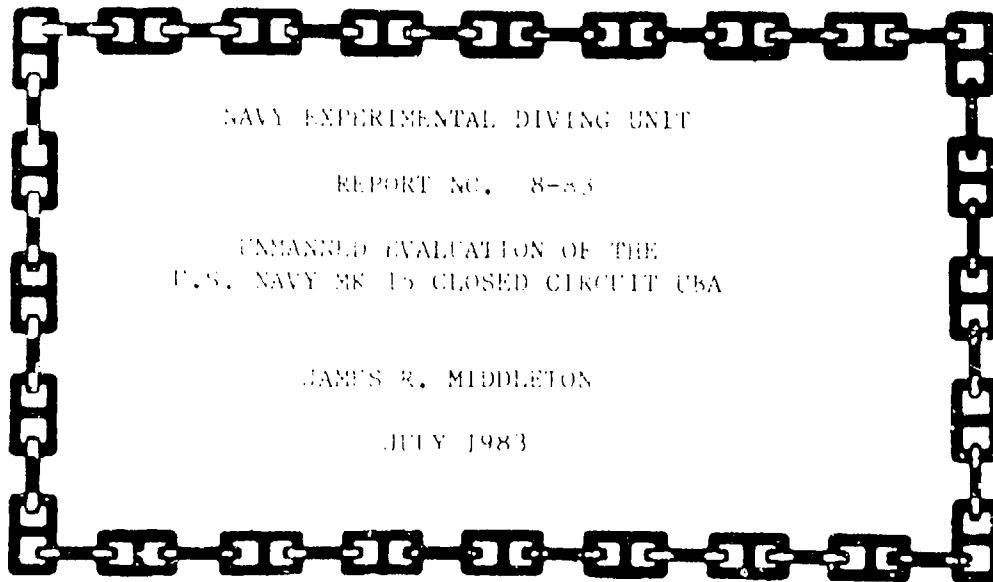


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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 8-83

UNMANNED EVALUATION OF THE
U.S. NAVY MK 15 CLOSED CIRCUIT CBA

JAMES R. MIDDLETON

JULY 1983

NAVY EXPERIMENTAL DIVING UNIT

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JAMES R. MIDDLETON

JULY 1983

Approved for public release; distribution unlimited

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Breathing resistance/breathing work studies were made using five different mouthpiece/hose and FFM configurations at depths to 150 FSW at simulated work rates ranging from light to extreme. CO₂ canister duration tests were conducted in water temperatures ranging from 29 to 90°F. ←

Results of these unmanned performance tests revealed that:

a. MK-15 breathing resistance/breathing work can be significantly lowered by use of the AGA/ACSC hoses and mouthpiece assembly vice the standard Scott mouthpiece.

b. The MK-15 FFM using the standard Koegel valves exhibits slightly better breathing resistance/breathing work performance than the same mask using Rexnord, Inc. mushroom valves.

c. The MK 15 UBA when used in conjunction with the WIDOLF FFM and its associated hoses exhibited breathing resistance/breathing work values significantly higher than the standard MK 15 FFM with Koegel valves.

d. The MK 15 CO₂ absorbent canister experiences approximately a 20% decrease in canister duration life in water temperatures below 55°F in unmanned testing. This trend was not observed during manned testing in reference 1.

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Glossary

ACSC	alternating closed/semi closed circuit
BPM	breaths per minute
C/C	closed-circuit
Canister Breakthrough	point at which CO ₂ concentration in the inhaled gas reached 0.50 percent surface equivalent
°C	temperature degrees Centigrade
cmH ₂ O	centimeters of water pressure
CO ₂	carbon dioxide gas
EDF	Experimental Diving Facility Hyperbaric Chamber Complex
°F	temperature degrees Fahrenheit
FFM	full-face mask
FSW	feet-of-seawater
HP	high pressure
HP SODASORB	high-performance SODASORB
kg.m/l	kilogram-meters per liter (respiratory work)
lpm	liters per minute (flow rate)
MOD	modified
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
N ₂ -O ₂	nitrogen-oxygen gas mix
O ₂	oxygen gas
ΔP	pressure differential
PO ₂	partial pressure of oxygen
psid	pounds per square inch differential
psig	pounds per square inch gauge
RMV	respiratory-minute-volume in liters-per-minute

Glossary (continued)

SCUBA	self-contained underwater breathing apparatus
SDV	swimmer delivery vehicle
SEV	surface equivalent value
SI	System International (units of measure)
TEMP	temperature
Temp	exhaled gas temperature
TV	the liter-tidal volume of air breathed in and out of the lungs during normal respiration
UBA	underwater breathing apparatus
U/W	underwater

SI Unit Conversion Table

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
kg.m/l	joule per liter (J/L)	9.807
psi	kilopascal (kPa)	6.895
°C	kelvin (K)	$^{\circ}\text{K} = ^{\circ}\text{C} + 273.15$
°F	kelvin (K)	$^{\circ}\text{K} = (^{\circ}\text{F} + 459.67)/1.8$
FSW	meters of seawater (MSW)	0.305
FSW	kilopascal (kPa)	3.065

Abstract

The Navy Experimental Diving Unit (NEDU) performed unmanned testing on the U.S. Navy MK 15 closed-circuit (C/C) underwater breathing apparatus (UBA) using a hyperbaric breathing simulator. The purpose of these tests was twofold: (1) to evaluate breathing resistance/breathing work characteristics of the MK 15 UBA using a variety of mouthpiece/hose and full-face mask (FFM) configurations and (2) to evaluate carbon dioxide (CO₂) absorbent canister duration at a depth of 50 feet-of-seawater (FSW) in a wide range of water temperatures.

Breathing resistance/breathing work studies were made using five different mouthpiece/hose and FFM configurations at depths to 150 FSW at simulated work rates ranging from light to extreme. CO₂ canister duration tests were conducted in water temperatures ranging from 29 to 90°F.

Results of these unmanned performance tests revealed that:

a. MK 15 breathing resistance/breathing work can be significantly lowered by use of the AGA/ACSC hoses and mouthpiece assembly vice the standard Scott mouthpiece.

b. The MK 15 FFM using the standard Koegel valves exhibits slightly better breathing resistance/breathing work performance than the same mask using Rexnord, Inc. mushroom valves.

c. The MK 15 UBA when used in conjunction with the WIDOLF FFM and its associated hoses exhibited breathing resistance/breathing work values significantly higher than the standard MK 15 FFM with Koegel valves.

d. The MK 15 CO₂ absorbent canister experiences approximately a 20% decrease in canister duration life in water temperatures below 55°F in unmanned testing. This trend was not observed during manned testing in reference 1.

I. INTRODUCTION

During May 1982 NEDU tested the MK 15 UBA for breathing resistance/breathing work with various mouthpiece/hose and FFM combinations to determine how improvement in performance of its breathing loop could be accomplished. In addition, CO₂ absorbent canister life was evaluated to increase the data available on UBA canister performance. Manned canister duration testing at similar depths and water temperatures has also been conducted by NEDU and is described in reference 1.

Unmanned testing was conducted in the NEDU Experimental Diving Facility (EDF). The UBA was evaluated with respect to breathing work and breathing resistance at simulated diver work rates ranging from light to extreme using the five mouthpiece/hose and FFM combinations listed in Table 1 and illustrated in APPENDIX B (Figures 1 through 4). In addition, the MK 15 UBA was tested to determine the duration of its CO₂ absorbent canister at a variety of water temperatures ranging from 29°F to 90°F at 50 FSW.

II. FUNCTIONAL DESCRIPTION (Figure 5)

The MK 15 is a closed circuit rebreather capable of providing approximately 595 liters (21 cu. ft.) of both O₂ and a breathable diluent gas.

During normal operation, the diver inhales a mixture of O₂ and diluent gas and the diver's exhaled gas is recirculated back to the scrubber housing where it is filtered through the scrubber and CO₂ is removed.

As the diver descends, the MK 15 adds diluent to maintain the volume of the diver's breathing loop. Diluent gas is added to the breathing loop in response to actuation of the diluent addition valve by the motion of the molded neoprene diaphragm as a result of the reduced volume in the breathing loop.

While the diver is working at his assigned depth, his PO₂ is monitored by the three O₂ sensors and maintained at 0.70 ± 0.10 ATA. When the diver's PO₂ goes below a predetermined set-point, the sensors send a signal to the O₂ addition valve, via the electronics assembly, which opens to allow additional O₂ into the breathing loop. Oxygen addition continues until the PO₂ in the breathing loop is brought back to the predetermined set-point. A second signal is then sent by the electronics assembly causing the O₂ addition valve to close.

The primary display indicates relative oxygen concentration and qualitative electronics status. The primary display is mounted on the divers right arm and indicates the PO₂ in the breathing loop by means of status lights. Functional indications are: Normal O₂, High O₂ (0.8 ATA), Low O₂ (0.6 ATA) and transition from one state to another, low battery voltage and/or failure of components.

The diver is also equipped with a secondary display which directly monitors the O₂ sensors and the secondary battery level. The secondary

TABLE 1

MK 15 Mouthpiece/Hose and FFM Combinations Tested

- A. MK 15 UBA with standard hoses and Scott mouthpiece (Figure 1).
- B. MK 15 UBA with AGA/ACSC hoses and mouthpiece (Figure 2).
- C. MK 15 UBA with DIVEMATICS USA, Inc. WIDOLF FFM (Figure 3).
- D. MK 15 UBA with MK 15 FFM using standard Koegel valves (Figure 4).
- E. MK 15 UBA with MK 15 FFM using Rexnord, Inc. mushroom valves (Figure 4).

