AD-A156 596 PERFORMANCE COMPARISON OF THIRTY TWO-STAGE DEMAND REGULATORS(U) ADMIRALTY RESEARCH ESTABLISHMENT (MARINE TECHNOLOGY) PORTSMOU.. I A HIMMENS JAN 84 1/1

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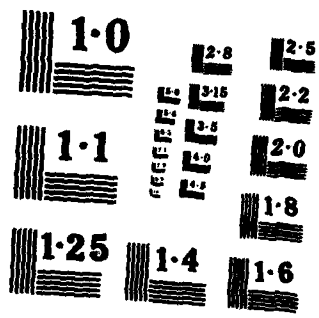
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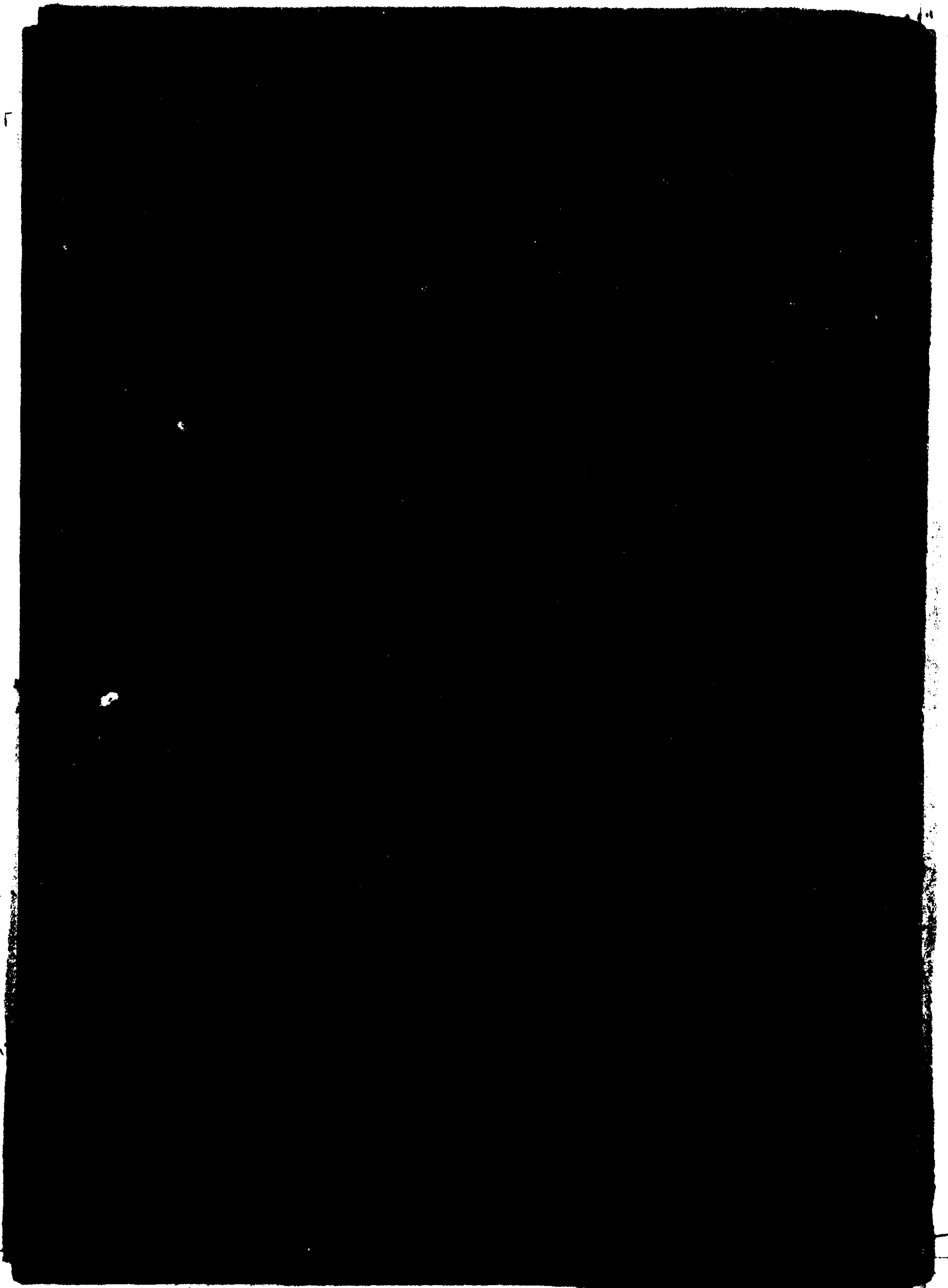

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ARE(M6) TM 83818

PERFORMANCE COMPARISON OF THIRTY, TWO-STAGE DEMAND REGULATORS

by

I A HIMMENS

Summary

Cont'd

The results of the ARE(EDU) tests on thirty, two-stage demand regulators showed that only two met the RECOMMENDED LIMITS for breathing resistance and work of breathing for the three ventilation rates at the maximum depth of 50 msw. A majority of the regulators exhibited a rapid degradation of inhalation response at a ventilation rate of 62.5 l/min, beyond their respective maximum depths or as cylinder pressures approached 30 Bar.

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January 1984

CONTENTS

INTRODUCTION

1. This report presents the results obtained from an evaluation of thirty commercially available two stage air demand regulators. The tests, carried out in the Admiralty Research Establishment Experimental Diving Unit (ARE/EDU) unmanned hyperbaric facility, followed procedures which have been agreed between ARE/EDU and NEDU Naval Experimental Diving Unit in the USA (1). One regulator of each type submitted for test was supplied to ARE/EDU by the BSAC and UEAMA on behalf of the Society for Underwater Technology.

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The objectives of the tests were:

a. to determine the variation in breathing resistance and work of breathing for each of the demand regulators submitted for test; and

b. to compare and assess the results with respect to chosen physiological limits (see Annex A).

For the purposes of this study:

Each demand regulator was tested in the "as received" condition, and the results were compared and assessed with respect to recommended and acceptable limits proposed by Morrison et al (2) for Work of Breathing and Breathing Resistance contained in Annex A.

TEST PROCEDURE

a. Setting up the Regulator for Test

2. The demand regulator was mounted vertically within the Hyperbaric Chamber as shown in Fig 1. The air supply to the first stage of the demand regulator was provided via a standard twin cylinder manifold, one side of which was connected to the air supply from the main control console of the test facility and the other side to a 82 cu/ft steel cylinder mounted within the pressure chamber. This arrangement enabled tests to be carried out.

a. at a constant supply pressure via the main control console, or

b. with a falling supply pressure via the steel cylinder: in this case the supply from the main control console was isolated after charging the cylinder to the required starting pressure.

3. First of all, air pressure was applied to the equipment and all connections were checked for leaks. The pressure vessel was then closed and flooded to a depth which prevented surface effects interfering with the performance of the regulator.

b. Testing the Regulators

4. Initially, each regulator was tested under surface conditions, ie normal atmospheric pressure, and then at pressures corresponding to depths between 10 msw and 50 msw in increments of 10 msw. At each depth the regulators were tested at the ventilation rates listed in Table 1. Testing was completed when results corresponding to all ventilation rates had been obtained at each test depth or when the breathing resistance of the demand regulator at a

ventilation rate of 62.5lRMV was high enough to exceed the recording limits of the instrumentation.

5. The main tests were carried out with a pressure of 70 Bar applied to the first stage of the demand regulator via the main control console supply. In addition, the effect of falling cylinder pressure on the performance of the demand regulator was investigated as the pressure of the air supply from the cylinder was reduced from 180 Bar to 30 Bar. This was determined at a ventilation rate of 62.5lRMV and at the depth at which the performance of the regulator just remained within the ACCEPTABLE LIMITS.

c. Instrumentation

6. During the testing of each regulator the first stage supply and outlet pressure were monitored by strain gauge type pressure transducers, the outputs being displayed on a Y-Time chart recorder. A differential pressure transducer was connected at the mouthpiece of the second stage of the demand regulator to measure the variations (Delta P) in pressure from ambient within the chamber. The output from this transducer was recorded simultaneously with the corresponding breathing machine piston displacement on an X-Y plotter to produce a pressure-volume diagram. An example of such a P-V loop is shown in figure 2, the area of which is proportional to work of breathing, measured in Joules/litre (J/l). The maximum inhale and exhale pressures in Kilo Pascals (kPa) are determined from a reference line on the P-V diagram, corresponding to zero pressure variation. At the intersection with this reference line there is assumed to be no gas flow. 'Spikes' within the P-V loop which were small in area were ignored in computing the Work of Breathing, unless clearly of significance.

