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U.S.N. PROCEDURES FOR TESTING THE
BREATHING CHARACTERISTICS OF OPEN
CIRCUIT SCUBA REGULATORS

Stephen D. Reimers

Navy Experimental Diving Unit
Washington, D. C.

11 December 1973

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NAVXDIVINGU REPORT 23-73
U S.N. PROCEDURES FOR
TESTING THE BREATHING CHARACTERISTICS OF
OPEN CIRCUIT SCUBA REGULATORS

S. D. REIMERS

11 December 1973

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13. ABSTRACT <p>Military Specifications, MIL-R-24169A (Single-Hose) and MIL-R-19558A (Double-Hose) list the specifications which open-circuit SCUBA regulators proposed for U.S. Naval service must meet. The Navy Experimental Diving Unit is the government agency which tests the breathing resistance characteristics of proposed SCUBA regulators for conformance with the applicable military specification. The procedures and standards used by NAVXDIVINGU in the testing of open-circuit SCUBA regulators and their relation to the appropriate military specification are described. Also discussed are changes being proposed in those procedures and standards and changes recommended in the Military Specifications themselves.</p> <p>Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE US Department of Commerce Springfield, VA. 22151</p>			

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ABSTRACT

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TABLE OF CONTENTS

	Page <u>No.</u>
ABSTRACT	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	iii
I. INTRODUCTION	1
II. MILSPEC REQUIREMENTS	3
A. Breathing Machine Test	3
B. Swimming Test	6
C. Supply Pressures	10
III. NAVXDIVINGU TESTING PRACTICES	11
A. Present Practices	11
B. Changes Under Consideration	19
IV. CONCLUSIONS	23
V. RECOMMENDATIONS	24
REFERENCES	25
Appendix A	26
Appendix B	41

LIST OF FIGURES

	Page <u>No.</u>
1. MIL-R-24169A and MIL-R-19558A, "Figure 2, Respiratory Pressures"	4
2. Simulated Swimming Test Arrangement MIL-R-24169A, Figure 4; MIL-R-19558A, Figure 3	7
3. Breathing Resistance Testing Apparatus for Open Circuit SCUBA Regulators	12
4. Regulator Testing Box Details, Single Hose SCUBA Regulators	13
5. Regulator Testing Box Details, Double Hose SCUBA Regulator	14
6. Typical Pressure-Volume Plot from a Single-Hose Regulator Tested wet at 150 fsw at a breathing rate of 15 breaths per minute	17
7. Proposed Limits on External Work of Breathing in the Depth Range 0 to 1000 fsw.	20

I. INTRODUCTION

Military Specifications MIL-R-24169A (single-hose regulators) and MIL-R-19558A (double-hose regulators) list the criteria which open circuit SCUBA regulators proposed for U.S. Naval service must meet.

When regulators are procured under Navy contract, government inspectors from the appropriate defense contract agencies perform the required manufacturing process inspections and tests. Sample regulators are then sent to the Navy Experimental Diving Unit for testing to determine their adherence to the MILSPEC breathing resistance requirements. Successful passage of the NAVXDIVINGU breathing resistance tests is required before the finished regulators can be delivered to the government.

Successful passage of NAVXDIVINGU breathing resistance tests is also required before a regulator submitted by a commercial manufacturer can be placed on the Approved Products List (APL) (3). Naval activities with the necessary funds can purchase any regulator on the APL on the open market without further approval from higher authority. Also, a manufacturer must have one or more regulators on the APL before he can bid on a government contract for regulators without first submitting sample regulators to NAVXDIVINGU for breathing resistance testing.

The purpose of this report is to make public the testing procedures currently used by NAVXDIVINGU, the changes that

are being proposed in those procedures, and the relationship of both the present procedures and the proposed changes to the SCUBA regulator MILSPECS.

II. MILSPEC REQUIREMENTS

The tests that are specified by the MILSPECS as being done by NAVXDIVINGU are outlined below. For ease of reference MILSPECS MIL-R-24169A and MIL-R-19558A are reproduced herein as Appendices A and B.

A. Breathing Machine Test

The appropriate sections of MIL-R-24169A (single-hose SCUBA regulators) are reproduced below:

3.19 Mechanical peak inhalation and exhalation pressures. - The demand regulator assembly shall exhibit, at a maximum, the values of peak inhalation and exhalation pressures of figure 2 (reproduced as Figure 1 herein) when tested on a mechanical breather in accordance with 4.3.1. in ambient pressures up to the equivalent of 200 ft. of sea water.

4.3.1 Mechanical peak inhalation and exhalation pressure test. - The suitability of the preproduction units for swimming to 200 feet in sea water shall be tested by a simulated breathing test using a breathing machine having a tidal volume of two liters set at a rate of 20 breaths per minute. For a given ambient pressure, the maximum pressure differential observed between ambient pressure and pressure inside the mouthpiece during any inhalation cycle shall be the mechanical peak inhalation pressure. For a given ambient pressure, the maximum pressure differential observed between ambient pressure and pressure inside the mouthpiece during any exhalation cycle shall be the mechanical peak exhalation pressure (see 3.19).

The appropriate sections of MIL-R-19558A (3.14 and 4.2.2(a)) are identical in content although the wording is slightly different.

The breathing machine test as defined above has proven very useful. It can be quickly and easily run, and it gives reproducible results. There are, however, several items which need to be considered.

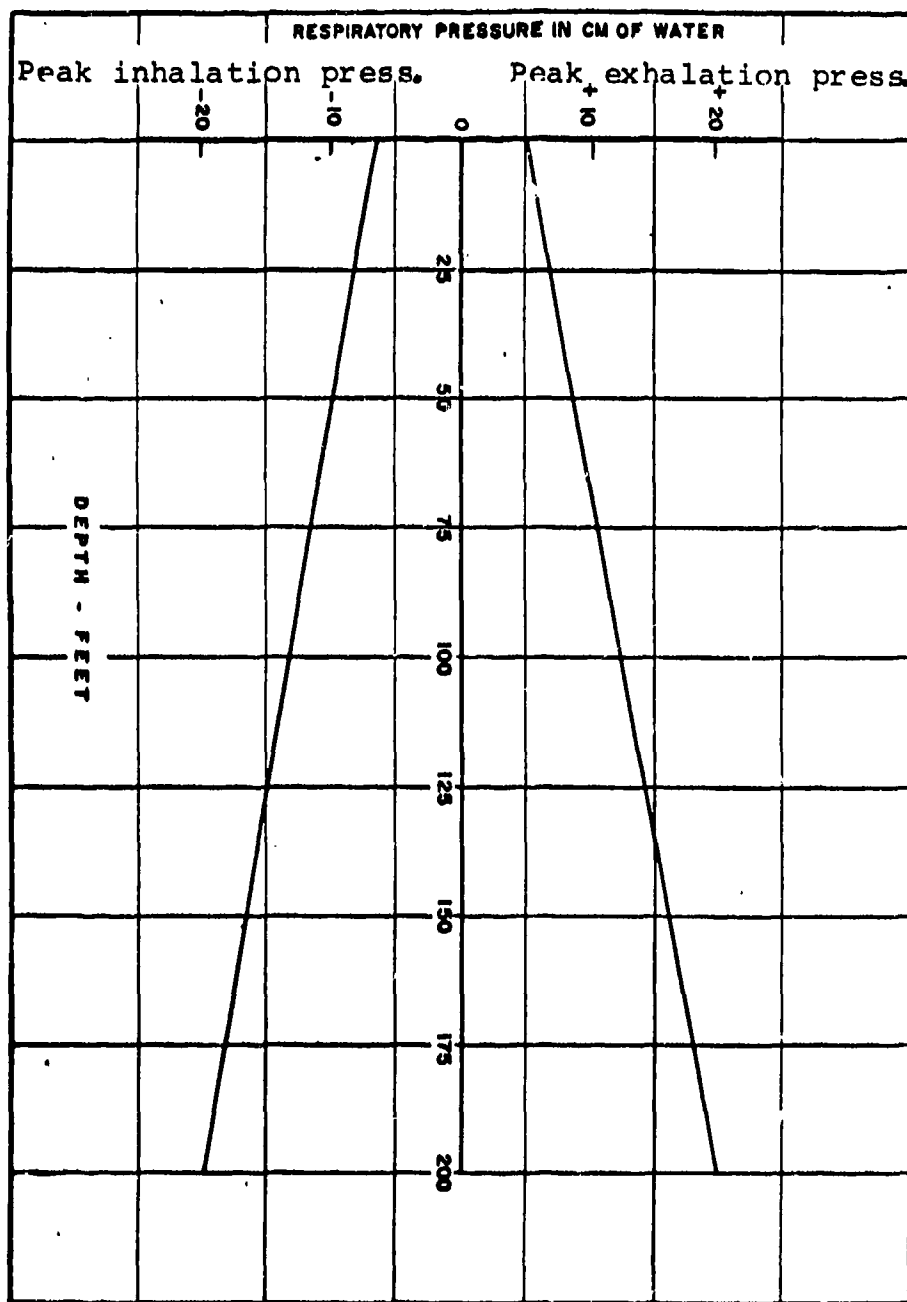


Figure 1

MIL-R-2/169A and MIL-R-19558A, "Figure 2, Respiratory Pressures"

1. The MILSPECS do not specify what waveform is to be produced by the breathing machine. The waveform that has been chosen for tests conducted in accordance with MIL-R-24169A and MIL-R-19558A is a sine wave modified to have an exhalation to inhalation time ratio of 1.1/1.0.

2. The MILSPECS do not specify whether the breathing machine test is to be run with the regulators dry or wet (submerged in water). Submergence can sometimes result in significant degradations in a regulator's performance. It also makes maintaining a stable reference pressure difficult. Current practice is to test the regulators wet.

3. The breathing machine test as defined by the MILSPECS leaves a great deal to the test operator's judgement, particularly when the regulators are tested wet. The level of the reference pressure is not spelled out, nor is the treatment of signal noise caused by bubbles and electrical interference. NAVXDIVINGU practice with respect to these two items is detailed in Section III. A.

4. The test parameters of 2 liters per breath and 20 breaths per minute (40 liters per minute, Respiratory Minute Volume, RMV) are appropriate to moderately heavy work (oxygen consumption, \dot{V}_{O_2} of 1.68 standard liters per minute, slpm; swimming at 0.85 knots) (4) (5). A higher minute volume warrants consideration.

B. Swimming Test

The appropriate sections of MIL-R-24169A (single-hose) are reproduced below:

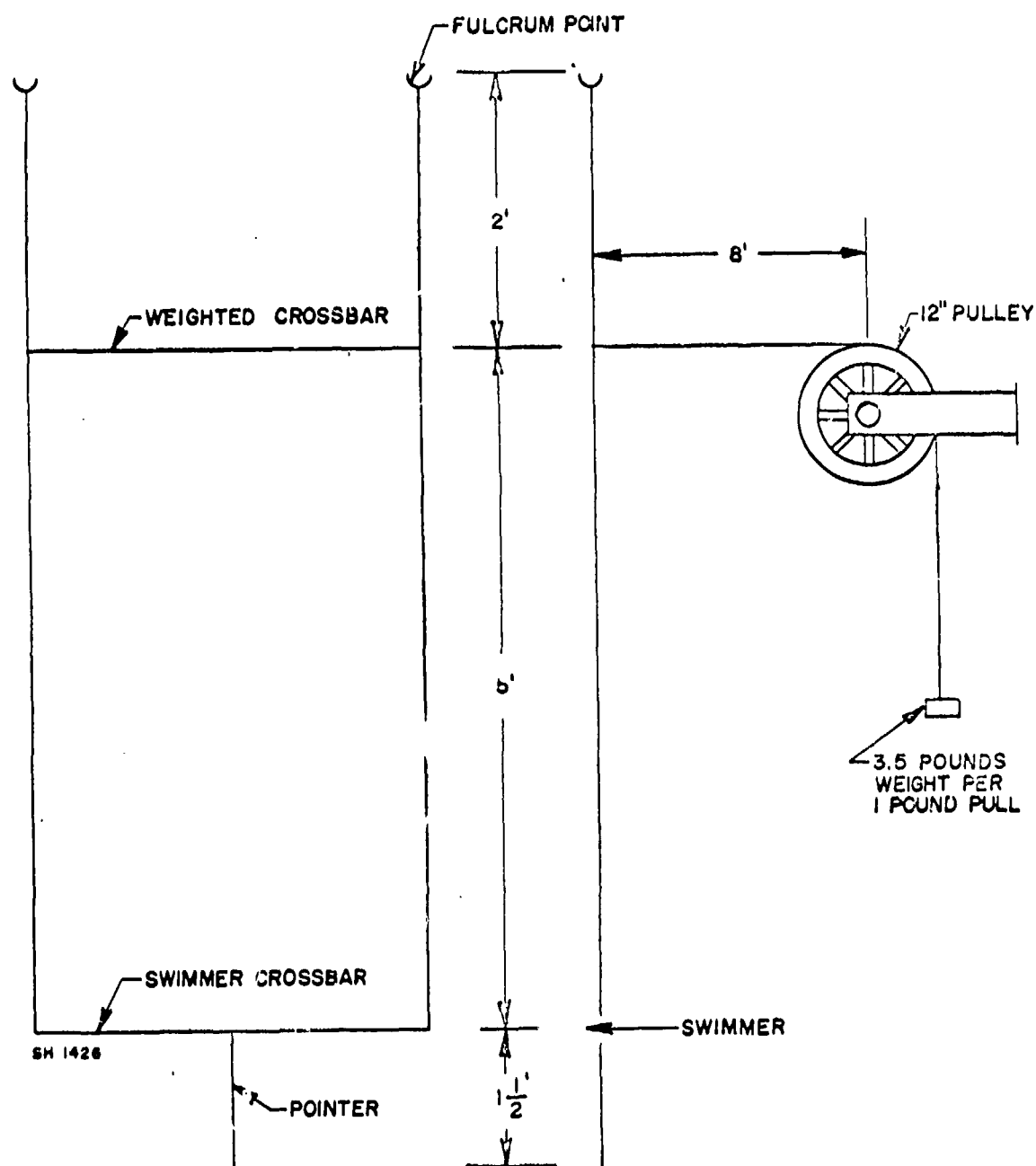
3.20 Subjective peak inhalation and exhalation pressures. - The demand regulator assembly shall demonstrate, at a maximum, the values of peak inhalation and exhalation pressure of figure 2 (Figure 1 herein) when used by a typical U.S. Navy diver having a maximum tidal volume of 5 liters at simulated depths up to 200 feet of sea water swimming against a 12-pound force (see 4.3.2).

4.3.2 Subjective peak inhalation and exhalation pressure test. - When preproduction units have successfully passed the testing of 4.3.1, they shall be additionally tested using the arrangement shown on Figure 4 (Figure 2 herein). For a given depth, the maximum pressure differential observed between ambient pressure at mouthpiece level and pressure inside the mouthpiece during any inhalation cycle shall be the subjective peak inhalation pressure. For a given depth the maximum pressure differential observed between ambient pressure at mouthpiece level and pressure inside the mouthpiece during any exhalation cycle shall be the subjective peak exhalation pressure. (see 3.20).

The appropriate sections of MIL-R-19558A (double-hose) are reproduced below:

3.4 The demand regulator shall operate in accordance with all requirements of this specification when used with high pressure air flasks. When using high pressure cylinders the apparatus shall operate satisfactorily in accordance with this specification when swimming to 200 feet.

3.14 The demand regulator in combination with breathing tubes, mouthpiece, or face mask shall have satisfactory inhalation and exhalation pressures with a man swimming at speed of 1 mile per hour and have a maximum tidal volume of 5 liters. The inhalation and exhalation pressures shall not exceed the values shown on figure 2 (Figure 1 herein) for machine test with breathing tubes and mouthpiece or with mask when tested as specified in 4.2.



Front View

Side View

Figure 2

SIMULATED SWIMMING TEST ARRANGEMENT
MIL-R-24169A, Figure 4; MIL-R-19558A, Figure 3

3.15 The demand regulator in combination with breathing tubes and mouthpiece or face mask shall not have inhalation or exhalation pressures which exceed 200 centimeters of water at 200 feet when swimming against a 12-pound force.

This swimming test for SCUBA has not been used for several years. The reasons for this lack of utilization follow:

1. Swimming against a 12-pound force represents a severe exercise level that can be maintained for only very short periods of time (^{oxygen} consumption \approx 2.95 slpm; RMV \approx 70 lpm; appropriate to swimming at about 1.3 knots) (4) (5). Not only does this test represent severe exercise, it also is inconsistent with the 40 lpm RMV used in the breathing machine tests. Enforcement of this provision of the MILSPECS would result in the disqualification of nearly every SCUBA regulator currently in use by the U.S. Navy.

2. The 1 mile per hour (0.87 knot) swimming speed specified in MIL-R-19558A, Section 3.14 would be a much more reasonable test. It is appropriate to an oxygen consumption of roughly 1.5 slpm, an RMV of approximately 35 lpm or swimming against a steady force of about 8.2 pounds. It is, however, inconsistent with the 12-pound steady force specified in Sections 3.15 and 4.2.2.(b) of the same MILSPEC. The 200 cm H₂O pressure limit specified in Section 3.15 of MIL-R-19558A is also an obvious error. It should read 20 cm H₂O.

3. This type of test is difficult to perform accurately, and it does not normally yield reproducible

results. The respiratory demands that the diver places on the regulator (in particular his respiratory waveform) vary widely from diver to diver, and they are difficult to measure or monitor. Consequently a regulator may easily pass when used by one diver and fail when used by another.

C. Supply Pressures

The appropriate sections of the two MILSPECS are reproduced below:

MIL-R-24169A (Single-hose)

3.8 Supply pressures. - The demand regulator assembly shall function in accordance with this specification with supply pressures from 3,000 pounds per square inch (psi) to 200 psi. The high pressure regulator shall withstand application of 5,000 psi hydrostatically without sustaining damage.

MIL-R-19558A (Double-hose)

3.5 When used with high pressure cylinders the demand regulator shall function in accordance with this specification from 3000 pounds per square inch (p.s.i.) to 100 p.s.i.

Almost all SCUBA regulators in current military or commercial use will meet the above supply pressure limits at 0 fsw. However, very few will operate satisfactorily with a supply pressure of 200 psi at 200 fsw (MIL-R-24169A). At 200 fsw, 200 psi is only 111 psi over bottom pressure (assuming psi in the MILSPECS to mean psig and not psia). The 100 psi minimum supply pressure specified in MIL-R-19558A is completely unrealistic. At 200 fsw it is only 11 psi over bottom pressure. Enforcement of that specification would preclude the use of double-hose SCUBA regulators by the U.S. Navy. Current practice is to pass a regulator under test as long as it operates satisfactorily at all supply pressures above 200 psi over bottom pressure.

III. NAVXDIVINGU TESTING PRACTICES

A. Present Practices

1. Apparatus

Figures 3, 4 and 5 show the experimental apparatus used to test both single and double hose open circuit SCUBA regulators.

The breathing machine is set up to deliver 20 breaths per minute with a tidal volume of 2.0 liters per breath. The volume-time waveform produced is that of a sinusoid modified to have a ratio of exhalation time to inhalation time of 1.1/1.0. Reference 6 contains a complete description of the breathing machine and its characteristics.

The end of the breathing pipe is formed to conform to the mouthpiece shape of the regulator under test.

The differential pressure transducer is connected so that it indicates the pressure differential between the interior of the regulator mouthpiece and water pressure (air pressure, if dry) at the centerline level of the second stage diaphragm. The transducers used are usually 1 psid (psi differential) variable reluctance transducers with a minimum frequency response range of 0 to 100 Hz. The amplifiers and oscillographic strip chart recorders used with the transducers have a minimum frequency response range of 0 to 40 Hz at a full scale deflection of 50 mm. The X-Y plotter has a maximum acceleration capability of 1750 in/sec² in the X direction and 2750 in/sec² in the Y direction with a maximum writing speed of 100 inches/second.

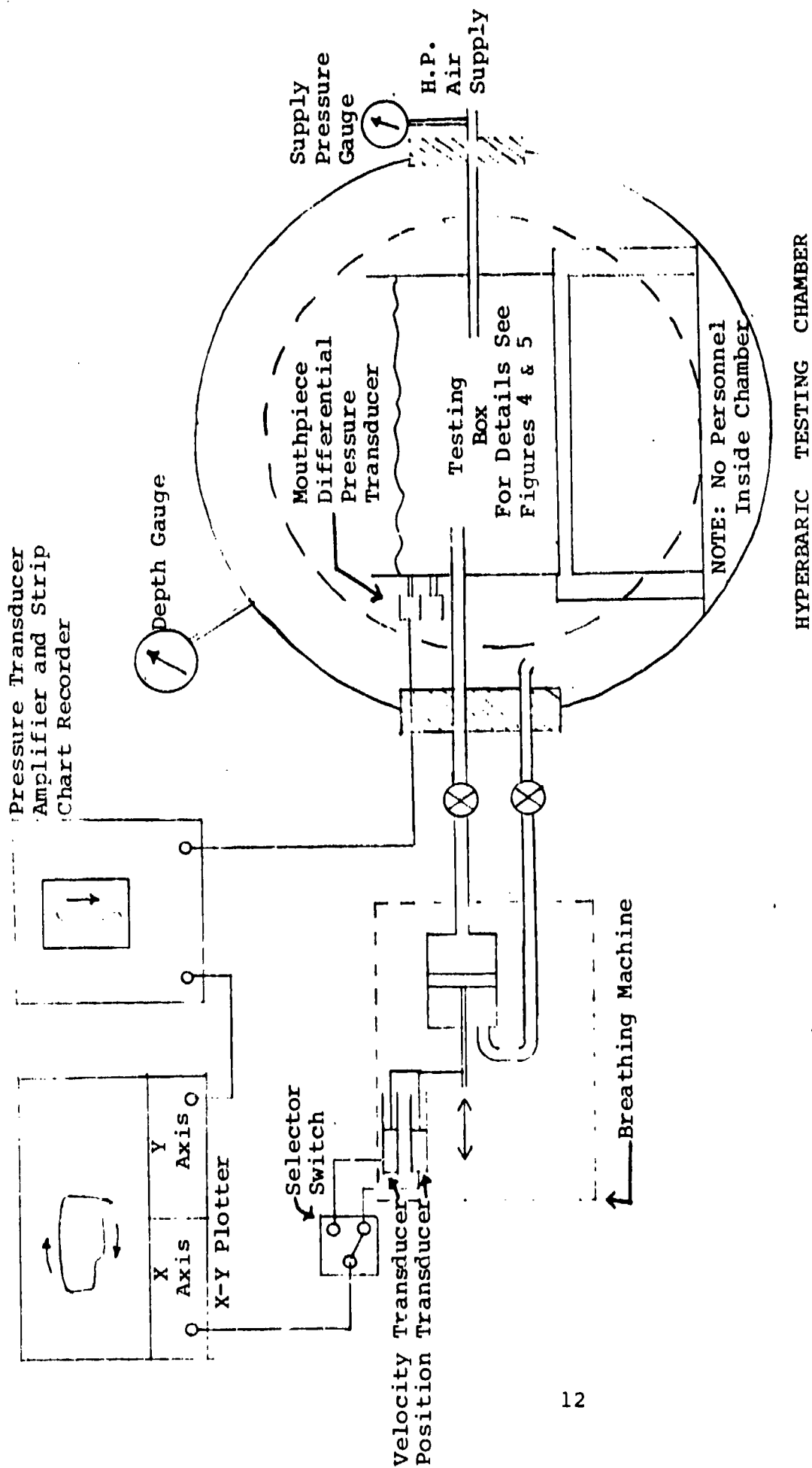


Figure 3
Breathing Resistance Testing Apparatus for
Open Circuit SCUBA Regulators