NOTE: All CO₂ absorbent canister duration tests were conducted using the MK 15 in its standard configuration (Figure 1).

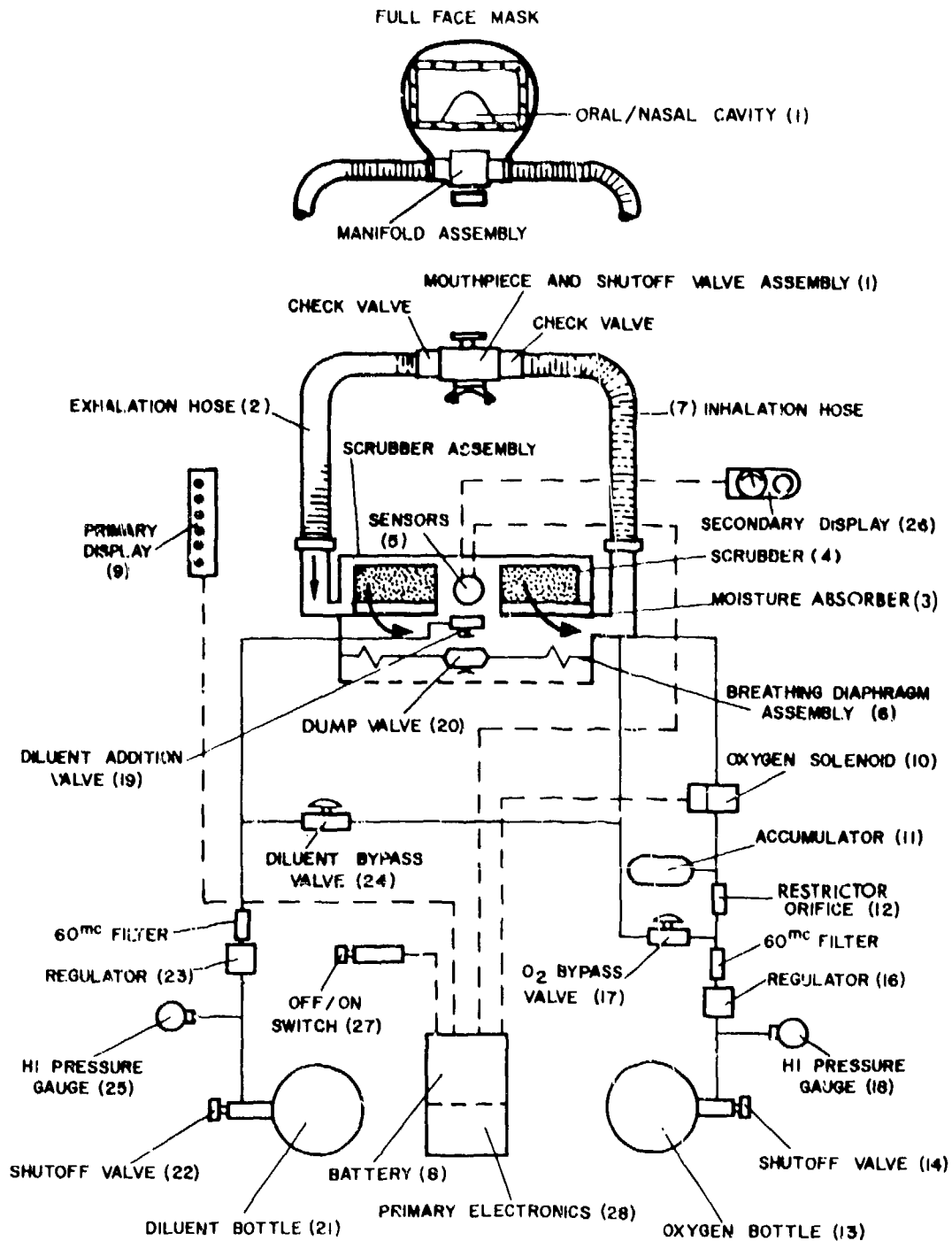


Figure 5. MK 15 Functional Block Diagram

display consists of an analog meter which is powered independently. The manual bypass valves permit the diver to control the addition of diluent or O₂ to the breathing loop should the automatic system fail.

III. EQUIPMENT PHOTOS

APPENDIX B contains photos of the MK 15 and the mouthpiece/hose and FFM combinations tested (Figures 1 through 4).

IV. TEST PROCEDURE

A. Test Plan. Figure 6 illustrates the test equipment set-up. APPENDIX C provides the complete test plan and the test equipment illustrated in Figure 6 is listed in APPENDIX D. A breathing simulator and hyperbaric chamber simulated inhalation and exhalation at various depths and diver work rates. The wet box in which the UBA was submerged simulated the wide range of water temperatures in which the UBA might be used. 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 oral cavity of the mouthpiece or the oral-nasal cavity of the FFM.

B. Controlled Parameters

1. Breathing Resistance Tests - Breathing resistance controlled parameters included:

(a) Standardized NEDU breathing rates, tidal volume, exhalation/inhalation time ratio and breathing waveform were controlled as set forth in NEDU Report 3-81 (reference 2).

(b) UBA breathing gas: air.

(c) Depths: 0, 33, 66, 99, 132 and 150 FSW.

(d) Diluent supply pressure: 1000 psig.

2. Canister Duration Tests - Canister duration controlled parameters included:

(a) Standardized CO₂ add rates and exhaled gas temperatures controlled as set forth in NEDU Report 3-81 (reference 2).

(b) UBA breathing gas: air.

(c) CO₂ absorbent: HP SODASORB with moisture content between 13.5 and 15%.

(d) Water TEMP: 90, 70, 55, 40, 35 AND 29°F.

(e) Relative humidity of exhaled gas: 90-95%.

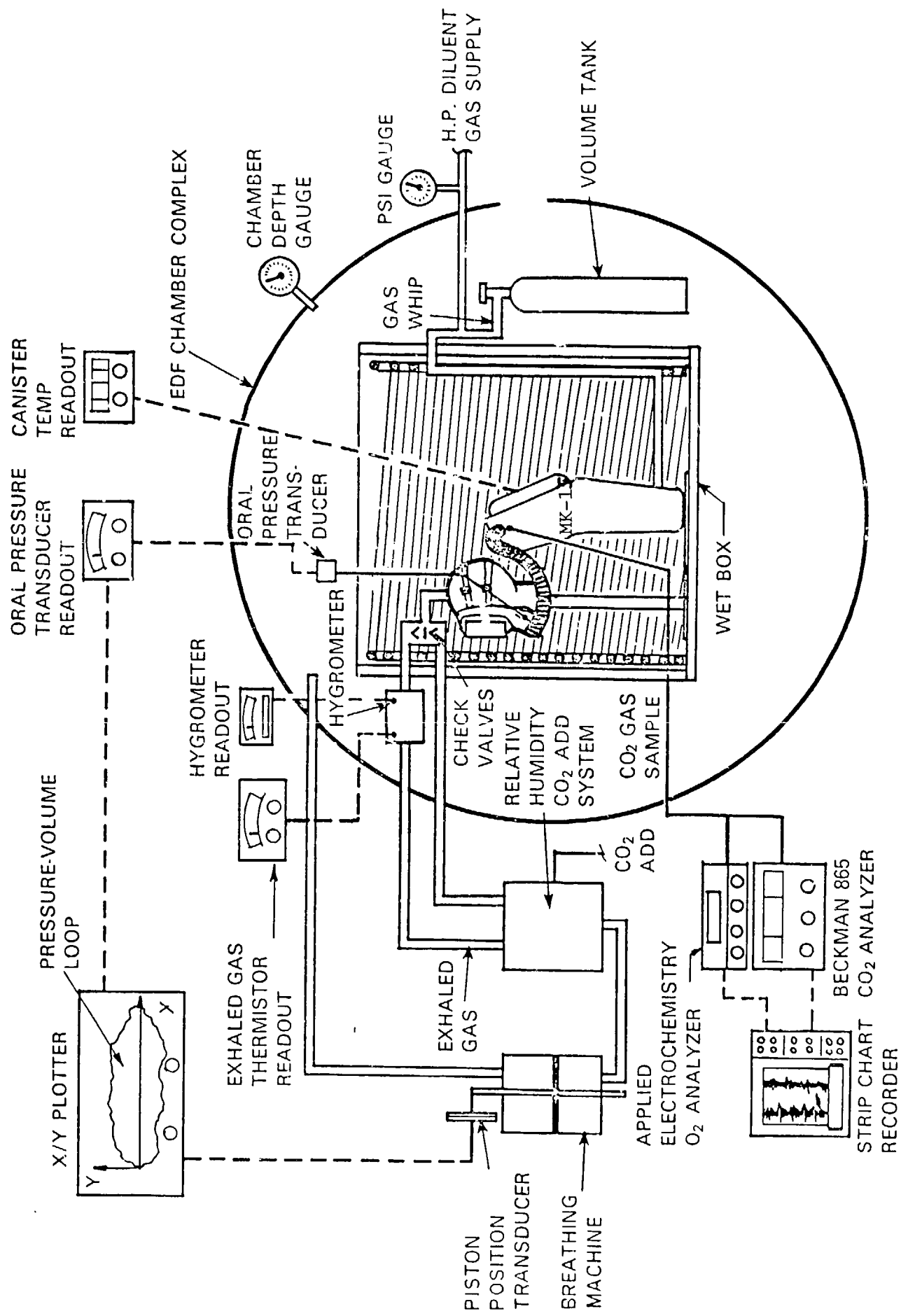


Figure 6. Test Setup

(f) Depth: 50 FSW.

(g) Diluent supply pressure: 1000 psig.