RESULTS

7. A large number of P-V diagrams were obtained during this trial and these are held under separate cover at ARE(EDU). Only selected P-V loops have been included in this report in order to illustrate specific points raised in the discussion of results. Figures 3 and 4 show the maximum depths at which the RECOMMENDED LIMITS were met for inhale and exhale breathing resistance respectively, at ventilation rates equivalent to 22.5, 40.0 and 62.5 litre RMV. Figures 5 and 6 show the depths at which the combined results for inhale/exhale breathing resistance and work of breathing met the RECOMMENDED LIMITS AND ACCEPTABLE LIMITS respectively, for the ventilation rates of 22.5, 40.0 and 62.5 litre RMV.

DISCUSSION OF RESULTS

a. General Comments

8. The performance of the regulators varied greatly over the entire depth range. It would be desirable for the breathing resistance and work of breathing of any underwater breathing apparatus to be independent of depth and ventilation rate but in practice this is not generally so. (It would also be desirable for the inhale and exhale work to be of similar magnitude when the total work of breathing approached the RECOMMENDED LIMITS and this was the case for some of the regulators tested). The P-V diagrams for a typical two stage demand regulator, as shown in figure 7, indicate that the inhalation resistance and work of breathing increases more rapidly with increasing depth at a ventilation rate of 62.5lRMV. In one case, however,

(see figure 8) the breathing resistance and work of breathing increased with depth gradually. Of the thirty regulators which were tested only two met the RECOMMENDED LIMITS for breathing resistance and work of breathing, at the three ventilation rates and at the maximum test depth of 50 msw (see figure 5). One regulator, indeed, did not even meet the RECOMMENDED LIMITS for work of breathing at any of the ventilation rates for surface conditions.

9. In one particular regulator there was a very low inhalation resistance which appeared to be independent of both depth and ventilation rate, but the exhale resistance exceeded the RECOMMENDED LIMITS at a depth of only 18 msw. In this case, shown in figure 9, the exhale work of breathing for a ventilation rate of 62.5 l/min at 50 msw represents over 90% of the total work measured. Several regulators exhibited very high cracking pressures at the beginning of inhalation so that a significant level of work was required to initiate glas flow as illustrated in figure 10. The response of one of the regulators with a venturi assisted second stage contained a very high positive pressure during inhalation (see figure 11). The magnitude of this positive peak was found to be both depth and ventilation rate dependent, and results from a gas flow rate which greatly exceeds that required during inhalation. Although such conditions reduce the area contained within the PV diagram the diver is required to do work in resisting the excess gas flow during inhalation as shown in figure 11. The work of breathing is then that contained in the two half cycles as shown cross hatched in figure 12. The work done in resisting excess gas flow during inhalation has been neglected in deriving the results contained in figures 5 and 6. However, the physiological implications of such high levels of positive pressure during inhalation requires further investigation.

b. <u>Effect of Cylinder Pressure on Demand Regulator Performance</u>

10. The results obtained from the initial 70 Bar cylinder pressure tests were used to determine the depth at which the regulator could reasonably be used with reducing cylinder pressures. In general, the design of a first stage regulator can be classified as balanced or unbalanced; the output pressure above ambient being controlled by a piston or diaphragm sensing mechanism respectively. It would be expected that a balanced first stage regulator would have an output pressure above ambient that did not change significantly with cylinder pressure. The series of P-V diagrams for a balanced first stage shown in figure 13, for a ventilation rate of 62.5 l/min at the maximum depth of 50 msw, indicates relatively small increases of inhalation resistance and work of breathing for decreasing cylinder pressure. In contrast, the output pressure from an unbalanced first stage regulator would be expected to change significantly with decreasing cylinder pressure, as shown in figure 14.

11. In the present tests, approximately fifty per cent of the demand regulators, irrespective of type (balanced or unbalanced) showed a rapid increase of inhalation resistance and work of breathing at their respective maximum depths, as the cylinder pressure approached 30 Bar. The different depths and cylinder pressures at which these effects were measured makes graphic comparisons between regulators impracticable.

c. Demand Regulator Classification

12. The criteria by which the performance of underwater breathing apparatus should be judged on a generally agreed basis has yet to be resolved. Morrison has suggested that the limits for breathing resistance and work of breathing proposed by him (2) might be used to determine the suitability of a demand regulator for use at depths of 30m and 50m. The depth of 30m was selected as the "normal practical limit for most sports divers" whilst 50m is the recommended maximum depth for air diving. If adopted, regulators meeting the lower limit (see Annex A) would be classified as RECOMMENDED for use at the appropriate depth whilst those meeting the upper limit would only be classified as ACCEPTABLE for use at the appropriate depth. The results presented in Figure 5 show that even at 30 msw a large proportion of the regulators tested failed to meet the RECOMMENDED LIMITS. Figure 6 shows that the spread in the results is reduced if the ACCEPTABLE LIMITS are used as the acceptance criteria. However, this is only achieved at the expense of a significant reduction in the acceptance standards.

13. These tests have demonstrated that the RECOMMENDED LIMITS proposed by Morrison are achieveable. However, in view of the wide variation in the measured performance of the regulators, it seems that it would be difficult to obtain universal acceptance of the RECOMMENDED LIMITS proposed by Morrison. The minimum information required to define the performance of each demand regulator is contained in Table 2.

CONCLUSIONS

1. Marked variations in performance were observed during the testing of 30 demand regulators at ARE/EDU. In general, the breathing resistance and work of breathing increased with increasing depth and ventilation rate.

2. Approximately fifty per cent of regulators, irrespective of type, showed a rapid decrease in performance as the cylinder supply pressure was reduced to 30 Bar. A small degradation in performance during inhalation was achieved by only a few balanced first stage regulators at a cylinder pressure of 30 Bar.

3. Only two demand regulators were able to meet the performance limits proposed by Morrison, and recommended by the SUT at a depth of 50 msw and a ventilation rate of 62.5lRMV, but there was a greater ability in meeting the acceptable limits.

References:

1) Standardised unmanned underwater breathing apparatus test procedures.

2) Proposed unmanned test procedures and physiological acceptance criteria.

J B Morrison, J T Florio, A G Thornton and M K Todd.
Journal of the Society of Underwater Technology.
Spring 1982

ACKNOWLEDGEMENTS

My thanks to Mr A Luboff and Mr S Parvin for their persistence in completing the enormous number of repetitive tests, and Dr J Livesey for his assistance in completing this report.

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AMTE (EDU) HYPERBARIC TEST FACILITY

