3627

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OFFSHORE TECHNOLOGY REPORT - OTO 98 147

"J" Type Reserve Valves

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TO QUANTIFY THE EFFECT OF 'J' TYPE RESERVE VALVE ASSEMBLIES ON THE DYNAMIC PERFORMANCE OF DEMAND REGULATORS

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1. ISSUE RECORD

ISSUE	CHANGE	Authorised	DATE
1	AS ISSUED		27 July 1998

2. SUMMARY

ANSTI TEST SYSTEMS LTD was contracted by the HEALTH & SAFETY EXECUTIVE, Offshore Safety Division, Agreement : D 3627 to undertake a study to quantify the effect of 'J' type reserve valve assemblies on the dynamic performance of demand regulators.

The results of the breathing simulator tests show a new 'J' type reserve valve will provide an increase in inhalation pressure during successive breaths to warn the diver that the air pressure in the cylinder has reached the critical reserve level. Worn or leaky reserve valves may not provide the same level of warning. The reserve pressure, and hence reserve capacity, varies as a function of ventilation and depth i.e. the higher the ventilation and the deeper the depth the greater the reserve pressure. However, when breathing at a low ventilation the results show that as the cylinder pressure declines below critical levels an increase in ventilation rate would not be possible unless the reserve lever was immediately actuated. Even then, particularly at the deeper depths, the higher ventilation rate could not be sustained for more than a few breaths before the cylinder pressure again declined below it's critical value.

An earlier study of reserve valves completed by the DERA showed that two reserve devices of complex design gave no warning breaths on reaching the critical reserve pressure. They each shut off the air supply during mid-inhalation. One device caused this effect to occur at a low ventilation and the other at a high ventilation. The latter reserve device, when actuated, only permitted a few further breaths at the high ventilation, effectively providing little or no reserve capacity.

Consideration should be given to include a warning to the diver regarding the possible insidious effects of ventilation and depth on the duration of the reserve.

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4. INTRODUCTION

4.1 The objective of the study is to quantify the effect of 'J' type reserve valve assemblies on the dynamic performance of demand regulators. Ansti Test Systems conducted the study on behalf of the Health and Safety Executive, Offshore Safety Division, under agreement: D 3627, dated 30 January 1998.

4.2 Laboratory tests were conducted with a CE type approved demand regulator [1] connected to the outlet of a conventional cross flow pillar valve and a manual 'J' type reserve valve, respectively.

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5. SCOPE OF WORK

5.1 Conduct a literature search for information on performance aspects of ‘J’ type reserve valve assemblies.

5.2 Undertake laboratory measurements to quantify the effect of a ‘J’ type reserve valve assembly on the dynamic (breathing) performance of a demand regulator before and after activation.

5.3 Produce a report of the findings of the literature search and the dynamic performance tests. Specific points raised in discussion to be illustrated with the pressure-volume diagrams recorded during the test programme.

5.4 The dynamic performance tests to be conducted with the demand regulator immersed in fresh water at a temperature of 10°C and retained as though the diver’s head is in the upright position. The breathing simulator is to be set to ventilation rates of 15.0 and 62.5 l.min^{-1}, respectively. The chamber is to be pressurised from the surface to the equivalent depths of 10, 30 and 50 msw.

5.5 Parameters to be measured :

- High pressure supply
- Inter-stage pressure (First Stage Output pressure)
- Mouth pressure
- External work of breathing
- Peak Inhale pressure
- Peak Exhale pressure
- Depth
- Water Temperature

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6. PROCEDURES

6.1 The ANSTI test facility was specifically designed to test the dynamic (breathing) performance of demand regulators in accordance with the requirements of EN250, the European Standard for SCUBA [2,3]. The facility comprises a stainless steel breathing simulator and test chamber linked to a computerised instrumentation and data acquisition system. A conventional cross flow cylinder valve with known performance (pressure drop) was connected via the quick release lid assembly to an external air source. The demand regulator first stage was connected to outlet of the cylinder valve and supplied with air from a high pressure supply. The demand valve (second stage) was connected to the breathing simulator and breathed at the test ventilation rates. The cylinder was isolated from the main bank and the decline in pressure monitored along with inhalation pressure. The tests were suspended when the physiological limit [2,3,4] for inhalation pressure of 25 mbar was reached, and the corresponding cylinder pressure noted. The chamber was pressurised to each of the test depths and data recorded via the computer system. The results were printed in the form of test certificates which showed the conditions of test, calculated results and the associated Pressure -Volume (P-V) Diagram.

6.2 A Pressure-Volume diagram is generated by continuously plotting the variation in mouth pressure occurring within the demand valve, with the corresponding displaced volume of the breathing simulator. The P-V diagram shown in Figure 1, illustrates the response of the demand regulator used during the test programme. Mouth pressure is measured with a sensitive differential pressure transducer referenced to the air space above the immersed equipment. The zero reference point is unique to each demand regulator and it's depth of immersion and has therefore to be measured prior to each test. The zero in all cases is denoted by the horizontal (Volume) axis line of P-V diagram. Inhalation is indicated by a reduction in mouth pressure below the zero line and begins on the right hand side of the diagram. The plotted points traverse in a clockwise direction. In this particular case the pressure rises slightly above the zero line indicating positive pressure during inhale. This response is typical of a venturi type system which minimises the effort expended during inhalation. Exhalation begins on the left hand side indicated by the increase mouth pressure above the horizontal axis and the positive inhalation pressure line. The area bounded by the diagram is proportional to external work of breathing and computed for each printed test cycle. The area of the graph bounded by the positive inhalation pressure line corresponds to positive work and is therefore computed separately.

6.3 The conventional cylinder valve was replaced with a 'J' type reserve valve, in new condition, and the demand regulator reconnected. The tests were conducted in the manner previously described for the conventional cylinder valve but with the reserve actuating lever moved, after charging, to the standby position.

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6.4 The cylinder was isolated from the main bank and the decrease in pressure monitored. The pressure at which the inhalation pressure increased to 25mbar was noted and the reserve lever actuated to the full open position. The tests were continued and the decrease in cylinder pressure again monitored. The pressure at which inhalation reached 25 mbar was noted.

6.5 Prior to each test programme the system was prepared and calibrated in accordance with ANSTI 's ISO 9001 Quality Assurance System Procedures [5].

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7. RESULTS and DISCUSSION

7.1 In principle, the 'J' type reserve valve is designed to provide the diver with a positive warning that the air in the cylinder has declined to a critical (reserve) pressure. The warning is created by a restriction of the air supply, which increases as the cylinder pressure declines, ideally causing inhalation to become gradually more difficult with successive breaths. Actuating the reserve lever cancels the effect of the restriction completely and allows access to the air remaining in the cylinder. Thus by monitoring the change in the demand regulator's dynamic performance it is possible to quantify the effect of the reserve valve and define the cylinder pressure at which actuation of the reserve is necessary.