(h) Canister packing density: Canister duration in any UBA is quite sensitive to how the absorbent is packed. Consequently, uniformity of canister packing was maintained at ± 4 ounces in order to achieve consistent results.

NOTE: In both breathing resistance/breathing work and CO₂ canister duration studies air was used as the breathing medium since its density and heat transfer properties are virtually identical to the N₂O₂ breathing mix normally used in the MK 15.

C. Measured Parameters

1. Breathing Resistance Tests - Maximum ΔP in cmH₂O (i.e. total pressure excursion between full exhalation and full inhalation cycles).

2. Canister Duration Tests: CO₂ level out of scrubber expressed as percentage of surface equivalent value (SEV).

D. Computed Parameters

1. Breathing Resistance Tests: 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 7.

2. Canister Duration Tests: Exhaled gas TEMP was calculated and controlled as a function of water temperature based on the standardized procedure in reference 2.

E. Data Plotted

1. The following plots were developed from data obtained in the breathing resistance tests:

a. Peak exhalation to peak inhalation ΔP (cmH₂O) vs depth (FSW) at each RMV (lpm) tested.

b. Respiratory work per liter (kg·m/l) vs depth (FSW) at each RMV (lpm) tested.

2. The following plots were developed from data obtained in the canister duration tests: canister effluent CO₂ (% SEV) vs time (min.).

V. RESULTS

A. Breathing Resistance and Breathing Work Tests. APPENDIX E (Figures 8 through 12) contains plots of peak differential breathing pressures vs depth and APPENDIX F (Figures 13 through 17) contains plots of breathing work vs depth for each equipment combination tested. Peak inhalation to peak

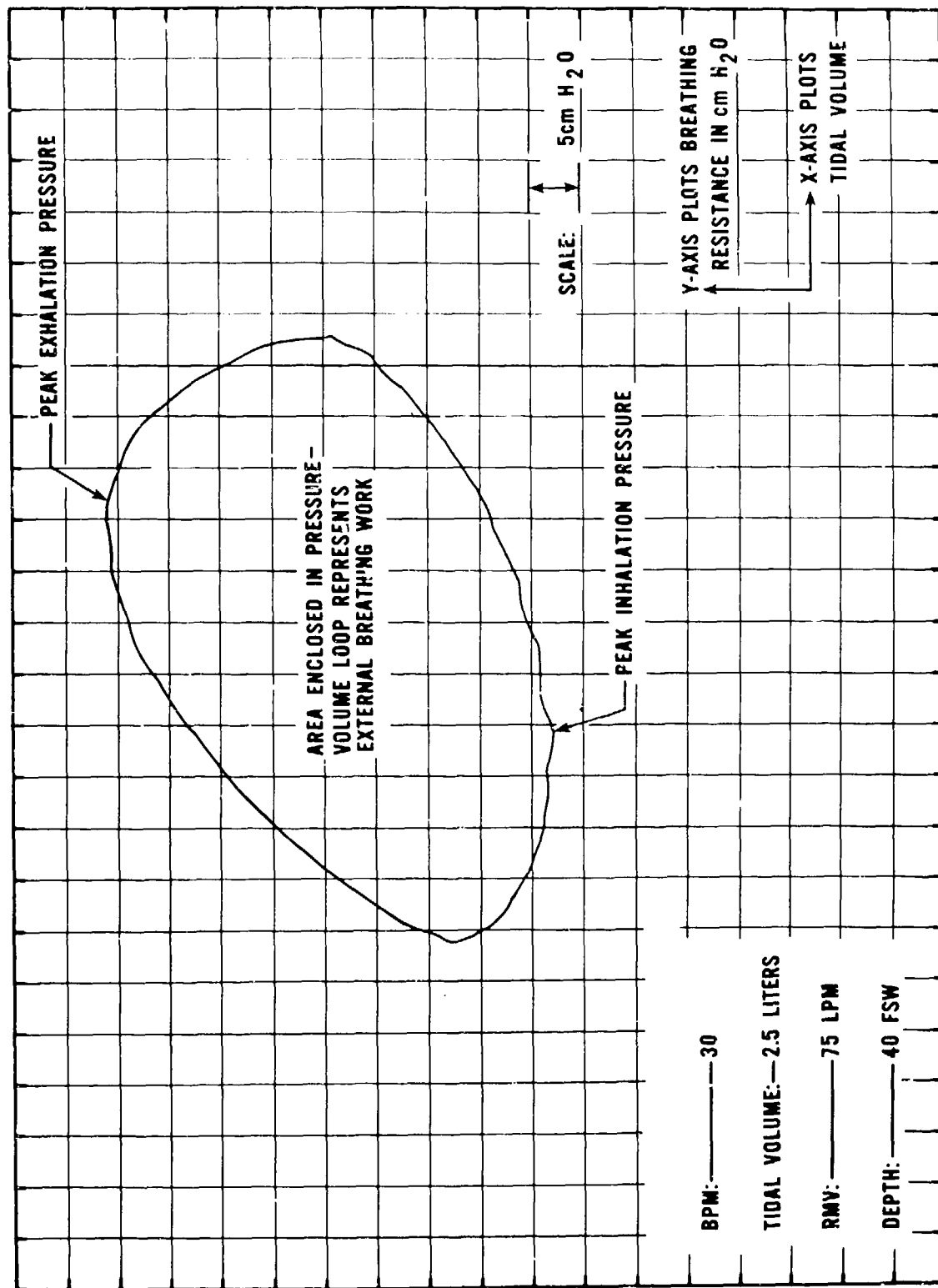


Figure 7. Pressure - Volume Loop Generated at 75 RMV at a depth of 150 FSW

exhalation in cmH_2O was measured at each RMV tested. Breathing work is measured in $\text{kg}\cdot\text{m}/1$ 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 2 provides a comparison of the peak differential pressures in each mouthpiece/hose and FFM combination tested at 150 FSW and 75 RMV while TABLE 3 provides a similar comparison of breathing work. The numbers in parenthesis in TABLES 2 and 3 represent the relative position in which that particular combination finished in each test (i.e., (1) would represent the best performance of the five combinations and (6) the worst).

B. CO₂ Absorbent Canister Duration Tests. A total of 15 canister duration tests were conducted as part of this evaluation series. All canister duration tests were conducted at 50 FSW with ambient water temperature being varied from 29 to 90°F. Two runs were conducted at each set of test conditions and canister duration differences of more than 20 minutes were never observed. The canister durations at all water temperatures are summarized in TABLE 4.

Figure 18 is a sample of the type of CO₂ absorbent canister duration plots generated during unmanned testing. Rest and work cycles are readily observed as continuing for the duration of each test. APPENDIX G (Figure 19) plots only the mean % SEV CO₂ vs time generated during the work cycles in order to display the results of testing at all temperatures on one graph. The data on the graph is carried beyond 0.50% SEV CO₂ during work cycles to give a more complete picture of UBA performance.

VI. DISCUSSION

A. Breathing Resistance and Breathing Work Tests. NEDU Report 3-81, "Standardized NEDU Unmanned UBA Test Procedures and Performance Goals," (reference 2) establishes a performance goal of a total maximum breathing resistance of 22 cmH_2O and 0.18 $\text{kg}\cdot\text{m}/1$ respiratory work at 75 RMV and maximum normal operating depth for C/C diver breath-driven UBA using air. This goal does not represent a minimum acceptable performance level. Rather, the goal when met by a UBA will insure that the UBA is not the limiting factor in diver performance.

Examination of the data presented in Tables 2 and 3 shows that none of the combinations tested met the established performance goal. However, manned testing as documented in reference 3 has proved that C/C O₂ UBA with performance similar to the MK 15 UBA in standard configuration will adequately support a working diver. Consequently, since the goals established in reference 1 are dynamic in nature, as more data is gathered, they will be updated to reflect the most recent and realistic performance requirements available.

The MK 15 with MK 15 FFM (Koegel valves) exhibited the lowest breathing work and peak differential pressures measured during the evaluation. This is due to the large flow passages in the mask and the extremely low pressure loss across the Koegel one-way valves. However, as evidenced in Tables 2 and 3 the

TABLE 2

Comparison of Total Breathing Resistance
Peak Inhalation to Peak Exhalation
Breathing Pressures at 150 FSW and 75 RMV

UBA COMBINATION	PEAK TO PEAK DIFFERENTIAL BREATHING PRESSURE (cmH ₂ O)
MK 15 w/Standard Hoses and Scott Mouthpiece	N/A (4)
MK 15 w/AGA ACSC Hoses and Mouthpiece	50.0 (2)
MK 15 w/WIDOLF FFM	54.5 (3)
MK 15 w/MK 15 FFM and Koegel Valves	46.5 (1)
MK 15 w/MK 15 FFM and Rexnord Mushroom Valves	50.0 (2)

NOTES:

- a. NEDU Performance Goal: 0.18 kg·m/l with peak to peak breathing pressures not exceeding 22 cmH₂O at 75 RMV and 150 FSW.
- b. N/A: Performance at this work level not attainable.
- c. Numbers in parenthesis represent the relative position in which that equipment combination finished.

TABLE 3

Comparison of Breathing Work
at 150 FSW and 75 RMV

UBA COMBINATION	BREATHING WORK (kg·m/l)
MK 15 w/Standard Hoses and Scott Mouthpiece	N/A (4)
MK 15 w/AGA ACSC Hoses and Mouthpiece	0.34 (2)
MK 15 w/WIDOLF FFM	0.40 (3)
MK 15 w/MK 15 FFM and Koegel Valves	0.31 (1)
MK 15 w/MK 15 FFM and Rexnord Mushroom Valves	0.34 (2)

NOTES:

- a. NEDU Performance Goal: 0.18 kg·m/l with peak to peak breathing pressures not exceeding 22 cmH₂O at 75 RMV and 150 FSW.
- b. N/A: Performance at this work level not attainable.
- c. Numbers in parenthesis represent the relative position in which that equipment combination finished.