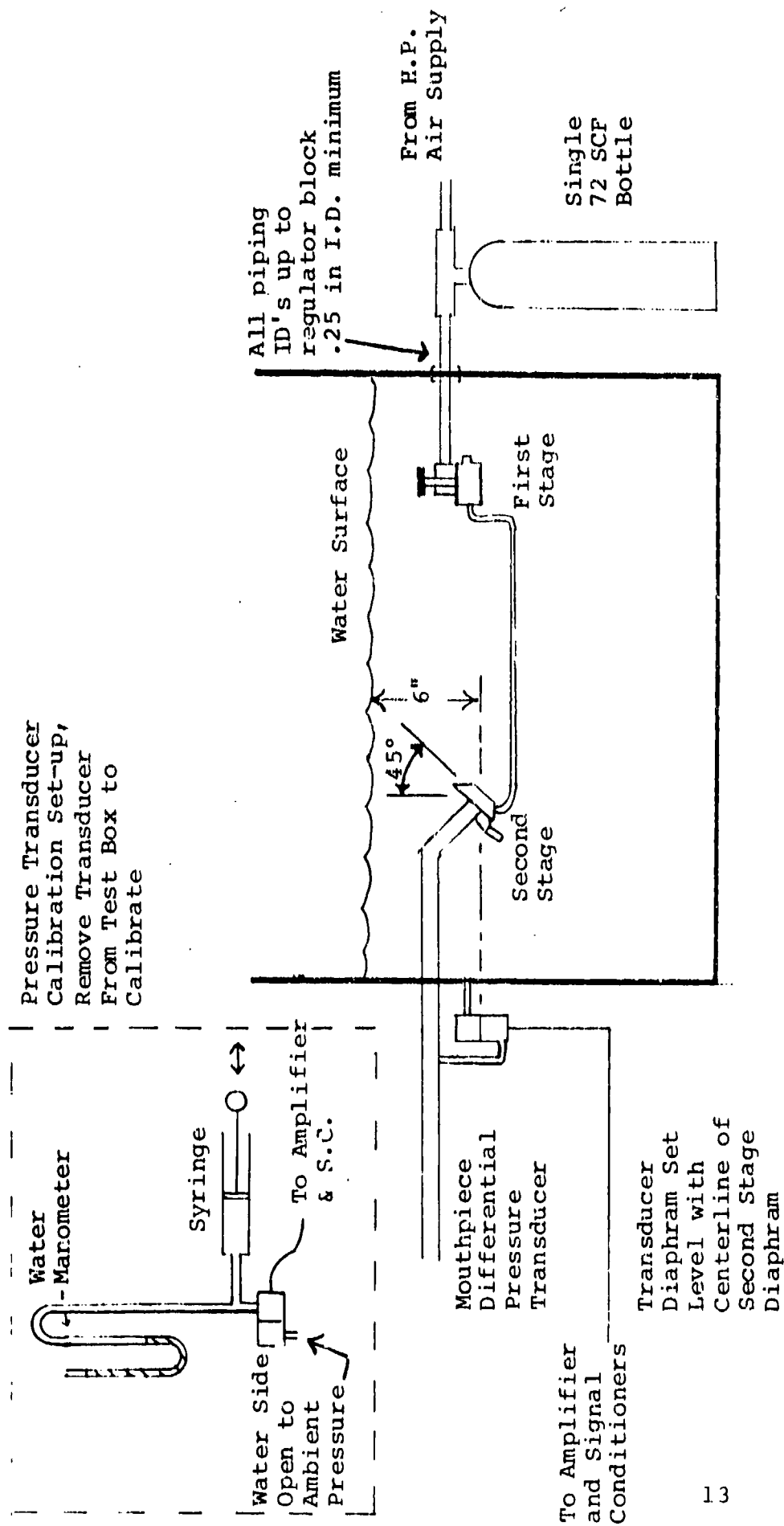


Figure 4

Regulator Testing Box Details, Single Hose SCUBA Regulators

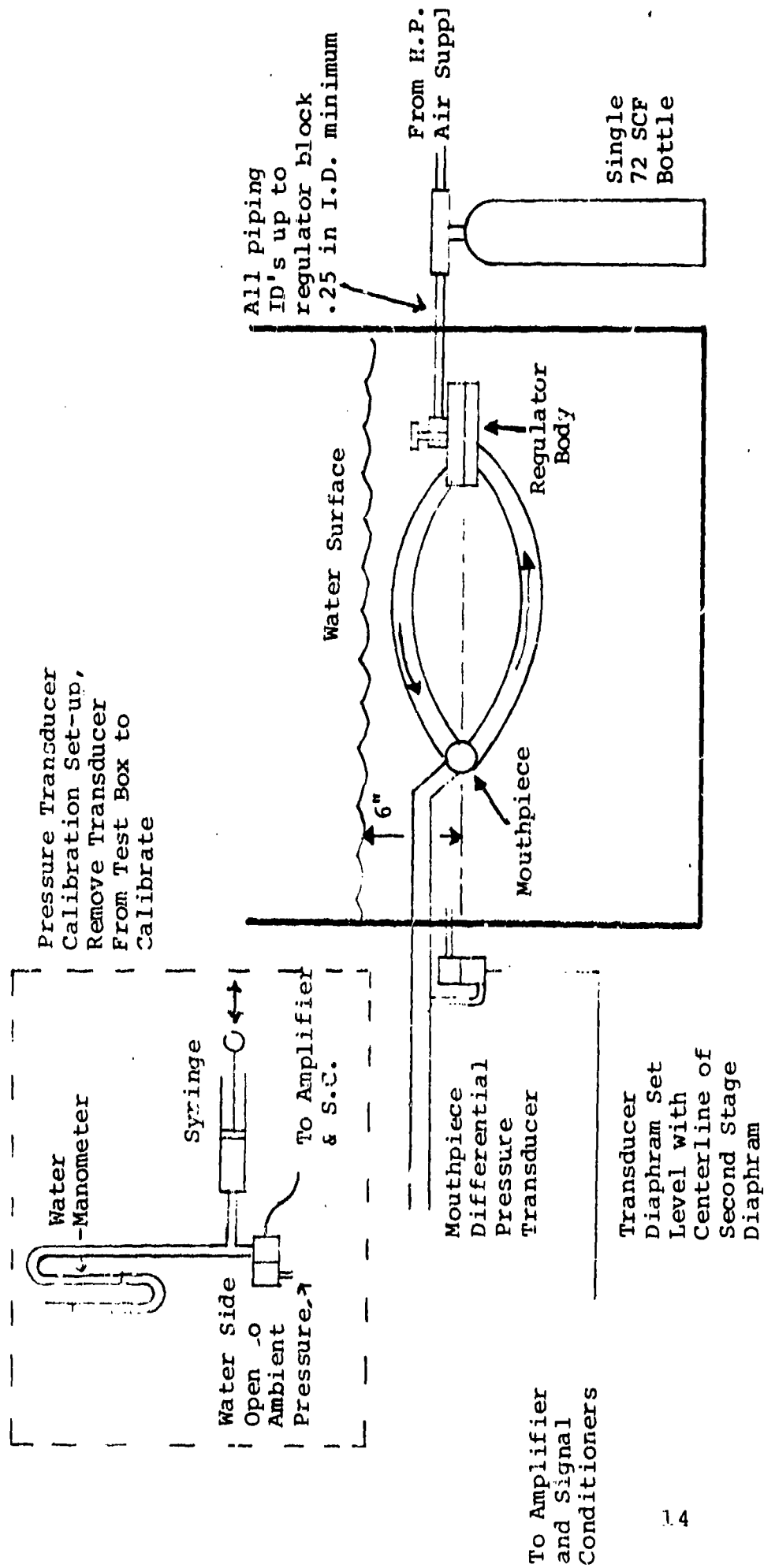


Figure 5
Regulator Testing Box Details, Double Hose SCUBA Regulator

Inspired-expired volume is measured by means of a linear position transducer in the breathing machine piston shaft. Inspiratory-expiratory flow rates are measured by a similarly located velocity transducer. Either volume or flow rate information can be feed into the X axis of the X-Y plotter yielding respectively pressure-volume or pressure-flow rate traces.

The free volume of the plumbing between the breathing machine piston and the regulator is kept below 2 liters. Assuming a maximum pressure change of 20 cm H₂O, this results in a maximum volume error due to compression of the gas enclosed in the plumbing of 39 cc at 0 fsw. 39 cc represents an error of less than 2% of the 2 liter tidal volume normally used. This compression error, of course, decreases with increasing depth. At 200 fsw, it is only 5.6 cc or 0.3% of the normal 2.0 liter tidal volume.

2. Procedures

Figures 3, 4 and 5 show the test apparatus used when a regulator is to be tested "wet". The test apparatus used when a regulator is to be tested "dry" is identical with the exception that no water is placed in the testing box. All regulators are normally tested either wet or both wet and dry.

During dry testing the regulator mouthpiece pressure is measured relative to chamber ambient pressure.

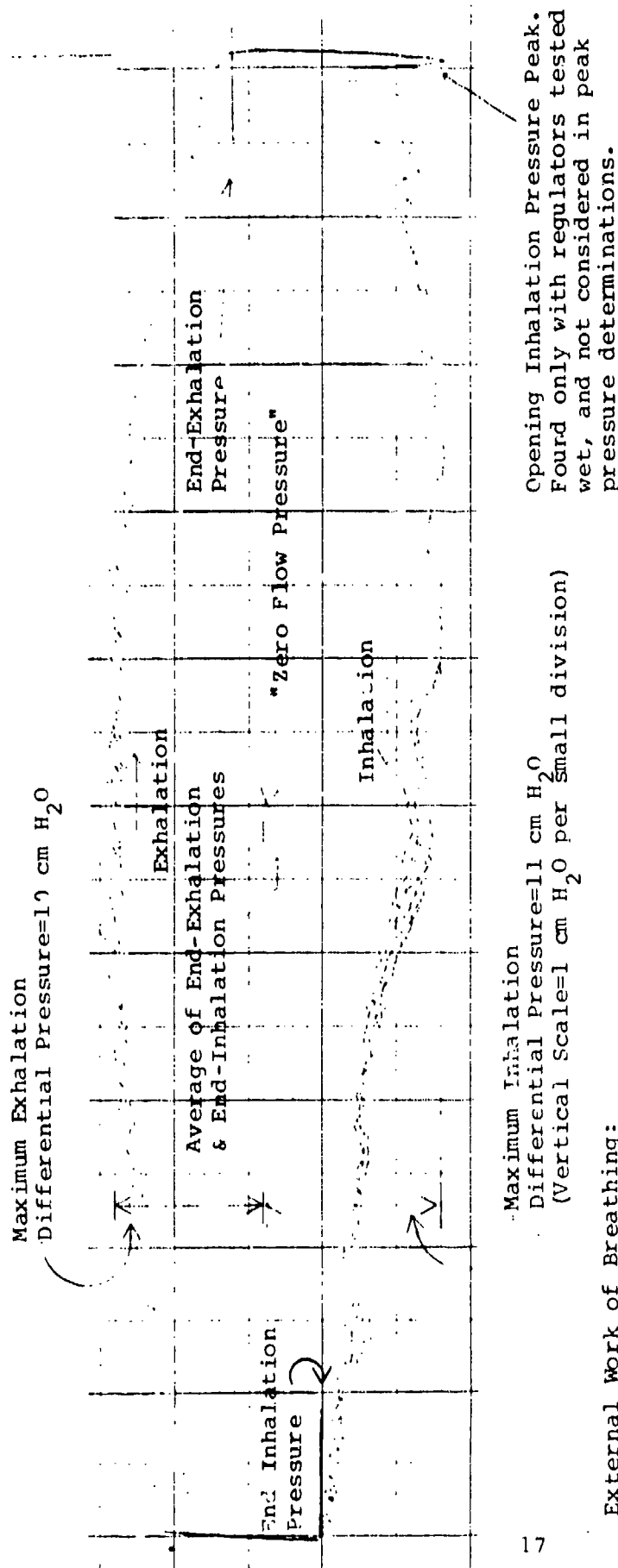
During wet testing, however, even with the equipment set-up shown in Figures 3, 4 and 5, maintaining a

valid reference pressure for the transducer is sometimes difficult. Aeration of the water and water splash-out are two of the main sources of difficulty. Consequently the reference pressure used during wet tests is the "zero flow condition pressure" determined by securing the breathing machine and recording the equilibrium pressure reached in the regulator mouthpiece with no gas flowing. This method has been found to give stable, reliable reference pressures which have proven valid over a wide range of conditions.

The "zero flow condition pressure" is nearly always essentially midway between the end-exhalation and end-inhalation pressures. See Figure 6. Consequently, the average of the end-exhalation and end-inhalation pressures serves as a reasonably accurate on-line check of the "zero flow condition pressure". Indeed in some cases where it is inconvenient or impossible to frequently start and stop the breathing machine, this average pressure can be used as the reference pressure. The "zero flow condition pressure" however must be checked at least once each time the test depth is changed.

The peak inhalation and peak exhalation pressure differentials relative to the reference pressure are read from the pressure-volume plot as shown in Figure 6. They may also be read from the strip chart recorder trace. However, the pressure-volume plot is normally easier to read. It is not as easily degraded by noise as is the pressure-time trace, and the end-inhalation, end-exhalation pressures

Tidal volume=2 liters



External Work of Breathing:
Exhale Work=.167 Kg-m/breath
Inhale Work=.182 kg-m/breath
Total Work =.348 Kg-m/breath
or .174 Kg-m/liter

Figure 6

Typical Pressure-Volume Plot from a Single-Hose Regulator Tested wet at 150 fsw at a breathing rate of 15 breaths per minute. Plot represents 8 breaths. Note the reproducibility from breath to breath. Note also that the external work of breathing of this regulator slightly exceeds the .17 Kg-m/liter standard under consideration (See Figure 7).

are much easier to identify. Also the nature of the pressure-volume plot permits a much better understanding of how the regulator is operating, and this makes interpretation much easier whenever judgement decisions must be made.

Pressure-flow rate plots are not normally made during routine regulator tests. They are made only if there is an anomaly in the pressure-volume plots or if additional information is desired beyond an answer to the basic question "Does the regulator meet the MILSPEC requirements?".

Peak inhalation and exhalation pressure measurements are made at 25 foot increments during both descent and ascent from 0 to 200 fsw with a supply pressure of 1000 psig. At 0 and 200 fsw only the regulators are additionally tested at 3000 psig and 500, 400, 300 and 200 psi over bottom pressure.

3. Standards

The breathing resistance characteristics of open circuit SCUBA regulators are currently considered satisfactory when they meet the peak pressure limits of Figure 1 when tested in accordance with Sections III.A.1 and III.A.2 herein.

B. Changes Under Consideration

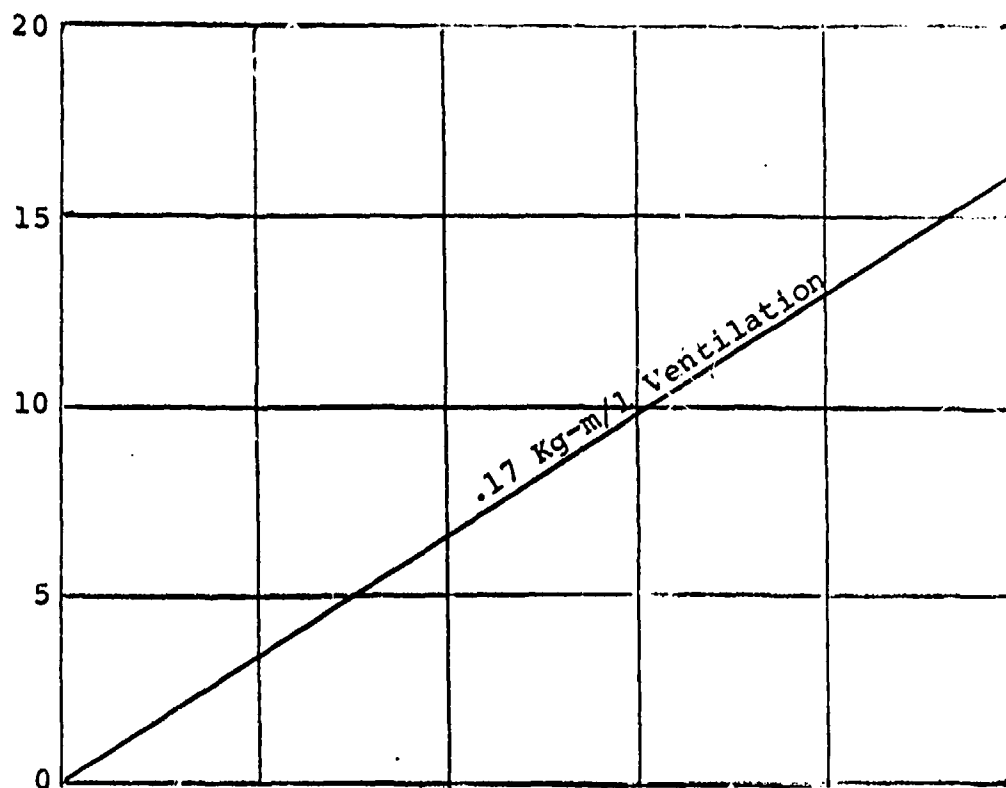
The only significant changes to the apparatus procedure and standards detailed in Section III. A. under consideration at this time are those proposed in Reference 7.

Reference 7 has proposed that the current peak pressure standards shown in Figure 1 be replaced with external work of breathing standards as shown in Figure 7. Note that the proposed standards are independent of depth in the depth range 0 to 1000 fsw.

Reference 7 has also recommended that the test conditions be broadened to include respiratory minute volumes of 22.5, 40 and 62.5 liters per minute produced by breathing rates of 15, 20 and 25 breaths per minute at tidal volumes of respectively 1.5, 2.0 and 2.5 liters. The recommended waveform in each case is a flattened sinusoid with a ratio of peak flow rate to minute ventilation of 2.7 (the present true sinusoid has a ratio of 3.14) and a ratio of exhalation to inhalation time of 1.1/1.0. Aside from the slight change in the respiratory waveform, the 40 liter per minute respiratory minute volume test condition is the same test condition currently in use. The 62.5 lpm RMV test condition, however, represents a test condition substantially more severe than the present 40 lpm test condition.

Moving 1 liter of gas in and out of one's mouth (or in and out of a breathing machine) against a volume-averag

Total External Respiratory Work Rate
(Kg-m/Minute)



Per Cent of Total External
Work of Breathing That May
Be Expiratory Work

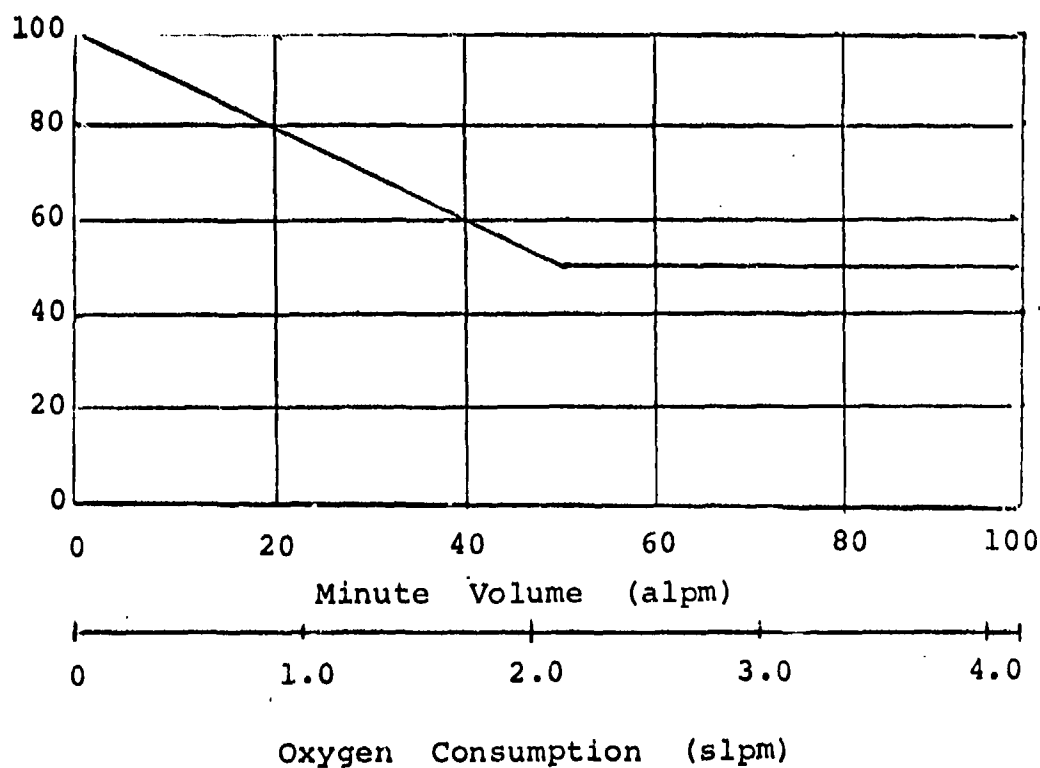


Figure 7

Proposed Limits on External Work of Breathing in the
Depth Range 0 to 1000 fsw. (7)

resistive pressure of 1 cm H₂O results in the expenditure of 0.02 Kg-m of work. Therefore, the limit of .17 Kg-m external work per liter of ventilation recommended by Reference 7 requires that the average inhalation and exhalation pressures be less than 8.5 cm H₂O, independent of both depth and respiratory minute volume. Due to the nature of SCUBA regulators, volume-average respiratory pressures of 8.5 cm H₂O usually correspond to peak respiratory pressures of 10-11 cm H₂O. See Figure 6. There the average exhalation pressure is 8.4 cm H₂O; the peak, 10 cm H₂O. The average inhalation pressure is 9.1 cm H₂O; the peak, 11 cm H₂O.

Thus adoption of the external work of breathing standards proposed by Reference 7 will in effect require open circuit SCUBA regulators to exhibit peak respiratory differential pressures of not more than about 10 cm H₂O, independent of depth and respiratory minute volume. At a 40 lpm RMV, this represents a standard less severe than the present one at depths less than 50 fsw, and more severe at depths greater than 65 fsw. Between 50 and 65 fsw at 40 lpm RMV the two standards are essentially equal. (See Figure 1)

Sufficient test experience has not yet been accumulated to determine the effect of the standards proposed by Reference 7 in SCUBA regulators currently in U. S. Naval service. It is expected that almost all of them will pass

the 40 lpm RMV test and that very few of them will pass the 62.5 lpm RMV test except at depths very near the surface.

For more details on the proposed standards, the reader is referred to Reference 7.

IV. CONCLUSIONS

1. The swimming test defined by MIL-R-24169A and MIL-R-19558A is impractical.
2. The breathing machine test specified by MIL-R- 24169A and MIL-R-19558A is not completely defined since the respiratory waveform is not specified.
3. The minimum supply pressures specified in MIL-R-19558A and MIL-R-24169A need revision.

V.

RECOMMENDATIONS

1. It is recommended that the portion of the preproduction tests identified in MIL-R-24169A and MIL-R-19558A as the swimming tests be deleted or revised.
2. It is recommended that the external work of breathing standards recommended in Reference 7 be incorporated into MIL-R-24169A and MIL-R-19558A after a suitable trial period.
3. It is recommended that the minimum pressure on which a regulator must operate satisfactorily be changed to 200 psi over bottom pressure.
4. It is recommended that quality control tests specified by MIL-R-24169A, Section 4.7 and MIL-R-19558A, Section 4.5 be reviewed for possible errors.
5. It is recommended MIL-R-24169A and MIL-R-19558A be reviewed and revised at the earliest practical date to include the above recommendations as well as any other changes the review might indicate.

REFERENCES

1. Military Specification, MIL-R-24169A (SHIPS),
"Regulator, Air, Demand, Single Hose, Nonmagnetic,
Diver's" 22 March 1967.
2. Military Specification, MIL-R-19558A (SHIPS),
"Regulator, Air, Demand, Diver's", 17 May 1960, and
Amendment 1, 7 January 1963.
3. NAVSHIPS Instructions 9940.21 Series
4. Lamphier, E.H., "A Trapeze Swim-Ergometer", Navy
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0994-003-7010, June 30, 1971.
6. Caudy, D.W. and J. S. Glasgow, "The Design, Development,
and Construction of a High Pressure Mechanical Respirator
for Testing Underwater Breathing Apparatus", Final Report,
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6 November 1973.

APPENDIX A

MILITARY SPECIFICATIONS

REGULATOR, AIR, DEMAND, SINGLE HOSE, NONMAGNETIC, DIVER'S

MIL-R-24169A

MILITARY SPECIFICATION

REGULATOR, AIR, DEMAND, SINGLE HOSE, NONMAGNETIC, DIVER'S

1. SCOPE

1.1 This specification covers a demand type regulator for use with self contained underwater breathing apparatus that will provide a diver with sufficient air on inhalation and will stop flow of air at the end of inhalation.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY

- MIL-D-1000/2 - Drawings, Engineering and Associated Lists.
- MIL-M-15071 - Manuals, Equipment, and Systems.
- MIL-M-19595 - Magnetic Effect Limits for Nonmagnetic Equipment Used in the Proximity of Magnetic Influence Ordnance.