7.2 The dynamic performance of a demand regulator is currently defined using a breathing simulator to generate inhalation and exhalation flows whilst the regulator is immersed at hyperbaric pressures. Unlike humans, the breathing simulator has an unsympathetic response to the failure of a demand regulator to meet the inhalation flow demand. The P-V diagram, shown in Figure 2, illustrates this effect by showing how, at the point of failure, the mouth pressure drops steeply below the 25 mbar limiting line. The 25mbar inhalation / exhalation value is a physiological limit and is specified in the European Standard for SCUBA EN250. The breathing simulator test is therefore a particularly accurate method of defining the limiting depth performance of demand regulators.

Conventional Cylinder Valve

7.3 The dynamic (baseline) performance of a CE type approved demand regulator was determined when fitted to a conventional cylinder valve. The cylinder pressure was raised above any limiting threshold values and the baseline performance defined as shown in Figure 3. The breathing simulator tests were used to determine the minimum cylinder pressure at each depth that would maintain the inhalation pressure within the physiological limit of 25mbar. Examples of the successive increase of inhalation pressure is shown in Figure 4 & 5 for the test ventilation's of 15.0 and 62.5 $l.min^{-1}$, respectively. The minimum cylinder pressure was determined for each of the two ventilation rates and plotted against the corresponding depth (Figure 6).

'J' Type Reserve Valve

7.4 The breathing simulator tests were repeated with a commercially available 'J' type reserve valve and the actuating lever set in the standby position. The decline in high pressure was monitored along with the corresponding inhalation pressure. The cylinder pressure at which the inhale pressure increased to 25 mbar was defined as the Reserve Pressure and the tests temporarily suspended. The reserve lever was actuated to the fully open position and the tests continued until the inhalation pressure again increased to 25 mbar. This minimum cylinder pressure was again noted.

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7.5 The typical response of the demand regulator is shown in the P-V diagrams in Figures 7 - 10, respectively. The results for the Reserve Pressures were plotted for each ventilation against the corresponding depth and shown in Figure 11. The minimum cylinder pressures achieved after actuation of the reserve were plotted in the same manner and are also shown in Figure 11. The results show as cylinder pressure declines below the critical levels, successive breaths show increases in inhalation pressure.

7.6 The results of the tests indicated the dynamic performance of the demand regulator was unaffected by the presence of the reserve valve provided the cylinder pressure was above a critical ventilation dependent value. Similarly, after actuation of the reserve valve to allow access to the air remaining in the cylinder, the performance of the demand regulator regained it's former values and remained unaffected by the reserve valve until the pressure fell below the critical ventilation / depth dependent value. A comparison of the minimum cylinder pressures achieved with a conventional cylinder valve and the reserve valve, after actuation is shown in Figure 12. It can be seen that there is a slight difference in minimum pressure achieved with the greatest variation of 6 bar occurring at the deepest depth and highest ventilation.

7.7 The effectiveness of the basic type of 'J' type reserve valve is demonstrated by the results which clearly show that a correctly functioning reserve will provide a number of breaths warnings at high and low ventilation rates. The results also show that the reserve pressure varies as a function of both depth and ventilation rate. This is perhaps the most important of the performance characteristics measured because any changes in ventilation will significantly alter the response of the reserve valve, particularly when cylinder pressure has declined below critical values. Thus, if a diver breaths at a high ventilation rate throughout the period of the dive then :

i) The reserve pressure will be correspondingly higher when first warned that the air supply has reached a critical reserve level

and

ii) The diver's ventilation rate may be decreased at any point thereby extending the duration of the reserve.

7.8 The most significant characteristic which may have insidious consequences for the diver is if the ventilation rate is maintained at a low level throughout the period of the dive then :

i) The reserve pressure will be substantially lower when the diver is first warned that the air supply has reached a critical reserve level.

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ii) Most importantly, the diver would **not** be able to inhale at a high ventilation rate after the cylinder pressure has declined to this critical value unless the reserve valve is immediately actuated.

iii) Once the reserve is actuated the diver would however be able to breath at the higher rate but only for a short period. Access to the remaining air would only be achieved by adopting a lower ventilation, otherwise, the reserve would be ineffective.

7.9 It is also important to note that these results relate to the most basic design of reserve valve, which was in new condition. Leaking seats or mechanically worn or faulty reserve mechanism valves of similar design may not therefore provide the same level of warning or reserve pressure.

7.10 An earlier study, completed by the then Admiralty Research Establishment, Hyperbaric Research Laboratory, showed wide variations in response and warning characteristics. Selected results are reproduced herewith by kind permission of the DERA, Centre for Marine Technology, Gosport. This study revealed that two reserve valves exhibited rapid shut off responses which effectively provided no warning that the cylinder pressure had reached a critically low level. It was noted that these devices were more complex than the reserve valve tested in this study because they automatically set themselves into the standby position as the cylinders were charged with air. These results illustrate the extremes in response achieved by the two different devices. Figure 13 shows a rapid shut off characteristic occurring at low ventilation. At high ventilation the same device provided a gradual increase of inhalation pressure during successive breaths. Conversely, the other device provided no warning at high ventilation, as shown in Figure 14, but provided a gradual increase of inhalation pressure at the low ventilation rate. However, the latter device, when actuated to allow access to the reserve, only permitted a few more breaths at the high ventilation rate, effectively providing little or no reserve capacity.

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8.0 CONCLUSIONS

8.1 The results suggest that a 'J' type reserve valve of the most basic design and in new condition will provide a progressive warning that the air supply has declined to a critically low level of reserve. The tests also showed that the reserve pressure varies as a function of both ventilation and depth i.e. the higher the ventilation and the deeper the dive the greater the reserve. Thus allowing the diver at any point to decrease ventilation and extend the duration of the reserve. Most importantly, if a low ventilation is maintained throughout the period of the dive, it would not then be possible to breath at a higher ventilation unless the reserve was immediately actuated. At the deeper depths, the diver would only be able to take one or two more breaths before the cylinder pressure again declined below the critical ventilation dependent value thereby providing little or no reserve. Whilst the reserve valve tested was in new condition and provided consistent results, leaking or mechanically worn reserve valves may not provide the same level of warning.

8.2 Some reserve valves of more complex design, previously tested by DERA, provide no warning of impending low cylinder pressure by shutting off the air supply during mid-inhalation. One device, when breathed at the high ventilation rate, effectively prevented access to the air remaining in the cylinder after the reserve had been actuated.

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9. RECOMMENDATIONS

9.1 Consideration should be given to providing the diver with information on the ‘J’ type reserve valve assembly and possible insidious effects of ventilation / depth on the duration of the reserve capacity of the cylinder.

