NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 7-83

UNMANNED EVALUATION OF THE U.S. NAVY MK 16 FIRST ARTICLE CLOSED-CIRCUIT UBA

JAMES R. MIDDLETON

JULY 1983

NAVY EXPERIMENTAL DIVING UNIT

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

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In accordance with Naval Sea Systems Command (NAVSEA) Task No. 78-19, The Navy Experimental Diving Unit (NEDU) conducted unmanned performance testing on two first production article MK 16 underwater breathing apparatus (UBA) in October 1982.

Breathing resistance/breathing work and oxygen (O_2) set-point control studies were conducted in the NEDU Experimental Diving Facility (EDF) on air

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and helium oxygen (HeO_2) at depths to 300 FSW using a hyperbaric breathing simulator. In addition, carbon dioxide (CO_2) absorbent canister durations were conducted on both air and HeO_2 at depths to 300 FSW in water temperatures ranging from 29 to 90°F.

Results of the unmanned performance testing revealed the breathing resistance/breathing work and CO_2 absorbent canister durations were slightly improved over the pre-production model tested in January 1980. Initial testing of the MK 16 first article O_2 set-point control system showed both units to be operating properly and within established limits. However, each UBA O_2 add system completely failed to calibrate in the latter stages of the evaluation. This serious life support system failure requires that follow-on testing of the MK 16 O_2 add system be conducted by NEDU after the problem is corrected.

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Glossary

ATA	atmospheres
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_2O	centimeters of water pressure
CO_2	carbon dioxide gas
EDF	Experimental Diving Facility Hyperbaric Chamber Complex
EOD	Explosive Ordnance Disposal
°F	temperature degrees Fahrenheit
FFM	full-face mask
FSW	feet-of-seawater
HeO_2	helium/oxygen gas mixture
HP	high pressure
HP SODASORB	high-performance SODASORB
kg.m/l	kilogram-meters per liter (respiratory work)
LCD	liquid crystal display
LED	light emitting diodes
LIS	low influence signature
lpm	liters per minute (flow rate)
MOD	modified
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
N_2O_2	nitrogen-oxygen gas mix
O_2	oxygen

Glossary (continued)

PO_2	oxygen partial pressure
ΔP	pressure differential (cmH_2O)
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
Texp	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

To Convert From	To	Multiply By
kg.m/l	joule per liter (J/L)	9.807
psi	kilopascal (kPa)	6.895
°C	kelvin (K)	°K = °C + 273.15
°F	kelvin (K)	°K = (°F + 459.67)/1.8
FSW	meters of seawater (MSW)	0.305
FSW	kilopascal (kPa)	3.065

Abstract

In accordance with Naval Sea Systems Command (NAVSEA) Task No. 78-19, the Navy Experimental Diving Unit (NEDU) conducted unmanned performance testing on two first production article MK 16 underwater breathing apparatus (UBA) in October 1982.

Breathing resistance/breathing work and oxygen (O_2) set-point control studies were conducted in the NEDU Experimental Diving Facility (EDF) on air and helium oxygen (HeO_2) at depths to 300 FSW using a hyperbaric breathing simulator. In addition, carbon dioxide (CO_2) absorbent canister durations were conducted on both air and HeO_2 at depths to 300 FSW in water temperatures ranging from 29 to 90°F.

Results of the unmanned performance testing revealed the breathing resistance/breathing work and CO_2 absorbent canister durations were slightly improved over the pre-production model tested in January 1980 (reference 1). Initial testing of the MK 16 first article O_2 set-point control system showed both units to be operating properly and within established limits. However, each UBA O_2 add system completely failed to calibrate in the latter stages of the evaluation. This serious life support system failure requires that follow-on testing of the MK 16 O_2 add system be conducted by NEDU after the problem is corrected.

KEY WORDS: UBA, closed-circuit, breathing resistance, first article, breathing work, canister duration, MK 16

I. INTRODUCTION

In accordance with NAVSEA Task No. 78-19, the Navy Experimental Diving Unit (NEDU) conducted unmanned performance testing on two first production article MK 16 underwater breathing apparatus (UBA) in October 1982.

Breathing resistance/breathing work and O_2 set-point control studies were conducted in the NEDU Experimental Diving Facility (EDF) on air and HeO_2 at depths to 300 FSW using a hyperbaric breathing simulator. In addition, carbon dioxide (CO_2) absorbent canister durations were conducted on both air and HeO_2 at depths to 300 FSW in water temperatures ranging from 29 to 90°F.

The MK 16 UBA has previously been evaluated in both manned and unmanned tests as described in references 1 and 2. These reports provide the basis for comparative performance in determining first article adequacy.

II. EQUIPMENT DESCRIPTION

A. Technical Description. The UBA MK 16 is a low influence signature (LIS) closed circuit, mixed gas, constant partial pressure oxygen (PO_2), underwater life support system developed to support the low magnetic and acoustic signature requirements of Explosive Ordnance Disposal (EOD). Conceptually, it is identical to the USN MK 15 UBA currently in use by the Special Warfare community with the exception of the magnetic and acoustic properties only required by EOD. The breathing medium is kept at a calibrated PO_2 set-point (0.75 $\pm$ .05 ATA) by use of oxygen sensors that monitor and control the level at 0.75 $\pm$ 0.15 ATA via a battery operated electronic module. The major individual components under development to support the LIS requirement consist of: (1) a LED primary display mounted in the face mask; (2) a plastic cased, rechargeable non-magnetic battery; (3) a solid state semi-conductor, expendable electronics package; (4) an LIS oxygen control valve; and (5) a liquid crystal display (LCD) secondary display. In addition the CO_2 scrubber assembly of the MK 16 uses Lexan materials and is replenished through the top vice the side as in the MK 15 UBA.

Most components are fabricated of fiberglass, polycarbonate, nylon, brass, neoprene, or some other non-magnetic material. By necessity, certain components such as the oxygen and diluent bottles (high pressure components) are fabricated of materials such as Inconel 718 which could have a magnetic signature imparted to them.

B. Functional Description. The MK 16 is a closed circuit rebreather which recirculates the diver's respired gases. The system is capable of providing approximately 595 liters (21 cu. ft.) of both O_2 and a breathable diluent gas.

The diver inhales a mixture of O_2 and diluent gas from the breathing loop and the diver's exhaled gas is recirculated back to the scrubber housing where it is filtered through the scrubber where CO_2 is removed.

As the diver descends, the MK 16 adds diluent to maintain the pressure of the diver's breathing loop gas supply equal to ambient pressure. As the diver descends, the breathing loop volume decreases causing the molded neoprene diaphragm to move closer to the canister housing. Eventually the diaphragm moves close enough to the housing to activate the addition valve during inhalation, thus adding diluent gas to the breathing loop and thus maintaining its volume.

While the diver is working, his PO_2 is monitored by the three O_2 sensors. When the diver's PO_2 goes below a predetermined set-point, the sensors send a signal to the O_2 addition valve, via the electronics assembly, which opens to allow additional O_2 into the breathing loop. Oxygen addition continues until the PO_2 in the breathing loop is brought back to the predetermined set-point. A second signal is then sent by the electronics assembly causing the O_2 addition valve to close. This system maintains the breathing loop PO_2 level at a fairly constant value at any depth and exercise rate.

The primary display indicates relative oxygen partial pressure and qualitative electronics status. The primary display is mounted on the right side of the diver's mask and indicates the PO_2 in the breathing loop by means of two (red and green) LEDs. Functional indications are: Normal O_2 (steady green), High O_2 (blinking green), Low O_2 (blinking red), and transition from one state to another, low battery voltage and/or failure of logic components (blinking red and green). In the event of a dead battery of blown fuse, the display is blanked.

The diver is also equipped with a secondary display which directly monitors the O_2 sensors and the secondary battery level. The secondary display consists of a single LCD which is powered independently. The manual bypass valves permit the diver to control the addition of diluent or O_2 to the breathing loop should the automatic system fail.

III. EQUIPMENT PHOTOS

APPENDIX A contains photos of the MK 16 UBA (Figures 1 through 3).

IV. TEST PROCEDURE

A. Test Plan. Figure 4 provides a schematic diagram of the test equipment set-up. APPENDIX B provides the complete test plan and the test equipment illustrated in Figure 4 is listed in APPENDIX C. A breathing simulator and hyperbaric chamber simulated diver inhalation and exhalation at various depths and diver work rates. The tank 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. UBA oxygen set-point control and CO_2 absorbent canister durations were monitored using paramagnetic and infrared sensors respectively.

