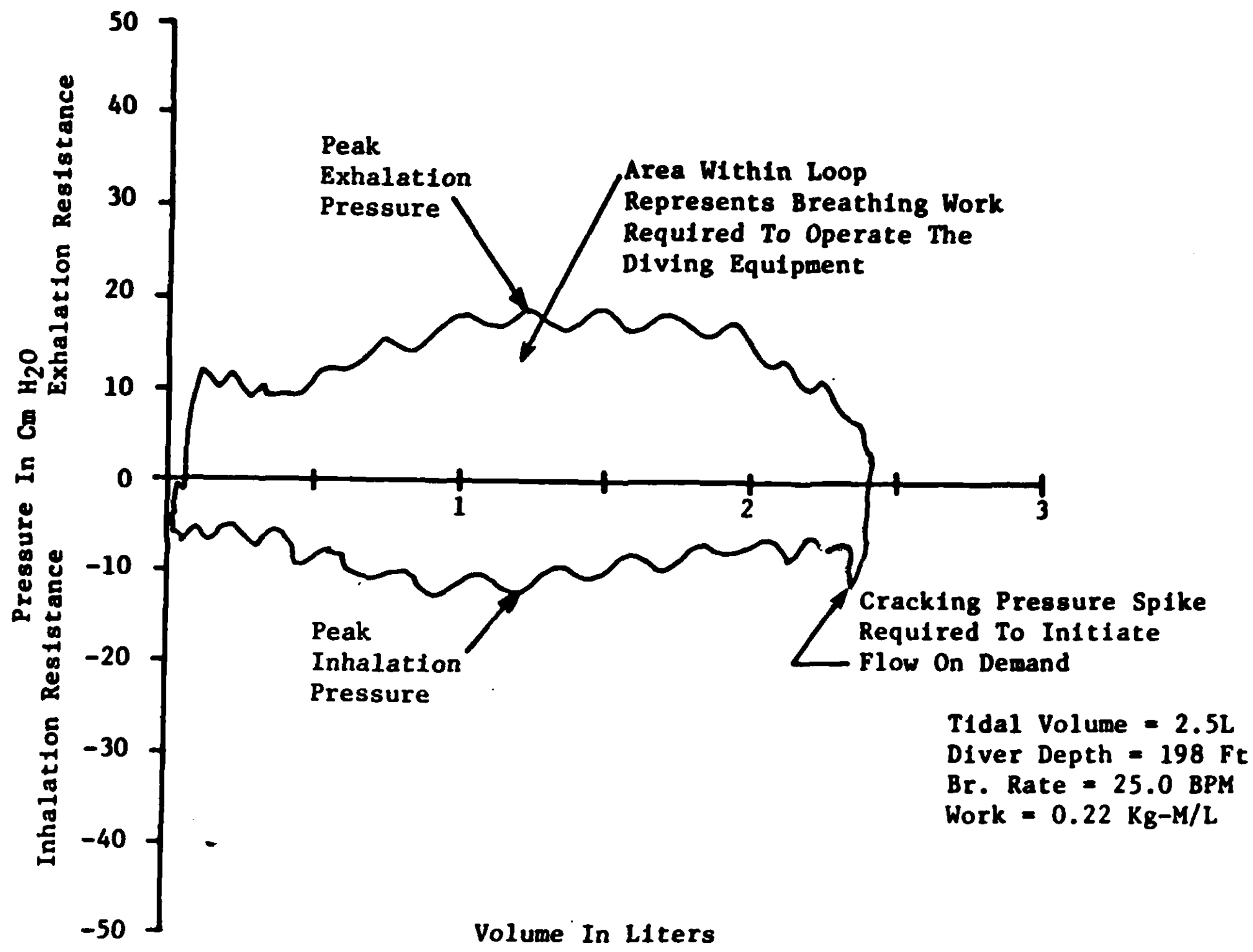
6. Umbilical length: 200 ft. and 300 ft.

C. Measured Parameters

1. Maximum oronasal ΔP in cmH_2O (i.e. total pressure excursion between full exhalation and full inhalation cycles) at each depth and RMV.

2. Umbilical pressure drop in psig upon inhalation at each depth and RMV.

D. Computed Parameters. Respiratory work per liter tidal volume measured in kg·m/l from ΔP vs volume plots. A typical pressure-volume plot is illustrated in Figure 4.



Breathing Pressure Versus Tidal Volume Loop

Figure 4. Sample Pressure-Volume Loop

E. Data Plotted. The following graphs were developed from data obtained:

1. Peak exhalation and peak inhalation ΔP vs depth at each RMV tested.

2. Respiratory work per liter vs depth at each RMV tested.

3. Umbilical pressure drop vs depth for each RMV, umbilical length and umbilical ID tested.

IV. UNMANNED RESULTS

A. Breathing Resistance and Respiratory Work. APPENDIX D (Figures 5 through 24) plot peak differential breathing pressures vs depth and APPENDIX E (Figures 25 through 28) plot breathing work vs depth for each UBA tested. Peak inhalation and peak exhalation was measured in cmH_2O at each RMV tested. Breathing work is measured in kg·m/l and is also plotted at each RMV evaluated.

Breathing work is a measure of the respiratory energy expended by the diver to operate his UBA. When used in conjunction with breathing resistance data, it provides a useful tool in the evaluation of UBA. TABLE 1 provides a synopsis of the peak differential pressures at various depths and 62.5 RMV while TABLE 2 provides a similar summary of breathing work. A moderately heavy diver work rate of 62.5 RMV is tabulated since it represents the standard RMV for evaluation performed on this type UBA in reference 1.

B. Umbilical Pressure Drop. APPENDIX F (Figures 29 through 32) plot peak umbilical pressure drop on inhalation vs depth for each umbilical length and ID combination tested. Umbilical pressure drop was measured in psig.

This data may be used in conjunction with peak differential breathing pressures and respiratory work to determine the effect of various umbilical combinations on mask performance.

TABLE 3 is a synopsis of peak umbilical pressure drop at 62.5 RMV and various depths.

V. UNMANNED DISCUSSION

A. Breathing Resistance and Respiratory Work. NEDU Report 3-81, "Standardized NEDU Unmanned UBA Test Procedures and Performance Goals," (reference 1) establishes a performance goal of a total respiratory work of 0.18 kg·m/l 62.5 RMV and 132 FSW. This goal does not represent a minimum acceptable performance level. Rather, the goal when met, will insure that the UBA is not the limiting factor in diver performance.

The goal set forth in reference 1 is established as a function of depth and breathing mixture. Since this UBA in its modified configuration was designed as an inherently shallow water device, the performance goal, which is

TABLE 1

SYNOPSIS OF PEAK EXHALATION TO PEAK INHALATION DIFFERENTIAL PRESSURES (CmH_2O) AT 62.5 RMV WITH EACH UMBILICAL TESTED

	DEPTH (FSW)				
UMBILICAL	0	33	66	99	132
200' X 3/8" ID	15.5	17.5	23.0	26.5	35.0
300' X 3/8" ID	15.5	20.0	25.0	32.0	38.0
200' X 1/2" ID	13.5	17.5	21.5	28.5	34.0
300' X 1/2" ID	13.5	19.5	22.5	27.5	33.0

TABLE 2

SYNOPSIS OF BREATHING WORK VALUES (kg·m/l) AT 62.5 RMV WITH EACH UMBILICAL TESTED

	DEPTH (FSW)				
UMBILICAL	0	33	66	99	132
200' X 3/8" ID	.10	.12	.17	.22	.23
300' X 3/8" ID	.10	.16	.18	.24	.30
200' X 1/2" ID	.09	.12	.15	.20	.24
300' X 1/2" ID	.12	.14	.16	.22	.28

TABLE 3

SYNOPSIS OF UMBILICAL PRESSURE DROPS (PSIG) AT 62.5 RMV WITH EACH UMBILICAL TESTED

	DEPTH (FSW)				
UMBILICAL	0	33	66	99	132
200' X 3/8" ID	2.5	5.5	9.0	14.0	21.0
300' X 3/8" ID	3.0	6.0	12.0	18.0	25.0
200' X 1/2" ID	1.5	3.0	5.0	7.0	10.0
300' X 1/2" ID	2.0	4.0	6.5	9.0	11.5

described for O/C demand umbilical supply UBA with a maximum operating depth of 132 FSW, is applied here at the maximum normal operating depth of 60 FSW.

Examination of the data in Tables 1 and 2 shows that at depths to 66 FSW the DIVEX AGA mask met the performance goal as it is applied here with all umbilical combinations tested. Beyond 66 FSW respiratory work increased beyond the 0.18 kg•m/l goal. However, a comparison of performance between the DIVEX AGA mask and the stock AGA Divator 324 O/C SCUBA mask tested in reference 2, reveals performance which is similar. The Divator 324 also did not meet the performance requirement as strictly stated in reference 1 for open circuit SCUBA regulators. It was however, Authorized for Navy Use (reference 3) because of its unique features described previously, based on its meeting the pre-1979 NEDU SCUBA regulator performance requirement also described in reference 2.

Exhalation resistance was slightly increased in the DIVEX AGA mask over the stock Divator 324. This is probably due to the free flow modification which is used to depress the demand diaphragm causing a slight restriction in the movement of the mushroom exhaust valve. Conversely, inhalation performance of the DIVEX AGA mask was considerably better than the stock Divator 324 SCUBA previously tested at deeper depths and high work rates. This is due to a design modification by AGA Spiro Corporation which now allows the supply pressure to be set at 135 psig O/B. Tests conducted in reference 2 on the Divator 324 were done at a then required 90 psig O/B. This higher supply pressure to the demand regulator is now standard on all AGA masks and resulted in improved inhalation performance. Cracking pressure was minimal on both versions of the AGA mask and both exhibited stable flow during inhalation. Breathing resistance and respiratory work were superior to the existing Jack Browne masks at all depths and RMV (reference 4).

B. Umbilical Pressure Drop. 3/8" and 1/2" ID umbilicals were tested for use with the DIVEX AGA mask since both are commonly available to fleet operators conducting shallow water diving operations. Table 3 reveals that smaller ID and longer length umbilicals exhibit greater pressure drops than do the large ID, short ones. However, all four combinations were found to perform satisfactorily when used in conjunction with the subject mask at depths not exceeding 66 FSW.

By correlating the umbilical pressure loss data (Table 3) with the peak differential breathing pressure and respiratory work data (Tables 1 and 2), an interesting performance characteristic of the AGA demand valve becomes clear. The maximum umbilical pressure drop measured was 40 psig at 198 FSW and 62.5 RMV. However, at any umbilical ΔP over 25 psig, mask performance decreased markedly. Demand valves generally are not this sensitive to supply pressure as evidenced by previous tests conducted at NEDU (references 5 and 6). This sensitivity to supply pressure is probably the reason the mask did not achieve the NEDU performance goal at the normally applied depth of 132 FSW. It should be stressed, however, that the AGA mask was originally designed for use as open circuit SCUBA. There, a first stage regulator mounted on the divers air bottles can supply a larger volume of air at a more stable supply pressure to the demand regulator than is experienced in an umbilical supplied mode.

VI. UNMANNED CONCLUSIONS

The DIVEX AGA commercial mask performed adequately during unmanned tests with all umbilical combinations at depths to 132 FSW. In addition, performance at depths to 66 FSW was within the NEDU unmanned performance goal (reference 1) which insures that the UBA will not be the limiting factor in diver performance.