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10. REFERENCES

1. Guidance Document on the UK Regulations (the Personal Protective Equipment (EC Directive) Regulations S.I. 1992/3139) implementing Council Directive 89/686/EEC as amended by the Personal Protective Equipment (EC Directive) (Amendment) regulations S.I. 1993/3074 implementing Council Directive 93/95/EEC and the Personal Protective Equipment (EC Directive) (Amendment) Regulations 1994 S.I. 1994/2326 implementing Council Directive 93/68/EEC as it relates to PPE.

2. Respiratory equipment - Open-circuit self-contained compressed air diving apparatus - Requirements, testing, marking , EN 250 : 1993.

3. Respiratory equipment - Open-circuit self-contained compressed air diving apparatus - Requirements, testing, marking , prEN 250 : 1997 E (Revision of EN250).

4. Guidelines for the evaluation of breathing apparatus for use in manned underwater operations in the petroleum activities. Norwegian Petroleum Directorate / Department of Energy, 1991. ISBN 81-7257-308-3.

5. System function and Calibration Checklist, Ansti Test Systems Ltd, Form F425/01, Issue 1, December 1996.

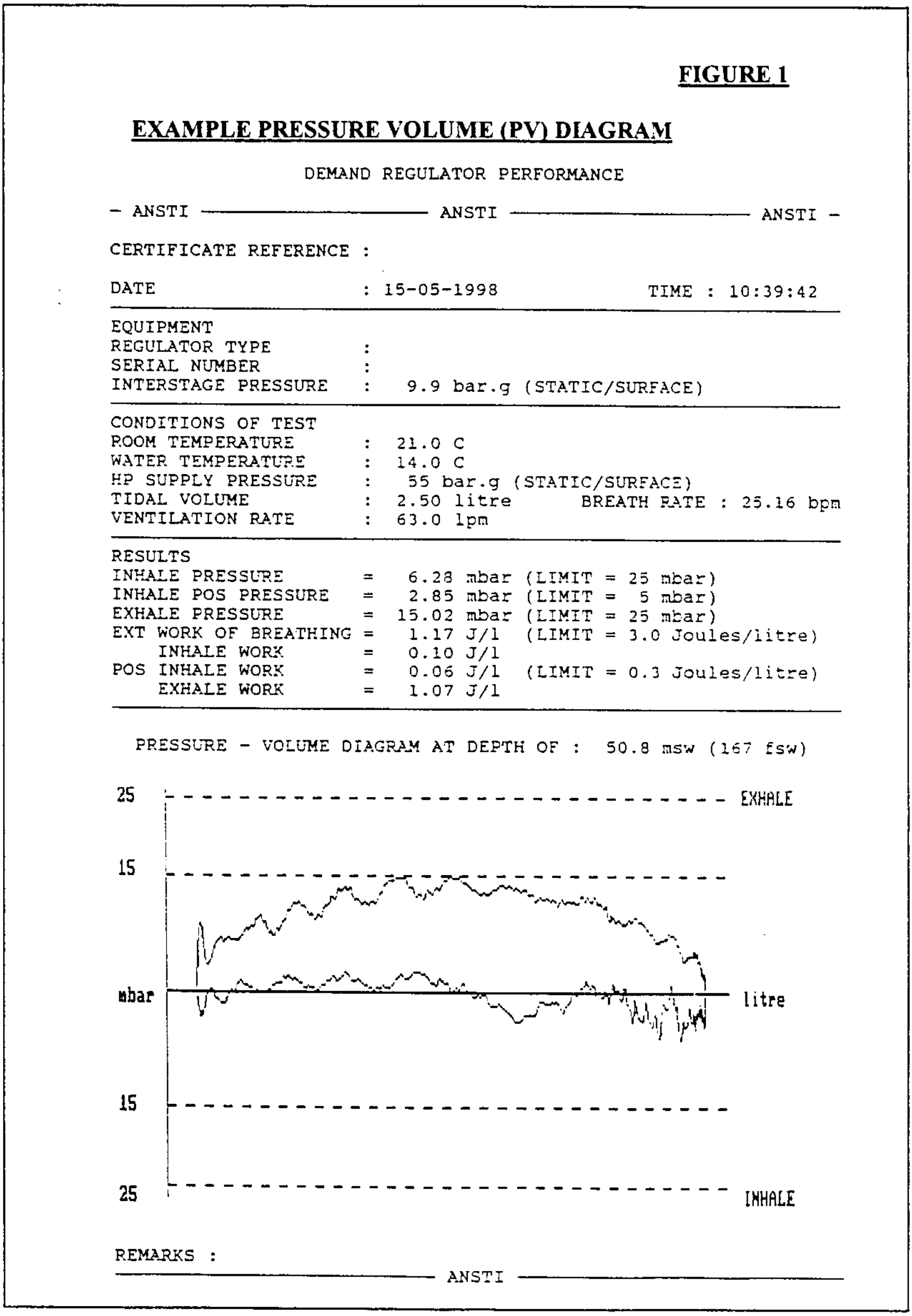

FIGURE 1

EXAMPLE PRESSURE VOLUME (PV) DIAGRAM

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                    DEMAND REGULATOR PERFORMANCE

- ANSTI ------------------------ ANSTI ------------------------ ANSTI -

CERTIFICATE REFERENCE :

DATE                      : 15-05-1998            TIME : 10:39:42
-----------------------------------------------------------------------
EQUIPMENT
REGULATOR TYPE            :
SERIAL NUMBER             :
INTERSTAGE PRESSURE       :   9.9 bar.g (STATIC/SURFACE)
-----------------------------------------------------------------------
CONDITIONS OF TEST
ROOM TEMPERATURE          :  21.0 C
WATER TEMPERATURE         :  14.0 C
HP SUPPLY PRESSURE        :   55 bar.g (STATIC/SURFACE)
TIDAL VOLUME              :  2.50 litre      BREATH RATE : 25.16 bpm
VENTILATION RATE          :  63.0 lpm
-----------------------------------------------------------------------
RESULTS
INHALE PRESSURE           =   6.28 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE       =   2.85 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE           =  15.02 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING     =   1.17 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK           =   0.10 J/l
POS INHALE WORK           =   0.06 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK           =   1.07 J/l
-----------------------------------------------------------------------

  PRESSURE - VOLUME DIAGRAM AT DEPTH OF :  50.8 msw (167 fsw)
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REMARKS  :
----------------------------- ANSTI ------------------------------
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FIGURE 2

TYPICAL INHALATION FAILURE RESPONSE P-V DIAGRAM

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                    DEMAND REGULATOR PERFORMANCE