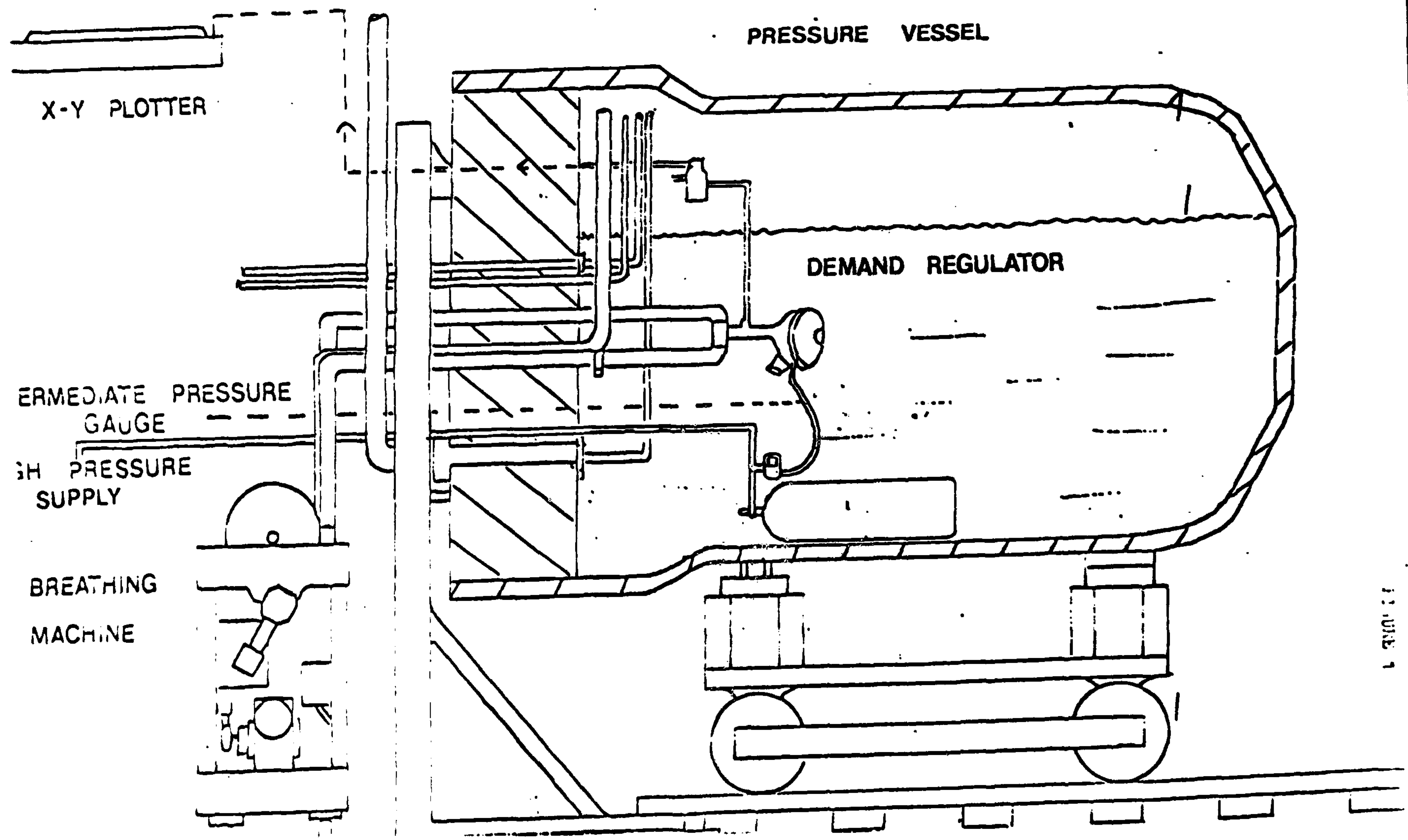


FIGURE 1

FIGURE 2

PRESSURE-VOLUME DIAGRAM

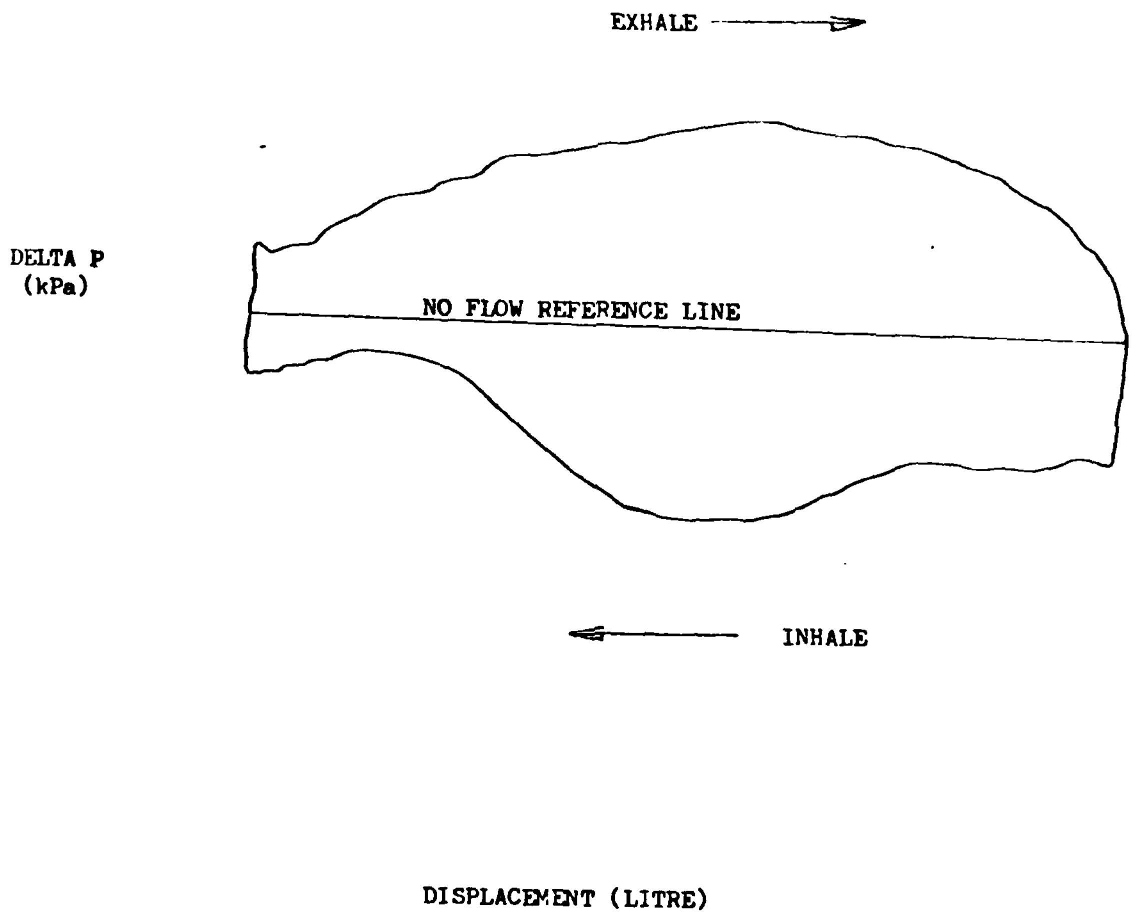
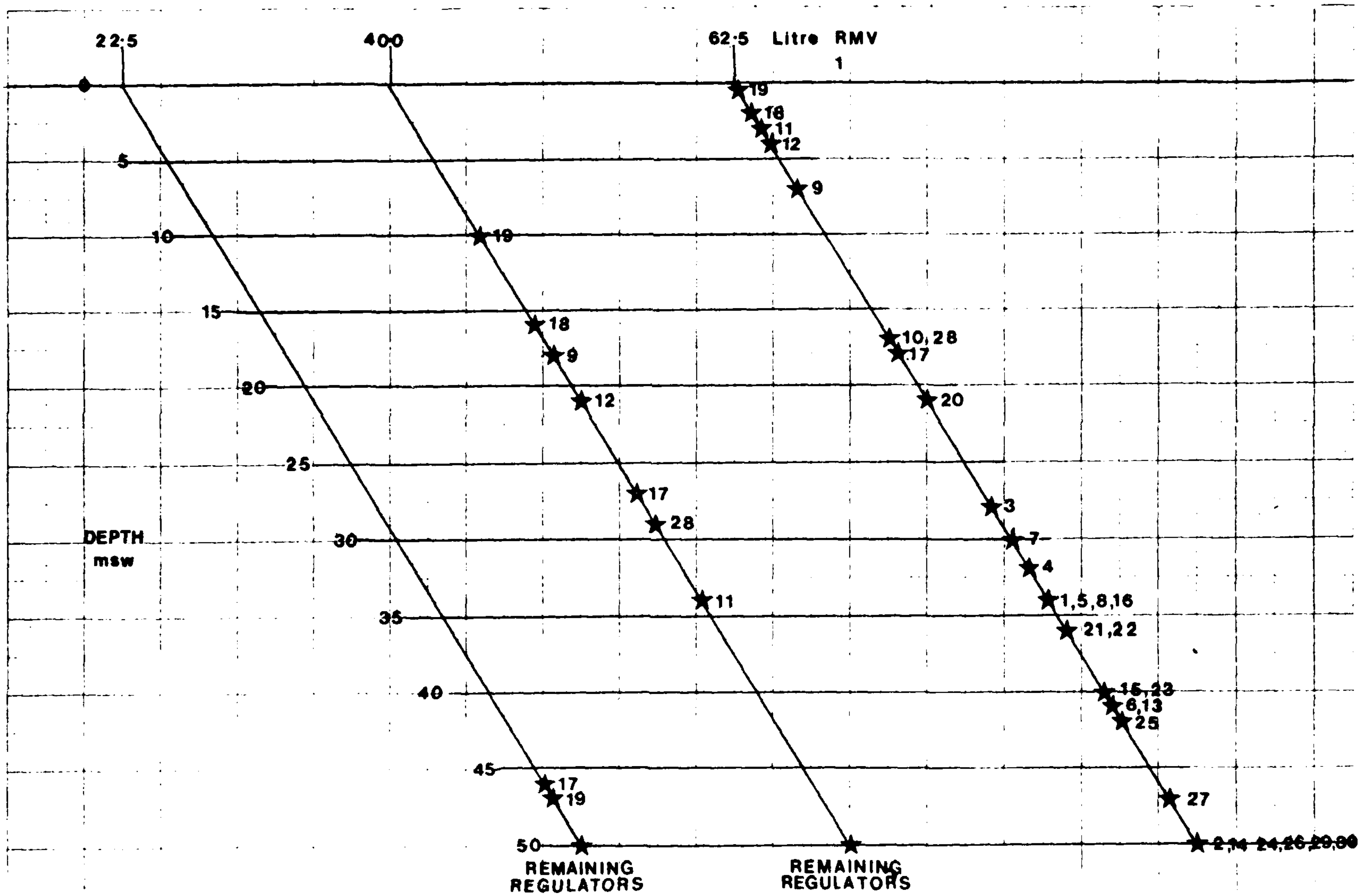