STANDARDS

MILITARY

- MIL-STD-8 - Dimensioning and Tolerancing
- MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes
- MS33586 - Metals, Definition of Dissimilar.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. - The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASA B46.1 - Surface Texture.

(Application for copies should be addressed to the American Society of Mechanical Engineers, 345 East 47th Street, New York, N. Y. 10017.)

NATIONAL BUREAU OF STANDARDS

Handbook H28 - Screw Thread Standards for Federal services.

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402.)

OFFICIAL CLASSIFICATION COMMITTEE

Uniform Freight Classification Rules.

(Application for copies should be addressed to the Official Classification Committee, 1 Park Avenue at 33rd Street, New York, N. Y. 10016.)

FSC 4220

MIL-R-24169A(SHIPS)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. REQUIREMENTS

3.1 Qualification. - The regulator assemblies furnished under this specification shall be a product which is qualified for listing on the applicable qualified products list at the time set for opening of bids (see 4.2 and 6.3).

3.2 Preproduction unit. - Before production is started, two regulator assemblies shall be submitted for testing in accordance with 4.3.

3.3 Material. - All material used shall be nonmagnetic and, except as specifically authorized in this specification, shall be made from metals suitable to the intended purpose.

3.4 Dissimilar metals. - Dissimilar metals as defined by MS-33586 shall not be placed in contact with each other.

3.5 Screw threads. - Screw threads shall be in accordance with Handbook H28.

3.6 Surface roughness. - Surface finishes of working parts shall be in accordance with ASA B46.1. Surface finish of outside surfaces shall have a maximum roughness height rating of 125 prior to the application of any finish.

3.7 Demand regulator assembly. - The demand regulator assembly shall be two stage design. Reference to the demand regulator assembly or regulator assembly shall be understood to include the first stage (high pressure) regulator, the connecting hose and the demand regulator, including all subassemblies and affixtures thereto. The first stage or high pressure regulator shall be back-mounted, i.e., affixed to the high pressure cylinder manifold which is attached to the high pressure air cylinder(s) carried by the diver on his back. The first stage regulator shall be mounted to extend from the manifold no more than 3 inches toward the diver (see figure 1). The second or low pressure stage, hereinafter referred to as the demand regulator, shall be connected to the high pressure stage by the hose of 3.15. The mouthpiece, exhaust valve(s), exhaust manifold and demand regulator shall be a single integral unit.

3.7.1 Purge feature. - The demand regulator shall include a feature that will allow a diver to depress its diaphragm in order to cause it to free flow, purging its mouthpiece of water.

3.8 Supply pressures. - The demand regulator assembly shall function in accordance with this specification with supply pressures from 3,000 pounds per square inch (psi) to 200 psi. The high pressure regulator shall withstand application of 5,000 psi hydrostatically without sustaining damage.

3.9 Continuous flow. - The demand regulator assembly shall be designed so that regardless of the swimmer's position, continuous flow will not occur.

3.10 Leakage. - The demand regulator assembly shall not leak (see 4.7.2).

3.11 Manifold connection. - The demand regulator assembly shall be compatible with the manifolds, single and twin cylinder type, currently in the Navy System, connection being accomplished with a yoke type fitting.

3.12 Parts exposed to pressure. - All parts subjected to pressure shall be made of brass.

3.13 Exterior finish. - Externally exposed parts shall have a dull black nonreflecting finish which shall neither crumble or flake. The finish of exposed metal parts will be non-corroding. The finish will be easily repairable by operators. Materials required to maintain and repair the finish shall be furnished in small amounts, with the special tools of 3.23.

3.14 Nonmagnetic requirements. - The demand regulator assembly shall meet the requirements of MIL-M-19595 except that the limit shall be 0.05 millioersteds. Each stage of the regulator assembly shall be legibly and permanently stamped, etched or engraved as follows:

"1" (Nonmagnetic low mu)

3.15 Hose. - The hose connecting the high pressure stage and the demand stage shall be exceedingly flexible. It shall be resistant to deterioration due to exposure to sunlight, salt water and oil or other hydrocarbons. It shall have a safe working pressure of 250 psi.

3.15.1 Hose couplings. - One of the hose couplings shall be a "swivel" type connection that will allow the alignment of the hose to be changed to eliminate torques that would otherwise be transferred to the mouth bit. The hose with coupling shall be between 24 and 26 inches long. The hoses with couplings that will be presented for delivery shall have been tested to 250 pounds per square inch gage (psig) with a static tension of 50 pounds applied at the couplings.

3.16 High pressure filter. - The air inlet of the first stage regulator shall have a sintered bronze filter. The filter porosity shall be determined on the basis of the valve opening of the demand regulator.

3.17 Protective cap. - There shall be a protective cap of plastic or other suitable material for the air inlet. The protective cap shall be secured to the yoke fitting by some flexible means to preclude its loss when not in use.

3.18 Exhaust gas. - Exhaust gases shall be vented in a manner such as to least inhibit the divers vision.

3.19 Mechanical peak inhalation and exhalation pressures. - The demand regulator assembly shall exhibit, at a maximum, the values of peak inhalation and exhalation pressures of figure 2 when tested on a mechanical breather in accordance with 4.3.1 in ambient pressures up to the equivalent of 200 ft. of sea water.

3.20 Subjective peak inhalation and exhalation pressures. - The demand regulator assembly shall demonstrate, at a maximum, the values of peak inhalation and exhalation pressure of figure 2 when used by a typical U. S. Navy diver having a maximum tidal volume of 5 liters at simulated depths up to 200 feet of sea water swimming against a 12-pound force (see 4.3.2).

3.21 Steady flow inhalation and exhaust pressures. - When tested in accordance with 4.7.3, the regulator assembly shall exhibit a steady flow inhalation pressure not to exceed 5 inches of water. When tested in accordance with 4.7.5, the steady flow exhaust pressure shall not exceed 4 inches of water.

3.21.1 Steady flow inhalation pressure variation with flow rate. - The steady flow inhalation pressures required by the demand regulator assembly to attain various flow rates shall be no greater than the values of figure 3.

3.22 Flow rates. - When tested in accordance with 4.7.4, the air flow rate at reduced pressure shall be not less than 60 percent of the air flow rate at the initial air supply pressure.

3.23 Special tools. - The design of the regulator shall be such that the need of special tools for adjustment and maintenance shall be kept at a minimum. Sufficient special tools shall be supplied as a part of each regulator assembly to adjust and maintain it. Special tools are defined as those tools, nonmagnetic in accordance with MIL-M-19595, not listed in the Federal Supply Catalog, Department of Defense Identification List. (Copies of this catalog may be consulted in the office of the Government Inspector.)

3.24 Drawings. - Drawings in accordance with MIL-D-1000/2 shall be furnished to the Command or agency concerned. Dimensioning and tolerancing shall be in accordance with MIL-STD-8, surface finishes shall be indicated in accordance with ASA B46.1.

3.25 Manuals. - One complete manual, in accordance with type II of MIL-M-15071, shall be furnished with each demand regulator assembly. Manuals required in addition to this amount will be called out in the contract or order (see 6.2). The manual will call particular attention to the maintenance requirements, preventative and routine, inherent to the nonmagnetic characteristics of the regulator. The manual shall also include instructions for maintaining and repairing the black, nonreflecting exterior finish of the regulator.

3.26 Workmanship. - Workmanship shall be first class in every respect.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as

MIL-R-24169A(SHIPS)

otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Qualification tests. - When authorized by the Naval Ship Engineering Center, the manufacturer shall submit a sample regulator assembly with special tools specified in 3.23 (see 4.2.1) to the Officer in Charge of the U. S. Navy Experimental Diving Unit, Navy Yard, Washington, D. C. 20390 for testing in accordance with 4.3.1 and 4.3.2 for conformance with 3.19 and 3.20, and for determination of the sufficiency of the special tools (see 3.23 and 4.2.1).

Application for Qualification tests shall be made in accordance with "Provisions Governing Qualification" (see 6.3 and 6.4).

4.2.1 Qualification sample tools. - The special tools specified in 3.23 that are supplied as part of the qualification sample need not be nonmagnetic.

4.3 Preproduction tests. - Prior to submission to the Government laboratory (see 3.2), the preproduction units specified in 3.2 shall be tested at the place of manufacture, under the surveillance of the Government inspector, to be in accordance with the requirements of section 3, except 3.14, 3.19, 3.20 and as specified elsewhere in this specification. The preproduction units shall then be submitted to the Officer in Charge, Experimental Diving Unit, Navy Yard, Washington, D. C. 20390 for testing in accordance with 4.3.1, 4.3.2 and 4.3.3 for conformance with the requirements of 3.14, 3.19, and 3.20.

4.3.1 Mechanical peak inhalation and exhalation pressure test. - The suitability of the preproduction units for swimming to 200 feet in sea water shall be tested by a simulated breathing test using a breathing machine having a tidal volume of two liters set at a rate of 20 breaths per minute. For a given ambient pressure, the maximum pressure differential observed between ambient pressure and pressure inside the mouthpiece during any inhalation cycle shall be the mechanical peak inhalation pressure. For a given ambient pressure, the maximum pressure differential observed between ambient pressure and pressure inside the mouthpiece during any exhalation cycle shall be the mechanical peak exhalation pressure (see 3.19).

4.3.2 Subjective peak inhalation and exhalation pressure test. - When preproduction units have successfully passed the testing of 4.3.1, they shall be additionally tested using the arrangement shown on figure 4. For a given depth, the maximum pressure differential observed between ambient pressure at mouthpiece level and pressure inside the mouthpiece during any inhalation cycle shall be the subjective peak inhalation pressure. For a given depth the maximum pressure differential observed between ambient pressure at mouthpiece level and pressure inside the mouthpiece during any exhalation cycle shall be the subjective peak exhalation pressure. (see 3.20).

4.3.3 Preproduction magnetic signature determination. - The preproduction demand regulator assembly units and tools shall be tested for compliance with MIL-M-19595, except that the limit shall be 0.05 millioersteds for the demand regulator assemblies (see 3.14).

4.4 Production magnetic signature determination. - Production demand regulator assembly units and tools shall be subjected to 100 percent testing for compliance with MIL-M-19595, except that the limit shall be 0.05 millioersteds (see 3.14).

4.5 Sampling. -

4.5.1 Lot. - All regulators offered for delivery at one time shall be considered a lot.

4.5.2 Sampling for visual and dimensional examination. - From each lot of regulator assemblies, samples shall be selected for examination in accordance with MIL-STD-105 at General Inspection Level III for the examination specified in 4.6.

4.5.3 Sampling for operating tests. - From each lot of regulator assemblies, samples shall be selected for testing in accordance with special inspection level S-4 of MIL-STD-105 for the tests specified in 4.7.

4.6 Quality conformance inspection. - Each of the sample regulator assemblies selected in accordance with 4.5.2 shall be inspected to verify conformance with all of the requirements of this specification which

do not involve the tests in 4.7. Any sample regulator having one or more defects shall not be offered for delivery. Lots shall be accepted or rejected in accordance with Acceptable Quality Level (AQL) 1.5 percent.

4.7 Quality conformance operational tests and procedures. - Each of the sample regulator assemblies selected in accordance with 4.5.3 shall be subjected to the tests specified in 4.7.1, 4.7.2, 4.7.3, 4.7.4 and 4.7.5 to meet the requirements of section 3 (see 4.5.3).

4.7.1 Hydrostatic test. - The high pressure regulator of each sample shall be hydrostatically tested not to sustain damage at 5,000 psi applied internally. The high pressure regulator shall not leak during this test (see 3.8).

4.7.2 General setup and leakage test. - The sample regulator assembly shall be mounted in the test tank and shall be connected to the appropriate inlet and outlet air lines as shown on figure 5. The main throttling valve of figure 5 shall be closed and high pressure air, at a pressure of 3,000 plus or minus 25 pounds per square inch gage (psig), shall then be supplied to the regulator assembly. The tank shall then be partially filled with water up to a level such that the assembly under test is submerged to a depth of 2 inches at its highest point. Causes of air leakage from the regulator assembly shall be determined and if found to be due to mismatching with the test apparatus, eliminated. Low pressure air shall then be admitted into the top of the tank and the pressure raised to and maintained at 5 plus or minus 0.2 psig for all tests. All tests shall be conducted at an ambient temperature of 70° plus or minus 5°F. Leakage at any time, other than that due to mismatching with the test apparatus or ambient pressure decrease, shall be cause for failure of the leakage test (see 3.10).

4.7.3 Steady flow inhalation pressure test. - The main throttling valve of figure 5 shall be adjusted to a setting such that an air flow rate through the air outlet line, as indicated on the direct reading flowmeter, of 6 plus or minus 0.25 cubic feet of free air per minute is attained and sustained. Determinations shall be made under steady flow conditions of the pressure differential as indicated by the water manometer and the head of water above the center of the demand valve diaphragm as indicated by the tape rule mounted inside the tank, the sum of these pressures, in inches of water, being the Steady Flow Inhalation Pressure (see 3.21).

4.7.4 Flow rate test. - The throttle valve in the air outlet line shall be opened slowly and shall be adjusted to a setting such that the air flow rate through the air outlet line, as indicated on the direct reading flowmeter, is 8 plus or minus 0.5 cubic feet of free air per minute. When steady flow conditions have been obtained, the total pressure differential on the sample shall be noted. With this valve held constant by suitable adjustment of the throttle valve in the air outlet line, the air supply pressure to the sample assembly shall be reduced from 3,000 psig to 200 plus or minus 10 psig. When steady flow conditions have again been obtained the flow rate will again be noted. This air flow rate shall be the air flow rate at reduced pressure. (Samples equipped with air reserve valves shall have the air reserve valve in the open position for this test.) (see 3.22).

4.7.5 Steady flow exhalation pressure test. - The pressure differential necessary across the installed exhaust valve to sustain a flow through the exhaust valve of 6.00 ± 0.25 CFM while exhausting to a minimum pressure of 0.083 psig (or 2-1/4 inches of water) shall be determined. The demand (second stage) regulator shall be immersed to a minimum depth of two inches in water, secured in that attitude in which it will normally be held in the mouth of a diver while swimming. Low pressure air will be supplied to the mouthpiece by a system which shall contain devices for measuring flow through the mouthpiece and pressure inside the mouthpiece. The pressure at the highest (shallowest) point of the highest port through which air passes to the surrounding water is the ambient exhaust pressure. By means of the low pressure air supply, a steady flow of 6.00 ± 0.25 CFM of air shall be sustained from the mouthpiece through the exhaust valve and the exhaust manifold to the surrounding water. The differential between the pressure observed inside the mouthpiece during the sustained flow and the ambient exhaust pressure shall be the Steady Flow Exhaust Pressure. To start the test, the exhaust manifold shall be filled with water. (see 3.21).

4.8 Inspection of preparation for delivery. - Preservation, packaging, packing, and marking shall be inspected to assure compliance with section 5 of this specification.

5. PREPARATION FOR DELIVERY

5.1 Domestic shipment and early equipment use. -

5.1.1 Packaging. - Special tools (see 3.23) shall be wrapped and enclosed in a snug-fitting box. This box, a demand regulator assembly (see 3.7) and a manual (see 3.25) shall be suitably cushioned and boxed

MIL-R-24169A(SHIPS)

in a single package in accordance with the suppliers best commercial practice sufficient to afford adequate protection against physical damage during shipment from the supply source to the using activity for immediate use.

5.1.2 Packing. - Packing shall be accomplished in a manner which will insure acceptance by common carrier, at lowest rate, and will afford protection against physical or mechanical damage during direct shipment from the supply source to the using activity for early installation. The shipping containers or method of packing shall conform to the Uniform Freight Classification Rules and Regulations or other carrier regulations as applicable to the mode of transportation and may conform to the suppliers commercial practice.

5.1.3 Marking. - Shipment marking information shall be provided on interior packages and exterior shipping containers in accordance with the contractor's commercial practice. The information shall include nomenclature, Federal stock number or manufacturer's part number, contract or order number, contractor's name and destination.

5.2 Domestic shipment and storage or overseas shipment. - The requirements and levels of preservation, packaging, packing and marking for shipment shall be specified by the procuring activity (see 6.2).

(5.2.1 The following provides various levels of protection during domestic shipment and storage or overseas shipment, which may be required when procurement is made (see 6.2).

5.2.1.1 Preservation and packaging. -

5.2.1.1.1 Level A. - Preservation and packaging shall be in accordance with MIL-P-116 as follows:

- (a) **Tools.** - Meeting the requirements of Method III, special tools (see 3.23) shall be wrapped and contained in a snug-fitting folding or set-up paperboard box conforming to the requirements of PPP-B-566 or PPP-B-676 at the option of the shipper. Box closure shall be in accordance with the appendix to the applicable box specification.
- (b) **Demand regulator assembly.** - Each demand regulator assembly (see 3.7) shall be packaged in a heat sealed plastic bag.
- (c) One set of special tools, one demand regulator assembly and a manual (see 3.25) shall be cushioned and packaged in a snug-fitting fiberboard box conforming to PPP-B-636. Box closure and sealing shall be in accordance with the box specification.

5.2.1.1.2 Level C. - Level C shall be as specified in 5.1.1.

5.2.1.2 Packing. -

5.2.1.2.1 Level A. - Equipment, packaged as specified (see 6.2), shall be packed in fiberboard boxes conforming to PPP-B-636 (class weather-resistant) or PPP-B-640 (Class 2) at the option of the contractor. All center and edge seams and the manufacturers joints shall be sealed and waterproofed with pressure sensitive tape in accordance with the applicable fiberboard box specification. Box closure and banding shall be in accordance with the applicable box specification, when specified (see 6.2). Unit fiberboard containers conforming to class weather-resistant, closed, sealed and banded as specified herein, may be used as the shipping container and need not be overpacked.

5.2.1.2.2 Level B. - Units of basic equipment, packaged as specified (see 6.2), shall be packed in fiberboard boxes conforming to PPP-B-636 (class domestic) or PPP-B-640 (class 1) at the option of the contractor. Shipping containers shall be closed and banded in accordance with the applicable container specification, except that fiberboard containers may be sealed with tape conforming to PPP-T-45. When specified (see 6.2), unit containers closed, sealed and banded as specified herein may be used as the shipping container and need not be overpacked.

5.2.1.3 Marking. - In addition to any special marking requirements, interior packages and exterior shipping containers shall be marked in accordance with MIL-STD-129.)

6. NOTES

6.1 Intended use. - The regulator covered by this specification is intended to supply life support air to a diver. It is to provide a flow of air to the diver upon his inhalation and to stop the flow of air upon the end of inhalation.

6.2 Ordering data. - Procurement documents should specify the following:

- (a) Title, number, and date of this specification.
- (b) Number of extra manuals required (see 3.25).
- (c) Preservation, packaging, packing, or marking requirements other than those required by 5.1 (see 5.2).

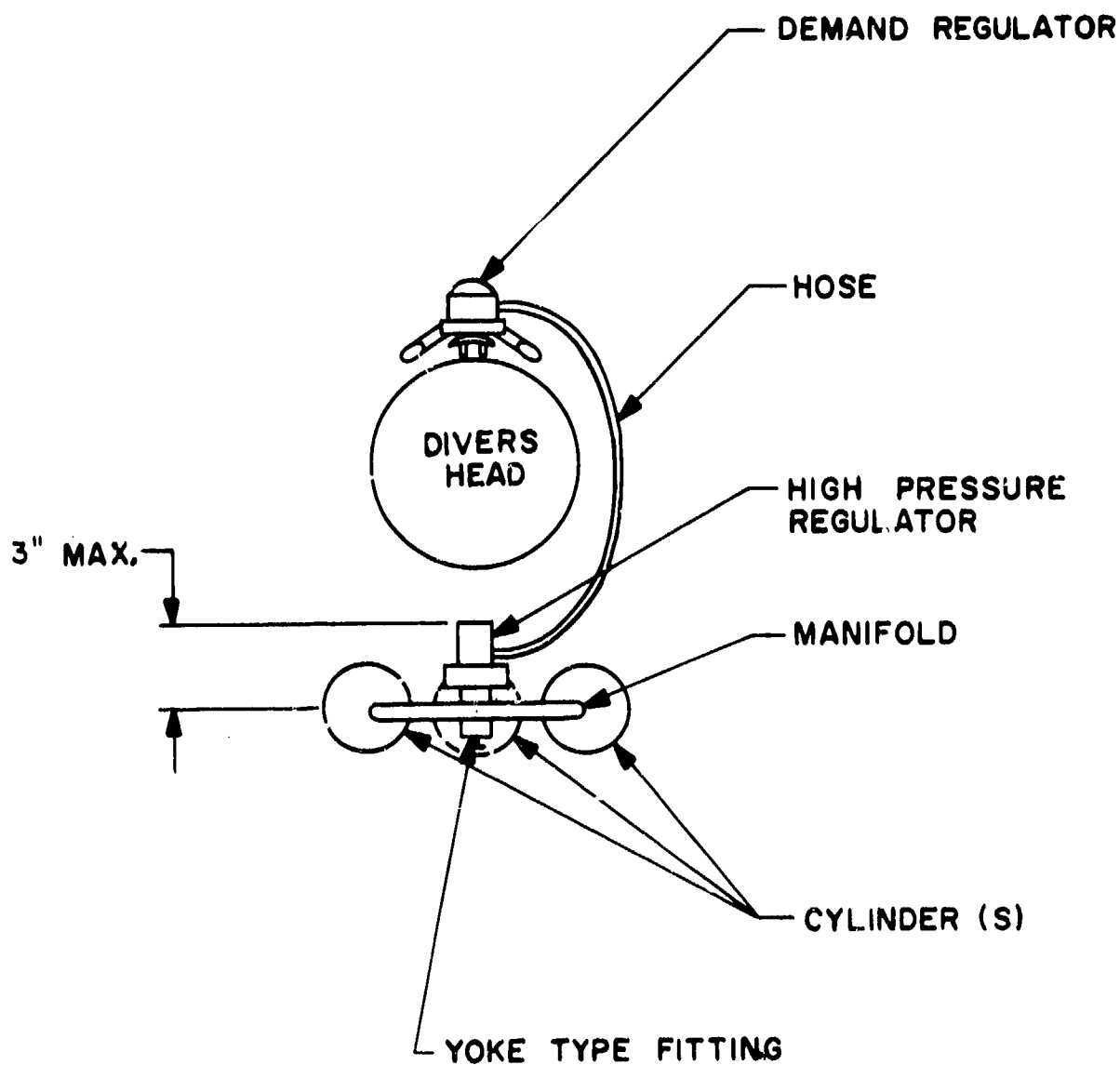
6.3 With respect to products requiring qualification, awards will be made only for products which are at the time set for opening of bids, qualified for inclusion in applicable Qualified Products List 24169 whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification, in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the qualified products list is the Naval Ship Engineering Center, Department of the Navy, Washington, D. C. 20360, and information pertaining to qualification of products may be obtained from that activity. Application for Qualification tests shall be made in accordance with "Provisions Governing Qualification" (see 6.4).

6.4 Copies of "Provisions Governing Qualification" may be obtained upon application to Commanding Officer, Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.

6.5 Preproduction. - Invitations for bids should provide that the Government reserves the right to waive the requirement for preproduction samples as to those bidders offering a product which has been previously procured or tested by the Government, and that bidders offering such products, who wish to rely on such production or test, must furnish evidence with the bid that prior Government approval is presently appropriate for the pending procurement.