- ANSTI ------------------- ANSTI -------------------- ANSTI -

CERTIFICATE REFERENCE ·

DATE                     : 18-03-1998          TIME : 17:02:52
---------------------------------------------------------------
EQUIPMENT
REGULATOR TYPE           :
SERIAL NUMBER            :
INTERSTAGE PRESSURE      :   9.8 bar.g (STATIC/SURFACE)
---------------------------------------------------------------
CONDITIONS OF TEST
ROOM TEMPERATURE         :  20.0 C
WATER TEMPERATURE        :  11.0 C
HP SUPPLY PRESSURE       :   50 bar.g (STATIC/SURFACE)
TIDAL VOLUME             :  2.50 litre      BREATH RATE : 24.98 bpm
VENTILATION RATE         :  62.5 lpm
---------------------------------------------------------------
RESULTS
INHALE PRESSURE          =  31.33 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE      =   0.98 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE          =  13.16 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING    =   2.02 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK          =   1.06 J/l
POS INHALE WORK          =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK          =   0.97 J/l
---------------------------------------------------------------

  PRESSURE - VOLUME DIAGRAM AT DEPTH OF :  35.6 msw (117 fsw)
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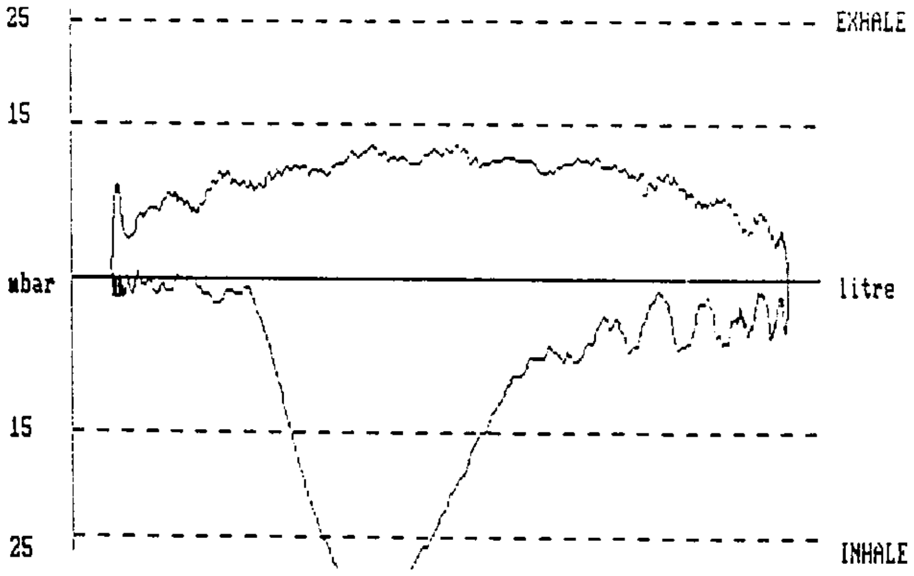

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REMARKS :
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FIGURE 3

LOW VENTILATION

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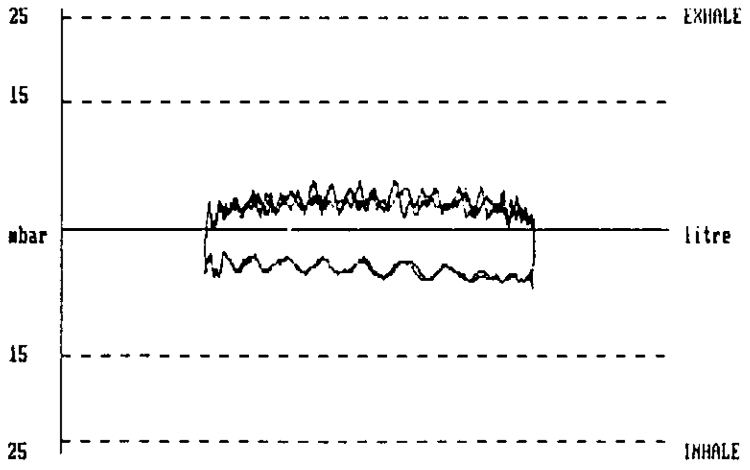
RESULTS
INHALE PRESSURE        =   7.06 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =   5.68 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   0.78 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.48 J/l
POS INHALE WORK        =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.30 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.3 msw (165 fsw)



REMARKS :

ANSTI

HIGH VENTILATION

```
RESULTS
INHALE PRESSURE        =  13.55 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   6.58 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =  13.94 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   1.07 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.09 J/l
POS INHALE WORK        =   0.23 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.98 J/l
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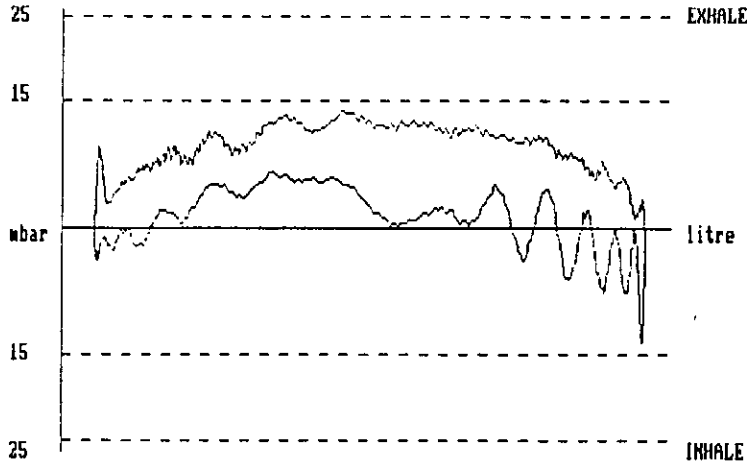
PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 51.2 msw (168 fsw)



REMARKS :

ANSTI

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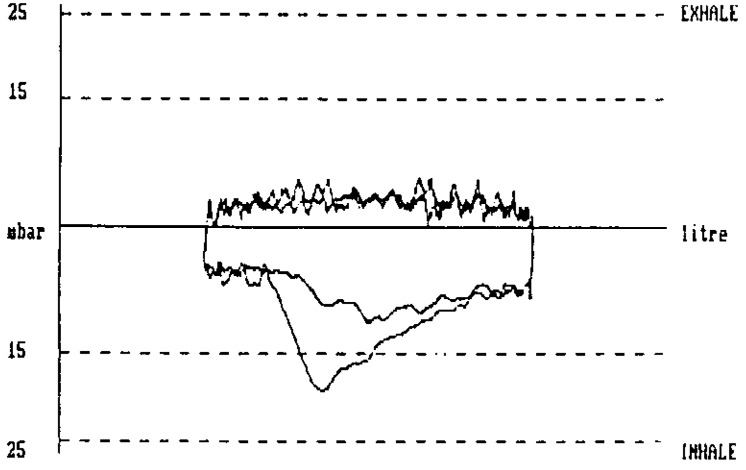
CONVENTIONAL CYLINDER VALVE : MINIMUM CYLINDER PRESSURES - 50m

FIGURE 4 : LOW VENTILATION