NOTE: Two MK 16 first article UBA (serial numbers 1 and 2) were received for evaluation. Since there were no dimensional discrepancies in the UBA

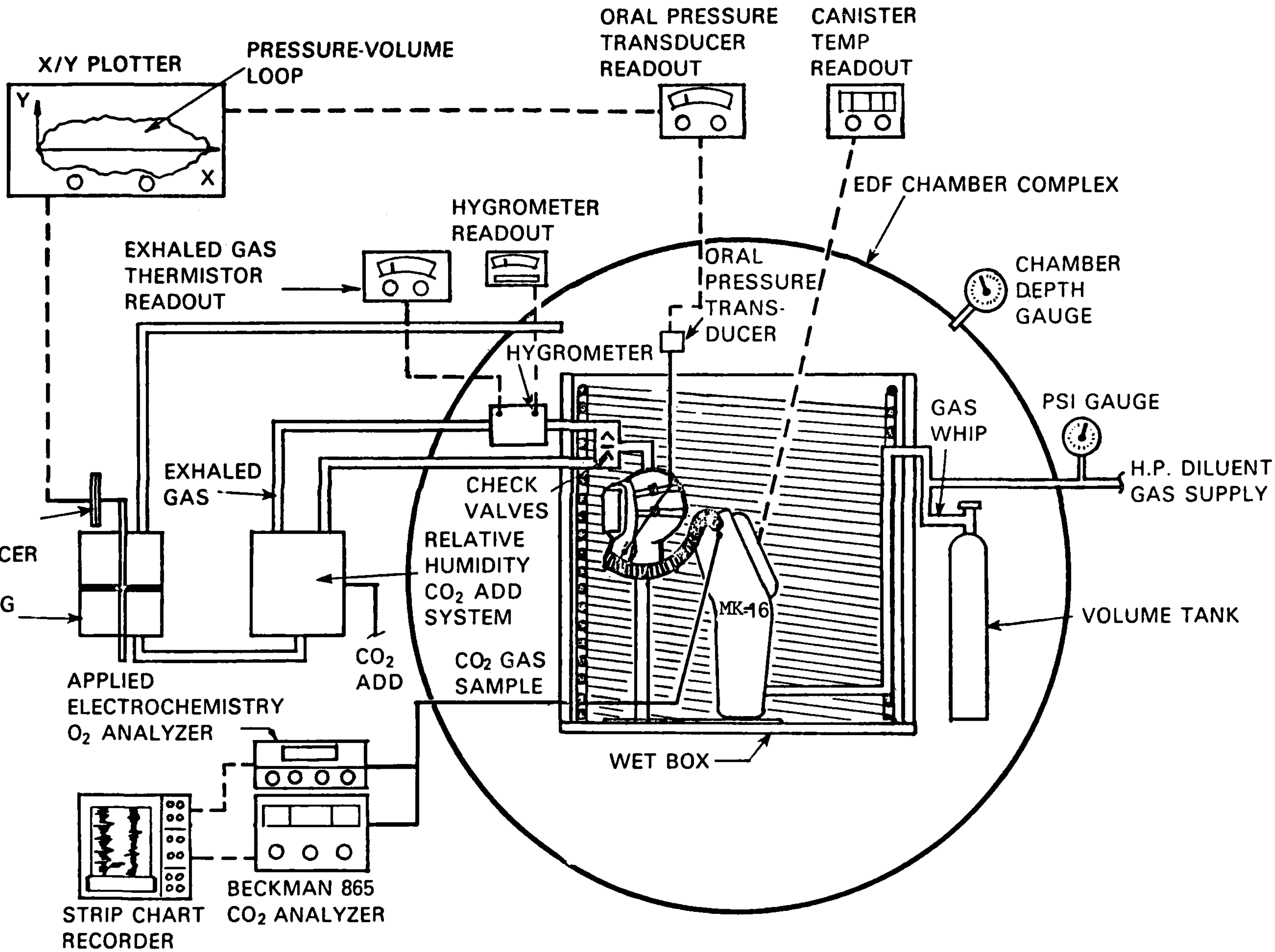


FIGURE 4. TEST SETUP

breathing loops which would affect breathing resistance, only serial number 2 was used to conduct breathing resistance/breathing work tests.

Both serial number 1 and 2 were used during the canister duration studies to facilitate turnaround time between tests. No discrepancies in test data were noted between rigs and consequently the results are not delineated according to serial number. A complete O_2 set point control evaluation was conducted on both UBA.

B. Controlled Parameters

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

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

b. Diluent gas: air and HeO_2 (84/16).

c. Depths: 0 to 198 FSW on air in 33 FSW increments.
0 to 300 FSW on HeO_2 in 33 FSW increments.

d. Diluent supply pressure: 1000 psig.

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

a. CO_2 add rates and exhaled gas temperatures controlled as set forth in NEDU Report 3-81 (reference 2).

b. UBA diluent gas: air and HeO_2 (84/16)

c. CO_2 absorbent: HP SODASORB.

d. Water TEMP: 90, 70, 55, 40, 35 and 29°F.

e. Relative humidity of exhaled gas: 90 to 95%.

f. Depths:

(1) Air: 50, 100 and 150 FSW.
(2) HeO_2: 100, 200 and 300 FSW.

g. Diluent supply pressure: 1000 psig.

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

3. Oxygen Set-Point Control tests - Controlled parameters included:

a. O_2 consumption of 0.9 LPM @ 22.0 RMV and 2.0 LPM @ 50 RMV.

b. 100% O_2 was plumbed into O_2 side of UBA gas addition system.

c. 02 supply pressure: 1000 psig.

d. Depths:

(1) Air: 30, 60 90 and 150 FSW.
(2) HeO_2: 50, 100, 200 and 300 FSW.

NOTE: Although the MK 16 is a mixed gas UBA in both the N_2-O_2 and HeO_2 operating modes, air was used as the breathing mix during all testing where N_2-O_2 was required. The density and heat transfer characteristics of air and N_2-O_2 are virtually identical making air a convenient alernative for unmanned evaluations.

C. Measured Parameters

1. Breathing Resistance Tests - Maximum ΔP in cmH_2O (i.e. total pressure excursion between full exhalation and full inhalation.

2. Canister Duration Tests:

a. CO_2 level out of scrubber expressed as percentage of surface equivalent value (SEV).

b. Moisture content of the HP SODASORB was measured for each can of absorbent used. Moisture ranged from 14.5 to 15.5%.

3. O_2 Set-point Control Tests:

a. O_2 level in inhalation tubing expresed as percentage of SEV.

b. O_2 add valve firing sequence.

D. Computed Parameters

1. Breathing Resistance Tests: Respiratory work per liter tidal volume measured in kg$\cdot$m/l from ΔP vs volume plots. A typical pressure volume plot is illustrated in Figure 5.

2. Canister Duration Tests: Exhaled gas TEMP was calculated and controlled as a function of water temperature based on the standardized procedure set in NEDU Report 3-81 (reference 2).

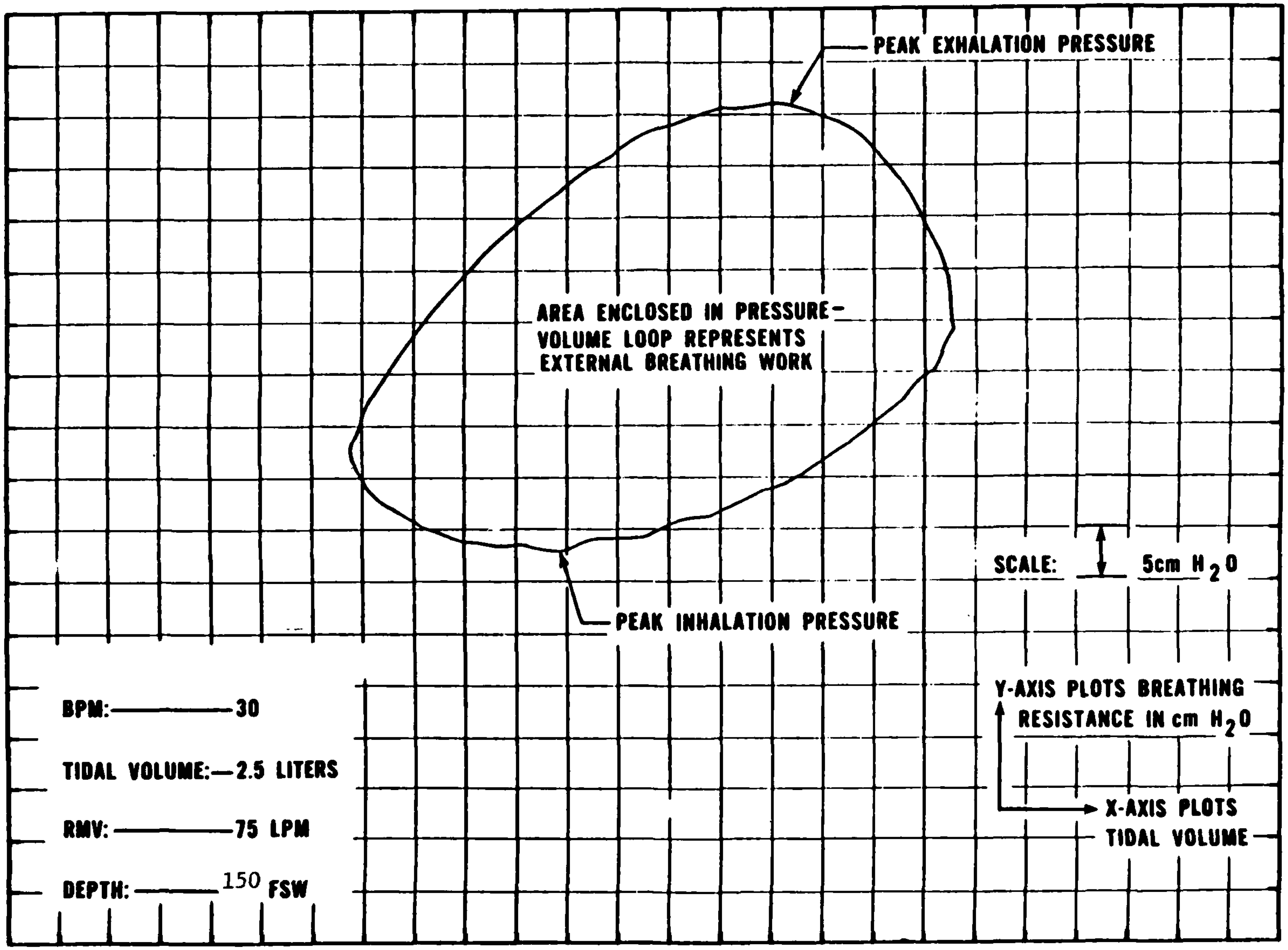


Figure 5. Pressure - Volume Loop Generated at 75 RMV at a depth of 150_{FSW} on air

3. O_2 Set-point Control Tests: Convert % O_2 SEV into atmospheres absolute (ATM ABS).

E. Data Plotted

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

a. Peak exhalation to peak inhalation ΔP (cmH_2O) 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 CO_2 (% SEV) vs time (min).