PART II - MANNED

I. INTRODUCTION

In January 1983, NEDU performed manned testing of the DIVEX AGA Commercial Mask on board an operational submarine tender. Testing provided human factors and operational suitability data on mask performance.

II. MANNED TEST PROCEDURE

DIVEX AGA Commercial Mask was used 5 days for all diving operations on board an operational submarine tender. On site, 3/8 inch I.D. Gates hose and existing communications systems were adapted to the mask. Following every dive, the diver filled out a questionnaire (Appendix G) which evaluates set up time, ease of use, diver comfort, mask maintenance, and communications. Manned testing was limited to 5 days due to the submarine tenders operational requirements. Those five days provided 13 working man dives; one of which was in an enclosed space.

III. MANNED RESULTS

Six divers made 13 working man dives on board an operational submarine tender. The following is a synopsis of the answers to the diver questionnaires (Appendix G):

1. Ten of 13 dives rated the mask comfortable to very comfortable during the dive. The lowest rating was OK.

2. All divers rated breathing resistance slight and none and explained as similar to open-circuit SCUBA.

3. Only two of 13 dives reported any mask fogging and that was slight.

4. Twelve of 13 dives reported no visibility problems while wearing the mask. One dive reported a slight problem due to the parallex caused by the wrap around style faceplate.

5. Two of 13 dives reported that water entered the mask, but did not describe how much or what caused it.

6. Communications could not be adequately tested as the on board communicator was failing during the dives to the point that finally communications were not used on five dives. Dives made with communications showed the potential benefit for use in a lightweight mask and identified problem areas of the exhaust bubbles noise interference and the need for an improved electrical connection.

7. One of eight dives which required clearing reported the mask not as easy to clear as the Jack Browne. Five dives didn't require clearing.

8. One of eight dives which required clearing reported the mask not as easy to clear as the MK 1 MOD 0. Five dives didn't require clearing.

9. On one of the 13 dives the mask performance was reported POOR. Eight of 13 dives reported performance as good to excellent.

10. The following suggestions were made by the divers for improving the mask.

a. A nose clearing device would eliminate trying to get your hand inside the mask to valsalva.

b. Modify mask skirt for thinner faces.

c. Modify purge button, possibly flush mounted, to prevent accidental mask purging by your arm while working overhead.

d. Relocate the communications bone conductor earphone to left ear to reduce the noise interference caused by the exhaust bubbles on the right side.

e. Remove the mask hanging strap as it serves no useful purpose.

f. Improve the lay of the air hose from the shackle to the mask to prevent hose kinks which could restrict air flow.

g. Make the mask harness straps out of less flexible material.

11. Six divers had made from 25-250 dives with the Jack Browne.

12. Six divers had made from 2-100 dives with the MK 1 MOD 0 Mask.

13. On 11 of 13 dives the comfortability was rated the same or better than the Jack Browne; on two of 13 dives it was rated as worse. These two dives represent one of the six divers who had approximately 100 dives previously in the Jack Browne. Another diver with approximately 200 dives in the Jack Browne rated the DIVEX AGA mask better than the Jack Browne.

14. On 11 of 13 dives the comfortability on the DIVEX AGA Mask against that offered by the MK 1 MOD 0 was rated much better; on two of the 13 dives it was rated as worse. These two dives represent one of the six divers and he had approximately 100 dives previously in the MK 1 MOD 0, the most of any diver-subject. The most dives any other diver had was 30 and most had less than 10 previous dives in the MK 1 MOD 0.

15. Regardless of experience level, the divers were equally divided in rating the AGA mask set-up, post dive maintenance and normal PMS compared to the Jack Browne as the same or worse.

16. The AGA mask set-up, post dive maintenance and normal PMS was rated as the same or better when compared to the MK 1 MOD 0 mask.

IV. MANNED DISCUSSION

Overall, the DIVEX AGA FFM was well received as a potential replacement for the Jack Browne mask because it performed well, was comfortable, was easy to maintain, has communications and conserves the limited air supply on the dive boat. The following diver recommendations are considered necessary modifications to make the DIVEX AGA Commercial Mask suitable for Navy diving. Further testing of these modifications by NEDU would be required before making a final recommendation.

A. Install a device aiding valsalva. Divers could then valsalva without inserting a hand underneath the mask skirt.

B. Install a potted Marsh-marine connector to the removable communications cover plate. This should improve communications reliability and reduce maintenance.

C. Reduce the size of the bone conductor earphone to fit underneath a wet suit hood in cold water. The existing earphone is very uncomfortable inside a wet suit hood. The divers subjectively thought reception was better with the earphone inside the wet suit hood.

D. Wear the bone conductor on the left side to be opposite the regulator exhaust bubbles induced noise interference on the right side. This factor contributed to the poor communications experienced during testing.

E. Make the purge button flush with the cover to prevent accidental purging by the diver's right arm when reaching high in front of his face. This causes an annoyance and reduces the effectiveness of a diver at work when the mask vibrates on his face during a purge.

F. Remove the mask hanging strap as it is not a standard Navy feature on other full facemasks or SCUBA.

Diving station air systems must be equipped with a handloader overbottom pressure regulator to accurately control pressure to the AGA mask and prevent free flow. This capability is not required for the MK 1 or Jack Browne in shallow water applications.

V. MANNED CONCLUSIONS

Manned testing on board an operational submarine tender indicates further testing, after human factor modifications have been made to the DIVEX AGA Commercial Mask, will be required to determine its suitability for Navy diving. Manned testing did confirm the DIVEX AGA Commercial Mask's comfort, suitability in confined space diving, and minimal daily maintenance. Through no fault of the mask, communications were not adequately tested. However, the capability for diver to surface communications was considered a tremendous advantage for dive supervisor control of confined space diving compared to the lack of communications in the Jack Browne mask. NEDU does not recommend approval of the DIVEX AGA commercial mask at this time.

V. REFERENCES

1. NEDU Report 3-81, "Standardized NEDU Unmanned UBA Test Procedures and Performance Goals," James R. Middleton and Edward D. Thalmann, CDR, MC, USN, July 1981.

2. NEDU Report 2-80, "Evaluation of Commercially Available SCUBA Regulators," James R. Middleton, March 1980.

3. NAVSEAINST 9597.1, Change 4, April 1982.

4. NEDU Report 14-78, "Evaluation of the U.S.N. Lightweight Diving Mask," James R. Middleton, June 1978.

5. NEDU Report 9-79, "Evaluation of the DSI SUPERLITE 17B Helmet," James R. Middleton, November 1979.

6. NEDU Report 8-78, "Unmanned Evaluation of the USN MK 1 MOD 0 Mask in Umbilical and Emergency Modes," James R. Middleton, May 1978.

APPENDIX A

MANUFACTURERS ADDRESSES

1. Manufacturer: AGA SPIRO AB
   S-181 81 LIDINGO, Sweden
   Telephone: 08-731-1211

   Model: AGA DIVATOR 324

2. Manufacturer: DIVER'S EXCHANGE, INC. (DIVEX)
   2245 Breaux Avenue
   Post Office Box 504
   Harvey, Louisiana 70058, USA
   Telephone: 504-368-2986

   Model: AGA Commercial Mask Model 9800

NOTE: The basic mask is manufactured by AGA SPIRO AB. It is then modified for umbilical supplied use and distributed by DIVEX.

APPENDIX B

UNMANNED TEST PLAN

Test plan for breathing resistance, breathing work and umbilical pressure drop:

(1) (a) Insure that FFM is set to manufacturer's specification and is working properly with 200 ft., 3/8" ID umbilical.

(b) Chamber on surface.

(c) Calibrate transducers.

(d) Open make-up gas supply valve to test UBA.

(e) Adjust breathing machine to 1.5 TV and 15 BPM and take data.

(f) Adjust breathing machine to 2.0 TV and 20 BPM and take data.

(g) Adjust breathing machine to 2.5 TV and 25 BPM and take data.

(h) Adjust breathing machine to 2.5 TV and 30 BPM and take data.

(i) Adjust breathing machine to 3.0 TV and 30 BPM and take data.

(j) Stop breathing machine.

(2) (a) Pressurize chamber to 198 FSW in 33 FSW increments.

(b) Repeat steps (1)(e) - (1)(j) at each depth.

(3) (a) Bring chamber to surface.

(b) Check calibration on transducers.

(4) Repeat steps (1)-(3) with each of the other three test umbilicals.

APPENDIX C

UNMANNED TEST EQUIPMENT

1. Breathing machine.

2. VALIDYNE DP-15 pressure transducer w/1.00 psid diaphragm (oral pressure) (1 ea).

3. VALIDYNE DP-15 pressure transducer w/50.0 psid diaphragm (umbilical pressure drop) (1 ea).

4. Wet test box.

5. MFE Model 715M X-Y plotter.

6. VALIDYNE CD-19 transducer readout (2 ea).

7. External air supply pressure gauge.

8. Chamber depth gauge.

9. Test UBA: DIVEX AGA Commercial Mask, Model 9800.

10. Breathing machine/piston position transducer.

11. Strip chart recorder.

12. Bubble dampening mat.

13. Mannikin.

14. Umbilicals:

    a. 200' x 3/8" ID

    b. 300' x 3/8" ID

    c. 200' x 1/2" ID

    d. 300' x 1/2" ID

APPENDIX D

UNMANNED BREATHING RESISTANCE DATA

Peak inhalation and peak exhalation differential pressure vs depth is plotted for each umbilical configuration.

KEY

Figures 5 - 9 : DIVEX AGA w/200', 3/8" ID Umbilical at all RMV.

Figures 10 - 14 : DIVEX AGA w/300', 3/8" ID Umbilical at all RMV.

Figures 15 - 19 : DIVEX AGA w/200', 1/2" ID Umbilical at all RMV.

Figures 20 - 24 : DIVEX AGA w/300', 1/2" ID Umbilical at all RMV.