```
RESULTS
INHALE PRESSURE       =  11.27 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE   =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE       =   6.08 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING =   1.05 J/l   (LIMIT = 3.0 Joules/litre)
    INHALE WORK       =   0.76 J/l
POS INHALE WORK       =   0.00 J/l   (LIMIT = 0.3 Joules/litre)
    EXHALE WORK       =   0.29 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 49.8 msw (163 fsw)



REMARKS : CP 11 TO 10 BAR

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FIGURE 5 : HIGH VENTILATION

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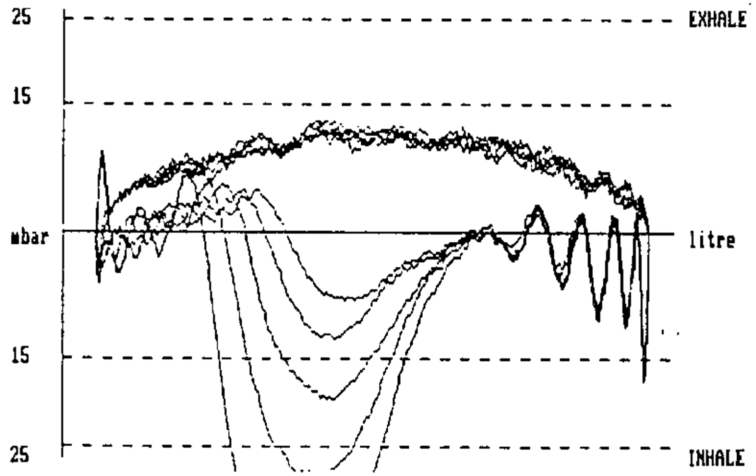
RESULTS
INHALE PRESSURE       =  17.64 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE   =   5.10 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE       =  12.54 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING =   1.14 J/l   (LIMIT = 3.0 Joules/litre)
    INHALE WORK       =   0.25 J/l
POS INHALE WORK       =   0.08 J/l   (LIMIT = 0.3 Joules/litre)
    EXHALE WORK       =   0.89 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 49.6 msw (163 fsw)



REMARKS : CP 41 - 36 BAR

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CONVENTIONAL CYLINDER VALVE : MINIMUM CYLINDER PRESSURES v DEPTH

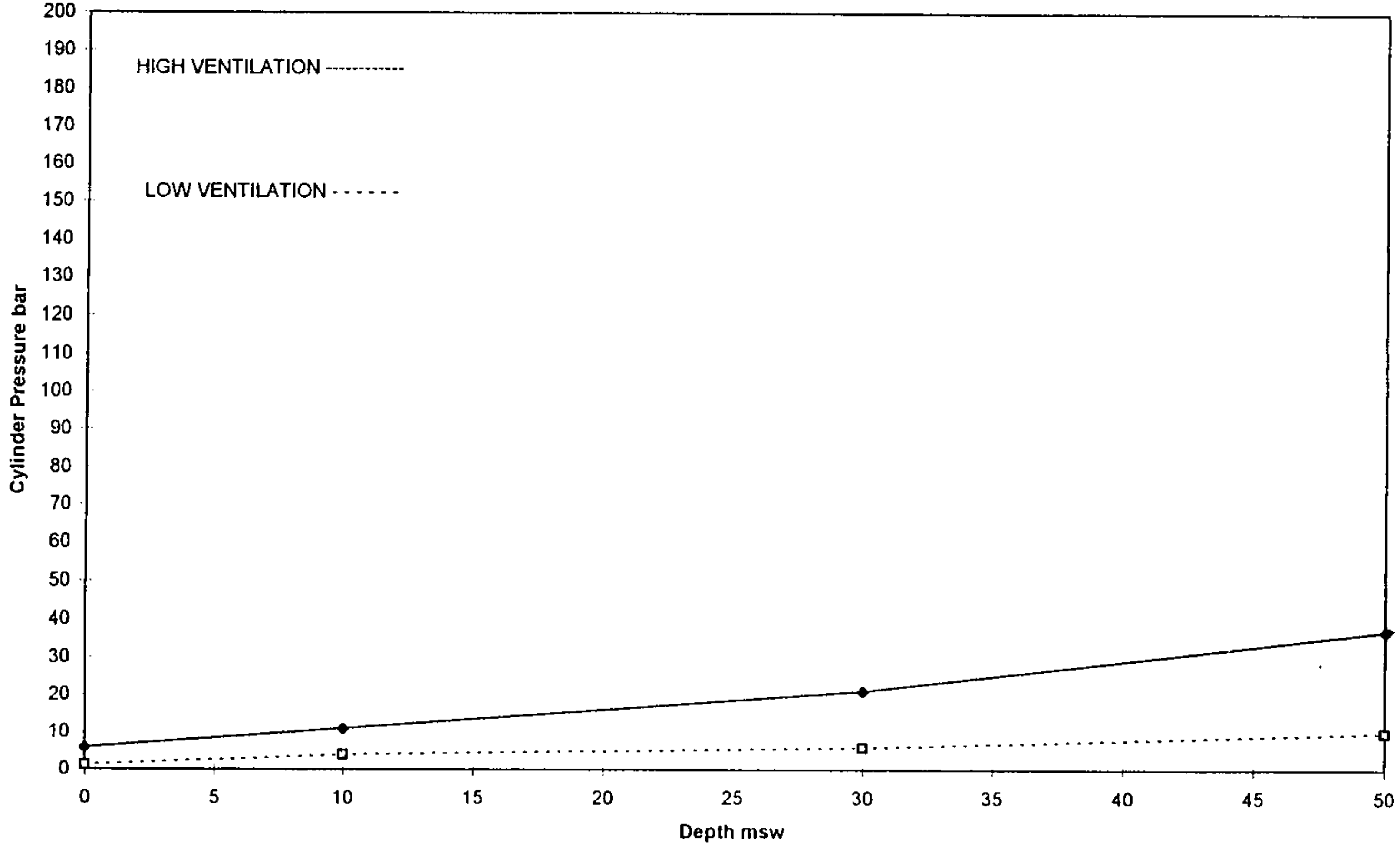

FIGURE 6

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EFFECTS OF THE RESERVE VALVE ON DEMAND REGULATOR PERFORMANCE - 50m HIGH VENTILATION

FIGURE 7 : BEFORE ACTUATION

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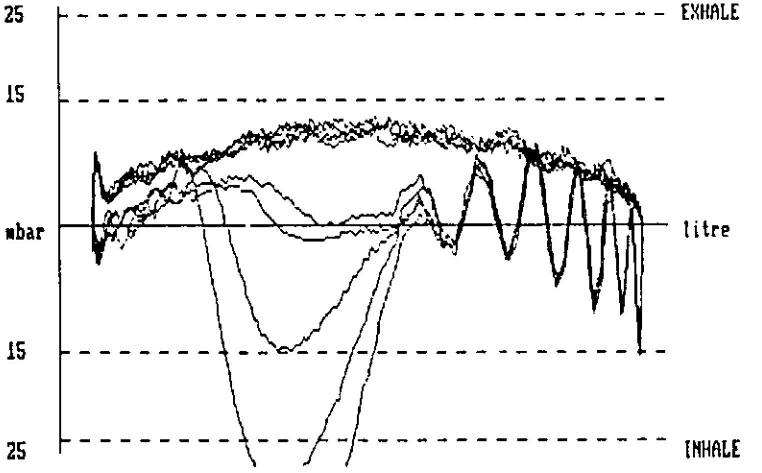
RESULTS
INHALE PRESSURE        =  15.61 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   9.13 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =  13.06 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING =    0.98 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.10 J/l
POS INHALE WORK        =   0.25 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.88 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.0 msw (164 fsw)