3. The following plots were developed from data obtained in the O_2 set-point control tests: O_2 in inhalation gas (PO_2) vs time (min) and O_2 add valve firing sequence (event).

V. RESULTS

A. Breathing Resistance and Breathing Work Tests. APPENDIX D (Figures 6 and 7) contain the plots of peak differential breathing pressures vs depth and APPENDIX E (Figures 8 and 9) contain the plots of breathing work vs depth. Peak inhalation to peak exhalation pressure in cmH_2O was measured 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. Tables 1 and 2 provides a comparison of the peak differential pressures at 150 and 300 FSW at 75 RMV for air and HeO_2 respectively. Tables 3 and 4 provide similar comparisons of breathing work.

B. CO_2 Absorbent Canister Duration Tests. A total of 39 canister duration tests were conducted as part of this evaluation series. Canister duration tests were conducted between 0 and 300 FSW using air and HeO_2 diluents with ambient water temperature being varied from 29 to 90°F. A minimum of two runs were conducted at each set of conditions and whenever duration differences of more than 20 minutes were observed additional tests were performed. The mean canister durations at all water temperatures are summarized in Table 5. This table also contains comparable data points from the pre-production model EX-16 tested unmanned in reference (2) for comparison.

APPENDIX F (Figure 10) is an example of the type of CO_2 absorbent canister duration plots generated during unmanned testing. Rest and work cycles are readily observed as continuing for the duration of each test. APPENDIX F (Figures 11 through 19) plot only the % SEV CO_2 vs time generated

TABLE 1

Comparison of Total Breathing Resistance

Peak Inhalation to Peak Exhalation

Breathing Pressure at 150 FSW and 75 RMV

Breathing Gas: Air

UBA	PEAK TO PEAK DIFFERENTIAL BREATHING PRESSURE (cmH_2O)
MK 16 First Production Article	38.5
EX 16 Pre-production Model (reference 2)	46.0

TABLE 2

Comparison of Total Breathing Resistance

Peak Exhalation to Peak Inhalation

Breathing Pressure at 300 FSW and 75 RMV

Breathing Gas: HeO_2

UBA	PEAK TO PEAK DIFFERENTIAL BREATHING PRESSURE (cmH_2O)
MK 16 First Production Article	25.5
EX 16 Pre-production Model (reference 2)	31

NOTE: NEDU performance goal (reference 2) for closed-circuit diver breath driven UBA:

a. Air: 0.18 Kg·m/l at 75 RMV and 150 FSW with peak to peak breathing pressures not greater than 22 cmH_2O.

b. HeO_2: 0.22 Kg·m/l at 75 RMV and 300 FSW with peak to peak breathing pressures not greater than 28 cmH_2O.

TABLE 3

Comparison of Breathing Work

At 150 FSW and 75 RMV

Breathing Gas: Air

UBA	BREATHING WORK (Kg·m/l)
MK 16 First Production Article	0.26
EX 16 Pre-production Model (reference 2)	0.32

TABLE 4

Comparison of Breathing Work

At 300 FSW and 75 RMV

Breathing Gas: HeO_2

UBA	BREATHING WORK (Kg·m/l)
MK 16 First Production Article	0.15
EX 16 Pre-production Model (reference 2)	0.23

NOTE: NEDU performance goal (reference 2) for closed-circuit diver breath driven UBA:

a. Air: 0.18 Kg·m/l at 75 RMV and 150 FSW with peak to peak breathing pressures not greater than 22 cmH_2O.

b. HeO_2: 0.22 Kg·m/l at 75 RMV and 300 FSW with peak to peak breathing pressures not greater than 28 cmH_2O.

TABLE 5

Unmanned Canister Duration Tests Comparison of Results

NOTE: A minimum of two tests were run at each set of test conditions.

WATER TEMP (°F)	DEPTH (FSW)	EX 16 / MK 16 MEAN TIME 0.5% SEV (MIN)	EX 16 / MK 16 MEAN TIME 1.0% SEV (MIN)
I. AIR DILUENT TESTS			
29	30	280 / 275	335 / 340
	50	270 / 252	332 / 299
	100	109 / 178	154 / 238
	150	71 / 107	108 / 148
40	50	256 / 285	322 / 325
	100	233 / 227	302 / 288
	150	97 / 167	145 / 217
50	150	217 / 194	286 / 261
70	150	218 / 252	293 / 305
II. HeO_2 DILUENT TESTS			
29	150	186 / 199	258 / 266
	200	139 / 136	188 / 187
	300	71 / 93	96 / 136
40	30	279 / 267	328 / 325
	150	276 / 278	333 / 328
	200	124 / 154	189 / 228
	300	114 / 102	149 / 149
50	200	210 / 207	290 / 272
	300	120 / 154	190 / 218
60	200	299 / 256	367 / 360
70	100	293 / 289	344 / 345
	300	242 / 275	310 / 317

during the work cycles in order to display the results of testing each UBA at all temperatures on one graph. The data on each plot is carried beyond 0.50% SEV CO_2 during work cycles to give a more complete picture of UBA performance. Due to the large number of tests conducted only a representative plot for each set of test conditions with each UBA is shown. In addition, a complete set of data (i.e. all six water temperatures at each depth and gas mix) was not obtained during this evaluation. Generally only maximum and minimum water temperatures were evaluated at each depth to spot check the entire range of canister performance and compare it with the preproduction data obtained in reference 1.

C. O_2 Set-point Control Tests. Tests simulating oxygen consumption by the diver were conducted to determine whether or not the MK 16 could maintain PO_2 on the inhalation side of the UBA at its required set-point of 0.75 ± 0.15 ATA absolute.

The tests were conducted at various depths on both air and HeO_2 mixes. Maximum normal ascent and descent rates were simulated before reaching test depths where standard rest/work cycles were begun. The diver-inhaled gas was monitored using a paramagnetic analyzer specifically designed to measure oxygen content. In addition, a pressure transducer on the LP side of the O_2 bottle regulator provided a continuous monitor of O_2 add valve firing.

APPENDIX G (Figure 20) provides a typical graph of inhaled PO_2 vs time and O_2 add valve firing. Table 6 provides a synopsis of the high and low PO_2 levels measured at simulated rest and work conditions for each depth and breathing gas tested.

VI. DISCUSSION

A. Breathing Resistance and Breathing Work Tests. NEDU Report 3-81, "Standardized NEDU Unmanned UBA Test Procedures and Performance Goals," (reference 3) establishes a performance goal of a total maximum breathing resistance of 22 cmH_2O and 0.18 kg•m/l respiratory work at 75 RMV and maximum normal operating depth for C/C diver breath-driven UBA with air as the breathing mix and 0.22 Kg•m/l at 75 RMV with 28 cmH_2O peak to peak breathing pressure at maximum normal operating depth for HeO_2. These goals do not represent minimum acceptable performance levels. Rather, the goals when met by a UBA will insure that the UBA is not the limiting factor in diver performance. The goals set forth in reference 3 are established as a function of depth and breathing mixture.

Examination of the data presented in Tables 1 through 4 shows that the UBA tested did not meet the established performance goal on air but did meet it on HeO_2. However, manned testing as documented in reference 4 has proven that C/C UBA with performance similar to the MK 16 first article on air will adequately support a working diver. Consequently, since the goals established in reference 3 are dynamic in nature, as more data is gathered, they will be updated to reflect the most recent and realistic performance requirements available. APPENDIX D (Figures 6 and 7) and E (Figures 8 and 9) provide a complete graphic presentation of all breathing resistance and breathing work data.

TABLE 6

O_2 Set-point Control
High and Low PO_2 Levels Measured Under
Simulated Diver Rest and Work Conditions

I. Diluent: Air
First Article #1

DEPTH (FSW)		REST	WORK
30	High PO_2 (ATA)	0.84	0.85
	Low PO_2 (ATA)	0.76	0.80
60	High PO_2 (ATA)	0.84	0.84
	Low PO_2 (ATA)	0.73	0.78
90	High PO_2 (ATA)	0.82	0.76
	Low PO_2 (ATA)	0.67	0.67
150	High PO_2 (ATA)	0.83	0.80
	Low PO_2 (ATA)	0.67	0.69

I. Diluent: HeO_2
First Article #2

DEPTH (FSW)		REST	WORK
50	High PO_2 (ATA)	0.85	0.85
	Low PO_2 (ATA)	0.75	0.78
100	High PO_2 (ATA)	0.83	0.83
	Low PO_2 (ATA)	0.71	0.74
200	High PO_2 (ATA)	0.88	0.88
	Low PO_2 (ATA)	0.74	0.74
300	High PO_2 (ATA)	0.88	0.86
	Low PO_2 (ATA)	0.71	0.75

Analysis of the data in Tables 1 through 4 shows a significant improvement in breathing resistance/breathing work performance of the MK 16 compared to the EX 16 preproduction model (reference 2). This improvement is due to the larger and smoother gas flow passage in the CO_2 absorbent canister housing and the large breathing hose fittings mounted external to the canister housing. It is also noteworthy that performance of the MK 16 first production article in this area represents a major improvement over the current MK 15 UBA as tested on air in reference 5.

