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UNMANNED EVALUATION OF VARIOUS UMBILICAL SUPPLIED OPEN  
CIRCUIT DEMAND UBA (U) NAVY EXPERIMENTAL DIVING UNIT  
PANAMA CITY FL C J TARMY SEP 86 NEDU-11-86

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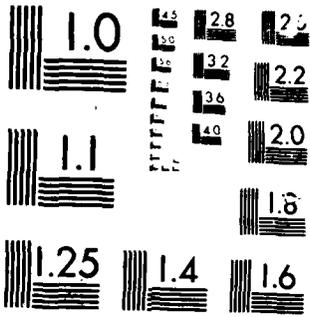
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E. Diving Systems International Superlite 17B Helmet with GSOL Ultraflow 350 Demand Regulator and Sideblock Assembly. The GSOL Ultraflow 350 is an improved DSI Superflow regulator and sideblock. Gas flow has been improved by re-design of various parts and increasing the size of the porting within the assembly. The following extract from the manufacturers operation and maintenance manual describes the changes that are made to the DSI "Superflow":

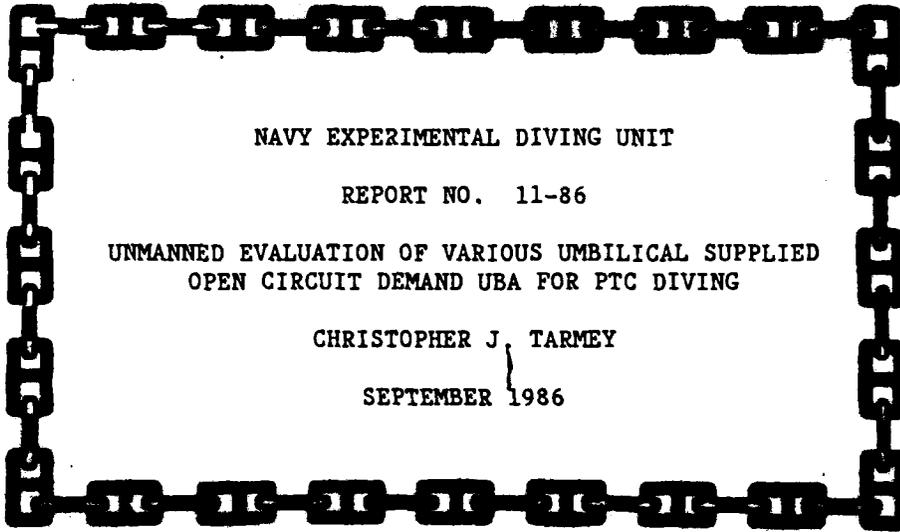
1. Inlet/exhaust pipe internal diameter increased from 3/4 inch to 7/8 inch.



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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 11-86

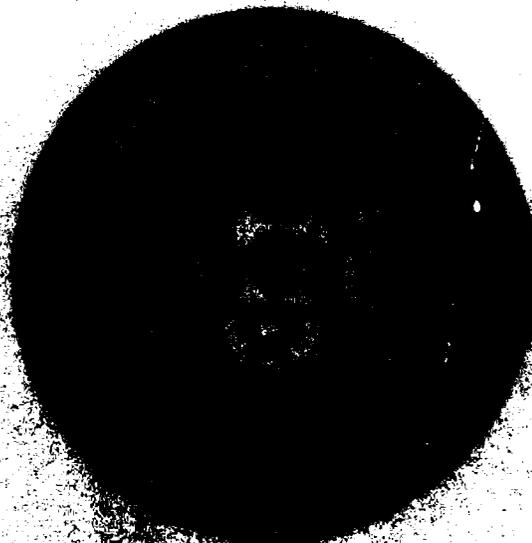
UNMANNED EVALUATION OF VARIOUS UMBILICAL SUPPLIED  
OPEN CIRCUIT DEMAND UBA FOR PTC DIVING

CHRISTOPHER J. TARMEY

SEPTEMBER 1986

NAVY EXPERIMENTAL DIVING UNIT

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 PANAMA CITY, FLORIDA 32407-5001

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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 11-86

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 OPEN CIRCUIT DEMAND UBA FOR PTC DIVING

CHRISTOPHER J. TARMEY

SEPTEMBER 1986

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USN MK 1 MOD S	ULTRAFLOW 500	NEDU TEST PLAN 86-07
SUPERFLOW REGULATOR	OPEN CIRCUIT DEMAND	CHANGE 1
SUPERLITE 17B	UMBILICAL SUPPLIED	
HELIOX 18B	PTC DIVING	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>During July and August 1986 NEDU conducted unmanned studies to evaluate a number of umbilical supplied, open circuit, demand UBAs for potential use in saturation diving from PTCs. The following UBAs were tested at various depths and RMVs to 1000 FSW using both 100 ft 3/8 in ID and 100 ft 1/2 in ID diver's umbilicals</p> <p>USN MK 1 MOD 0 Bandmask USN MK 1 MOD S Bandmask</p>		

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AGA Divator MK II Full Face Mask)  
DSI Superlite 17B  
DSI Heliox 18B  
DSI Superlite 17B/GSOL Ultraflow 350  
DSI Superlite 17B/GSOL Ultraflow 500

The use of a volume tank in the PTC was also investigated. The results of the testing showed that only the DSI Superlite 17B or Heliox 18B fitted with GSOL Ultraflow 500 and GSOL Ultraflow 350 were able to meet current NEDU performance goals to 1000 FSW. All other UBAs failed to meet NEDU performance goals for work of breathing.

New performance goals based on 75 RMV are proposed as a further result of this testing to ensure that UBA performance will not be a limiting factor in diver performance. Only the Superlite 17B or Heliox 18B with Ultraflow 500 was capable of meeting these proposed performance goals.

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Table of Contents

	<u>Page</u>
Report Documentation Page.....	ii
Table of Contents.....	iv
Abbreviations.....	vi
Abstract.....	viii
 <u>Section</u>	
I. INTRODUCTION.....	1
II. FUNCTIONAL DESCRIPTION OF THE HELMET AND MASKS TESTS	
A. USN MK 1 MOD 0 and USN MK 1 MOD S Band Masks.....	3
B. Diving Systems International Superlite 17B Helmet with Standard Superflow Regulator.....	3
C. Diving Systems International Heliox 18B with Standard Superflow Regulator.....	3
D. AGA Divator II Full Face Mask.....	3
E. Diving Systems International Superlite 17B Helmet with GSOL Ultraflow 350 Demand Regulator and Sideblock Assembly.....	4
F. Diving Systems International Superlite 17B Helmet with GSOL Ultraflow 500 Demand Regulator and Sideblock Assembly.....	9
III. TEST PROCEDURES.....	13
IV. TEST RESULTS.....	14
V. DISCUSSION	
A. Performance Goals.....	14
B. USN MK 1 MOD 0 Bandmask.....	18
C. USN MK 1 MOD S Bandmask.....	18
D. DSI Superflow Demand Regulator and Sideblock (Superlite 17B and Heliox 18B).....	19
E. GSOL Ultraflow 350.....	22
F. AGA Divator II Full Face Mask.....	22
G. GSOL Ultraflow 500 Demand Regulator and Sideblock.....	23
H. Factors that Effect Regulator Performance.....	24
VI. CONCLUSIONS AND RECOMMENDATIONS.....	26
VII. REFERENCES.....	28

ANNEXES

- A. List of Manufacturers and Suppliers..... A-1
- B. Unmanned Test Plan..... B-1
- C. Ultraflow 350 and 500 Installation Instructions..... C-1

APPENDICES

- 1. Test Results..... 1-1
- 2. Pressure: Tidal Volume Loops..... 2-1

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### Abbreviations

BPM	breaths per minute
cmH <sub>2</sub> O	centimeters of water (pressure)
cu ft	cubic feet
°F	degree fahrenheit
DSI	Diving Systems International
EDF	Experimental Diving Facility (NEDU Unmanned Test Facility)
FSW	feet of seawater
ft	foot
GSOL	Gas Services Offshore Ltd.
HP	high pressure
ID	inside diameter
in	inches
J/L	joules per liter (unit respiratory work)
kg·m/l	kilogram-meters per liter (unit respiratory work)
kPa	kilopascals
lpm	liters per minute (flow rate)
MOD	modified
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
ΔP	pressure differential
psi	pounds per square inch
psid	pounds per square inch differential
psig	pounds per square inch gauge
PTC	personnel transfer capsule (bell)

RMV                   respiratory-minute-volume in liters-per-minute  
 SI                     System International (units of measure)  
 TV                    the tidal volume in liters of air breathed in and out  
                       of the lungs during normal respiration  
 UBA                   underwater breathing apparatus  
 USN                   United States Navy

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
kg·m/l	joules per liter (J/L)	9.807
psi	kilopascals (kPa)	6.895
feet	meters (m)	0.305
FSW	meters of seawater (MSW)	0.305
FSW	kilopascals (kPa)	3.065
cmH <sub>2</sub> O	kilopascals (kPa)	0.098

### Abstract

During July and August 1986 NEDU conducted unmanned studies to evaluate a number of umbilical supplied, open circuit, demand UBAs for potential use in saturation diving from PTCs. The following UBAs were tested at various depths and RMVs to 1000 FSW using both 100 ft 3/8 in ID and 100 ft 1/2 in ID diver's umbilicals:

- USN MK 1 MOD 0 Bandmask
- USN MK 1 MOD S Bandmask
- AGA Divator MK II Full Face Mask
- DSI Superlite 17B
- DSI Heliox 18B
- DSI Superlite 17B/GSOL Ultraflow 350
- DSI Superlite 17B/GSOL Ultraflow 500

The use of a volume tank in the PTC was also investigated. The results of the testing showed that only the DSI Superlite 17B or Heliox 18B fitted with GSOL Ultraflow 500 and GSOL Ultraflow 350 were able to meet current NEDU performance goals to 1000 FSW. All other UBAs failed to meet NEDU performance goals for work of breathing.

New performance goals based on 75 RMV are proposed as a further result of this testing to ensure that UBA performance will not be a limiting factor in diver performance. Only the Superlite 17B or Heliox 18B with Ultraflow 500 was capable of meeting these proposed performance goals.

#### KEY WORDS:

- USN MK 1 MOD 0
- USN MK 1 MOD S
- Superflow Regulator
- Superlite 17B
- Heliox 18B
- Ultraflow 350
- Ultraflow 500
- Open circuit demand
- Umbilical supplied
- PTC diving
- Saturation diving
- NEDU Test Plan 86-07 Change 1

## I. INTRODUCTION

In August 1985 the Navy Experimental Diving Unit (NEDU) was tasked by Naval Sea Systems Command (NAVSEA) to conduct analysis, test and evaluation of the USN MK 1 MOD 0 bandmask. NEDU was to determine if it could be used in lieu of the currently approved USN MK 1 MOD S for saturation diving from Personnel Transfer Capsules (PTCs).

Reference (a) established standardized NEDU unmanned test procedures and performance goals for all types of underwater breathing apparatus (UBA). A review of previous testing of the USN MK 1 MOD 0 was conducted (references (b) through (d)). This review revealed that no testing had been conducted on this mask using HeO<sub>2</sub> breathing mixtures.

Investigation revealed that no formal testing of the USN MK 1 MOD S had been conducted prior to approval for Navy use. Since then, unmanned testing of the MOD S has been conducted only in the bail-out mode.

It was therefore impossible to provide a comparative study of the MOD 0 and MOD S from a review of previous testing. It was decided that a full unmanned test to 1000 FSW should be properly conducted on all UBA's using appropriate HeO<sub>2</sub> breathing gases per reference (a). Furthermore the testing should be arranged to simulate, as closely as possible, the current USN PTC diving practice. The masks would be supplied with appropriate bottom breathing mixtures through 100 ft. of 3/8 in. ID umbilical.

In 1983, manned studies were conducted in the NEDU Ocean Simulation Facility (OSF) to a simulated depth of 850 FSW. The purpose of these studies was to compare the performance of the Diving Systems International (DSI) Superlite 17B to the approved USN MK 1 MOD S, with a view to approving the Superlite 17B for Navy use for PTC diving.

Work of breathing cannot be measured during manned studies however peak inhalation and exhalation effort in both rigs was recorded and compared at various diver work rates. Both rigs were found to have the same breathing resistance. The results are in reference (e).

During Deep Dive 84, further manned tests were conducted at 856 FSW using the Superlite 17B to investigate potential CO<sub>2</sub> problems in the helmet that had been reported during studies at DCIEM. During these studies no CO<sub>2</sub> problem was found and peak inhalation and exhalation measurements were again recorded during a series of graded exercises. Although breathing resistance was not unusually high, the majority of the diver-subjects were unable to complete their work cycles due to dyspnea (difficulty in breathing). This was an unexpected occurrence, particularly since all the divers had successfully completed similar work cycles during the previous 850 FSW tests.

The problem experienced on Deep Dive 84 was attributed to either poor rig performance or to diver conditioning (poor diver performance). In an attempt to rule out poor rig performance a volume tank was placed in line between the

overbottom regulator and the diver's umbilical. The diver's umbilical was shortened from 300 ft. to 50 ft. and the overbottom supply pressure to the umbilical increased to 185 psig.

The majority of divers were still unable to complete their work cycles at the highest work rates. Unmanned work of breathing studies were not available, other than those conducted using air, to predict any rig problem but the breathing resistance measurements were satisfactory. It could only be concluded from the data available that the divers were beyond their endurance. The results of this evaluation are contained in reference (g) and will be further discussed in Section V. The Superlite 17B was subsequently approved for Navy use for PTC diving.

Since these dives were conducted, the Royal Navy has completed an evaluation of the Superlite 17B (and Heliox 18B). The results of this evaluation, which was conducted using air to 180 FSW, indicate that the Superlite 17B (and Heliox 18B) failed to meet their performance goals, and USN performance goals, beyond 132 FSW. At RMVs of 62.5 and above work of breathing and breathing resistance, particularly inhalation resistance, increased rapidly with depth. These results, which are contained in reference (h), are similar to those contained in reference (f).

Due to the lack of data available from unmanned testing of the Superlite 17B with its Superflow regulator using HeO<sub>2</sub> mixtures, it was considered prudent to include the Superlite 17B in this evaluation to 1000 FSW.

In July 1986, NAVSEA tasked NEDU to evaluate the AGA Divator MK II full face mask and second stage as a potential standby diver's rig for PTC diving. It had been reported in reference (i) that this full face mask had an excellent second stage regulator whose performance was far superior to the USN MK 1 MOD 0. Even though the AGA Divator II had only been tested on air to 198 FSW it had shown great potential for wider application than lightweight diving to 60 FSW - perhaps even PTC diving for a standby diver, if it could be suitably configured. Accordingly the AGA Divator MK II was added to the unmanned testing program.

Possible problems were discussed concerning configuration, human factors and thermal protection when using the AGA Divator II to 1000 FSW. This led to consideration of the DSI Heliox 18B as a potential open circuit demand saturation diving rig, particular for standby diver use.

This UBA offered a number of potential advantages. It is identical to the Superlite 17B, only it is a bandmask. It is connected to the divers umbilical in the same way as the Superlite 17B and the existing USN MK 1 MOD S. Thermal protection and gas heating can be provided with no change to existing USN MK 1 MOD S arrangements.

Since it is functionally identical to the Superlite 17B, any work of breathing concerns about the Superlite 17B would apply equally to the Heliox 18B. Conversely, if the Superlite 17B concerns were to prove unfounded

then there would be no problem in recommending use of the Heliox 18B without further testing.

The Royal and Royal Canadian Navies have recently collaborated in the evaluation of Gas Services Offshore Ltd. (GSOL) regulators fitted to the DSI Superlite 17B and Heliox 18B helmets. Informal discussions indicate that the results of both manned and unmanned testing beyond 1000 FSW were impressive.

GSOL manufactures two deep diving demand regulators which can be supplied with, or as conversion kits to, both the Superlite 17B and the Heliox 18B. They are the Ultraflow 350 and Ultraflow 500. These regulators are designed for diving to 350 MSW (1148 FSW) and 500 MSW (1640 FSW) respectively. They can be procured with or without the Gas Services topside mounted divers' exhaled gas recovery system. Ultraflow 350 and 500 conversion kits were procured for testing on the Superlite 17B and Heliox 18B.

The purpose of the testing then, was to collect missing data and to identify which open circuit UBAs would best meet the Navy's requirements for saturation diving. Additionally, the testing included evaluations of possible gas supply improvements that could be made to get the best performance from each UBA tested.

## II. FUNCTIONAL DESCRIPTIONS OF THE HELMET AND MASKS TESTED

A. USN MK 1 MOD 0 and USN MK 1 MOD S Bandmasks. A full functional description of the USN MK 1 MOD 0 is contained in reference (j). The USN MK 1 MOD S differs only in the configuration of the sideblock assembly. They both have the same non-balanced demand regulator.

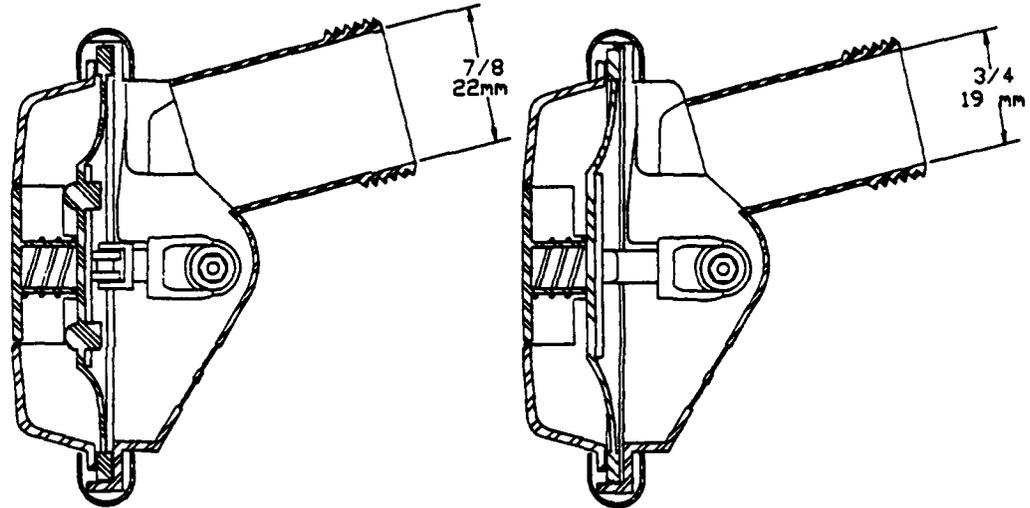
B. Diving Systems International Superlite 17B Helmet with Standard Superflow Regulator. A functional description of this helmet, is contained in references (c) and (f). The demand regulator is not of a "balanced" design. Gas, hot water and communications connections are the same as those for the USN MK 1 MOD S bandmask.

C. Diving Systems International Heliox 18B with Standard Superflow Regulator. The Heliox 18B with its Superflow demand regulator and sideblock assembly is identical to the Superlite 17B save only that it is a bandmask and similar in appearance to the USN MK 1 bandmasks. Form and fit are the same as the USN MK 1 bandmasks, as are the gas, hot water and communications connections.

D. AGA Divator II Full Face Mask. A full functional description of this mask is contained in reference (i). For the purpose of this testing it was rigged in the same way as the lightweight enclosed space system but without a bail-out cylinder. The gas distribution port that accepts the bail-out cylinder whip was blanked. (This configuration has recently been chosen for enclosed space diving operations and has recently been approved for Navy Use in that configuration.) The Divator MK II utilizes a "balanced" second stage regulator.

E. Diving Systems International Superlite 17B Helmet with GSOL Ultraflow 350 Demand Regulator and Sideblock Assembly. The GSOL Ultraflow 350 is an improved DSI Superflow regulator and sideblock. Gas flow has been improved by re-design of various parts and increasing the size of the porting within the assembly. The following extract from the manufacturers operation and maintenance manual describes the changes that are made to the DSI "Superflow":

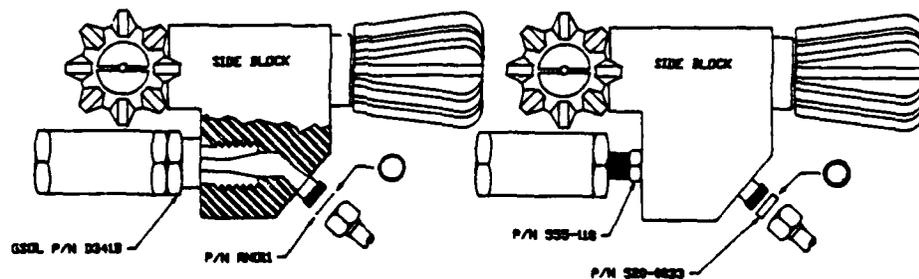
1. Inlet/exhaust pipe internal diameter increased from 3/4 inch to 7/8 inch.



ULTRAFLOW 350

SUPERFLOW

2. Adaptor P/N 555-118 is replaced with a high flow adaptor GSOL P/N D341B and the washer P/N 520-033 is replaced by an 'o' ring P/N RN011.

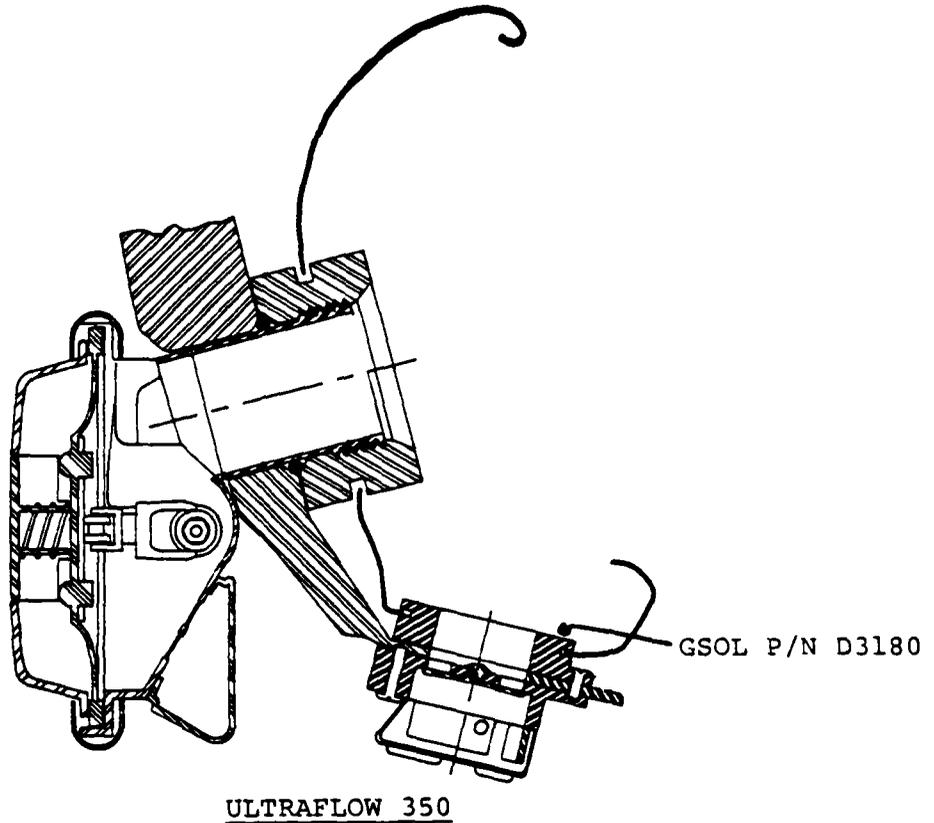


ULTRAFLOW 350

SUPERFLOW

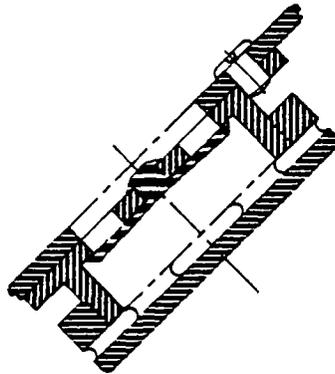
The high flow adaptor gives improved check valve support and improved internal flow characteristics. The 'O' ring provides improved flow characteristics.

3. Exhaust connector GSOL P/N D381D fits between the oral nasal and the diverter valve. It is unique to the Ultraflow 350.



This gives an improved exhalation path and prevents water from entering the exhaust gas flow.

4. The water dump valve GSOL P/N D337C is fitted to both Heliox 18B and Superlite 17B and is required when using the exhaust connector GSOL P/N D381D.



GSOL P/N D337c

ULTRAFLOW 350

Provides means of expelling water from helmet or band mask.

5. Deeper than 200 MSW the following parts are required to be changed out:

Standard spring set 10A & 11 part no. DSI No.

INNER & OUTER - 535-807

Must be replaced with GSOL heavy duty spring set 10B & 11 part no.

INNER - DE 018

OUTER - D 3800

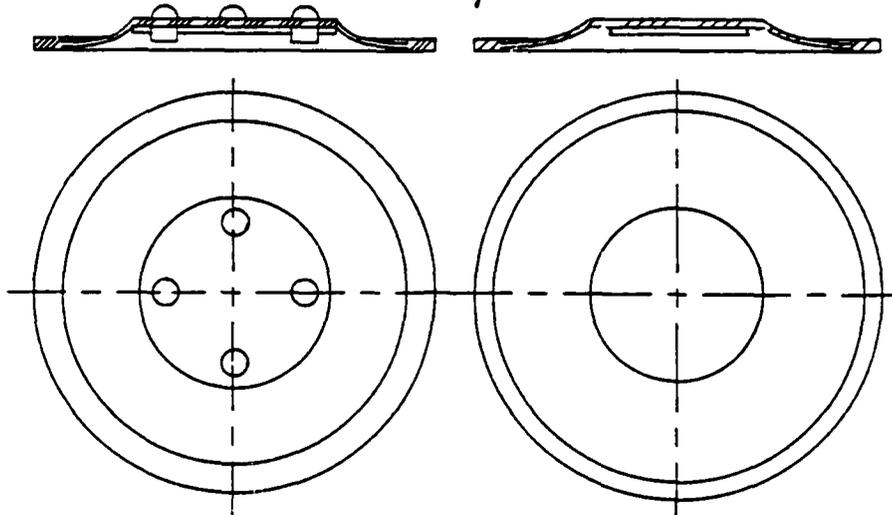
(During this evaluation heavy duty springs were used throughout.)

6. Diaphragm P/N 510-553 is replaced with a diaphragm with a larger backing plate of 01.377 in. (35 mm) U.S.D. P/N 1037-32.

4 BOSSES

DISC  $\phi$  25 MM

DISC  $\phi$  35 MM

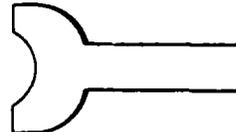
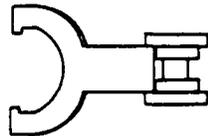
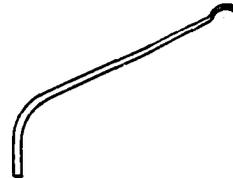
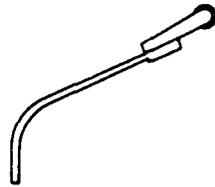


ULTRAFLOW 350

NOT RECOMMENDED

PROVIDES GREATER EFFECTIVE  
AREA ON DIAPHRAGM. 1.9 TIMES  
GREATER EFFECTIVE AREA.

7. The lever should be roller type D.S.I. P/N 545-038.

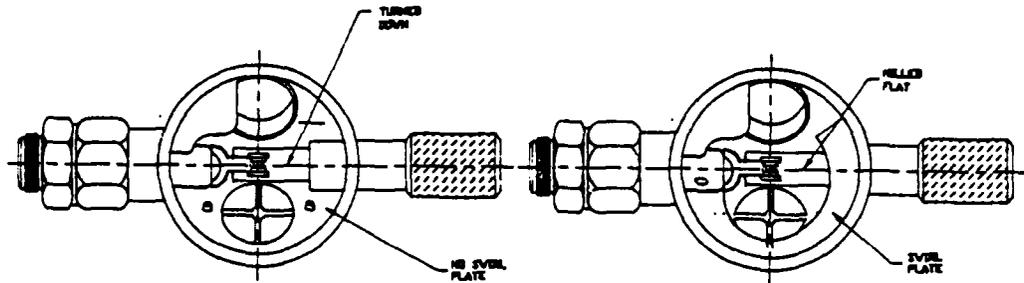


ULTRAFLOW 350

NOT RECOMMENDED

ROLLER PROVIDES LESS  
MOVEMENT FRICTION.

8. Note that the guide tube is reduced in diameter and there is no swirl plate.

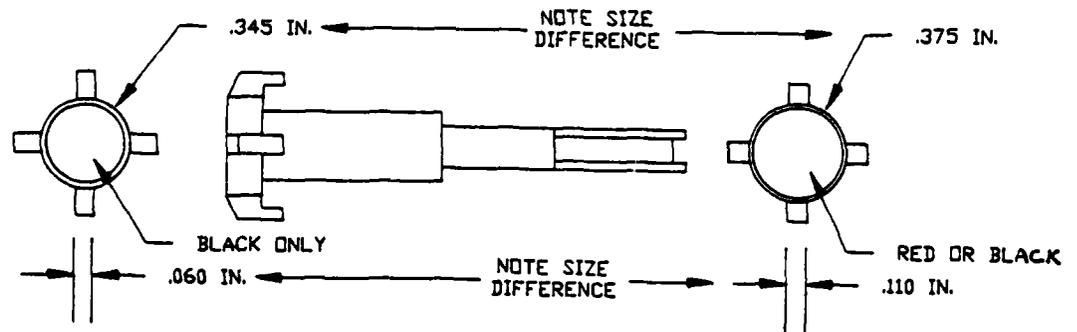


ULTRAFLOW 350

SUPERFLOW

PROVIDES A LESS OBSTRUCTED  
ROUTE FOR EXHALED GAS.

9. Inlet valve P/N 545-026 is changed for GSOL P/N D378A.



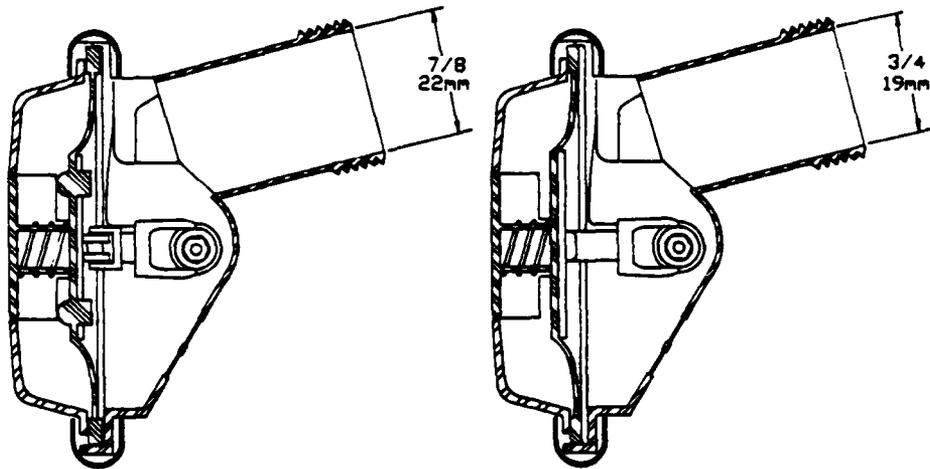
ULTRAFLOW 350

STANDARD

PROVIDES MORE AREA FOR GAS  
FLOW. SEAT MATERIAL RESISTS  
EROSION AT HIGHER PRESSURES.