REMARKS : LEVER READY TO USE/CP 100-96 BAR

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FIGURE 8 : AFTER ACTUATION

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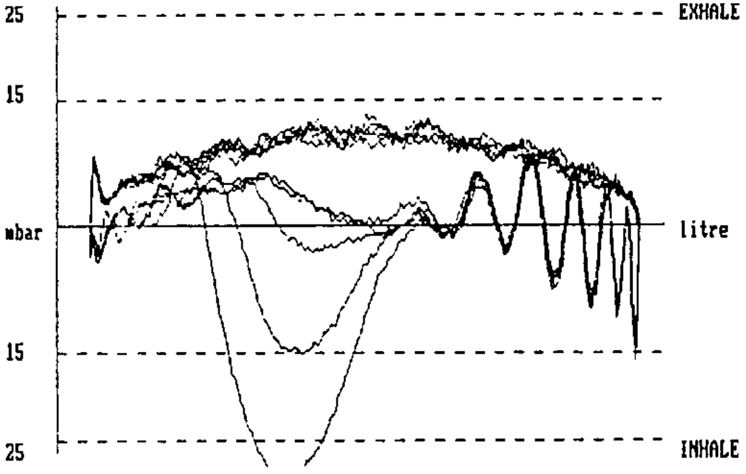
RESULTS
INHALE PRESSURE        =  14.53 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   8.45 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =  12.18 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING =    0.93 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.09 J/l
POS INHALE WORK        =   0.24 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.84 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.2 msw (165 fsw)



REMARKS : LEVER ACTUATED/CP 44-41 BAR

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EFFECTS OF THE RESERVE VALVE ON DEMAND REGULATOR PERFORMANCE - 50m
LOW VENTILATION

FIGURE 9 : BEFORE ACTUATION

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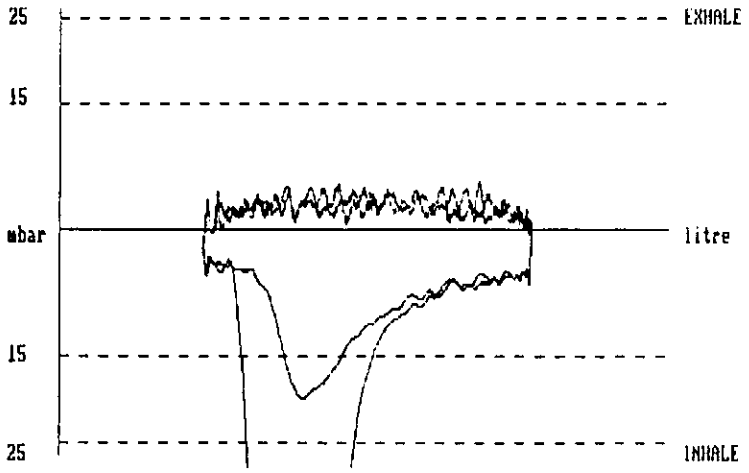
RESULTS
INHALE PRESSURE        =  20.23 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =   5.20 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   1.21 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.94 J/l
POS INHALE WORK        =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.27 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.5 msw (166 fsw)



REMARKS : CP 49.4 - 48.6 / BEFORE ACTUATION
ANSTI

FIGURE 10 : AFTER ACTUATION

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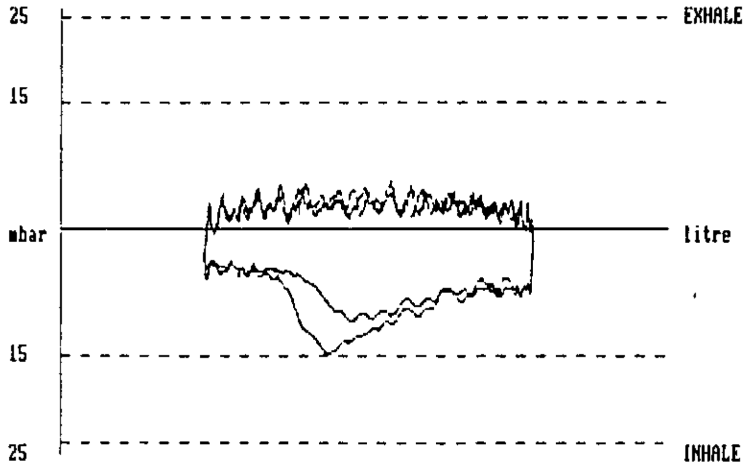
RESULTS
INHALE PRESSURE        =  11.10 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =   5.60 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   1.01 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   0.74 J/l
POS INHALE WORK        =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.27 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 49.8 msw (163 fsw)



REMARKS : CP 11 BAR / AFTER ACTUATION
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RESERVE VALVE : MINIMUM CYLINDER PRESSURES v DEPTH