FIG. 5 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UNBILICAL AT 22.5 R.M.V. AND 135 PSIG O/B

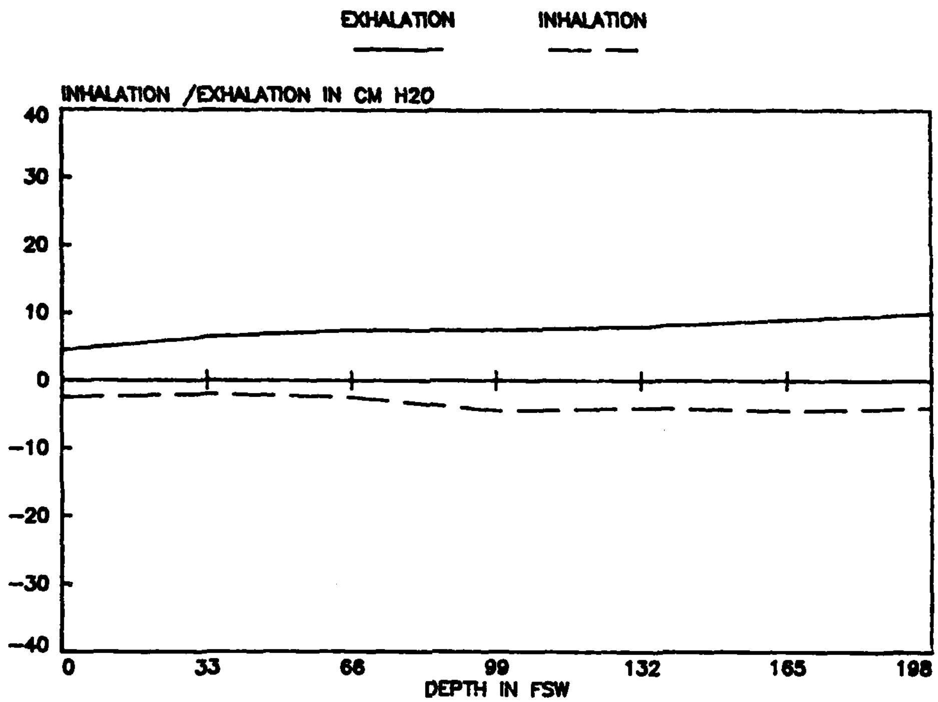


FIG. 6 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UMBILICAL AT 40.0 R.M.V. AND 135 PSIG O/B

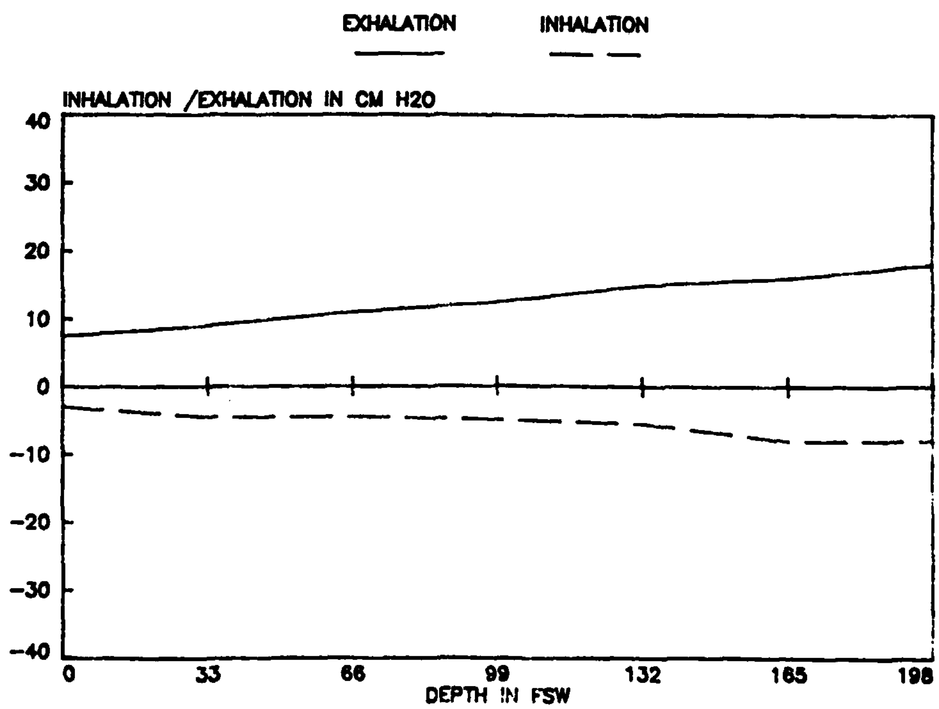


FIG. 7 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200' ,3/8" I.D. UMBILICAL AT 62.5 R.M.V. AND 135 PSIG O/B

EXHALATION ——— INHALATION — —

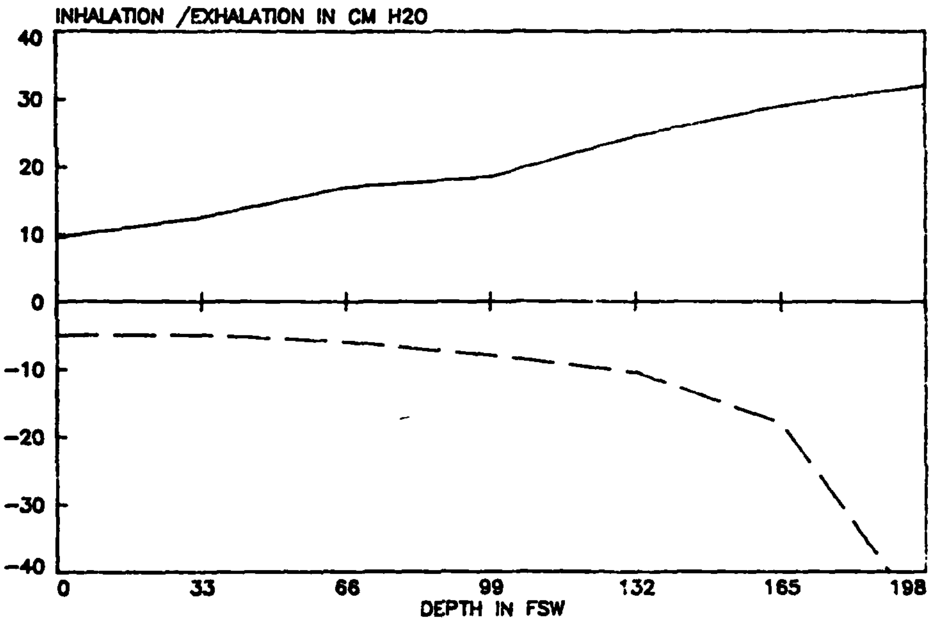


FIG. 8 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UMBILICAL AT 75.0 R.M.V. AND 135 PSIG O/B

EXHALATION ——— INHALATION — —

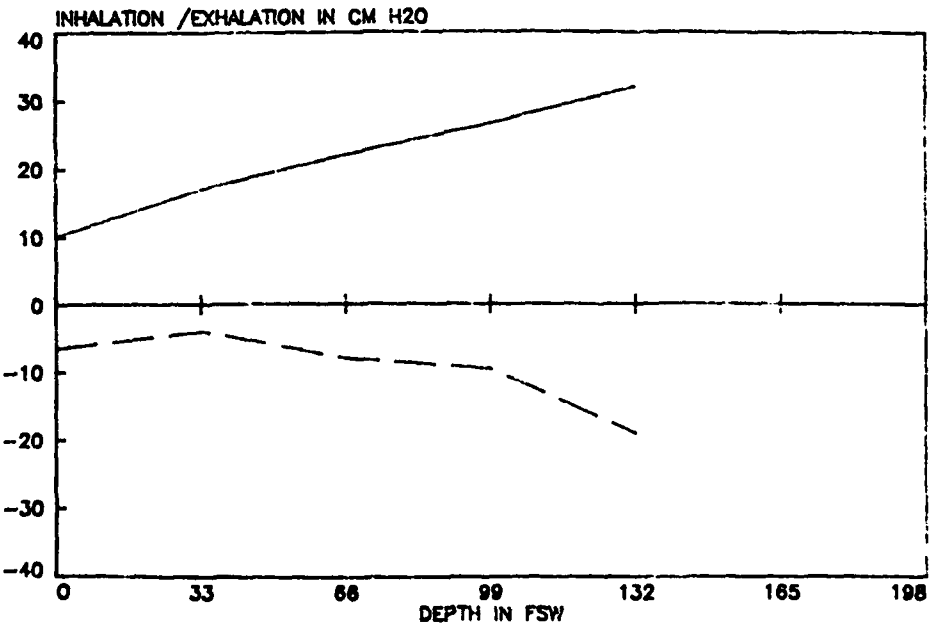


FIG. 9 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UMBILICAL AT 90.0 R.M.V. AND 135 PSIG O/B

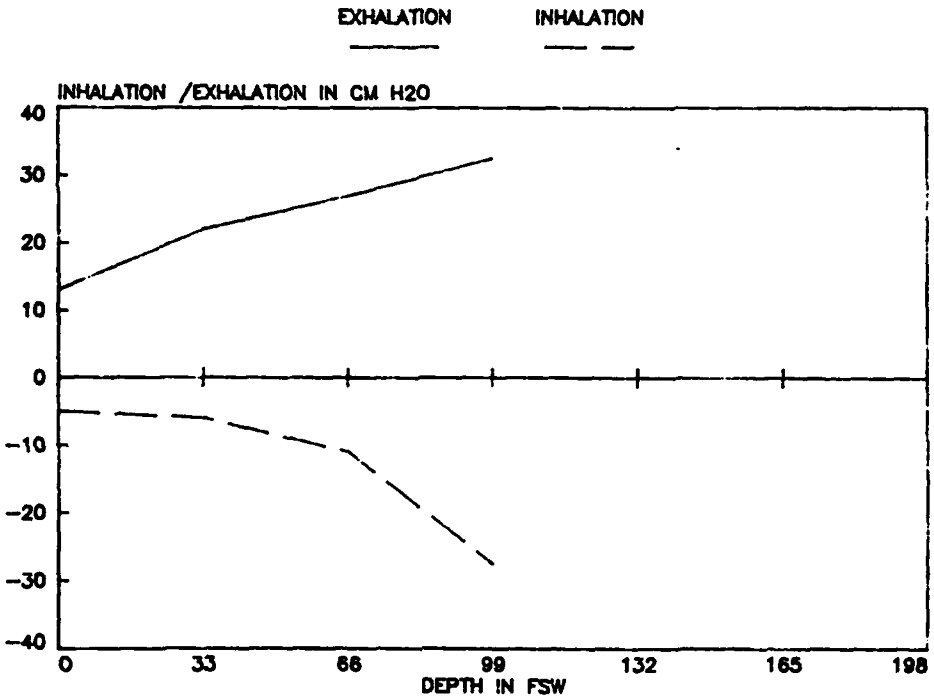


FIG. 10 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 22.5 R.M.V. AND 135 PSIG O/B

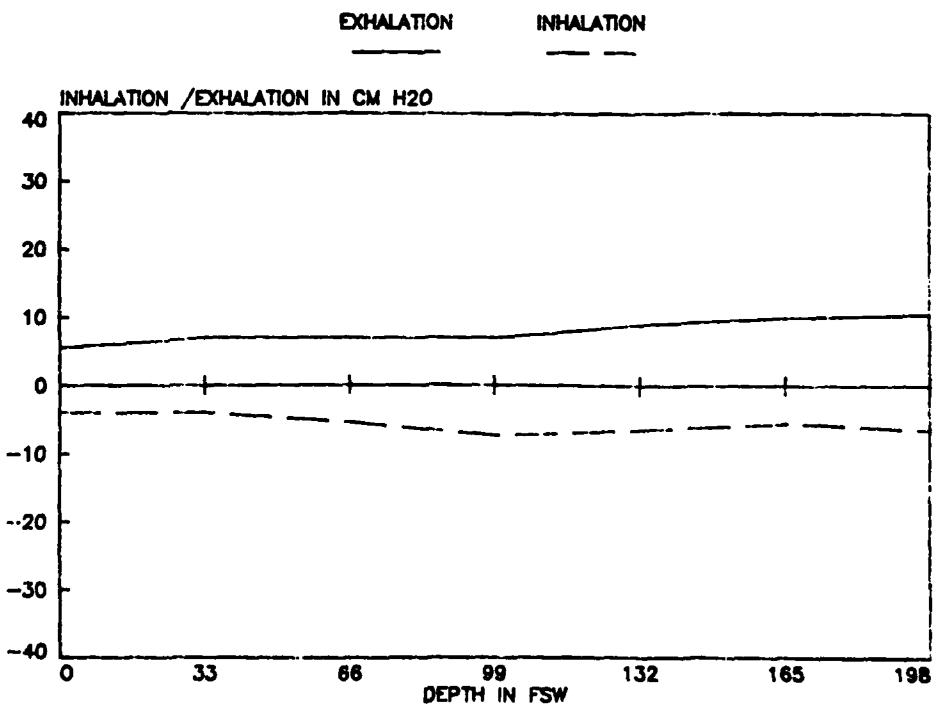


FIG. 11 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 40.0 R.M.V. AND 135 PSIG O/B