TABLE 4

Unmanned Canister Duration Tests

Summary of Results

WATER TEMP (°F)	TIMES TO 0.5% CO ₂ SEV (MIN)		TIMES TO 1.0% CO ₂ SEV (MIN)	
	RUN 1	RUN 2	RUN 1	RUN 2
29	175	175	217	220
35	190	205	226	240
40	215	208	260	245
55	220	230	266	280
70	274	256	280	300
90	225	225	280	300

breathing work/peak differential pressures measured using the MK 15 FFM with Rexnord mushroom valves was insignificantly greater. In addition, the superior check valve properties and lower cost of the mushroom type valve over the Koegel valves makes this combination a logical future replacement in the MK 15 FFM.

Performance of the AGA ACSC mouthpiece/hose assembly with the MK 15 UBA was essentially the same as the MK 15 FFM with mushroom valves. The flow passages and mushroom valves in the AGA assembly are quite similar to those in the MK 15 FFM w/Rexnord mushroom valves and account for the similar performance. The AGA mouthpiece/hose assembly was also evaluated in reference 3 and represents state-of-the-art in a high flow/low resistance design while retaining a superior check valve function.

The WIDOLF mask performed adequately when compared both to the AGA mouthpiece/hose assembly and standard MK 15 hose/Scott mouthpiece configuration. This mask is originally of Dutch design, but is now manufactured, with modifications, in the United States. Improvements currently in progress on this mask and its local manufacture may make it attractive for future U.S. Navy C/C UBA applications.

Breathing work/peak differential pressure performance of the standard MK 15 UBA configuration is indicative of its mid 1960's design. As stated above however, manned testing (reference 3) has shown performance for UBA with these work and differential pressures to adequately support the working diver.

B. CO₂ Absorbent Canister Duration Tests. The standard NEDU unmanned canister duration test scenario as described in APPENDIX C was conducted. This procedure simulates a diver resting in the water on a bicycle-ergometer for 4 minutes at a CO₂ production rate of 0.90 LPM and then working at an CO₂ production rate of 1.60 LPM for 6 minutes. This routine is alternated until the canister output reaches a minimum level of 0.50% SEV CO₂.

As demonstrated in Table 4 and Figure 19, performance of the MK 15 CO₂ absorbent canister's remained almost constant in water temperatures between 90 and 40°F. At lower temperatures however, canister durations dropped by about 10% to 0.5% CO₂ SEV. This phenomena was not observed during manned testing conducted in reference 1 (i.e. no significant canister duration decrease was observed at the colder water temperatures). Canister performance in cold water is hindered by the stainless steel construction which rapidly transmits heat, vitally needed to sustain the reaction between CO₂ and the HP SODASORB, away from the absorbent bed and into the surrounding water. Large improvements in CO₂ absorbent canister performance have been accomplished in the MK 16 UBA (reference 4). Design of this canister is similar to the MK 15 but the construction material has been changed to LEXAN which provides better thermal insulation in cold water.

VII. CONCLUSIONS

Use of the AGA ACSC mouthpiece/hose assembly will significantly improve breathing work/peak differential pressure performance of the MK 15 UBA. In

addition, converting to a high flow/low resistance mushroom valve in the MK 15 FFM will not significantly affect performance while providing a much better check-valve function than the existing Koegel valves.

The MK 15 UBA CO₂ canister configuration is essentially fixed. Consequently, the use of alternate CO₂ absorbent materials to improve canister durations is a viable alternative for possible improved performance.

VIII. REFERENCES

1. NEDU Report 6-83, 'Manned Evaluation of MK 15 Closed-circuit UBA Canister Duration at 13.4°C and 2°C,' F. R. Jaggars, Jr. and E. D. Thalmann, June 1983.

2. 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.

3. NEDU Report 5-79, 'Evaluation of Modified DRAEGER LAR V Closed-Circuit Oxygen Rebreather,' James R. Middleton and Claude A. Piantadosi, August 1979.

4. NEDU Report 2-80, 'Unmanned Evaluation of U.S. Navy UBA EX-16 Pre-production Model Closed Circuit Rebreather,' James R. Middleton, December 1979.

APPENDIX A

List of Commercial Manufacturer's Addresses

Model: AGA ACSC Mouthpiece/Hoses

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

Model: WIDOLF

Manufacturer: DIVEMATICS U.S.A., Inc.
2909 Oregon Court, #G12
Torrance, California 90503
Telephone: 213-320-6291