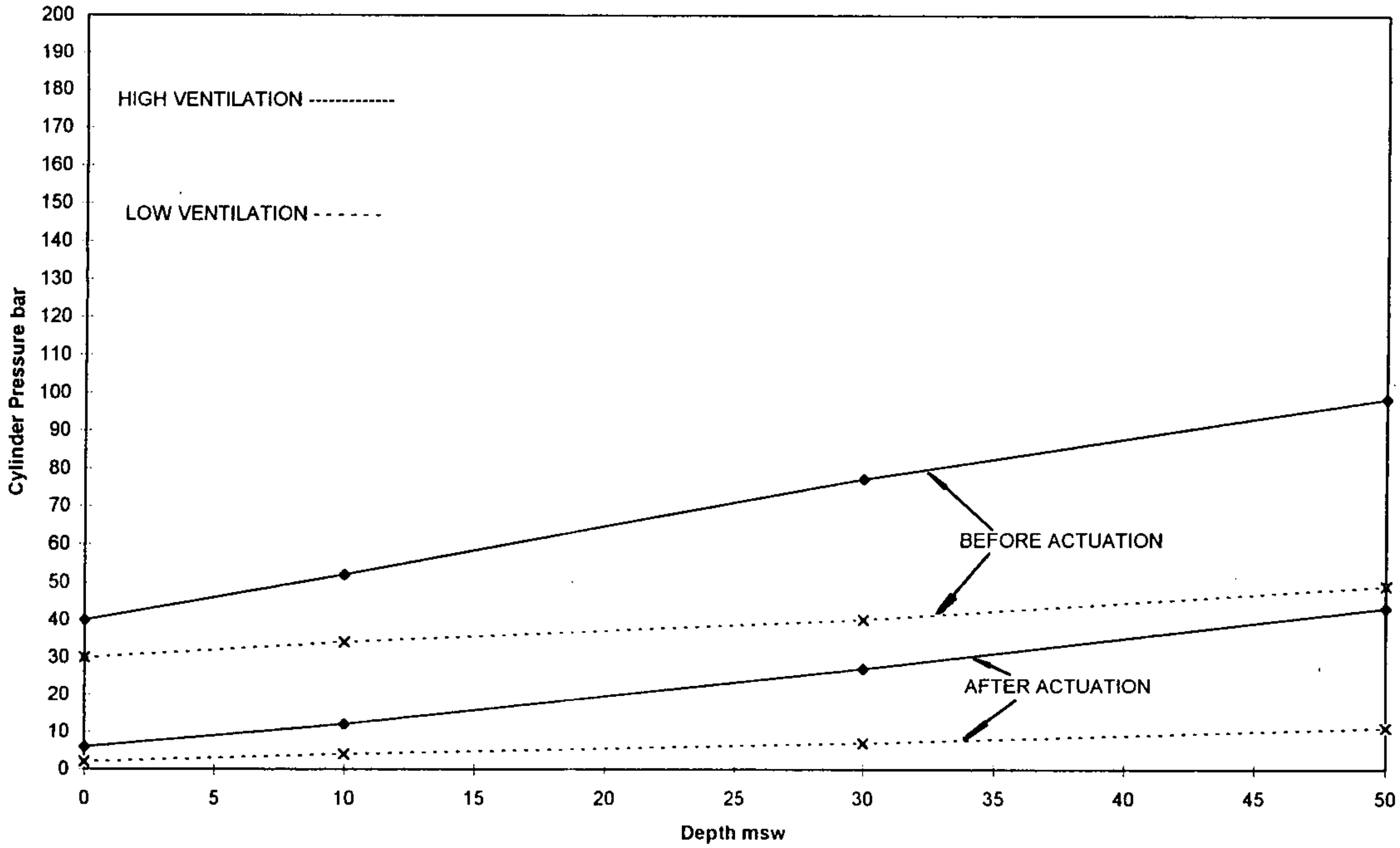

FIGURE 11

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COMPARISON OF MINIMUM CYLINDER PRESSURES v DEPTH

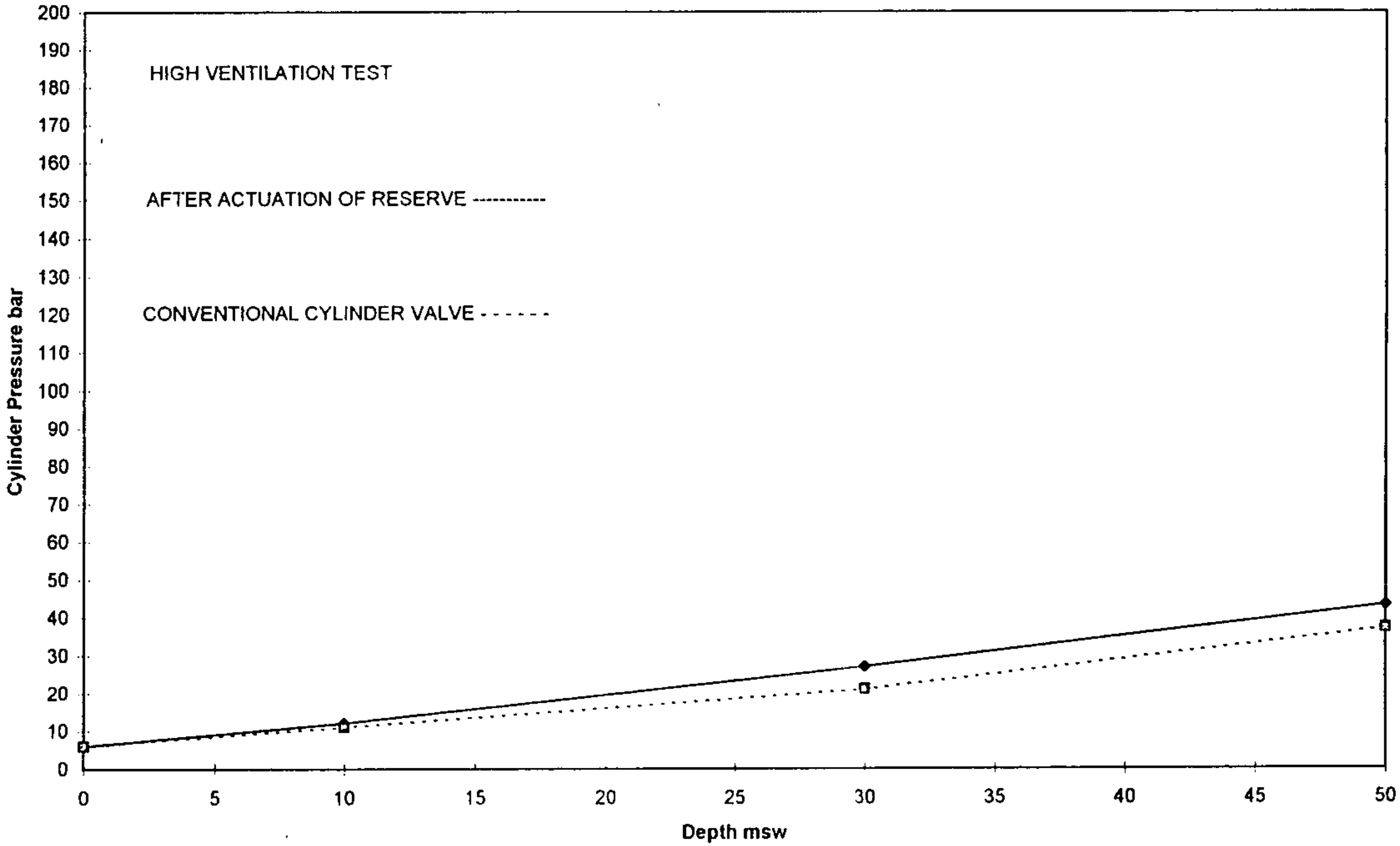

FIGURE 12

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FIGURE 13

Low Ventilation : Rapid shut off mid-inhalation