F. Diving Systems International Superlite 17B with GSOL Ultraflow 500 Demand Regulator and Sideblock Assembly. The GSOL Ultraflow 500 utilizes a 'balanced' demand regulator and has improved gas flow between the supply check valve and DSI sideblock. This assembly is available fitted to either the Superlite 17B helmet or Heliox 18B bandmask. The following extract from the manufacturers operation and maintenance manual describes the Ultraflow 500:

1. Internal diameter of inlet/exhaust pipe changed from 3/4 inch to 7/8 inch to provide an increased area of 41%.



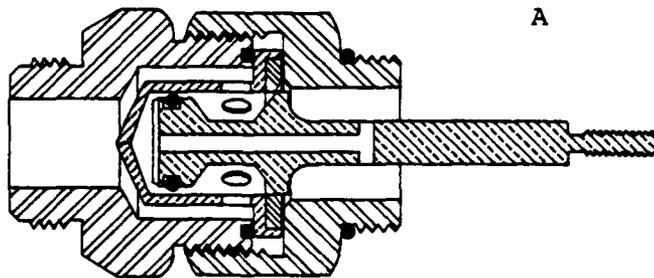
ULTRAFLW 500

SUPERFLOW

2. Ultraflow 500 inlet valve assembly

This balanced inlet valve assembly is unique to the Ultraflow 500. The balanced valve overcomes the problem of pressure fluctuations in the divers umbilical affecting breathing resistance. (On dives below 650 FSW the umbilical pressure can change by as much as 145 psi.

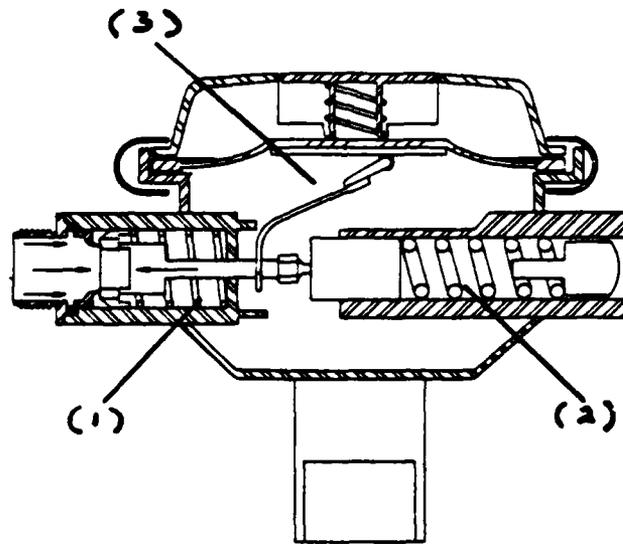
This pressure change has little effect on the Ultraflow 500 as the pressure is acting equally on both ends of the valve stem (A).



ULTRAFLW 500 INLET VALVE

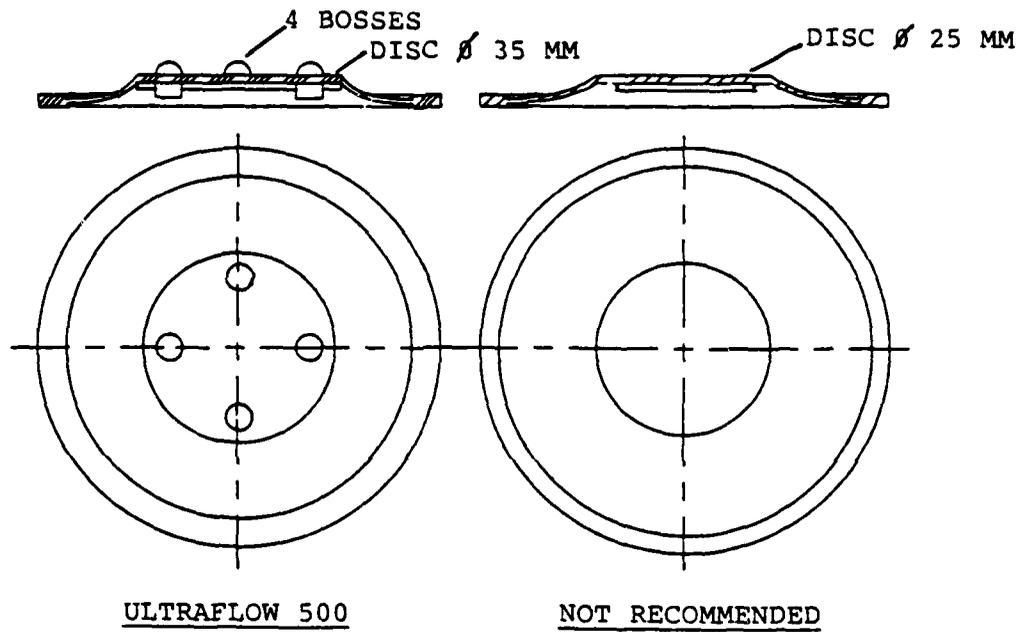
On a standard Superflow regulator which has been preset for a 10 bar supply, the springs (1) and (2) balance the gas pressure on the inlet valve (3).

If the supply pressure changes to 75 psi the spring force is now much greater than the gas pressure on the inlet valve and a much greater force is required at the roller fork assembly to keep the diver supplied with gas.

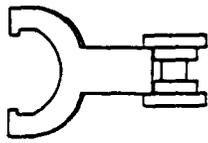
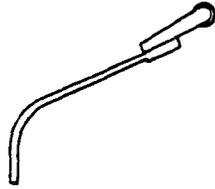


SUPERFLOW REGULATOR

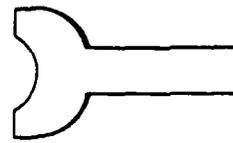
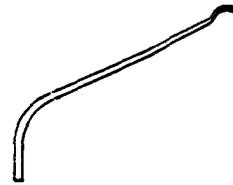
3. Diaphragm P/N 510-553 is replaced with a diaphragm with a larger backing plate of 1.4 in. (35 mm) U.S.D. P/N 1037-32. This provides a diaphragm having 1.9 times greater effective area.



4. The lever should be of the roller type D.S.I. P/N 545-038, the roller provides less friction.

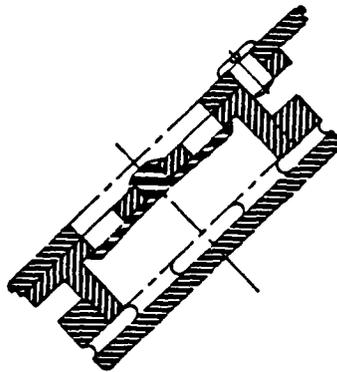


ULTRAFLOW 500



NOT RECOMMENDED

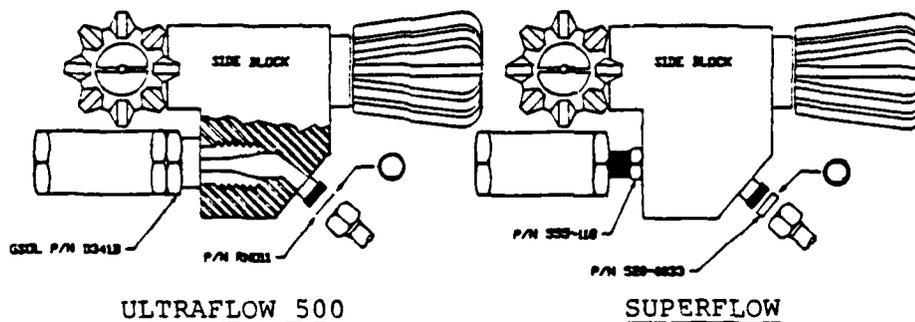
5. The water dump valve GSOL P/N D337C is fitted to both Heliox 18B and Superlite 17B and is required when using the exhaust connector GSOL P/N D381D, to provide means of expelling water from helmet or bandmask.



GSOL PN D337c

6. Adaptor P/N 555-118 is replaced with a high flow adaptor GSOL P/N D341B and the washer P/N 420-033 is replaced by an "O" ring P/N RN011.

The high flow adaptor gives improved check valve support and improved internal flow characteristics. The "O" ring provides improved flow characteristics.



7. Exhaust connector GSOL P/N D3810 fits between the oral nasal and the lower exhaust.

This gives an improved exhalation path for the exhaust gas.

### III. TEST PROCEDURES

All the UBAs were first tested per the test plan in Annex B, using a 100 ft. 3/8 in. ID supply umbilical. This umbilical size was chosen to best represent current USN saturation diving practice. All UBAs were tested using the overbottom supply pressures recommended by the manufacturer or Navy Operation and Maintenance Manual. HeO<sub>2</sub> mixtures were used that were appropriate for the depth of dive:

0 - 300 FSW	84/16 HeO <sub>2</sub>
400 FSW	95/5 HeO <sub>2</sub>
500 - 1000 FSW	97/3 HeO <sub>2</sub>

Prior to testing, each UBA was prepared for diving per its relevant O&M Manual, taking care to readjust the second stage regulator prior to any required changes in supply pressures for different depths.

The rigs were tested at various depths and at the various RMVs that simulate diver work rates:

- 22.5 RMV - light work
- 40 RMV - moderate work
- 62.5 RMV - moderately heavy work
- 75 RMV - heavy work
- 90 RMV - extreme work

Pressure - volume loops at each depth and RMV were recorded from which breathing resistance and work of breathing were calculated. Umbilical pressure drops were also measured at each test depth and RMV.

Upon completion of testing with the 3/8 in. ID umbilicals the testing was repeated for selected UBAs using a 100 ft. 1/2 in. ID umbilical to investigate the potential benefit to rig performance by a reduction in umbilical pressure drop.

The possible advantage of using a volume tank in the PTC between the divers supply regulator and the divers umbilical was also investigated. A 50 cu/ft SCUBA cylinder was "teed" into the test facility. A locally manufactured 3/8 in. ID T-fitting was inserted into the neck of the SCUBA cylinder to ensure smooth gas flow and both 3/8 in. ID and 1/2 in. ID diver umbilicals were used. The UBA chosen for this test was the GSOL Ultraflow 500. The overbottom supply regulator was a Tescom Series 26-1121-382 regulator.

#### IV. TEST RESULTS

The detailed test results are shown in Appendices A and B.

#### V. DISCUSSION

A. Performance Goals. The NEDU performance goals [reference (a)] were established having taken into account the results of manned physiological studies and the state of UBA technology in 1981. UBAs were grouped into categories according to type, and performance goals were set for each category. The categories are:

- Category 1: Open circuit demand SCUBA regulators.
- Category 2: Open circuit umbilical-supplied demand UBA (i.e. full-face bandmasks and dry helmets).
- Category 3: Open circuit umbilical-supplied free-flow UBA (i.e. full-face masks and dry helmets).
- Category 4: Closed and semi-closed circuit diver breath driven UBA, i.e. MK 15 and MK 11 type rigs with full face masks, mouthpiece or dry helmets.
- Category 5: Closed and semi-closed circuit ejector or pump-driven UBA (push-pull) (i.e. MK 12 mixed gas or MK 14 type rigs with dry helmets).

With the exception of category 1 and 2 UBAs, the performance goals for work of breathing and breathing resistance were established at 75 RMV. 75 RMV is the RMV expected of a diver performing heavy work and had been proved attainable during both manned and unmanned studies of category 3, 4, and 5 UBAs. It was considered that if a UBA could meet 75 RMV performance goals it would not be a limiting factor in diver performance.

75 RMV was not considered attainable for umbilical supplied open circuit demand UBAs in 1981 due to the effect of umbilical and sideblock pressure drop on demand regulator performance. 62.5 RMV was selected as the attainable for category 1 and 2 UBAs and is the RMV expected during moderately heavy diver work rates. Implicit in the selection of 62.5 RMV was recognition that use these UBAs would be a limiting factor in diver performance.

The following table summarizes the 1981 NEDU performance goals for UBAs used in saturation diving:

TABLE 1  
1981 NEDU PERFORMANCE GOALS [reference (a)]

					CATEGORY 2 1000 FSW HeO <sub>2</sub> (132 FSW-AIR)	CATEGORIES 3&5 1500 FSW HeO <sub>2</sub> (200 FSW-AIR)		CATEGORY 4 1500 FSW HeO <sub>2</sub> (200 FSW-AIR)	
LPM	RMV LPM	TV ℓ	FREQ	PEAK FLOW RATE LPS	WORK/ kg-m/ℓ	ΔP** CmH <sub>2</sub> O	WORK/ kg-m/ℓ	ΔP** CmH <sub>2</sub> O	WORK/ kg-m/ℓ
0.90	22.5	1.5	15	1.18		1.5	0.02	1.5	0.02
1.60	40.0	2.0	20	2.09		4.0	0.06	4.0	0.06
2.50	62.5	2.5	25	3.27	0.18*	10.0	0.15	10.0	0.15
3.00	75.0	2.5	30	3.93		14.0	0.22	14.0	0.22
3.60	90.0	3.0	30	4.71		20***	0.32	20***	0.32

\* Category 2 is not capable of making the 75 RMV performance requirements at the maximum operating depth. State-of-the-art in open circuit demand UBA is such that 62.5 RMV is the absolute limit for reasonable breathing work values at the present time. (1981)

\*\* ΔP max is measured from neutral (no flow) to full inhalation or exhalation.

\*\*\* 3.60 VO<sub>2</sub> and 90 RMV is of data interest but 75 RMV is the actual performance goal.

Since 1981, there have been a number of major improvements in regulator design particularly with the introduction of "balanced" second stage demand regulators which are less affected by changes in supply and umbilical pressures. 75 RMV has become attainable, and represents a work rate that should be considered in our evaluation of all umbilical supplied UBAs so that UBA breathing performance need no longer be a limiting factor in a diver's performance.

Figure 1 shows a typical pressure to tidal volume breath loop taken during unmanned testing from which work of breathing and breathing resistance are measured. It will be noted that the 1981 performance goals do not establish peak to peak inhalation and exhalation goals for demand regulators for the reasons given in reference (a). None-the-less inhalation and exhalation resistance is considered in the evaluation of all UBAs particularly during manned studies when work of breathing cannot be measured directly. Accordingly, for the purposes of evaluating the UBAs tested during this evaluation two limits are considered.

The first is the milspec limit in reference (k). This limit was established based on the measured peak inhalation and exhalation resistance of a 1950's demand regulator. The upper milspec limit for breathing resistance is 40 cmH<sub>2</sub>O (4.0 Kpa) representing peak inhalation and exhalation differential pressures of 20 cmH<sub>2</sub>O (2.0 Kpa). During manned studies divers have achieved higher inhalation and exhalation peaks near the limit of their endurance, but this milspec probably represents a satisfactory upper limit for breathing apparatus. Twenty-eight cmH<sub>2</sub>O (2.8 Kpa) has previously been shown to be an attainable performance goal for category 3, 4 and 5 UBAs with peak inhalation and exhalation effort not to exceed 14 cmH<sub>2</sub>O (1.4 Kpa) [reference (a)].

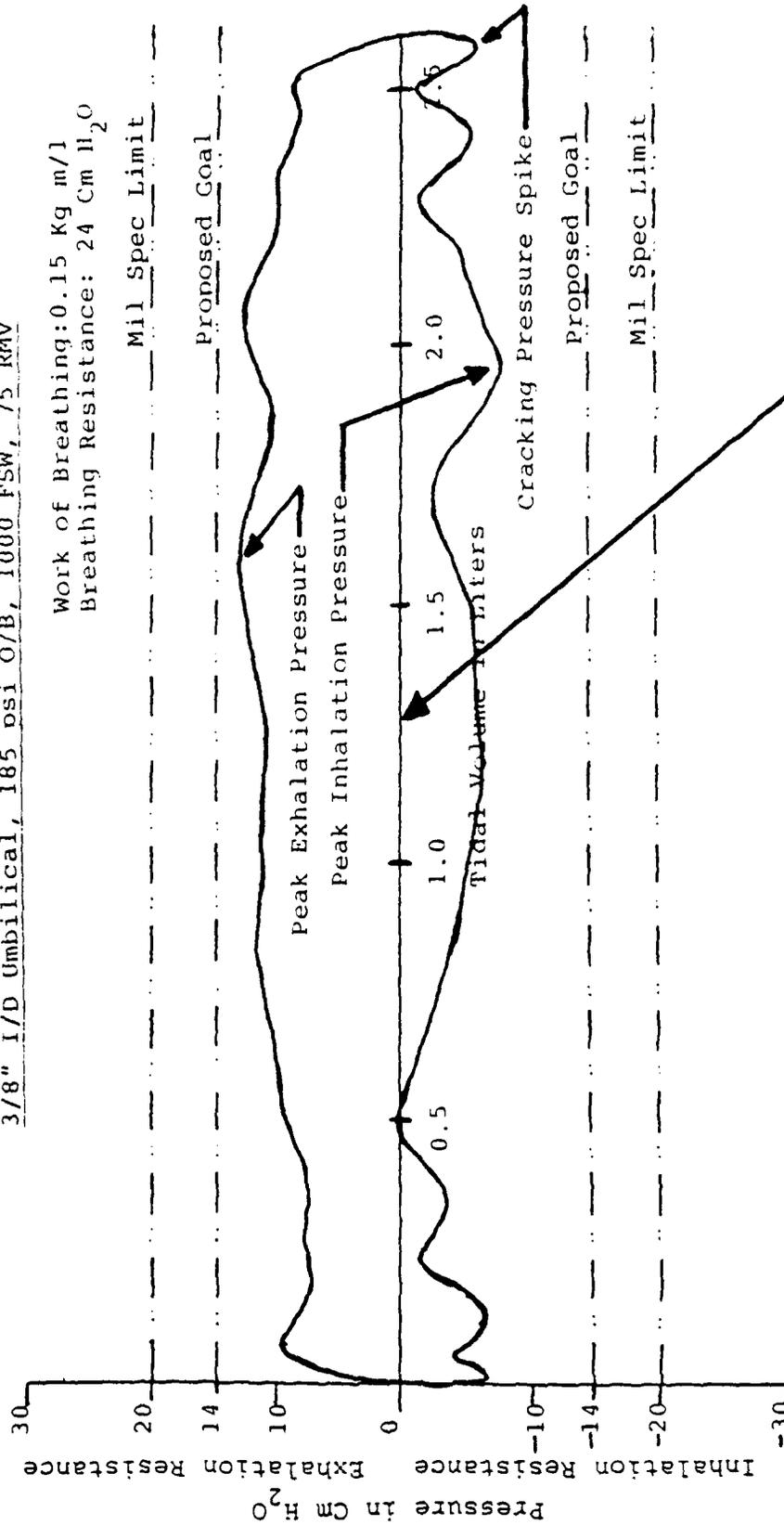
During this evaluation we shall consider the milspec as the upper acceptable limit for breathing resistance but propose that the category 3, 4 and 5 breathing resistance performance goal be adopted for these category 2 UBAs.

In summary, the following performance goals are proposed for open circuit umbilical supplied demand UBA (category 2) for use with HeO<sub>2</sub> mixtures to 1000 FSW. Meeting these performance goals would ensure that the effort of breathing a UBA would not be a limiting factor in diver performance.

GSOL ULTRAFLOW 500

3/8" I/D Umbilical, 185 psi O/B, 1000 FSW, 75 RMV

Work of Breathing: 0.15 Kg m/l  
Breathing Resistance: 24 Cm H<sub>2</sub>O



Area inside loop represents 'work of breathing'.  
NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

TYPICAL PRESSURE : TIDAL VOLUME LOOP

FIGURE 1

TABLE 2  
PROPOSED PERFORMANCE GOALS

					CATEGORY 2	
VO <sub>2</sub> LPM	RMV LPM	TV ℓ	FREQ	PEAK FLOW RATE LPS	ΔP** CmH <sub>2</sub> O	WORK/ kg-m/ℓ
0.90	22.5	1.5	15	1.18	1.5	+
1.60	40.0	2.0	20	2.09	4	+
2.50	62.5	2.5	25	3.27	10	0.18
3.00	75.0	2.5	30	3.93	14	0.18
3.60	90.0	3.0	30	4.71	20	+

+ To be decided.

B. USN MK 1 MOD 0 Bandmask. This UBA was only tested using the standard PTC configuration of 100 ft 3/8 inch ID divers umbilical. Given its poor performance little improvement could have been expected with an improved gas supply.

At 40 RMV (moderate work) the USN MK 1 MOD 0 functioned satisfactorily to 900 FSW. However at 62.5 RMV work of breathing exceeded the current NEDU performance goal deeper than 200 FSW. The UBA did continue to function to 600 FSW at this RMV but with increasing breathing resistance which exceeded 20 cmH<sub>2</sub>O at 600 FSW.

C. USN MK 1 MOD S Bandmask. The performance of the USN MK 1 MOD S bandmask was very much better than that of the MOD 0. This is attributed to its improved sideblock. (The demand regulators in both USN MK 1 bandmasks are identical.) This UBA was tested with a 100 ft. 3/8 in. ID divers umbilical at an overbottom supply pressure of 135 psig.

At 62.5 RMV (moderately heavy work) the MOD S met NEDU performance goals for work of breathing with acceptable breathing resistance to 700 FSW. Beyond 700 FSW inhalation resistance increased rapidly so that it exceeded the milspec limit of 20 cmH<sub>2</sub>O deeper than 800 FSW.

At 75 RMV (heavy work rate) the proposed performance goals were exceeded at 600 FSW inhalation resistance having begun to increase rapidly from 500 FSW.

At 90 RMV the UBA was unable to function satisfactorily beyond 200 FSW.

The USN MK 1 MOD S was not tested with 1/2 in. ID umbilicals since the design and performance of this UBA is so similar to the Superflow regulator which was tested with a 1/2 in. ID umbilical.

D. DSI Superflow Demand Regulator and Sideblock (Superlite 17B and Heliox 18B)

1. 3/8 in. ID Umbilical Tests. The DSI Superflow regulator and sideblock was tested on both the DSI Superlite 17B helmet and Heliox 18B bandmask with a supply pressure to the sideblock of 165 psig OB. the Superlite 17B results were considered unreliable due to a poor oral nasal seal on the manikin head. Excessive movement of the neck dam and low exhalation pressures indicated that exhaled gas was passing into the helmet dead space. Low inhalation  $\Delta$ P's indicated that the breathing machine was partly rebreathing from the dead space. In man this would have been equivalent to the diver wearing a poorly fitting helmet liner and would have resulted in high CO<sub>2</sub> levels in the inspired gas.

A good seal was achieved between the oral nasal and manikin for the Heliox 18B test. Since the two UBAs are functionally identical this data is considered satisfactory for the evaluation of the Superlite 17B.

The Superflow performance was similar to that measured during the evaluation of the USN MK 1 MOD S. Work of breathing at 62.5 RMV met the 1981 NEDU performance goals to 600 FSW. The Superflow continued to function at this RMV, but with increasing breathing resistance to 800 FSW where it exceeded the 20 cmH<sub>2</sub>O inhalation milspec.

The proposed 75 RMV performance goal was exceeded at 300 FSW but the Superflow continued to function deeper, with increasing breathing resistance, until it exceeded the milspec at 600 FSW. Ninety RMV was feasible to 200 FSW.

2. 1/2" ID Umbilical. Both the Superlite 17B and Heliox 18B were then evaluated with a 100 ft. 1/2 in. ID divers umbilical at the same 165 OB supply pressure. In view of the similar design and performance of the Superflow assembly to that of the USN MK 1 MOD S the results of this evaluation were considered to be applicable to both demand regulators and sideblocks.

Pressure drops to the sideblock were significantly reduced using the 1/2 in. ID vice 3/8 in. ID umbilicals at 62.5 RMV and higher. However, there was no significant improvement in the work of breathing or breathing resistance results. This indicates that UBA had indeed reached the limits of its performance during the 3/8 in. umbilical test, and that, independent of umbilical ID, its maximum operating depth could be considered to be about 800 FSW for moderately heavy work rates with some degradation in a divers ability to do work.

These results seem to confirm the results of two manned tests of the Superlite 17B at 850 and one manned evaluation of the USN MK 1 MOD S, even though they do not entirely support the conclusions of these tests [references (f) and (g)].

3. Comparison of Unmanned Results with Manned Tests. From the results of unmanned testing we are able to objectively determine the functional limits of UBA performance. By applying performance goals and with our knowledge of diver physiology we can predict with some confidence the impact that a UBA will have on diver performance at various RMVs and ultimately the UBA's maximum depth capability.

The results of manned breathing studies are less easy to interpret. During manned studies breathing resistance, at different work rates, is determined by measurement of differential helmet or mask oral nasal pressures during inhalation and exhalation. Because one diver may be able to complete a particular work rate with less effort than another, the measurement of differential pressure in this way may be as much a measurement of diver performance as UBA performance. Low  $\Delta P$ s may indicate a lower RMV for a particular work rate than expected. A low  $\Delta P$  may be equally compatible with a high RMV when the divers have learned from experience to adapt their breathing pattern to avoid the high inhalation peaks that determine breathing resistance. Then again, high breathing resistance ( $\Delta P$ s) could indicate poor UBA performance or that the diver-subjects are overbreathing the UBA. In other words UBA performance is difficult at best, to deduce from manned studies. In these studies work of breathing often becomes a subjective evaluation by diver-subjects. This is an unsatisfactory and unreliable method of determining a UBA's suitability for Navy use. The very different results obtained during the manned evaluation of the Superlite 17B during two 850 FSW deep dives highlight the difficulties in interpreting manned results, references (f) and (g), particularly when, as we now know from this unmanned study, that the UBA was at the limits of its performance at 850 FSW and 62.5 RMV, exceeding the 1981 performance goals.

During the first dives, reference (f), all divers successfully completed work cycles up to 150 watts (normally considered equivalent to 75 RMV). Breathing resistance was uniformly low and the UBA was considered capable of supporting heavy work.

During the second dive, only one of the five diver-subjects was able to complete the work. He completed the work with low breathing resistance. The remaining subjects experience high breathing resistance and quit 100 and 150 watt work cycles. In discussing the results of these tests it was concluded, reference (g), that the divers who were not able to complete the work were not as fit or as well prepared for the dives as the previous test subjects. The divers, not the UBA had reached the peak of their performance. A review of the other UBA tests conducted during the same two dives [references (l) and (m)] now reveals that these same divers, who failed to complete the Superlite 17B work cycles, performed as well in the other UBAs as had the diver-subjects in the first dive. This seems to contradict the conclusion of reference (g).

To provide further evidence that the divers had reached the limit of their performance, rather than the UBA, breathing resistance measurements taken during both deep dives were compared to unmanned test results obtained using air, reference (f). Then by using HeO<sub>2</sub> gas density equivalent depths, the data taken during air testing of the UBA was extrapolated to predict performance at depth using HeO<sub>2</sub> mixtures. From this it was concluded that the Superlite 17B could meet the 1981 performance goals at 850 FSW.

In order to determine if this was a valid method for comparison the following tables are plotted using data taken from the unmanned air testing of the Superlite 17B and the AGA Divator MK II and data obtained during this unmanned evaluation using HeO<sub>2</sub> mixtures.

DSI Superlite 17B at 62.5 RMV

Air Depth	HeO <sub>2</sub> "Equivalent Density Depth" (Reference (f))		NEDU Report 9-79 Results Using Air			HeO <sub>2</sub> Results at "Equivalent Density Depth"		
			Work of Breathing	Inh AP	Exh AP	Work of Breathing	Inh AP	Exh AP
58	(1:6)	300	0.10	-4	10	0.21	-17	12
68	(1:7.3)	500	0.11	-4	11	0.21	-19	13
109	(1:7.3)	800	0.14	-7	10	0.24	-23	12
136	(1:7.3)	1000	0.17	-11	11	0.28	-34	9
FSW		FSW	Kg-m/l	cmH <sub>2</sub> O		Kg-m/l	cmH <sub>2</sub> O	

AGA Divator MK II at 62.5 RMV

Air Depth	HeO <sub>2</sub> "Equivalent Density Depth" (Reference (f))		NEDU Report 7-86 Results Using Air			HeO <sub>2</sub> Results at "Equivalent Density Depth"		
			Work of Breathing	Inh AP	Exh AP	Work of Breathing	Inh AP	Exh AP
58		300	0.06	-5	4	0.09	-5	7
68		500	0.07	-4	6	0.09	-5	6
109		800	0.09	-4	8	Exceeded		
136		1000	0.10	-5	9	Measurable Limits		
FSW		FSW	Kg-m/l	cmH <sub>2</sub> O		Kg-m/l	cmH <sub>2</sub> O	

While the results of unmanned testing using air can be useful in determining the relative performance of different UBAs it is clear from the results shown in the above tables that great caution should be used in predicting actual UBA performance using HeO<sub>2</sub> mixtures from data obtained during air testing. With all the difficulties in interpreting manned breathing resistance data, the impression that clearly emerges is that UBA breathing performance is best measured unmanned. Unmanned data should be collected using the appropriate breathing gas for each test depth and the UBA test configuration should be as close as possible to the intended operational configuration.

Manned testing is of course necessary but primarily for human factors, physiological and total system evaluations.

E. GSOL Ultraflow 350

1. 3/8 in. ID Umbilical. With a supply pressure of 185 psi OB the Ultraflow 350 was able to meet the 1981 NEDU performance goals at 62.5 RMV to 1000 FSW. Breathing resistance was within the proposed performance goals.

At 75 RMV the Ultraflow 350 was able to meet the proposed performance goals to 700 FSW. Deeper than 700 FSW inhalation resistance increased very rapidly at 75 RMV and exceeded the milspec 20 cmH<sub>2</sub>O limit at 800 FSW.

At 90 RMV the UBA performed well to 500 FSW and then continued to function with rapidly increasing inhalation resistance to 600 FSW.

2. 1/2 in. ID Umbilical. The testing was repeated using 1/2 in. ID umbilicals with a significant reduction in umbilical pressure drop to the sideblock. This resulted in some improvement in regulator performance at 75 and 90 RMV permitting the UBA to function 100 feet deeper within the proposed performance goals.

3. General Observations of the Ultraflow 350. From the above results it is clear that the GSOL Ultraflow 350 is significantly superior in work of breathing and breathing resistance performance to the USN MK 1 MOD S and DSI Superflow UBAs. Improved performance has been achieved by enlarging supply porting, and smoothing the gas flow in a modified Superflow regulator and sideblock. However, many of the Superflow and MK 1 regulator parts will fit into the Ultraflow 350 regulator, and use of some of these parts would degrade the Ultraflow 350's performance. There may therefore be a disadvantage in bringing into service another regulator that is so similar in design to existing USN equipment.

F. AGA Divator II Full Face Mask. The AGA Divator MK II full face mask was tested using a 100 ft. 3/8 in. ID divers umbilical. The Divator II has a balanced demand regulator and so is tolerant of large changes in umbilical supply pressure. At 40 RMV (moderate work) breathing was smooth to 1000 FSW and both breathing resistance and work of breathing were within all performance goals.

At 62.5 RMV breathing resistance and work of breathing were very low to 600 FSW. From 600 to 700 FSW inhalation effort increased sharply. At 700 FSW work of breathing was still well within NEDUs 1981 performance goals but inhalation resistance had increase beyond the proposed performance goal of 14 cmH<sub>2</sub>O. Exhalation remained good. Deeper than 700 FSW the regulator failed to supply sufficient gas to support work. From an inspection of umbilical pressure drop data it is clear that the reason for this is the small size of the inlet orifice.