APPENDIX B

Equipment Photos

Figures 1 through 4

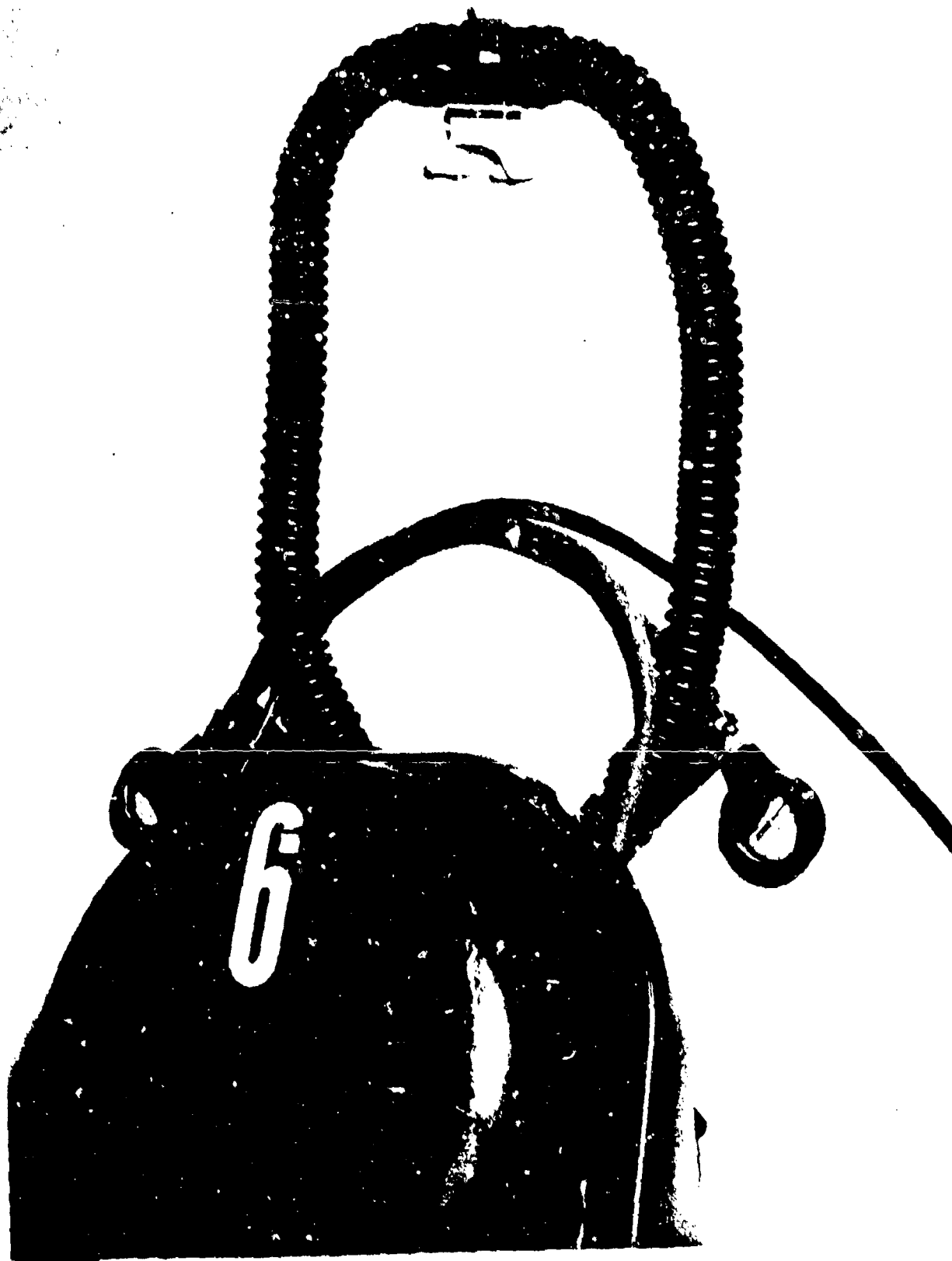


Figure 1. MK 15 with Standard Roses



Figure 2. MK 15 with AGA/ACSC Hoses and Mouthpiece

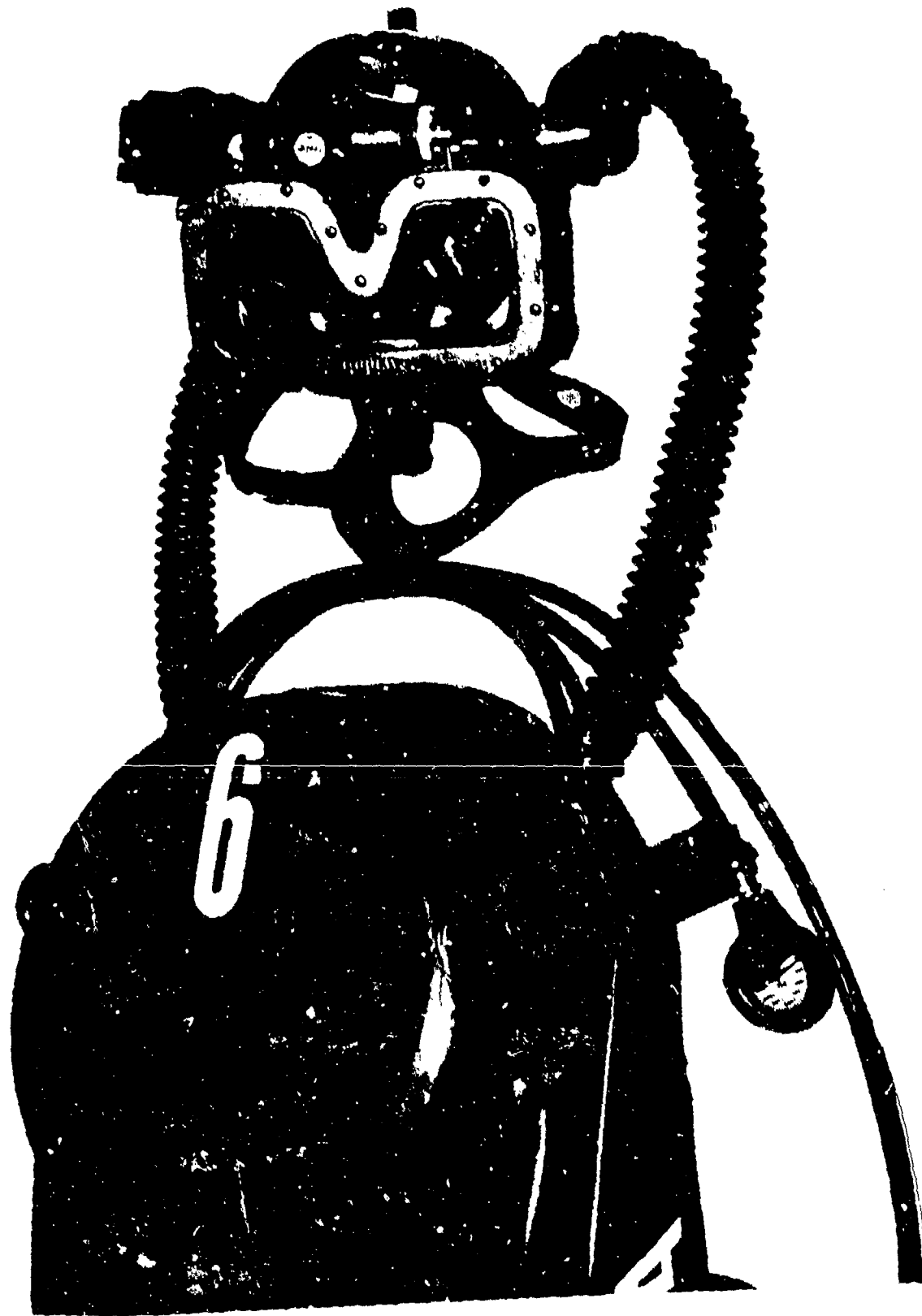


Figure 3. MK 15 with WIDOLF FFM

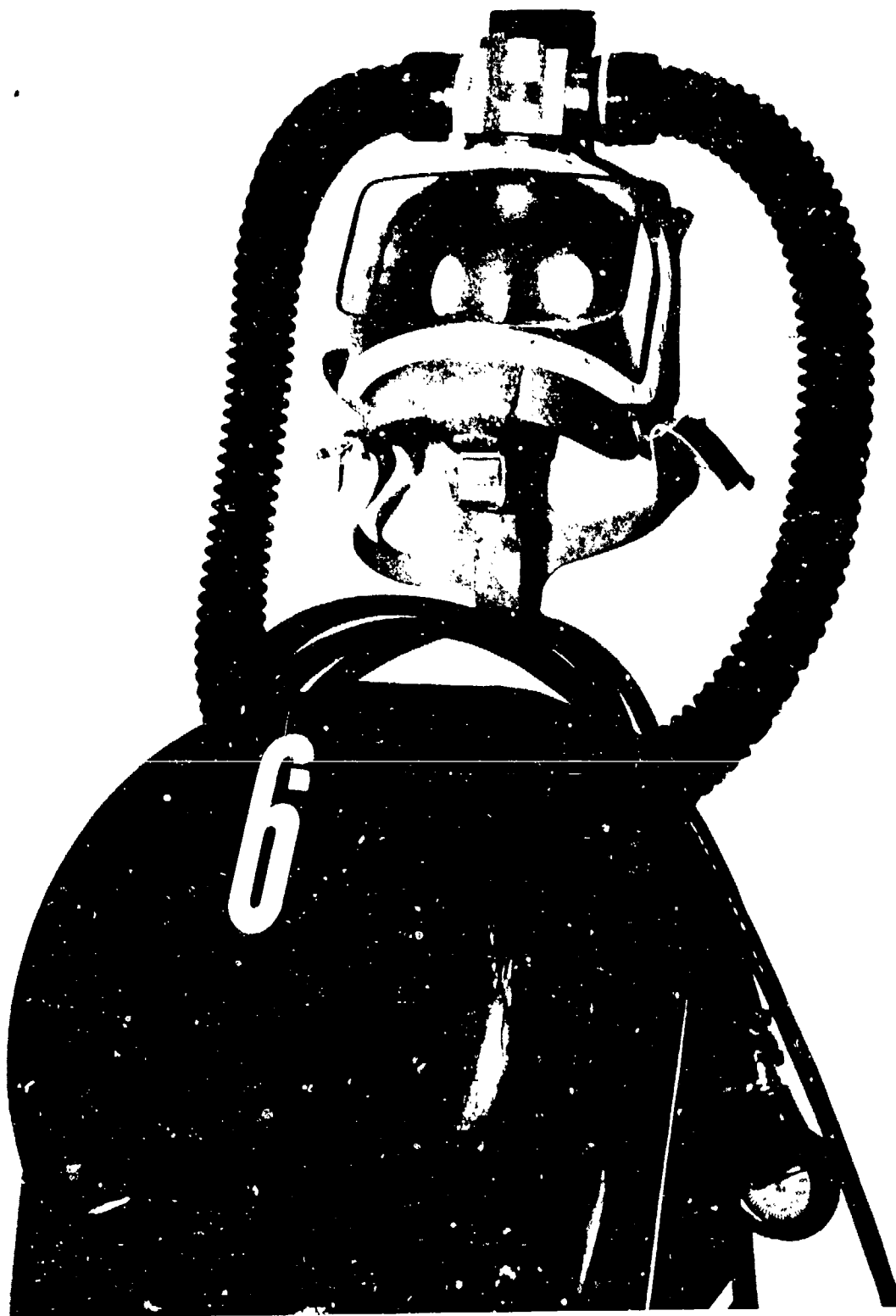


Figure 4. MK 15 with MK 15 FFM

APPENDIX C

Test Plan

A. Test Plan for Breathing Resistance Evaluation:

(1) (a) Insure that UBA is set to manufacturers specification and is working properly using HP SODASORB.

(b) Chamber on surface.

(c) Calibrate transducers.

(d) Open diluent 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 33, 66, 99, 132 and 150 FSW.

(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 other mouthpiece and FFM assemblies, as applicable.

B. Test Plan for CO₂ Canister Duration Evaluation:

(1) (a) Insure that UBA is set to manufacturers specification and is working properly using HP SODASORB.

(b) Chamber on surface.

(c) Calibrate transducers and CO₂ analyzers.

(d) Open diluent gas supply valve to test UBA.

(e) Water TEMP to be approximately 90°F.

(f) Start humidity add system.

(g) Pressurize chamber to 50 FSW.

(h) Start CO₂ add and maintain following procedure until 1.0% SEV CO₂ is reached:

4 minutes at 0.9 LPM CO₂ add/2.0 TV and 11.5 BPM.

6 minutes at 2.0 LPM CO₂ add/2.0 TV and 25 BPM.

(i) Take data every 30 seconds to breakthrough.

(2) Repeat steps (1)(a) - (1)(i) at 70, 55, 40, 35 and 29°F, respectively.

APPENDIX D

Test Equipment

1. Breathing machine.
2. VALIDYNE DP-15 pressure transducer w/1.00 psid diaphragm (oral pressure) (1 ea).
3. Arc.
4. The EDF heating and cooling system will be used to control water temperature during the canister duration tests.
5. MFE Model 715M X-Y plotter.
6. VALIDYNE CD-19 transducer readout (1 ea).
7. External air supply pressure gauge.
8. Chamber depth gauge.
9. Test UBAs.
10. Breathing machine/piston position transducer/ CO_2 and humidity-add system.
11. Relative humidity sensor.
12. Strip chart recorder.
13. Thermistor for exhaled gas TEMP (1 ea).
14. Thermistor for Arc water TEMP (1 ea).
15. DIGITEC HT-5820 thermistor readouts (2 ea).
16. BECKMAN/865 infrared analyzers for monitoring CO_2 out of the scrubber (2 ea).
17. HEWLETT-PACKARD Model HP 1000 computer system.

APPENDIX E

Breathing Resistance Data

Peak inhalation to peak exhalation differential pressure vs depth is plotted for all five combinations tested.