B. CO_2 Absorbent Canister Duration Tests. The standard NEDU unmanned canister duration test scenario as described in APPENDIX B was conducted. This procedure simulates a diver resting in the water on a bicycle-ergometer for 4 minutes at an O_2 consumption rate of 0.90 LPM and then working at an O_2 consumption rate of 1.60 LPM for 6 minutes. This routine is alternated until the canister output reaches a minimum level of 0.50% SEV CO_2.

The data presented in Table 5 verifies that performance of the first article CO_2 absorbent canister is at least as good as that found in the pre-production model. Differences in canister duration were well within the normal variance expected between canisters tested under identical conditions. Exceptions to this were at 150 FSW, 29 and 40°F water temperature with air as the breathing medium. A definite increase in canister life of approximately 30% was seen in the first production articles. This performance increase under worst case conditions is thought to be due to improvements made to the lid of the absorbent canister. These design improvements result in a better lid seal and thus incresed thermal protection for the absorbent bed.

One problem identified in the CO_2 canister housing during tl numerous canister packing routines conducted during the evaluation was housing cover fit. The tolerance between the housing cover and body was extremely tight thus making assembly difficult. This problem could be simply solved by reducing the 'o'-ring squeeze between the two parts.

In addition, the diluent bypass valve assembly leaked gas to the surroundings in the area of the brass to plastic interface on the backside of the valve assembly.

C. O_2 Set-point Control Tests. The simulation was accomplished by removing a quantity of mixed gas from the exhalation side of the UBA breathing loop equivalent to the quantity of O_2 desired to be "consumed". At the same time a volume of inert gas identical to that removed in the mix is added back to the UBA in the inhalation loop. This provides a net "consumption" of O_2 from the UBA. In addition, a respiratory quotient of 1.0 is assumed and a volume of CO_2 equal to the O_2 consumed is added to the UBA, thus maintaining a complete volumetric balance.

Examination of APPENDIX G (Figure 20), which provides a typical representation of the O_2 set point control measured during testing, reveals that during this phase of the evaluation the MK 16 O_2 addition system successfully maintained PO_2 in the divers inhaled gas within acceptable limits of $\pm$ 0.15 ATA. Examination of the data in Table 6 shows that under steady state conditions (i.e., no depth change) the O_2 sensing and addition system maintained the 0.70 ATA set-point within 0.84 ATA on the high side and 0.67 ATA on the low side for rig number one and 0.88 ATA on the high side and 0.71

ATA on the low side for rig number 2. In addition, serial number 1 was approximately 0.05 ATA lower under rest and work conditions than serial number 2. This is probably due to manufacturing tolerences and slight variations in calibration.

In addition, during the O_2 addition system calibration procedures the high and low PO_2 alarms were tested as per the operating manual and were found to be operating properly (i.e. low alarm light came on at 0.60 ATA and the high alarm light lit up at 0.90 ATA).

However, at the end of the canister duration studies, during which time the O_2 system was not in use, the MK 16 O_2 addition was again turned on and a calibration procedure initiated. Both first articles ceased to function and calibration could not be accomplished. Trouble shooting indicated that either the O_2 add valve or the main electronics had malfunctioned. During canister duration studies the O_2 addition system normally has both power and gas supply secured. Maintaining the correct PO_2 in the breathing loop has no effect on canister duration and the procedure simplified conduct of the test. Each first article had completed approximately fifteen dives since the O_2 system was last used with no evidence of rig floodout. All set point control testing on the O_2 systems was completed prior to the failures and consequently it did not affect the results presented in this report.

VII. CONCLUSIONS

Breathing resistance/breathing work and CO_2 absorbent caniste durations of the first article MK 16 UBA are at least as good as the preproduction models and are satisfactory for full production. However, although initial testing of both first article units demonstrated the UBA to adequately maintain PO_2 in the breathing loop, subsequent failure of the O_2 addition system in both units is considered extremely serious in a first production article. Additional manned and unmanned testing of the O_2 addition system by NEDU is required to verify MK 16 life support adequacy.

VIII. REFERENCES

1. NEDU Report 13-80, "Manned Evaluation of Preproduction MK 16 UBA," C. G. Gray and E. D. Thalmann, August 1980.

2. NEDU Report 9-80, "Unmanned Evaluation of U.S. Navy UBA EX 16 Preproduction Model Closed Circuit Rebreather," James R. Middleton, May 1980

3. 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

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

5. NEDU Report 8-83, "Unmanned Evaluation of U.S. Navy MK 15 Closed-circuit UBA," James R. Middleton, June 1983

APPENDIX A

Equipment Photographs

Figures 1 through 3

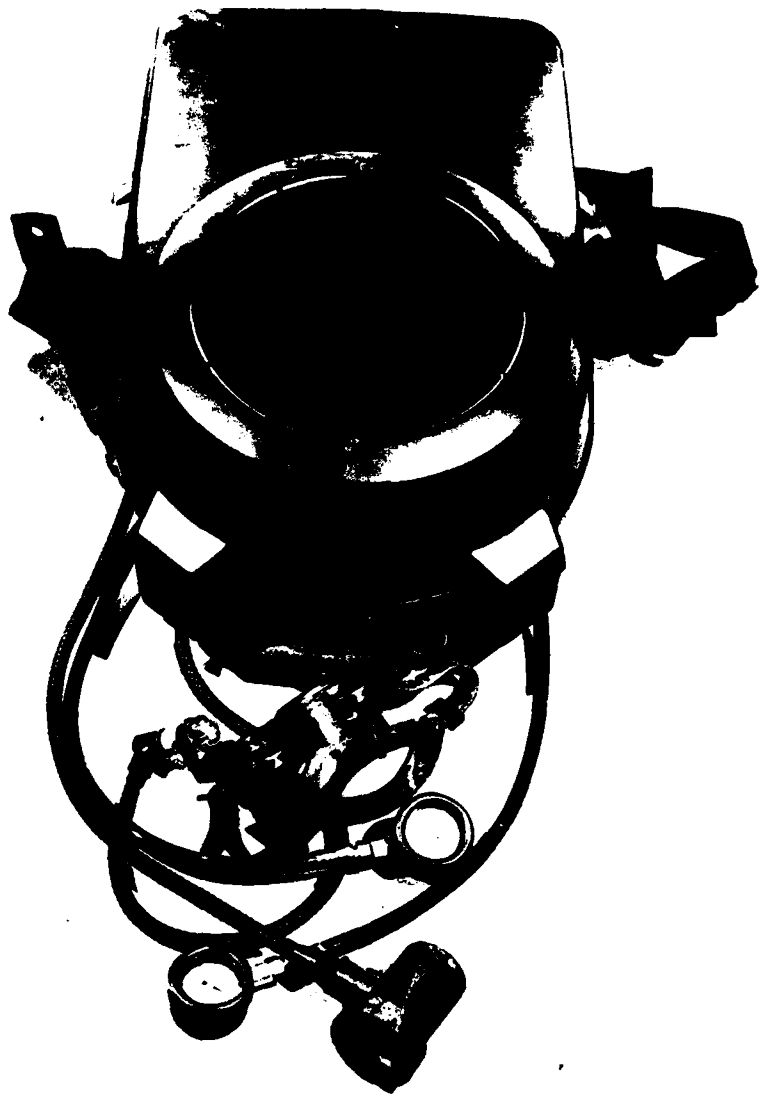


Figure 1. Front View With Cover

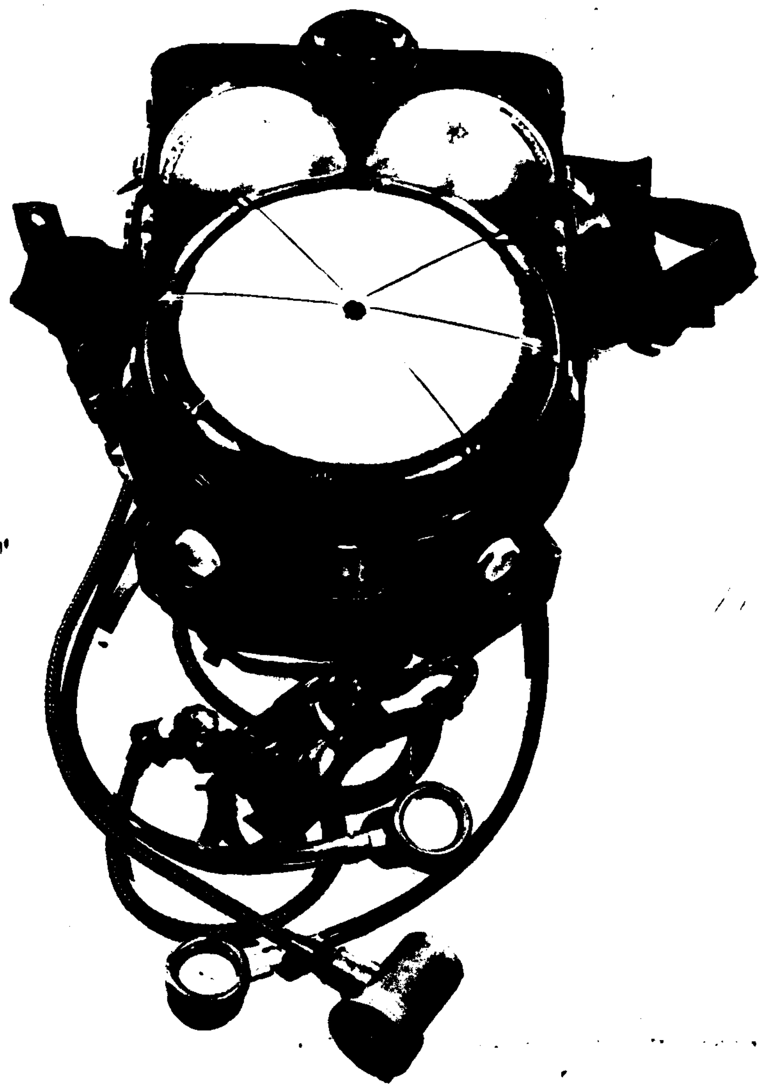


Figure 2. Front View Without Cover

Figure 3. Rear View

APPENDIX B

A. Test plan for breathing resistance evaluation:

(1) (a) Ensure the MK 16 is set to specification and is working properly.