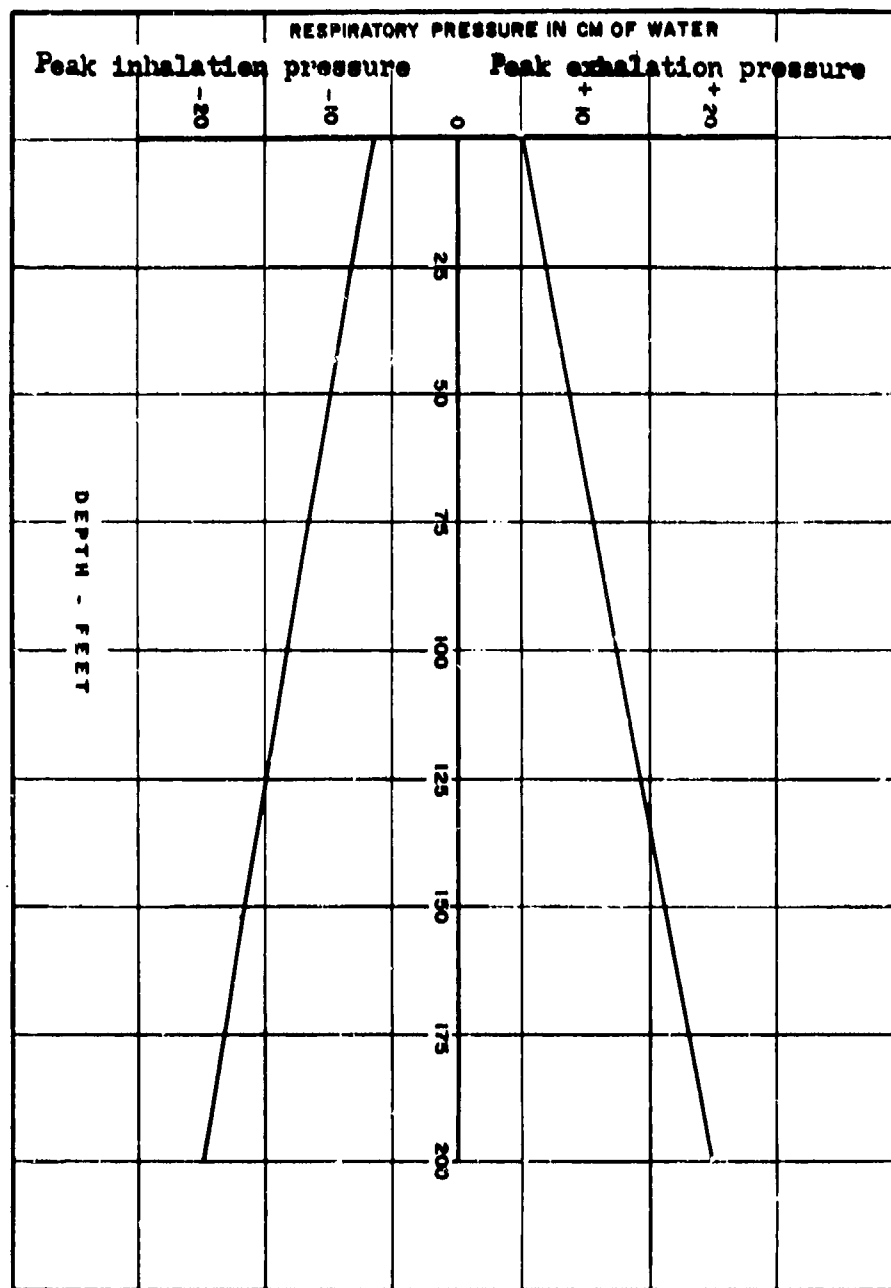
6.6 CHANGES FROM PREVIOUS ISSUE. THE EXTENT OF CHANGES (DELETIONS, ADDITIONS, ETC.) PRECLUDE THE ANNOTATION OF THE INDIVIDUAL CHANGES FROM THE PREVIOUS ISSUE OF THIS DOCUMENT.

Preparing activity:
Navy - SH
(Project 4220-N076Sh)



SH6427

Figure 1. - First stage regulator extension limitation.



SH 8552

Figure 2. - Respiratory pressures.

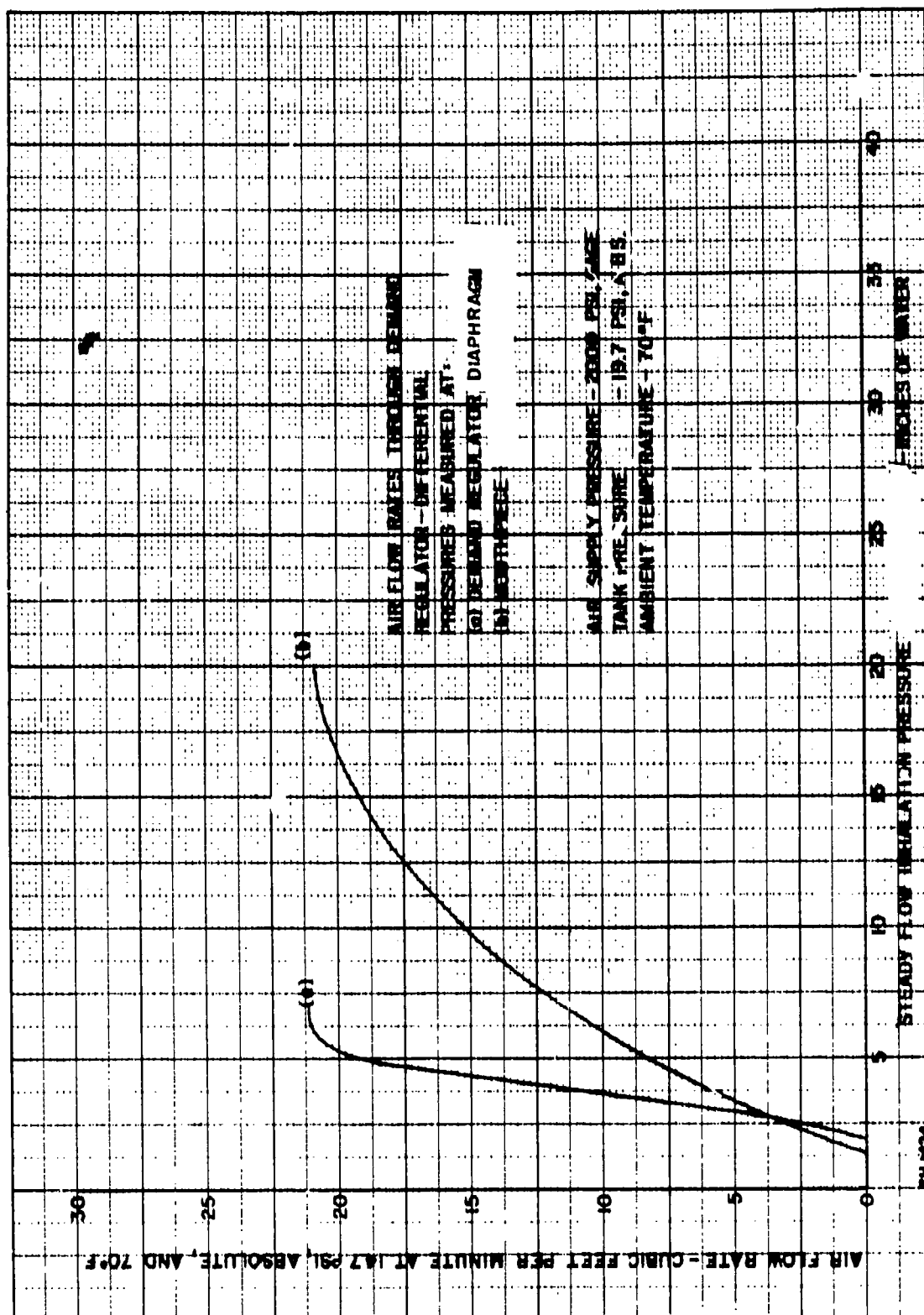


Figure 3. - Flow rates.

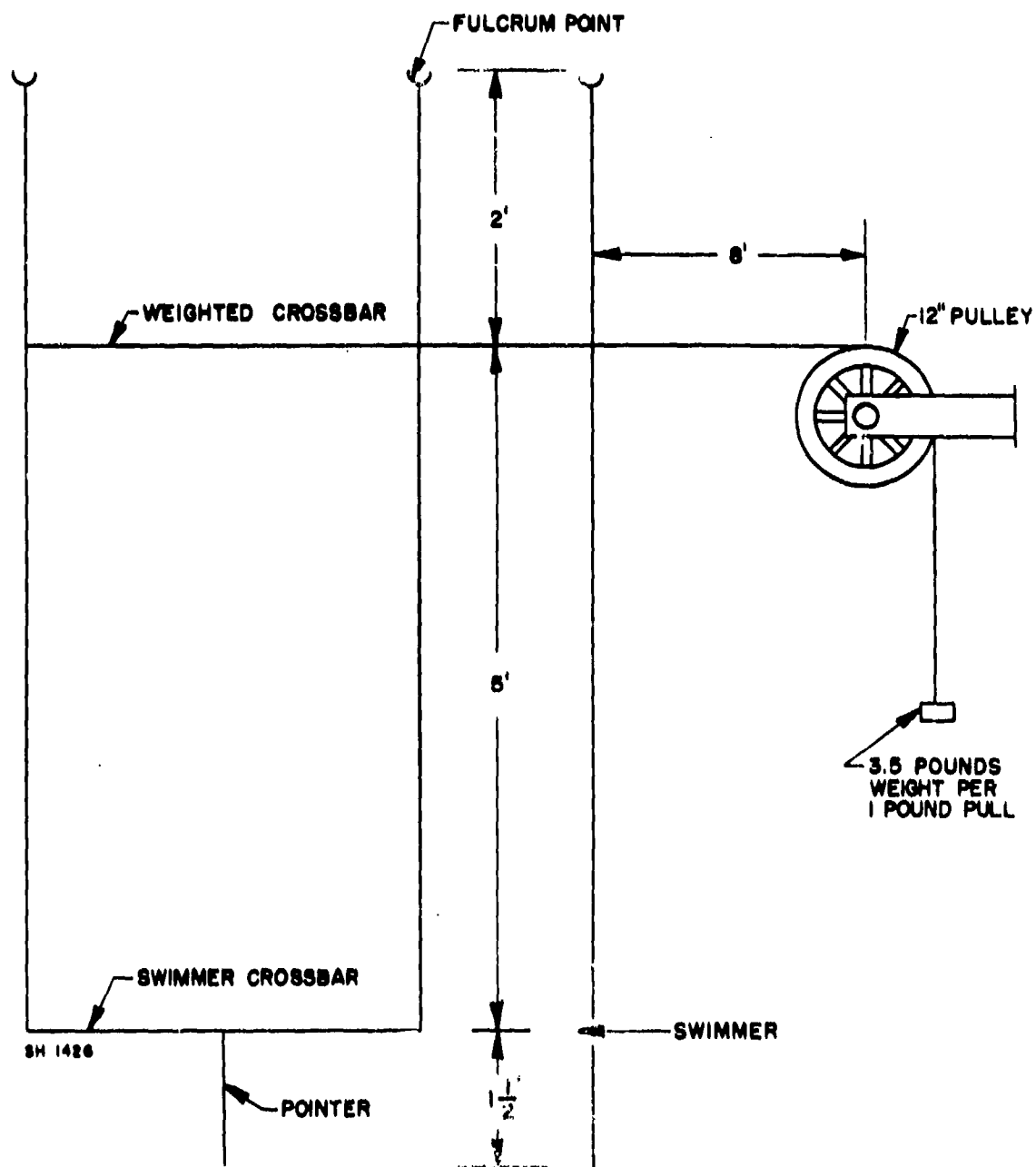


Figure 4. - Simulated swimming test arrangement.

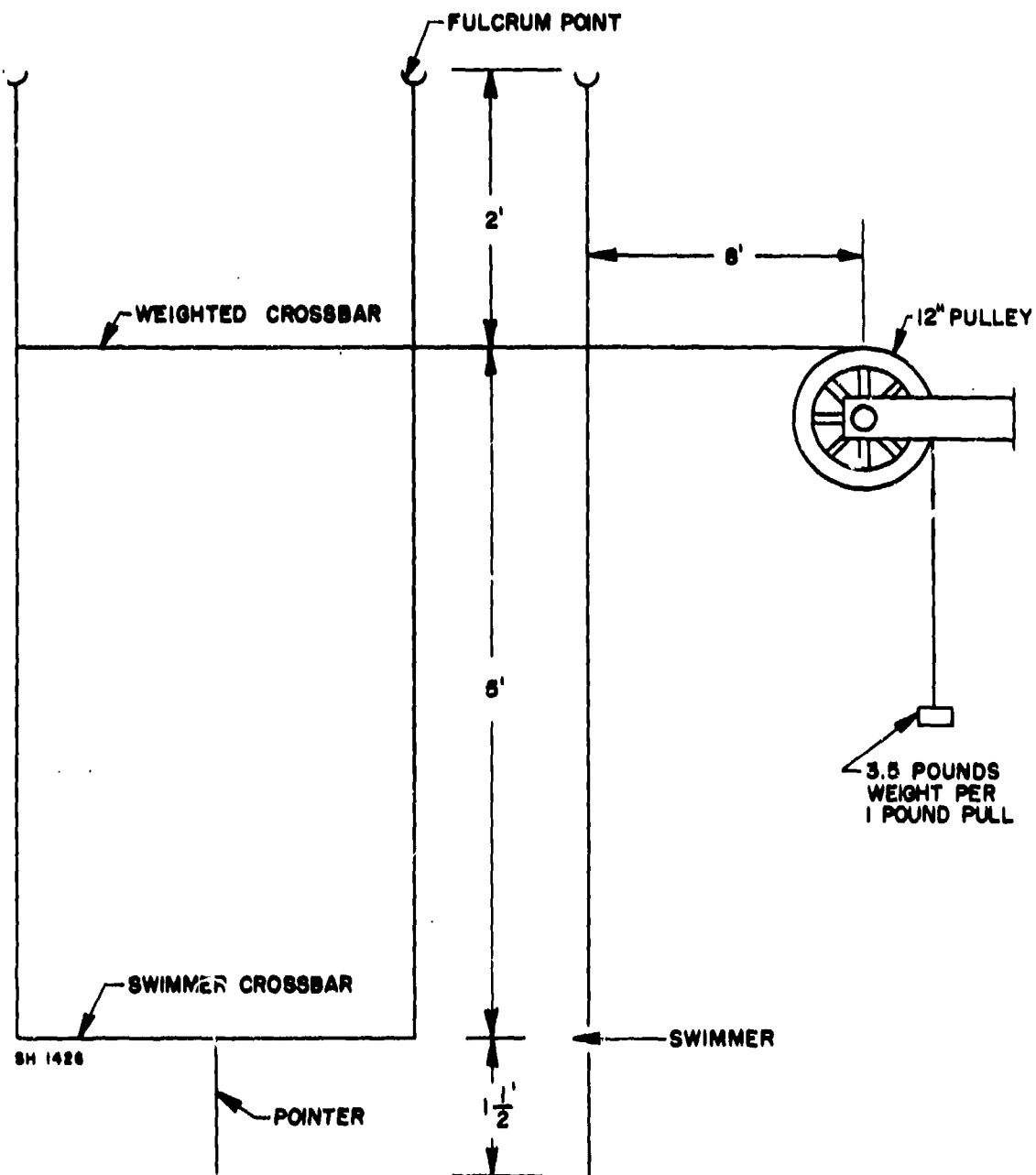


Figure 4. - Simulated swimming test arrangement.

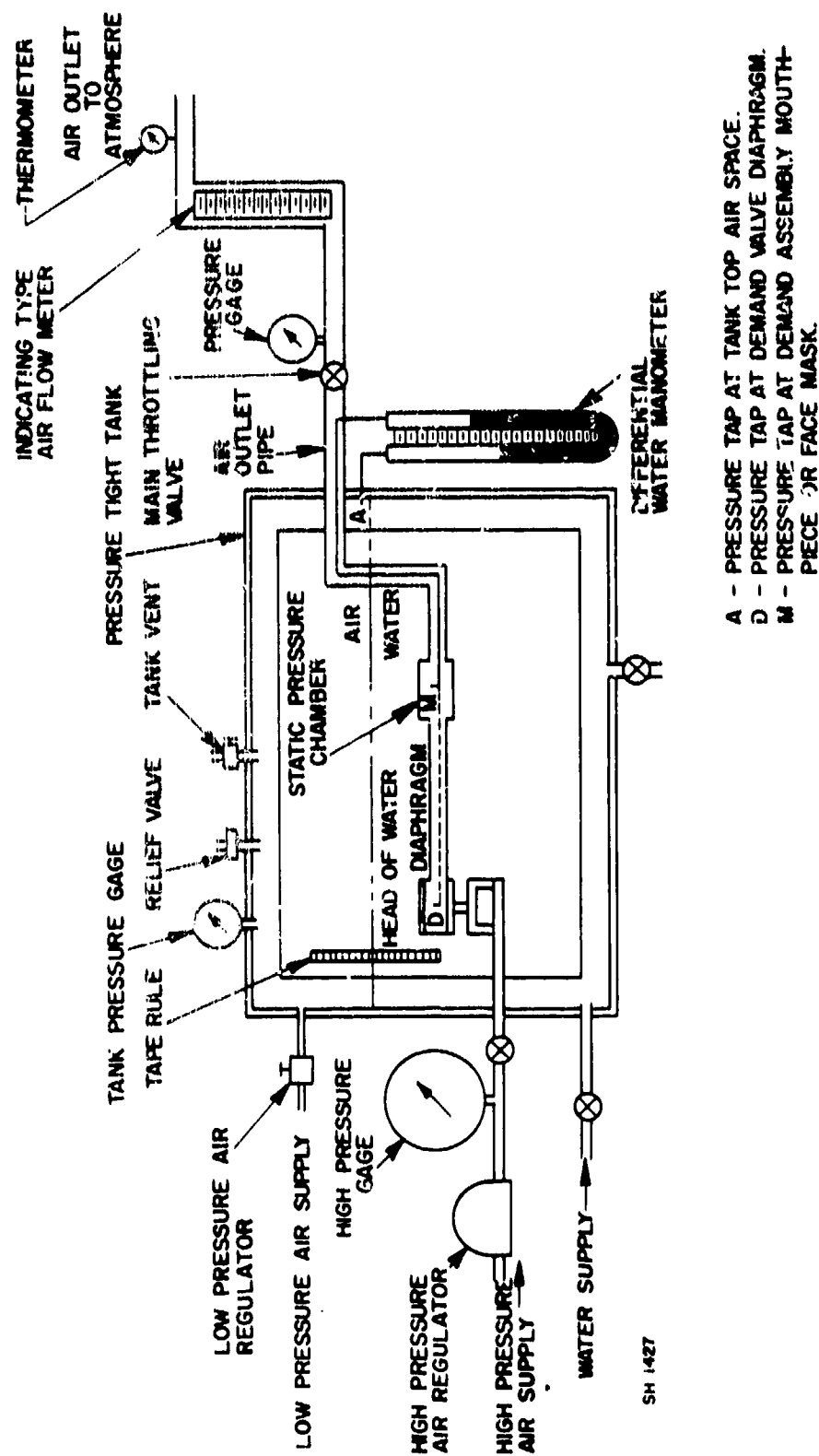


Figure 5. - Test arrangement for determining flow rate.

SPECIFICATION ANALYSIS SHEET		Form Approved Budget Bureau No. 119-R004
<p style="text-align: center;">INSTRUCTIONS</p> <p>This sheet is to be filled out by personnel either Government or contractor, involved in the use of the specification in procurement of products for ultimate use by the Department of Defense. This sheet is provided for obtaining information on the use of this specification which will insure that suitable products can be procured with a minimum amount of delay and at the least cost. Comments and the return of this form will be appreciated. Fold on lines on reverse side, staple in corner, and send to preparing activity (as indicated on reverse hereof).</p>		
SPECIFICATION		
ORGANIZATION (of submitter)		CITY AND STATE
CONTRACT NO.	QUANTITY OF ITEMS PROCURED	DOLLAR AMOUNT \$
MATERIAL PROCURED UNDER A		
<input type="checkbox"/> DIRECT GOVERNMENT CONTRACT <input type="checkbox"/> SUBCONTRACT		
1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE? A. GIVE PARAGRAPH NUMBER AND WORDING.		
B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES.		
2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID		
3. IS THE SPECIFICATION RESTRICTIVE? <input type="checkbox"/> YES <input type="checkbox"/> NO IF "YES", IN WHAT WAY?		
4. REMARKS (Attach any pertinent data which may be of use in improving this specification. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity)		
SUBMITTED BY (Printed or typed name and activity)		DATE

DD FORM 1426
1 APR 65

REPLACES NAVSHIPS FORM 4883, WHICH IS OBSOLETE
(NAVSHIPS OVPRT 12-66)

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APPENDIX B

MILITARY SPECIFICATION
REGULATOR, AIR, DEMAND, DIVER'S
MIL-R-19558A

MILITARY SPECIFICATION REGULATOR, AIR, DEMAND, DIVER'S

This amendment forms a part of Military Specification MIL-R-19558A(SHIPS), 17 May 1960.

Page 2, paragraph 3.3: Delete and substitute:

"3.3 The demand regulator may be either a single or two stage type. The demand regulator shall be configured such that when mounted on a cylinder manifold, it shall not extend toward the diver's head more than 3-3/4 inches from the center of the manifold as shown on figure 6."

Page 2, paragraph 3.10: Add as last sentence:

"The inlet and outlet breathing tubes shall be located such that the inlet breathing tube shall be to the diver's right side and the outlet breathing tube shall be to the diver's left side (see figure 6)."

Page 6, paragraph 4.1: Delete and substitute:

"4.1 Responsibility for inspection. - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements."

Page 6: Add the following as "Figure 6"

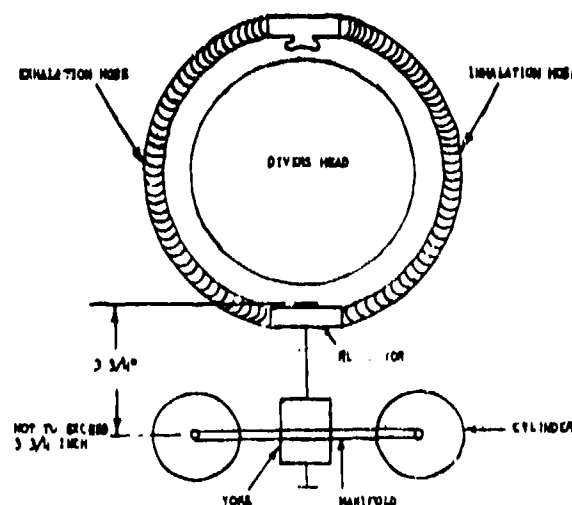


Figure - 6.

Preparing activity:
Navy - Ships
(Project 4220-N037Sh)

FSC 4220

MIL-R-19558A(SHIPS)
17 May 1960
~~SUPERSEDING~~
MIL-R-19558(SHIPS)
14 August 1956

MILITARY SPECIFICATION
REGULATOR, AIR, DEMAND, DIVER'S

1. SCOPE

1.1 This specification covers a demand type regulator for use with self-contained underwater breathing apparatus that will provide a diver with sufficient air on inhalation and will stop flow of air at the end of inhalation.

Parts for Electrical and
Mechanical Equipment
(Naval Shipboard Use).

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids form a part of this specification to the extent specified herein:

MIL-P-17555 - Preparation for Delivery of Electronic Equipment; Miscellaneous Electrical Equipment (Except Rotating Electrical Equipment) and Associated Repair Parts.

SPECIFICATIONS

FEDERAL

- PPP-B-585 - Boxes, Wood, Wirebound.
- PPP-B-591 - Boxes, Fiberboard, Wood-Cleated.
- PPP-B-601 - Boxes, Wood, Cleated-Plywood.
- PPP-B-621 - Boxes, Wood, Nailed and Lock-Corner.
- PPP-B-636 - Boxes, Fiber.
- PPP-T-76 - Tape, Pressure-Sensitive Adhesive, Paper, Water Resistant.
- PPP-T-97 - Tape, Pressure-Sensitive Adhesive, Filament Reinforced.

MILITARY

- MIL-P-116 - Preservation, Methods of.
- MIL-D-963 - Drawings, Production, Electrical Hull and Mechanical Equipment.
- MIL-B-10377 - Boxes: Wood-Cleated, Veneer, Paper Overlaid.
- MIL-L-10547 - Liners, Case, Waterproof.
- MIL-M-15071 - Manual, Technical, for Mechanical and Electrical Equipment (Less Electronics).
- MIL-P-15137 - Provisioning and Technical Documentation for Repair

STANDARDS

MILITARY

- MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.
- MIL-STD-129 - Marking for Shipment and Storage.

DRAWINGS

BUREAU OF SHIPS

- S7603-1, 543, 156 - Demand Apparatus Breathing Tube.

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids shall apply.

OFFICIAL CLASSIFICATION COMMITTEE

Uniform Freight Classification Rules.

(Application for copies should be addressed to the Official Classification Committee, 1 Park Avenue at 33rd Street, New York 16, New York.)

REQUIREMENTS

3.1 Preproduction unit. - Before production is started, a regulator shall be submitted for testing in accordance with 4.2.