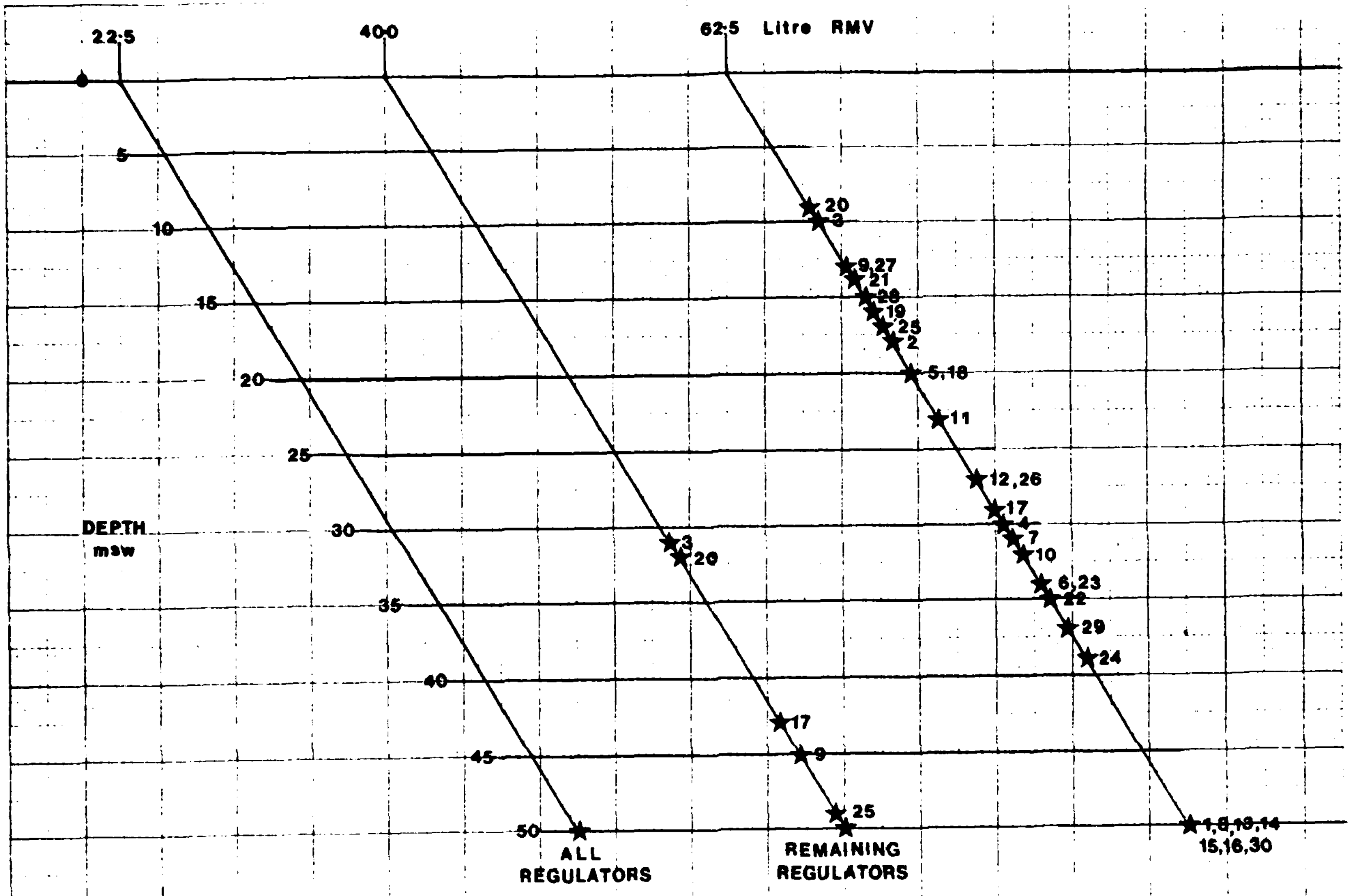
FIGURE 3



DEMAND REGULATOR PERFORMANCE

RECOMMENDED LIMIT FOR INHALE RESISTANCE V DEPTH

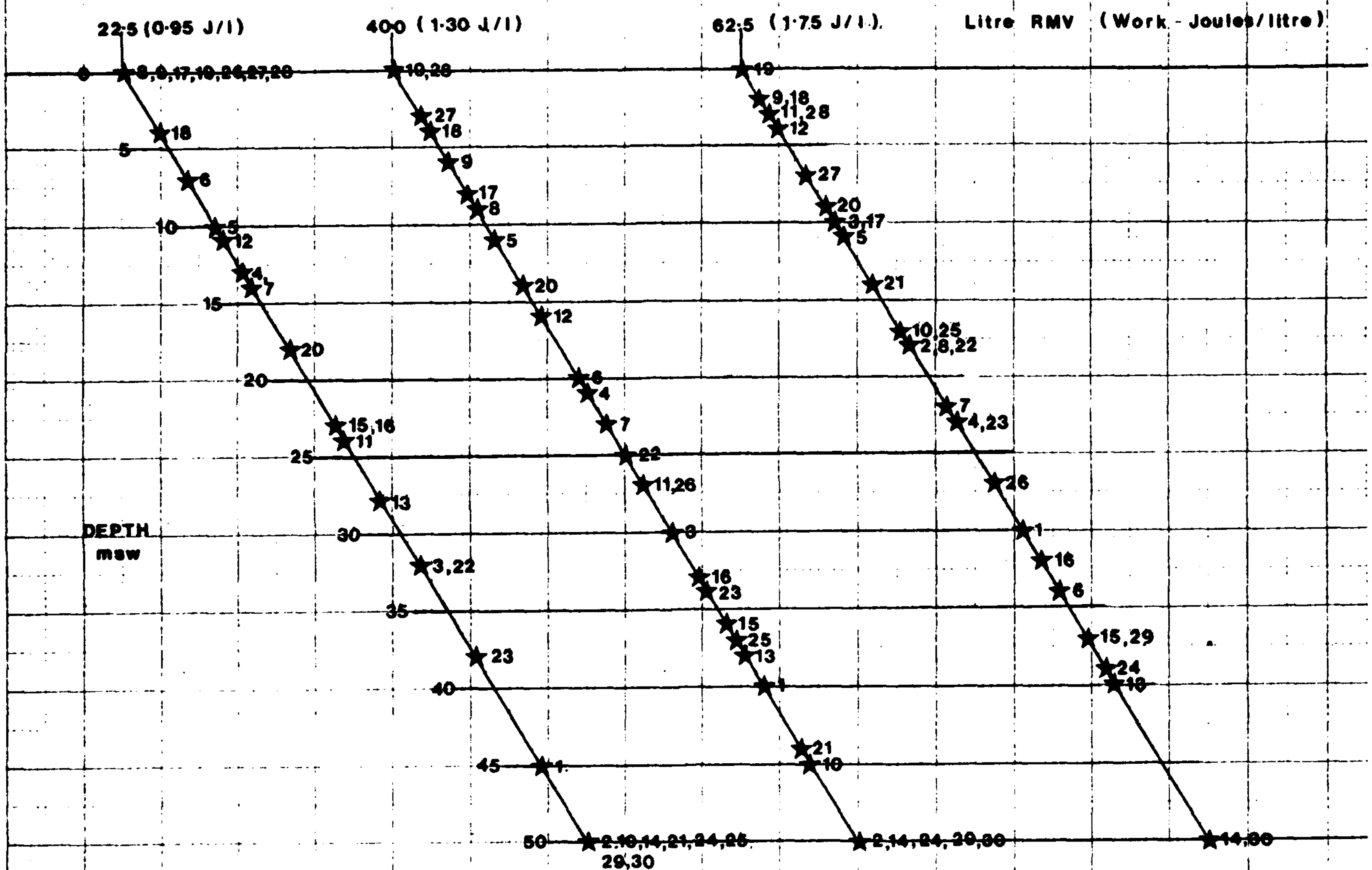
FIGURE 4



DEMAND REGULATOR PERFORMANCE