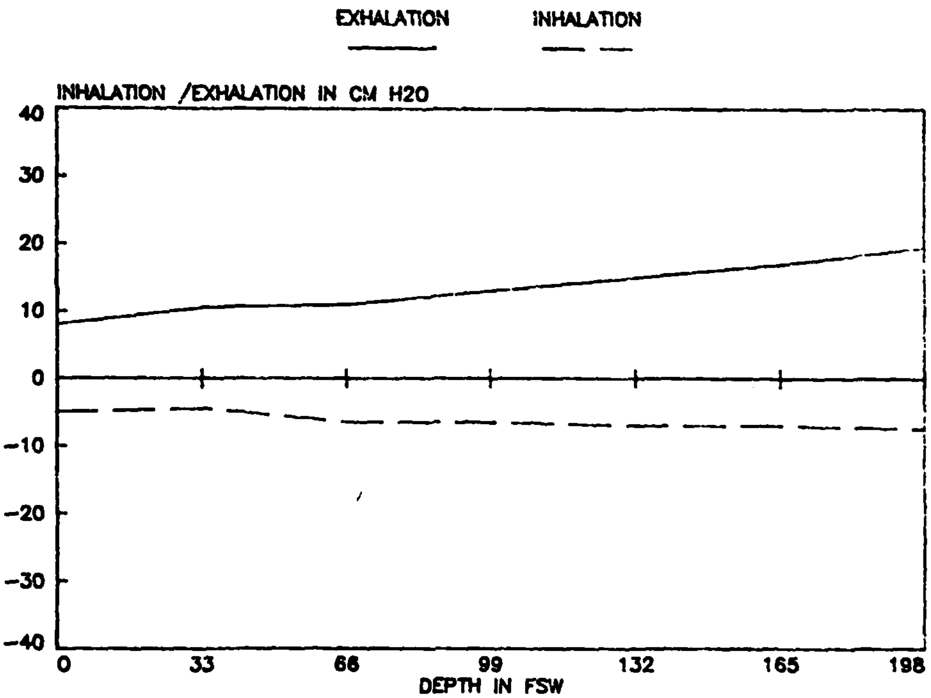


FIG. 12 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 62.5 R.M.V. AND 135 PSIG O/B

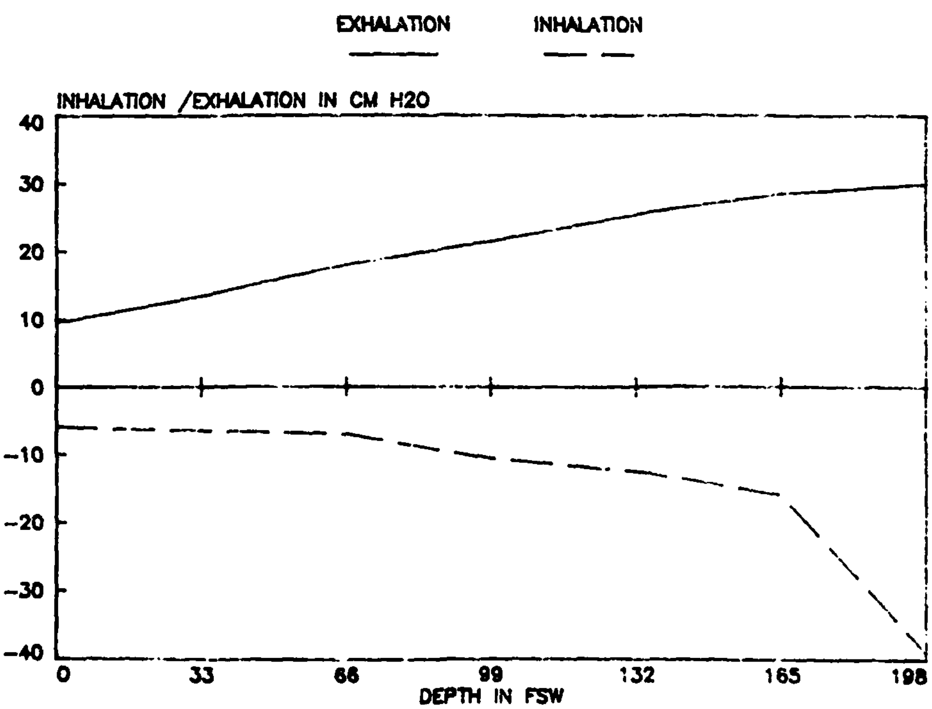


FIG. 13 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 75.0 R.M.V. AND 135 PSIG O/B

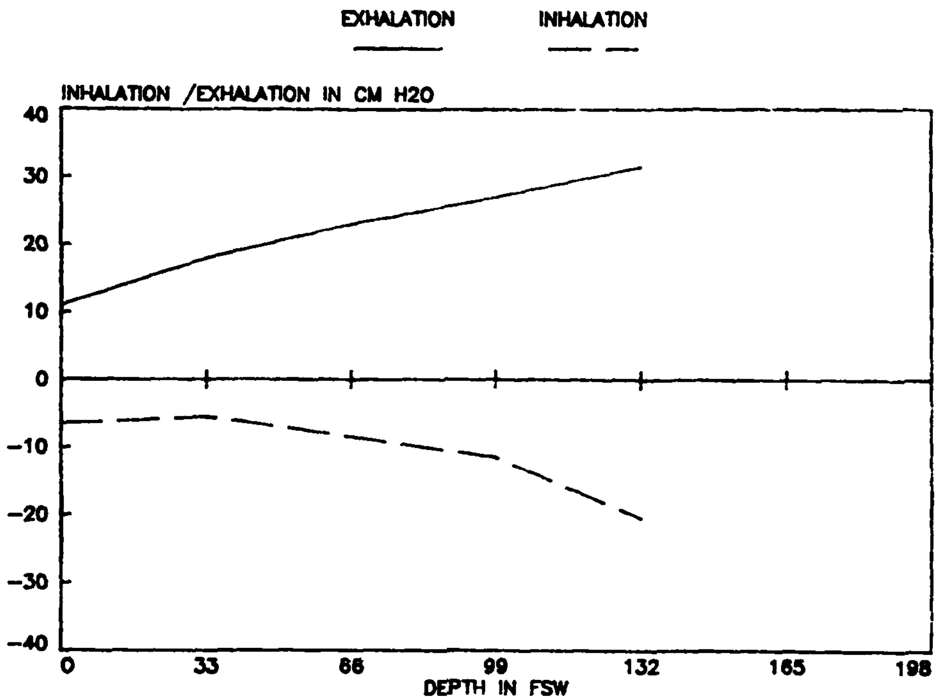


FIG. 14 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 90.0 R.M.V. AND 135 PSIG O/B

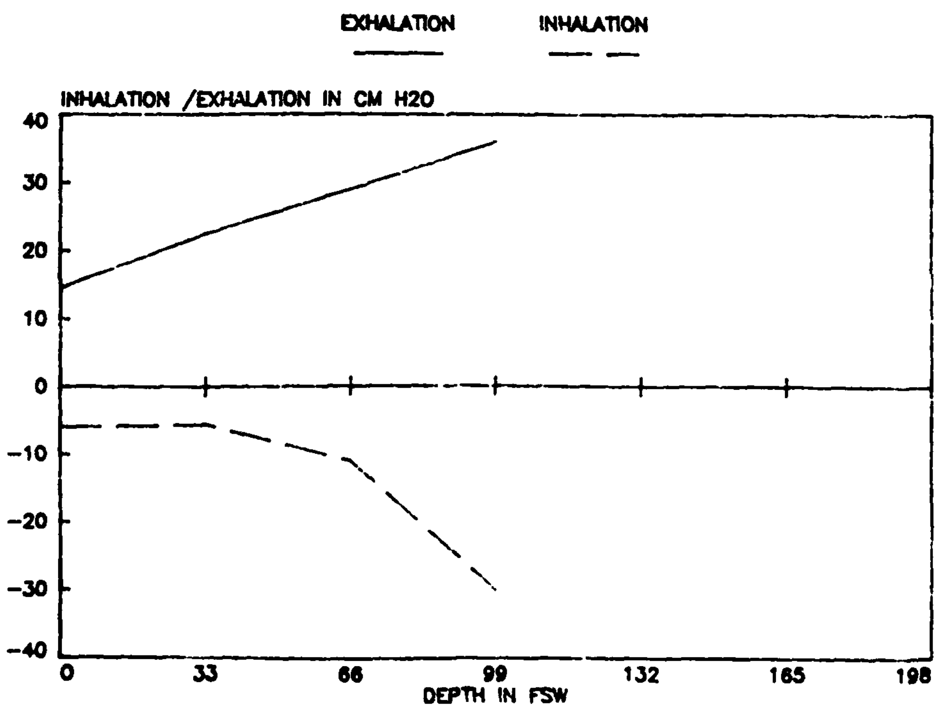


FIG. 15 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 22.5 R.M.V. AND 135 PSIG O/B

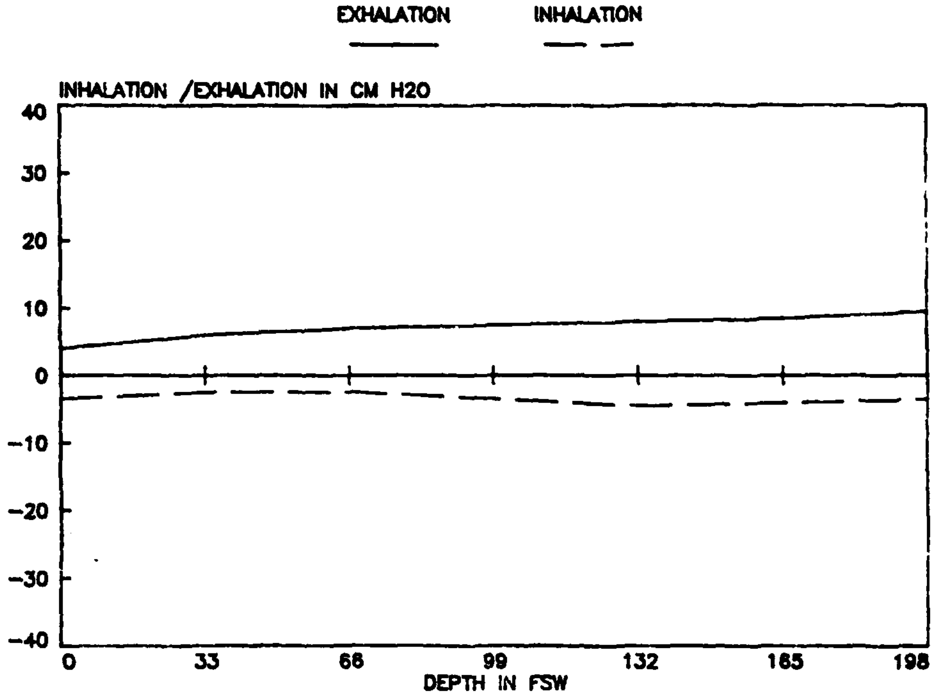


FIG. 16 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 40.0 R.M.V. AND 135 PSIG O/B