Depth : 50 msw

Ventilation : 22.5 l /min

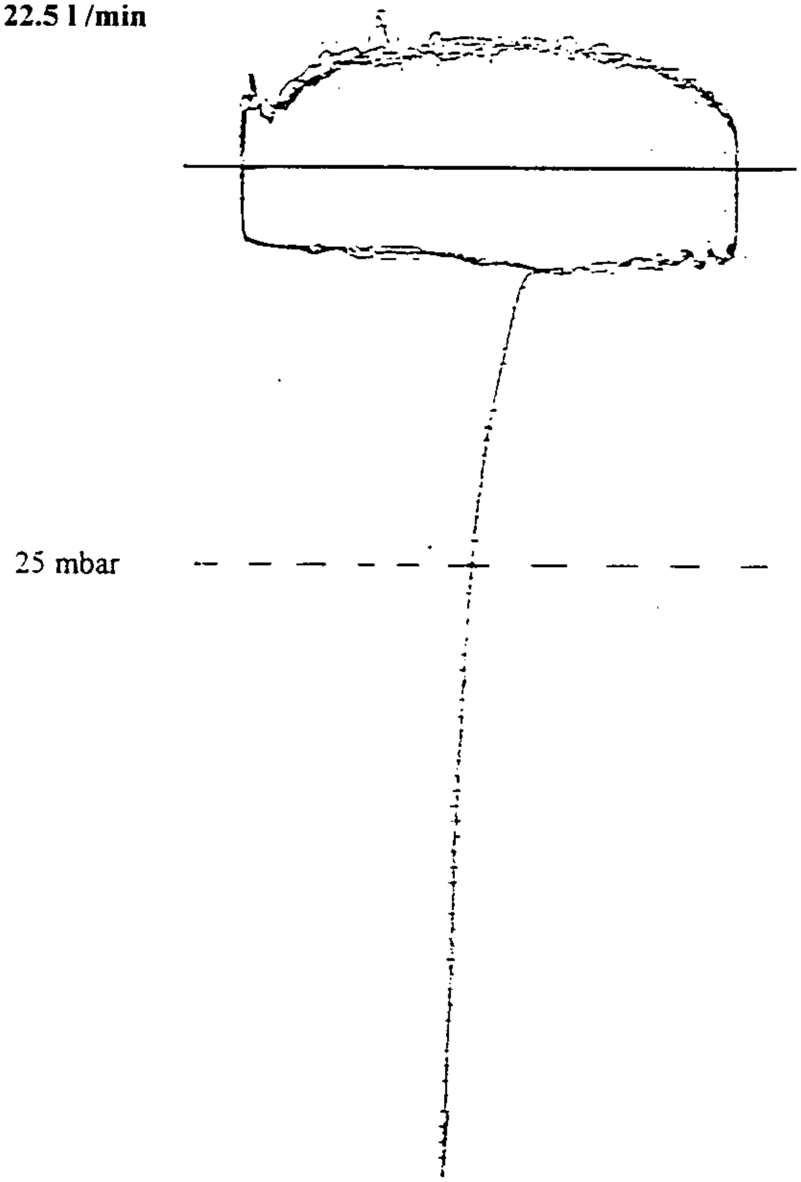

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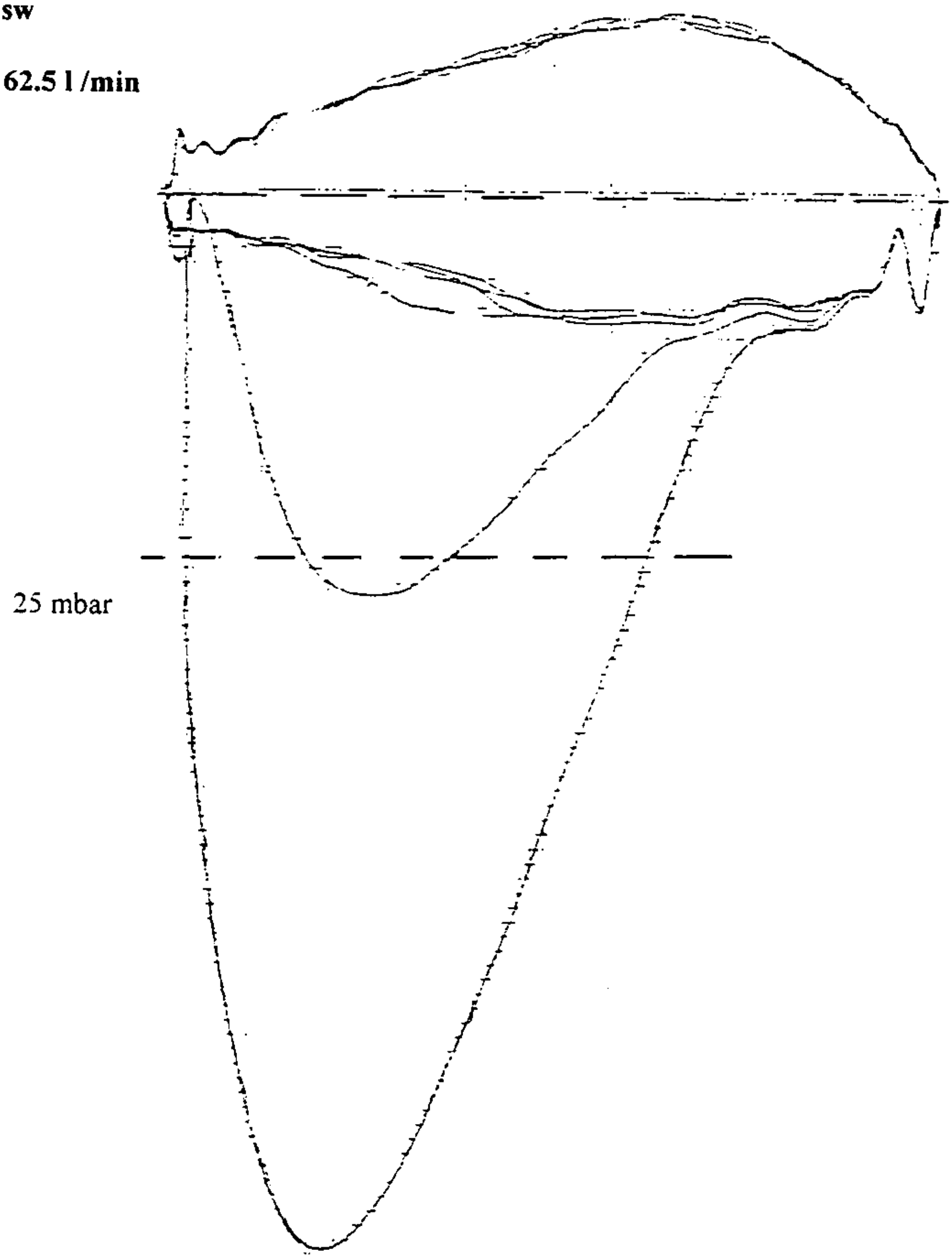
FIGURE 14

High Ventilation : Rapid shut off mid-inhalation

Depth : 50 msw

Ventilation : 62.5 l /min



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