RECOMMENDED LIMIT FOR EXHALE RESISTANCE V DEPTH

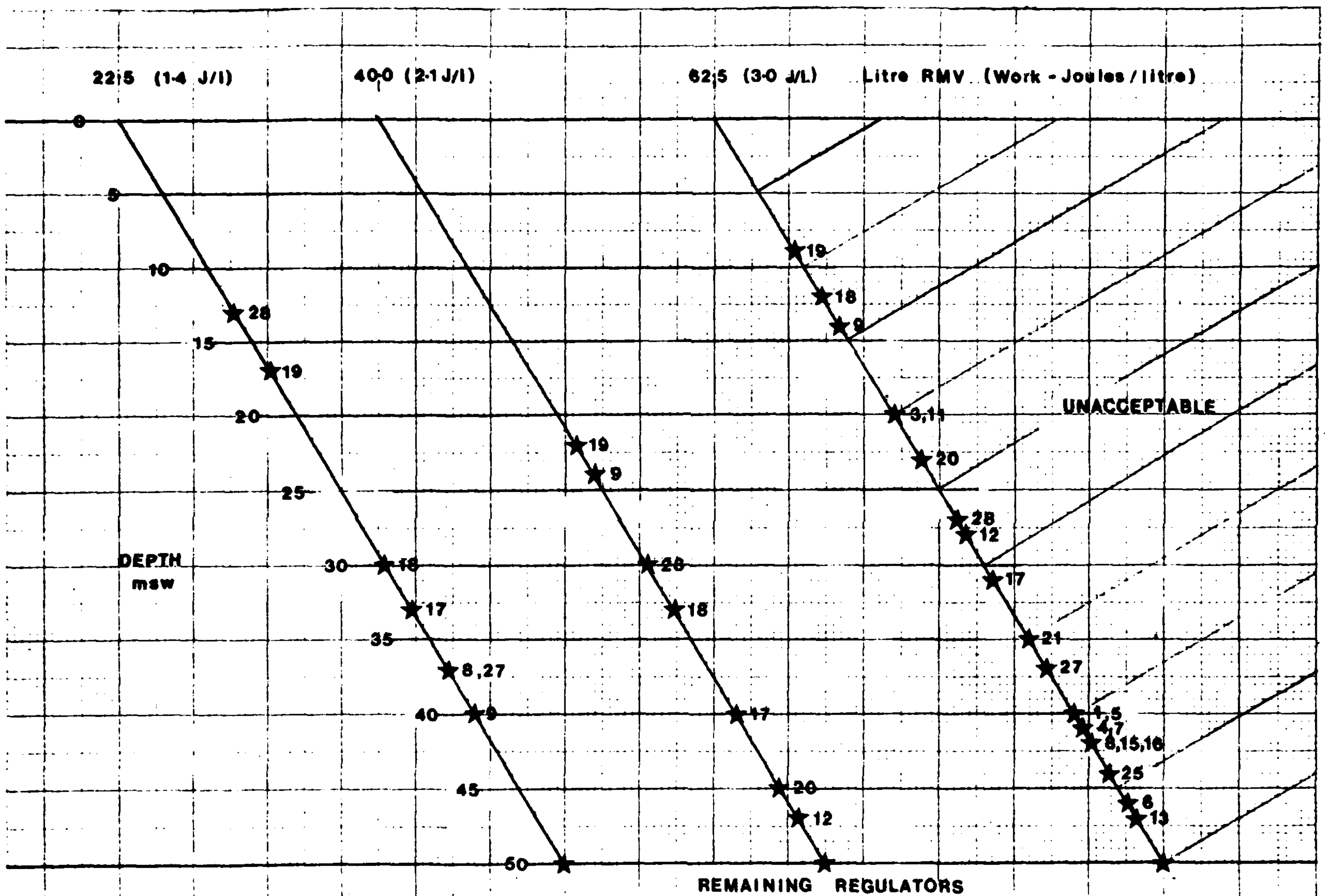
FIGURE 5



DEMAND REGULATOR PERFORMANCE

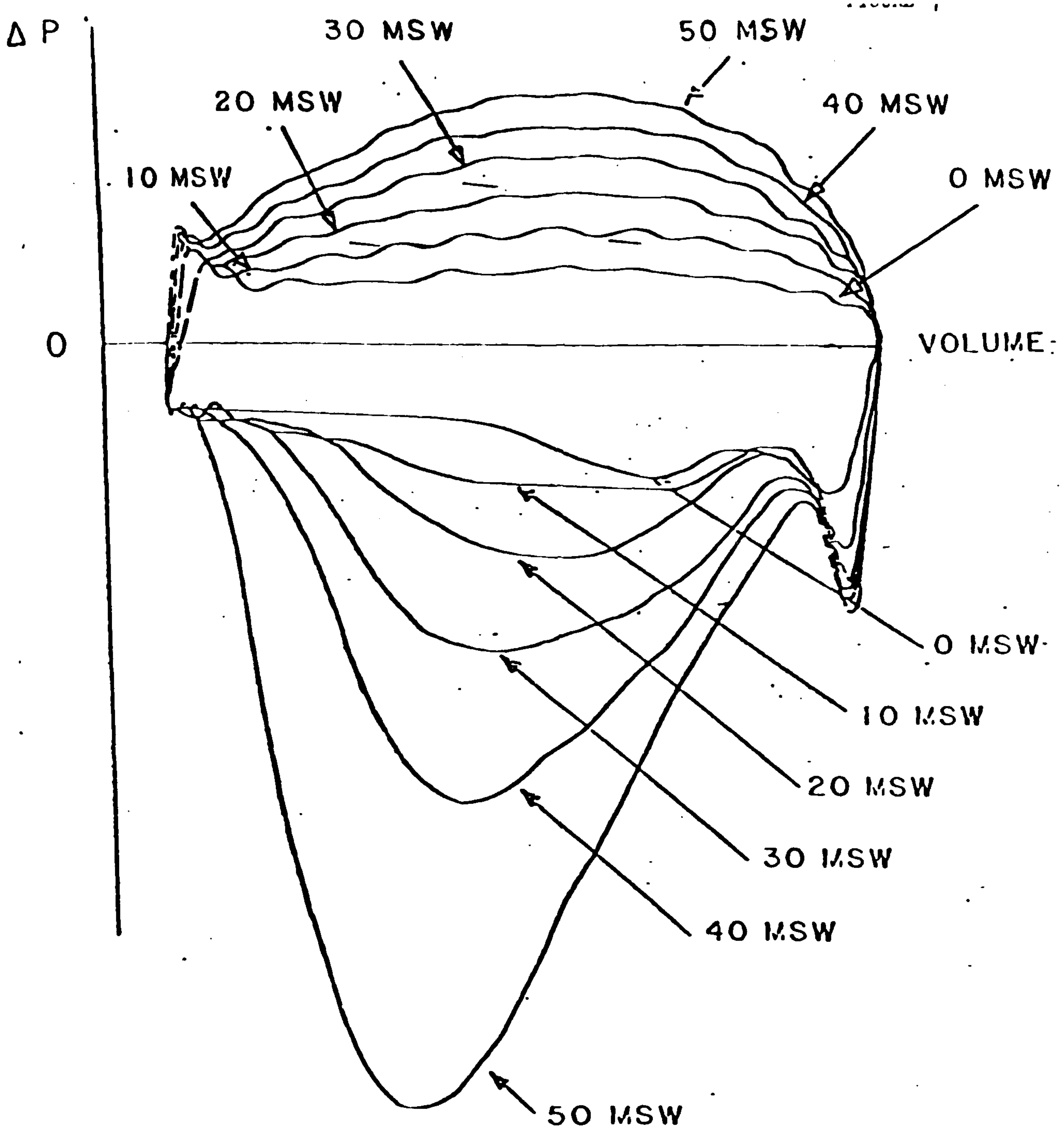
MORRISON'S RECOMMENDED LIMITS FOR WORK OF BREATHING AND BREATHING RESISTANCE V DEPTH