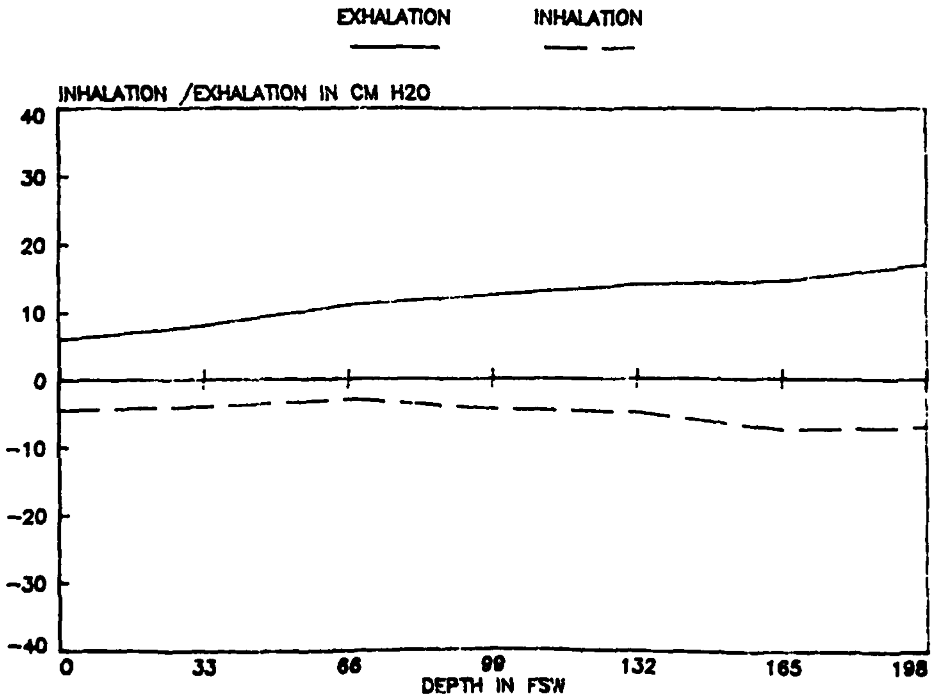


FIG. 17 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 62.5 R.M.V. AND 135 PSIG O/B

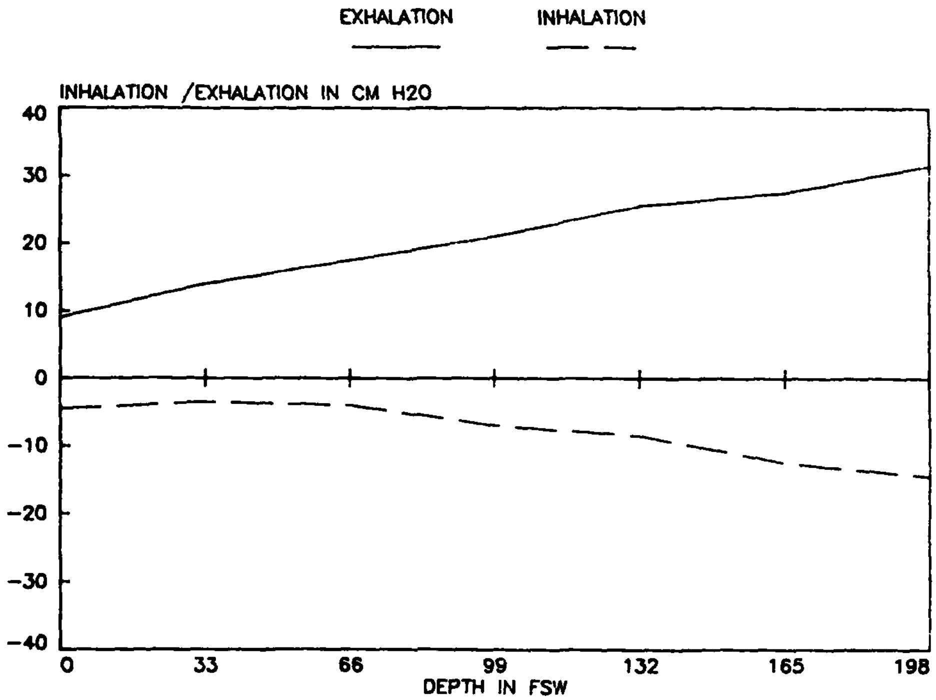


FIG. 18 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 75.0 R.M.V. AND 135 PSIG O/B

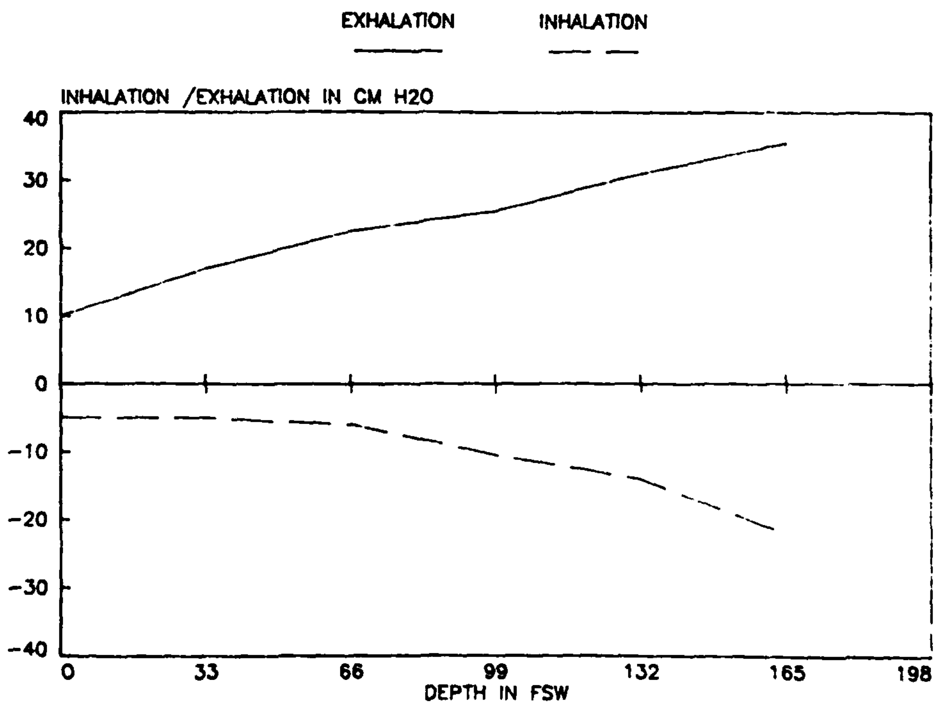


FIG. 19 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 90.0 R.M.V. AND 135 PSIG O/B

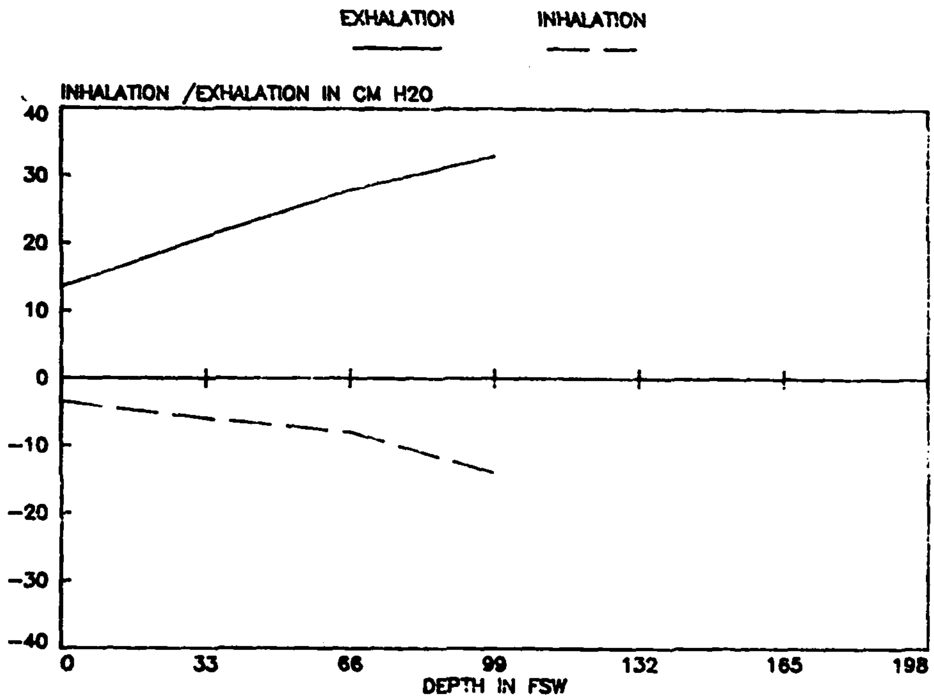


FIG. 20 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 22.5 R.M.V. AND 135 PSIG O/B

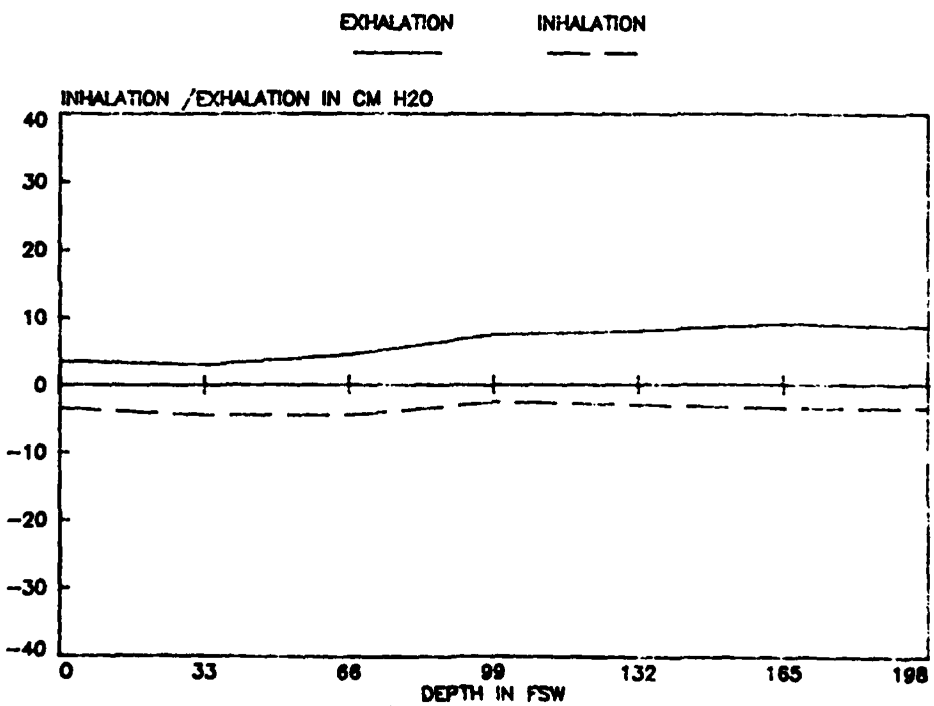


FIG. 21 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 40.0 R.M.V. AND 135 PSIG O/B