At 75 RMV inhalation effort rose sharply from 200 FSW so that both the proposed breathing resistance performance goal and the milspec were exceeded deeper than 300 FSW. Work of breathing remained within the proposed goals to 500 FSW at 75 RMV, thereafter the regulator failed. Extreme work (90 RMV) was possible to 200 FSW.

G. GSOL Ultraflow 500 Demand Regulator and Sideblock. GSOL recommend a supply pressure of 145 psi overbottom to the Ultraflow 500 for depths up to 600 FSW. For deeper diving they recommend increasing the supply pressure to 246-290 psi overbottom. These high supply pressures, while being perhaps desirable for ultimate rig performance to the claimed maximum depth of the UBA (1640 FSW) are not at present suitable for USN PTC diving. They do not match the USN bail-out first stage supply pressure of 180 psi overbottom or the pressure rating of the USN approved Kinergetics Contraflow gas heater. Accordingly, testing of the Ultraflow 500 was conducted at both 145 psi overbottom and 185 psi overbottom with the following results.

1. 3/8 in. ID Umbilical. Using a 3/8 in. ID 100 ft. divers umbilical with a supply pressure of 145 psi overbottom the GSOL Ultraflow 500 showed smooth inhalation and exhalation gas flow at all depths and RMVs to 700 FSW (100 ft. deeper than recommended). At this supply pressure the UBA had extremely low breathing resistance and was well within NEDU's performance goals at 62.5 RMV to 1000 FSW.

At 75 RMV, work of breathing and breathing resistance were well within the proposed performance goals to 900 FSW. At 1000 FSW inhalation effort had increased significantly but was within milspec limits while work of breathing remained within the proposed limit.

At extreme work rates (90 RMV) the UBA functioned well to 700 FSW, thereafter inhalation increased rapidly so that it was beyond the milspec limits for breathing resistance by 800 FSW.

The evaluation was then repeated using the same 3/8 in. ID umbilical but with an increased supply pressure of 185 psi overbottom. The second stage regulator was readjusted to this new supply pressure before testing.

At depths up to 300 FSW inhalation was ragged with the 185 psi supply pressure compared to the very smooth breathing loops taken at 145 psi overbottom. At 600 FSW and deeper both inhalation and exhalation were smooth at all RMVs.

At all RMVs up to 75 RMV, both work of breathing and breathing resistance were well within NEDU performance goals and proposed goals to 1000 FSW. At 90 RMV this UBA functioned well to 800 FSW. Thereafter, inhalation effort increased rapidly so that work of breathing exceeded the performance goals and breathing resistance exceeded the milspec limit.

2. 1/2 in. ID Umbilical. Knowing that at 145 psig overbottom the Ultraflow 500 could smoothly and easily meet all performance goals at all RMVs to 700 FSW (and deeper), testing with a 100 ft. 1/2 in. ID umbilical was only conducted at 185 psig overbottom, primarily to evaluate the effect of reduced pressure drops at high RMVs and deeper depths.

Inhalation at 185 psig was again ragged at all RMVs to 300 FSW confirming that 145 psi is the preferred supply pressure at shallower depths. However, once again the breathing loops were smooth at all RMVs from 600 to 1000 FSW.

Use of the 1/2 in. ID umbilical resulted in a considerable reduction in umbilical pressure drops, particularly at RMVs of 62.5 and above. This had little impact upon work of breathing or breathing resistance at 62.5 RMV but both were reduced at 75 RMV at 1000 FSW. The greatest improvement observed as a result of reduced umbilical pressure drop was at 90 RMV (extreme work). Work of breathing and breathing resistance, at this work rate was significantly improved between 700 to 1000 FSW.

Using a 1/2 in. ID umbilical the Ultraflow 500 was easily capable of meeting NEDU performance goals for work of breathing and breathing resistance to 1000 FSW at all RMVs including 90 RMV.

3. Use of Volume Tanks. The use of a 50 cu. ft. volume tank teed into the test facility between the divers supply regulator console and the divers umbilical (in the PTC) had no discernible impact upon rig performance or umbilical pressure drop when using a 100 ft. 3/8 in. ID umbilical.

With the combination of volume tank and 1/2 in. ID umbilical there was some slight reduction in umbilical pressure drop at 90 RMV but this did not significantly improve work of breathing or breathing resistance. That the volume tank had little impact on UBA performance may well be attributed to the high flow characteristics of the Tescom Series 44-1100 over bottom supply regulator.

H. Factors that Effect Regulator Performance. The following observations were made during the testing which may impact upon UBA performance but which were not specifically investigated as a part of the test plan in Annex B.

1. Rig Set Up. Even though the manufacturers recommendations were followed during the preparation of the UBAs for testing a number of test runs were aborted because the results showed that the UBA was not performing to its expected capability. This was usually apparent from unexpectedly high breathing resistance or work of breathing when compared to a rigs of similar design or type. It was noted that a small difference in the adjustment of the

inhalation valve or dial a breath setting could have a large impact on work of breathing results, invariably to the detriment of rig performance. This was particularly apparent with the USN MK 1 MOD 0, MOD S, Superflow (Superlite 17B and Heliox 18B) and Ultraflow 350 regulators.

2. Effects of Change in Supply Overbottom Pressure. During compression of the test chamber actual supply pressure had to be increased with increasing depth, so that at each new test depth the correct overbottom pressure was supplied to the UBA. During this operation it was noted that the USN MK 1 MOD 0, MOD S, Superflow and Ultraflow 350 regulators would free flow at a supply pressure of approximately 10 psi higher than the required overbottom pressure for the depth. The "balanced" second stage Ultraflow 500 and AGA Divator MK II regulators would not free flow until the supply pressure was more than about 35 psi higher than required for the depth.

3. Effect of a Free Flowing Regulator on Work of Breathing. A number of USN divers have reported that they prefer to dive "bandmask" (USN MK 1 MOD 0 or S) with a slight free flow believing that it makes the UBA easier to breathe. On a number of occasions, when either a dial-a-breath or a supply pressure was incorrectly set prior to a test run causing the regulator to free flow slightly, it was noted that work of breathing and breathing resistance were degraded. Inhalation resistance was slightly improved but exhalation was usually considerably worse.

4. Effect of Dial-a-Breath Adjustments on Work of Breathing. On several occasions, early in the testing program, overbottom pressures were increased beyond that for which the UBA had been set up in order to investigate the effect of a different overbottom supply pressure. To compensate for this increased pressure the dial-a-breath was adjusted by a remote actuator to the point where free flow stopped. Breathing loops were then taken and both work of breathing and breathing resistance were recorded. Both were always significantly worse than before, particularly if the overbottom pressure had been increased by about 30 psi. It did not take long to realize that this was not the correct way to measure UBA performance at different supply pressures. The inlet valve setting should have been readjusted before the next test to match the new supply pressure. This ensures that the inlet valve lever is in the optimum position when the supply pressure and spring pressures are balanced. Degraded performance may also have been caused by bottoming out one or other of the springs. The information was useful however because in practice divers routinely adjust the dial-a-breath to compensate for changes in depth and overbottom supply pressure. In doing so they inevitably, but necessarily, degrade the performance of their UBA. This is particularly true of the USN MK 1 MOD 0, MOD S, Superflow and Ultraflow 350 regulators that are sensitive to changes in supply pressure.

5. Overtightening of the Dial-a-Breath. Overtightening of a dial-a-breath inevitably led to increased inhalation breathing resistance which of course increased work of breathing. This occurred with both 'balanced' and standard dial-a-breath regulators.

6. Ideal Dial-a-Breath Setting. Assuming that the intake valve has been properly set to the supply OB pressure prior to diving, the ideal dial-a-breath position is the point where free flow is just stopped. This should be set without the breathing machine (or diver) breathing from the UBA. Care should be taken not to overtighten the dial-a-breath which increases inhalation effort, or dive the UBA with a free flowing regulator which increases exhalation effort. Ideally, the overbottom supply pressure for which the demand regulator was adjusted prior to the dive should be maintained to the sideblock during diver excursions from the PTC depth. This would ensure that the dial-a-breath would need no further adjustment during the dive and could be best achieved by use of tracking regulators in the PTC that followed the diver's depth from his pneumofathometer.

Where this is not possible due to the configuration in the PTC, changes in supply pressure due to divers changes of depth have to be compensated for by readjusting the dial-a-breath. As described above, this will impact on the UBAs performance and may become a significant factor in diver performance, particularly if the UBA is near the limit of its useful performance at the PTC depth.

## VI. CONCLUSIONS AND RECOMMENDATIONS

This evaluation has clearly demonstrated the importance of unmanned testing in the evaluation of UBAs. By the objective measurement of work of breathing, breathing resistance, and umbilical pressure drop it has been possible to directly compare the performance different UBAs, discredit a number of myths, determine optimum umbilical size, and demonstrate which UBAs could best meet the Navy's requirements.

In addition by using this data it has been possible to reevaluate the previous results of manned testing of certain UBAs [references (e) and (g)] and arrive at different conclusions about those UBAs' capabilities and likely limitations.

It is recommended, that during future UBA evaluations, unmanned testing precede any manned testing.

It is also recommended that reference (a) should be updated to reflect the current state-of-the-art technology and that performance goals need to be established for umbilical supplied open circuit demand UBA at 75 RMV (vice 62.5 RMV).

The following conclusions are made concerning the performance of each UBA tested:

A. USN MK 1 MOD 0 Bandmask. The USN MK 1 MOD 0 is unsuitable for deep diving or saturation diving operations using HeO<sub>2</sub> mixtures. Its sideblock is not capable of supporting the gas flow required at depth or RMVs over 62.5. The review of references (b), (c) and (d) indicate that even for air diving the USN MK 1 MOD 0 could not meet NEDU'S 1981 performance goals deeper than 100 FSW. Today this UBA would not be recommended for diving operations deeper than 100 FSW.

B. USN MK 1 MOD S Bandmask. The use of USN MK 1 MOD S bandmask for saturation diving will continue to be a limiting factor in diver performance at depth. Based upon unmanned testing this UBA reaches the limit of its useful performance at about 800 FSW under ideal conditions. Its performance may be unsatisfactory at this depth if proper adjustment of the inlet valve is not carried out before diving. Furthermore, since this UBA is greatly affected by changes in supply pressure, and by misadjustment of the dial-a-breath by divers, it is possible that its useful working depth would be less than 800 FSW. Increasing umbilical size is unlikely to significantly improve the performance of the USN MK 1 MOD S. Furthermore, in considering the wider use of the USN MK 1 MOD S, this UBA failed to meet the proposed performance goals for work of breathing and breathing resistance at 300 FSW. It will probably function satisfactorily at this depth with some limitations on the diver's ability to do hard work, but would not be the preferred UBA for surface supplied mixed gas bounce diving.

C. AGA Divator II. The AGA Divator MK II is unsuitable for standby diver use deeper than 700 FSW due to the high work rates that a standby diver may have to achieve. The positive pressure feature of the full face mask may make this UBA an attractive choice for habitat diving, such as for hyperbaric welding, provided only moderate work rates are expected.

D. DSI Superflow Demand Regulator and Sideblock Assembly (Superlite 17B and Heliox 18B). The performance of the DSI Superflow regulator and sideblock assembly is very similar to that of the USN MK 1 MOD S. This equipment reaches the limit of its performance at about 800 FSW at moderately heavy work rates. In common with other nonbalanced regulators, the Superflow performance may be worse in practice than was measured during the ideal conditions used for unmanned testing. Continued Approval for Navy Use of this UBA to 1000 FSW may well impact on diver performance at depth. Increasing the umbilical size had no significant impact on UBA performance.

E. The GSOL Ultraflow 350 Demand Regulator and Sideblock Assembly. Although superior in performance to the other non balanced regulators tested, the GSOL Ultraflow 350 modification to the DSI Superlite 17B helmet or Heliox 18B bandmask has distinct disadvantages. It has many parts that look similar to those supplied with U.S. Divers, DSI, or Morse diving equipment, and which would fit into, but degrade, the performance of the regulator.

F. GSOL Ultraflow 500 Demand REgulator and Sideblock Assembly. Of all the UBAs tested during this evaluation the Superlite 17B and Heliox 18B modified with a GSOL Ultraflow 500 regulator and sideblock assembly was by far the most impressive. The Ultraflow 500 was the only demand regulator and sideblock capable of meeting both the 1981 NEDU performance goals (a) and the proposed performance goals to 1000 FSW. Both work of breathing and breathing resistance are so low that use of the Ultraflow 500 would not be a limiting factor in diver performance. This UBA could be satisfactorily used with existing 3/8 in ID umbilicals to 1000 FSW although even better performance would be possible with 1/2 in ID umbilicals deeper than 800 FSW.

The DSI Heliox 18B bandmask, modified with GSOL Ultraflow 500 regulator and sideblock assembly is the preferred UBA for standby diver use, being easier and quicker to don and doff than a helmet.

For the working diver the Superlite 17B modified with an Ultraflow 500 regulator and sideblock assembly is the preferred UBA when head protection is a primary consideration. This would include cutting and welding operations and operations where there may be a danger of head injury. When mobility, swimming or simple survey work is called for, the preferred UBA for the working dive could be the Heliox 18B bandmask with the Ultraflow 500 modification. Thermal protection in the bandmask is provided with hot water in the same way as is currently provided for the USN MK 1 MOD S bandmask. Thermal protection to the helmet is afforded by its dry hat configuration. Both are considered satisfactory.

Given that the performance of the Ultraflow 500 is so superior to all the other UBAs tested it is worth considering the use of Ultraflow 500 modifications to the DSI Heliox 18B bandmask or Superlite 17B helmet for surface supplied diver using air or HeO<sub>2</sub> .

In addition the regulator may be worthy of consideration for SCUBA use if it were suitably modified to accept a high flow first stage regulator, possibly with the dial-a-breath removed. It is understood that GSOL are considering this possibility with the obvious advantage of having many common parts for SCUBA, saturation or bounce diving.

#### VII. REFERENCES

- a. NEDU Report 3-81, 'Standardized NEDU Unmanned UBA Test Procedures and Performance Goals', James R. Middleton, Edward D. Thalmann, CDR, MC, USN. June 1981.
- b. NEDU Report 7-78, 'Comparison Tests of USN MK 1 MOD 0 Mask in Standard Configuration and USN MK 1 MOD 0 with SCUBA Pro Pilot Second Stage at Varying Supply Pressures', James R. Middleton. March 1978.
- c. NEDU Report 8-78 Part I, 'Unmanned Evaluation of USN MK 1 MOD 0 Mask in Umbilical and Emergency Modes', James R. Middleton. May 1978.
- d. NEDU Technical Memorandum TM85-08, 'Conshelf XIV First Stage for Emergency Gas Supply with MK 1 MOD 0 or MOD S, J. Schmitt. June 1985.
- e. NEDU Report 4-83, 'Manned Testing of Superlite 17B Diving Helmet Compared with MK 1 MOD S Divers Mask', H.J.C. Schwartz, CDR, MC, USNR. June 1983.
- f. NEDU Report 9-79, 'Evaluation of Diving Systems International Superlite 17B Helmet', James R. Middleton. November 1979.
- g. NEDU Report 1-86, 'Manned Testing of the Superlite 17B with the Oronasal One Way Valve Removed', Henry J.C. Schwartz, CDR, MC, USN.

- h. ARE TM (ASD) 86705, S.J. Lavin, I.A. Himmens. April 1986.
- i. NEDU Report 7-86, 'Evaluation of AGA Divator II Lightweight Enclosed Space Diving System', Christopher J. Tarmey, LCDR, MCD, RN. June 1986.
- j. MK 1 MOD 0 Lightweight Diving Outfit Operation and Maintenance Instructions, NAVSEA SSS20-AE-MMA-010/DIV OFT.
- k. Department of the Navy Military Specification MIL-R-24169A.
- l. NEDU Report 5-83 (official use only).
- m. NEDU Technical Memorandum TM5-84 (official use only).

ANNEX A

MANUFACTURERS AND SUPPLIERS

1. USN MK 1 MOD 0 and MOD S Bandmasks

Manufacturer Morse Diving and Equipment Company  
954 Hingham Street  
Rockland, Massachusetts 02370  
Telephone 617-871-1700

Supplier Standard Stock Items or  
M and E Marine Supply Co., Inc.  
Box 601  
Camden, New York 08101  
Telephone 609-692--8719

2. AGA Spiro Divator II Full Face Mask and Umbilical Supply Assembly

Manufacturer AGA Spiro AB  
S-181 81 Lindingo  
Sweden  
Telephone 468-767-9480

Supplier Interspiro  
11 Business Park Drive  
Branford, Connecticut 06405  
Telephone 203-481-3899

3. Superlite 17B (with Superflow Demand Regulator) and Heliox 18B (with Superflow Demand Regulator)

Manufacturer Diving Systems International  
425 Garden Street  
Santa Barbara, California 93101  
Telephone 805-965-8538

Supplier Manufacturer or  
M and E Marine Supply Co., Inc.  
Box 601  
Camden, New York 08101  
Telephone 609-692-8719

4. Ultraflow 350 and Ultraflow 500 Demand Regulator Conversion Kit for Superlite 17B or Heliox 18B

Manufacturer	Diving Systems International, Inc. (under license) or  Gas Services Offshore Ltd. Westhill Industrial Estate Westhill, Aberdeen Scotland AB3 6TQ Telephone (0224)-740-145 (from USA 011-44-224-740-145)
Suppliers (See Note)	Diving Systems International, Inc. or  Gas Services Offshore Ltd. 3816 140th Avenue NE Bellvue, Washington 98005 Telephone 206-881-9282
UBA Technical Support	Gas Services Offshore Ltd. P. O. Box 456 West Fork, Arkansas 72774 Telephone 501-839-2888  or  Gas Services Offshore Ltd. Westhill Industrial Estate Westhill, Aberdeen Scotland AB3 6TQ Telephone (0224)-740-145 (from USA 011-44-224-740-145)

NOTE: Diving Systems International are able to supply Superlite 17B helmets or Heliox 18B bandmasks with either an Ultraflow 350 or Ultraflow 500 fitted, under license from GSOL. Conversion kits are also available.

ANNEX B

UNMANNED TEST PLAN

1. Test Parameters

a. Equipment to be used:

- (1) "C" Breathing machine.
- (2) EDF "C" chamber ark.
- (3) EDF "C" chamber complex.
- (4) Validyne pressure transducer w/1.00 psid diaphragm for inhalation/exhalation  $\Delta P$  (1 ea).
- (5) Validyne pressure transducer w/50 psi diaphragm for umbilical pressure drop.
- (6) X-Y plotter.
- (7) Gould strip chart recorder 5 channel:
  - (a) Channel 1 umbilical pressure drop.
  - (b) Sideblock assembly  $\Delta P$  drop.
  - (c) Oral  $\Delta P$ .
- (8) EDF bottlefield gas supply - appropriate HeO<sub>2</sub> mix (defined below).
- (9) EDF console gas supply regulator.
- (10) EDF console "C" depth gauge.
- (11) Test helmets: MK 1 MOD 0, MK 1 MOD S bandmasks, Superlite 17B, AGA Divator II, Heliox 18B with Ultraflow 350 and Ultraflow 500 demand regulator conversion.
- (12) Breathing machine piston position transducer.
- (13) Bubble dampening mat.
- (14) EDF HP 1000 breathing resistance computer program.
- (15) Remote control actuator for adjustment of dial-a-breath at depth.

b. Logistic support:

- (1) Helmet and masks to be tested.
- (2) 100-ft. 3/8 in ID umbilical and fittings.
- (3) MK 1 bandmask adapter whip.
- (4) 100-ft. 1/2 in. ID umbilical and fittings.
- (5) Air supply for chamber pressurization: 13,000 scf per 1000 FSW

run.

(6) HeO<sub>2</sub> supply:

84/16	0 - 300 FSW
95/5	301 - 400 FSW
97/3	401 - 1000 FSW

c. Parameters to be controlled:

(1) Breathing rate / tidal volume / RMV

- (a) 15 BPM / 1.5 liters / 22.50 RMV
- (b) 20 BPM / 2.0 liters / 40.0 RMV
- (c) 25 BPM / 2.5 liters / 62.5 RMV
- (d) 30 BPM / 2.5 liters / 75.0 RMV
- (e) 30 BPM / 3.0 liters / 90.0 RMV

(2) Exhalation/Inhalation time ratio: 1.00/1.00.

(3) Breathing waveform: sinusoid.

(4) Divers gas supply pressure: 135 psig overbottom pressure at all depths for AGA, MK 1 MOD 0, MOD S. 165 psig OB pressure for Superlite 17B, Heliox 18B (145 and 185 OB pressure for Ultraflow 350 and 500).

(5) Incremental descent stops: 0, then 200, to 1000 FSW in 100 FSW increments.

(6) Ark water temperature: ambient.

d. Parameters to be measured:

- (1) Inhalation peak  $\Delta P$  in  $\text{CmH}_2\text{O}$ .
- (2) Exhalation peak  $\Delta P$  in  $\text{CmH}_2\text{O}$ .

- (3)  $\Delta P$  vs. volume plots breathing work in  $\text{Kg}\cdot\text{m}/\text{l}$ .
- (4) Umbilical pressure drop in psig.
- e. Parameters to be computed: respiratory work from pressure vs. volume plots.
- f. Data to be printed:
  - (1) Inhalation max pressure at each depth and RMV.
  - (2) Exhalation max pressure at each depth and RMV.
  - (3) Respiratory work at each depth and RMV.
  - (4) Umbilical pressure drop at each depth and RMV.

## 2. Test Procedure

- a. (1) Ensure that bandmask/helmet is set to specification and is working properly for the OB supply pressure required.
  - (2) Chamber on surface.
  - (3) Calibrate transducers.
  - (4) Open divers  $\text{HeO}_2$  gas supply valve (84/16) to regulator and set supply overbottom pressure as required.
  - (5) Adjust dial-a-breath to a slightly positive free flow then back off until 1 psid pressure diaphragm (oral  $\Delta P$ ) indicates 0 psig.
  - (6) Adjust breathing machine to 1.5 liters tidal volume and 15 BPM and take data.
  - (7) Adjust breathing machine to 2.0 liters tidal volume and 20 BPM and take data.
  - (8) Adjust breathing machine to 2.5 liters tidal volume and 25 BPM and take data.
  - (9) Adjust breathing machine to 2.5 liters tidal volume and 30 BPM and take data.
  - (10) Adjust breathing machine to 3.0 liters tidal volume and 30 BPM and take data.
- b. Pressurize chamber to 200 FSW and repeat steps (a)(5) to (a)(10).
- c. Data is then to be taken at 100 FSW increments to 1000 FSW.

d. Divers gas is to be switched and the breathing loop to be purged before taking data at the following depths.

0 FSW Use            84/16 HeO<sub>2</sub>  
400 FSW switch to 95/5 HeO<sub>2</sub>  
500 FSW switch to 93/3 HeO<sub>2</sub>

e. On completion of testing with 3/8 in. ID umbilicals the results will be reviewed. Selected rigs will then be retested using 1/2 in. ID umbilicals to 1000 FSW.

f. The use of a volume tank in the PTC will be investigated by use of an adapted 50 cu ft SCUBA cylinder 'teed' into the facility between the divers supply regulator and divers umbilical; 3/8 in ID and 1/2 in ID umbilicals will be used.

ANNEX C

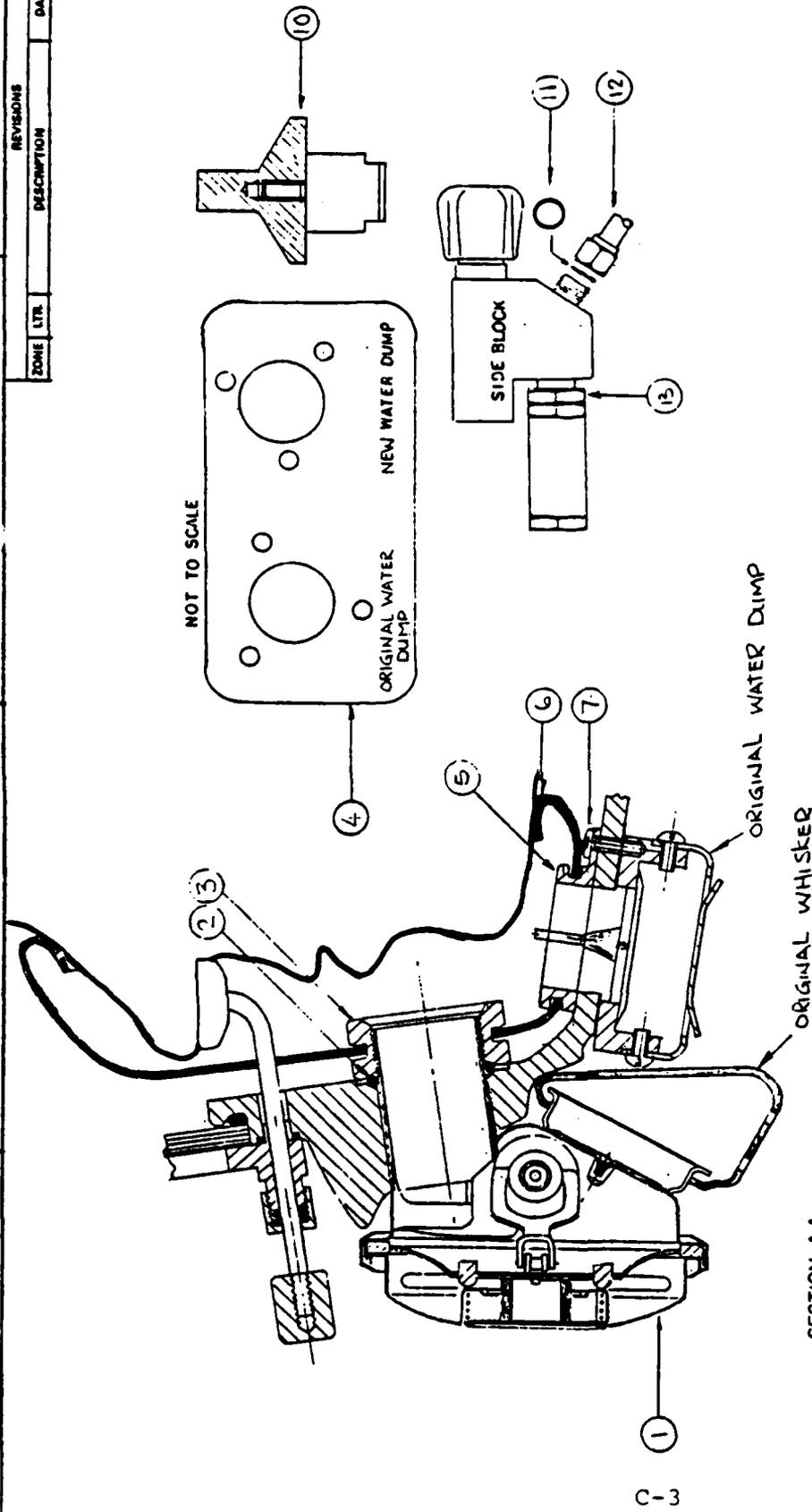
FITTING INSTRUCTION, GSOL HELMET OR BANDMASK CONVERSION INCORPORATING  
AN ULTRAFLOW 350 OR ULTRAFLOW 500 DEMAND REGULATOR

READ IN CONJUNCTION WITH DRAWING NOS 82015, 81856

1. Remove whisker assembly, standard kirby superflow regulator and exhaust unit from the helmet of bandmask. Retain all parts for re-instatement.
2. Enlarge regulator port in helmet to 1 inch diameter (25.4mm) to accept the Ultraflow regulator to be fitted. This is easily achieved by filing or reaming.
3. Offer the Ultraflow regulator Item 1 and bent tube assy Item 12 to the helmet front to ensure a snug fit. Adjust slightly as required.
4. Use the template, Item 4 to mark the position of the water dump valve on the bottom, left front of the helmet (bandmask), relative to the wearer.
5. Carefully make a 1 inch diameter (25.4mm) hole at the marked position and drill the three satellite holes 11.64 inch diameter (04.4mm).
6. Using a facing tool provided, Item 10, create a flat annulus onto which the dump valve will seat.
7. Apply silicone sealant to the mating surface and fit the dump valve Item 8 using screws Item 9. Allow to cure. Clean off excess sealant and check function by blowing.
8. Fit the regulator and bent tube assy to the helmet hand tight only. Apply further sealant round the regulator tube inside the helmet (bandmask) followed by the o-ring and regulator mount nut Items 2 and 3.
9. Using 8 UNC screws 3/4 inch LG, Item 7, passing through exhaust connector, Item 5, and silicone sealant, fasten the Kirby water dump to the helmet (bandmask). It is essential to achieve good sealing at this position to avoid ingress of water to the system but excessive sealant must also be avoided. Before final tightening check that regulator and Kirby water dump are mounted horizontally.
10. Install oral nasal, Item 6 onto regulator mount nut, square up, and press down head onto exhaust connector Item 5. This will mark the exhaust position at which a 3/8 inch diameter (10mm) hole must be punched.
11. Fit oral nasal Item 6 over exhaust connector Item 5.
12. Fit bent tube assy to regulator and side block using o-ring Item 11.
13. Reassemble whisker assy retaining screws.

14. Remove the inlet check valve, adaptor and o-ring from the side block. Replace the adaptor with GSOL part, Item 13 and re-fit.
15. Fully assemble the Ultraflow regulator, in accordance with the Ultraflow Demand Regulator Operating and Maintenance Instructions.
16. Replace original whisker kit.
17. The unit is now complete and ready for testing.