FIGURE 6



DEMAND REGULATOR PERFORMANCE

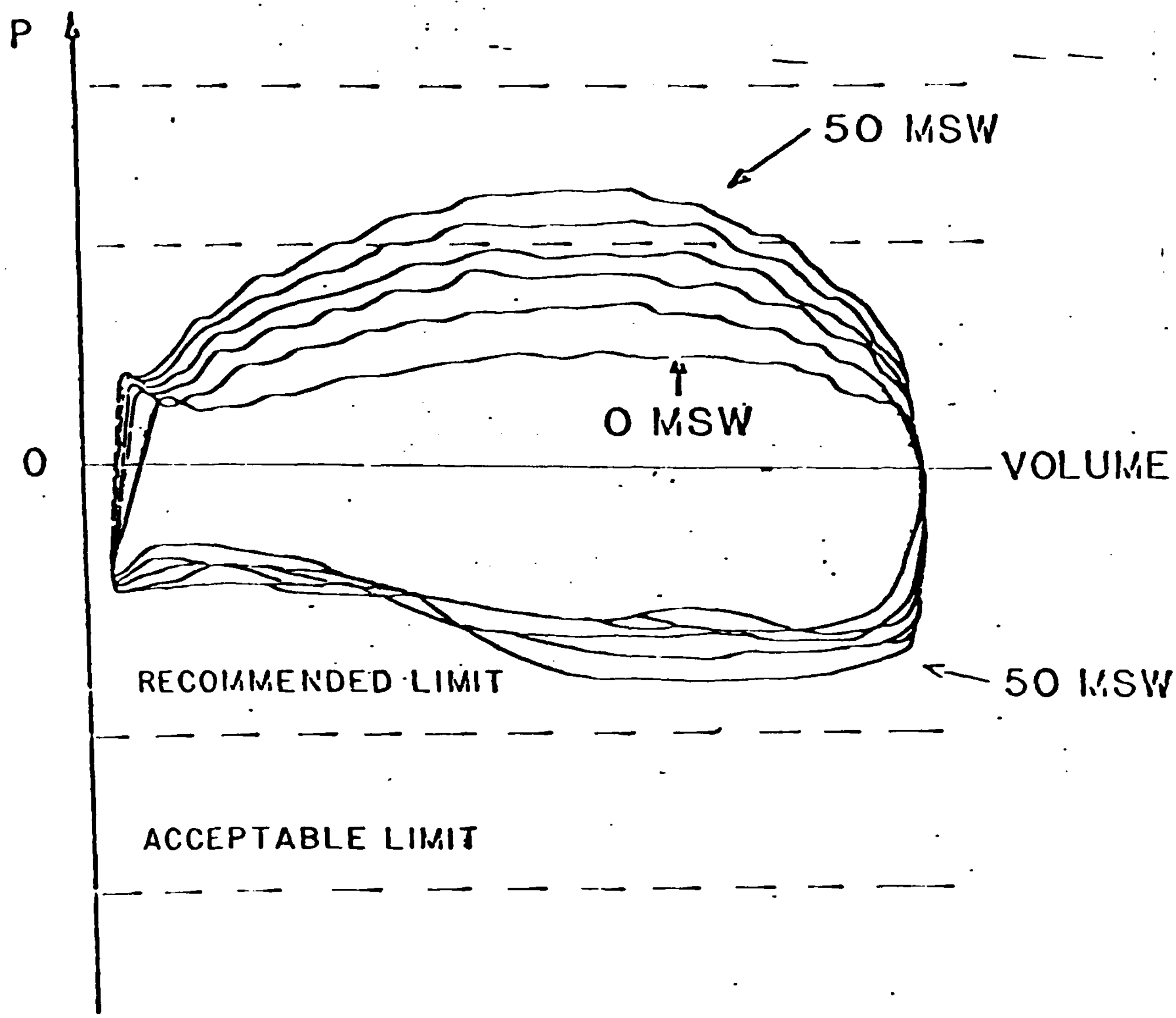
MORRISON'S ACCEPTABLE LIMITS FOR WORK OF BREATHING & BREATHING RESISTANCE V DEPTH



EFFECT OF DEPTH ON DEMAND REGULATOR PERFORMANCE

(2.5L TIDAL VOLUME x 25 BPM – 70 BAR SUPPLY)

FIGURE 8



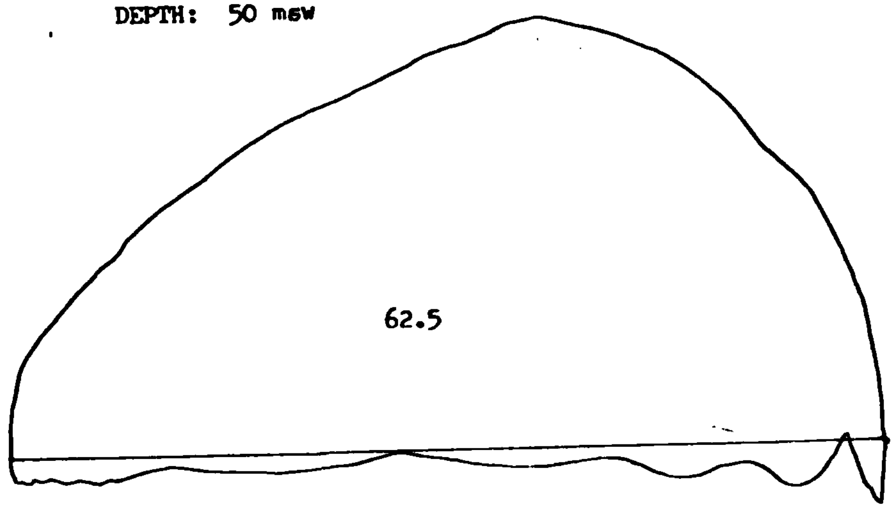
EFFECT OF DEPTH ON DEMAND REGULATOR PERFORMANCE

(2.5L TIDAL VOLUME x 25 BPM – 70 BAR SUPPLY)