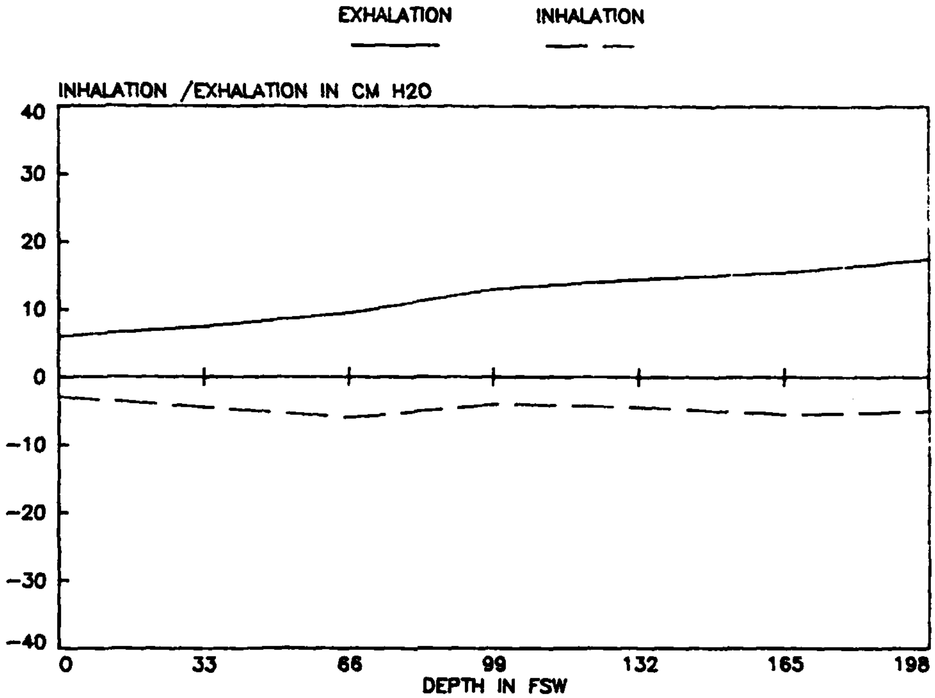


FIG. 22 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 62.5 R.M.V. AND 135 PSIG O/B

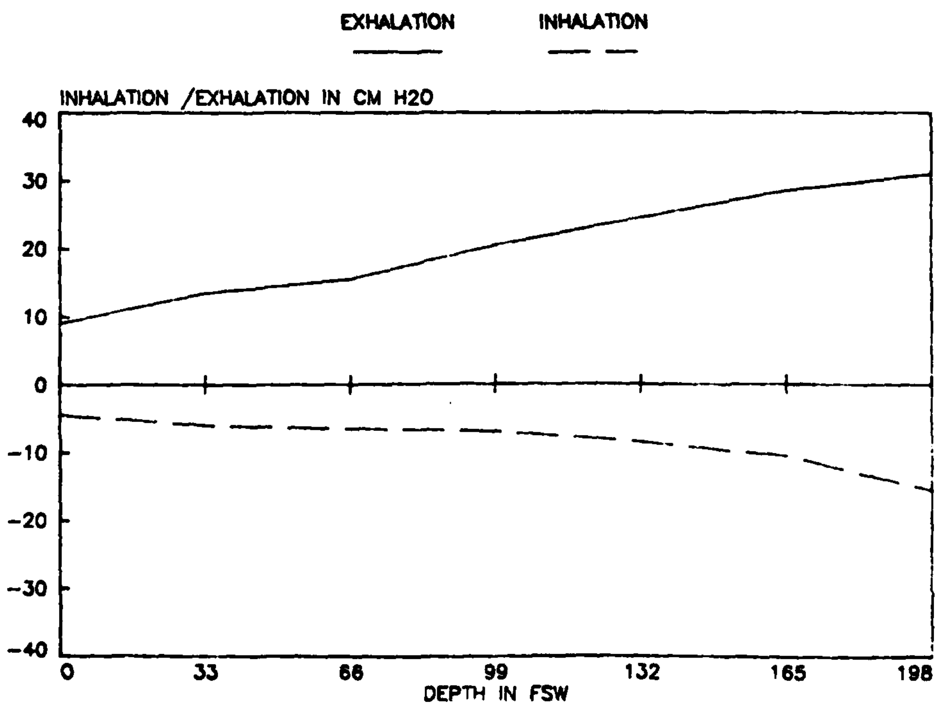


FIG. 23 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 75.0 R.M.V. AND 135 PSIG O/B

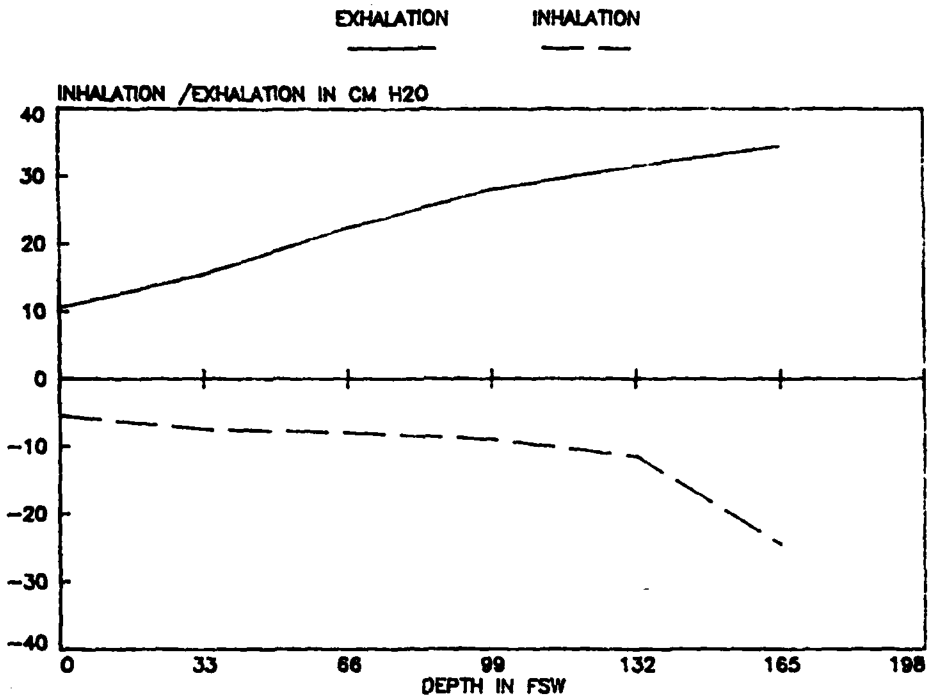
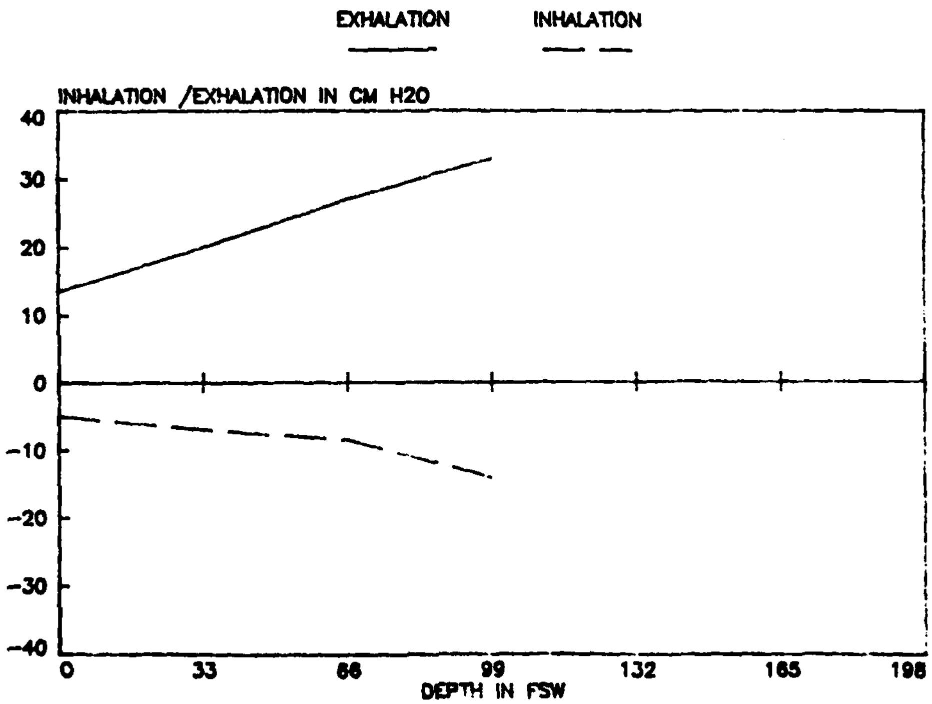


FIG. 24 PEAK DIFFERENTIAL PRESSURES VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 90.0 R.M.V. AND 135 PSIG O/B



APPENDIX E

UNMANNED BREATHING WORK

Breathing Work is plotted at all five RMV's vs Depth for each Umbilical configuration and O/B supply pressure. The NEDU maximum work goal of 0.18 kg·m/l is also plotted as a reference.

KEY

Figure 25 : DIVEX AGA w/200', 3/8" ID Umbilical for all RMV at 135 psig O/B.

Figure 26 : DIVEX AGA w/300', 3/8" ID Umbilical for all RMV at 135 psig O/B.

Figure 27 : DIVEX AGA w/200', 1/2" ID Umbilical for all RMV at 135 psig O/B.

Figure 28 : DIVEX AGA w/300', 1/2" ID Umbilical for all RMV at 135 psig O/B.

FIG. 25 RESPIRATORY WORK VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UMBILICAL AT 135 PSIG O/B

22.5 R.M.V. 40.0 R.M.V. 62.5 R.M.V. 75.0 R.M.V. 90.0 R.M.V.

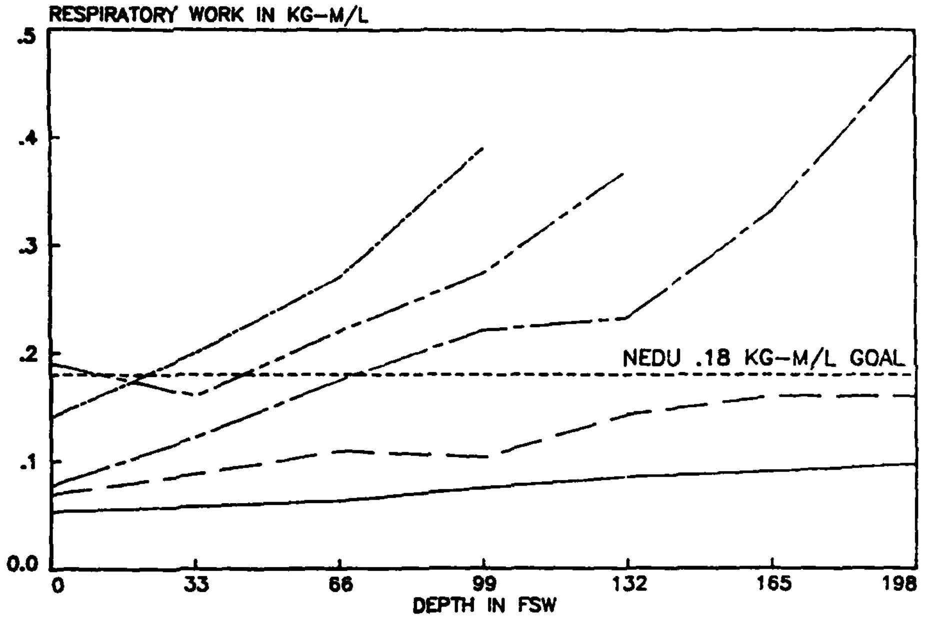


FIG. 26 RESPIRATORY WORK VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 135 PSIG O/B