ZONE	LTR	DESCRIPTION	DATE	APPROV

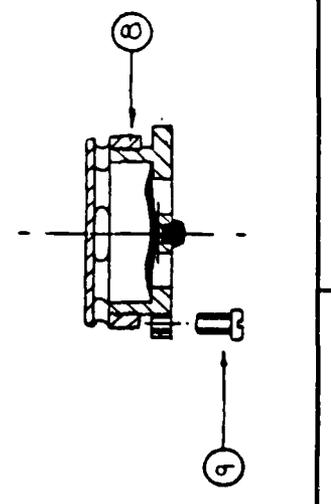


SECTION A-A

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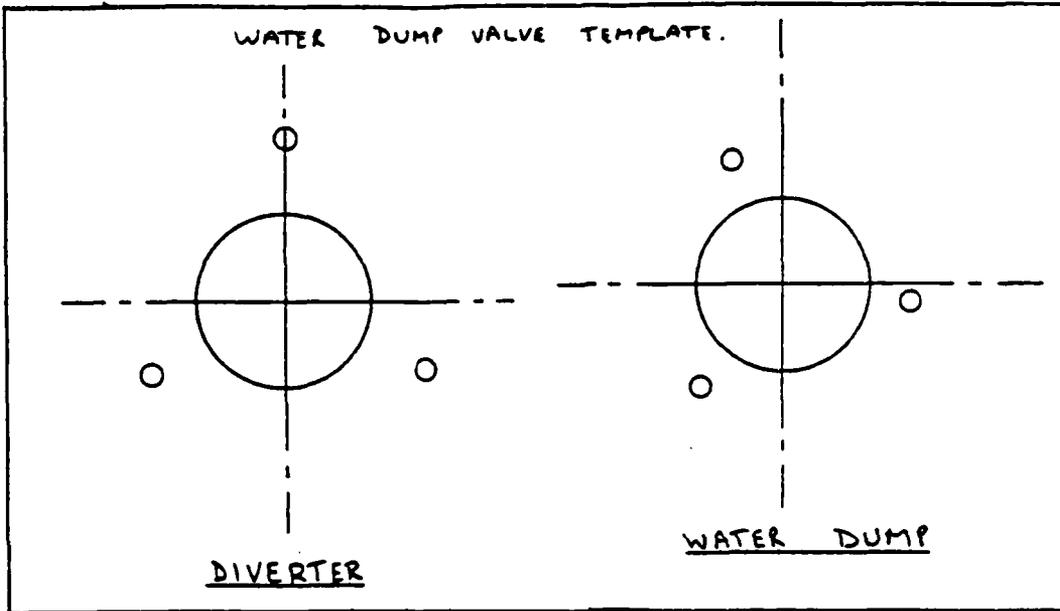
  

<b>GAS SERVICES</b> OFFSHORE LIMITED		2 Wharfedale Industrial Estate Wakefield, West Yorkshire WF1 3JH Telephone (01274) 740944 Telex 71336	
TITLE <b>ASSEMBLY - ULTRAFLOW REGULATOR</b>		DRAWING No. <b>82105</b> REVISION <b>1</b>	
MATERIAL UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS DECIMALS ANGLES 1/16 1/32 1/4 1/8 1/16 1/32 1/4 1/8 1/16 1/32		APPROVALS DRAWN: <i>H. S. [Signature]</i> DATE: 15 MAR 68 CHECKED: [Signature] APPROVED: [Signature]	
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DO NOT REDUCE WHEN PHOTOCOPYING



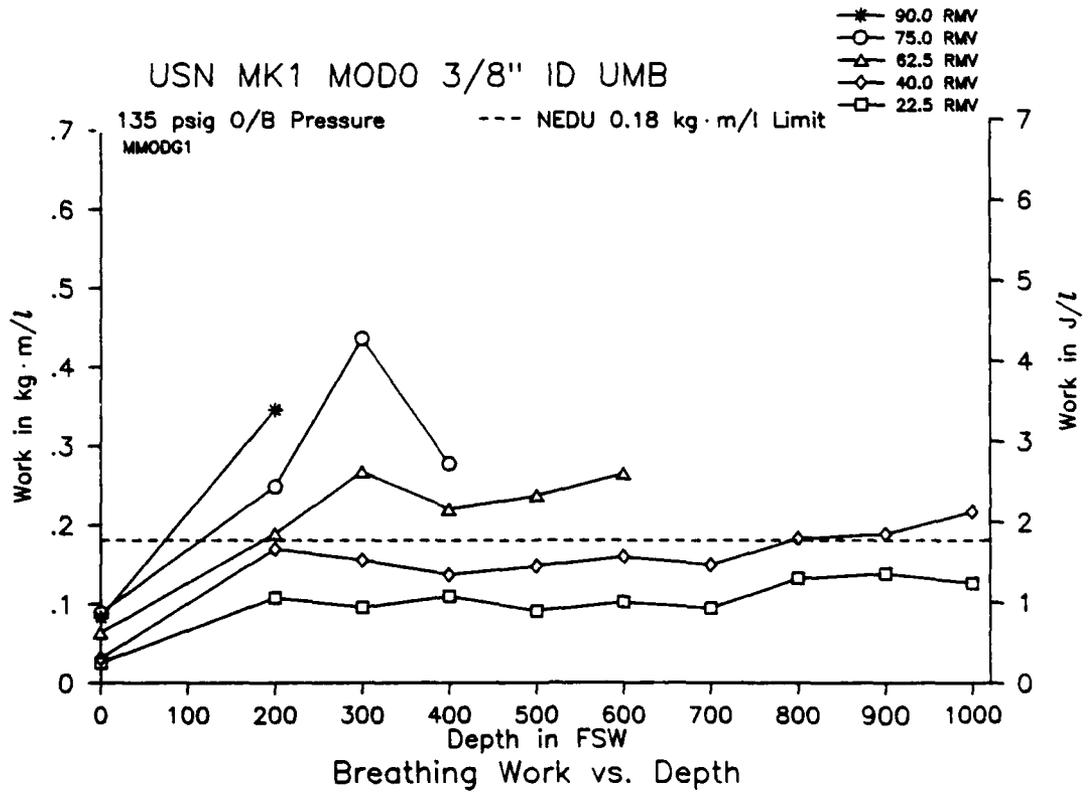
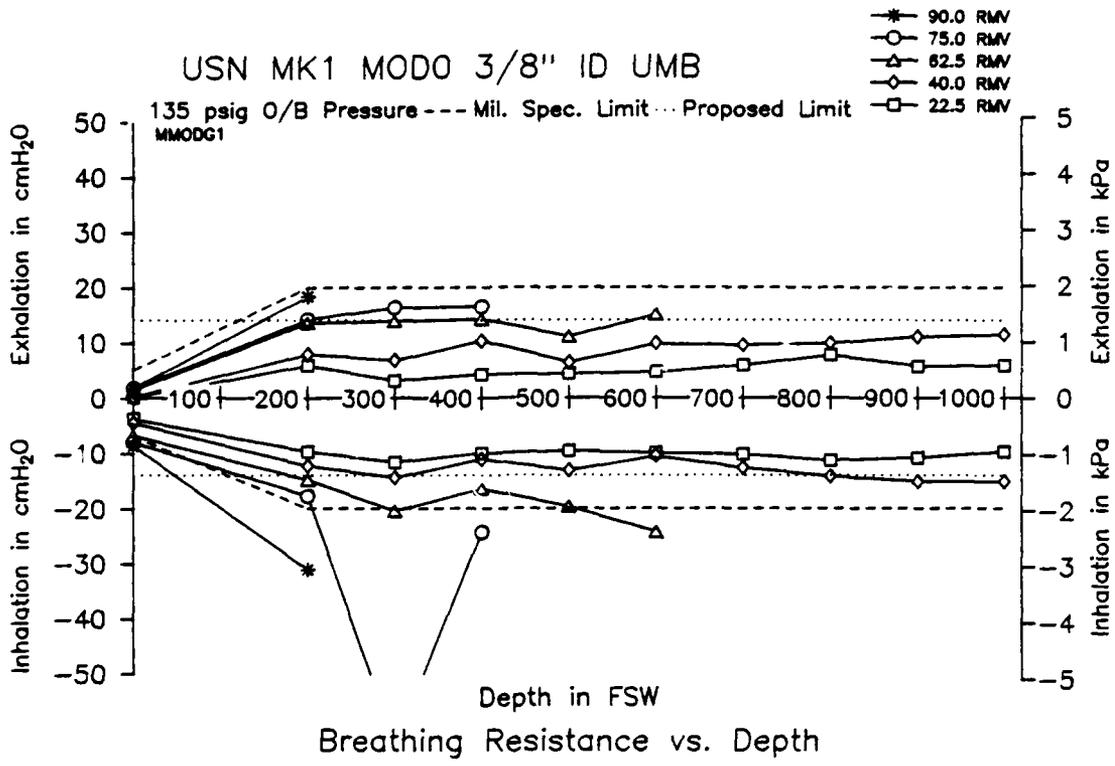
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		FINISH _____		
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		CHECKED J. RENOME	DATE 14 SEP 84	
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2

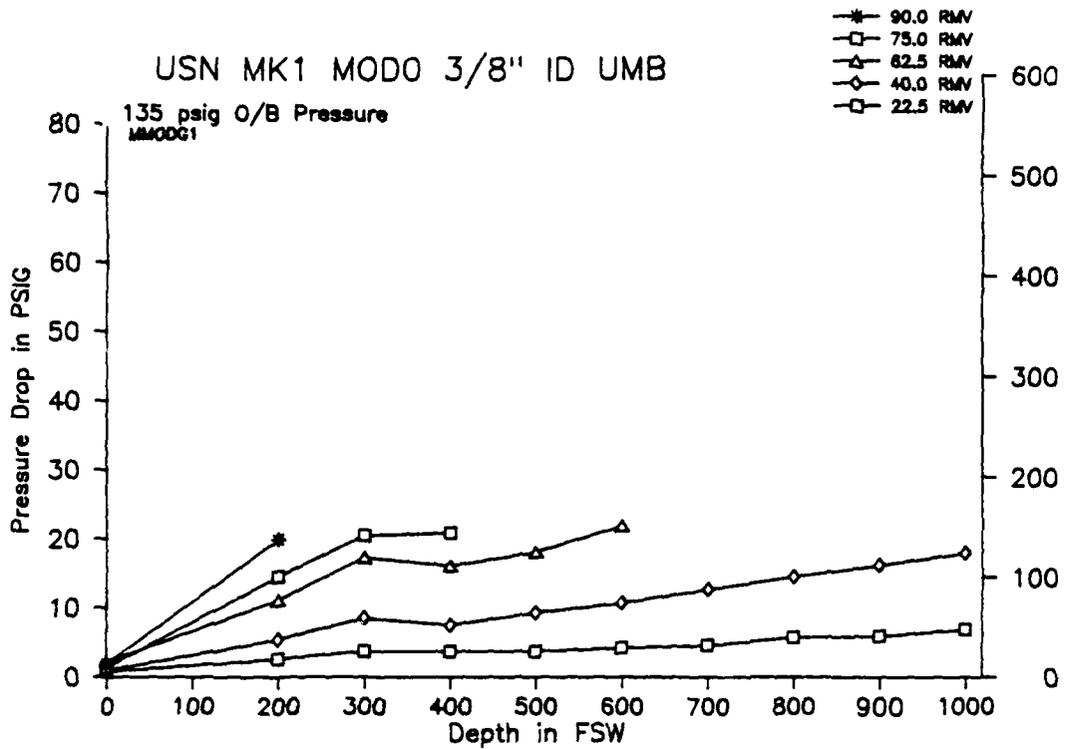
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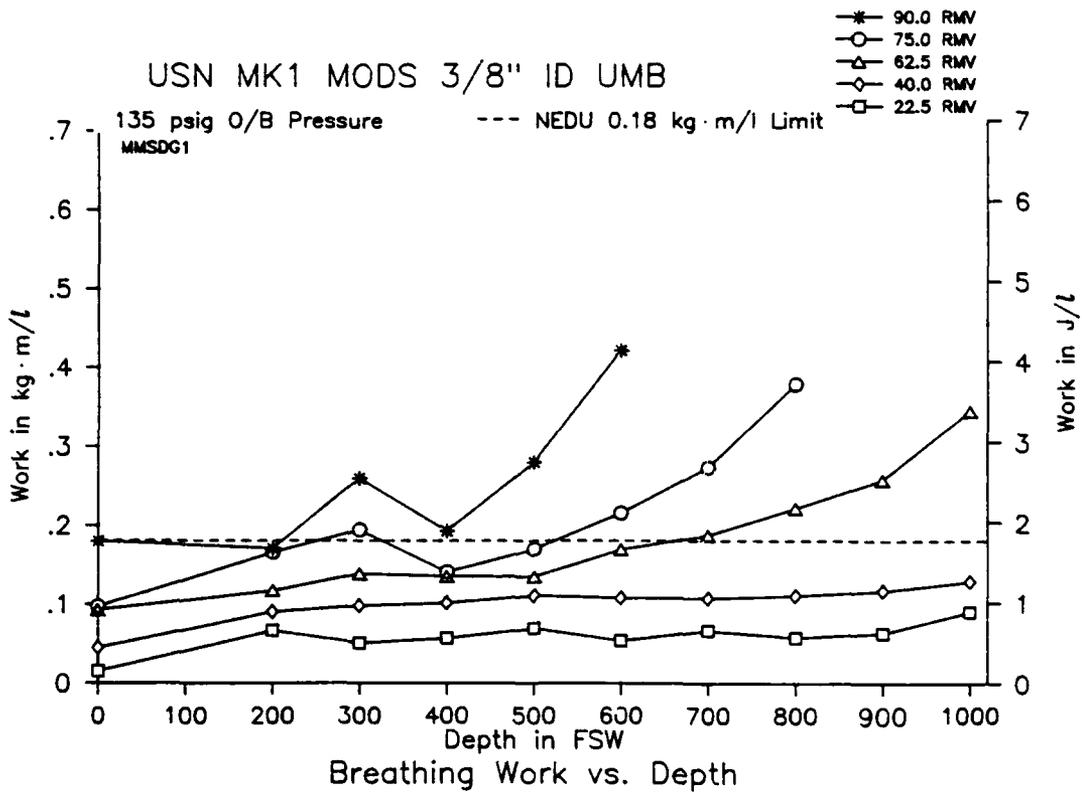
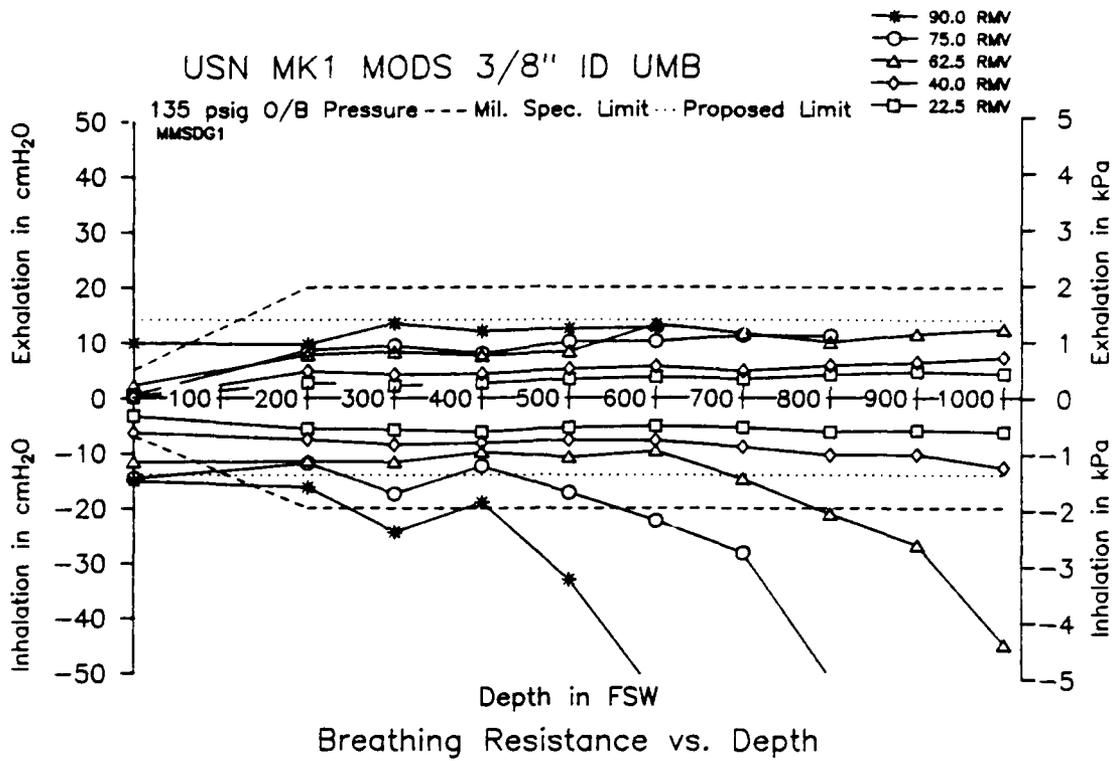
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TEST RESULTS

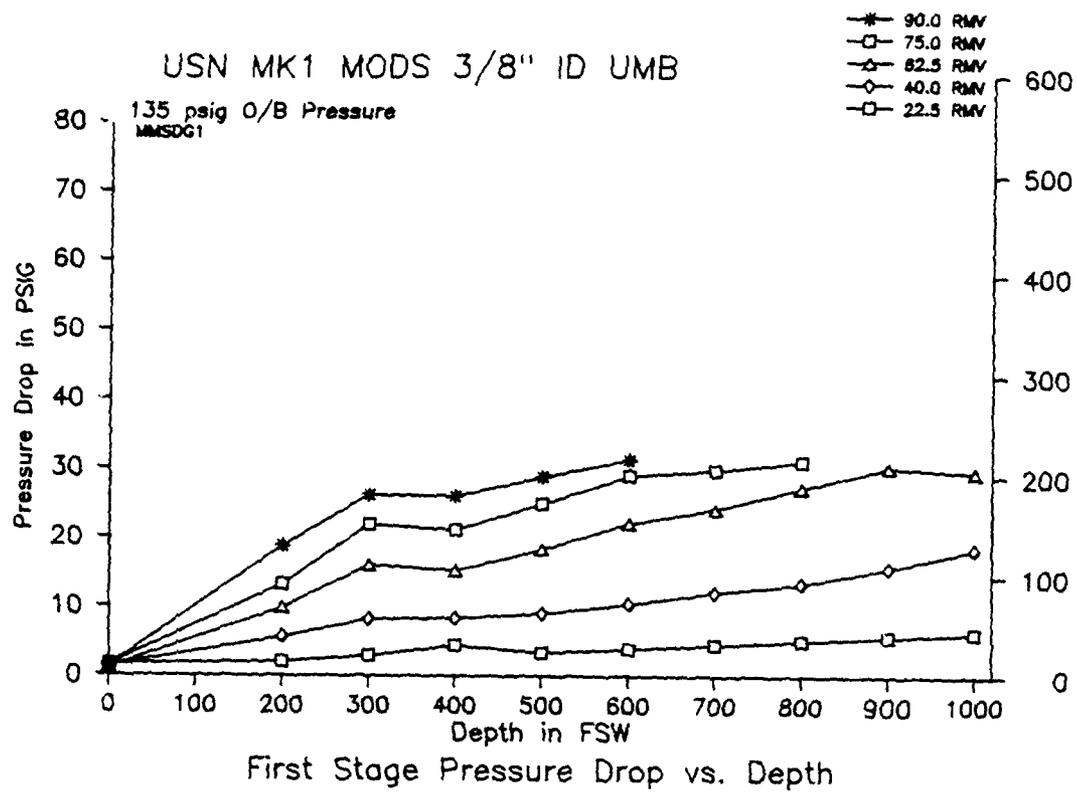


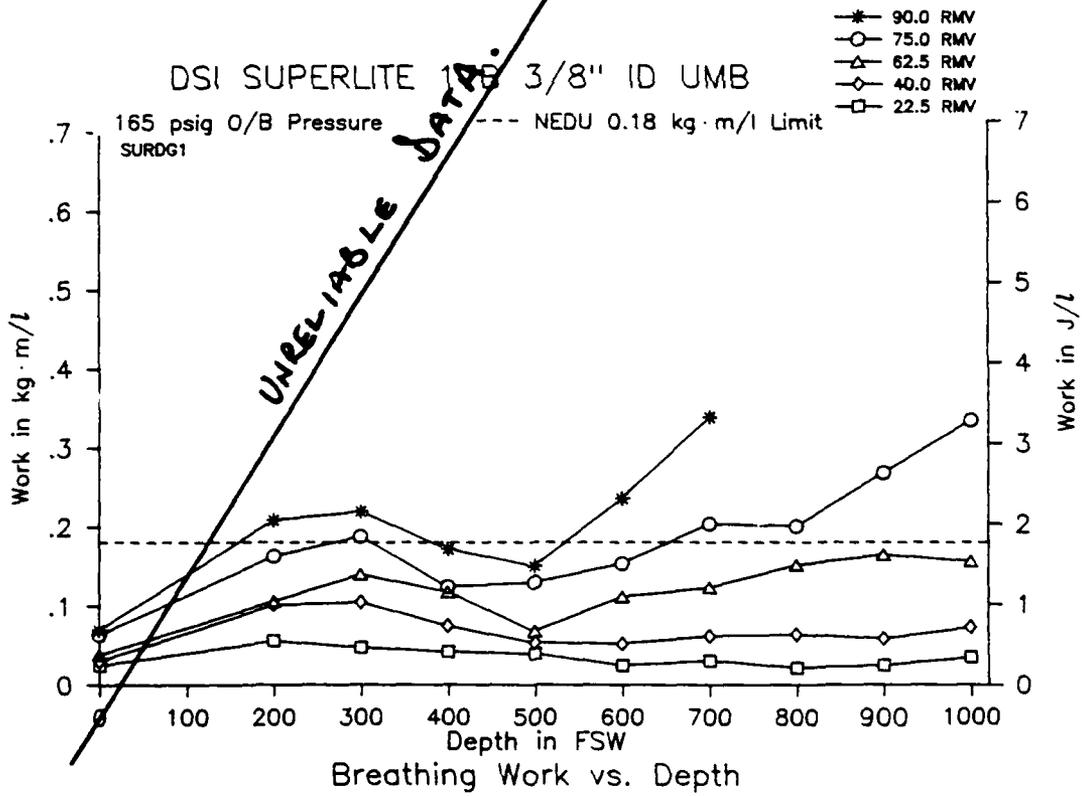
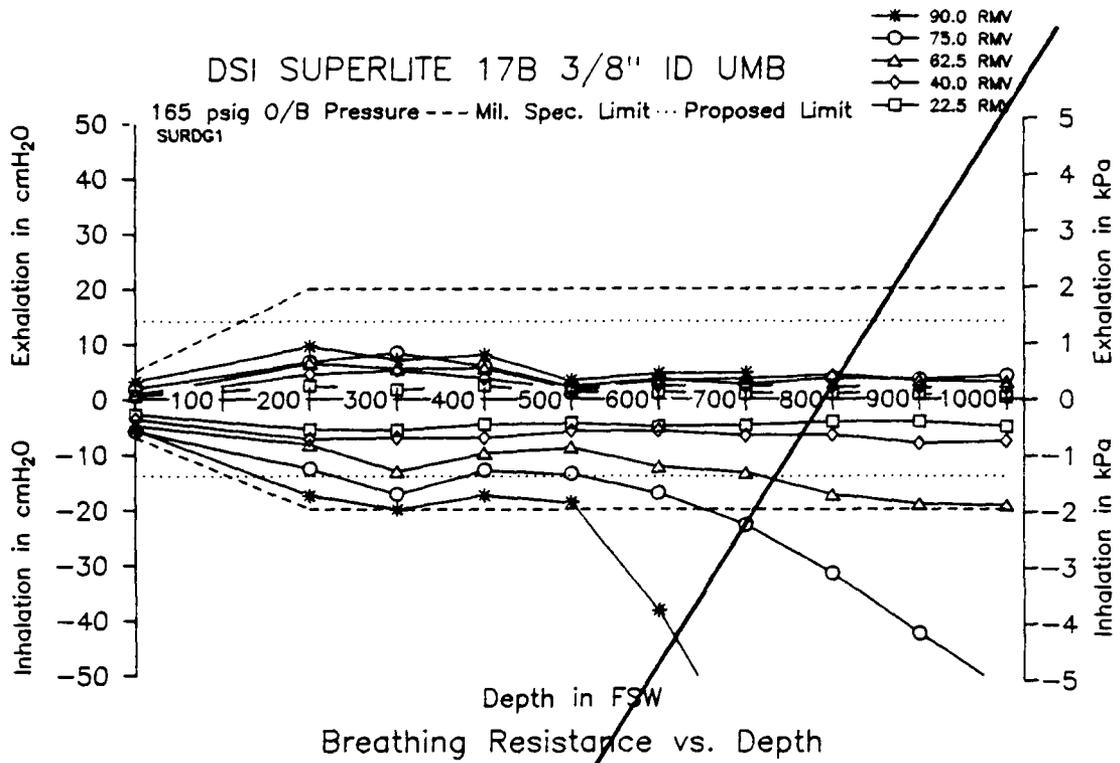
# USN MK1 MOD0 3/8" ID UMB

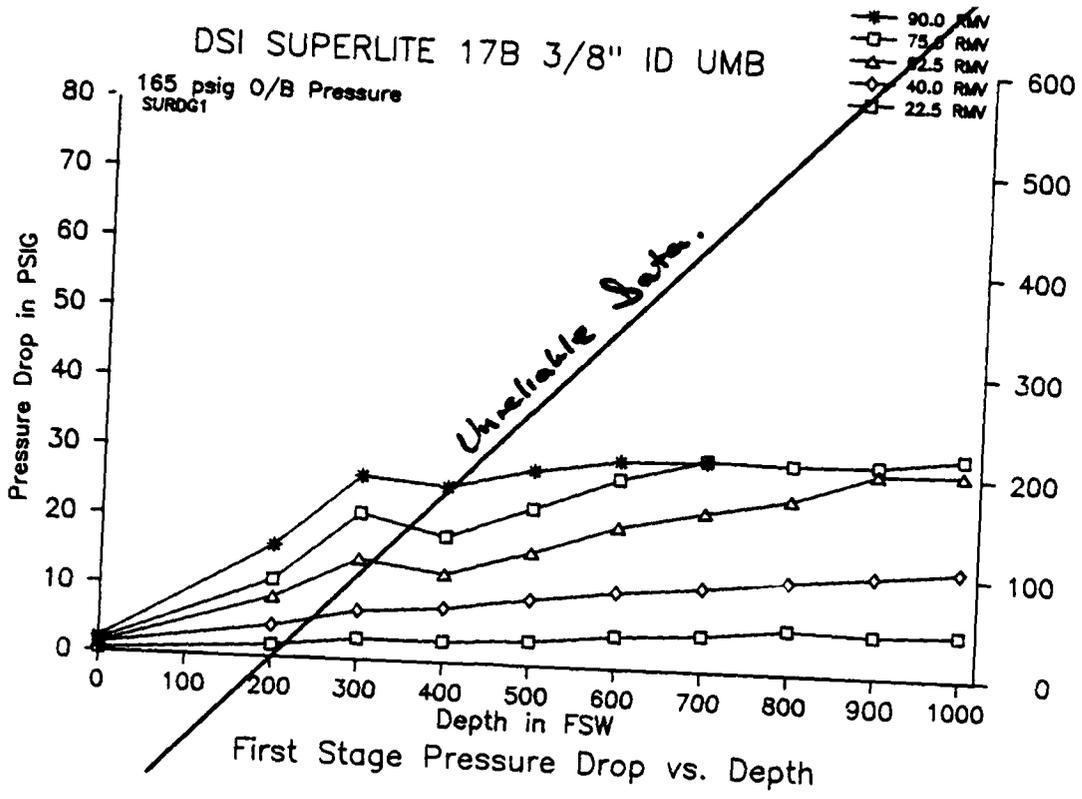


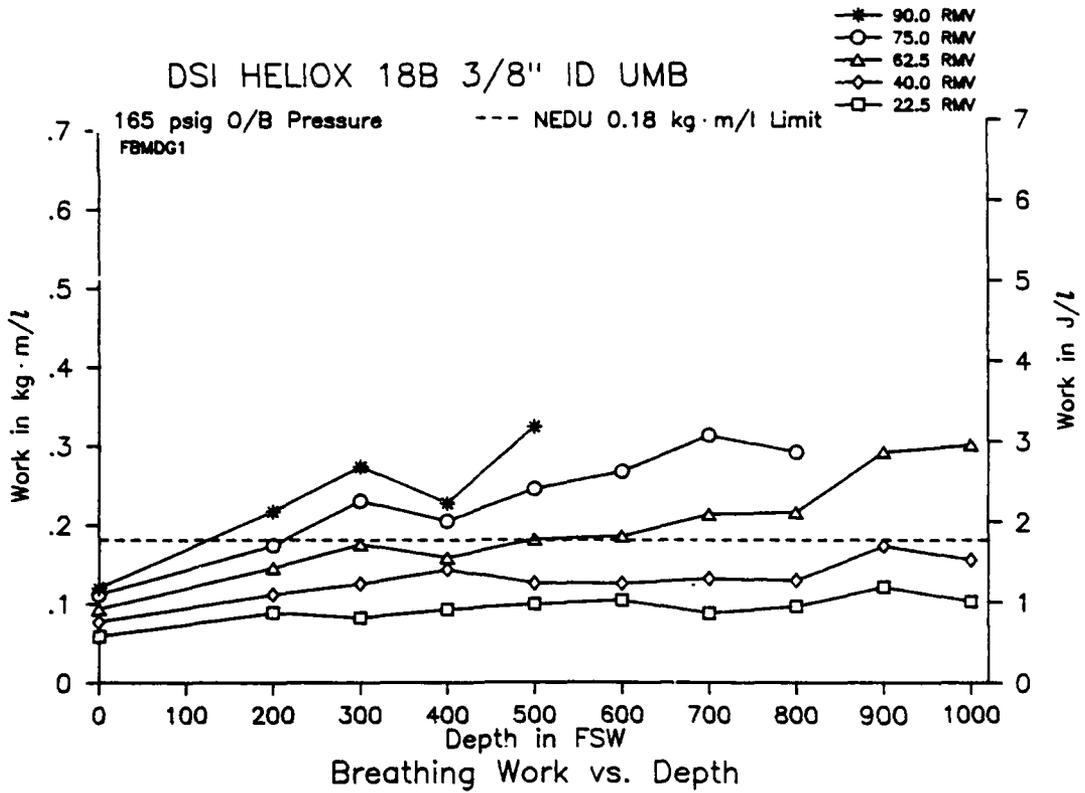
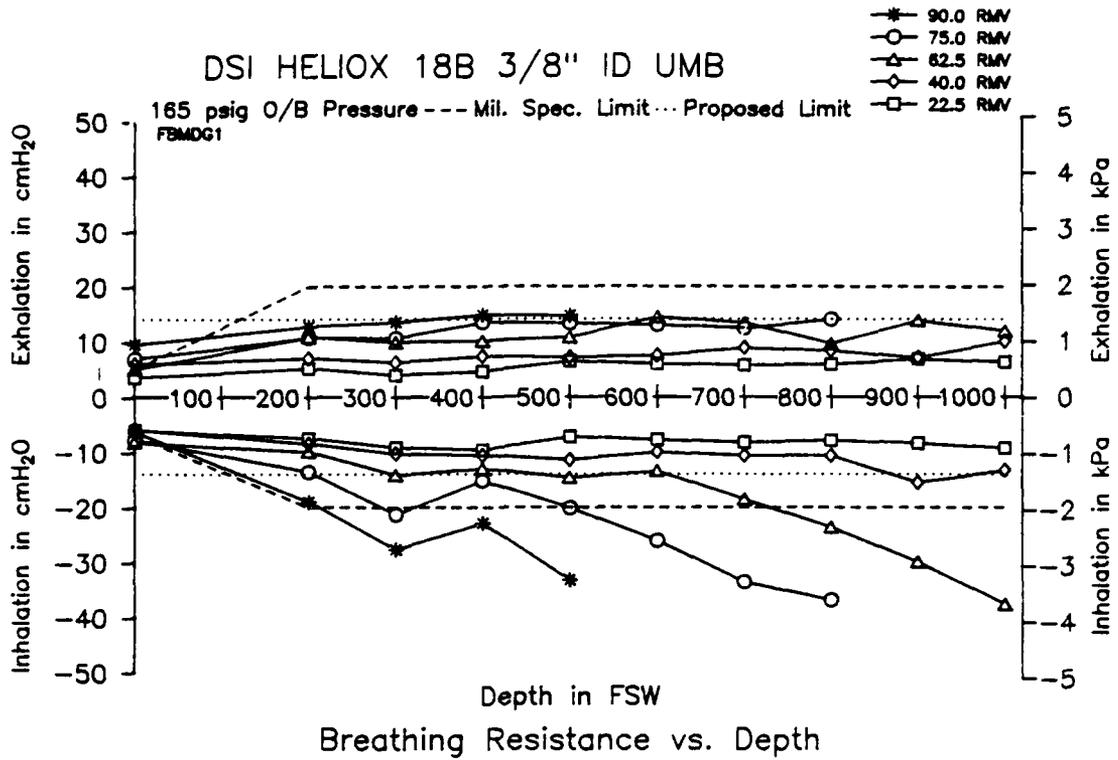
First Stage Pressure Drop vs. Depth