(b) Chamber on surface.

(c) Calibrate transducer.

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

(e) Adjust breathing machine to 1.5 liter tidal volume and 15 BPM and take readings.

(f) Adjust breathing machine to 2.0 liter tidal volume and 20 BPM and take readings.

(g) Adjust breathing machine to 2.5 liter tidal volume and 25 BPM and take readings.

(h) Adjust breathing machine to 2.5 liter tidal volume and 30 BPM and take readings.

(i) Adjust breathing machine to 3.0 liter tidal volume and 30 BPM and take readings.

(j) Stop breathing machine.

(2) (a) Pressurize chamber to 33 FSW.

(b) Repeat steps (1) (e) - (j).

(3) (a) Pressurize chamber to 66-198 FSW in 33 FSW increments.

(b) Repeat steps (1) (e) - (j).

(4) (a) Bring chamber to surface.

(b) Check calibration on transducers.

(5) Repeat steps 1 through 4 to depth of 300 FSW in 33 FSW increments using HeO_2 (84/16) as the diluent.

A. Test plan for CO_2 canister duration evaluation:

(1) (a) Ensure the MK 16 is set to factory specifications and is working properly using H.P. SODASORB.

(b) Chamber on surface.

(c) Calibrate transducers and Beckman 865 analyzers.

(d) Open makeup gas supply valve to test UBA (Diluent: air).

(e) Water temperature to be 90°F.

(f) Start humidity add system.

(g) Press chamber to 30 FSW.

(h) Start CO_2 add and maintain following procedure until 1.0% SEV CO_2 is reached:

4 minutes at 0.9 lpm CO_2 add/2.0 TV and 11.5 BPM

6 minutes at 2.0 lpm CO_2 add/2.0 TV and 25 BPM

(i) Take data every 10 minutes until breakthrough.

(2) Repeat steps (1) (a) - (i) at 70, 60, 50, 40 and 29°F.

(3) Repeat steps (1) and (2) at 50, 100 and 150 FSW.

(4) Repeat steps (1) and (2) using HeO_2 (84/16) at depths of 30, 100, 150, 200 and 300 FSW.

NOTE: A minimum of two tests are to be conducted at each set of test conditions.

C. Test plan for O_2 addition/control system evaluation:

(1) (a) Ensure the MK 16 is set to factory specifications and is working properly.

(b) Chamber on surface.

(c) Calibrate oral pressure transducer and Beckman 755 O_2 analyzer.

(d) Open makeup gas supply valve to test UBA (Diluent: air).

(e) Water temperature to be 70°F.

(f) Press chamber to 30 FSW at 75 FPM.

(g) Start CO_2 add system with the normal rest/work cycles.

(h) Start O_2 consumption systems when chamber reaches the bottom in cycle with the CO_2 add system.

(i) Take data every minute for 15 minutes.

(2) Repeat steps (1) (a) - (i) at 60, 90, 120 and 150 FSW.

(3) Repeat steps (1) (a) - (i) except using HeO_2 (84/16) as a diluent and take data at 50, 100, 150, 200 and 300 FSW.

APPENDIX C

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 O_2 supply pressure gauge.

8. Chamber depth gauge.

9. Test UBA.

10. Breathing machine w/piston position transducer, CO_2 and humidity-add systems, O_2 consumption simulator.

11. Relative humidity sensor.

12. Strip chart recorder.

13. Thermistor for exhaled gas TEMP (1 ea).

14. Thermistor for 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 (1 ea).

17. BECKMAN 755 paramagnetic analyzer for monitoring O_2 in the diver's inhaled gas (1 ea).

18. HEWLETT-PACKARD Model HP 1000 computer system.

APPENDIX D

Breathing Resistance Data

Peak exhalation to peak inhalation differential pressure vs depth at each RMV tested is plotted for air and HeO_2 breathing mixes.

KEY:

FIGURE 6: MK 16 UBA w/Air Diluent

FIGURE 7: MK 16 UBA w/HeO_2 Diluent

FIG.6 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
USN MK-16 UBA AIR

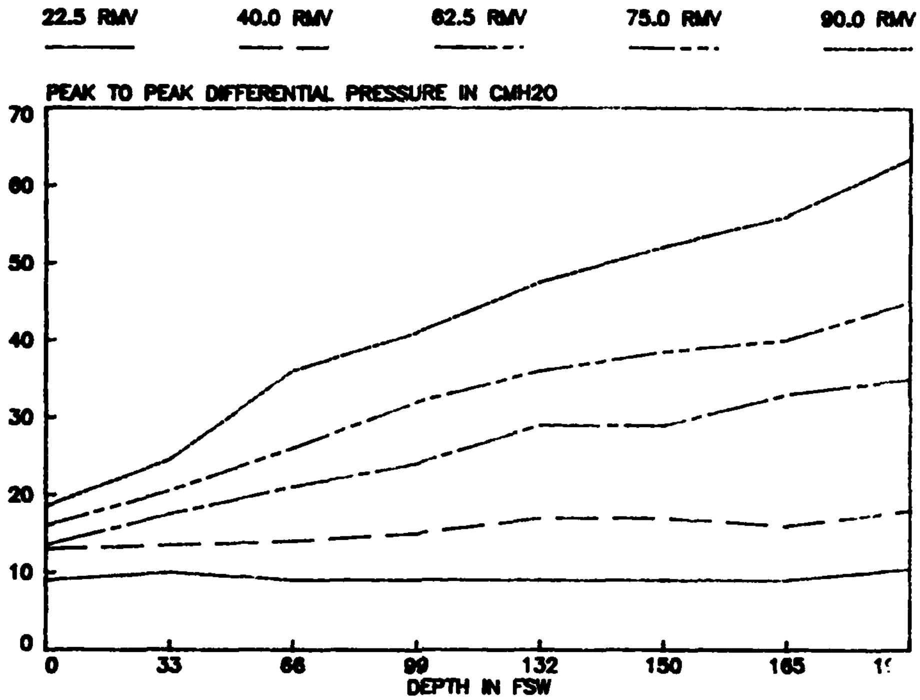
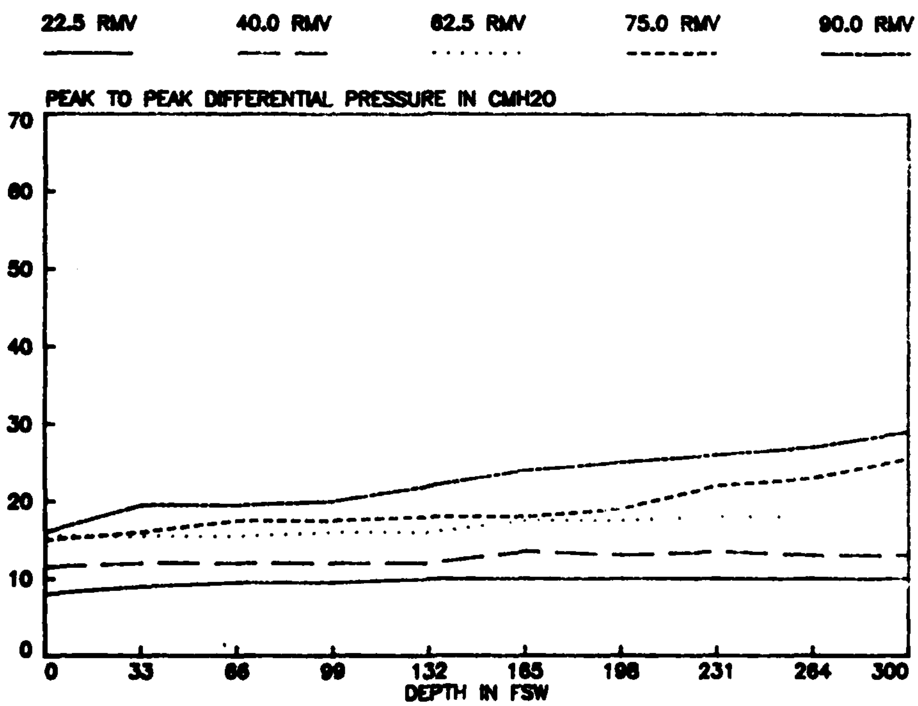


FIG.7 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
USN MK-16 UBA HEO2



APPENDIX E

Breathing Work Data

Flow resistance breathing work vs depth at each RMV tested is plotted for air and HeO_2 breathing mixes.