KEY

Figure 8: MK 15 with Standard Hoses and Scott Mouthpiece

Figure 9: MK 15 with AGA ACSC Hoses and Mouthpiece

Figure 10: MK 15 with WIDOLF FFM

Figure 11: MK 15 with MK 15 FFM (Koegel valves)

Figure 12: MK 15 with MK 15 FFM (Rexnord mushroom valves)

FIG.8 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
 MK-15 WITH STANDARD HOSES AND SCOTT MOUTHPIECE

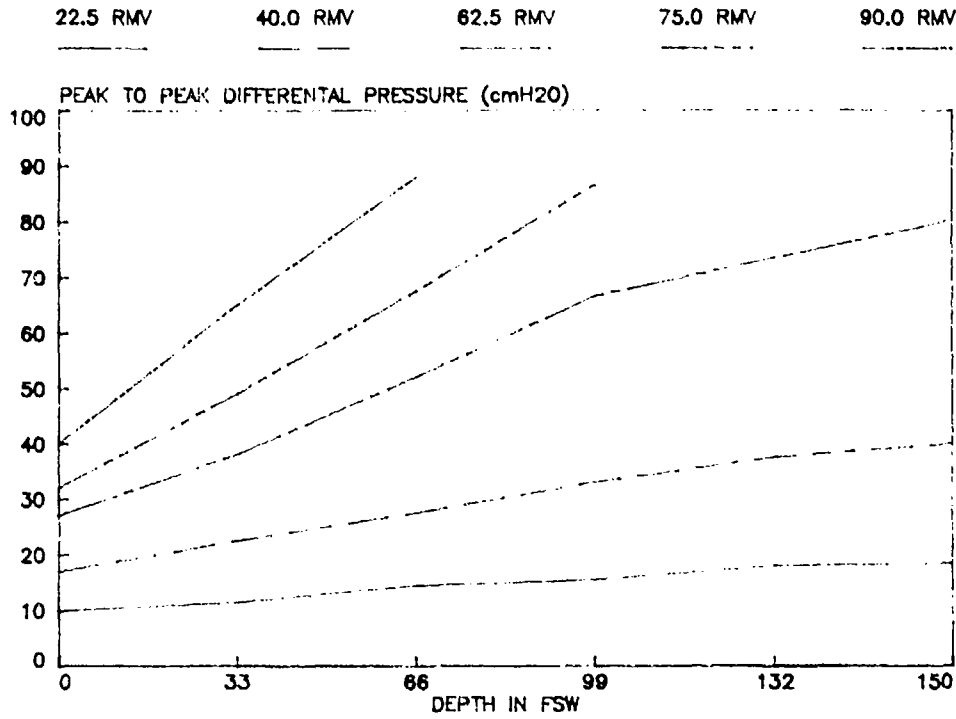


FIG.9 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
 MK-15 WITH AGA ACSC LARGE HOSES AND MOUTHPIECE

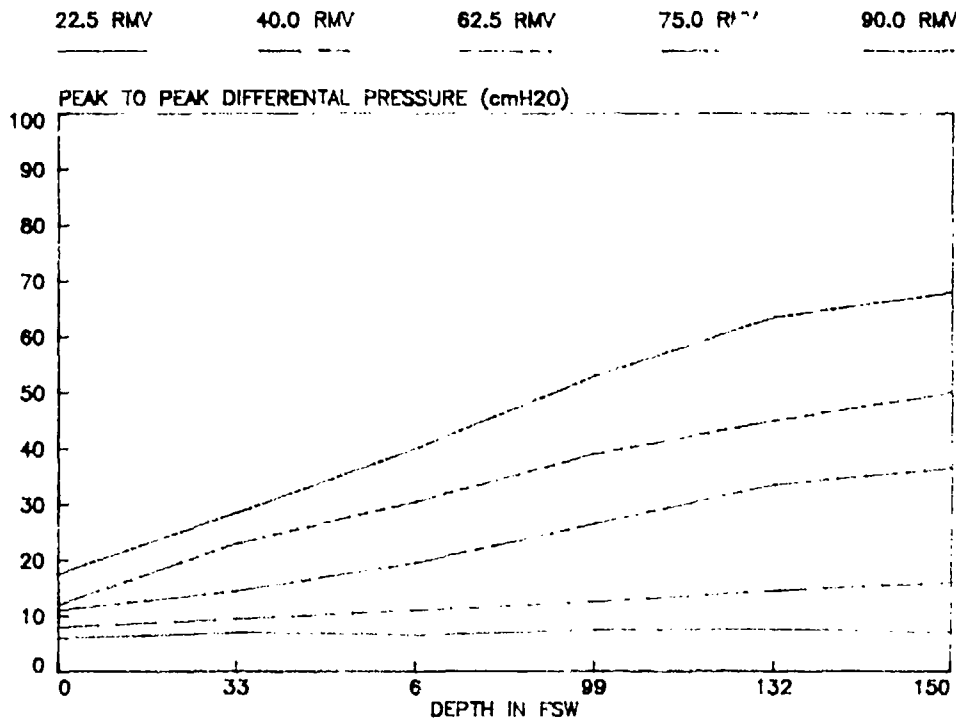


FIG.10 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
 MK-15 WITH WIDOLF FFM

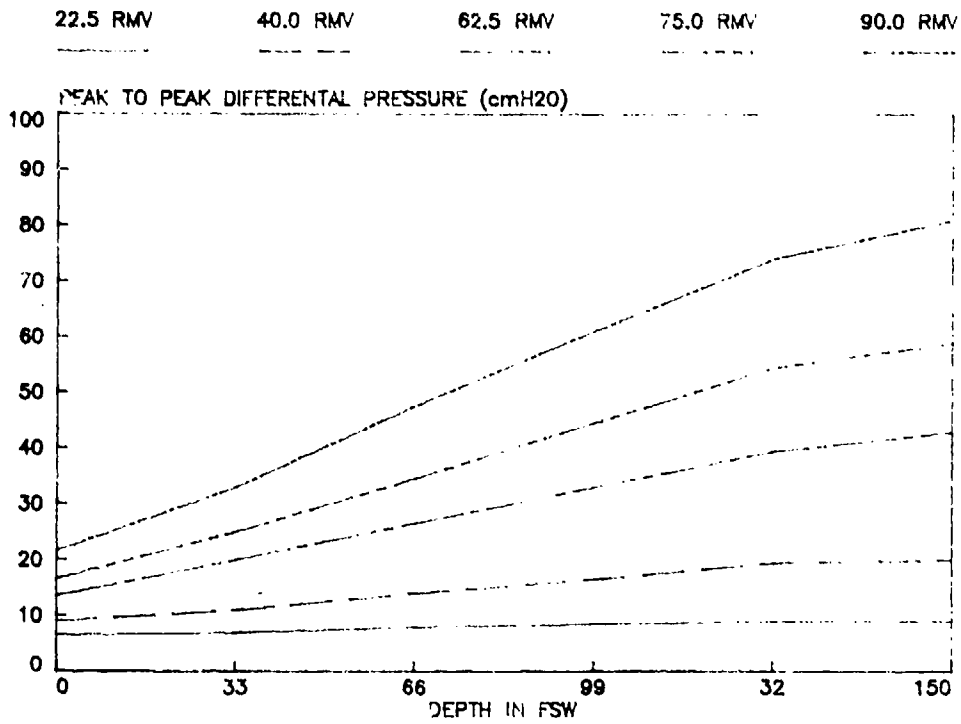


FIG.11 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
 MK-15 WITH MK-15 FFM (KOEGL VALVES)

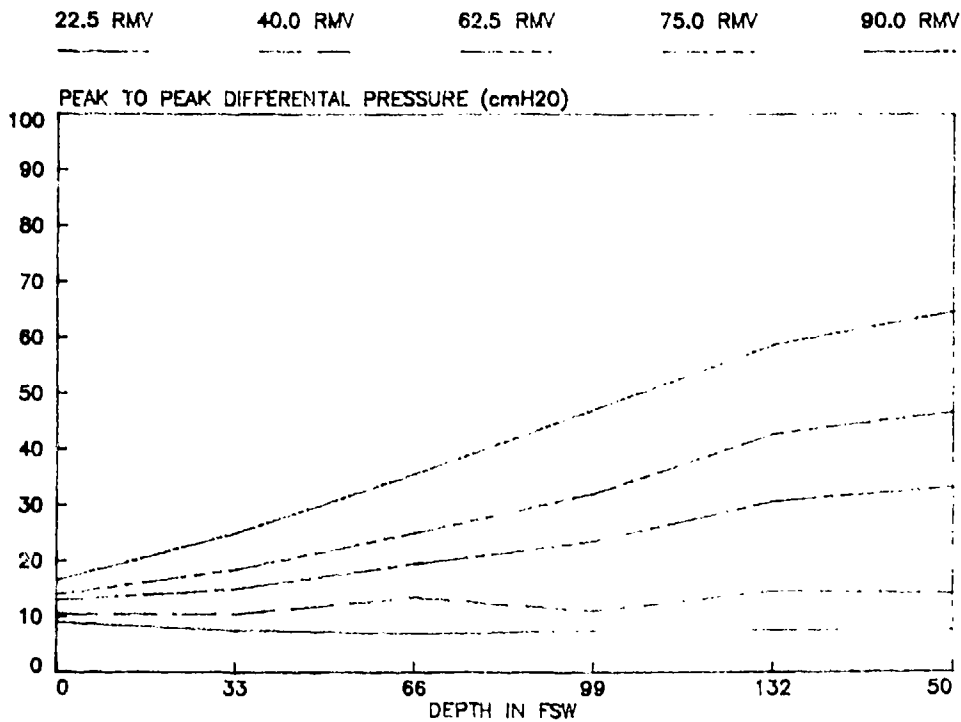
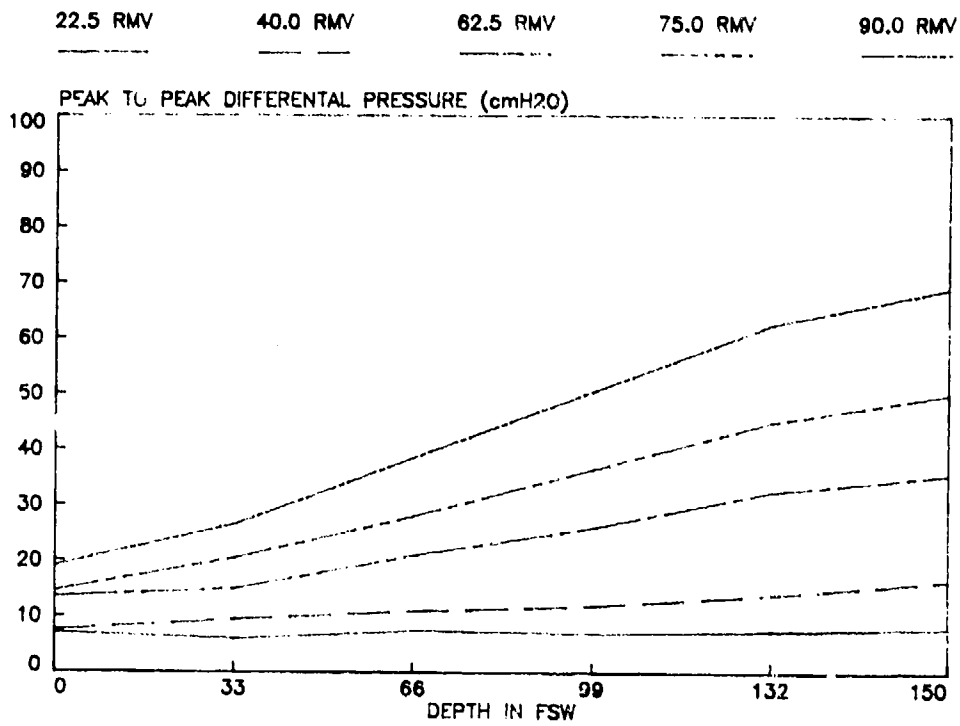