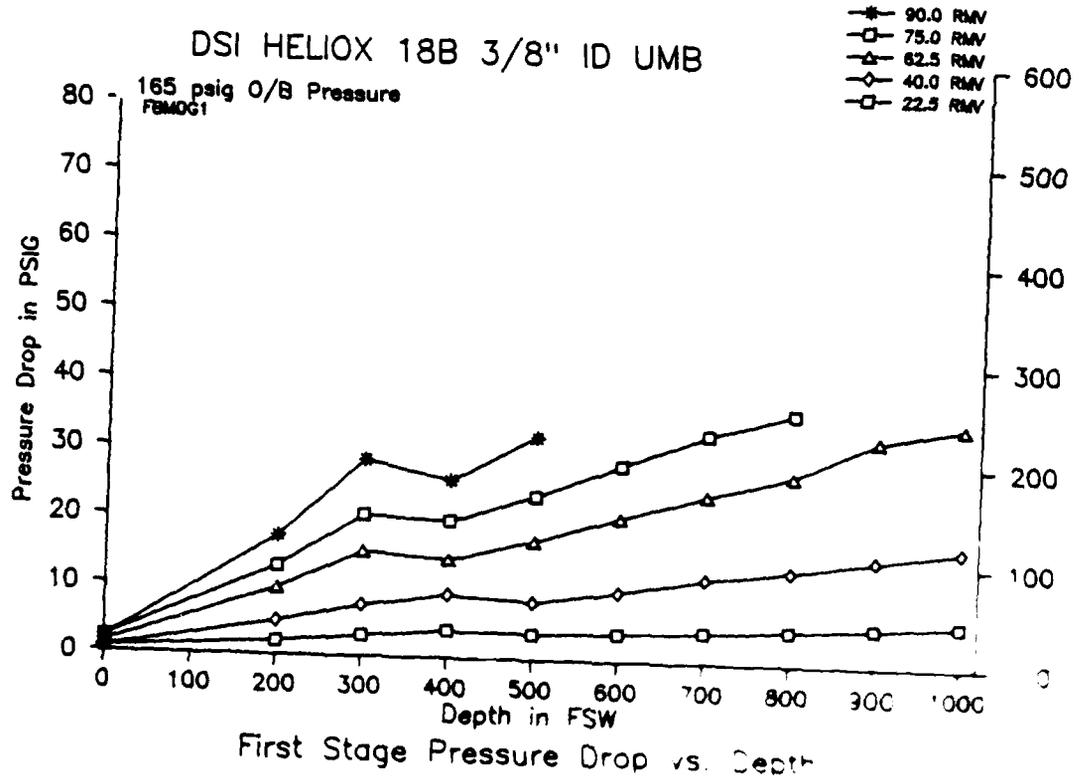


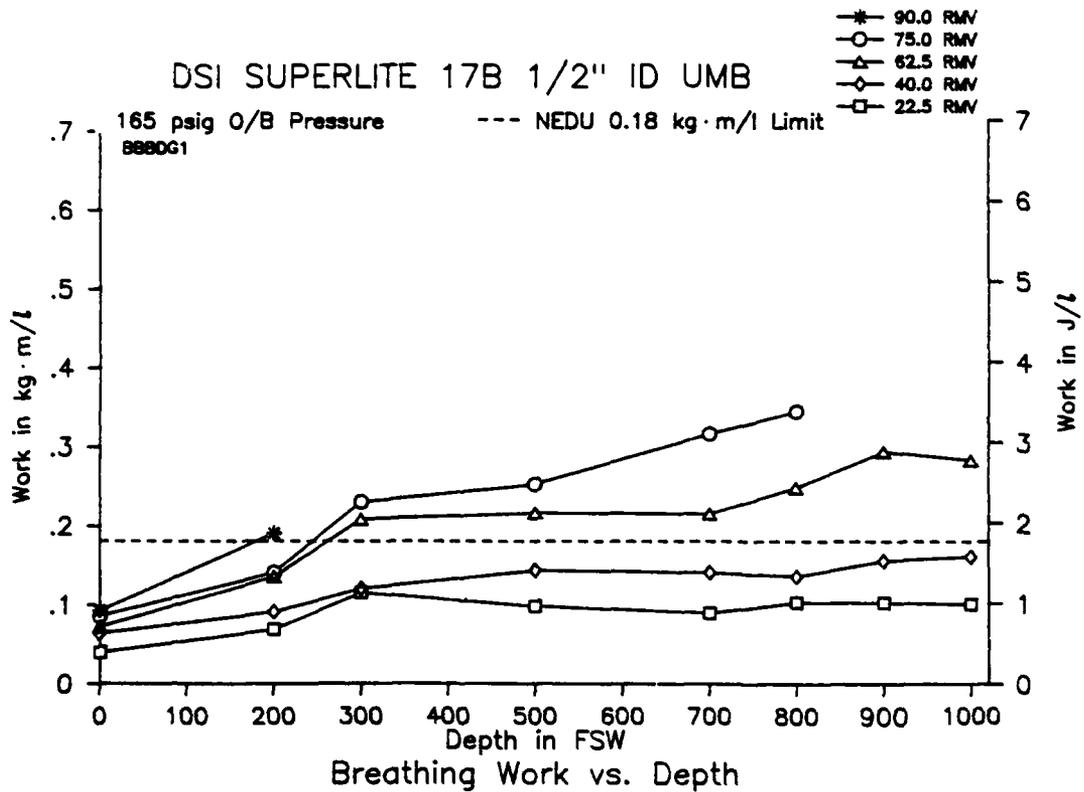
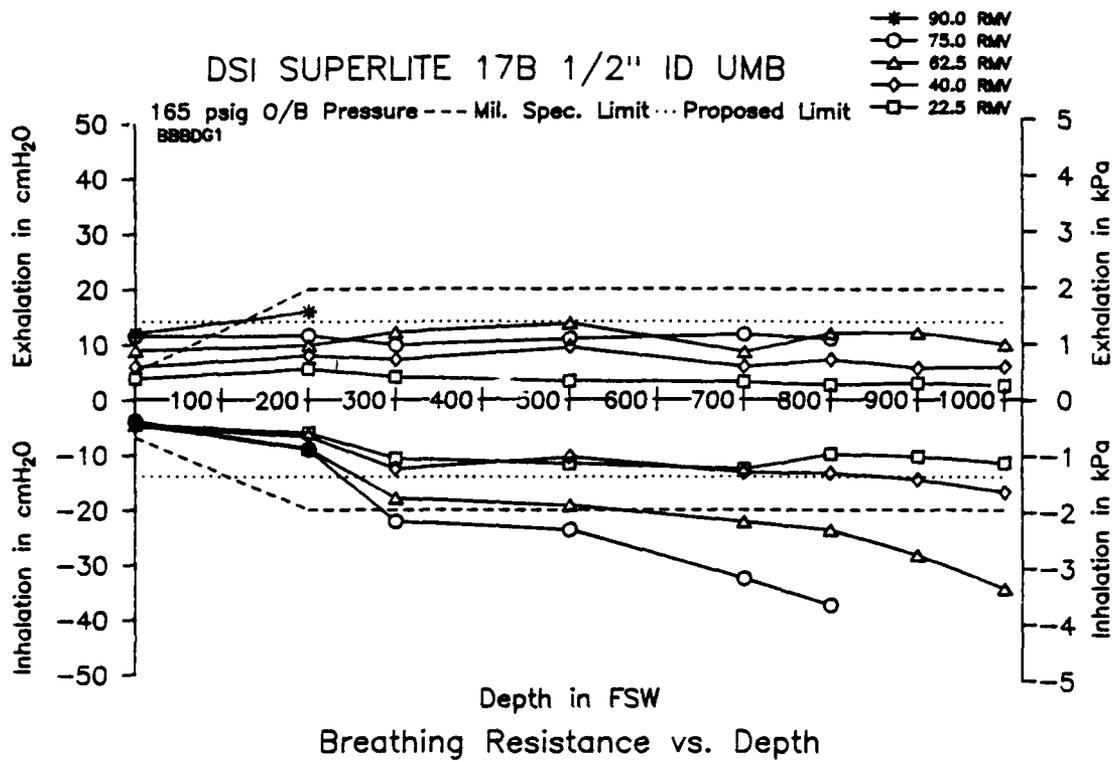




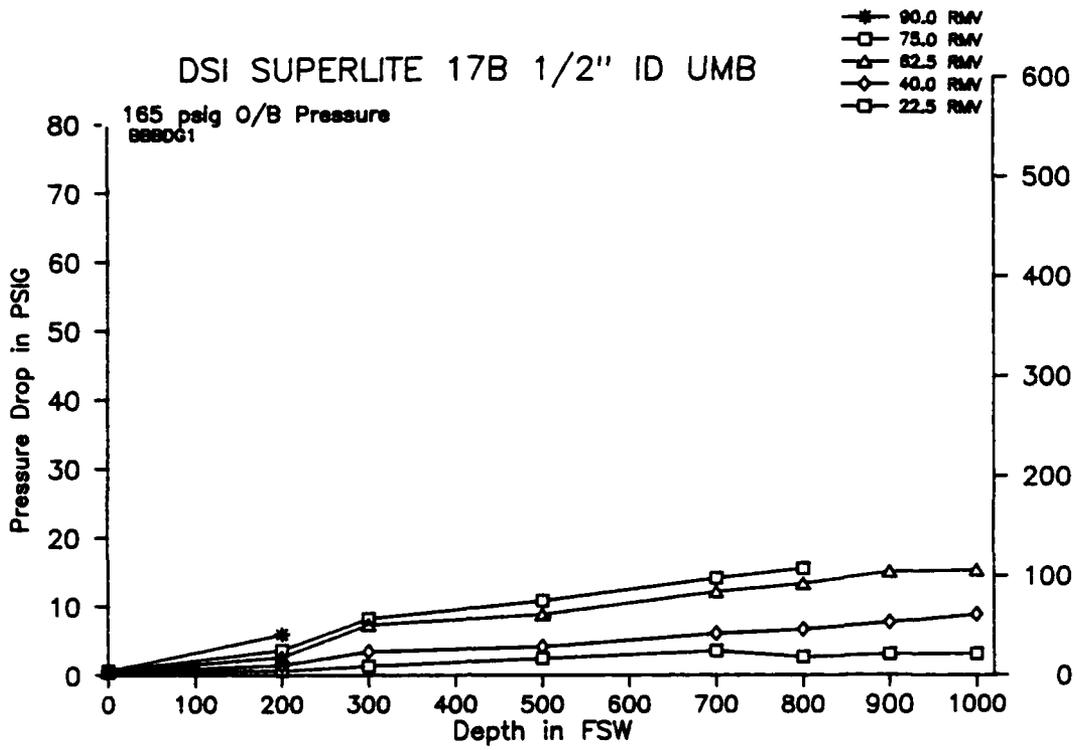


# DSI HELIOX 18B 3/8" ID UMB

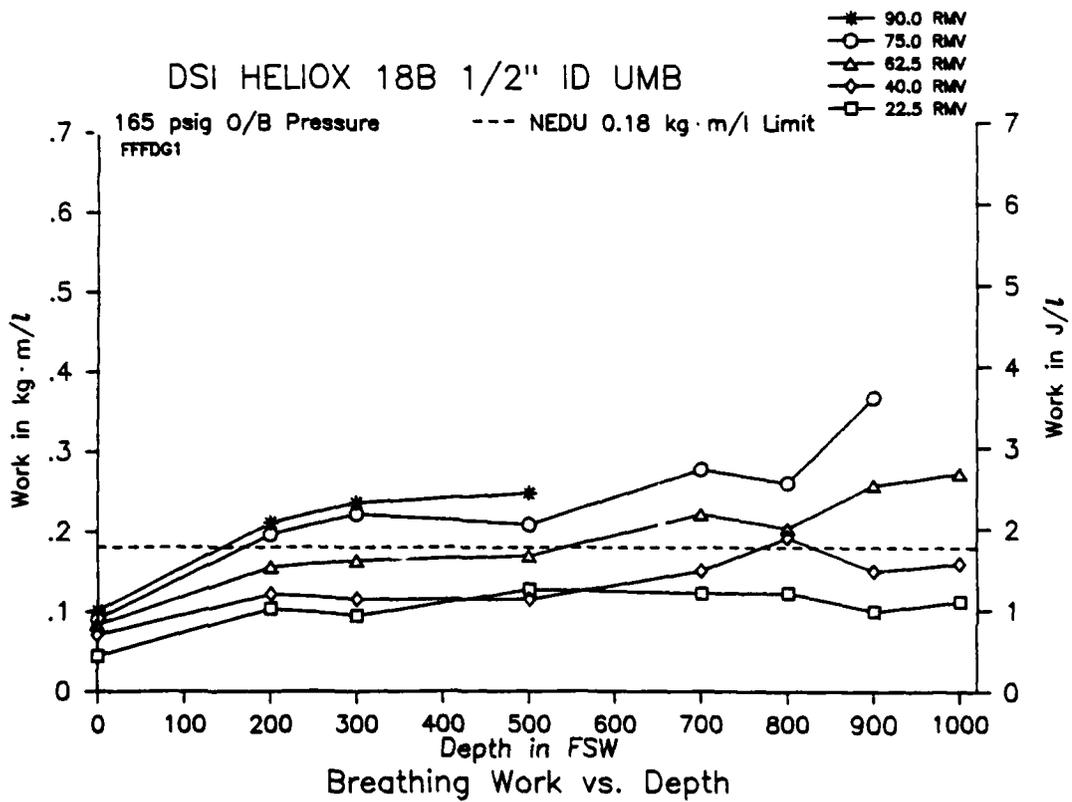
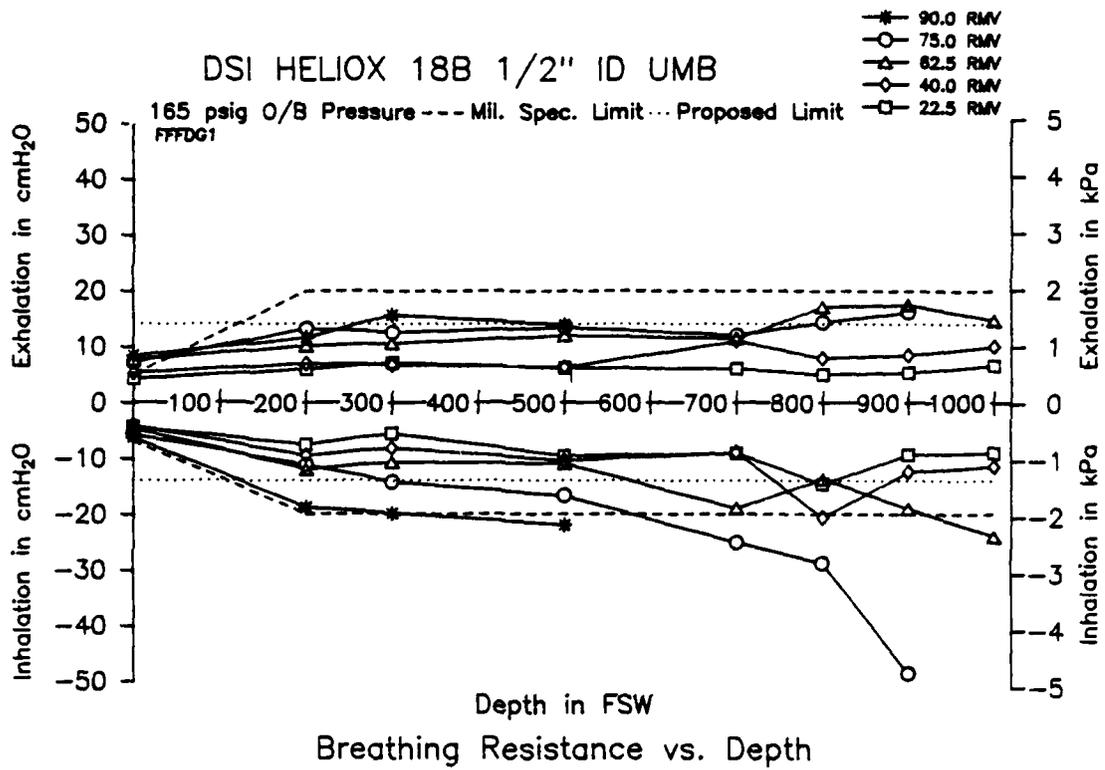




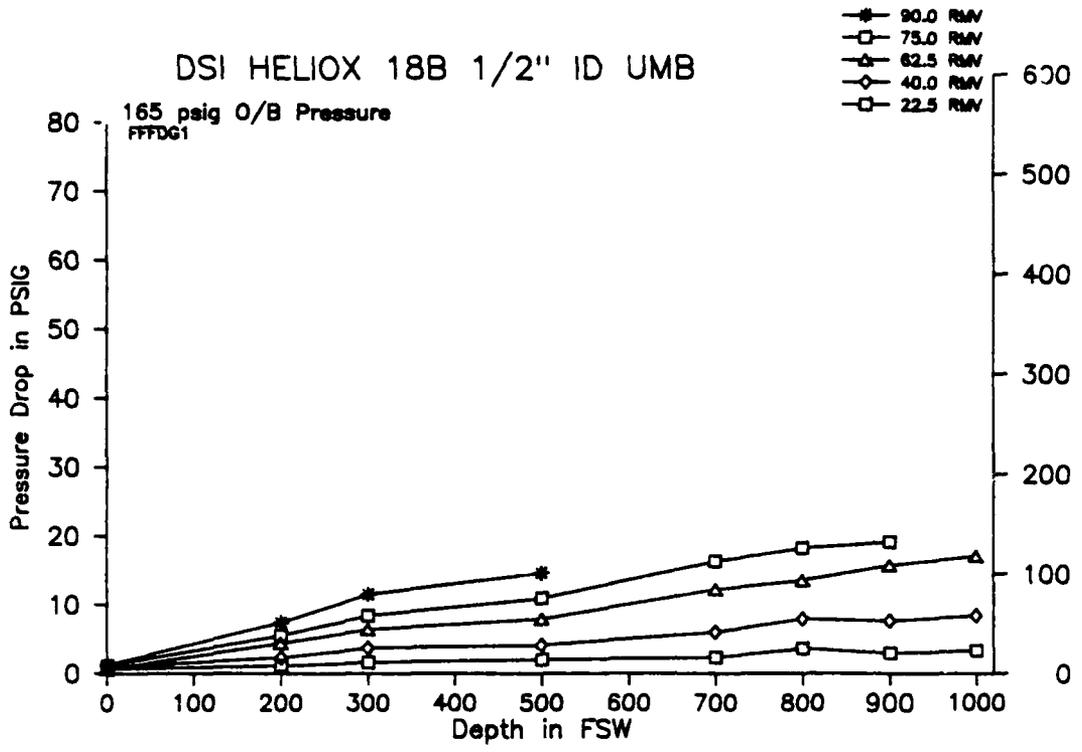
# DSI SUPERLITE 17B 1/2" ID UMB



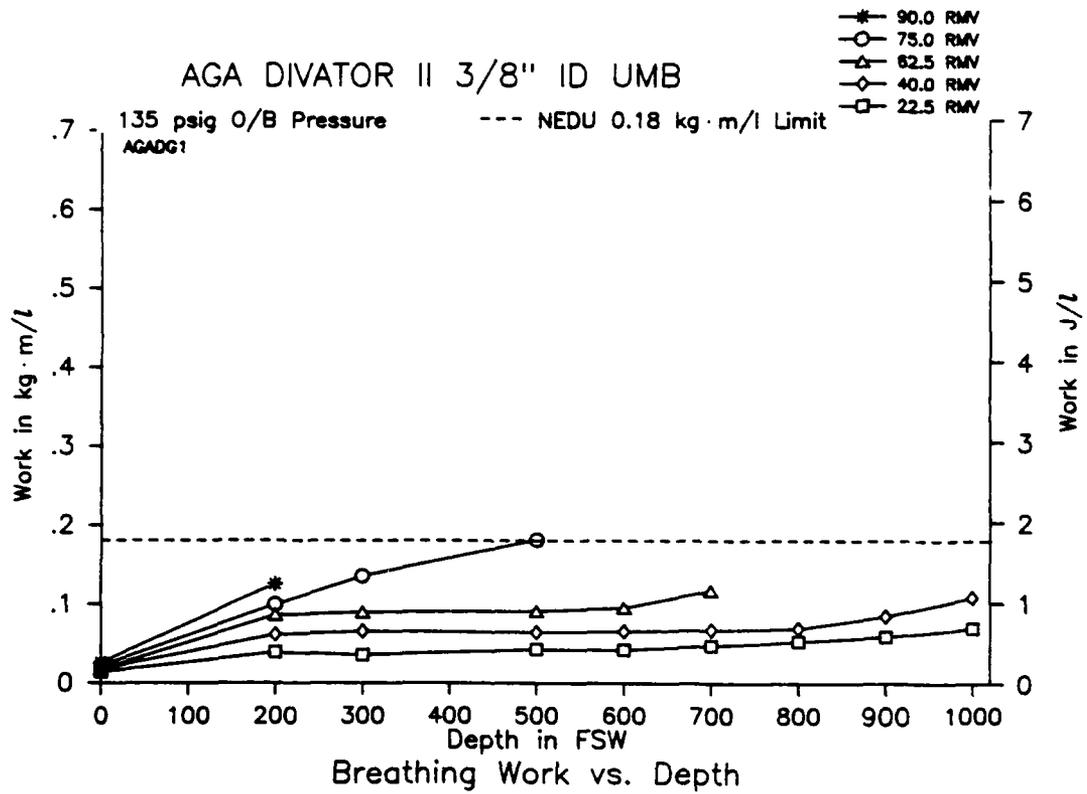
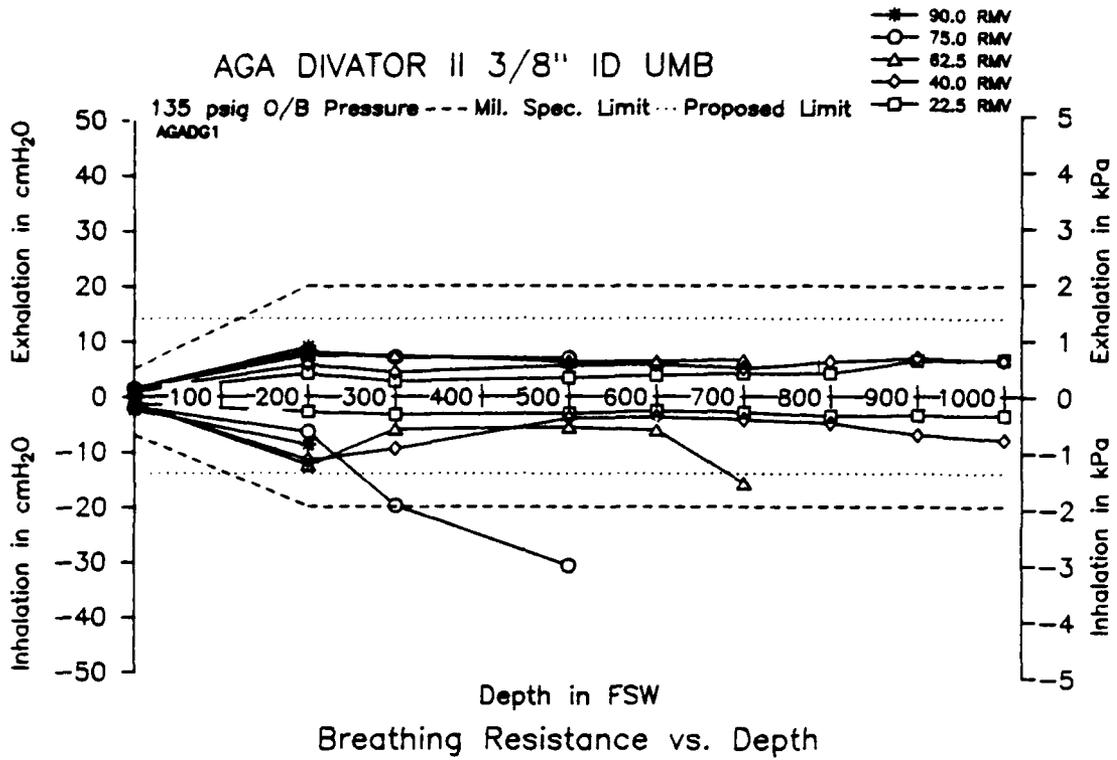
First Stage Pressure Drop vs. Depth

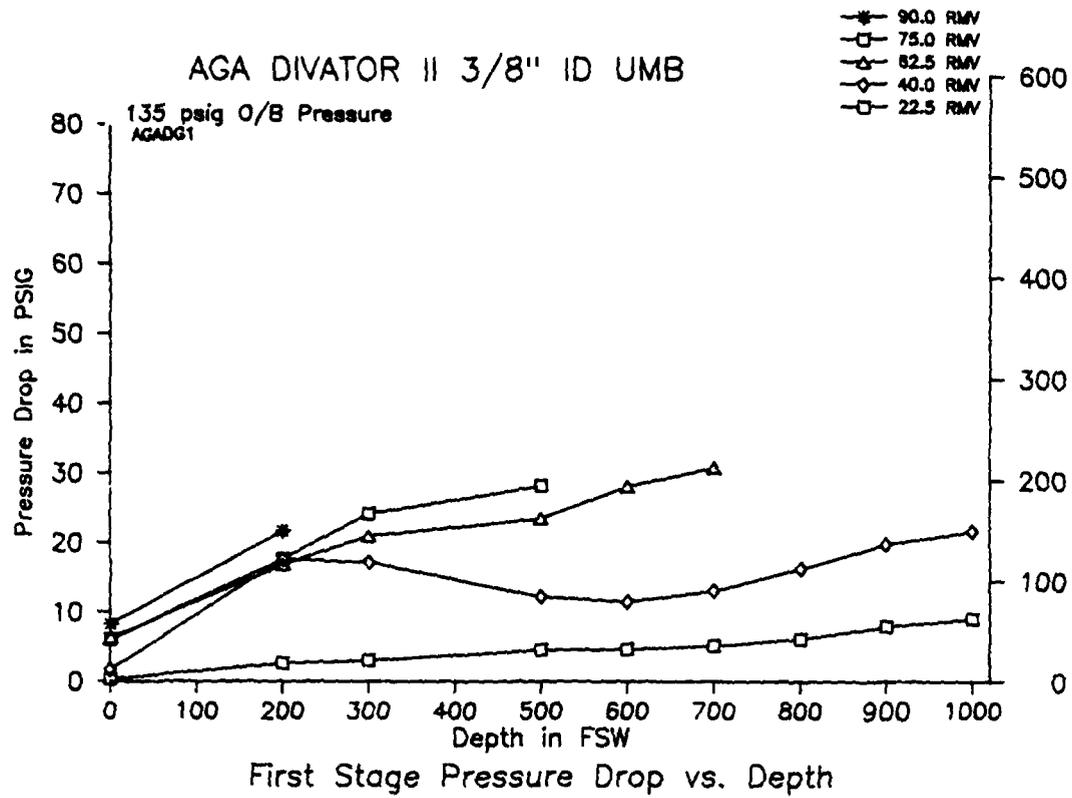


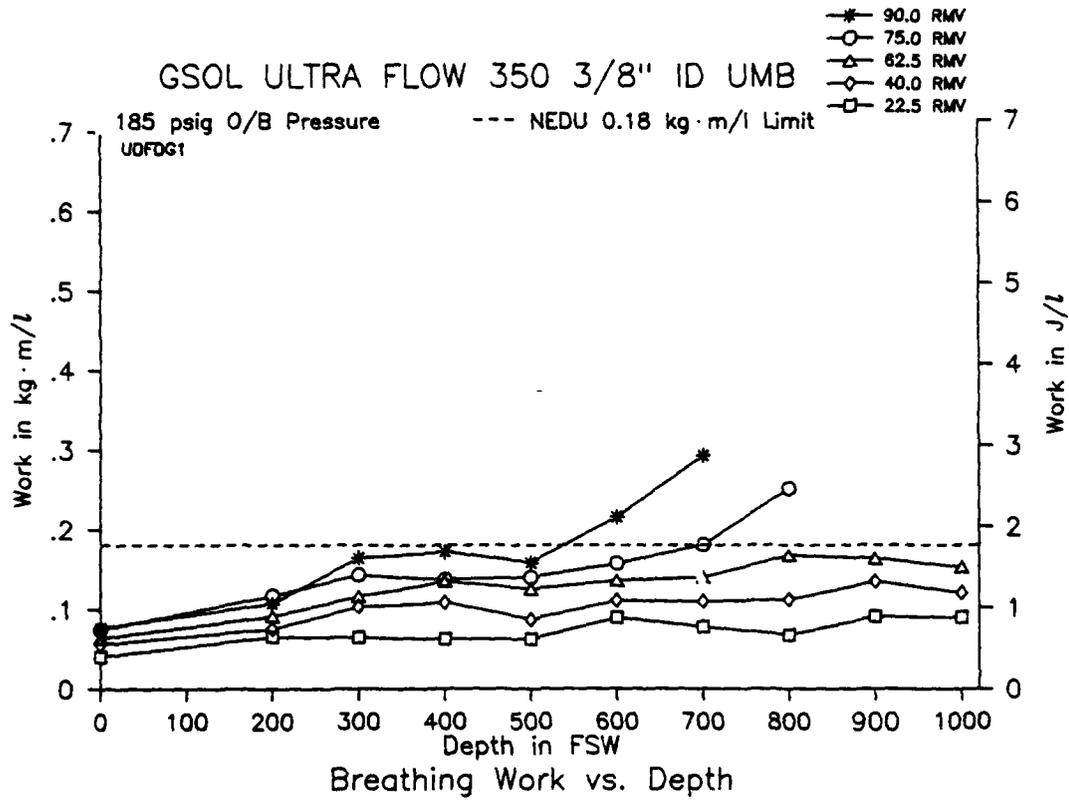
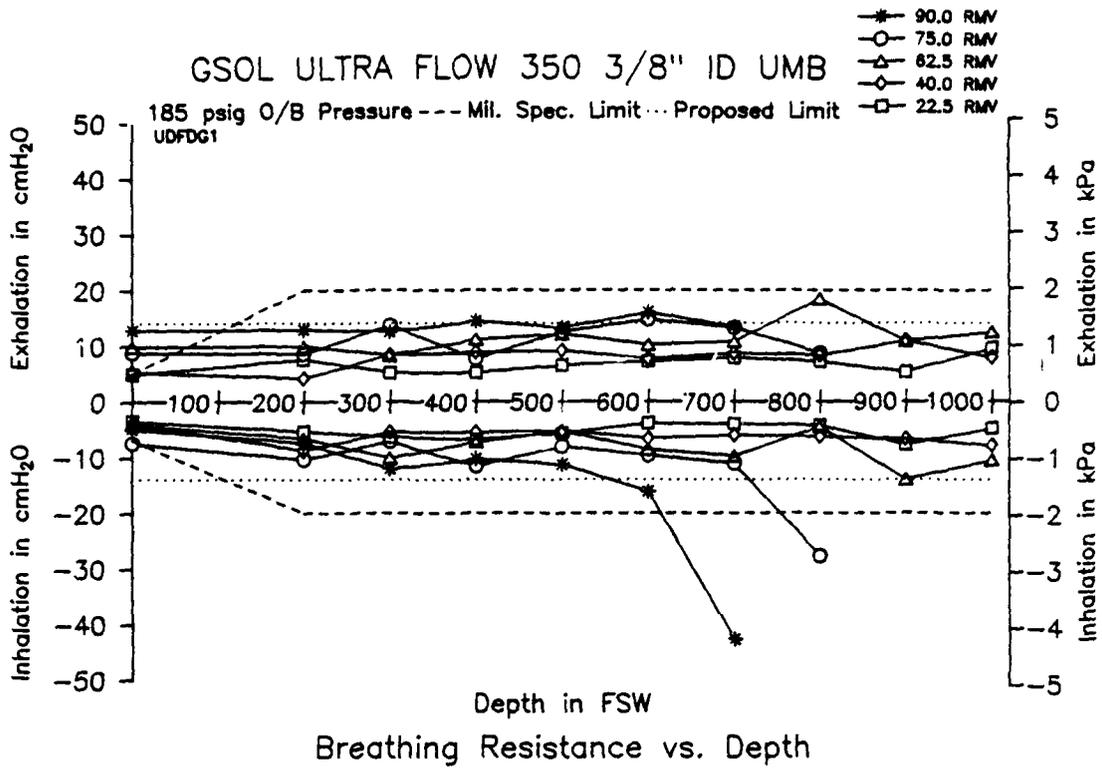
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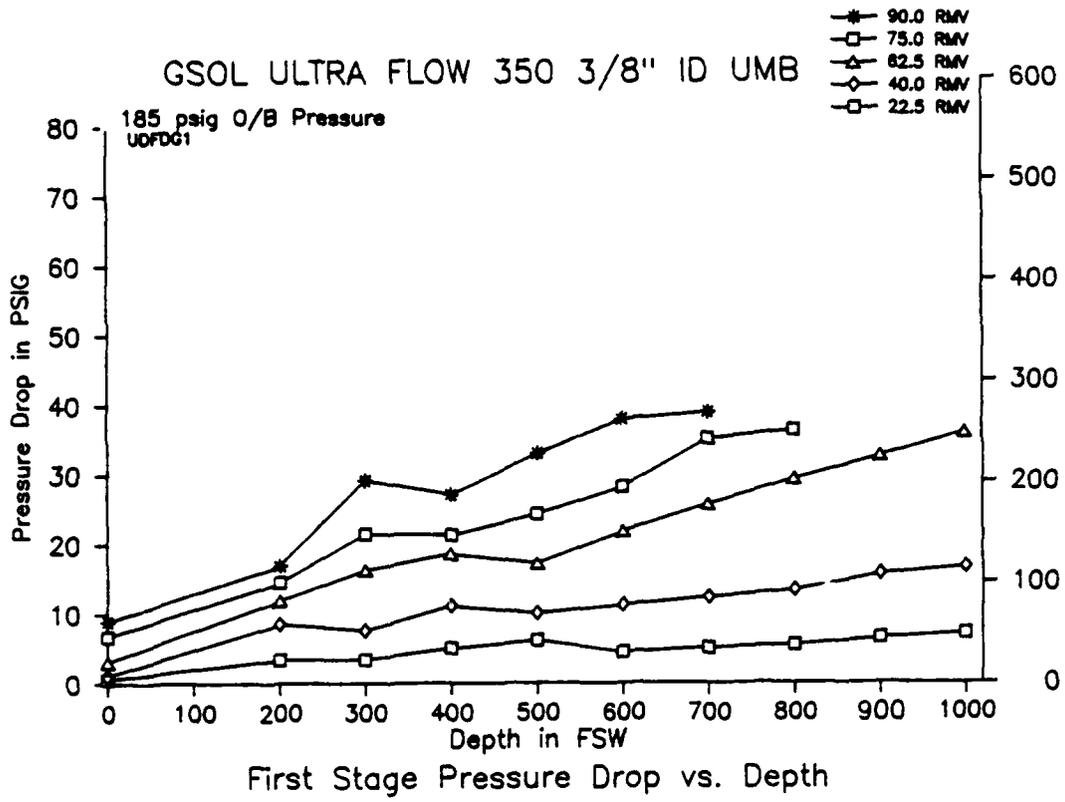
First Stage Pressure Drop vs. Depth