FIGURE 9

EXAMPLE OF HIGH EXHALE RESISTANCE

DEPTH: 50 msw

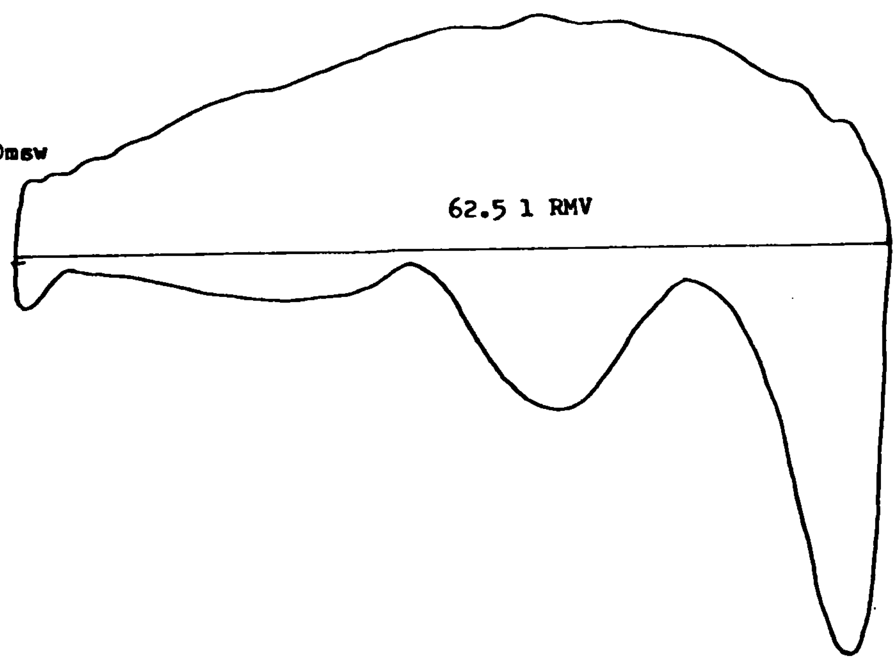


DELTA P
kPa

FIGURE 10

EXAMPLE OF HIGH CRACKING PRESSURE AT BEGINNING OF INHALATION

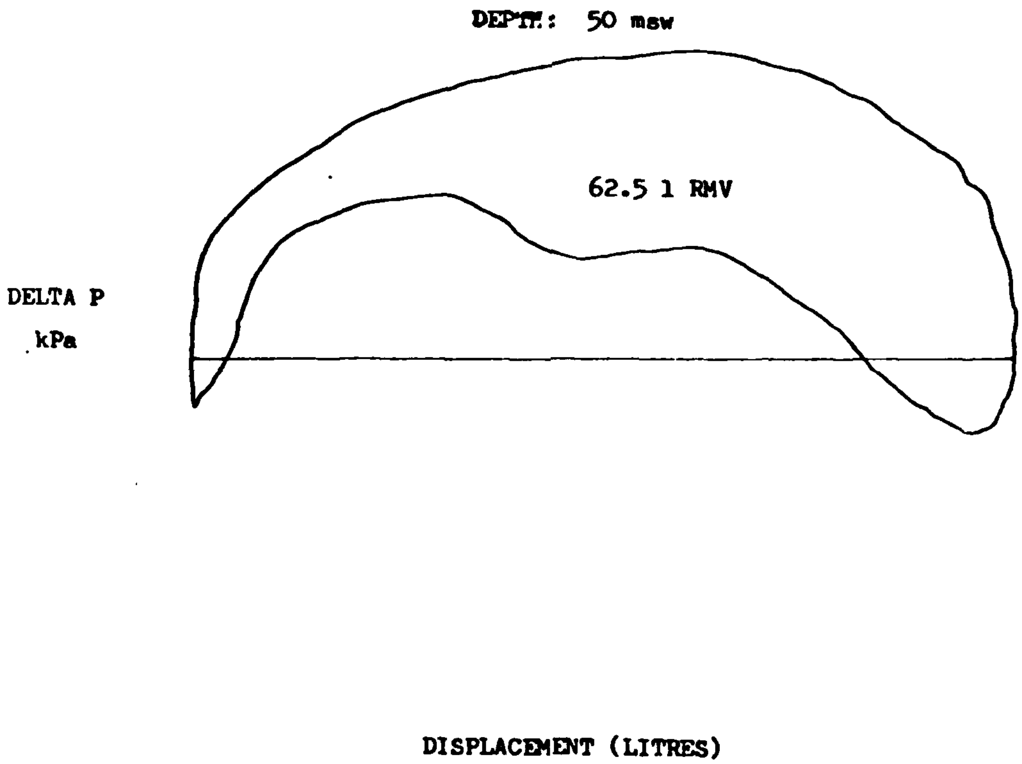
DEPTH: 20msw



DISPLACEMENT (LITRES)

FIGURE 11

EXAMPLE OF POSITIVE PRESSURE OCCURRING DURING INHALATION



EXTERNAL WORK OF BREATHING CALCULATION FOR POSITIVE PRESSURE INHALATION (REFER FIGURE 7)