22.5 R.M.V. 40.0 R.M.V. 62.5 R.M.V. 75.0 R.M.V. 90.0 R.M.V.

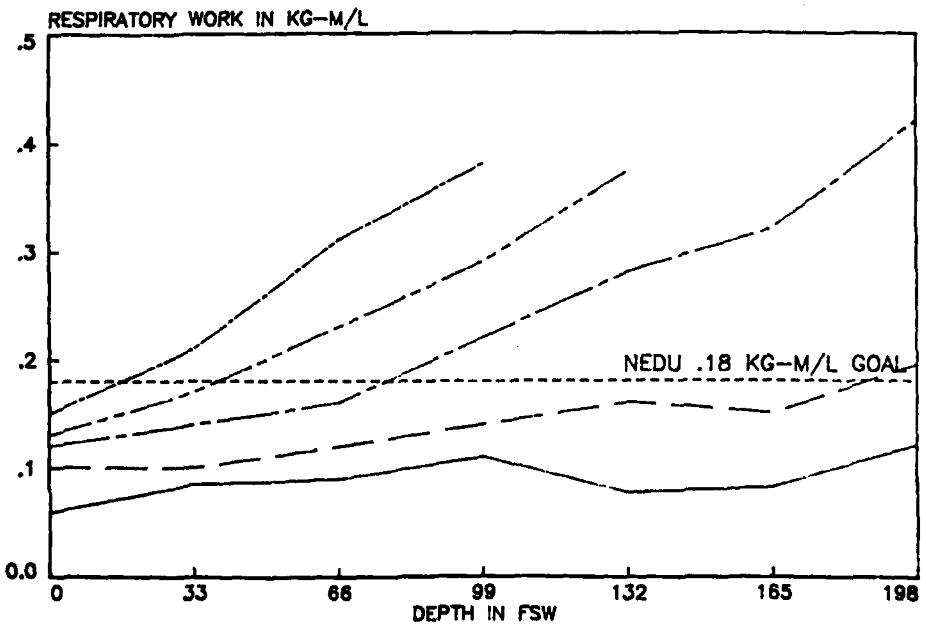


FIG. 27 RESPIRATORY WORK VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 135 PSIG O/B

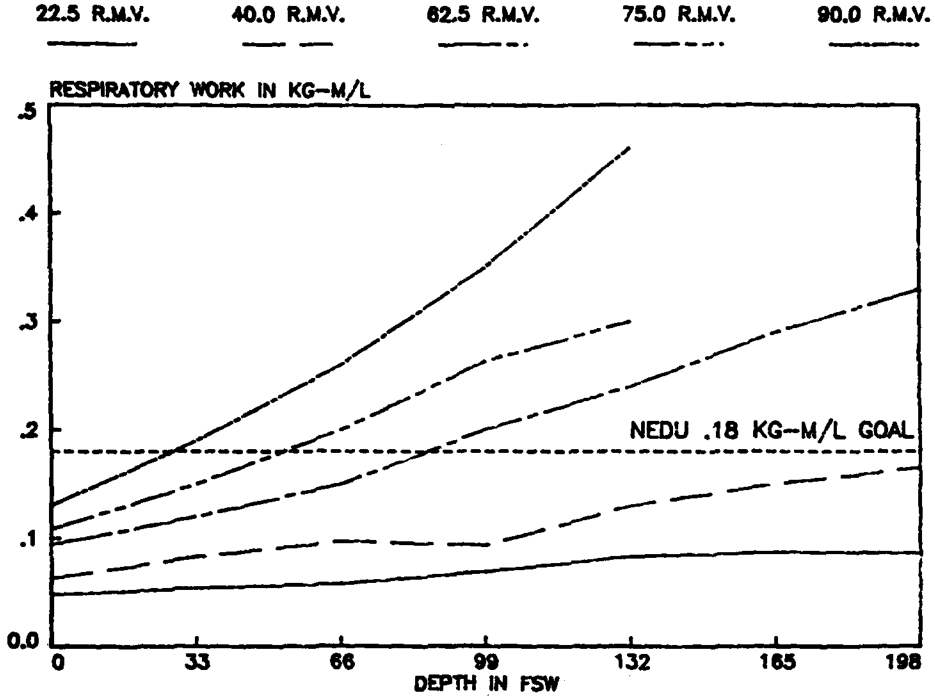
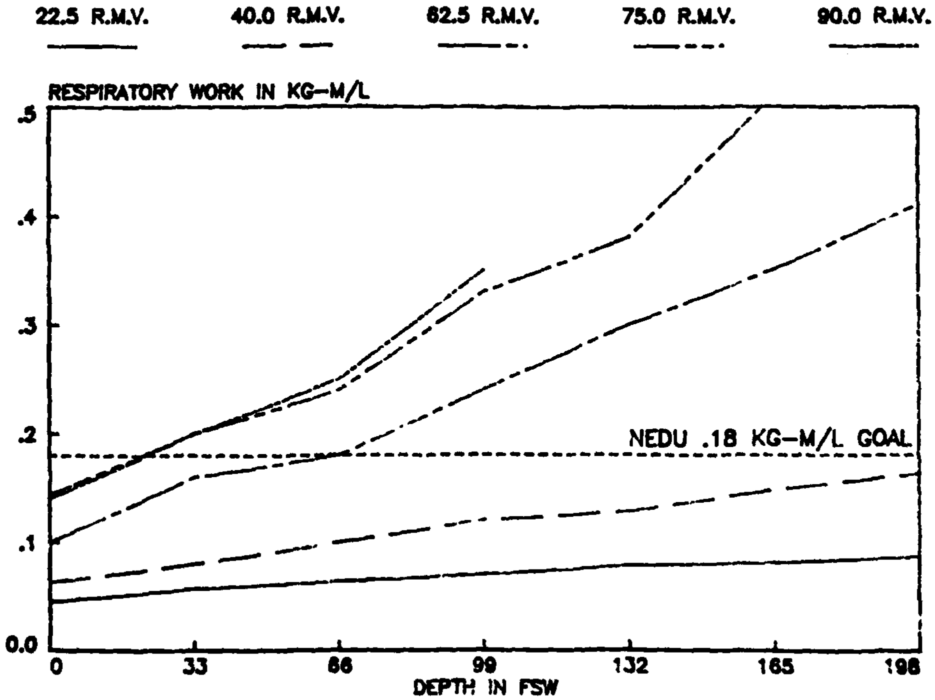


FIG. 28 RESPIRATORY WORK VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 135 PSIG O/B



APPENDIX F

UNMANNED UMBILICAL PRESSURE DROP DATA

Umbilical Pressure Drop is plotted at all five RMV vs Depth for each umbilical configuration at 135 psig O/B.

KEY

Figure 29 : DIVEX AGA w/200', 3/8" ID Umbilical for all RMV at 135 psig O/B.

Figure 30 : DIVEX AGA w/300', 3/8" ID Umbilical for all RMV at 135 psig O/B.

Figure 31 : DIVEX AGA w/200', 1/2" ID Umbilical for all RMV at 135 psig O/B.

Figure 32 : DIVEX AGA w/300', 1/2" ID Umbilical for all RMV at 135 psig O/B.