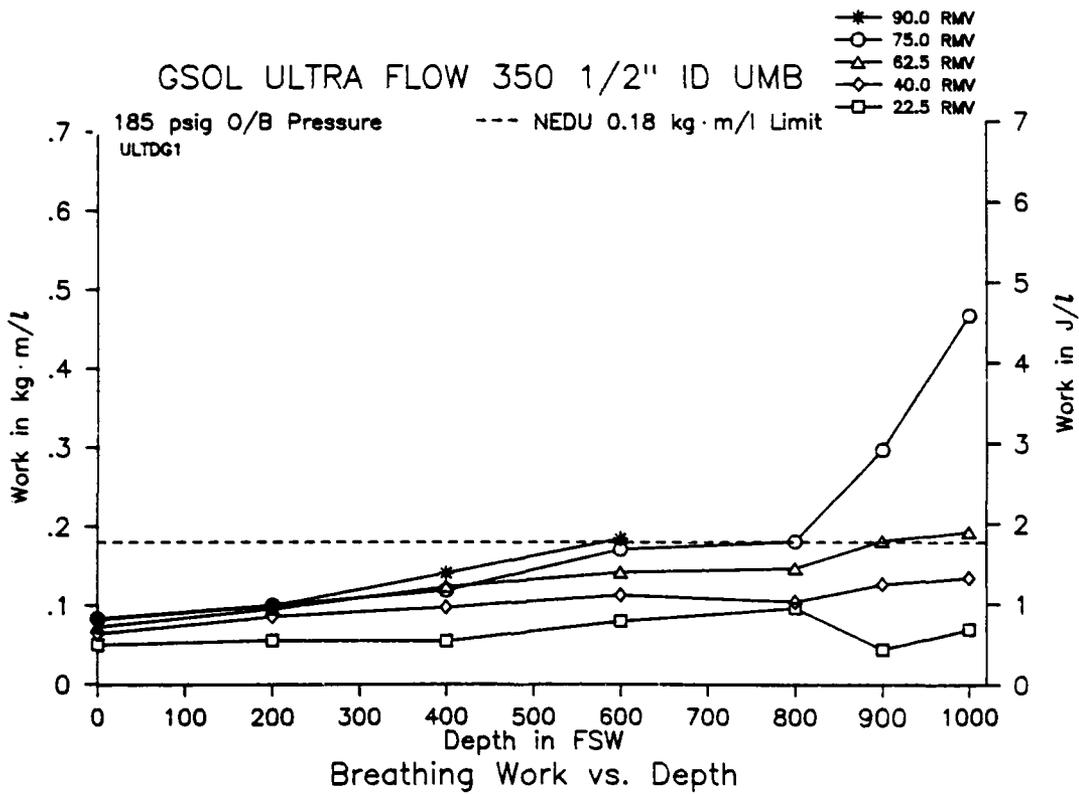
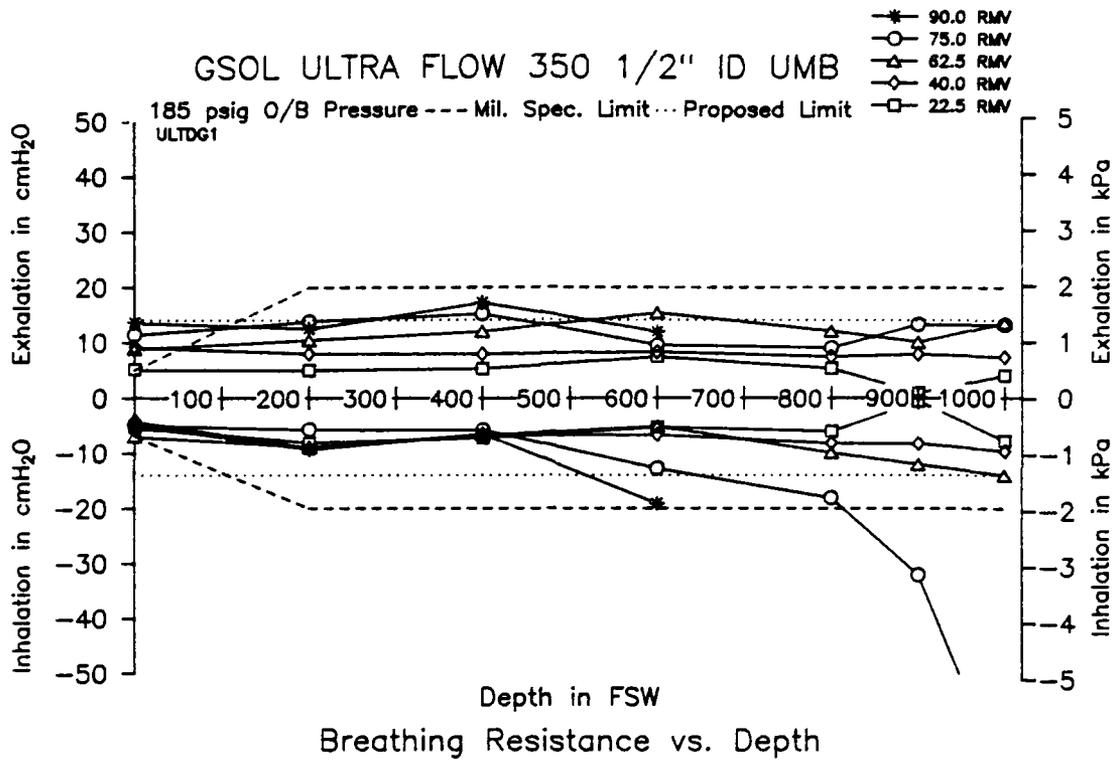




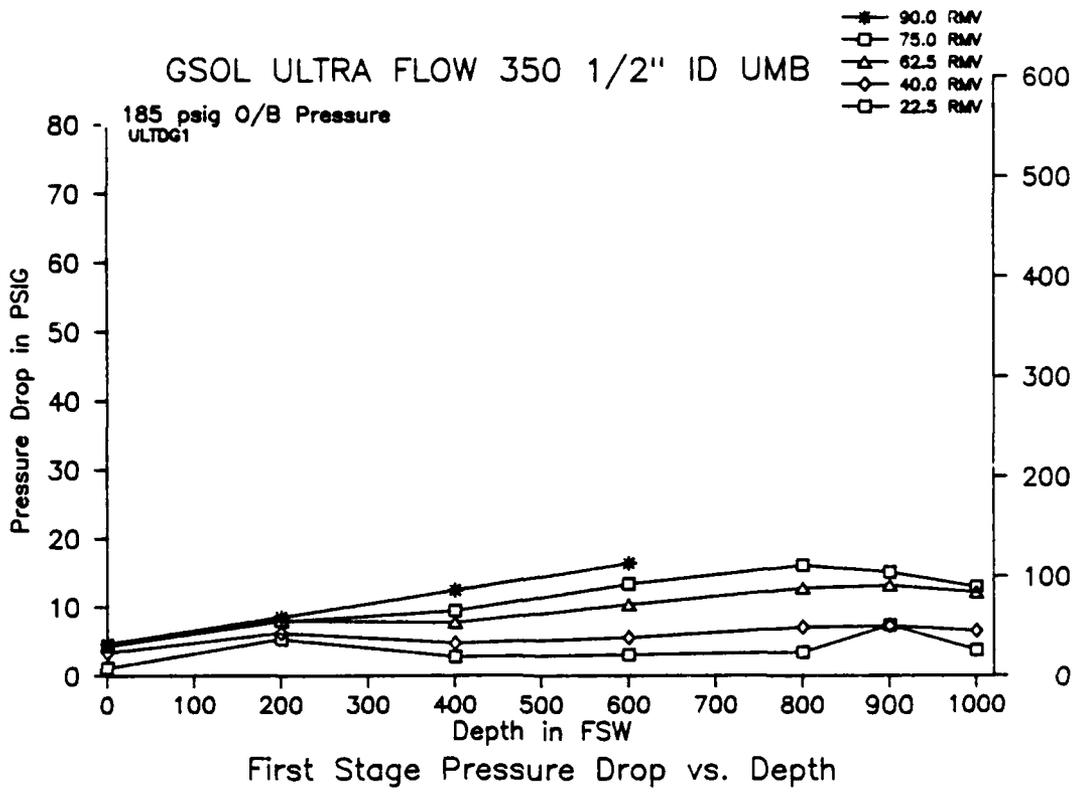


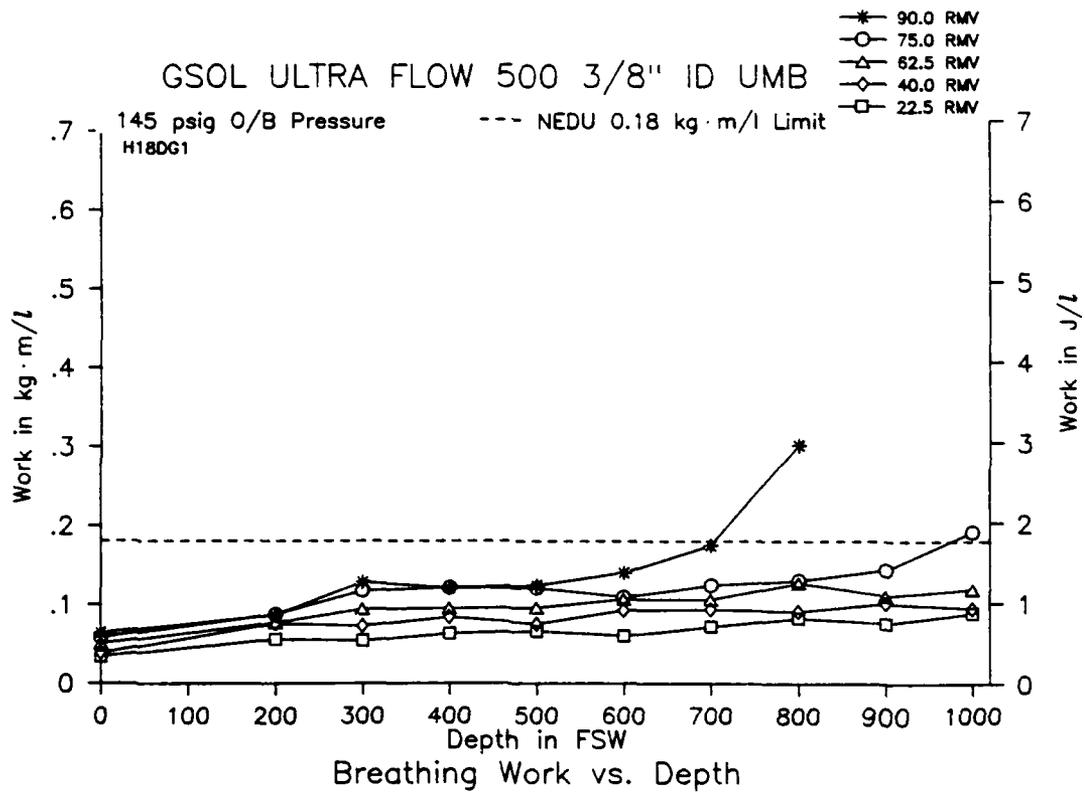
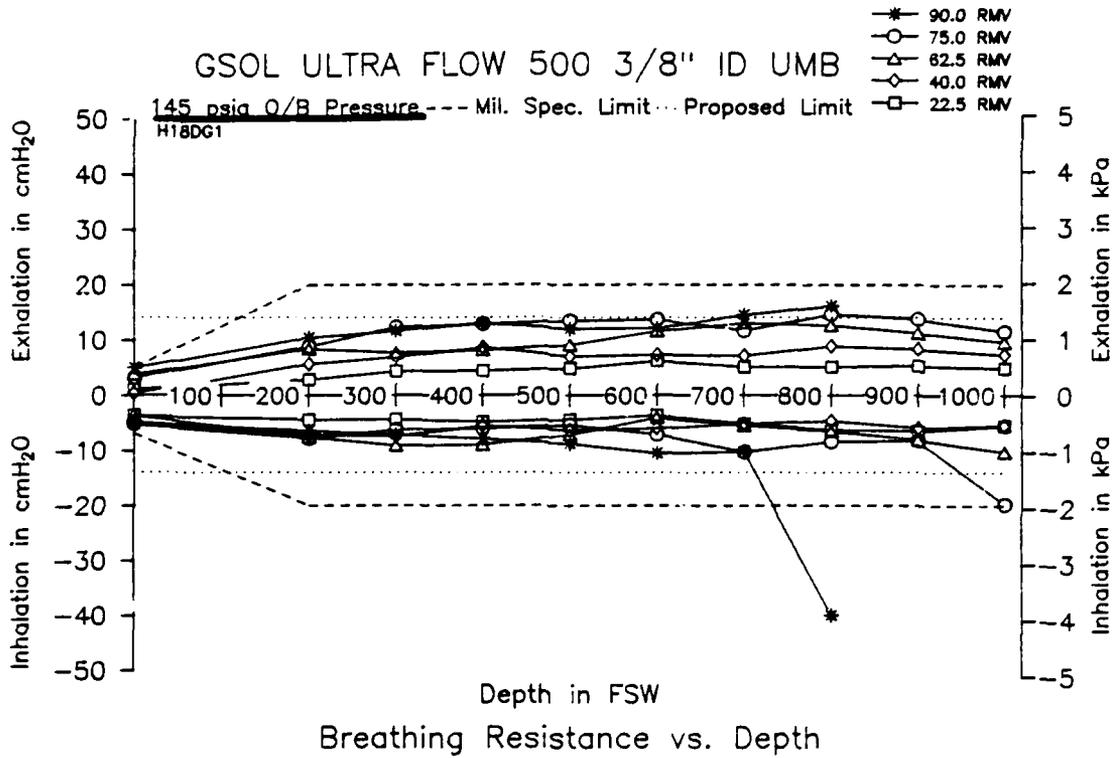
GSOL ULTRA FLOW 350 3/8" ID UMB



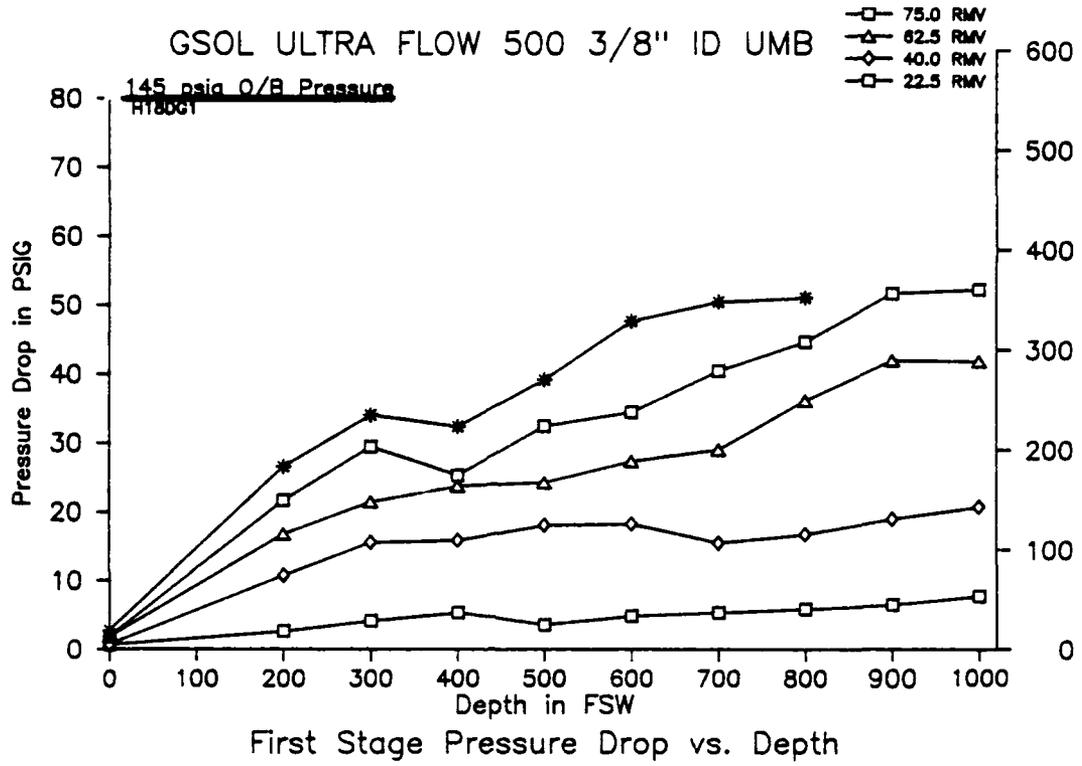


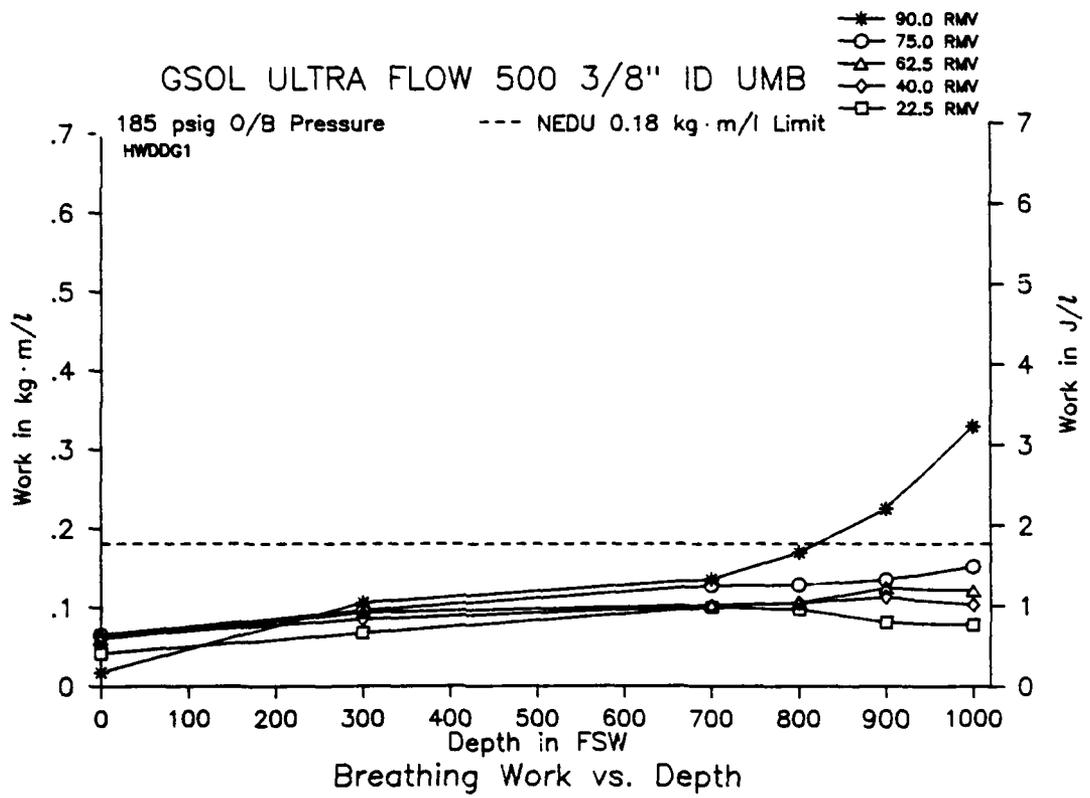
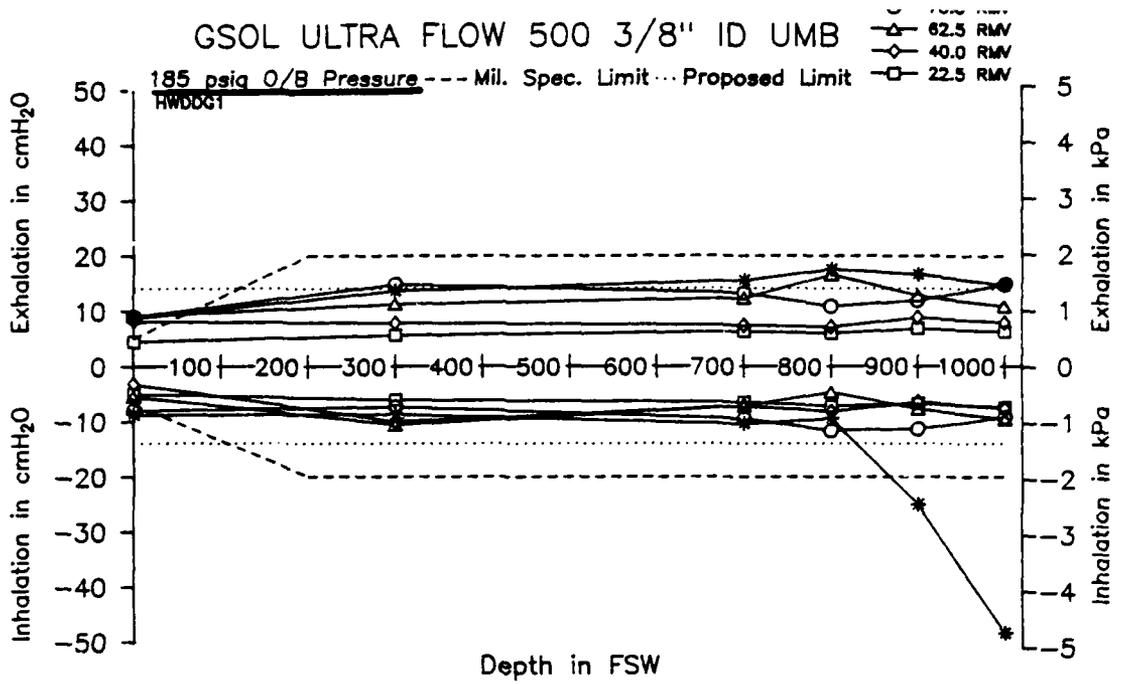
GSOL ULTRA FLOW 350 1/2" ID UMB

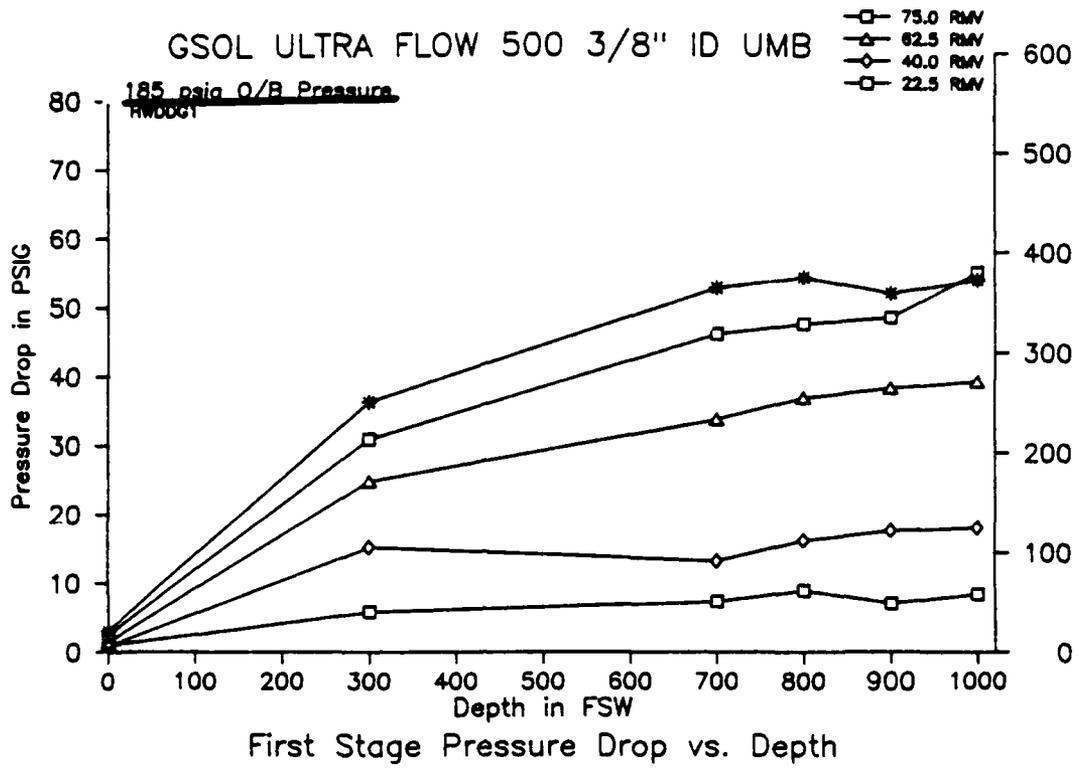


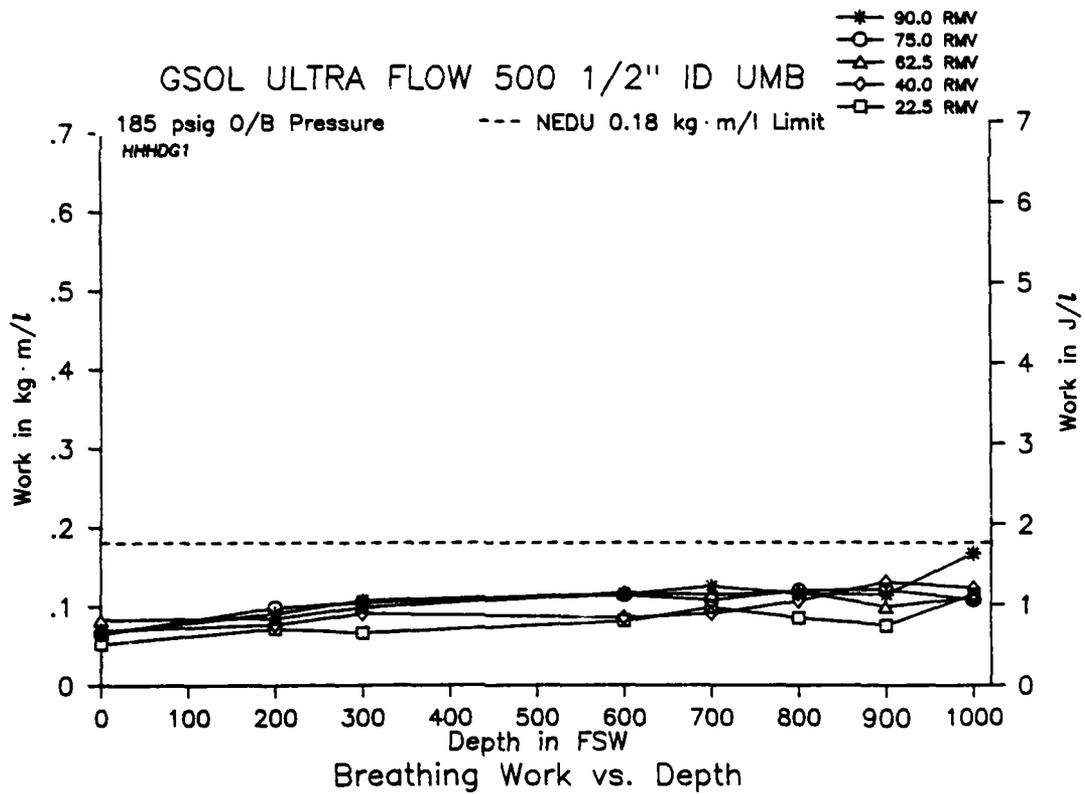
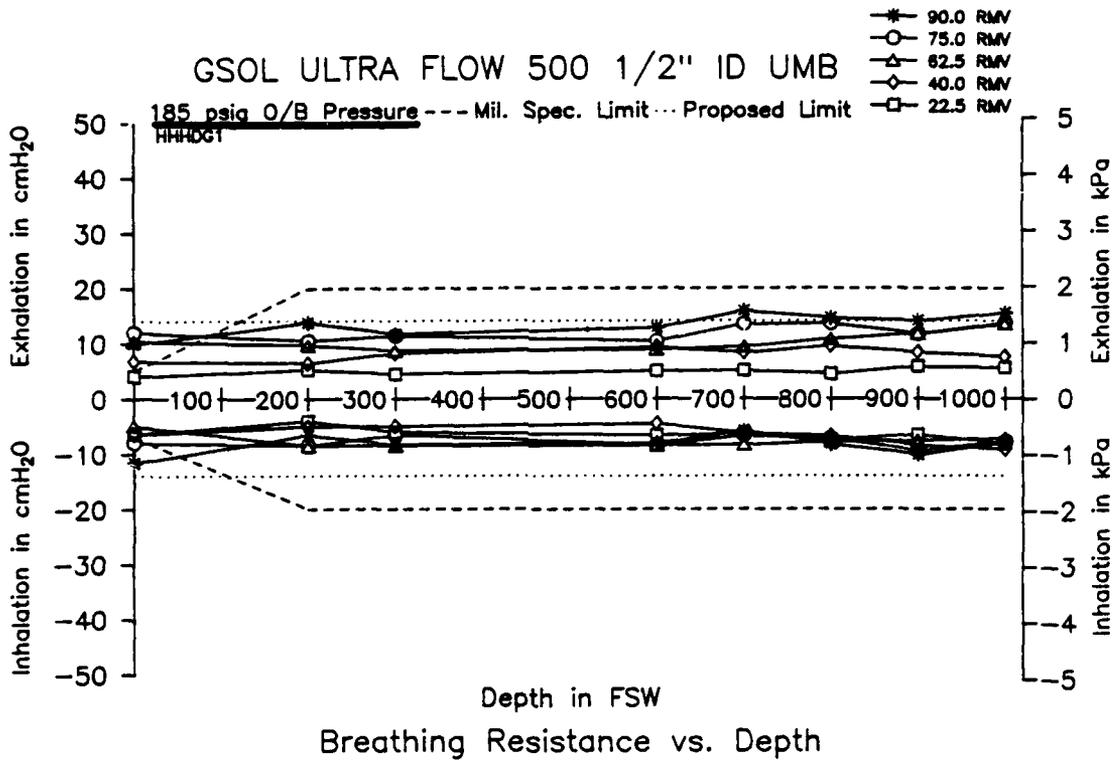