FIG.12 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
MK-15 WITH MK-15 FFM (REXNORD MUSHROOM VALVES)



APPENDIX F

Breathing Work Data

Total breathing work vs depth at each RMV tested is plotted in this section.

KEY

Figure 13: MK 15 with Standard Hoses and Scott Mouthpiece

Figure 14: MK 15 with AGA ACSC Hoses and Mouthpiece

Figure 15: MK 15 with WIDOLF FFM

Figure 16: MK 15 with MK 15 FFM (Koegel valves)

Figure 17: MK 15 with MK 15 FFM (Rexnord mushroom valves)

FIG.13 BREATHING WORK VS. DEPTH
 MK-15 WITH STANDARD HOSES AND MOUTHPIECE

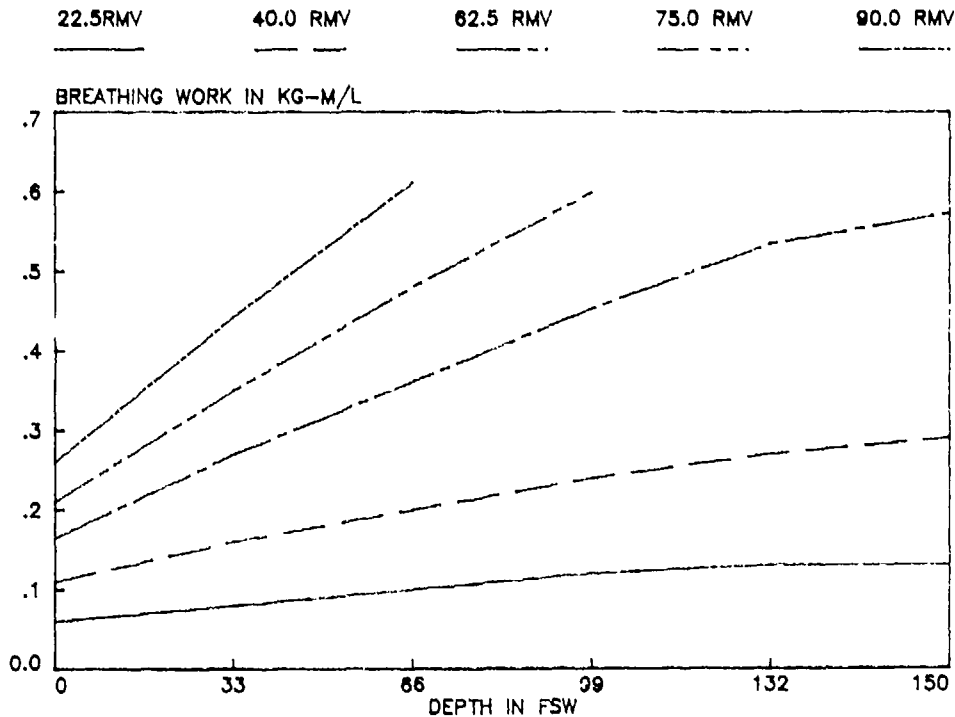


FIG.14 BREATHING WORK VS. DEPTH
 MK-15 WITH AGA ACSC LARGE HOSES AND MOUTHPIECE

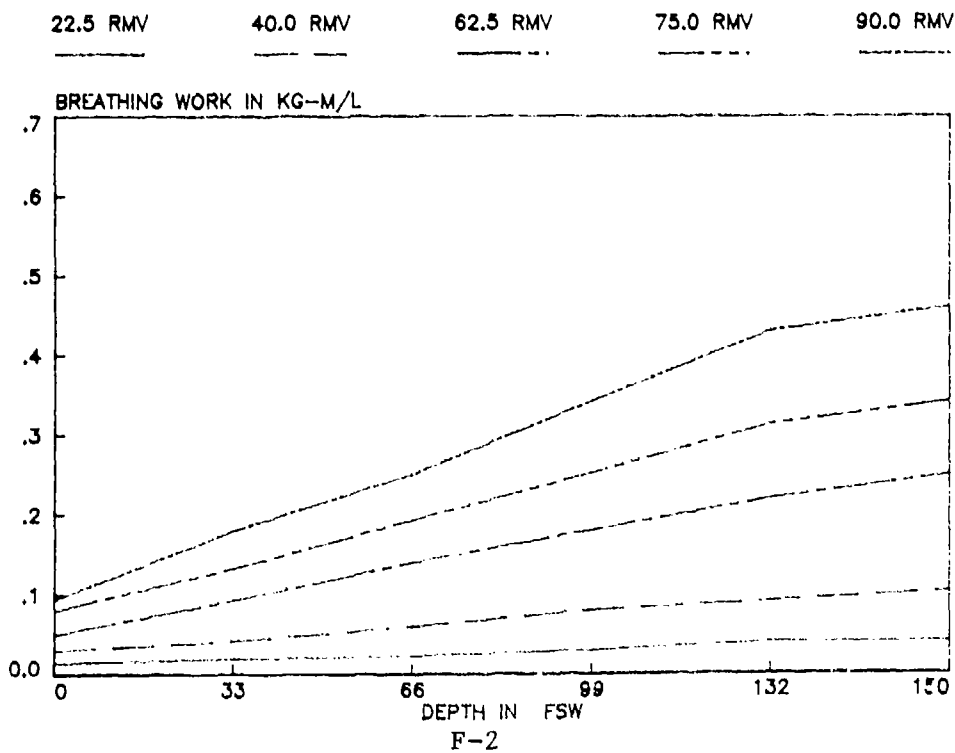


FIG.15 BREATHING WORK VS. DEPTH
 MK-15 WITH WIDOLF FFM

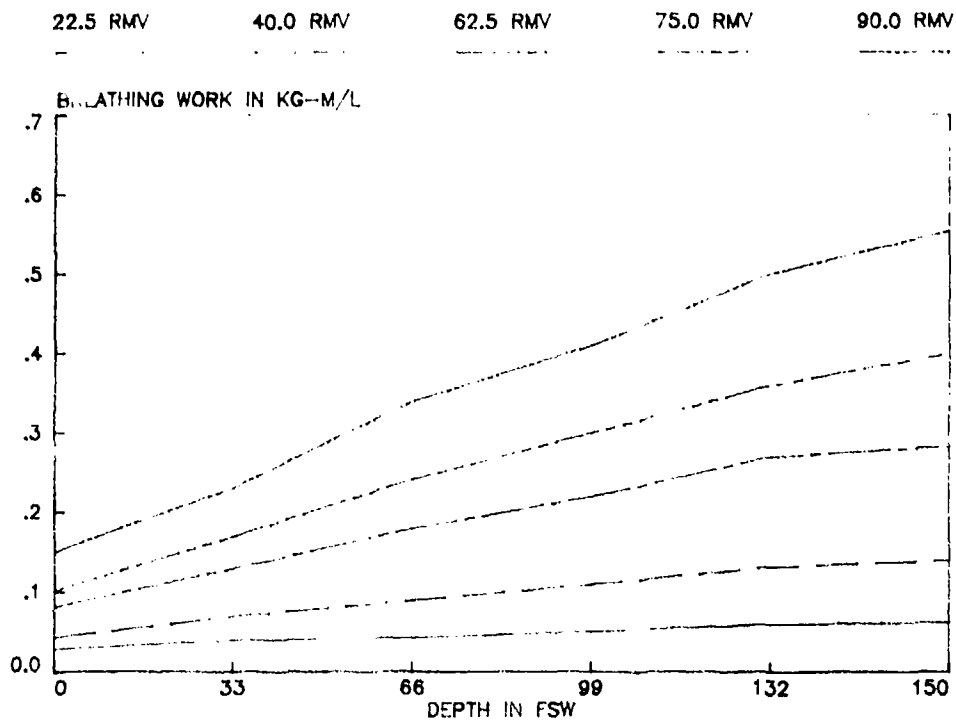


FIG.16 BREATHING WORK VS. DEPTH
 MK-15 WITH MK-15 FFM (KOEGL VALVES)