3.2 Material. - All material used shall be non-magnetic and, except as specifically authorized in

FSC 4220

this specification, shall be made from appropriate metals suitable for the purpose intended.

3.3 The demand regulator may be either a single or two stage type.

3.4 The demand regulator shall operate in accordance with all requirements of this specification when used with high pressure air flasks. When using high pressure cylinders the apparatus shall operate satisfactorily in accordance with this specification when swimming to 200 feet.

3.5 When used with high pressure cylinders the demand regulator shall function in accordance with this specification from 3000 pounds per square inch (p.s.i.) to 100 p.s.i.

3.6 The demand regulator shall be designed so that regardless of the swimmer's position the regulator will not give continuous flow.

3.7 The demand regulator shall be compatible with a manifold consisting of a plug in each cylinder leading to a common yoke type valve. It shall be mounted directly to the cylinder manifold valve through a yoke type fitting.

3.8 All parts subjected to high pressure shall be made of brass. The metal parts shall be coated to give maximum resistance to corrosion and inhibit collection of vertigris.

3.9 The complete demand regulator shall have a nonmagnetic permeability of not more than 1.004.

3.10 In inlet and exhaust breathing tubes shall be of proper size to connect to a 1-inch inside diameter (i.d.) corrugated hose shown in Drawing S7603-1, 543, 156. There shall be a bead on the regulator inlet and exhaust tubes. The bead shall fit into the first corrugation of the breathing tube.

3.11 The air inlet of the demand regulator or first stage regulator shall have a sintered bronze filter. The filter porosity shall be determined on the basis of the valve opening of the demand regulator.

3.12 The exhaust valve shall be located so that the bubbles will not interfere with diver's vision regardless of his position in any direction.

3.13 The demand regulator or first stage and demand regulator combination shall pass not less than the quantities of gas shown on figure 1 when tested in accordance with 4.5.2.

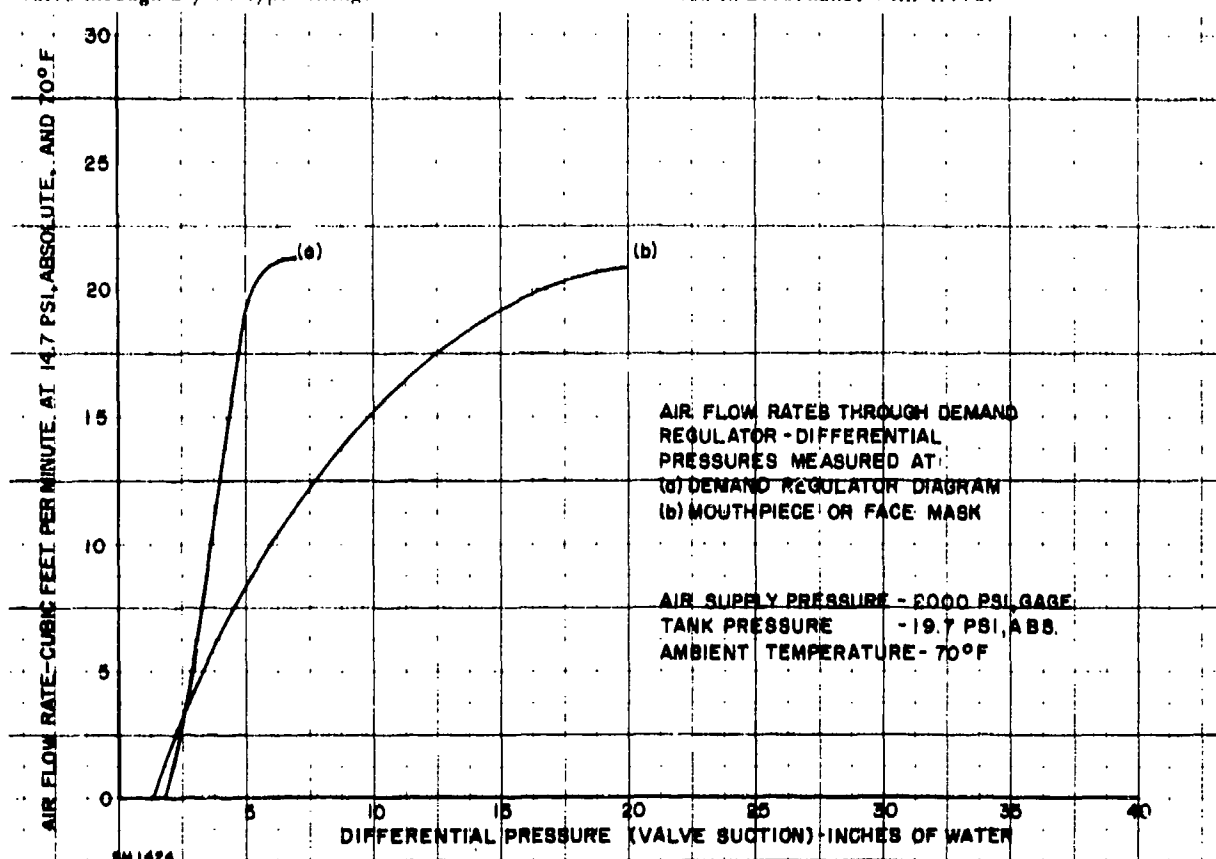


FIGURE 1

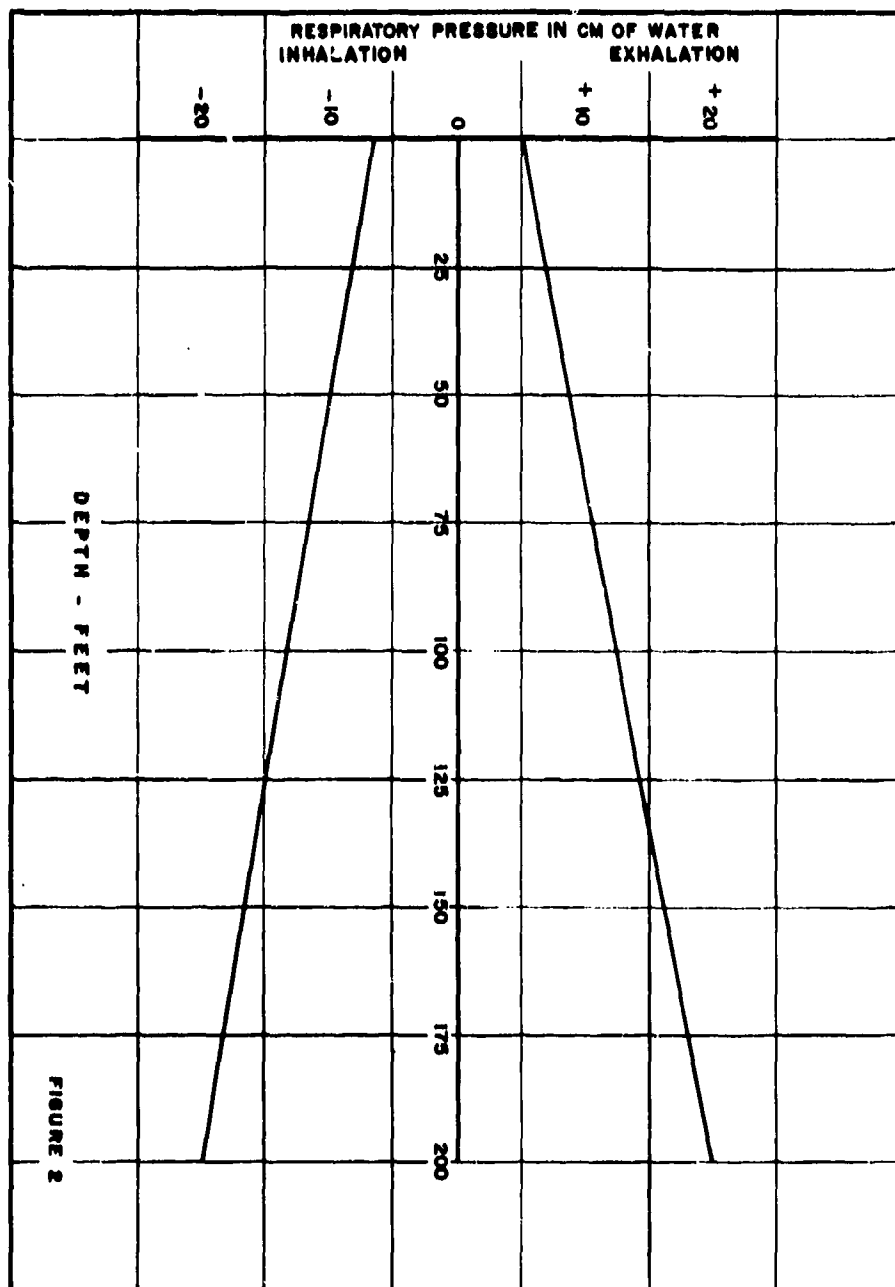


FIGURE 2

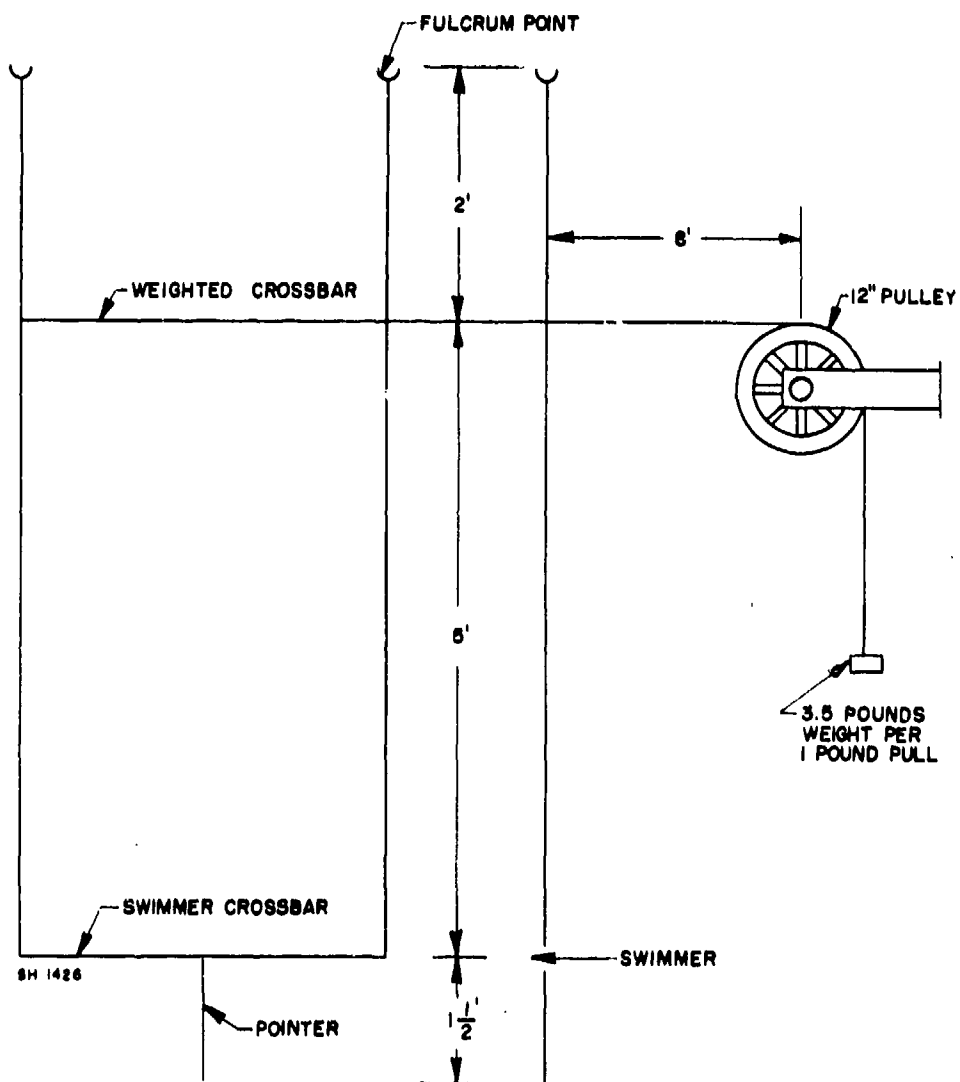


FIGURE 3.

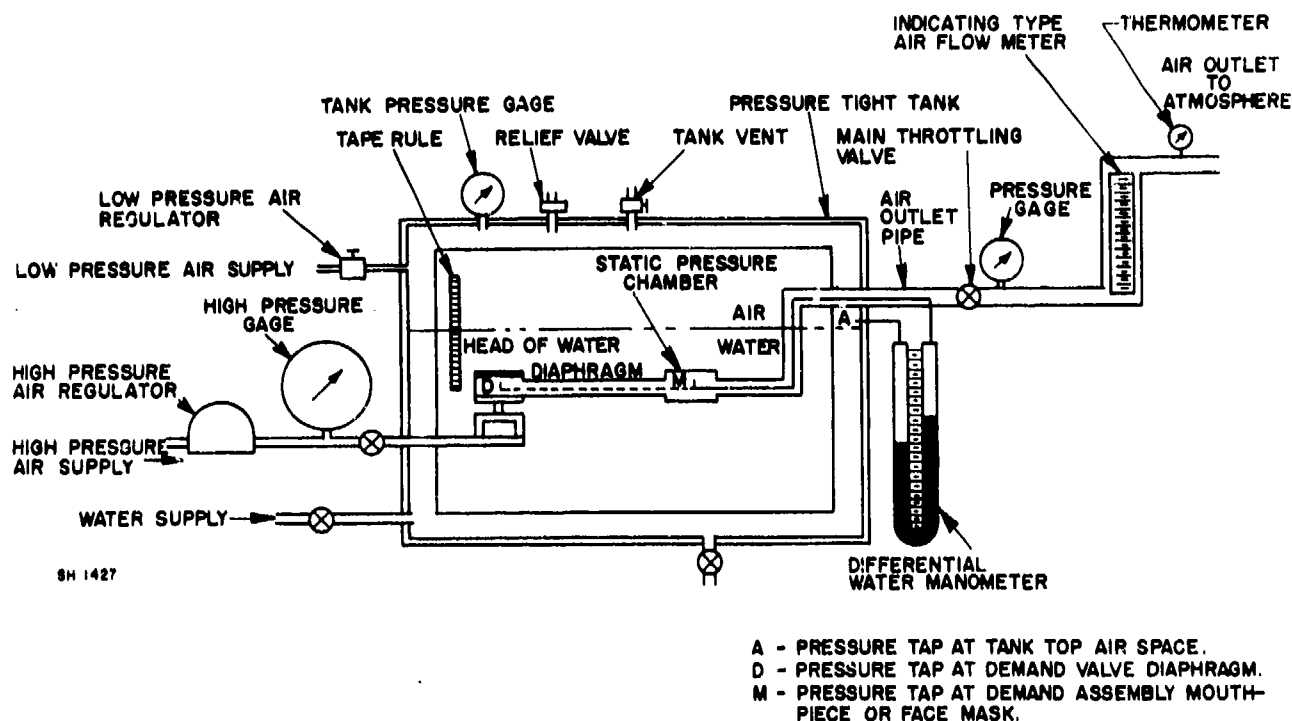


FIGURE 4.

3.14 The demand regulator in combination with breathing tubes, mouthpiece, or face mask shall have satisfactory inhalation and exhalation pressures with a man swimming at speed of 1 mile per hour and have a maximum tidal volume of 5 liters. The inhalation and exhalation pressures shall not exceed the values shown on figure 2 for machine test with breathing tubes and mouthpiece or with mask when tested as specified in 4.2.

3.15 The demand regulator in combination with breathing tubes and mouthpiece or face mask shall not have inhalation or exhalation pressures which exceed 200 centimeters of water at 200 feet when swimming against a 12-pound force (see 4.2).

3.16 There shall be a plastic or other suitable protective cap for the air ports.

3.17 Flow rate. - When tested in accordance with 4.5.2, the total differential pressure, or suction, on the sample valve, required to produce the specified flow rate, shall not exceed 5 inches of water. When tested in accordance with 4.5.4, the differential pressure resulting from the specified flow rate shall not exceed 4 inches of water.

3.18 Supply pressure. - When tested in accordance with 4.5.3, the air flow rate at reduced pressure shall be not less than 60 percent of the air flow rate at the initial air supply pressure.

3.19 Repair parts. - The bidder shall submit a list of recommended repair parts for approval of the bureau or agency concerned. The repair parts shall be in accordance with Specification MIL-P-15137.

3.20 Special tools. - The design of the regulator shall be such that the need of special tools for adjustment and maintenance shall be kept to a minimum. Special tools shall be supplied by the contractor. A list of special tools shall be supplied to the bureau or agency concerned for approval. Special tools are defined as those tools not listed in the Catalog of Naval Material, General Stores Section. (Copies of this catalog may be consulted in the office of the Government inspector.)

3.21 Drawings. - Drawings shall be in accordance with Specification MIL-D-963 and shall be furnished to the bureau or agency concerned.

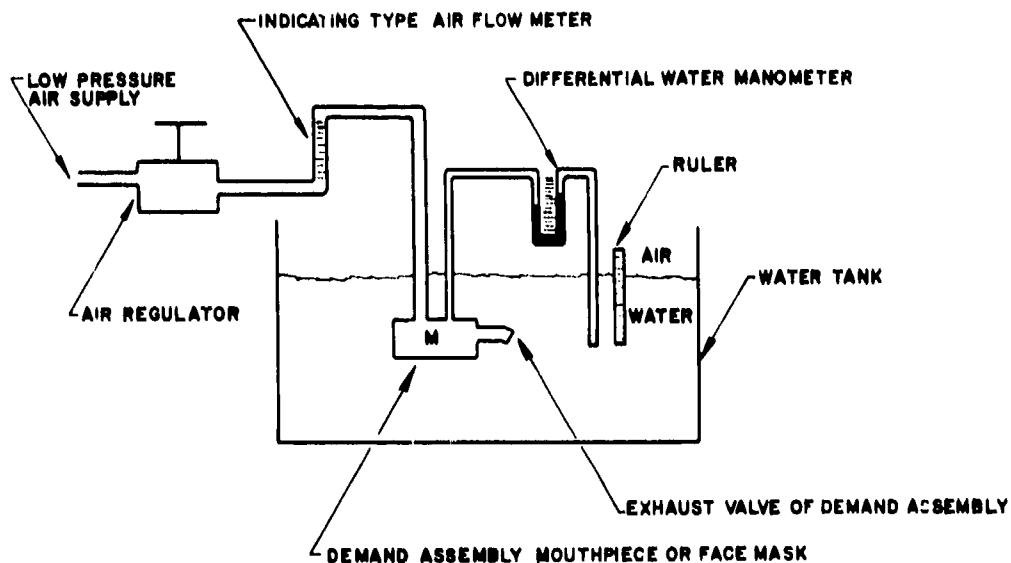
3.22 Technical manuals. - Two complete technical manuals in accordance with type II of Specification MIL-M-15071 shall be furnished with each demand regulator.

3.23 Workmanship. - Workmanship shall be first class in every respect.

4. QUALITY ASSURANCE PROVISIONS

4.1 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Preproduction tests. -



SH 5120

FIGURE - 5.

4.2.1 Contractor. - Prior to submission of the preproduction unit for testing in accordance with 4.2.2, the unit shall be subjected to the tests specified in 4.5.

4.2.2 Government. - After completion of testing in accordance with 4.2.1, the unit shall be subjected to the following tests at the Experimental Diving Unit of the Naval Weapons Plant:

- (a) The first test shall be a simulated breathing test using a breathing machine having a tidal volume of 2 liters and set at a rate of 20 breaths per minute.
- (b) The second test shall be simulated swimming runs using the arrangement shown on figure 3 and swimming against a 12-pound force.

4.3 Sampling. -

4.3.1 Lot. - All regulators offered for delivery at one time shall be considered a lot.

4.3.2 Sampling for visual and dimensional examination and flow rate test. - From each lot of regulators, samples shall be selected for examination in accordance with Standard MIL-STD-105 at inspection level III for examination of 4.3 and the flow rate test of 4.5.2.

4.3.3 Sampling for operating tests. - From each lot of regulators, samples shall be selected for testing in accordance with inspection level L-8 of Standard MIL-STD-105 and subjected to the tests specified in 4.5. If any regulator fails in any test, the lot shall be rejected.

4.4 Examination. - Each of the sample regulators selected in accordance with 4.3.2 shall be examined to verify conformance with all of the requirements of this specification which do not involve tests. Any regulator having one or more defects shall be rejected and lots shall be accepted or rejected in accordance with acceptable quality level (A. Q. L.) : 1.5 percent.

4.5 Test procedures. -

4.5.1 General. - The sample demand valve and regulator or complete demand assembly shall be mounted in the test tank and shall be connected to the appropriate inlet and outlet air lines as shown on figure 4. The throttle valve in outlet air line shall be closed and high pressure air, at a pressure of 3000 plus or minus 25 pounds per square inch gage (p.s.i.g.), shall then be admitted to the demand valve regulator. The tank shall then be partially filled with water up to a level such that the assembly under test is submerged to depth of 2 inches above the top of the sample. The sample under test shall then be examined for signs of air leakage and made completely airtight prior to test. Low pressure air shall then be admitted into the top of the tank and the pressure in the air space at the tank top shall be raised to, and maintained at 5 plus or minus 0.2 p.s.i.g. for all tests. All tests shall be conducted at an ambient temperature of 70° plus or minus 5° F.

4.5.2 Flow rate. - The throttle valve in the air outlet line shall be opened slowly and shall be adjusted to a setting such that the air flow rate through the air outlet line, as indicated on the direct reading flowmeter, is 12 plus or minus 0.5 cubic feet of free air per minute for tests of demand valves and regulators only, or 6 plus or minus 0.25 cubic feet of free air per minute for tests of complete demand assemblies. Under steady flow conditions, readings shall be taken of the differential pressure, as indicated by the water manometer, and of the head of water above the center of the demand valve diaphragm, as indicated by the tape rule mounted inside the tank. The sum of these pressures, in inches of water, shall be the differential pressure, or suction, on the sample under test.

4.5.3 Supply pressure. - The throttle valve in the air outlet line shall be opened slowly and shall be adjusted to a setting such that the air flow rate through the air outlet line, as indicated on the direct reading flowmeter, is 8 plus or minus 0.5 cubic feet of free air per minute. When steady flow conditions have been obtained, the total differential pressure, or suction on the sample shall be noted. With this valve of suction maintained constant by suitable adjustment of the throttle valve in the air outlet line, the air supply pressure to the sample valve or assembly shall be reduced from 2000 p.s.i.g. to 300 plus or minus 10 p.s.i.g. and a reading shall be taken of the air flow rate at this air supply pressure, when steady flow conditions have again been obtained. This air flow rate shall be the air flow rate at reduced pressure. Samples equipped with air reserve valves shall have the air reserve valve in the open position for this test.

4.5.4 Exhaust pressure test. - The exhaust assembly including the mouthpiece or face mask and all exhalation tubes and check valves or flapper valves shall be mounted in a test tank and connected to a supply of low pressure air as shown on figure 5. The tank shall be partially filled with water to a depth of 2 inches above the last exhaust valve. One side of a differential water manometer shall be connected to a tap in the mouthpiece or face mask and the other side shall be connected to a tube which has its open end at the same level as the final exhaust valve. The air regulator shall be adjusted to produce a flow of air through the exhaust assembly of 6 plus or minus 0.25 cubic feet of air per minute.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging (see 6.1). -

5.1.1 Level A. - Regulators shall be packaged in accordance with method III of Specification MIL-P-116. Contact preservative shall not be used. The inlet and exhaust breathing tube openings shall be sealed with plugs and pressure sensitive tape.

5.1.2 Level C. - Regulators shall be preserved and packaged in accordance with the supplier's commercial practice.

5.2 Packing (see 6.2). -

MIL-R-19558A(SHIPS)

5.2.1 Level A.- Regulators, packaged as specified, shall be packed in overseas type wood cleated fiberboard, nailed wood, fiber, wirebound wood, wood cleated veneer paper overlaid, or wood cleated plywood boxes conforming to Specification PPP-B-591, PPP-B-621, PPP-B-636 class 3, PPP-B-585, MIL-B-10377 or PPP-B-601, respectively at the option of the contractor. Shipping containers shall be closed and sealed in accordance with the appendix to Specification MIL-L-10547. Caseliner for boxes conforming to Specification PPP-B-636 may be omitted provided all joints and corners of the boxes are sealed with minimum 1-1/2-inch wide tape conforming to specification PPP-T-76. Boxes may be closed and strapped in accordance with the applicable box specification or appendix thereto, except fiber boxes shall be banded with tape conforming to type IV of Specification PPP-T-97 and the appendix thereto. The gross weight of wood or wood cleated boxes shall not exceed 200 pounds; fiber boxes shall not exceed the weight limitations of the applicable box specification.