GSOL ULTRA FLOW 500 3/8" ID UMB

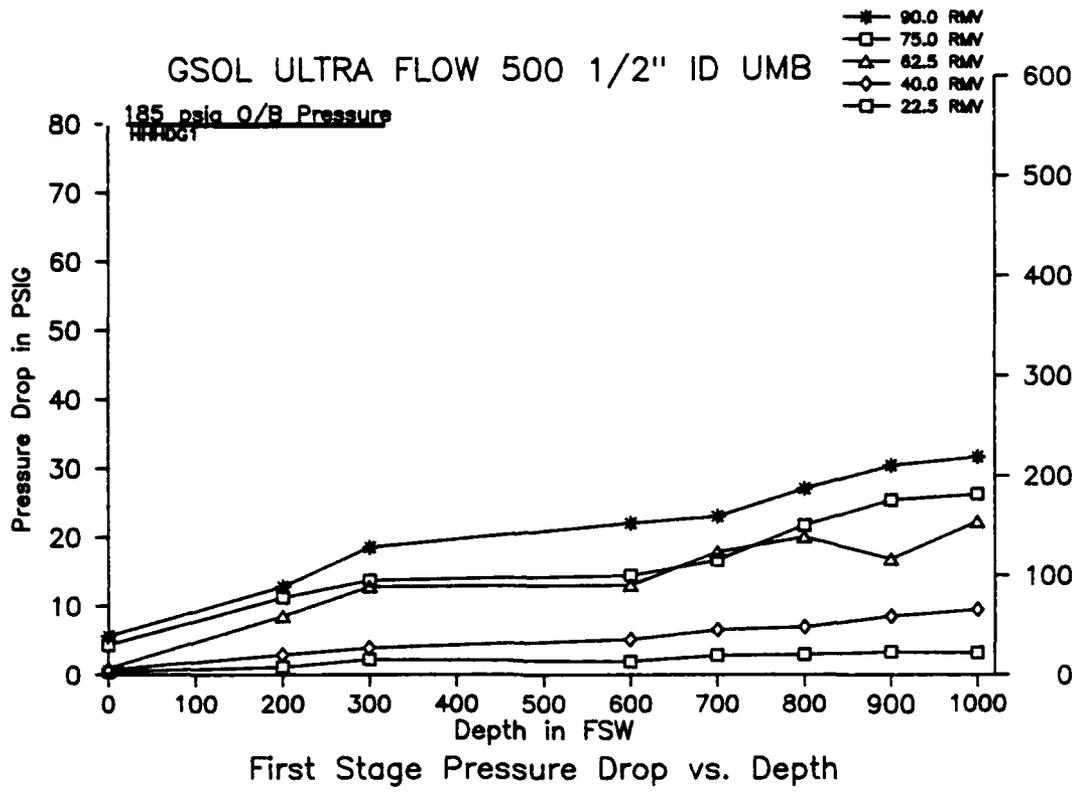


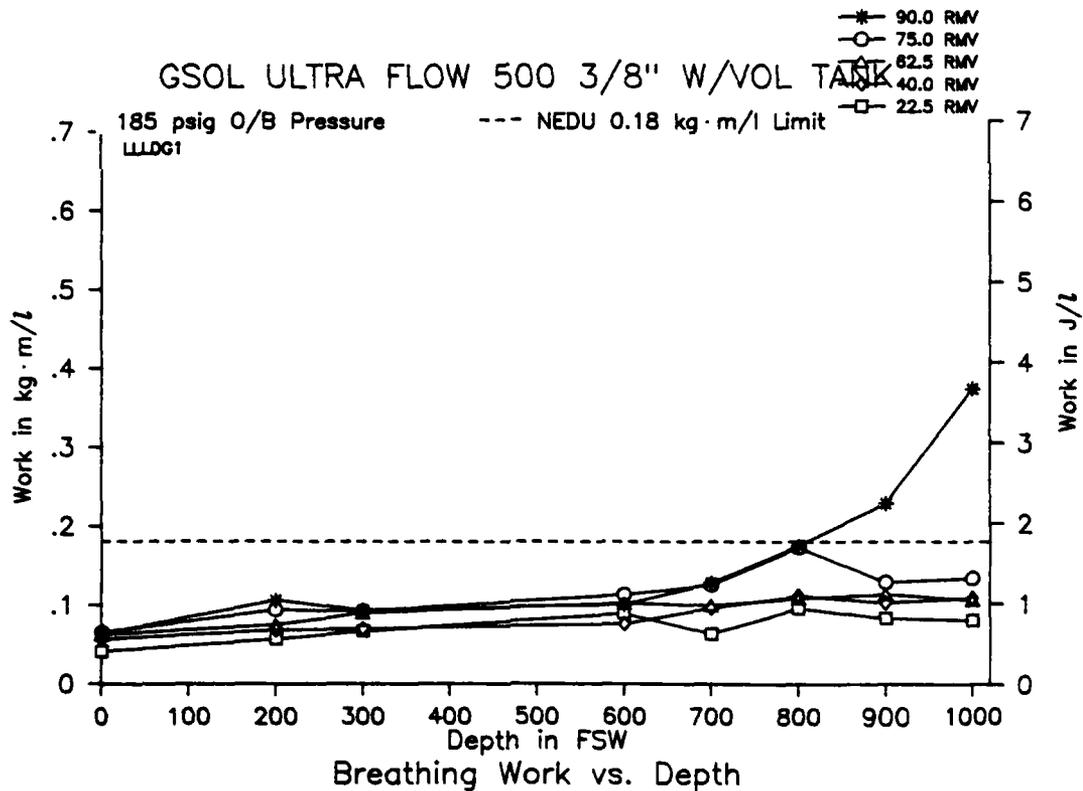
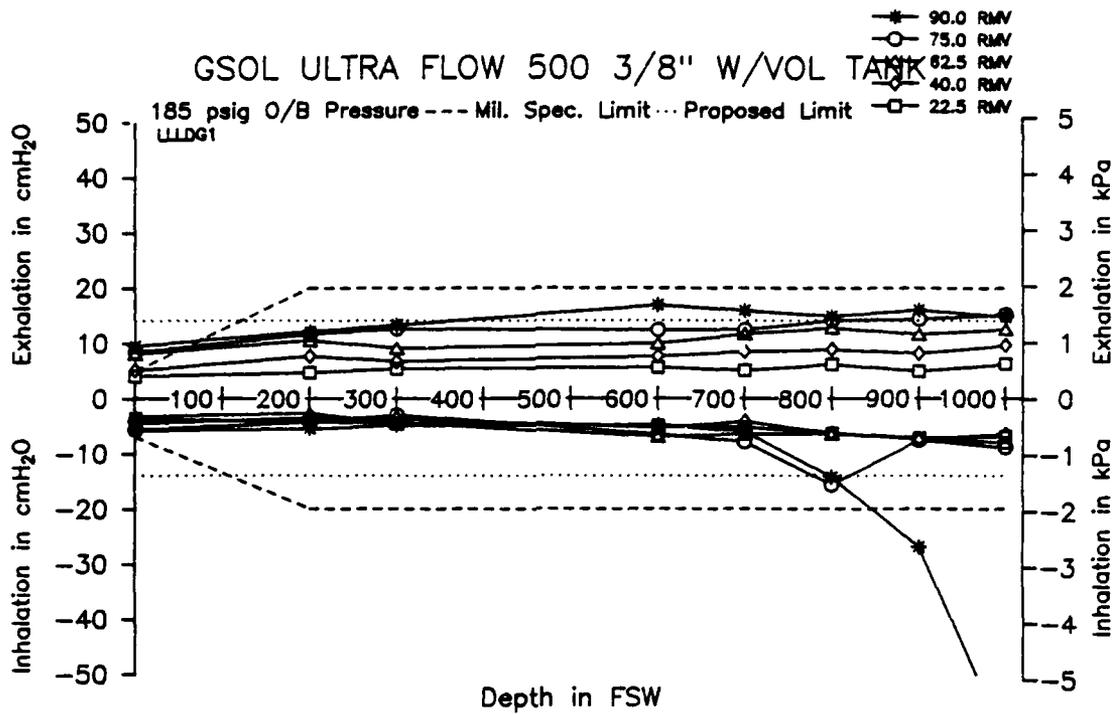


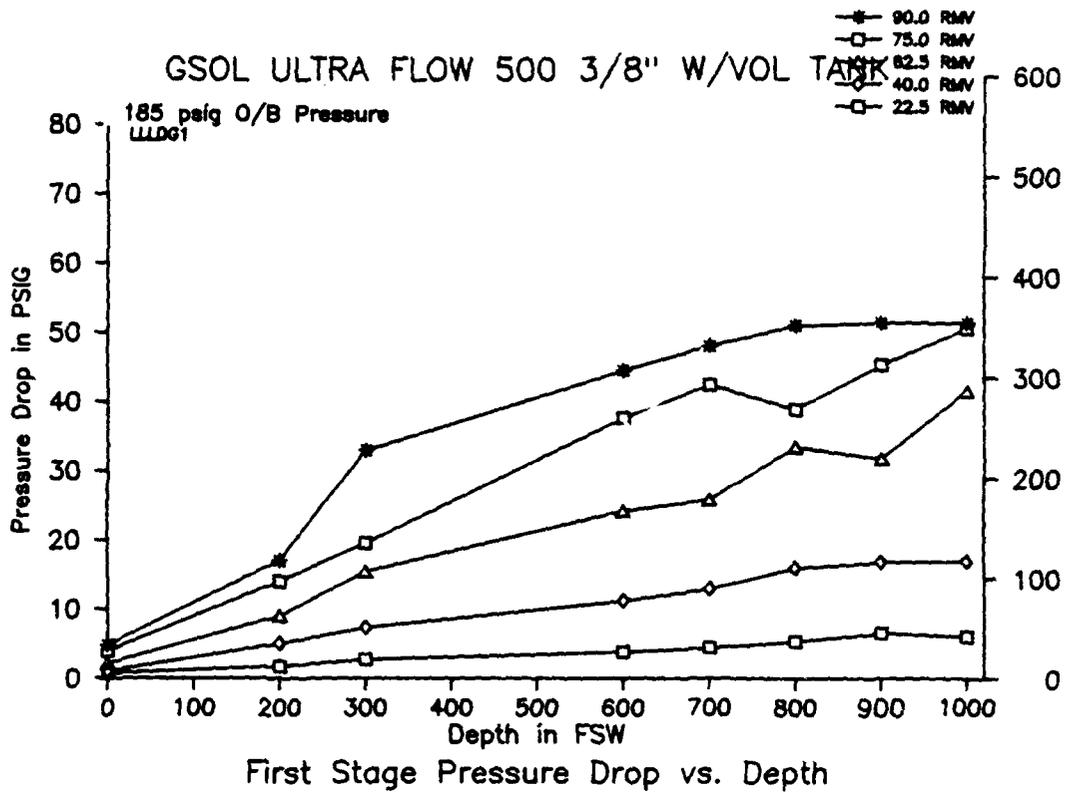


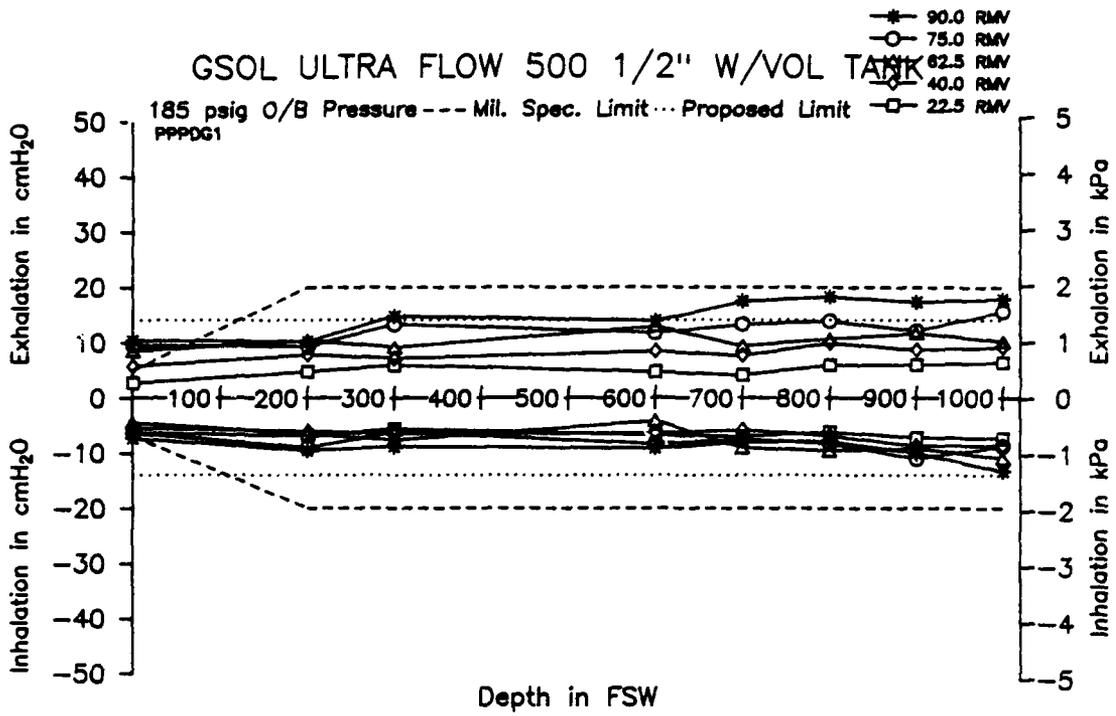


GSOL ULTRA FLOW 500 1/2" ID UMB

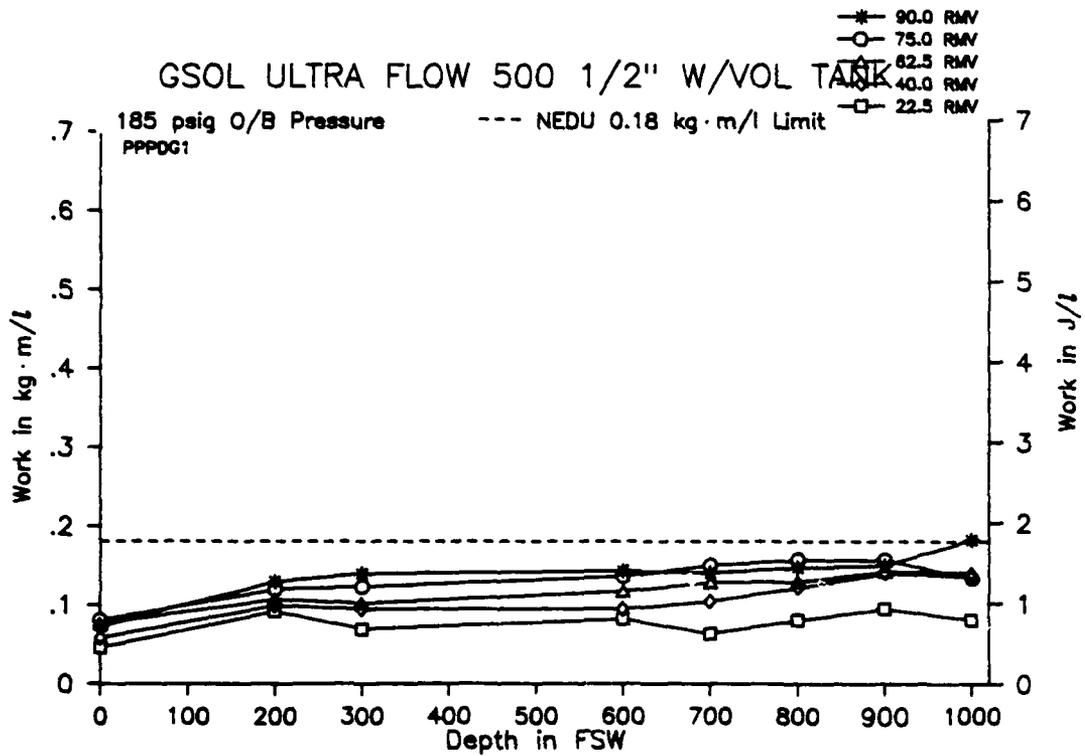




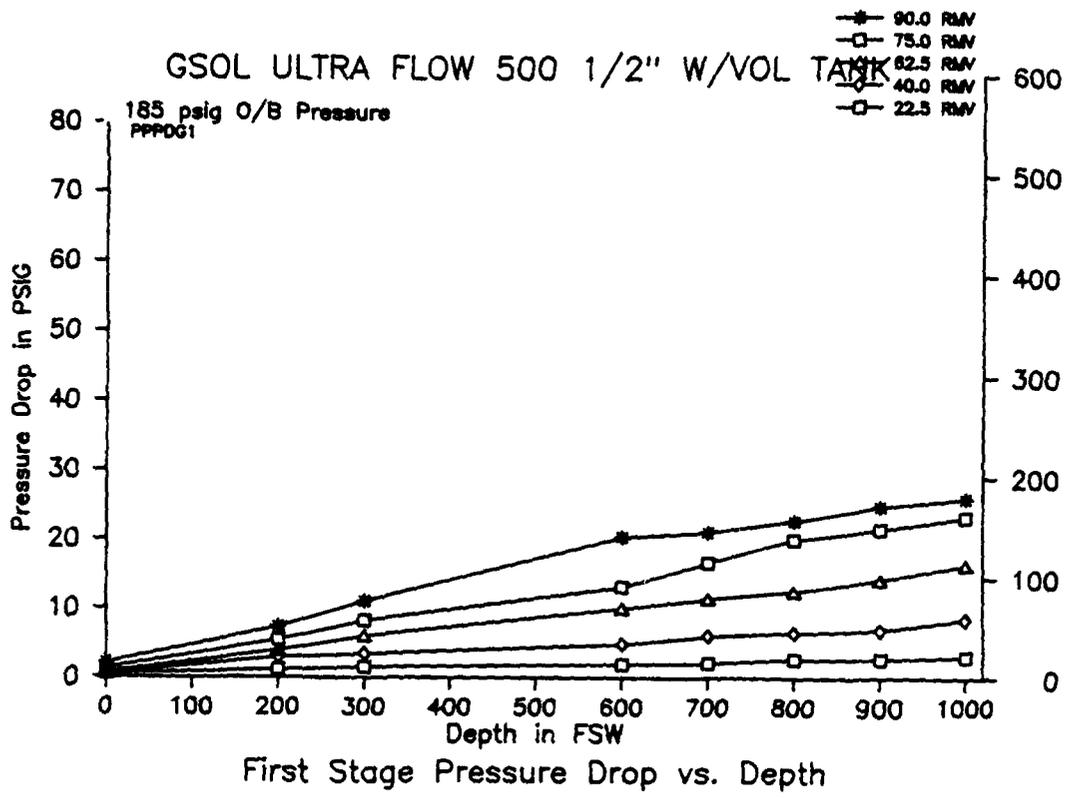




Breathing Resistance vs. Depth

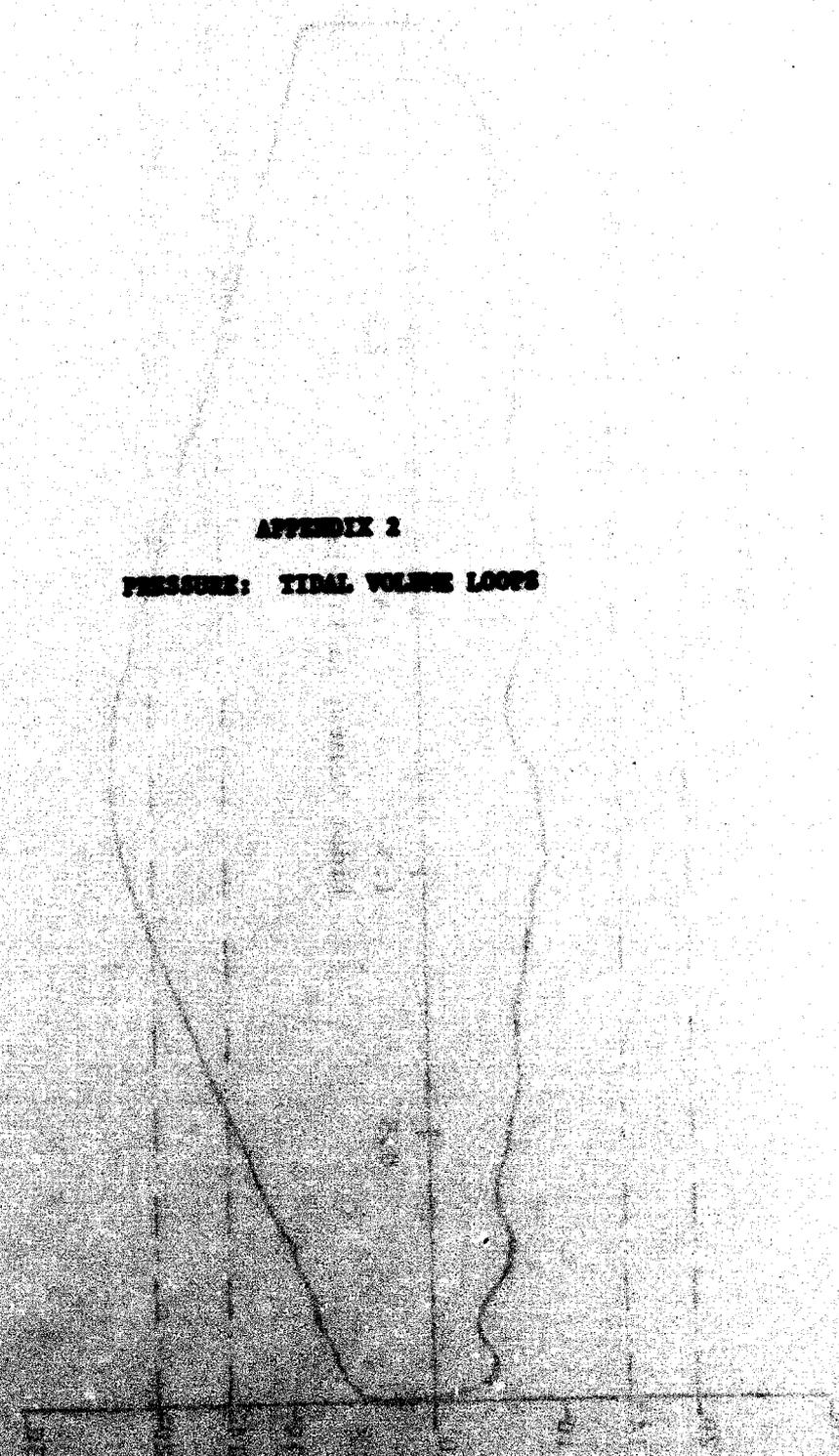


Breathing Work vs. Depth



**APPENDIX 2**

**PRESSURE: TIDAL VOLUME LOOPS**

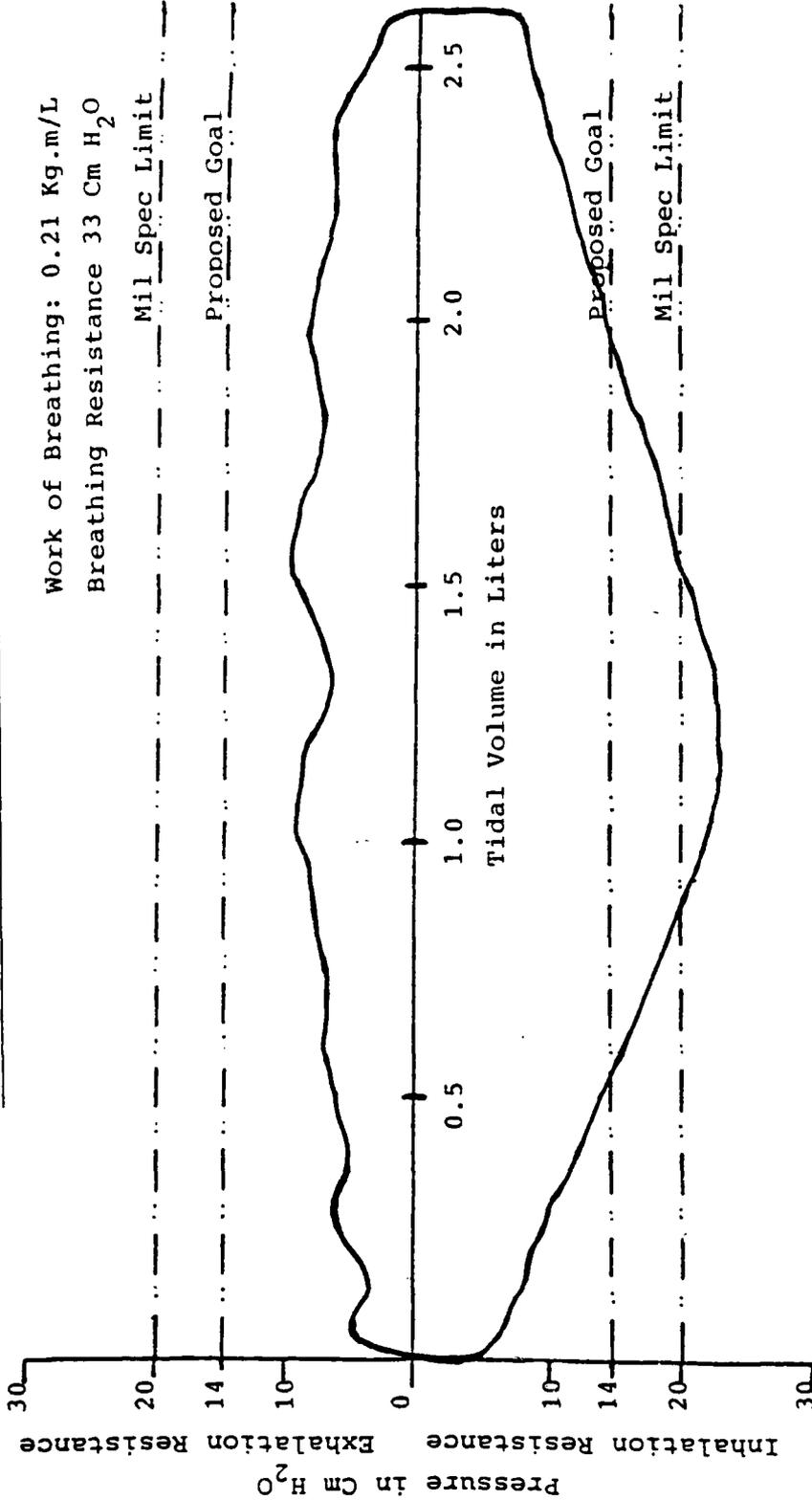


RESPIRATORY PHYSIOLOGY DEPARTMENT  
UNIVERSITY OF CALIFORNIA, SAN DIEGO

DSI SUPERFLOW

3/8" ID Umbilical, 165 psi O/B, 800 FSW, 62.5 RMV

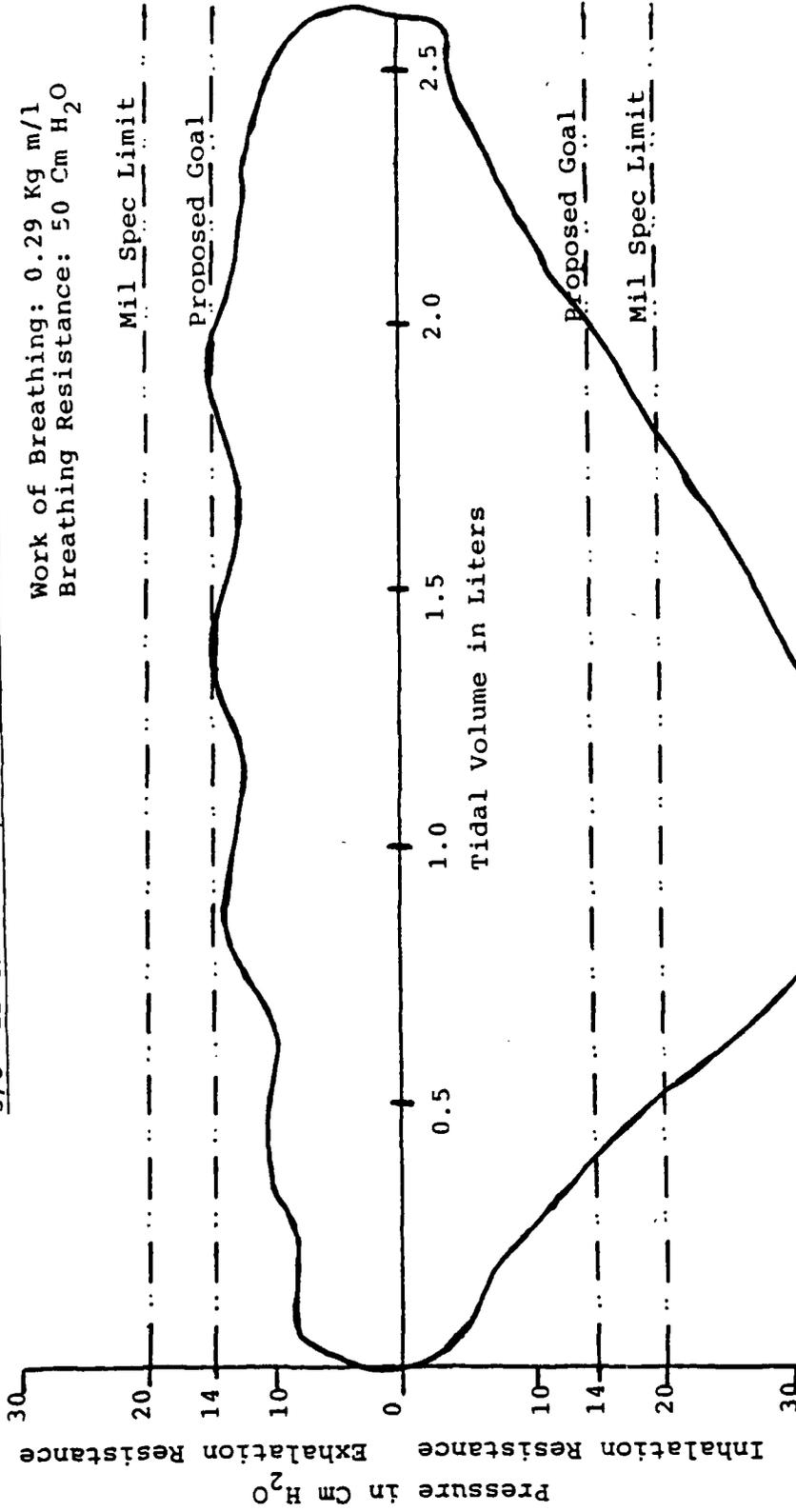
Work of Breathing: 0.21 Kg.m/L  
Breathing Resistance 33 Cm H<sub>2</sub>O



Note: Area inside loop represents 'work of breathing'.  
NEIU performance goal for work of breathing is 0.18 Kg.m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg.m/liter at 75 RMV.