FIG. 29 UMBILICAL PRESSSURE DROP VS DEPTH

DIVEX AGA WITH 200', 3/8" I.D. UMBILICAL AT 135 PSIG O/B

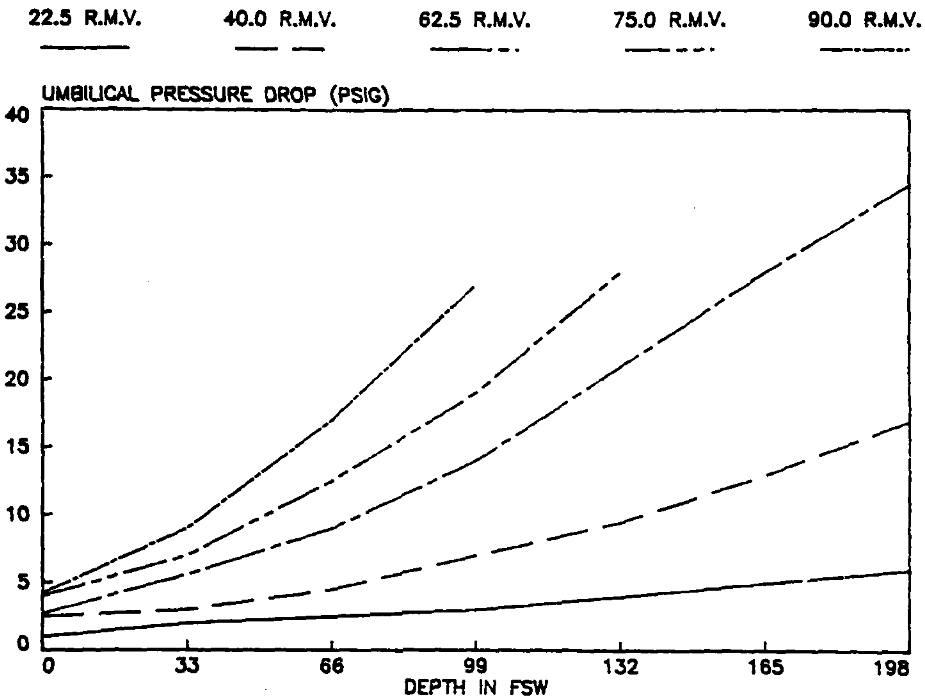


FIG. 30 UMBILICAL PRESSSURE DROP VS DEPTH

DIVEX AGA WITH 300', 3/8" I.D. UMBILICAL AT 135 PSIG O/B

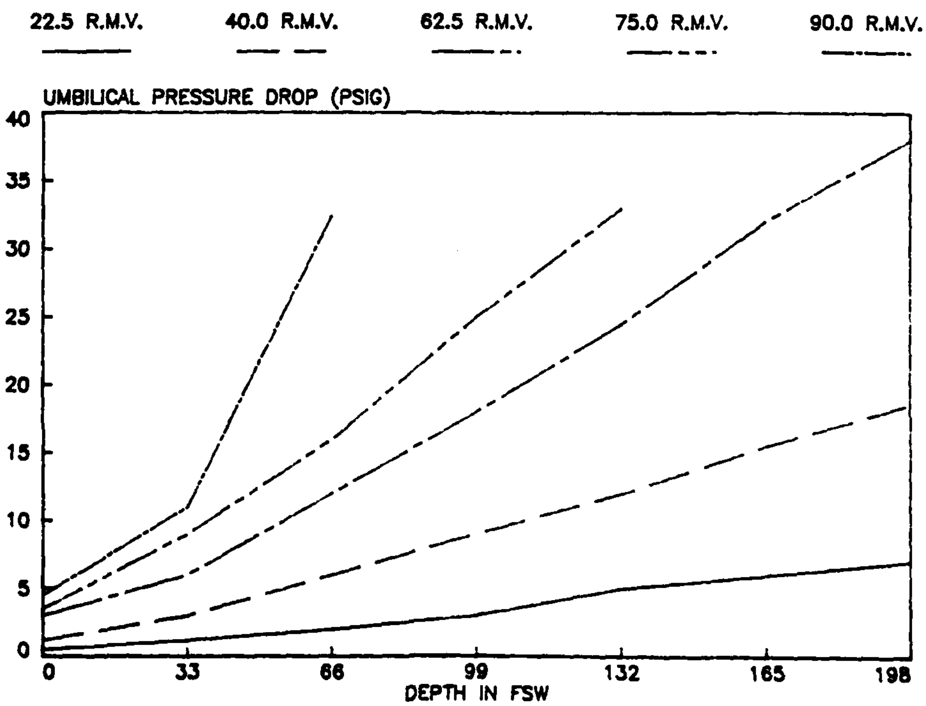


FIG. 31 UMBILICAL PRESSSURE DROP VS DEPTH

DIVEX AGA WITH 200', 1/2" I.D. UMBILICAL AT 135 PSIG O/B

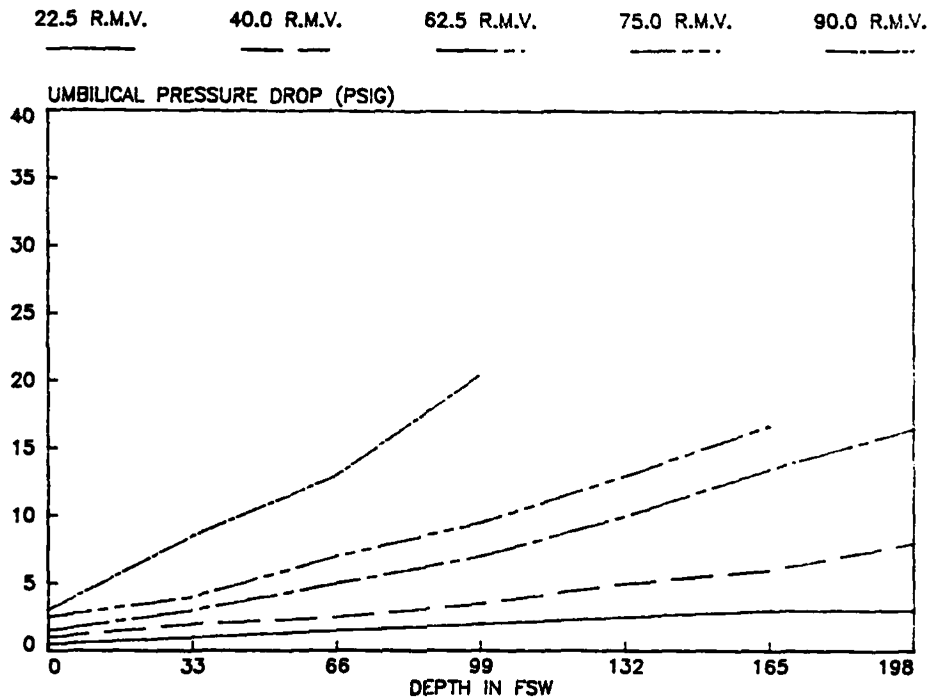
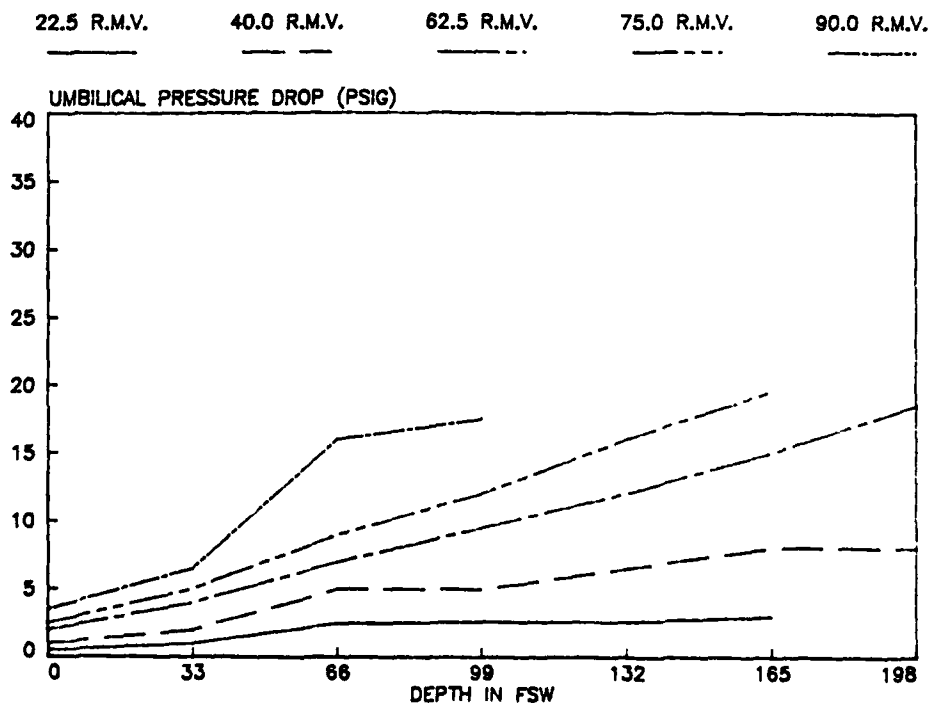


FIG. 32 UMBILICAL PRESSSURE DROP VS DEPTH

DIVEX AGA WITH 300', 1/2" I.D. UMBILICAL AT 135 PSIG O/B



APPENDIX G

SUMMARY OF DIVEX AGA FFM MANNED TEST QUESTIONNAIRES

NAME Open Water Evaluation Summary WEIGHT 125-198 AGE 21-33

DIVE DURATION(s) 15-90 minutes DEPTH(s) 15-35 FSW

NUMBER OF DIVES WITH THE MASK 6 Divers 13 Dives

Check the appropriate answer

1. WAS THE MASK COMFORTABLE DURING THE DIVE(S)?

   VERY UNCOMFORTABLE [0] UNCOMFORTABLE [0] OK [3]

   COMFORTABLE [4] VERY COMFORTABLE [6]

2. IF UNCOMFORTABLE, EXPLAIN: Conformed well to the face, once on the bottom didn't even think about rig.

3. DID YOU NOTICE ANY BREATHING RESISTANCE?

   EXCESSIVE [0] MODERATE [0] SLIGHT [6] NONE [7]

4. IF BREATHING RESISTANCE WAS NOTICED WAS IT DURING:

   EXHALATION [2] INHALATION [3]

   IF SO, EXPLAIN: Same as SCUBA regulator, a little resistance at exhalation, you have to really concentrate to exhale, exhalation resistance nothing that caused any concern, no worse than MK 1, demand mode while breathing heavily.

5. DID MASK FOGGING OCCUR?

   YES [2] NO [11]

   IF SO, WHEN? AND DID IT PREVENT YOU FROM COMPLETING YOUR ASSIGNED TASKS? Fogging occurred on descent, fogging was minimal and had no adverse effect on job.

6. DID YOU NOTICE ANY VISIBILITY PROBLEMS WHILE WEARING THE MASK?

SEVERE | 0 | MODERATE | 0 | SLIGHT | 1 | NONE | 12 |

IF SO, EXPLAIN: My face is too small for oral-nasal mask, you have much better visibility.

7. DURING YOUR DIVES DID WATER ENTER THE MASK AT ANYTIME?

YES | 2 | NO | 11 |

IF SO, DESCRIBE HOW MUCH WATER, WHAT CAUSED IT, DID YOU HAVE TO SURFACE, DID IF FLOOD OUT, WERE YOU ABLE TO CLEAR THE MASK? ______

8. WHEN USING THE COMMUNICATION SYSTEM, WERE YOU UNDERSTOOD CLEARLY AND WERE YOU ABLE TO UNDERSTAND CLEARLY WHEN OTHERS TALKED TO YOU?

YES | 3 | NO | 4 | NO COMMENT | 5 |

EXPLAIN: Comms underwater was very clear, comms OOC due to power failure, comms didn't work right, it might have been the earphone in the wrong place, on the surface was great but underwater wasn't so hot.

9. IS THE MASK AS EASY TO CLEAR AS THE JACK BROWNE?

YES | 7 | NO | 1 | NO COMMENT | 5 |

IF NO, PLEASE COMMENT: Harder to get fingers into mask. I didn't have to clear.

10. IS THE MASK AS EASY TO CLEAR AS THE MK 1 MOD 0?

YES | 6 | NO | 1 | NO COMMENT | 5 |

IF NO, PLEASE COMMENT: It didn't flood.

11. IN GENERAL, HOW WOULD YOU RATE THE PERFORMANCE OF THE MASK?

UNSATISFACTORY | 0 | POOR | 1 | FAIR | 4 |

GOOD | 3 | EXCELLENT | 5 |

12. WHAT SUGGESTIONS DO YOU HAVE FOR IMPROVING THE MASK?

a. Needs nose clearing device because suction of mask too great for putting hand into mask.

b. Need to modify for thinner faces.

c. Change mask harness rubber straps, suggest use Jack Browne straps.

d. Everytime I put my arm above my head I would hit the purge button and the mask would hammer against my face.

e. Change position of comms elbow to point to left side instead of right side where mask exhaust bubbles (then put bone conductor to left ear).

f. Get rid of mask hanging strap, serves no purpose except to get in the way when working.

g. Exhaust and earphone should not be on the same side.

h. Movable air supply elbow kinks the hose from the shackle to the mask.

i. Make the mask harness straps out of less flexible material.

j. Clearing device not really mandatory because had no problem getting hand into mask.

13. APPROXIMATELY HOW MANY DIVES HAVE YOU MADE WITH THE JACK BROWNE? 25-250

14. APPROXIMATELY HOW MANY DIVES HAVE YOU MADE WITH THE MK 1 MOD 0 MASK? 2-100

15. HOW WOULD YOU RATE THE COMFORTABILITY OF THE AGA MASK AGAINST THAT OFFERED BY THE JACK BROWNE?

MUCH WORSE [0] WORSE [2] SAME [3]

BETTER [4] MUCH BETTER [4]

16. HOW WOULD YOU RATE THE COMFORTABILITY OF THE AGA MASK AGAINST THAT OFFERED BY THE MK 1 MOD 0?

MUCH WORSE [0] WORSE [2] SAME [0]

BETTER [0] MUCH BETTER [11]

COMMENTS: It was lighter and not as heavy on head.

17. HOW DO YOU RATE AGA MASK SET-UP, POST-DIVE MAINTENANCE AND NORMAL PMS COMPARED TO THE JACK BROWNE?

MUCH WORSE [2] WORSE [4] SAME [7]

BETTER [0] MUCH BETTER [0]

IF WORSE, WHY? More time taking it apart and cleaning it, there are too many parts that raise your chance of breaking and/or losing something, Jack Browne does not need to be disassembled.

18. HOW DO YOU RATE AGA MASK SET-UP, POST-DIVE MAINTENANCE AND NORMAL PMS COMPARED TO THE MK 1 MOD 0 MASK?

MUCH WORSE [0] WORSE [0] SAME [6]

BETTER [1] MUCH BETTER [6]

IF WORSE, WHY? ______________________________