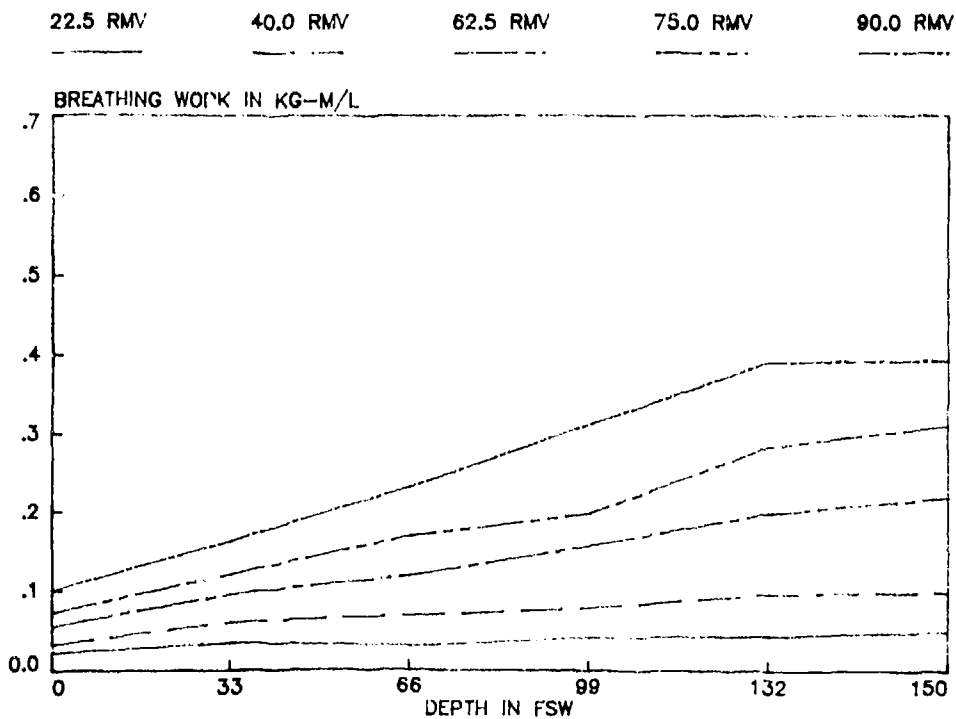
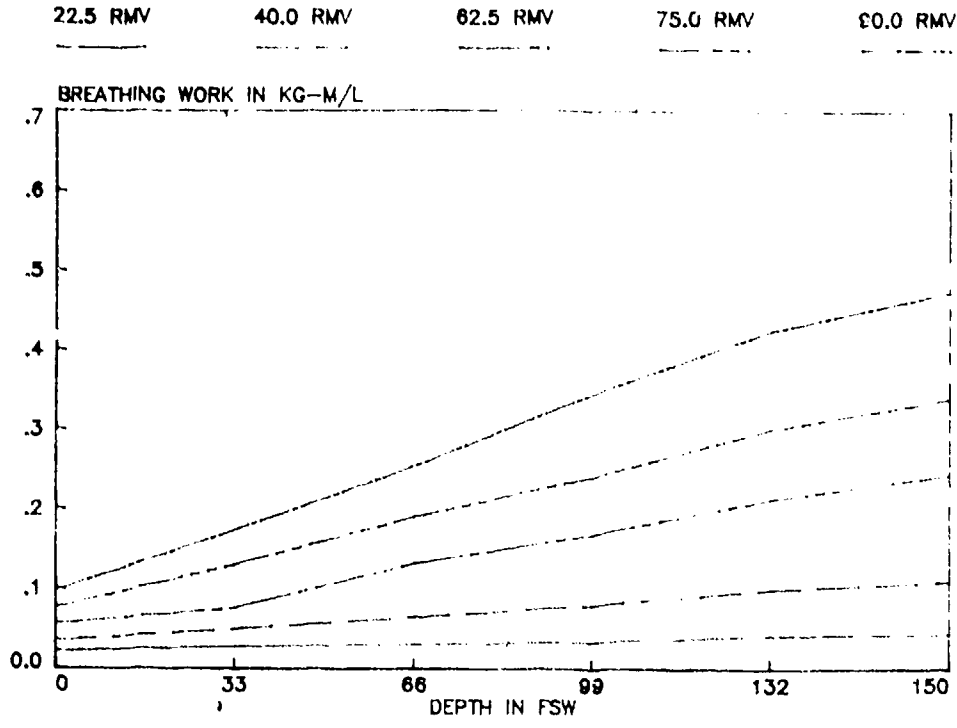


FIG.17 BREATHING WORK VS. DEPTH
MK-15 WITH MK-15 FFM (REXNORD MUSHROOM VALVES)



APPENDIX G

Canister Duration Data

Data for canister duration (% SEV vs time) is contained in this appendix for all six water temperatures tested. Effluent out of the canister was monitored during all tests to a level of 1.00% SEV and test results are plotted to this point on each graph. Canister breakthrough is considered to occur at 0.50% SEV. Data is gathered beyond this point to more fully examine the operational limits of the equipment.

KEY

Figure 18: Sample Graph of Raw Canister Duration Data

Figure 19: MK 15 UBA Canister Duration at 50 FSW in Water Temperatures Ranging from 29 to 90°F

FIGURE 18

UBA: CLOSED-CIRCUIT

WATER TEMP: 90°F

DEPTH: 50 FSW

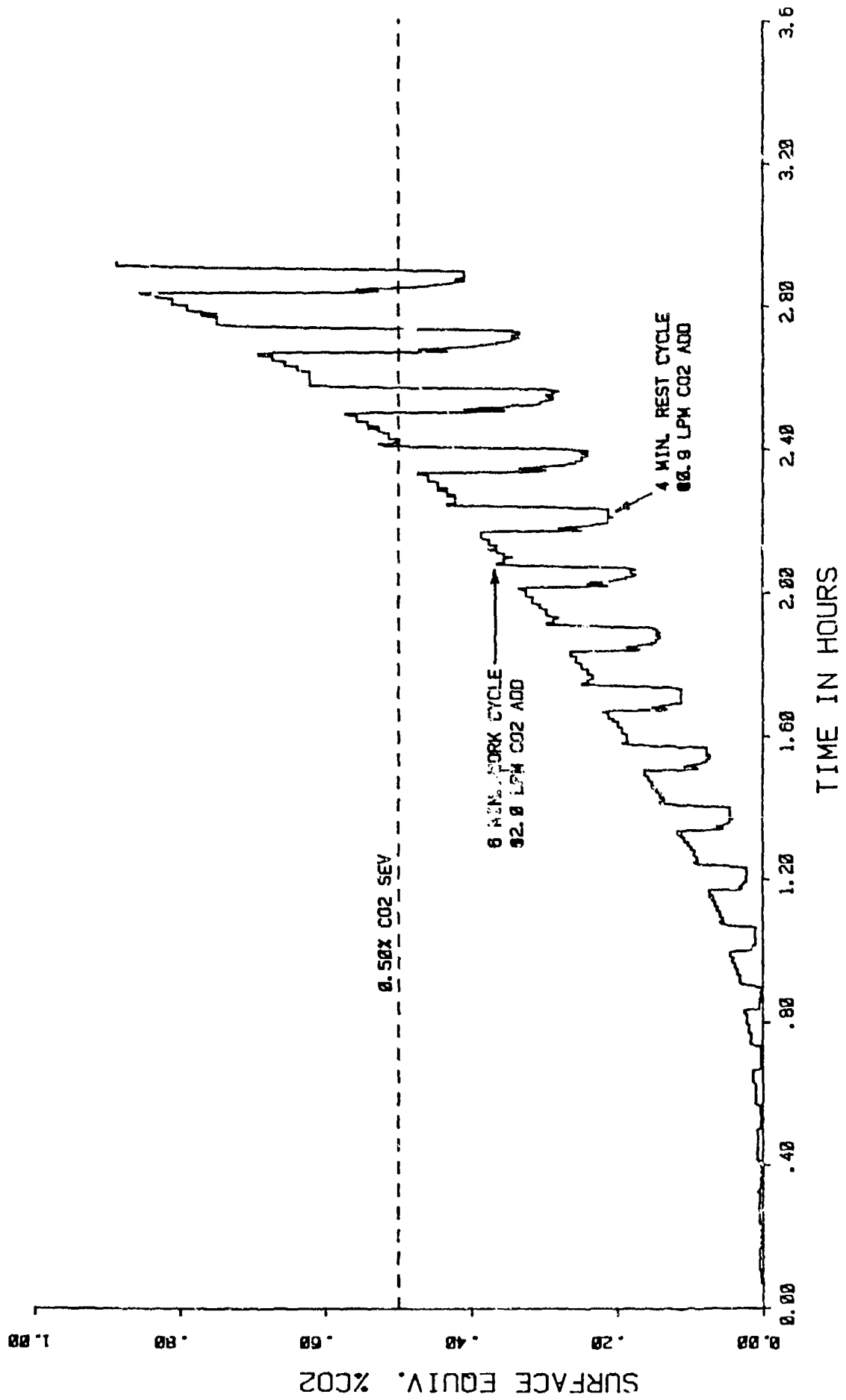


FIG. 19 CANISTER DURATION
USN MK-15 UBA AIR