KEY:

FIGURE 8: MK 16 UBA w/Air Diluent

FIGURE 9: MK 16 UBA w/HeO_2 Diluent

FIG.8 BREATHING WORK VS. DEPTH
USN MK-16 UBA AIR

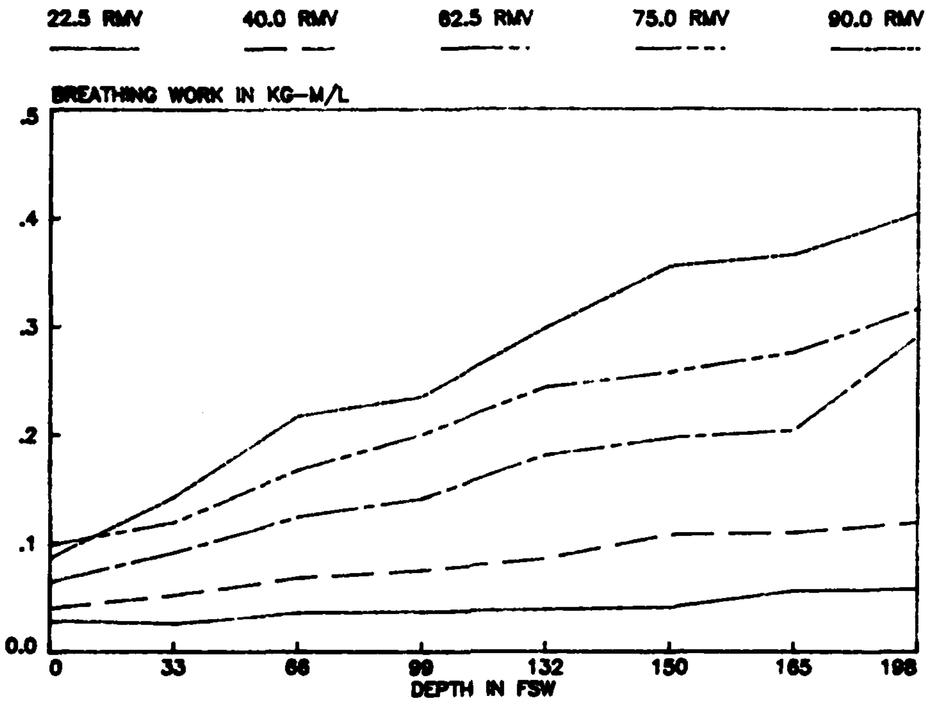
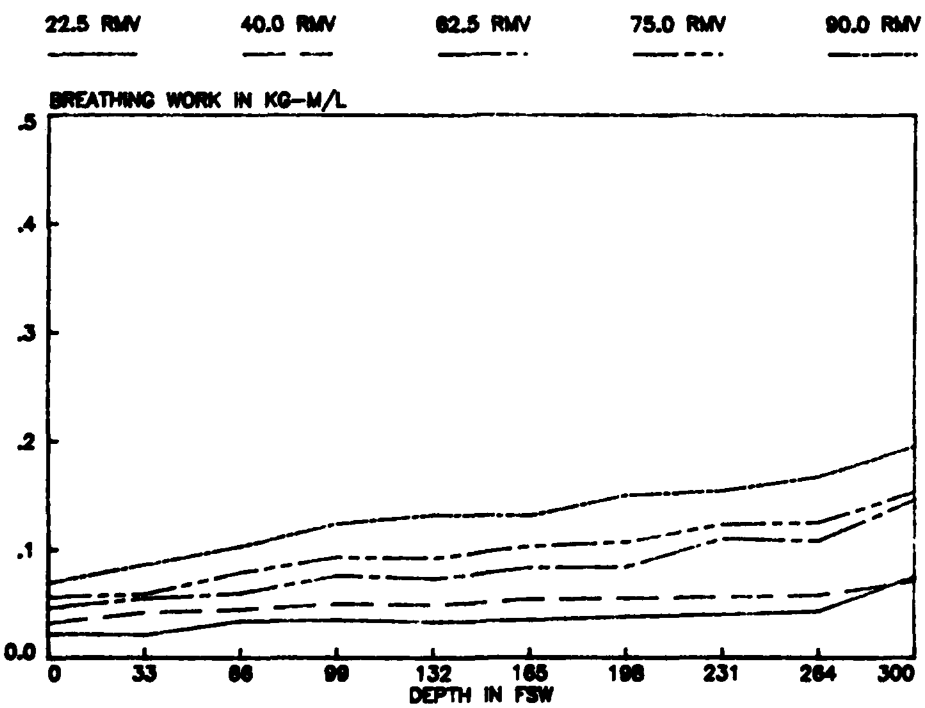


FIG.9 BREATHING WORK VS. DEPTH
USN MK-16 UBA HEO2



APPENDIX F

Canister Duration Data

Data for canister duration (% SEV vs time) is contained in this appendix. 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 10: Representative Plot of Actual CO_2 % SEV vs Time Data