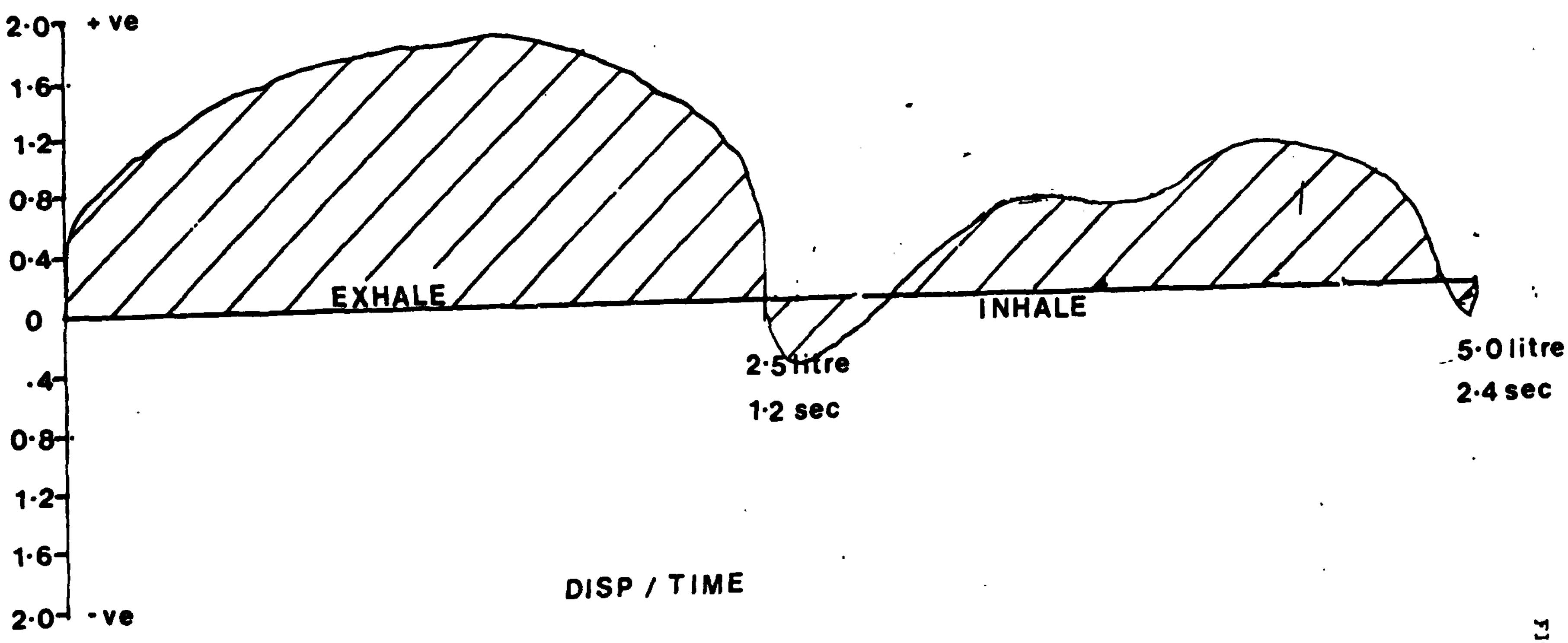


FIGURE 12

FIGURE 13

EFFECT OF REDUCING CYLINDER PRESSURE ON THE PERFORMANCE OF A BALANCE FIRST STAGE DEMAND REGULATOR

DEPTH: 50msw

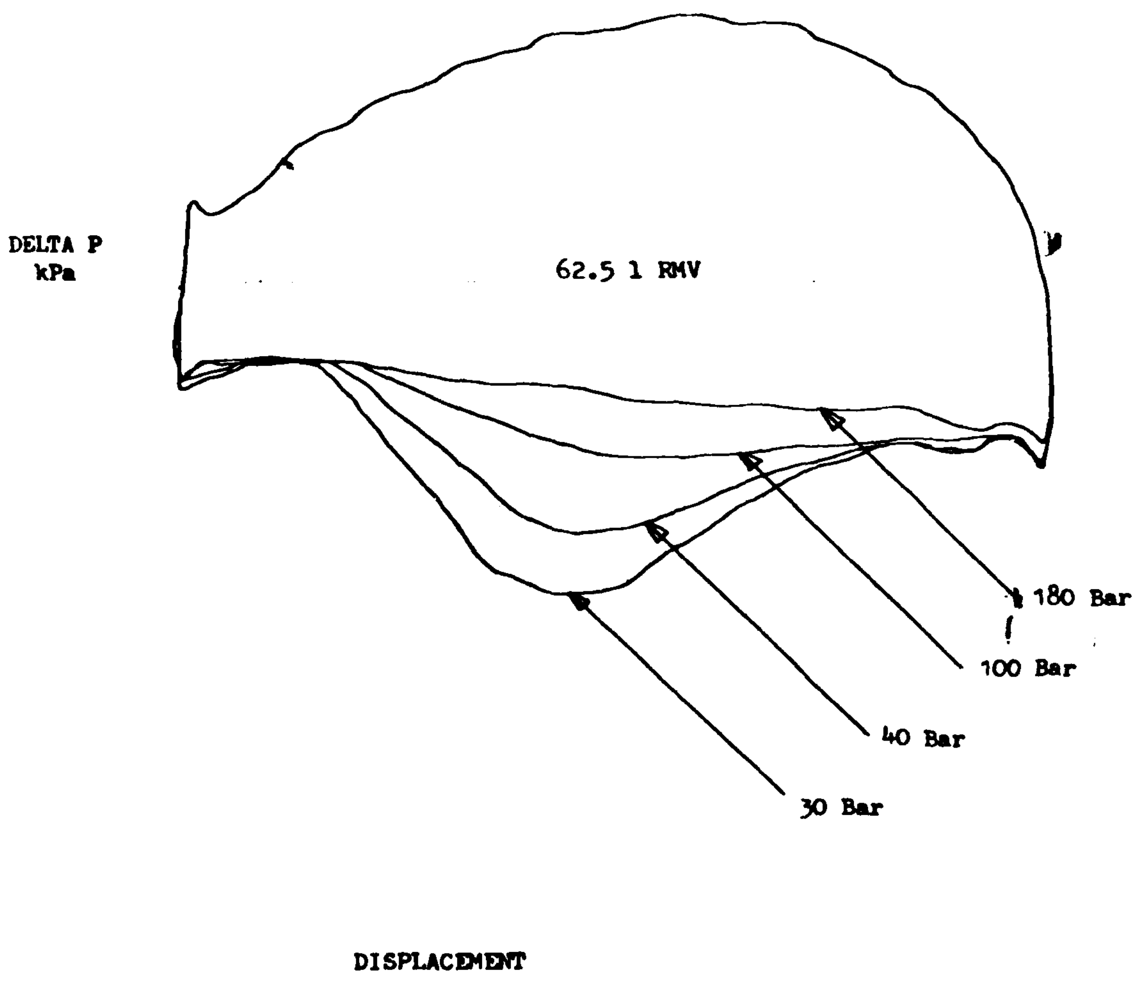


FIGURE 14

EFFECT OF REDUCING CYLINDER PRESSURE ON THE PERFORMANCE OF AN UNBALANCED FIRST STAGE DEMAND REGULATOR

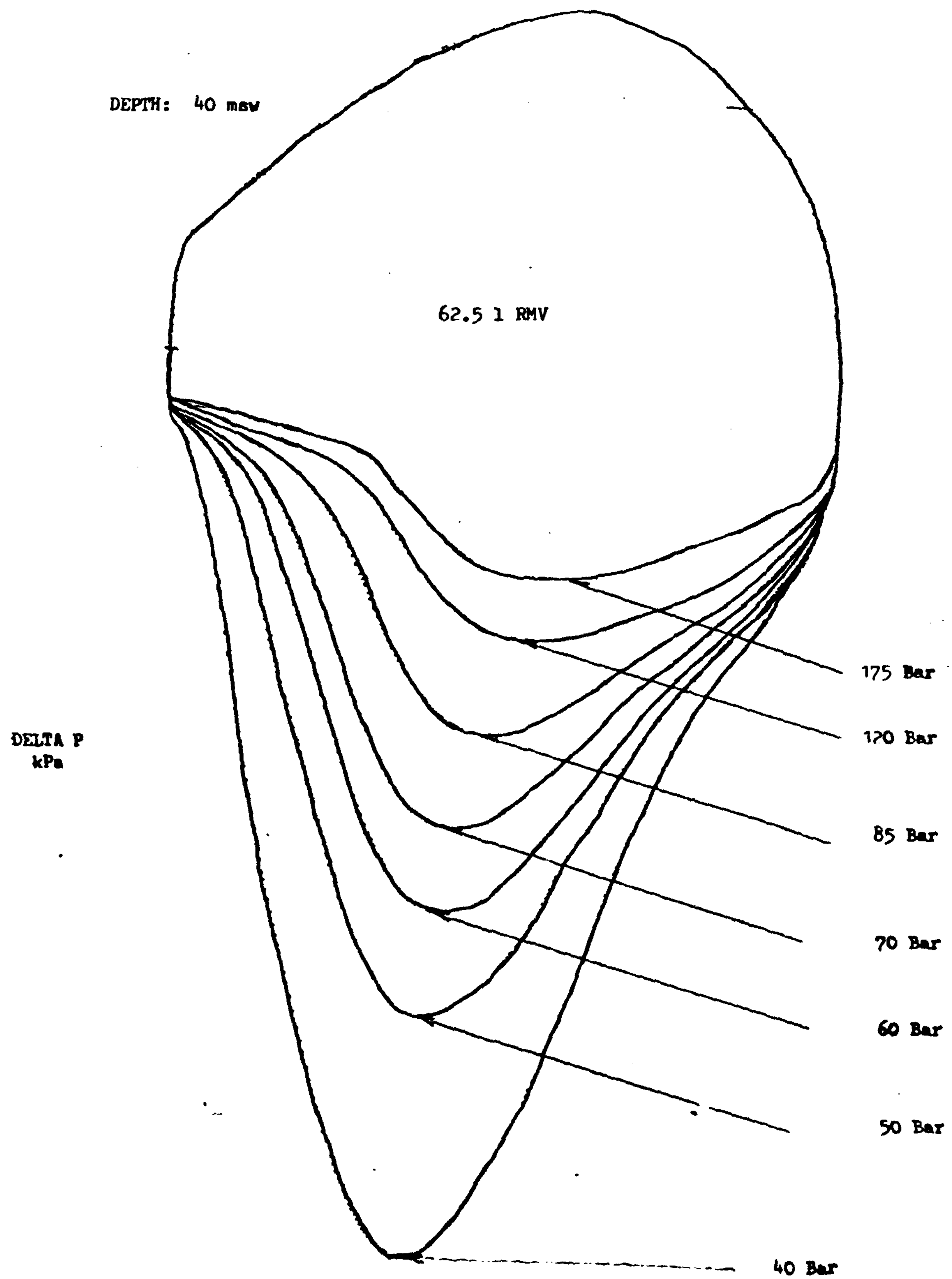


TABLE 1

BREATHING RESISTANCE TEST CONDITIONS

RMV	TV 1	FREQ	DIVER WORK RATE
22.5	1.50	15	Light
40.0	2.00	20	Moderate
62.5	2.50	25	Moderately Heavy
75.0	2.50	30	Heavy
90.0	3.00	30	Extreme *

* Ninety RMV represents an extreme work rate which can be sustained only for short durations. It has been achieved on manned wet dives at depths up to 1800 FSW and is included as a test parameter to determine the upper limits of a UBA's life support characteristics.

TABLE 2

ARE EXPERIMENTAL DIVING UNIT

HYPERBARIC TEST AND EVALUATION LABORATORY

CERTIFICATE OF DEMAND REGULATOR PERFORMANCE

DATE OF TEST: __.__.__ EDU Ref: ________________

DEMAND REGULATOR MODEL:-

MANUFACTURER/AGENT:-

MODEL TYPE:- SINGLE/TWO STAGE.

FIRST STAGE TYPE:- DIAPHRAGM - PISTON BALANCED/UNBALANCED

RECOMMENDED INTER-STAGE PRESSURE:- __._ Bar to __._ Bar.

FIRST STAGE Ser No:- ________________ SECOND STAGE Ser No:- ________________

RESULTS (STANDARD TESTS COMPLETED WITH 70 BAR SUPPLY)

WATER TEMPERATURE	:	__._ Centigrade
MEASURED INTER-STAGE PRESSURE	:	__._ Bar
DEPTH RECOMMENDED LIMITS MET FOR 62.5 1 RMV	:	__ msw (1.75 J/1, ± 1.5 kPa)
DEPTH ACCEPTABLE LIMITS MET FOR 62.5 1 RMV	:	__ msw (3.00 J/1, ± 2.5 kPa)
EFFECT OF CYLINDER PRESSURE MEASURED AT	:	__ msw
(A) for 62.5 1 RMV at 180 Bar	:	_.__ J/1,+__._ kPa, -__._ kPa
(B) " " " " " 70 Bar	:	_.__ J/1, + __._ kPa, -_._ kPa
(c) " " " " " 30 Bar	:	_.__ J/1, + __._ kPa, -__._ kPa

GENERAL COMMENTS

1.0 -

-

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MAXIMUM RECOMMENDED WORKING DEPTH : ___ msw

Annex A

Physiological performance criteria proposed by Morrison (1) for underwater breathing apparatus

(a) Maximum RECOMMENDED LIMITS for (i) Work $= 0.5 + 0.02 \times \dot{V}$ J/l

(ii) B/resist $= \pm 1.5$ kPa

(b) Maximum ACCEPTABLE LIMITS for (i) Work $= 0.5 + 0.04 \times \dot{V}$ J/l

(ii) B/resist $= \pm 2.5$ kPa

(Ventilation rate $\dot{V}$ l/min)

The breathing apparatus is considered to be UNACCEPTABLE for use, if the work of breathing and breathing resistance exceeded the ACCEPTABLE LIMITS.

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