5.2.2 Level B.- Regulators, packaged as specified, shall be packed in domestic type wood cleated fiberboard, nailed wood, wirebound wood, cleated plywood or wood cleated veneer paper overlaid boxes or class 2 fiber boxes conforming to Specification PPP-B-591, PPP-B-621, PPP-B-585, PPP-B-601, MIL-B-10377 or PPP-B-636, respectively at the option of the contractor. Box closure shall be as specified in the applicable box specification or appendix thereto. The gross weight of wood or wood cleated boxes shall not exceed 200 pounds; fiber boxes shall not exceed the weight limitations of the applicable box specification.

5.2.3 Level C.- Regulators, packaged as specified, shall be packed in containers which will insure

acceptance by common carrier and safe delivery at destination. Shipping containers shall comply to the Uniform Freight Classification Rules or other carrier regulations as applicable to the mode of transportation.

5.3 Repair parts and accessories.- Repair parts and accessories and special tools (when required) shall be preserved, packaged, and packed for the level of shipment as specified (see 6.1) in accordance with Specification MIL-P-17555.

5.4 Marking.- In addition to any special marking specified in the contract or order, each unit and intermediate package and shipping container shall be marked in accordance with Standard MIL-STD-129.

6. NOTES

6.1 Ordering data.- Procurement documents should specify the following.

- (a) Title, number, and date of this specification.
- (b) Selection of applicable levels of preservation, packaging and packing (see 5.1 and 5.2).

Notice.- When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility or any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

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TESTING PROCEDURES FOR
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UNDERWATER BREATHING APPARATUS
S. D. REIMERS

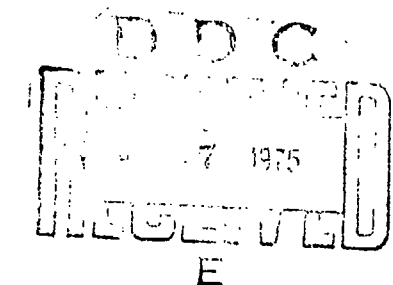
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TABLE OF CONTENTS

	<u>Page</u>
TABLE OF CONTENTS	i
LIST OF FIGURES	ii
LIST OF SYMBOLS AND TERMS	iii
I. INTRODUCTION	1
II. DESCRIPTION OF THE EQUIPMENT TESTED	3
A. Serial Numbers	3
B. Photographs	3
C. Physical Description	4
III. PERFORMANCE TESTS	6
A. Bench Tests	6
B. Pressure Volume (Compliance) Characteristics	6
C. Ventilation Tests	17
D. CO ₂ Absorbant Canister Duration Tests.	28
E. Manned Dives, Subjective Evaluation	33
F. Manned Dives, Physiological Testing	42
IV. INSTRUMENT SPECIFICATIONS	43
REFERENCES	44
APPENDIX A	45

LIST OF FIGURES

<u>Number</u>		<u>Page</u>
1.	Test Equipment Set-Up, Underwater Breathing Apparatus Compliance Tests, Apparatus Wet . . .	9
2.	Sample UBA Compliance Test Results	12
3.	Sample Graph, UBA Maximum Pressure Versus Exhaust Valve Setting	14
4.	Test Equipment Setup, Ventilation Test Semi-Closed Circuit UBA's	19
5.	Test Equipment Set-up, Manned Subjective Test, Semi-Closed Circuit Mixed Gas UBA	37

LIST OF SYMBOLS AND TERMS

acfm	cubic feet per minute at ambient conditions
scfm	cubic feet per minute at standard conditions of 14.7 psia and 70°F, 1 scfm=26.29 slpm
ata	atmospheres absolute
psia	lbs per sq. in. absolute
psig	lbs per sq. in. gauge
psid	lbs per sq. in. differential
psio _b	lbs per sq. in. over bottom pressure
RMV	respiratory minute volume
lpm	liters per minute at ambient conditions
alpm	liters per minute at ambient conditions, same as lpm
slpm	liters per minute at standard conditions of 14.7 psia and 0°C, 26.29 slpm = 1 scfm
cc	cubic centimeter
scc	cubic centimeters at standard conditions of 14.7 psia and 0°C
cm H ₂ O	centimeters of water pressure
Δp	differential pressure
free volume	free air space within a boundary
upper volume	the volume of a breathing bag/diaphragm system above which small increases in volume require large increases in Δp relative to outside ambient pressure
lower volume limit	the volume of a breathing bag/diaphragm system below which small decreases in volume require large negative increases in Δp relative to outside ambient pressure
ΔV	change in volume
UBA	underwater breathing apparatus

I. INTRODUCTION

The purpose of this protocol is to outline the general procedures and equipment to be used by EDU personnel in the evaluation of semi-closed circuit and closed circuit underwater breathing apparatus.

This protocol has been written in terms as general as possible consistent with clear understanding. It is not intended to be a step-by-step procedure which can be applied directly to the testing of a given piece of diving apparatus. Such a procedure would very quickly become out of date. It is rather intended as a detailed guide with which the Project Engineer can plan the evaluation of the apparatus to be tested. The quantities to be measured and controlled are specified for each type of test. The basic test equipment required is outlined along with the considerations governing its set-up, calibration and use. Typical test conditions and data handling requirements are also outlined for each type of test. With only a basic understanding of modern instrumentation and testing techniques, a Project Engineer should be able to readily make the detailed decisions necessary to apply this protocol to a specific piece of diving equipment.

The procedures outlined herein are concerned principally with evaluation of the functional performance of the diving apparatus being tested. No effort has been made to include specific material tests such as abrasion tests, salt spray tests, air-drop tests, etc. Those tests are very involved, very specific, and vary greatly with the system to be tested. They also,

for the most part, require equipment and facilities not available at NAVXDIVINGU. Consequently they are considered outside the scope of this protocol.

If material adequacy tests are to be performed, U.S. Army Material Test Procedure 8-2-113 for Self-Contained Air and Oxygen Breathing Apparatus (1) contains most of the material tests that would be required. MTP 8-2-113 is, however, written for surface breathing apparatus (gas masks, dust masks, fire fighters breathing apparatus, etc.) and does not contain the material tests specific to underwater operation. The principal tests missing are those pertinent to MIL-STD-MS 33586 for dissimilar metals and MIL-STD-167 for a salt water spray.

Also, no effort has been made to include specific reliability and maintainability tests. These tests are normally done during the traditional Techeval/Opeval cycles. Considerable insight into the reliability and maintainability of the apparatus tested will, however, be gained as a result of the tests described herein.

The tests outlined herein have been kept as simple as possible. Experience has shown that it is usually faster and more reliable to run a number of small tests where no more than two or three major variables are measured at one time than it is to do everything all at once.

II. DESCRIPTION OF THE EQUIPMENT TESTED

A. Serial Numbers

It is critically important that the piece of diving apparatus be positively identified. Most underwater breathing apparatus have serial numbers. Find the serial number (a call to the manufacturer may be necessary to find where to look), and record it. All data sheets used with the UBA will need the UBA serial number. If the UBA does not have a serial number, give it one.

B. Photographs

1. Equipment Tested

Photograph the apparatus to be tested from all appropriate angles. Usually these will include at least both sides, front, and rear. Also, take several photos of a diver dressed in the apparatus. If appropriate, disassemble the apparatus and take pictures of the individual components.

Take all photographs against a white background. Place a dark-bordered white placard so that it appears in the lower right-hand corner of the picture, giving the following information: manufacturer trade name; view (front, back, right side, left side, top or bottom, etc.); month and year. For any close-ups of the apparatus, place a 12-inch ruler so that it appears across the bottom center of the picture. For long shots of the apparatus, do not include a ruler.

2. The Test Equipment

Photographs of the UBA as it is rigged for the various tests described herein are very helpful when report writing

time arrives. Representative pictures should be taken of all test set-ups described, both with and without the UBA in place.

C. Physical Description

1. Material Description

A written description of the apparatus tested is essential. It must include a description of the overall apparatus configuration, the materials of construction, valve types and sizes, method of attachment to the diver (jocking system), communications arrangements, and any special features. Also to be detailed are the size, shape and absorbant capacity (in pounds) of the CO₂ absorbant canister, and the capacities (in scf), working pressures, shapes and methods of attachment of all gas storage bottles. Usually the manufacturer's own literature will be sufficient. However, if it is not, a description must be generated which meets the above requirements.

If possible, obtain exploded drawings of the apparatus from the manufacturer.

2. Size

Measure the overall size in inches. Include any projections. Record overall length, width and thickness, specifying the points of measurement. Record the size and shape of all display assemblies.

3. Weight

Measure the overall weight of the apparatus in air. Include all attachments. Record the apparatus weight with

all bottles first empty, then charged to their maximum working pressure.

Record the individual weights of all display units.

4. Buoyancy

Measure the buoyancy in pounds and ounces, either positive or negative. Before checking the cylinder pressures, be sure that they have reached room temperature. Then record the buoyancy in room temperature fresh water under the following conditions:

- a. Cylinder filled, canister filled with fresh dry Baralyme, breathing bags or diaphragm fully inflated.
- b. Cylinder filled, canister filled with fresh, dry Baralyme, breathing bags or diaphragm as empty of air as it is possible to get them without damage.

Also measure separately the buoyancy, positive or negative, of all display units such as wrist or chest displays.

III. PERFORMANCE TESTS

A. Bench Tests

1. Pressure test all cylinders to their maximum rated pressure.
2. Disassemble entire rig (regulators, valves, canisters, mouthpiece, etc.), and check for any burrs, foreign matter imbedded, cracks and rough surfaces. Note any of these and any dissimilar metals as per MIL-STD-MS 33586. Note any difficulties encountered in either disassembly or re-assembly. Note any special or unusual tools required.
3. Test all relief and low pressure valves to their designated pressure.
4. After 1, 2, and 3 have been completed, submerge entire rig, fully charged, and check for leaks.
5. Test the testing equipment furnished by contractors.
6. Have subject put on fully charged rig and walk about. Determine from subject: comfort, pressure points, ease and ability to move about, and to walk erect.

B. Pressure Volume (Compliance) Characteristics

1. Background

All types of closed circuit and semi-closed circuit underwater breathing apparatus have a gas storage device or "counter-lung" somewhere in their design. The purpose of the "counter-lung" is to receive the diver's exhaled gas and store it at the ambient pressure so that it may be re-inhaled again at the proper time. The "counter-lung" designs most commonly used are breathing bags. Displacement diaphragms (a very low differential pressure version of a hydraulic accumulator) are also used.

For the purposes of this test protocol, the quantity "base pressure" will be defined to mean the pressure that exists in the respiratory circuit when there is no respiratory flow

in the system. The base pressure in a breathing bag system is roughly equal to the external hydrostatic pressure at the level of the collapse plane of the breathing bags. In a diaphragm system, it is roughly equal to the hydrostatic pressure at the centerline level of the diaphragm.

In almost all systems, the base pressure will change with the inflation level of the breathing bags or the fill level of the diaphragm. This pressure change represents a form of resistance to breathing known as an elastic resistance. If severe enough, it can cause the apparatus to fail the breathing resistance standards, (see EDU report 19-73).

The purpose of this section is to determine the pressure-volume characteristics of the apparatus under test. The volume change per unit pressure change for the UBA is known as its respiratory "compliance". It is desirable that the compliance be as high as possible.

Also to be measured in related tests conducted under this section are the base pressures at which the UBA pop-off valve lifts, the base pressure at which the diluent add valve (if any) actuates, and the maximum flow rates of all purge valves and by-pass valves.

2. Quantities to be Measured:

- a. Mouthpiece (or oral-nasal) pressure re selected reference pressure
- b. UBA and mask position on test manikin (measure in sufficient detail so that the UBA and mask could be removed and replaced in exactly the same position
- c. Pressure at which the UBA exhaust (pop-off) valve lifts

- d. Pressure at which the diluent add valve actuates (closed circuit UBA only).
 - e. Maximum flow rate attainable through all by-pass and/or purge valves. (If these valves are located in the system so that the flow across them is always sonic regardless of the test depth, as is the case for most UBA, then the maximum by-pass/purge flow rates need be measured only at the surface. Otherwise, they must be measured at each test depth.)
3. Quantities to be controlled:
- a. Amount of gas added to and withdrawn from the mouthpiece or oral-nasal
 - b. UBA and mask position on the manikin
 - c. Setting of exhaust or "pop-off" valve
 - d. Supply pressure to the UBA
 - e. Supply gas mixtures
 - f. Manikin orientation
 - g. UBA tested wet or dry
 - h. Temperature
 - i. Depth
4. Equipment
- a. Specialized equipment required
 - 1) Large graduated syringe, preferably about 2 liters
 - 2) 3-way valves and plumbing as shown in Figure 1
 - 3) Test manikin and wet testing box
 - 4) Differential pressure transducer and transducer indicator, 1 psid
 - 5) Flowmeters (2), approximate sizes, 1.0 and 8.4 scfm air at 70°F. and 14.7 psia with a minimum working pressure of 600 psig

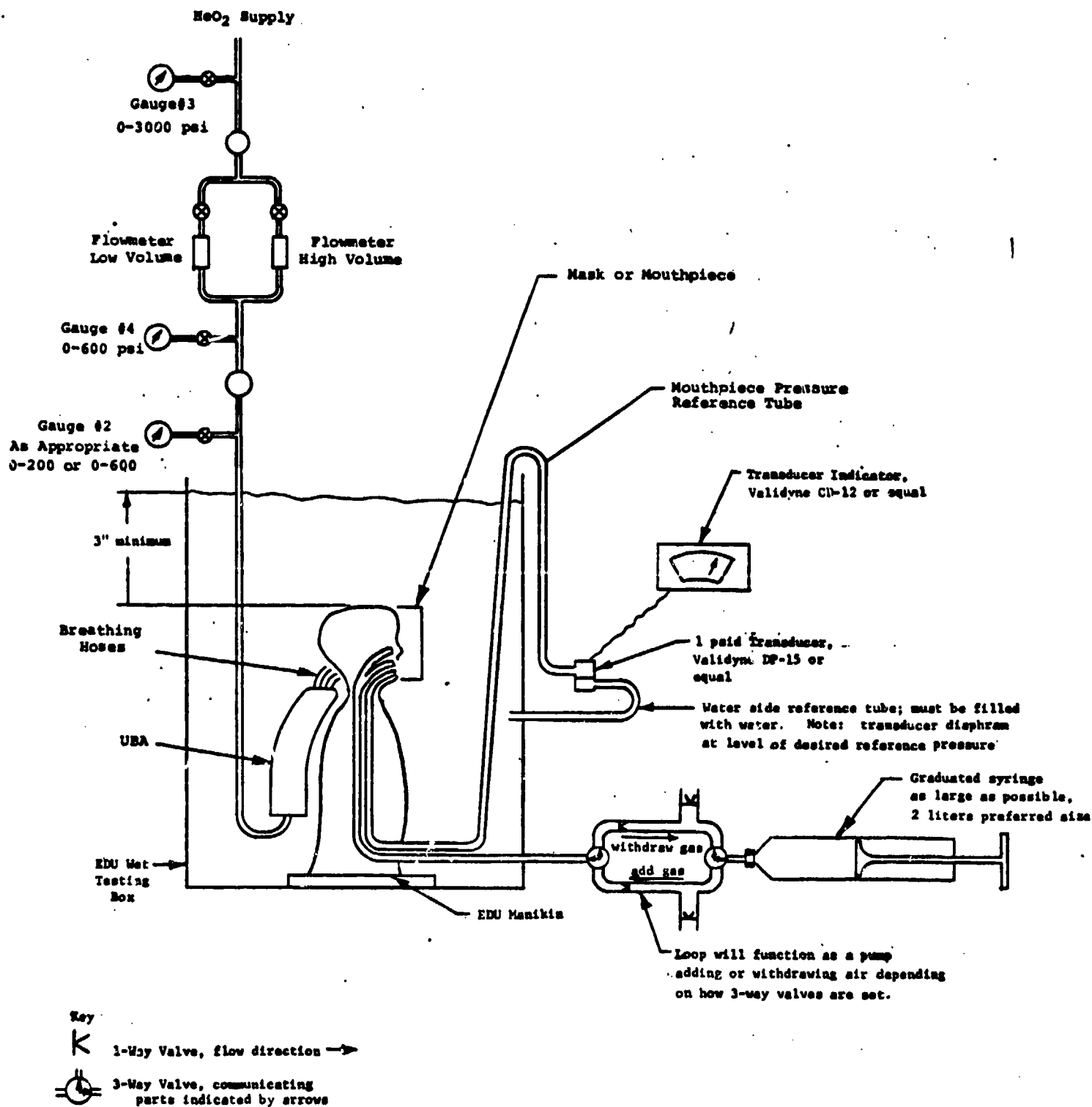


Figure 1

Test Equipment Set-Up, Underwater Breathing Apparatus Compliance Tests, Apparatus Wet.

For Dry Tests, Apparatus & Manikin need not be inside the Wet Testing Box

- b. Set up the UBA test equipment generally as shown in Figure 1. Figure 1 is intended only as a guideline, and minor modifications can be expected to accommodate the particular apparatus being tested.
- c. The UBA should be placed on the test manikin and jocked as nearly per manufacturer's instructions as possible. Measure the UBA position on the manikin in sufficient detail so that it can be exactly reproduced.
- d. All manikin openings inside the UBA facemask except the openings to the syringe and pressure transducer must be closed, and if necessary, sealed. Leaks may invalidate the test. Leaks may be checked for by adding 20 cm H₂O pressure to the UBA and observing the rate of decay. A system with a pressure decay of less than 1 cm H₂O per 15 seconds at 20 cm H₂O pressure can be considered leak-tight for this case. For the compliance tests, the gas supplies to the UBA must be secured, and, if necessary, sealed. The exhaust valve should be closed as tightly as possible, and, if necessary, sealed shut.
- e. The transducer line to the UBA and the syringe line must not be the same port.
- f. The reference pressure for the transducer may be any convenient pressure, as long as the pressure used is recorded. Hydrostatic pressure at the level of the manikin's 7th cervical vertebra, at the level of the centerline of the manikin's mouth (as shown in Figure 1) or at any other appropriate level may be used. The Project Officer should determine ahead of time which reference pressure is to be used. See EDU Report 19-73 for more information on reference pressures.

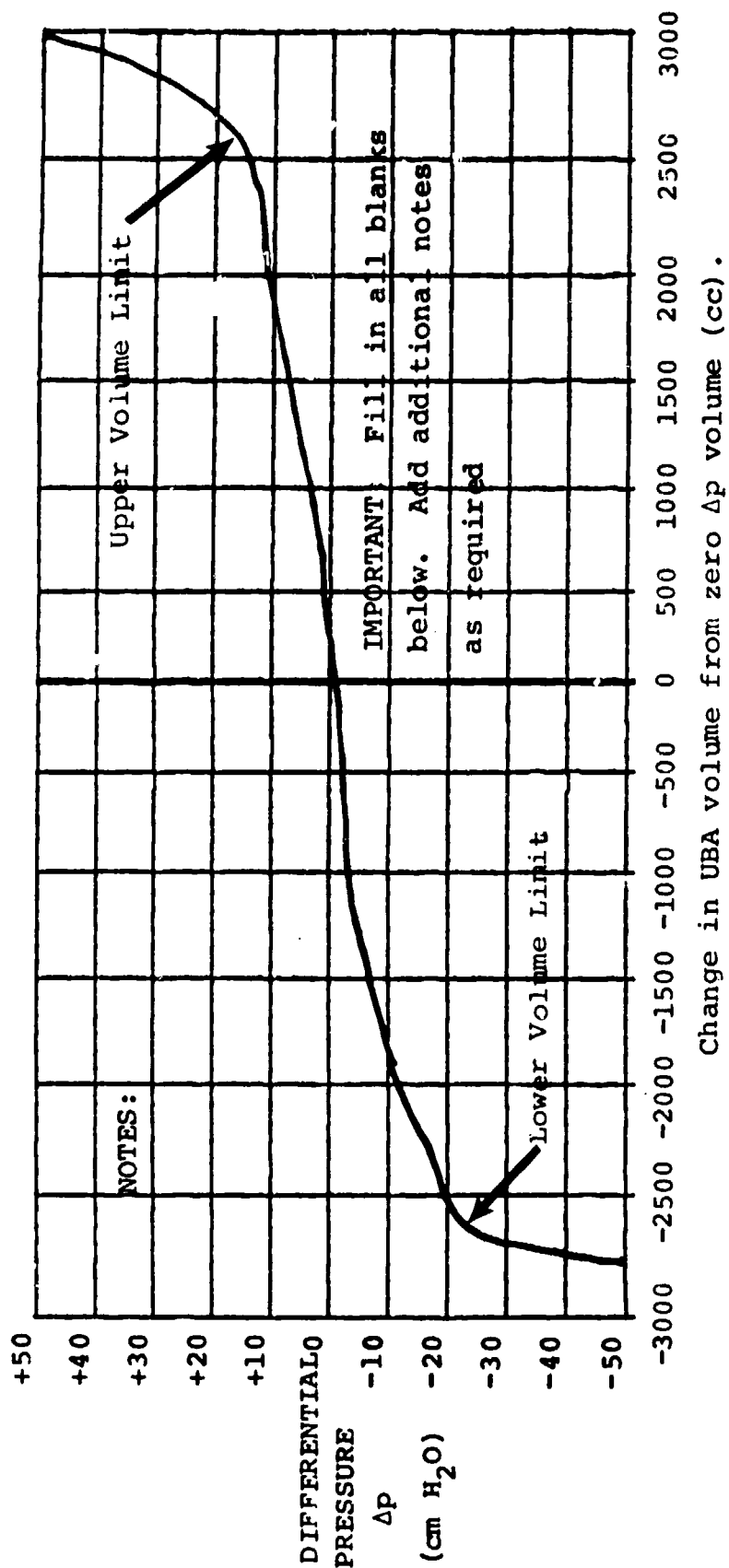
5. Calibration

Calibrate the transducer and transducer indicator against a water or mercury manometer prior to each major test. Recheck calibration at the end of the test. The flowmeters are factory calibrated and should not need calibration unless there is evidence of damage.

6. Test Conditions and General Procedures

a. Compliance Tests

- 1) The UBA should be tested first dry, then wet. When tested dry, the UBA will have essentially the same compliance in all orientations. When tested wet, it will exhibit different compliance characteristics in different orientations with respect to the pull of gravity. Normally it will be sufficient to test the UBA only in the head-up vertical orientation shown in Figure 1 and the face-down, horizontal orientation. However, if ventilation tests (Section III,C.) are to be run with the UBA in other orientations, compliance tests should be performed with the UBA in those orientations, as well.
- 2) Normally this test will be performed only at 0 fsw and room temperature. However, the Project Engineer may order additional test conditions.
- 3) Secure all gas supplies to the UBA, seal if necessary. Set the exhaust (pop-off) valve for maximum back-pressure. If necessary, seal it closed to prevent unwanted leaks.
- 4) With the UBA dry and at zero Δp , add 100 cc air, record the UBA Δp indicated, and return to zero Δp . Now from the zero Δp volume again, add 200 cc air, record the UBA Δp indicated and return to zero Δp . Continue this process until the upper volume limit of the UBA system is reached. The upper volume limit is that volume above which small increases in volume require very large Δp increases. Now proceed to the lower volume limit in the exact same fashion: withdrawing 100 cc air from the zero Δp volume, recording the UBA Δp , returning to zero Δp , withdrawing 200 cc air, etc. Repeat two more times. If you did not get reproducible results, you have a major leak somewhere; fix it and try again.
- 5) Fill the test box with water to a level at least three inches over the top of the manikin and repeat 4) above.
- 6) Plot the results as shown in Figure 2.