FIGURE 11: Depth: 30 FSW
Water TEMP: 29°F
Diluent: Air

FIGURE 12: Depth: 50 FSW
Water TEMP: 29 & 40°F
Diluent: Air

FIGURE 13: Depth: 100 FSW
Water TEMP: 29 & 40°F
Diluent: Air

FIGURE 14: Depth: 150 FSW
Water TEMP: 29, 40, 50 & 70°F
Diluent: Air

FIGURE 15: Depth: 30 FSW
Water TEMP: 40°F
Diluent: HeO_2

FIGURE 16: Depth: 100 FSW
Water TEMP: 29 & 70°F
Diluent: HeO_2

FIGURE 17: Depth: 150 FSW
Water TEMP: 29 & 40°F
Diluent: HeO_2

FIGURE 18: Depth: 200 FSW
Water TEMP: 29, 40, 50 & 60°F
Diluent: HeO_2

FIGURE 19: Depth: 300 FSW
Water TEMP: 29, 40, 50 & 70°F
Diluent: HeO_2

FIGURE 10
UBA: Closed-circuit
WATER TEMP: 90'F
DEPTH: 100 FSW

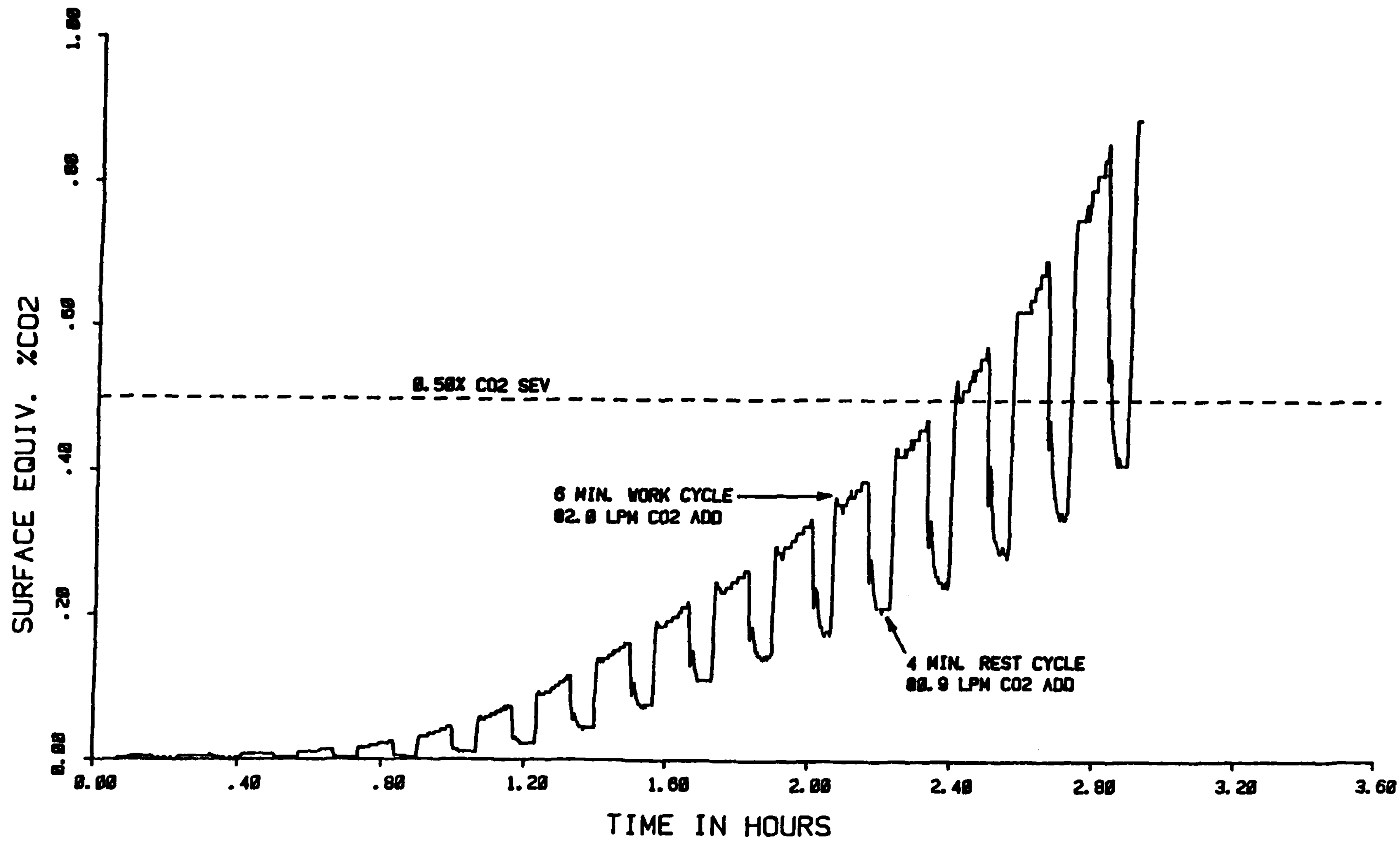


FIG.11 CANISTER DURATION
USN MK-16 UBA AIR

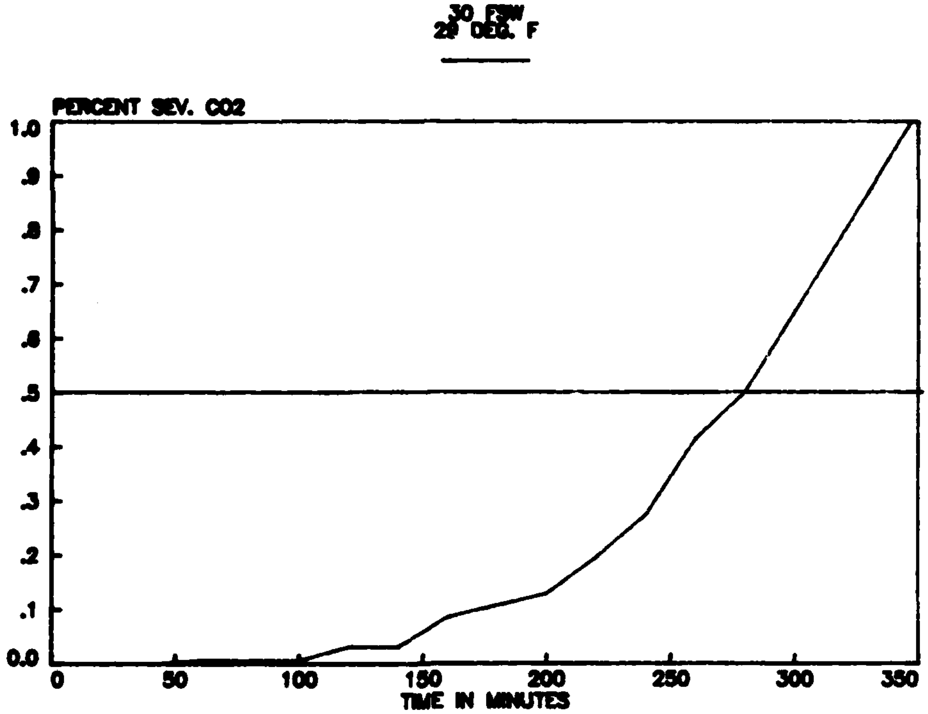


FIG.12 CANISTER DURATION
USN MK-16 UBA AIR

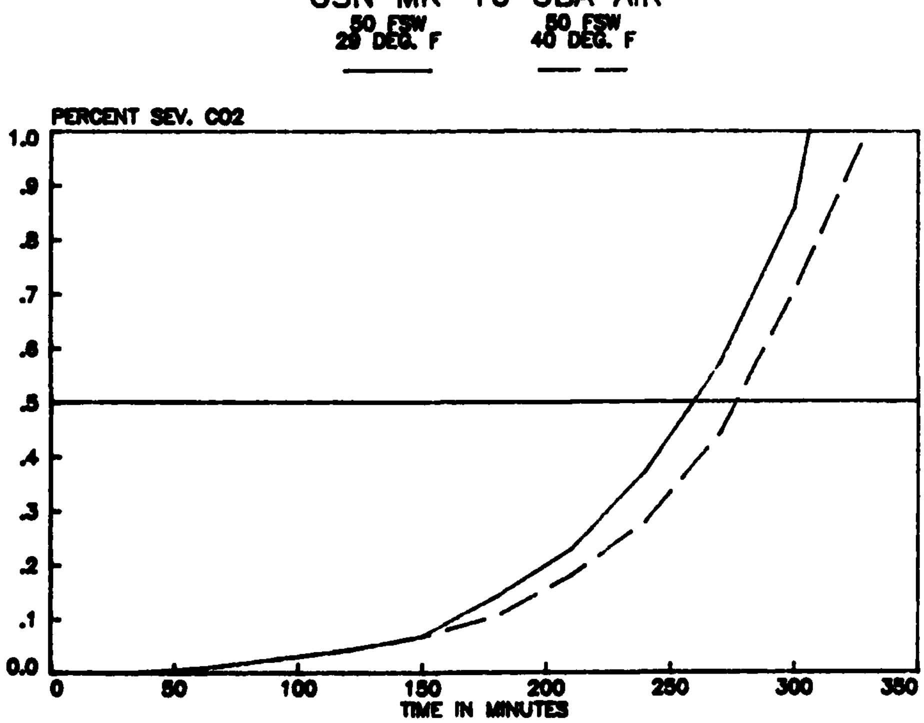


FIG.13 CANISTER DURATION

USN MK-16 UBA AIR

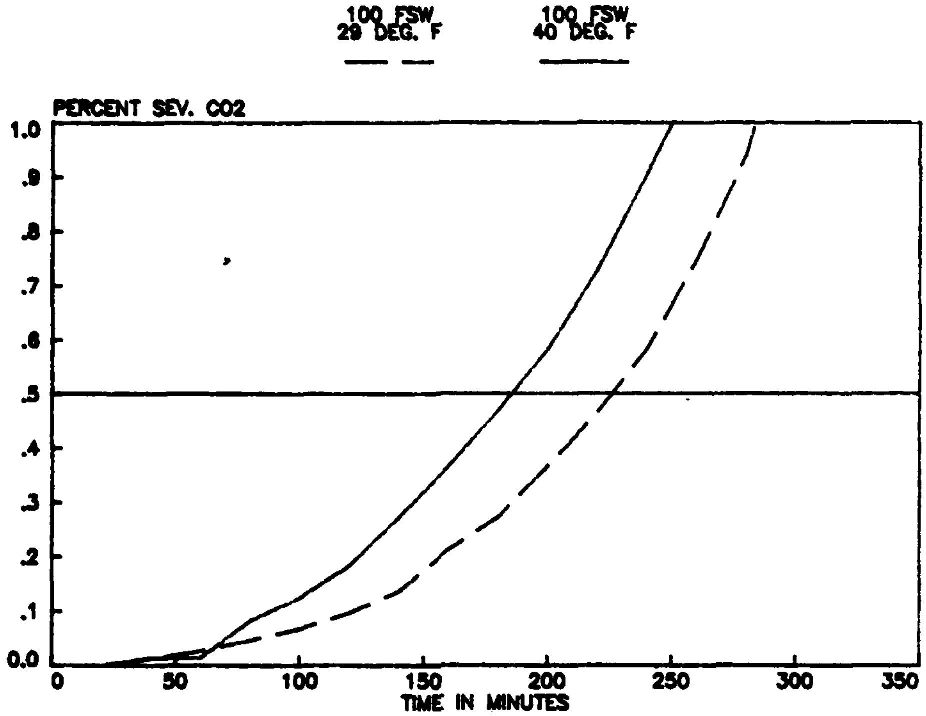


FIG.14 CANISTER DURATION

USN MK-16 UBA AIR

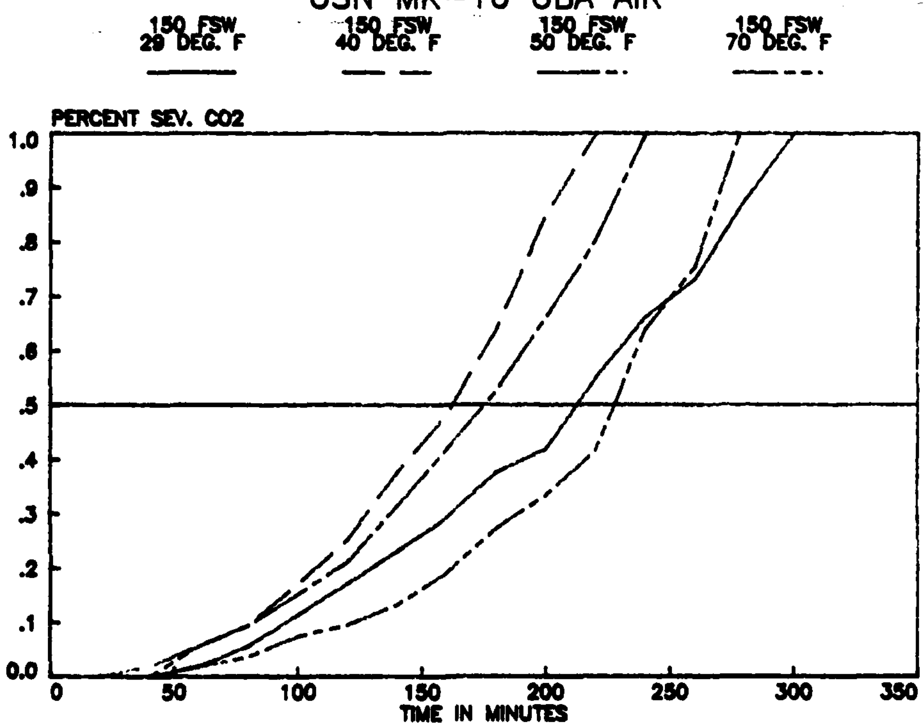


FIG.15 CANISTER DURATION

USN MK-16 UBA HEO2

30 FSW
40 DEG. F

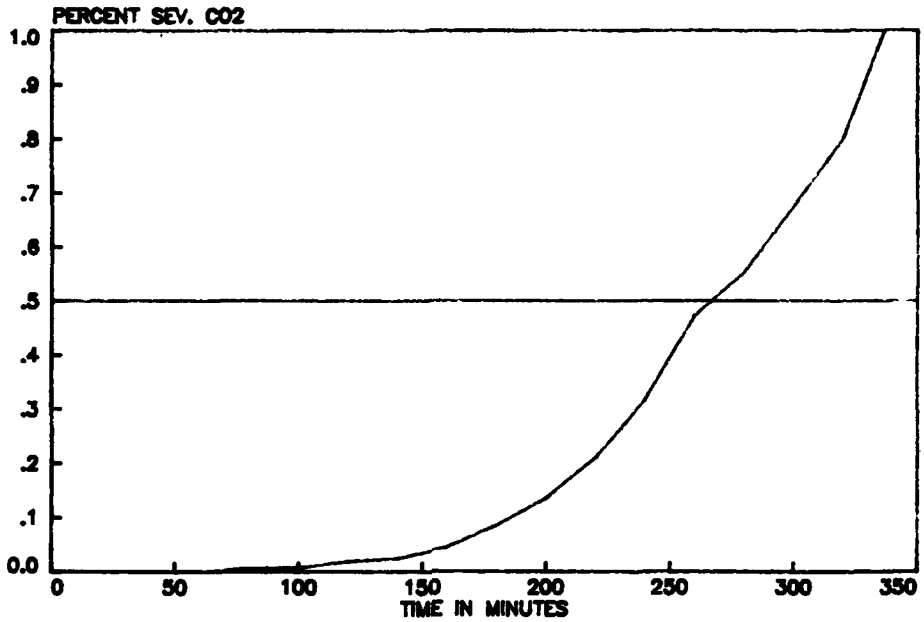


FIG.16 CANISTER DURATION

USN MK-16 UBA HEO2

100 FSW 29 DEG. F   100 FSW 70 DEG. F

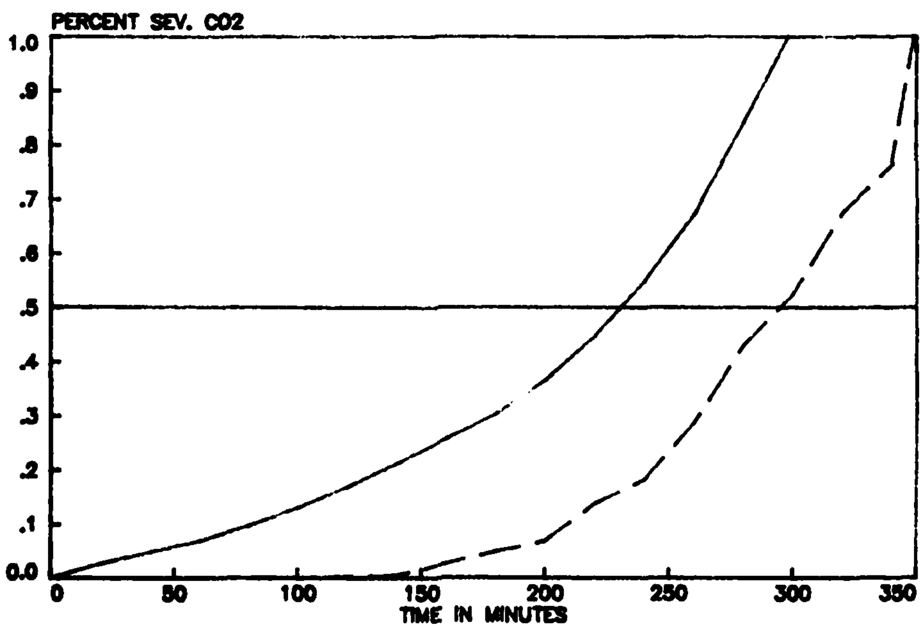


FIG.17 CANISTER DURATION

USN MK-16 UBA HEO2

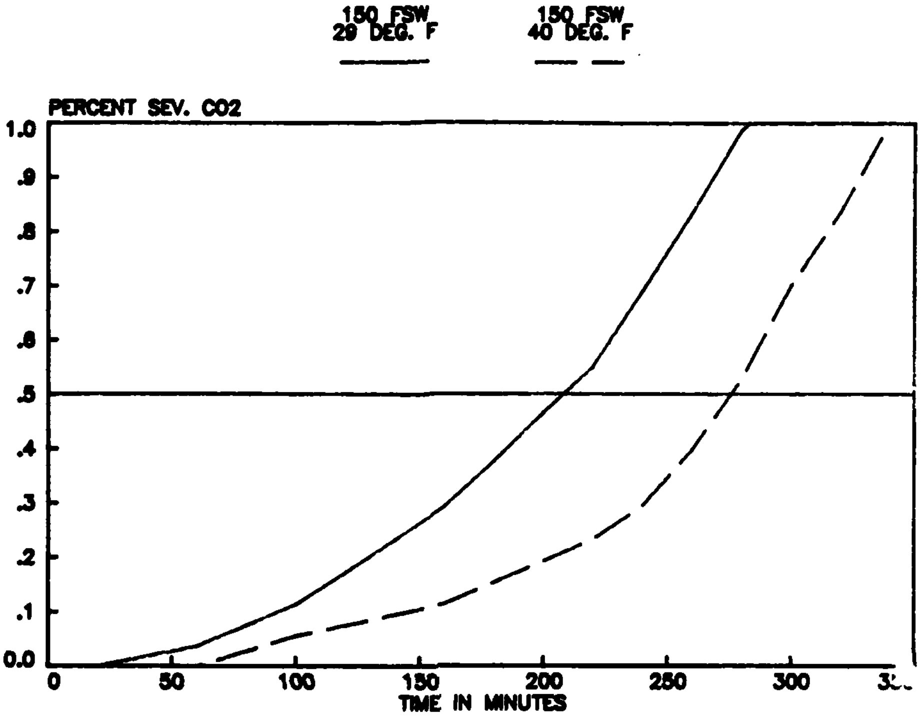


FIG.18 CANISTER DURATION

USN MK-16 UBA HEO2

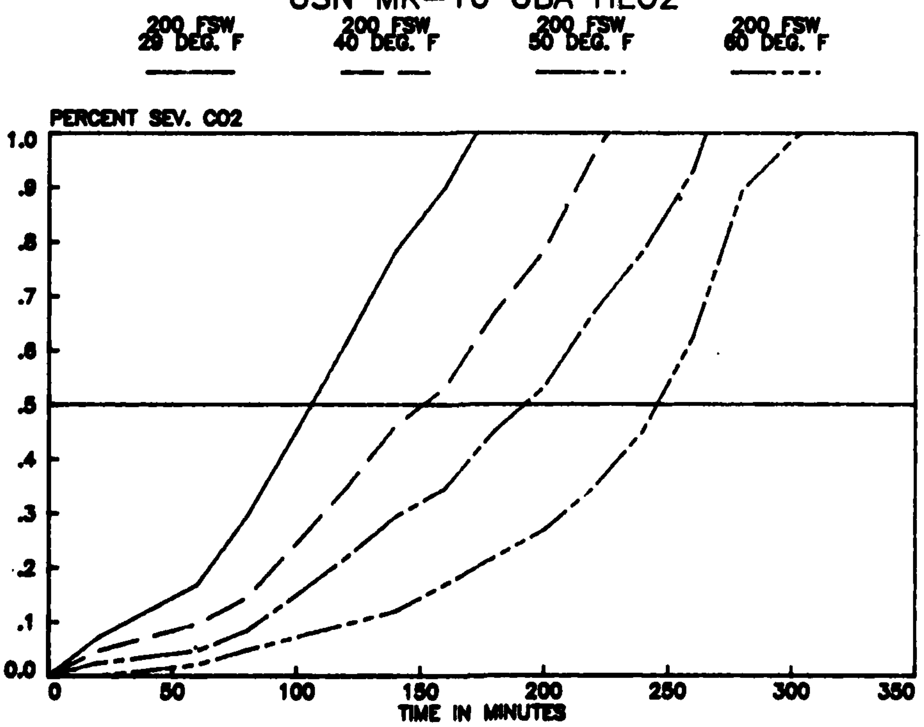
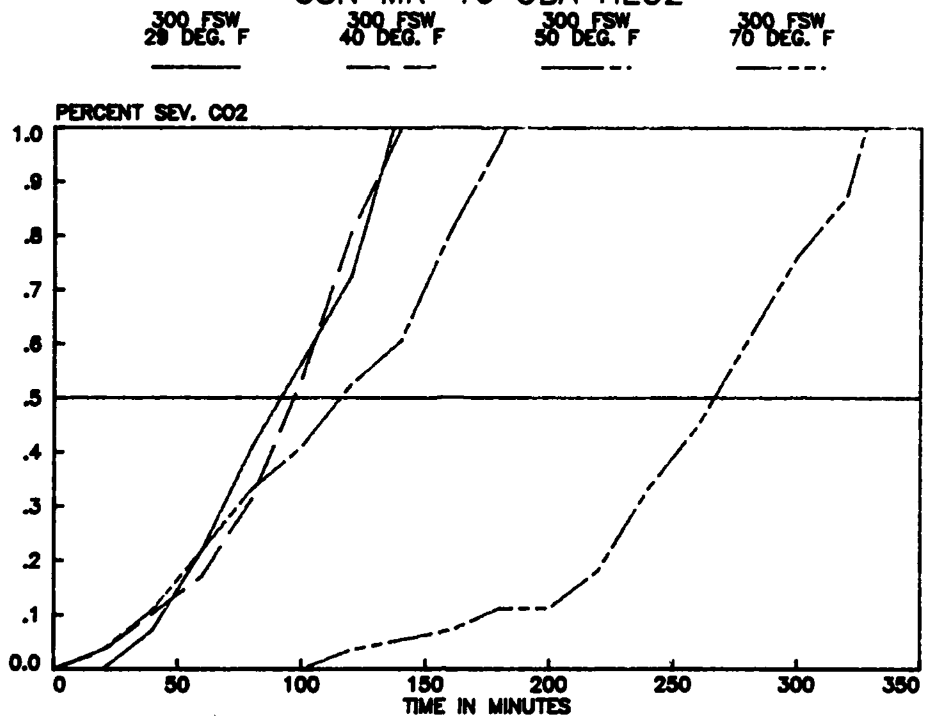


FIG.19 CANISTER DURATION
USN MK-16 UBA HEO2



APPENDIX G

Oxygen Set-point Control Data

Figure 20

Oxygen PO_2 in ATA absolute is plotted vs time and O_2 add valve firing sequence. Only one plot is included as it is typical of the set point control accomplished by the UBA.

FIG.20 OXYGEN SET POINT CONTROL TEST
USN MK-16 UBA