DSI SUPERFLOW  
3/8" ID Umbilical, 165 psi O/B, 800 FSW, 75 RMV

Work of Breathing: 0.29 Kg m/l  
Breathing Resistance: 50 Cm H<sub>2</sub>O

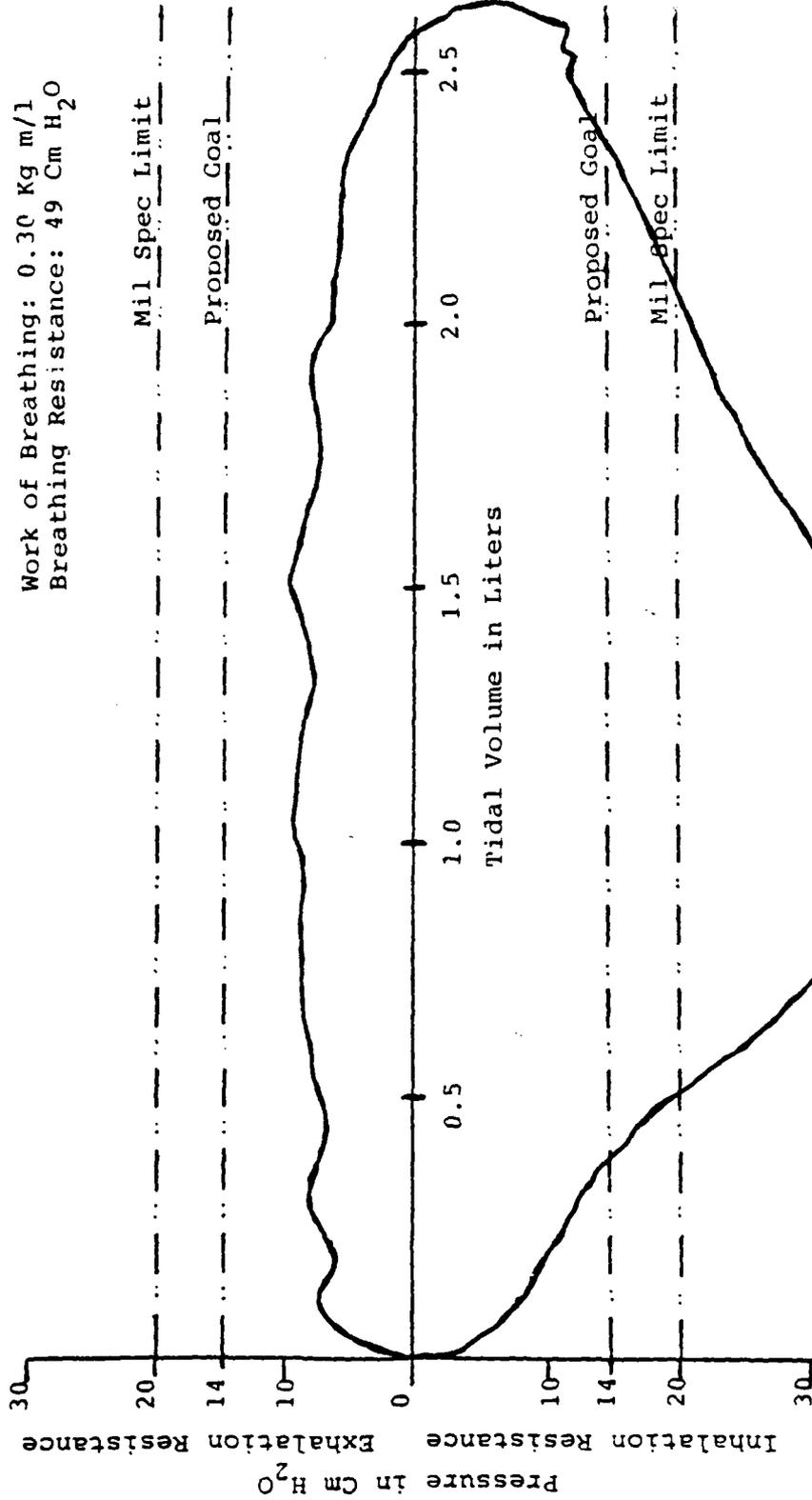


Note: Area inside loop represents 'work of breathing'.  
NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

DSI SUPERFLOW

3/8" ID Umbilical, 165 psi O/B, 1000 FSW, 62.5 RMV

Work of Breathing: 0.30 Kg m/l  
Breathing Resistance: 49 Cm H<sub>2</sub>O

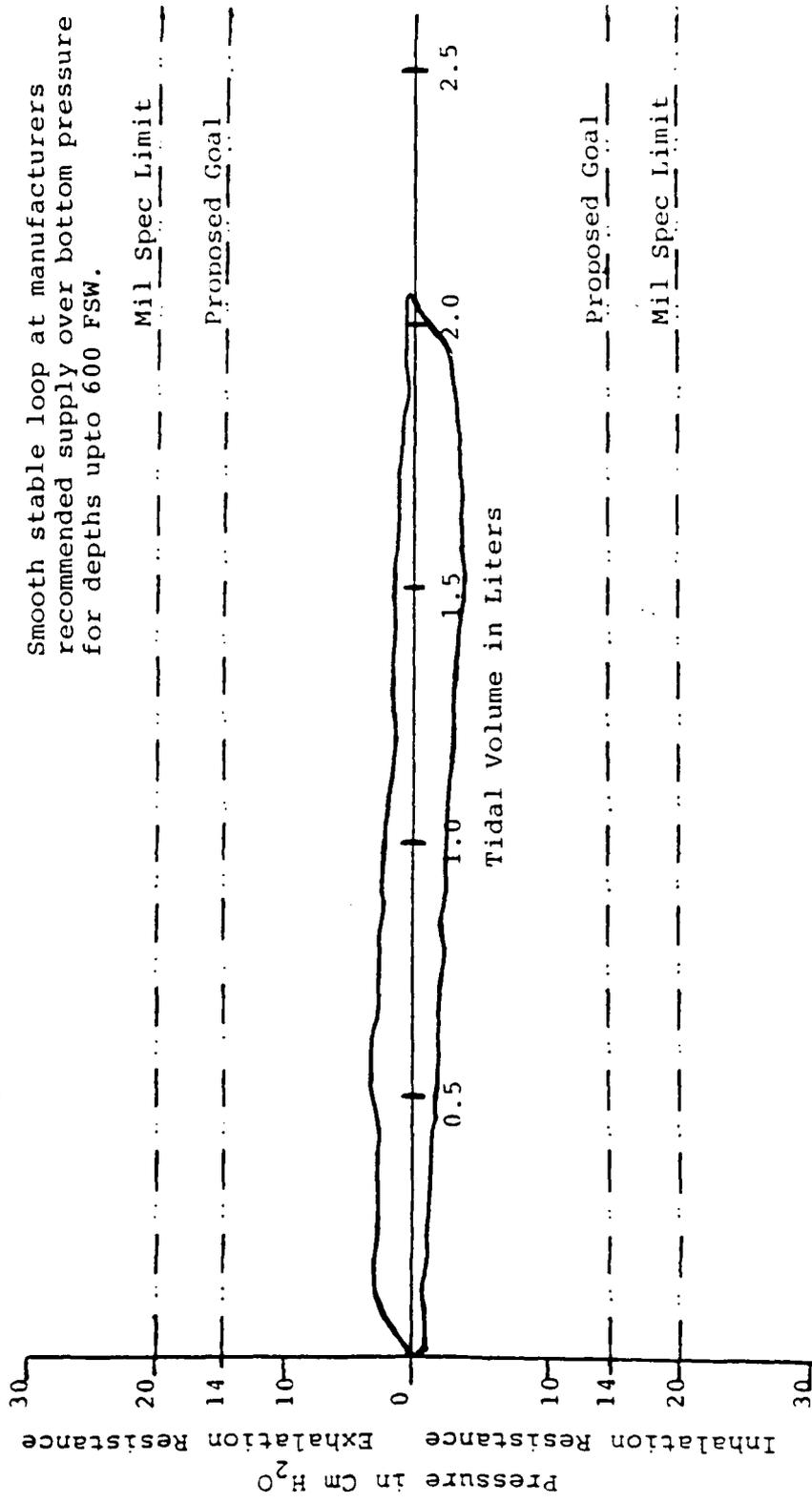


Note: Area inside loop represents 'work of breathing'.  
NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

GSOL ULTRAFLOW 500

3/8" ID Umbilical, 145 psi O/B, Surface, 40 RMV

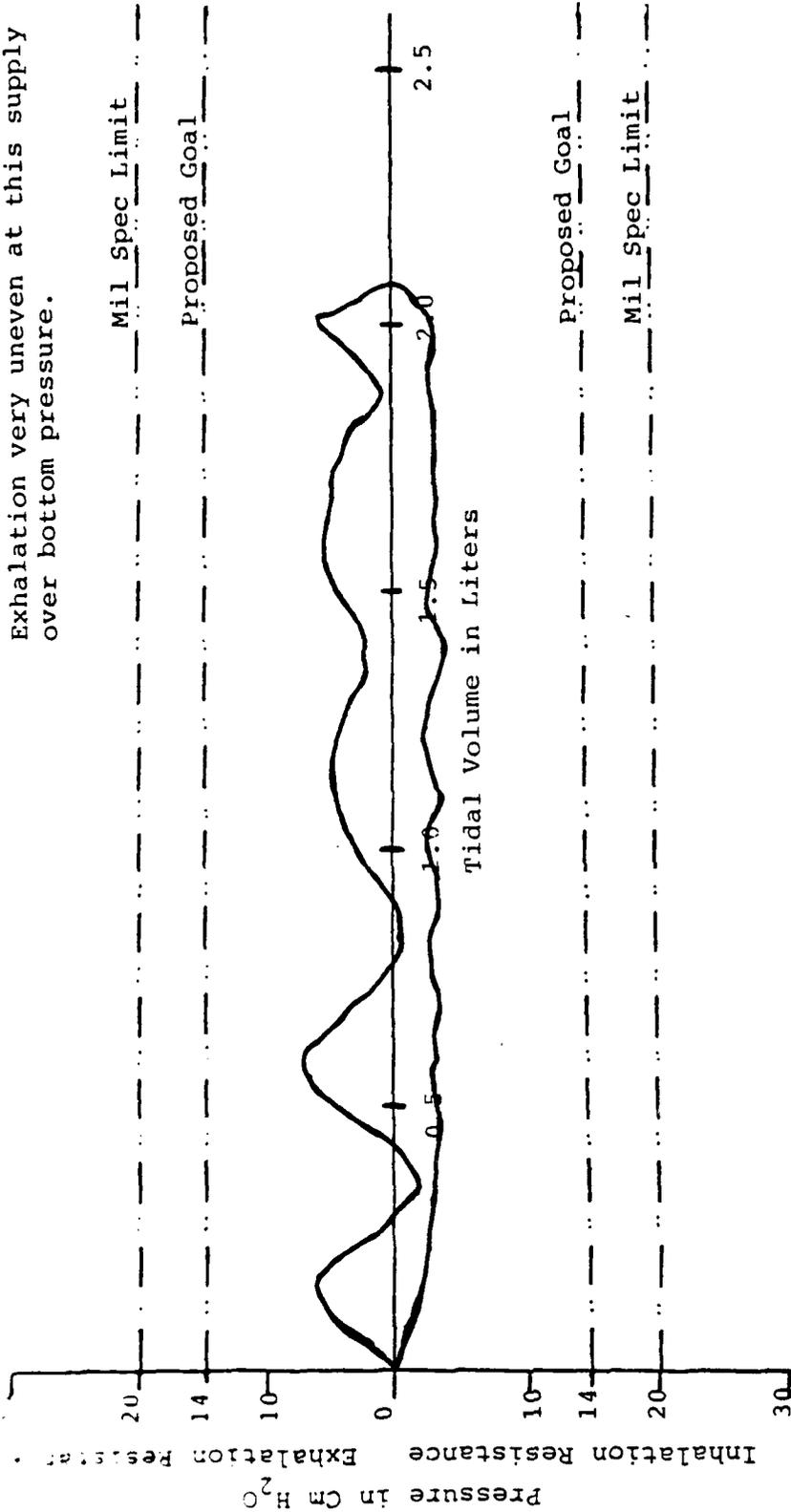
Smooth stable loop at manufacturers recommended supply over bottom pressure for depths upto 600 FSW.



Note: Area inside loop represents 'work of breathing'.  
 NEDU performance goal for work of breathing is 0.18  $\text{Kg}^*\text{m/liter}$  at 62.5 RMV  
 Proposed performance goal is 0.18  $\text{Kg}^*\text{m/liter}$  at 75 RMV.

GSOL ULTRAFLOW 500  
 3/8"-ID Umbilical, 185 psi O/B, SURFACE, 40 RMV

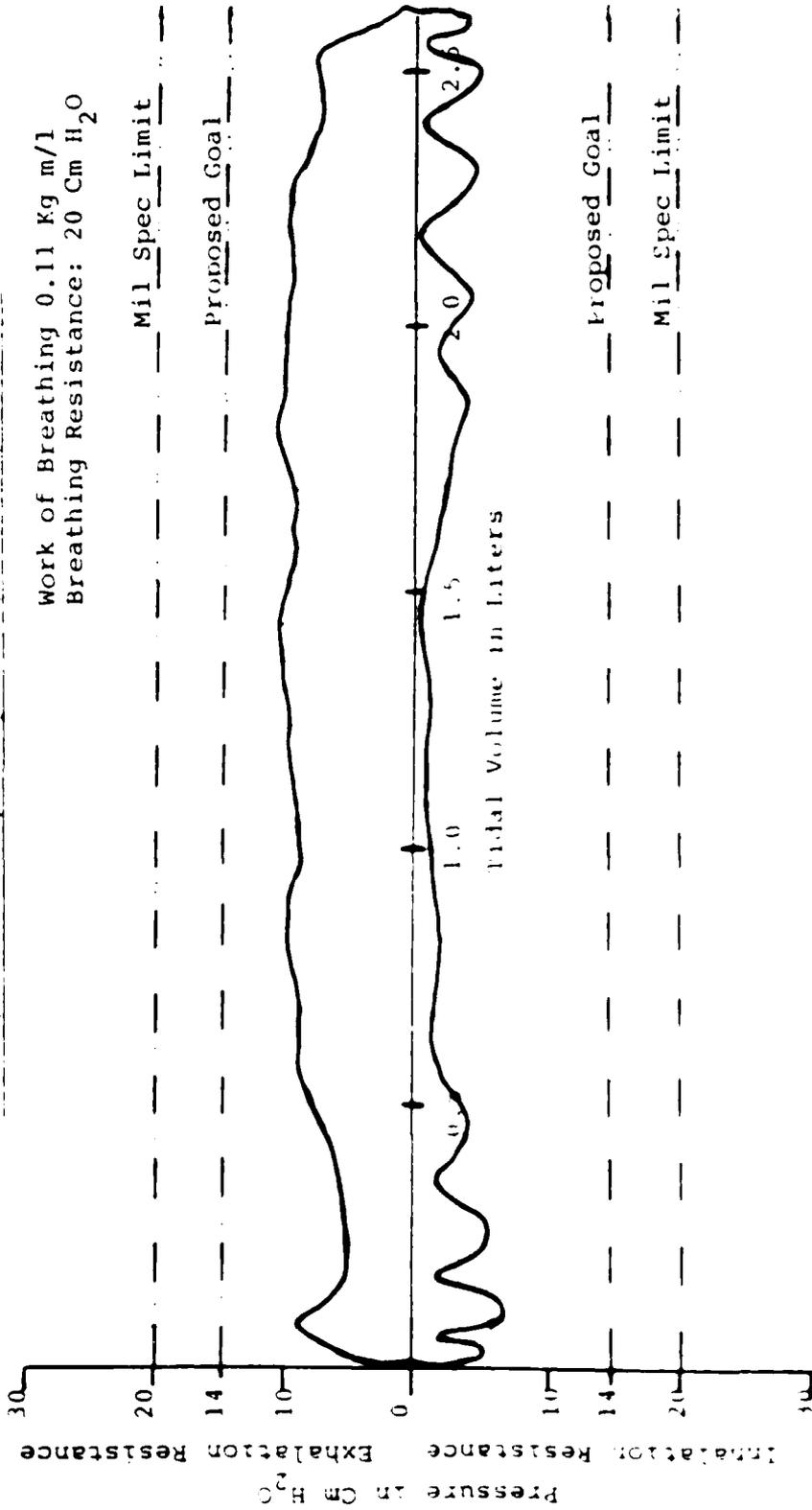
Exhalation very uneven at this supply  
 over bottom pressure.



Note: Area inside loop represents 'work of breathing'.  
 NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
 Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

GSOL ULTRAFLOW 500  
3/8" I/D Umbilical, 185 psi O/B, 800 FSW, 62.5 RMV

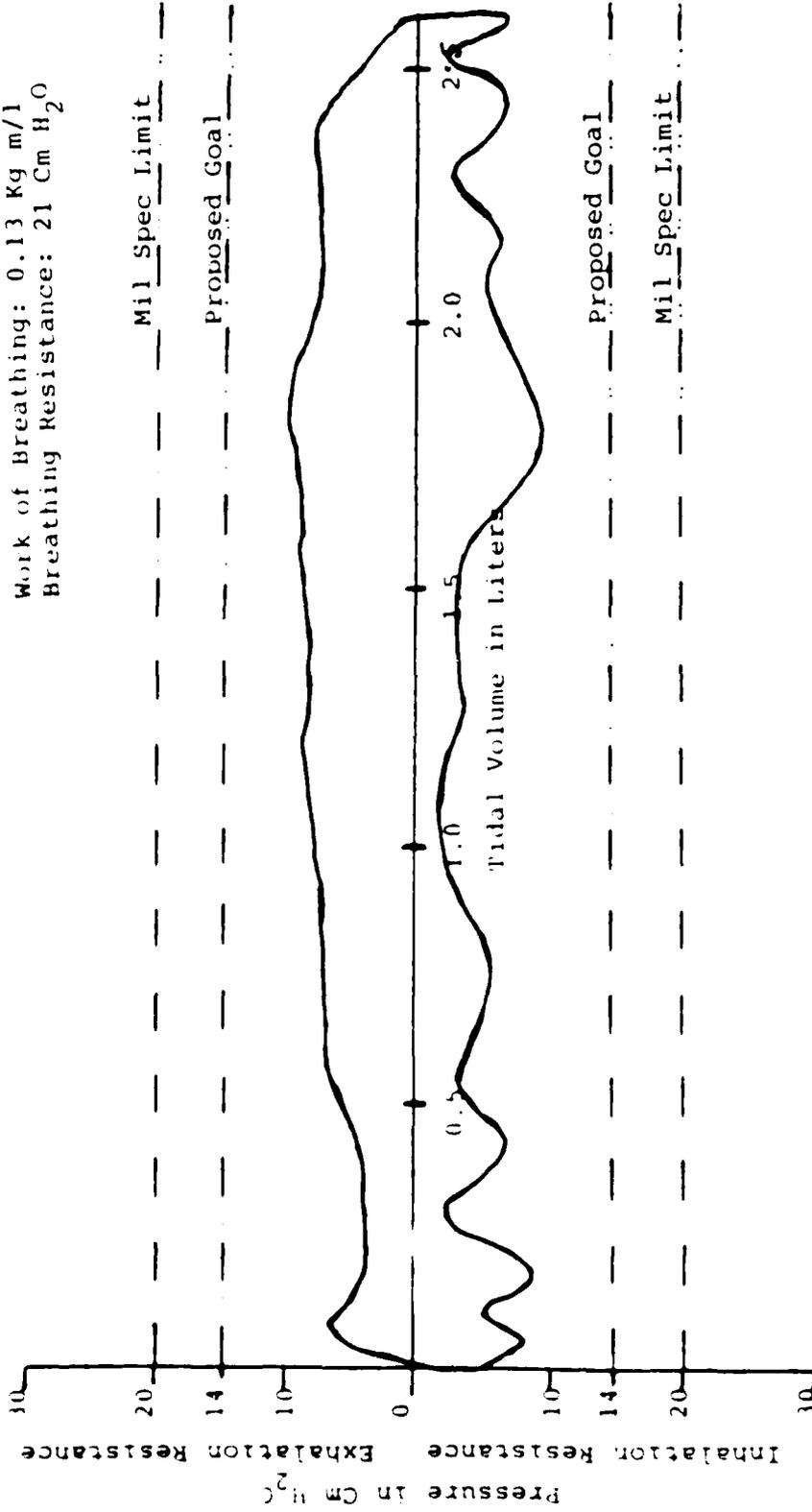
Work of Breathing 0.11 Kg m/l  
Breathing Resistance: 20 Cm H<sub>2</sub>O



Note: Area inside box represents 'work of breathing'.  
2000 performance goal for work of breathing is 0.18 Kg m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg m/liter at 75 RMV.

GSOL ULTRAFLOW 500  
 3/8" ID Umbilical, 185 psi O/B, 800 FSW, 75 RMV

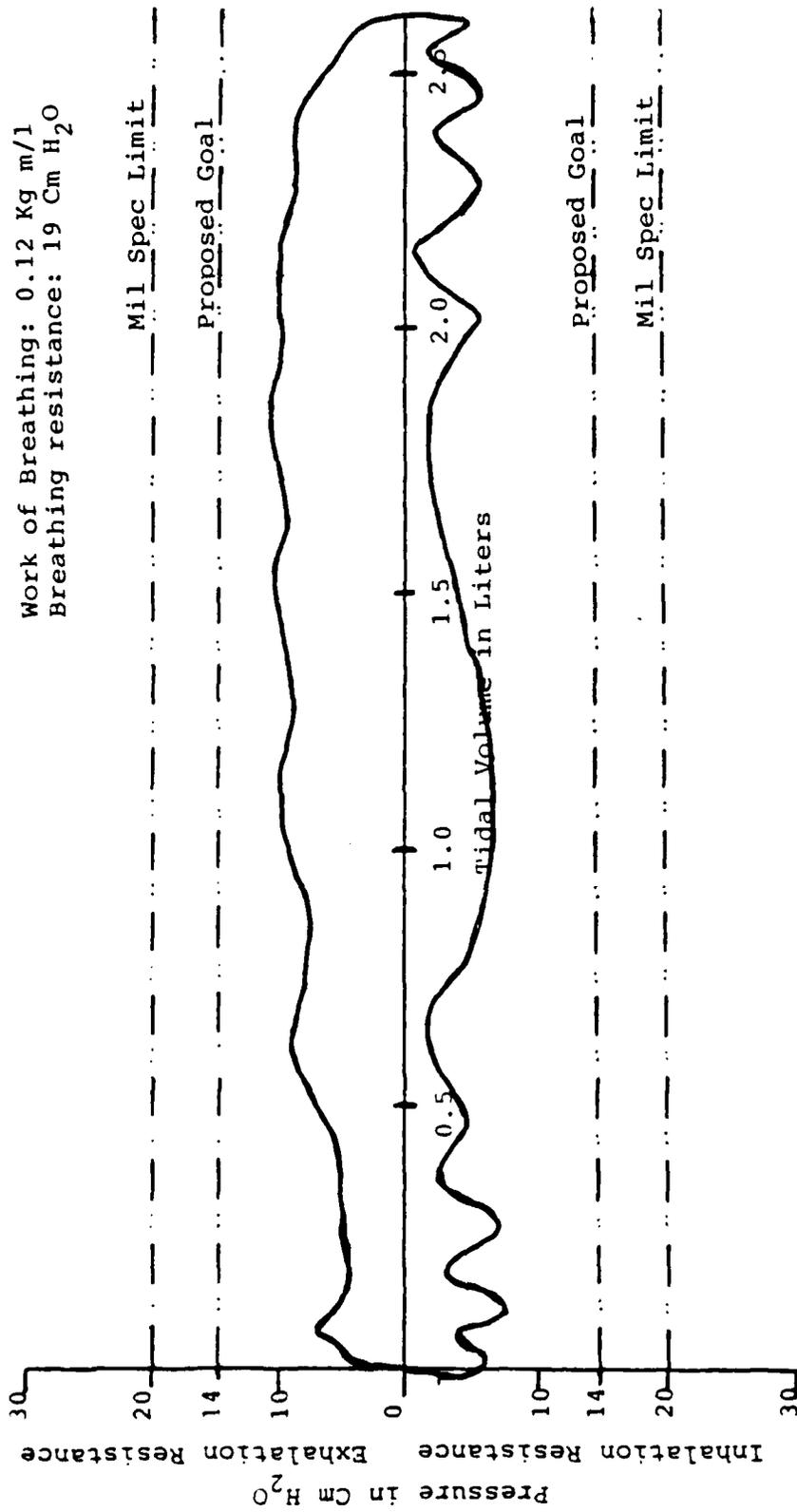
Work of Breathing: 0.13 Kg m/l  
 Breathing Resistance: 21 Cm H<sub>2</sub>O



Note: Area inside loop represents 'work of breathing'.  
 NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
 Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

GSOI. ULTRAFLLOW 500  
 3/8" ID Umbilical, 185 psi O/B, 1000 FSW, 62.5 RMV

Work of Breathing: 0.12 Kg m/l  
 Breathing resistance: 19 Cm H<sub>2</sub>O

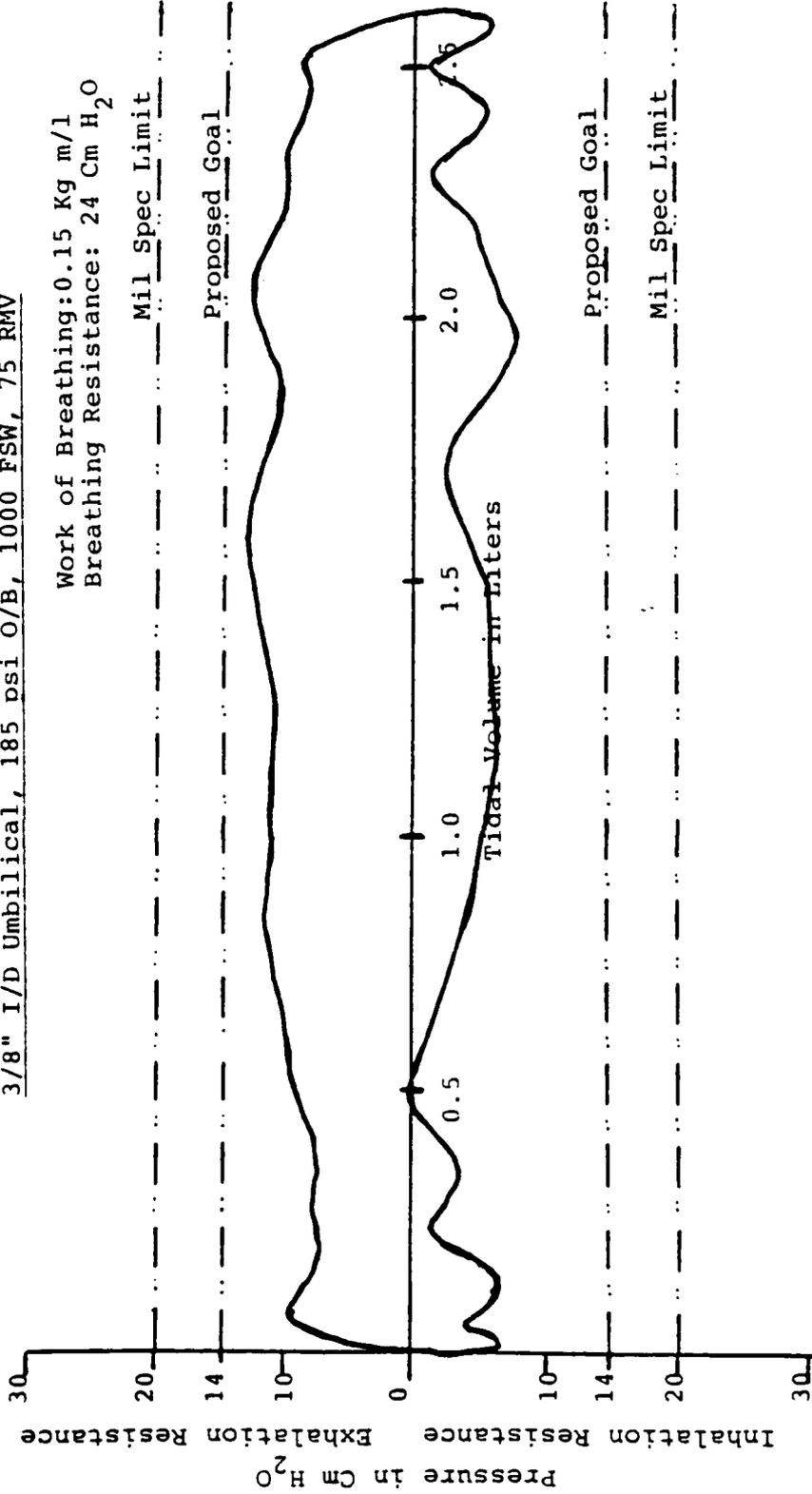


Note: Area inside loop represents 'work of breathing'.  
 NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
 Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

GSOL ULTRAFLOW 500

3/8" I/D Umbilical, 185 psi O/B, 1000 FSW, 75 RMV

Work of Breathing: 0.15 Kg m/l  
Breathing Resistance: 24 Cm H<sub>2</sub>O



01-2

Note: Area inside loop represents 'work of breathing'.  
NEDU performance goal for work of breathing is 0.18 Kg·m/liter at 62.5 RMV  
Proposed performance goal is 0.18 Kg·m/liter at 75 RMV.