Apparatus _____ Date _____ Recorder _____

UBA and Manikin Orientation _____

Reference Pressure _____

UBA Dry _____ or Submerged _____

Depth _____ Temperature _____

UBA Serial Number _____

Mask Used, if any _____

Figure 2. Sample UBA Compliance Test Results

b. Exhaust (Pop-Off) Valve Tests

- 1) Remove the sealing agents installed in the exhaust valve in section III.B.6.a, if any.
- 2) Perform these tests with the UBA submerged. With the exhaust valve set at several representative settings, slowly add gas to the UBA with the syringe. For each setting, note the pressure at which bubbles first appear from the exhaust valve.
- 3) With the appropriate by-pass valve, admit a steady flow of 0.5 acfm to the UBA, record the pressure level reached. Repeat with a steady flow of 1.0 acfm. Do this for each of the exhaust valve settings used in 2) above.
- 4) Plot the results as shown in Figure 3.

c. Diluent Add Valve Tests (Closed Circuit UBA Only)

- 1) Perform these tests with the UBA submerged.
- 2) With the syringe slowly withdraw gas from the UBA until the diluent add valve is heard to open. Repeat several times with different diluent supply pressures. Note any effect of diluent supply pressure on the performance of the diluent add valve. For each test, record the diluent supply pressure and the pressure at which the diluent add valve opened.

d. By-Pass and/or Purge Valve Flow Rates

- 1) For these tests, remove the water from the test box and disconnect the breathing bags or diaphragm. There is a danger of rupturing the breathing bags or diaphragm when these tests are performed on the surface.
- 2) Semi-Closed Circuit UBA Only
 - a) Record the flow rate and pressure settings of the metering orifice.

UBA _____ Date _____
 Recorder _____ Depth _____ fsw
 UBA, wet _____ or dry _____ Serial No. _____

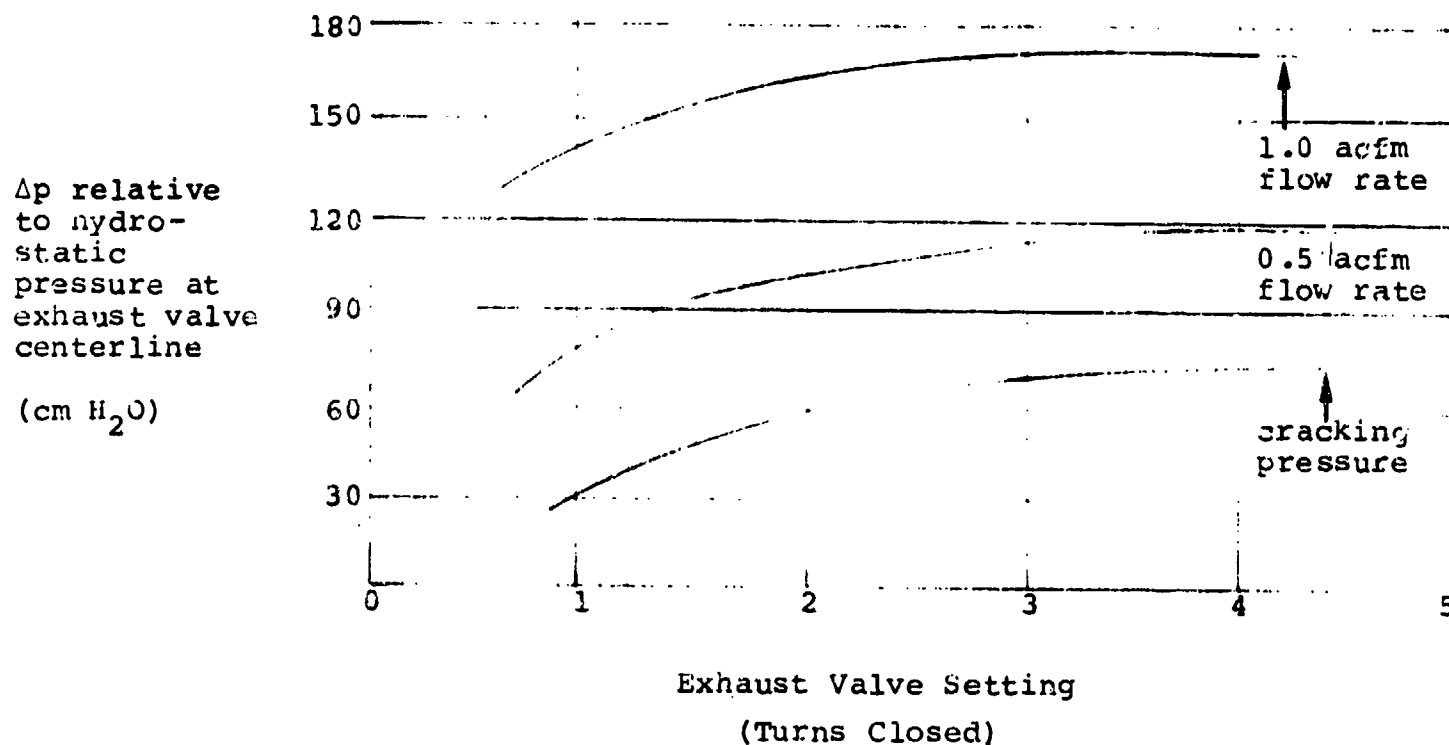


Figure 3. Sample Graph, UBA Maximum Pressure Versus Exhaust Valve Setting

- b) Depress the by-pass valve fully. Record the flow rate achieved and the supply pressure to the UBA. If the by-pass valve draws directly from the umbilical or bottle gas supply (as most do), repeat this test on a variety of representative supply pressures.
- c) Repeat this test on a variety of gas mixtures normally used with the UBA being tested.

3) Closed Circuit UBA Only

- a) By hand, depress the diluent add valve fully, and record the flow rate and the diluent supply pressure. Repeat for a full range of representative diluent supply pressures.
- b) Repeat a) above for the diluent by-pass valve.
- c) Perform a) and b) above on all diluent gases normally used with the UBA under test.
- d) Repeat a) above for the oxygen by-pass valve.

7. Data Handling

a. Compliance Tests

All results are to be recorded on a chart similar to Figure 2. Note that it is the Project Engineer's responsibility to correct for errors due to compression or expansion of the gas in the UBA and manikin plumbing. At 1 ata the error is 1 scc volume/cm H₂O pressure/liter of free volume.

b. Exhaust Valve Tests

Record the results on a chart similar to Figure 3.

c. All Other Tests

Record the data in neat tabular form unless otherwise directed by the Project Engineer.

- d. For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.
- e. The Project Engineer or his representative should keep a daily log of all significant events.

C. Ventilation Tests

1. Background

The purpose of these tests is to determine the ventilation characteristics of the UBA when it is in normal working order and normal working trim. The variables of primary interest are the breathing resistance, inspired PCO_2 levels, inspired PO_2 levels, and, in the case of semi-closed circuits UBA's, also the liter flow rate.

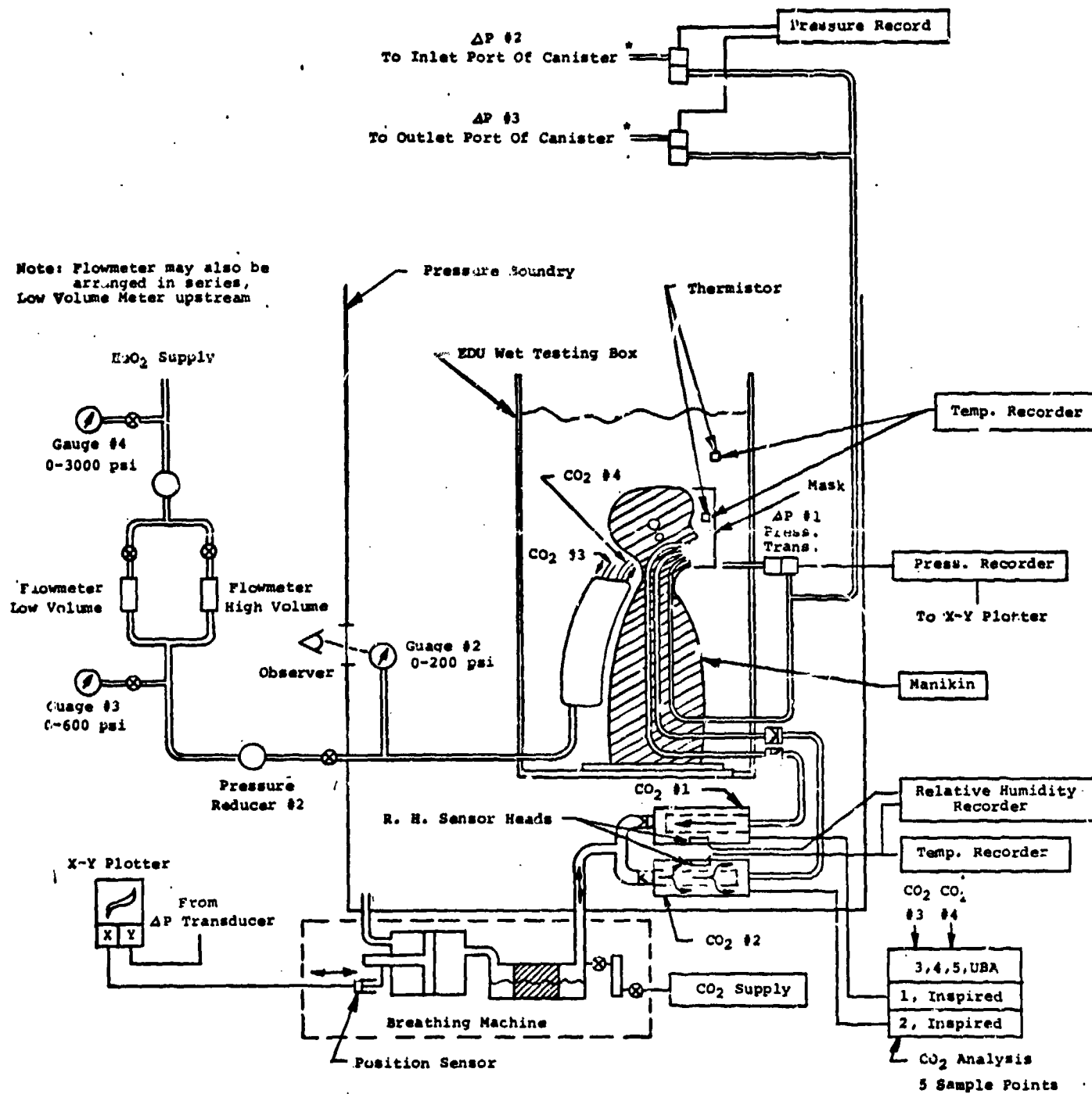
The breathing pressure data obtained from these tests should reflect the compliance results of Section III.B.

Measuring the duration of the CO_2 absorbant canister is not a goal of these tests. Canister duration tests should be run separately as noted in Section III. D. The tests outlined in this section are designed solely to determine the ventilation characteristics of the UBA given a properly operating CO_2 absorbant canister.

At this time, the mechanical breathing machine and related equipment do not have the ability to remove oxygen. Consequently, the ability of the UBA to maintain a safe PO_2 level cannot adequately be tested by this method. However, careful observations of liter flow rates in the case of semi-closed circuit UBA's, and observation of the PO_2 sensors in the case of closed circuit UBA's will give a good indication of how well the rig will perform when subjected to manned tests.

2. Quantities to be Measured

- a. PCO_2 levels at the following locations:
 - 1) Inhalation mixing box (inhaled PCO_2 level, CO_2 #1, Figure 4)
 - 2) Exhalation mixing box (exhaled PCO_2 level, CO_2 #2, Figure 4)
 - 3) Exhalation hose (CO_2 #3, Figure 4)
 - 4) Inhalation hose (CO_2 #4, Figure 4)
 - 5) Any other location(s) selected by the Project Engineer
- b. Differential pressures between the following locations:
 - 1) Mouthpiece pressure and hydrostatic pressure at the selected reference point
 - 2) Mouthpiece pressure and the pressure at the canister inlet port (Figure 4, Δp Transducer #2)
 - 3) Mouthpiece pressure and the pressure at the canister outlet port (Figure 4, Δp Transducer #3)
 - 4) Any other locations as directed by the Project Engineer
- c. Temperatures at the following locations:
 - 1) Inhalation mixing box
 - 2) Exhalation mixing box
 - 3) Mouthpiece or mask, if thermister installed
 - 4) Water bath
- d. Relative humidity of the inspired gas and expired gas.



*Or other locations as directed by project officer

Figure 4
Test Equipment Setup, Ventilation Test Semi-Closed Circuit UBA's

3. Quantities to be Controlled

- a. Depth
- b. Supply over bottom pressure (Gauge #2, Figure 4)
- c. Exhaust (pop-off) valve setting
- d. Position of UBA on test manikin
- e. Manikin orientation
- f. UBA condition: wet
- g. Water bath temperature
- h. Gas media
- i. Umbilical size and length
- j. Manikin respiratory parameters
 - 1) CO₂ addition rate
 - 2) Breathing rate
 - 3) Tidal volume
 - 4) Volume-time waveform
 - 5) Exhaled gas temperature and relative humidity

4. Equipment set-up

- a. Specialized equipment required
 - 1) EOU manikin with double tracheas, one for inhalation, one for exhalation. Manikin should also have provisions for monitoring the pressure and temperature inside the mouthpiece.
 - 2) Porthole blanks with reach rods or flexible shafts tailored to the UBA to be tested; one for the exhaust valve, and one for the by-pass valve (semi-closed circuit UBA) or the diluent add by-pass (closed circuit UBA).
 - 3) Flowmeters (2) for gas supply line, approximate sizes, 1 and 8 scfm air at 70°F. and 14.7 psia with a 600 psig minimum working pressure (semi-closed circuit UBA's only).

- 4) Differential pressure transducers (3), approximate range ± 5 psid, and associated signal conditions and recorders.
- 5) Thermistors and read-out unit.
- 6) Breathing machine with inhalation and exhalation mixing chambers.
- 7) At least two CO_2 analyzers, one with a range of 0 to 0.5% by volume, or 0 to 1% by volume; one with a range of 0 to 6% by volume. CO_2 levels #2 and #3 can be expected to run between 4 to 6% S.E., CO_2 levels #1 and #4 can be expected to run between 0 to 1% S.E.

- b. Set up the equipment generally as shown in Figure 4. Figure 4 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test. Figure 4 shows an umbilical supplied semi-closed circuit UBA. The set-up for a closed circuit UBA would be identical except for the gas supply plumbing. Flowmeters are not required for closed circuit UBA's.

Self-contained UBA's, for this test, should be supplied from banks rather than from their own bottles. This test is rather lengthy, with frequent, and sometimes large, depth changes. Consequently, the gas supplies carried in most self-contained UBA's will be quickly exhausted, resulting in many delays to refill bottles.

- c. Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 4.
- d. One Δp transducer should be set-up to monitor the pressure differential between the mouthpiece interior and the hydrostatic pressure at the level of the 7th cervical vertebra (chamber ambient pressure if UBA is tested dry). Use a different reference pressure if so directed by EDU report 19-73. The other Δp transducers are to be set-up as directed by the Project Engineer.

- e. The internal free volume of all inhalation plumbing components must not be greater than 10 liters. The internal free volume of all exhalation plumbing components must likewise be less than 10 liters. The internal free volume of components used for both inhalation and exhalation is to be charged against both 10 liter limits. 10 liters free volume is the most free volume that can be tolerated without introducing excessive errors due to pneumatic compliance (gas compressability). See EDU Report 20-73, Section III for more details.
- f. Total mechanical compliance (hose stretch, etc.) of the breathing loop plumbing must be kept below .05 liter per 20 cm H₂O pressure change.
- g. Water depth over the top of the manikin should be at least six inches. Water temperature should be 70 to 80° F.
- h. Set up the X-Y plotter so that it makes plots of mouthpiece pressure versus inspired-expired volume. Plots of mouthpiece pressure versus inspiratory-expiratory flow rates may also be useful.
- i. Great attention must be paid to the gas sampling system and the manner in which it is operated. The CO₂ sampling lines should be sized so that the time required for a gas sample to travel from the UBA to its appropriate analyzer is less than 30 seconds at the maximum test depth. However, the rate at which the gas is withdrawn from the UBA must be carefully monitored. It is very easy to withdraw so much gas for sampling purposes that the test becomes compromised. In general, breathing pressure measurements should not be made without first securing all of the gas sample lines.
- j. All sampling lines should have small water traps, located downstream of the pressure reduction point.

- k. All breathing loop components should have an I.D. of not less than 3/4". The lengths of the hoses carrying uni-directional flow are not critical and may be as long as required so long as the 10 liter free volume limit in e. above is observed. The lengths of the hoses and pipes carrying bi-directional flow are important and should be kept as short as possible with reasonable effort.
- l. The output of the Δp transducers must be continuously recorded. Continuous recording of the outputs of the CO_2 analyzers is highly recommended. The output² of the Δp transducer varies so rapidly with time that it cannot be read from a panel meter. The outputs of the CO_2 analyzers will vary enough with time to make accurate readings from a panel meter extremely difficult.
- m. Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the gas supply system (semi-closed UBA's only) can invalidate the flow rate data. Leaks in the breathing loop plumbing can invalidate the CO_2 data. The breathing loop plumbing can be² considered leak tight if, with the manikin's mouth sealed or corked shut, the system will hold both a 20 cm H_2O pressure and a 20 cm H_2O vacuum with a pressure (vacuum) decay rate of less than 1 cm H_2O per 10 seconds at 20 cm H_2O pressure (vacuum).

5. Calibration

- a. Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- b. The transducers should be calibrated against a water or mercury manometer; the thermistors against 32°F. water and room temperature.
- c. The flowmeter and gauges normally do not need daily calibration.
- d. The CO_2 analyzers should be calibrated against at least 3 known gases each; full scale, zero and mid-range CO_2 concentrations. If the CO_2 analyzer calibrations are non-linear, several more calibration points and a graphical calibration record will be required.

- e. Calibrate the X-Y plotter axes prior to each test. Re-check at the conclusion of each test. The Y-axis should read mouthpiece pressure; the X-axis, inspired-expired volume.

6. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for the complete test of a closed-circuit mixed gas UBA rated for a maximum service depth of 1000 fsw follow:

- a. Umbilicals As required to connect UBA to test chamber O₂ and H_e headers.
- b. Supply Pressures 3000, 2000, 1000 psig and 300 psia
- c. Test Depths 50 fsw increments to 1000 fsw
- d. Exhaust (pop-off) valve setting Fully closed, 1/2 open, fully open or as recommended by manufacturer
- e. Position of UBA on Manikin Normally jocked position. Be sure this position is known in sufficient detail so that it can be reproduced exactly.
- f. Manikin Orientation Face-down horizontal and head-up vertical. Other orientations may also warrant testing.
- g. UBA condition Wet
- h. Water Bath Temperature 70° to 80° F.
- i. Manikin Respiratory Parameters*

CO ₂ Add. Rate	.04 X RMV slpm (ex. 1.6 slpm at 40 lpm RMV)
Breathing Rate	15, 20, and 25 breaths per minute

* Parameters recommended by EDU Report 19-73

Tidal Volume	1.5, 2.0, and 2.5 liters per breath respectively at breathing rates of 15, 20, and 25 bpm
Volume-Time Waveform	Flattened Sinusoid with an exhalation to inhalation time ratio of 1.1 - 1.0 and a ratio of peak flow to minute volume of 2.7
Exhaled Gas Temperature	97° ± 2° F.
Exhaled Relative Humidity	Saturated at 97° F.

The test conditions for a semi-closed circuit UBA rated for 1000 fsw would be similar. The principal differences would be the addition of a test condition specifying the umbilical to be used, and the gas mixtures, supply pressures, and liter flows to be used.

7. General Procedures

- a. These tests are normally done only with the UBA wet.
- b. Test all of the conditions of interest on the surface. Get a feel for effects of pop-off (exhaust) valve settings and for the effects of various breathing bag/diaphragm inflation levels.
- c. Test the UBA under pressure. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to maximum test depth.
- d. During descent be very careful not to travel too fast and produce excessively negative pressures in the UBA relative to chamber pressure. This can quickly result in a flooded rig.

- e. It is usually best to let the breathing machine run continuously unless d. above requires that it be secured during descent.
- f. During all times when the respiratory load on the UBA is being increased (increasing minute volume or increasing depth) watch the mouthpiece Δp transducer output very carefully. If excessively negative Δp 's are observed, stop or slow down.
- g. During ascent from the maximum test depth repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.
- h. Maintain each test condition until all values stabilize. This may take as long as 15 minutes.
- i. If canister break-through occurs (CO_2 level #4, canister return, exceeds 0.5% S.E.), return to the surface obeying g. above, replace the CO_2 absorbant, return to the depth of break-through and complete the tests desired.
- j. Repeat c. and g. above as many times as required to obtain good confidence in the data.
- k. Take care that the amount of gas being drawn out the gas sample lines does not disturb conditions in the UBA. It is usually wise to make the mouthpiece Δp measurements and X-Y plots with all the sample lines secured.
- l. To the extent possible, all emergency breathing ~~modes~~ should also be tested. This, however, will most probably require a separate test run with somewhat different instrumentation. If the emergency breathing mask is open-circuit, demand breathing from an umbilical supply, the emergency breathing mode is equivalent to Bandmask diving. See EDU Reports 2-73 and X-74 for procedures and instrumentation set-ups for testing a Bandmask type system.

8. Data Handling

- a. On-line cross checking of data values is essential for this test. The best cross check to use is simple CO_2 conservation. There are two checks that can be used, as follows:
 - 1) PCO_2 #2 - PCO_2 #1 should equal 4.0% S.E.
 $\pm .3\%$ S.E.

- 2) The CO_2 addition rate should equal the CO_2 disappearance rate.
- $$\text{CO}_2 \text{ in} = \text{CO}_2 \text{ out} = (\text{PCO}_2 \#3 - \text{PCO}_2 \#4) \times (\text{RMV})$$
- $$+ (\text{PCO}_2 \#3) \times (\text{gas consumption rate})$$

The first term on the right hand side of the equation is the rate of CO_2 removal by the CO_2 absorbant canister;² the second is the rate at which CO_2 is exhausted out the exhaust valve. The CO_2 disappearance rate calculated as above should equal the CO_2 add rate $\pm 10\%$.

- b. Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip recordings or other permanent data records so that the data can be identified.
- c. For each test run, calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and the X-Y plotter.
- d. Plot the recorded data as directed by the Project Engineer.
- e. From the plots of mouthpiece pressure versus inspired-expired volume made on the X-Y plotter, calculate the external work of breathing expended by the manikin. Compare against the .17 Kg-m/liter ventilation limit proposed by EDU Report 19-73. If the work of breathing standards proposed by this report are adopted, a plot of the external work of breathing will also be required.
- f. The Project Engineer or his representative should keep a daily log of all significant events.

D. CO₂ Absorbent Canister Duration Tests

1. Background

The purpose of these tests is to determine the expected lifetime of the CO₂ absorbent canister under all of the conditions in which the UBA will be expected to operate.

These tests are very similar to those of Section III. C. The experimental set-up is almost identical. The principal differences are in the test conditions selected. In these tests the ventilation conditions in the UBA are held constant (manikin RMV, liter flow, exhaust valve setting, etc.) and the temperature of the water bath is varied. In Section III. C. the reverse was true.

Canister lifetime tests are extremely time consuming. Round-the-clock operation should be considered.

2. Quantities to be Measured

The quantities to be measured are the same as those in Section III. C. 2. except:

- a. The temperature of the gas entering and leaving the CO₂ absorbent canister must also be measured.
- b. Only the mouthpiece Δp transducer (Δp Transducer #1, Figure 4) is necessary. The others may be eliminated.
- c. The expired gas temperature and humidity are of critical importance in this test whereas in Section III. C. 2. they were of secondary interest.

3. Quantities to be Controlled

The quantities to be controlled are the same as those

in Section III. C. 3. Water bath temperatures, manikin exhaled gas temperature and relative humidity are, however, of critical importance here whereas in Section III. C. 3. they were of secondary interest.

4. Equipment Set-Up

- a. The recommended equipment set-up is identical to that outlined in Section III. C. 4. except:
 - 1) Thermistors must be added to monitor the temperature of the gas entering and leaving the CO₂ absorbent canister.
 - 2) Δp transducers #2 and #3 may be removed.
- b. Precise ($\pm 2^{\circ}\text{F}$) control of the water bath temperature is essential.

5. Calibration

The calibration procedures are the same as those outlined in Section III. C. 5.

6. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical test conditions for a complete canister lifetime test follow:

- | | | |
|----|------------------|---|
| a. | Umbilicals | As required to connect the UBA to the chamber O ₂ , He or Mixed Gas headers as appropriate |
| b. | Supply Pressures | 1000 psig or as recommended by the manufacturer |
| c. | Test Depths | 3 depths representative of the depth range in |

- which the apparatus is to be used
- d. Supply Gas Mixture Use mixtures representative to the depths chosen in c. above
 - e. Exhaust Valve Setting As recommended by the manufacturer
 - f. Position of UBA and mask on manikin Normally jocked position. Be sure this position is known in sufficient detail that it can be exactly reproduced.
 - g. Manikin Orientation Head-up vertical
 - h. UBA Condition Wet
 - i. Water Bath Temperatures 70°F, 60°F, 50°F, 40°F, 32°F, additional temperatures as directed by Project Engineer
 - j. Manikin Respiratory Parameters*
 - CO₂ Addition Rate 2.5 slpm
 - Breathing Rate 25 breaths per minute
 - Tidal Volume 2.5 liters
 - Volume-Time Waveform Flattened Sinusoid with an exhalation to inhalation time ratio of 1.1/1.0 and a ratio of peak flow to minute volume of 2.7
 - Exhaled Gas Temperature 97 ± 2°F
 - Exhaled Relative Humidity Saturated at 97°F

7. General Procedures

- a. The only test conditions which are not constant throughout are depth and water bath temperature.

*Severe Work Rate Parameters Recommended by EDU Report 19-73.

The best procedure is usually to test all of the desired water bath temperatures at 0 fsw, then go to 100 fsw, etc. on down to the maximum depth to be tested.

- b. Each individual test will consist of running the canister until breakthrough at one depth and one water bath temperature. The test is considered to start when the breathing machine is turned on. Once turned on, the breathing machine and CO₂ add system should not be secured until the test is completed.
- c. Run the test until the CO₂ level in the canister return line reaches 2.0% S.E.
- d. During these tests, once started, the breathing machine must run continuously. During descent evolutions, use the by-pass valve to admit extra gas if required to maintain a satisfactory mouthpiece Δp . Watch the mouthpiece Δp very carefully during descent.
- e. Due to the length of time required for each test, individual test runs are normally not repeated as long as everything worked properly and the test results are consistent with the results from the other canister lifetime test runs.
- f. Take care that the amount of gas being drawn out the gas sampling lines does not excessively disturb conditions in the UBA.

8. Data Handling

- a. The data handling procedures are essentially the same as those of Section III. C. 8.
- b. The CO₂ cross checking procedures are identical with those of Section III. C. 8. a. As before, they should be done on-line.
- c. The principal purpose of these tests is to determine the expected canister lifetime as a function of depth and water temperature. Consequently only the CO₂ level versus time data need be plotted separately. Whether or not other data obtained (UBA gas consumption, mouthpiece Δp , etc.) is to be plotted is to be determined by the Project Engineer. The best way to handle this data will probably be to plot it as additional data points on the graphs and plots

made as a result of the tests outlined in
Sections III. B. and III. C.

E. Manned Dives, Subjective Evaluation

1. Background

Definitive manned testing of the UBA for ventilation adequacy will be accomplished under section III. F., Physiological Testing.

This section is concerned with essentially subjective tests to obtain a rough measure of the comfort, human engineering and mobility of the UBA. To determine those qualities accurately requires a rather large program of manned tests considered to be outside the scope of this evaluation. The tests outlined below can be accomplished quickly and relatively easily. They will provide an indication of the UBA mobility, human engineering (are the controls easy to operate, etc.) and comfort which should be sufficient to point out any really serious troubles that must be addressed before larger scale manned tests such as Techeval/Opeval are undertaken.

The instrumentation recommended in this section is relatively sparse. This is so not because of design, but rather due to the difficulty in making measurements on a diver who is free to move about as he chooses in a relatively large body of water.

2. Pool Tests

- a. The tests will be conducted at the NDW Swimming Pool, although any suitable pool may be used.
- b. The purpose of these tests is to achieve a reasonable estimation of the apparatus comfort,

human engineering, and mobility when swimming in essentially open water.

WARNING!

DURING ALL POOL SWIMS THERE MUST BE ONE SAFETY DIVER OUTFITTED IN EITHER SNORKEL OR SCUBA GEAR WITH EACH TEST DIVER.

- c. The UBA pre-dive and post-dive check-outs are to be performed as required for the UBA under test.
- d. Static tests
 - 1) Lying face down on the bottom, observe the hydrostatic breathing resistance, buoyancy, and torque characteristics.
 - 2) Lying face up on the bottom, make the same observations.
 - 3) Standing completely submerged, make the same observations.
 - 4) Try to attain neutral buoyancy at mid-depth without swimming in each of the following positions: (a) vertical, head down, (b) vertical, head up, (c) horizontal, face down, and (d) horizontal, face up.
 - 5) As each subject completes the sequence, record his comments and recommendations immediately.
- e. Swimming tests
 - 1) Have each of four subjects swim 8 laps of the pool at an average speed of 0.8 knots (2½ minutes per lap at NDW Pool.
 - 2) Instruct the subject to observe the following factors during the test:
 - aa. general comfort of the apparatus
 - bb. general fit of the harness
 - cc. general swimmability
 - dd. specific buoyancy characteristics

ee. specific torque characteristics

- 3) As each subject completes his swim, record his comments and recommendations immediately. Use the Diver Equipment Analysis questionnaire contained in Appendix A or its equivalent.

f. Instrumentation for pool tests

The pool test swims will normally be conducted with un-instrumented apparatus. However, where applicable, bottle pressures pre- and post-swim, liter flows, etc. should be recorded. All apparatus malfunctions must be recorded.

3. Chamber Swims

a. Purpose

The purposes of these tests are to:

- 1) Obtain a reasonable estimation of the comfort, human engineering and mobility of the UBA when it is used at its normal operating depths.
- 2) Obtain some confirmation of the breathing machine test data gathered under Section III. C.

b. Quantities to be Measured

- 1) UBA gas consumption rate
 - aa. In semi-closed circuit UBA, measure liter flow
 - bb. In closed circuit UBA, measure bottle pressure drops
- 2) Inspired PCO_2 level
- 3) Inspired PO_2 level
- 4) Mouthpiece Δp relative to hydrostatic pressure at the 7th cervical vertebra. If a different reference pressure was used in Section III. C., then use that reference pressure instead.

- 5) Inspired gas temperature (if appropriate)
- 6) UBA exhaust valve positions selected by the divers (if valve adjustable)

c. Quantities to be Controlled

- 1) Depth
- 2) Diver work tasks
- 3) Wetpot temperature
- 4) Supply overbottom pressure (umbilical supplies UBA only)
- 5) Gas media

d. Equipment Set-Up

- 1) Specialized equipment required
 - aa. Flowmeters, approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure (required for umbilical supplied semi-closed circuit UBA only)
 - bb. Differential pressure transducers, approximate range ± 5 psid, and associated signal conditions and recorders
 - cc. Thermistors and read-out unit
 - dd. CO₂ analyser, 0 to 1.0% by volume range with recorders
 - ee. Oxygen analyser, 0 to 25% by volume range, with recorders
- 2) Set up the test equipment generally as shown in Figure 5. Figure 5 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.
- 3) Regular umbilicals are not necessary for these tests. Any suitable leader hoses will do.
- 4) All gas sampling lines should have water traps, downstream of the pressure reducing valves.

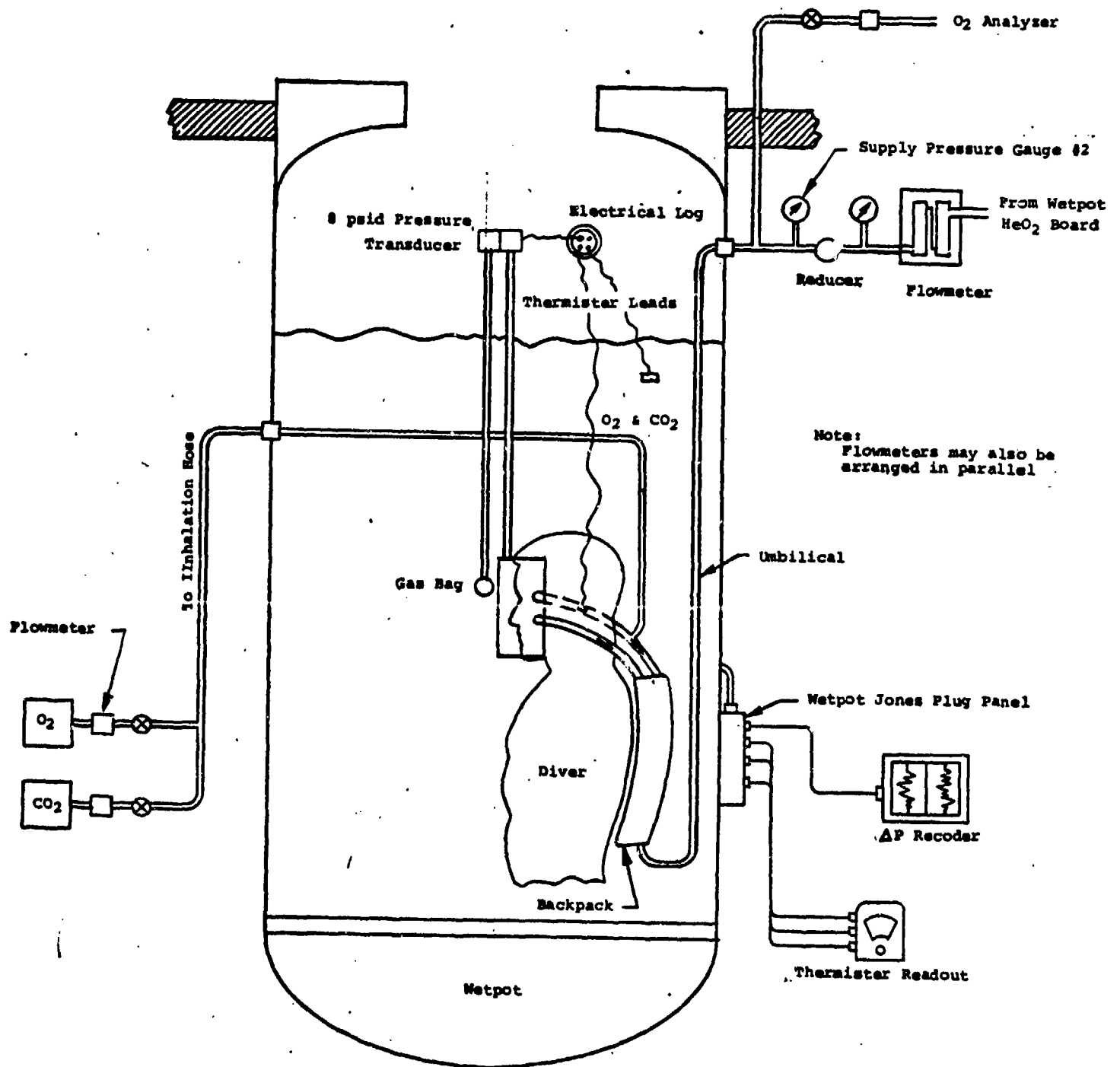


Figure 5
Test Equipment Set-up,
Manned Subjective Test,
Semi-Closed Circuit Mixed
Gas USA

- 5) The outputs of the O₂ and CO₂ analysers should be continuously recorded. The output of the Δp transducer must be continuously recorded. Hand recordings of the Δp , O₂ and CO₂ values every 5 minutes, as is commonly done, are of little value due to often rapidly changing values.
- 6) The sample gas flow rates to the O₂ and CO₂ analysers must be kept as low as possible consistent with an acceptable lag time in the instrument response. Too high sample flow rates will affect the breathing performance of the UBA. In self-contained apparatus, too high flow rates will also quickly exhaust the gas supply. Too low sample flow rates or excessively long and/or large sample lines will cause the analyser response to be several minutes behind the actual O₂ and CO₂ levels in the UBA.

e. Calibration

- 1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.
- 2) The Δp transducers should be calibrated against a water or mercury manometer; the thermistors against 32°F water and room temperature.
- 3) The flowmeter and gauges normally do not need daily calibration.
- 4) All gas analysis instruments should be calibrated against at least 3 known gases each: full scale, zero and mid-range concentrations. If the analysers, especially the CO₂ analysers, are non-linear, several more calibration points and a graphical calibration record is required.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing

required. The Project Engineer should determine the conditions to be tested prior to commencing the test.

It is not possible to predict what test conditions should be used. The following guidelines however should be followed:

Depth	At least 5 depths representative of the depth range in which the UBA is to be used
Supply Pressure	As recommended by operations manual for UBA under test
Supply Gas	
Liter Flow	
Wetpot Temperature	70°F or above (due to wetpot steel NDT considerations)
Diver Work Tasks	See Section III. E. 4. g. 3)

g. General Procedures

- 1) For a reasonably thorough subjective evaluation at least 5 dives should be made to each depth. Always use divers who have had sufficient exposure in the UBA so that they feel familiar with its controls.
- 2) Normal U.S. Navy diving procedures are to be followed.
- 3) The normal work routine while the divers are on the bottom consists of 10 minute periods of "moderate" work separated by 5 minute rest periods. Normally two divers are used and they alternate work tasks between lifting a 70-pound weight (78 lbs dry) a distance of 2½ feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (4). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (5) or to swimming in SCUBA at a steady

speed of approximately 0.8 knots (4)(5). An oxygen demand of 1.26 slpm results in a CO₂ production of about 1.13 slpm (6).

When possible, short periods of heavy and severe work should also be used. These can be effected by increasing the trapeze force to 10 and 12 lbs. respectively. Swimming against a 10 lb. stationary force is roughly equivalent to swimming at a speed of 1.0 knots. It can be expected to produce an oxygen consumption of 1.9 slpm, an RMV of 48 lpm, and a CO₂ production rate of 1.8 slpm (4)(5)(6). Swimming against a 12 lb. stationary force is roughly equivalent to swimming at a speed of 1.3 knots. This represents maximal effort and it can be expected to produce an oxygen consumption of about 3.0 slpm, an RMV of about 70 lpm and a CO₂ production rate of about 2.9 slpm (4)(5)(6). It can also be expected to very quickly produce very tired divers. In general the heavy and severe work loads should be held to not more than 5 minutes duration.

- 4) At the conclusion of each dive, the diver should fill out the applicable portions of the Diver Equipment Subjective Analysis Questionnaire reproduced in Appendix A or its equivalent.

h. Data Handling

- 1) Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip chart recordings or other permanent data records so that the data can be identified.
- 2) Compare the CO₂ levels and mouthpiece differential pressures measured to the results of Section III. C.
- 3) Tabulate and/or plot the data obtained as directed by the Project Engineer. There is usually sufficient variability in the data from these dives to make concise plotting difficult.
- 4) The Project Engineer or his representative should keep a daily log of all significant events.

- 5) For each day's test dives, calibration records must be made, clearly annotated and attached to the data generated by each respective instrument during the runs to which the calibration record applies.

F. Manned Dives, Physiological Testing

1. Background

The purpose of these tests is to determine quantitatively the ability of the apparatus under test to support the physiologic and respiratory requirements of a diver at hard work. The tests are normally conducted by the EDU Medical Department.

The procedures and equipment used for these tests are still being refined. A detailed protocol covering these tests is expected to be published by the EDU Medical Department sometime in the second quarter of CY 1974.

IV. INSTRUMENT SPECIFICATIONS

<u>Instrument</u>	<u>Type Normally Used</u>	<u>Accuracy</u>	<u>Minimum Frequency Response</u>
Flowmeters	Variable Area	$\pm 2\%$ of full scale	0.5 Hz
ΔP Transducers	Variable Reluctance	$\pm 1/2\%$ of full scale	200 Hz
Transducer Indicators	Meters	$\pm 1\%$ of full scale	1 Hz
Oxygen Analyzers	Paramagnetic	$\pm 0.5\%$ by volume	0.1 Hz
CO ₂ Analyzers	Non-dispersive Infrared	$\pm 1\%$ of full scale	1 Hz
Thermistors	Thermocouple	$\pm 1^\circ$ F	0.1 Hz
Relative Humidity Instruments	--	$\pm 3\%$	0.1 Hz
Pressure Gauges	Bourdon Tube	$\pm 1/4\%$ of full scale	0.5 Hz
Strip Chart Recorders	Electric, Oscillographic	$\pm 1\%$ of full scale 50 mm chart width	40 Hz at full chart width
X-Y Plotter	--	$\pm 1\%$ of full scale	maximum slewing speed = 40 in/sec maximum acceleration 1400 in/sec ² in X direction, 2000 in/sec ² in Y direction

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5. U.S. Navy Diving Gas Manual, Research Report Number 3-69, U.S. Navy Supervisor of Diving, Naval Ship Systems Command, October 1, 1969.
6. Henkener, J. A., "Low-Pressure Compressed Air Breathing Systems Study. Part II. Mark V Helmet Ventilation Studies" Battelle Memorial Institute, September 22, 1970, p. 16.
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APPENDIX A
DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVERS NAME _____ DATE _____

LOCATION _____ DEPTH _____ TIME _____

EQUIPMENT SET-UP

MANUFACTURER _____ MODEL _____

TYPE RIG _____ GAS USED _____ %O₂ _____ %N₂ _____ % He _____

SUPPLY-PRESSURE BEFORE _____ AFTER _____

REGULATOR PRESSURE BEFORE _____ AFTER _____

ORIFICE SIZE _____ LITER FLOW BEFORE _____ AFTER _____

HELMETS AND MASK

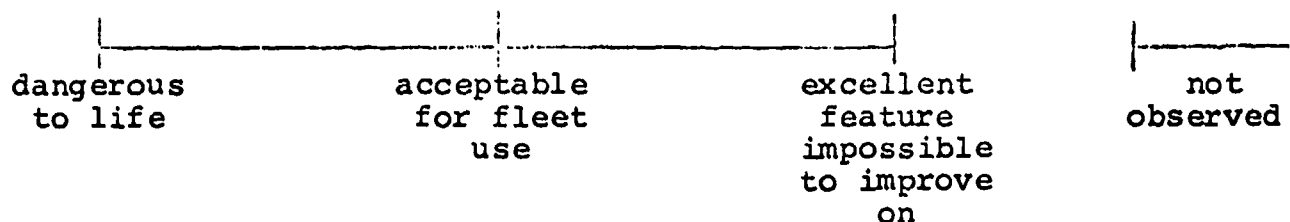
1. WHAT INLET AND EXHAUST SETTINGS DID YOU FIND COMFORTABLE WHILE WORKING AND WHILE STANDING AT REST? EXPRESS VALVE SETTINGS AS THE NUMBER OF TURNS OPEN OR CLOSED.

(example: inlet 2 1/4 turns open).

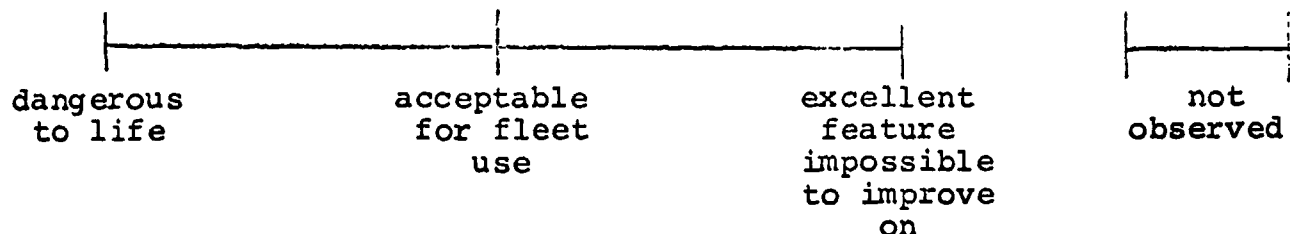
	INLET	EXHAUST
WORK	_____	_____
REST	_____	_____

TYPE OF WORK _____

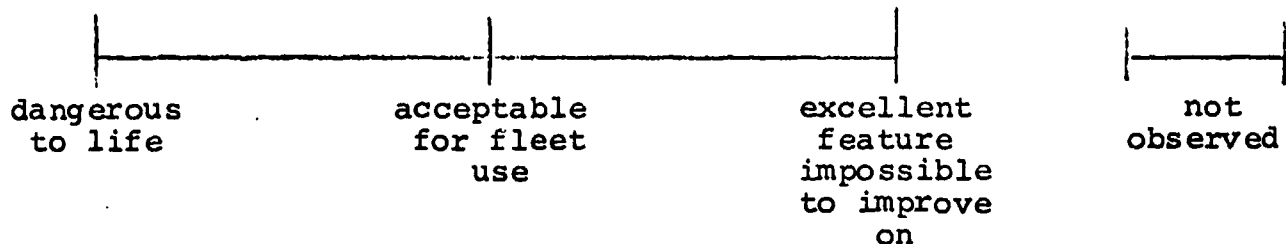
2. RATE AND COMMENT ON THE INHALATION RESISTANCE OF THE HELMET/MASK.



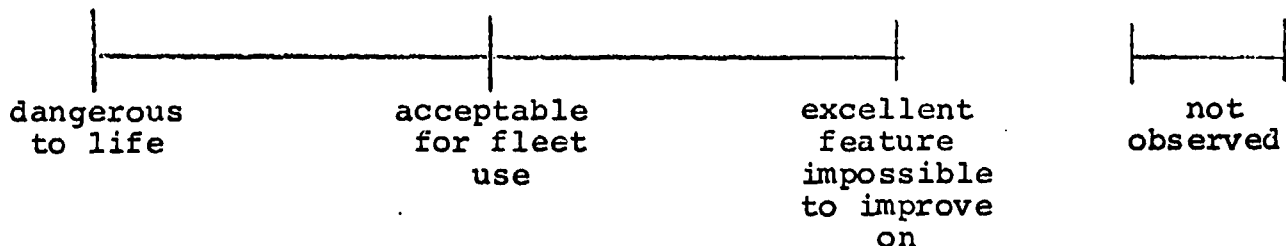
3. RATE AND COMMENT ON THE EXHALATION RESISTANCE OF THE HELMET/MASK.



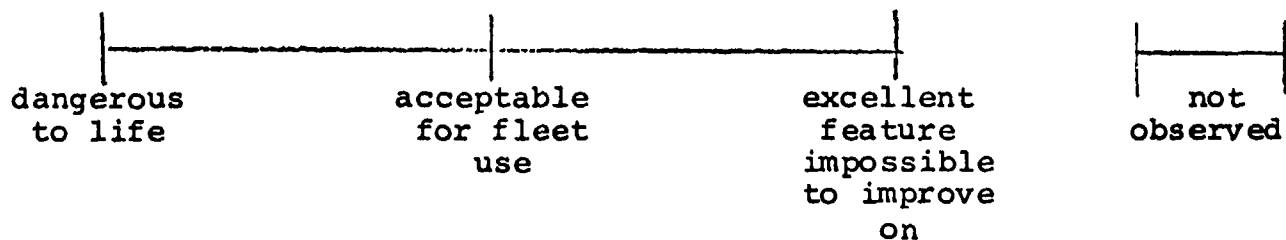
4. RATE AND COMMENT ON THE EASE OF DONNING THE HELMET/MASK AND ITS ACCESSORIES.



5. RATE AND COMMENT ON THE HELMET/MASK WEIGHT OUT OF THE WATER.



6. RATE AND COMMENT ON THE HELMET/MASK BUOYANCY IN THE WATER.



7. RATE AND COMMENT ON THE FIT AND COMFORT OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

8. RATE AND COMMENT ON THE NOISE LEVEL IN THE HELMET.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

9. RATE AND COMMENT ON THE ADEQUACY OF THE COMMUNICATIONS IN THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

10. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

11. RATE AND COMMENT ON THE VISIBILITY FROM THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

12. RATE AND COMMENT ON THE EASE OF CLEARING WATER FROM THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

13. RATE AND COMMENT ON THE HELMET/MASK TORQUE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

14. WHAT IS YOUR OVER ALL EVALUATION OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

BREATHING APPARATUS

15. RATE AND COMMENT ON THE WEIGHT OF THE APPARATUS OUT OF THE WATER.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

16. RATE AND COMMENT ON THE BUOYANCY OF THE APPARATUS IN THE WATER.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

17. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

18. RATE AND COMMENT ON THE SWIMMABILITY OF THE APPARATUS.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

19. RATE AND COMMENT ON THE APPARATUS TORQUE.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

20. RATE AND COMMENT ON THE INHALATION BREATHING RESISTANCE.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

21. RATE AND COMMENT ON THE EXHALATION BREATHING RESISTANCE.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

22. WHAT IS YOUR OVERALL EVALUATION OF THE APPARATUS.

<hr/>			
dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed