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PORTABLE OXYGEN SUBSYSTEM (POS)

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ABSTRACT

This report describes the concept selection, design, fabrication, and testing of a Portable Oxygen Subsystem (POS) for use in Space Shuttle operations. Tradeoff analyses were conducted to determine the POS concept for fabrication and testing. The fabricated POS was subjected to unmanned and manned tests to verify compliance with Statement of Work requirements. The POS used in the development program described herein met requirements for the three operational modes -- prebreathing, contaminated cabin, and Personnel Rescue System operations.

FOREWORD

This is the final report for the Portable Oxygen Subsystem (POS) Program. The program was conducted by AiResearch Manufacturing Company, Torrance, California, for the Lyndon B. Johnson Space Center, NASA Contract NAS 9-14457. The program started in January, 1975, and was completed in December, 1975.

AiResearch wishes to thank the contract Technical Monitor, Mr. Roger Tanner of the Crew Systems Division of the Lyndon B. Johnson Space Center, for his advice throughout this program.

CONTENTS

TABLES

ILLUSTRATIONS

ILLUSTRATIONS (CONTINUED)

SECTION I

SUMMARY

POS USES

Three discrete uses for a special breathing device for Shuttle Program operational and contingency modes have been identified. These three uses are: (1) an emergency oxygen system to be used in case of a contaminated cabin atmosphere, (2) a prebreather for denitrogenation of the crewman prior to extravehicular activity (EVA), and (3) a breathing system for use in the Personnel Rescue System (PRS). For this development program, a prototype Portable Oxygen System (POS), capable of providing the above three Shuttle Program functions was designed, fabricated and tested. The prototype, which met all basic POS requirements, is shown schematically in Figure 1-1 and pictorially in Figures 1-2 and 1-3. Figure 1-2 shows the POS configured for storage in the Orbiter. The mask assembly and flexible hose are contained within the POS, and the straps used to hold the POS on the crewman are wrapped around the POS and secured. Figure 1-3 shows the POS ready to use. The system was representative of flight hardware, except for the oxygen tank and turbofan, which were simulated.

POS REQUIREMENTS

The basic requirements for the POS are as follows:

1. The POS shall provide conditioned gas and full face protection, while in an atmospheric pressure of 55.2 to 101 kPa (8.0 and 14.7 psia) for 3 hours. The metabolic rate shall be 234.5 watts (800 Btu/hr) for 162 minutes, 322.4 watts (1100 Btu/hr) for 15 minutes, and 439.7 watts (1500 Btu/hr) for 3 minutes.

2. During EVA preparation, the POS shall be capable of denitrogenizing a crewman to less than 5 volume percent in ten minutes of operation and to less than three volume percent at the end of three hours of operation.

3. The POS shall provide one hour of independent operation at an ambient pressure of 34.5 kPa (5.0 psia) with a metabolic rate of 234.5 watts (800 Btu/hr).

4. The POS shall provide 10 minutes of independent operation while used in the Orbiter.

5. Mask inlet temperature shall be 43.3°C (110°F) maximum dry bulb and 37.8°C (100°F) maximum dewpoint.

6. Mask inlet carbon dioxide partial pressure shall be less than 1.013 kPa (7.6 mm Hg) at a metabolic rate of 234.5 watts (800 Btu/hr) and less than 2 kPa (15 mm Hg) at a metabolic rate of 322.4 watts (1100 Btu/hr).

7. The inspired gas shall contain no free water.

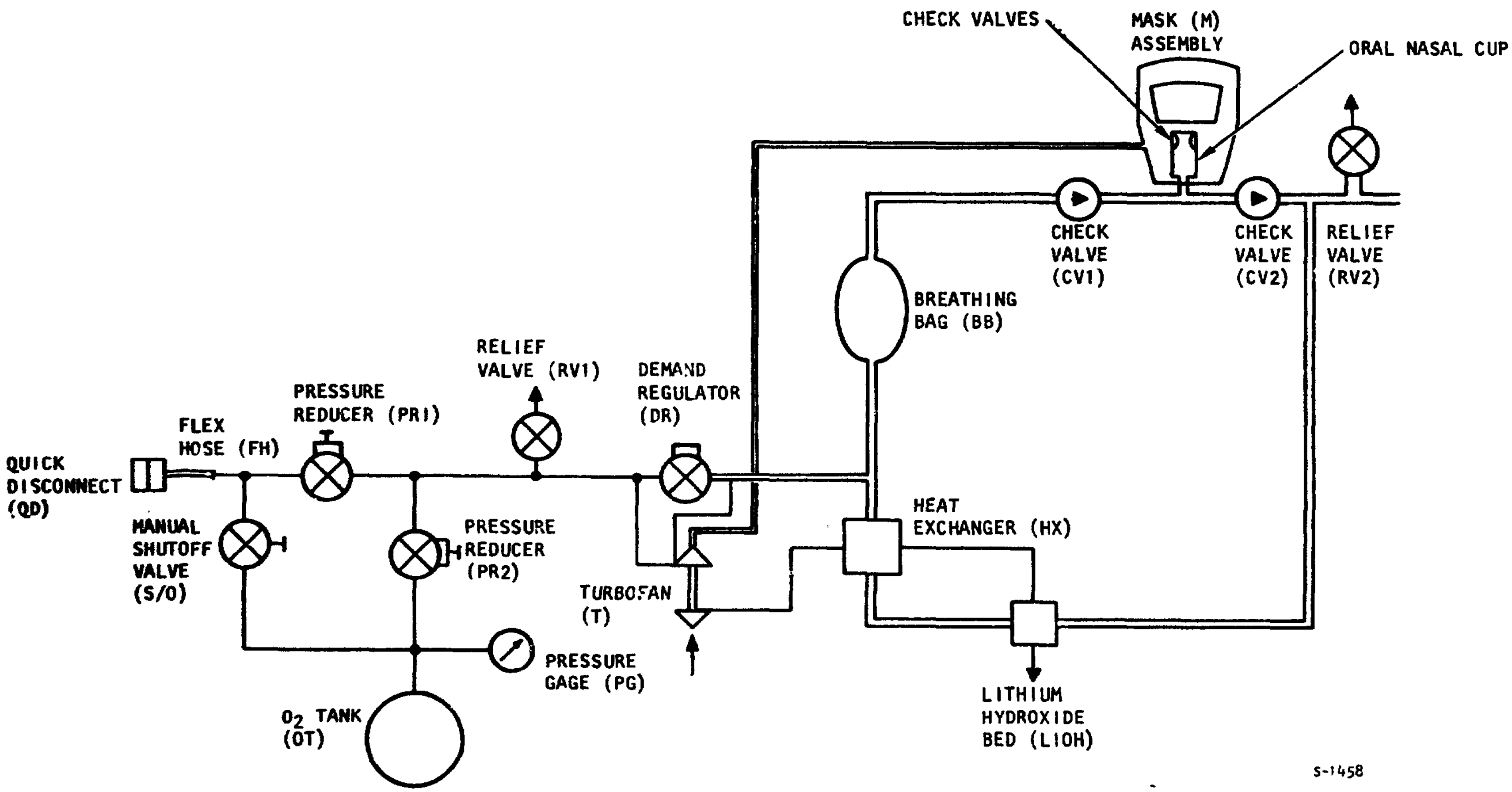

Figure 1-1. Fortable Oxygen System Schematic

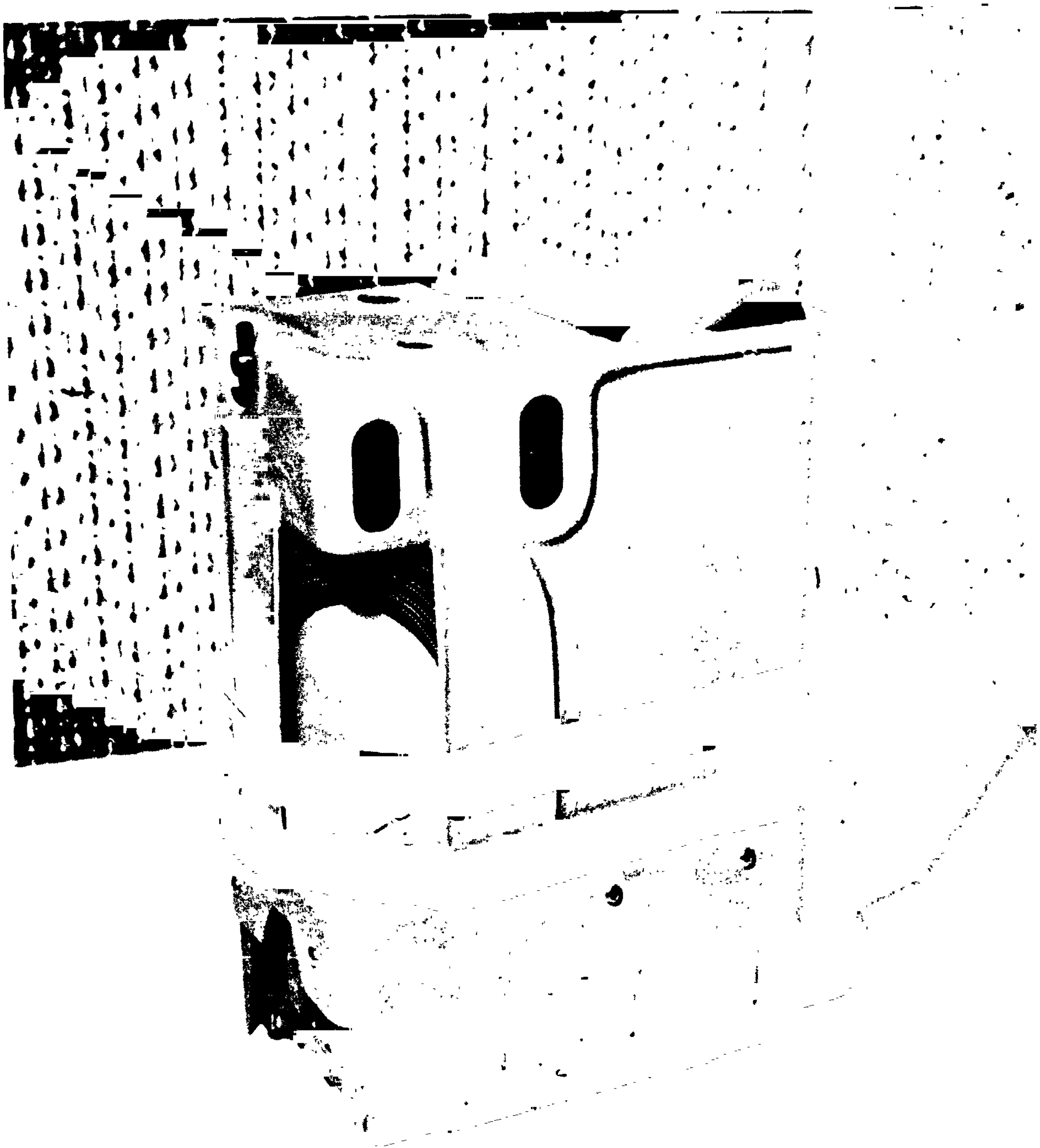

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Figure 1-2. Portable Oxygen System

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Figure 1-3. Portable Oxygen System Ready for Use

DEVELOPMENT PROGRAM

The POS, as fabricated for this program, has the following design parameters:

Weight:	6.9 kg (15.2 lb)
Size:	0.23 x 0.33 x 0.13 m (9 in. x 13 in. x 5 in.)
Oxygen Flow:	0.32 kg/hr (0.7 lb/hr) in Orbiter 0.27 kg/hr (0.6 lb/hr) in PRS
LiOH Quantity:	0.39 kg (0.85 lb)
Breathing Bag Volume:	2.0 liters
Cooling Capacity (Cabin Air):	6.8 kg/hr (15 lb/hr)
Breathing Resistance:	-0.249 to 0.871 kPa (-1.0 to 3.5 in. H_2O)

The POS development program consisted of four tasks: Task 1, Concept Evaluation; Task 2, Design; Task 3, Fabrication; and Task 4, Test.

The concept evaluation task consisted of (1) alternate system concept identification and analysis to determine the relative merits of each alternate, (2) concept selection, and (3) evaluation of the selected concept for specification compliance.

For evaluation purposes, the POS was divided into two subsystems: (1) the oxygen supply and delivery subsystem and (2) the breathing loop subsystem. An oxygen supply and delivery subsystem was selected after an FMEA (failure modes and effects analysis) was performed. Launch weight and volume penalties were determined as a function of oxygen flow rates into the breathing loop. Four heat rejection concepts were then evaluated along with results of the oxygen flow rate analysis. Heat rejection is required to condense the moisture in the exhaled breath and the moisture generated by the absorption of carbon dioxide by LiOH. Additional heat rejection is required to remove the sensible heat produced by the absorption process. The selected concept was then designed, fabricated, and subjected to a development test. The POS that was tested was representative of a flight unit, except for the oxygen tank and turbofan. Neither of these items were fabricated for the POS at this time, because the system could be properly evaluated without the fabrication expense involved. The oxygen tank was simulated with a cylinder fabricated from CRES bar stock. The turbofan, which provides the necessary cooling, was simulated with shop air.

Results of the development tests verified that the design was insensitive to metabolic variables and that Statement of Work requirements were surpassed. The POS was subjected to three unmanned tests and one manned test. Test results are summarized in Table 1-1.

TABLE I-1

POS DEVELOPMENT TEST SUMMARY

Test No.	Test Duration, hr:min	Metabolic Profile		Maximum Mask Inlet Conditions	
		Rate, Watts (Btu/hr)	Time at Conditions, minutes	CO_2 Volume, percent	Dry Bulb and Dew Point Temperature, °C (°F)
2	4:28	275.5 (940)	165	1.00	32.8 (91)
		375.2 (1280)	15	1.45	33.9 (93)
		498.3 (1700)	4	2.10	37.8 (100)
		275.5 (940)	46	1.70	33.3 (92)
3	5:23	234.5 (800)	162	0.74	30.0 (86)
		322.4 (1100)	15	1.04	30.6 (87)
		439.7 (1500)	4	1.10	31.1 (88)
		234.5 (800)	110	1.25	31.1 (88)
4	5:02	439.7 (1500)	4	0.00	23.1 (73.5)
		322.4 (1100)	16	0.04	26.1 (79)
		234.5 (800)	267	1.09	30.0 (86)
5 Manned	3:10	260.9 (890)	162	1.08	29.4 (85)
		360.3 (1230)	15	1.40	30.6 (87)
		489.5 (1670)	3	1.52	30.6 (87)
		260.9 (890)	10	1.40	31.1 (88)

SECTION 2

CONCEPT EVALUATION

COMPUTER PROGRAM

The first task performed during the POS program was to determine the component performance requirements. Although there are relatively few components in the system, integration of respiratory and metabolic relations into the overall system analysis greatly increases the complexity of the calculations. Since the system never reaches an equilibrium condition, transient calculations as a function of the breathing schedule are required for a meaningful analysis. A transient performance analysis program was prepared to perform transient calculations. One critical portion of the program, the transient analysis of the LiOH bed, was available from an existing LiOH-performance, computer program. Using this computer program, system performance was determined as a function of oxygen inflow into the breathing loop. The oxygen system and LiOH/heat exchanger combinations were then evaluated to determine which combination resulted in an overall POS that best meets Orbiter requirements. Orbiter design information is given in Table 2-1 for reference.

TABLE 2-1

ORBITER DESIGN INFORMATION

Cryogenic oxygen tank weight penalty:	0.296 kg tank/kg usable oxygen
Cryogenic oxygen tank volume penalty:	0.0044 m^3/kg (123 in.^{3}/lb) usable oxygen
Cryogenic oxygen temperature range:	4.4 to 32.2°C (40 to 90°F)
Cryogenic oxygen pressure range:	1.38 to 7.24 MPa (200 to 1050 psig)
Cabin temperature range	18.3 to 26.7°C (65 to 80°F)
Cabin pressure range:	101 ±1.4 KPa (14.7 ±0.2 psia) nominal 55.2 ±1.4 KPa (8.0 ±0.2 psia) emergency
Number of crewman:	2 to 7

OXYGEN SUPPLY SUBSYSTEM

The oxygen supply subsystem provides storage of sufficient oxygen for one hour of independent operation in the PRS at 34.5 kPa (5.0 psia) or 10 minutes in the Orbiter at 101 kPa (14.7 psia). Additionally, it provides a means of connecting to the Orbiter cryogenic oxygen supply, which is at 6.2 MPa (900 psia) nominal pressure, for use while inside the Orbiter. A pressure reducer is included to provide a constant pressure to the demand regulator and constant flow orifice.

An FMEA (Failure Modes and Effects Analysis) was performed on the baseline oxygen supply subsystem, shown schematically in Figure 2-1. Seven Criticality Class I failures, (ones that would place a crewman in an undue hazardous position) were identified. As a result, a new oxygen supply subsystem was defined that would eliminate the worst of these failures--a failed closed pressure reducer. A schematic of the redesigned subsystem is shown in Figure 2-2.

The number of Criticality Class I failures was thereby reduced to three: (1) oxygen tank leakage, (2) oxygen tank catastrophic failure, and (3) pressure reducer safety relief valve failed open. These three Criticality Class I failures can be precluded for the following reasons:

1. Oxygen tank structural integrity can be verified during a qualification program.

2. Safety relief valve is normally closed preventing (a) contamination from entering and holding the seat open, or (b) binding of the poppet in an open position.

Oxygen Tank Size Selection

A review of POS independent operational requirements showed that oxygen tank storage pressures higher than 6.2 MPa (900 psia) can be used. The maximum amount of oxygen to be stored--one hour of independent operation in the rescue sphere--is only required for those crewmen who do not perform extravehicular activities. Because only one emergency (either contaminated cabin or EVA rescue), need be considered for these crewman, the POS worn by them will not have previously been used. The two crewmen that perform EVA (extravehicular activities) will not use the rescue spheres; they will use their EVA equipment for extravehicular rescue. The POS, therefore, can be precharged on the ground to any desired pressure, the only limitation being that, when charged to 6.2 MPa (900 psia), it must supply sufficient oxygen for 10 minutes of cabin walk-around capability and for purging the POS.

The launch weight and volume penalty for oxygen delivery flow rates were evaluated for cabin inflow rates from 0.23 kg/hr (0.5 lb/hr) to 1.2 kg/hr (2.6 lb/hr) open loop flow. Oxygen flow rates of less than 0.23 kg/hr (0.5 lb/hr) were not considered because:

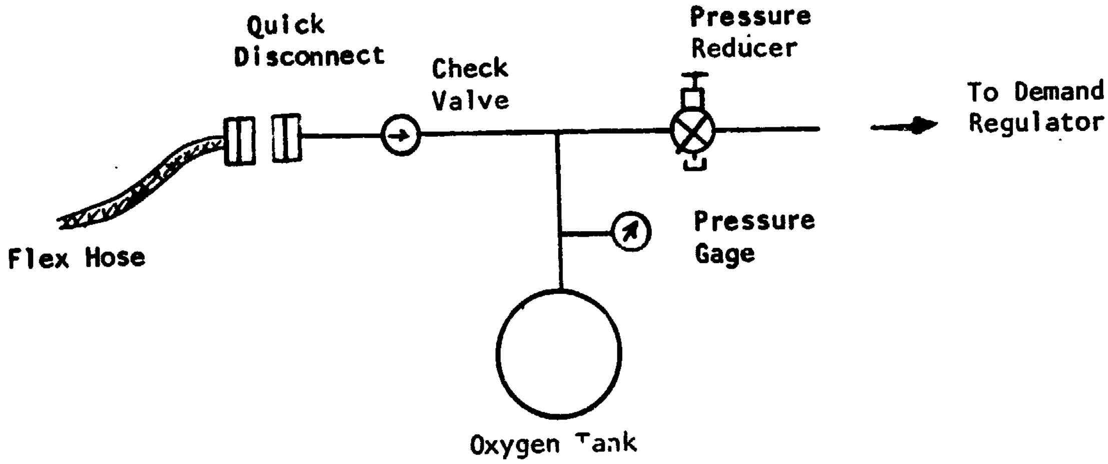

Figure 2-1. Baseline Oxygen Supply Subsystem

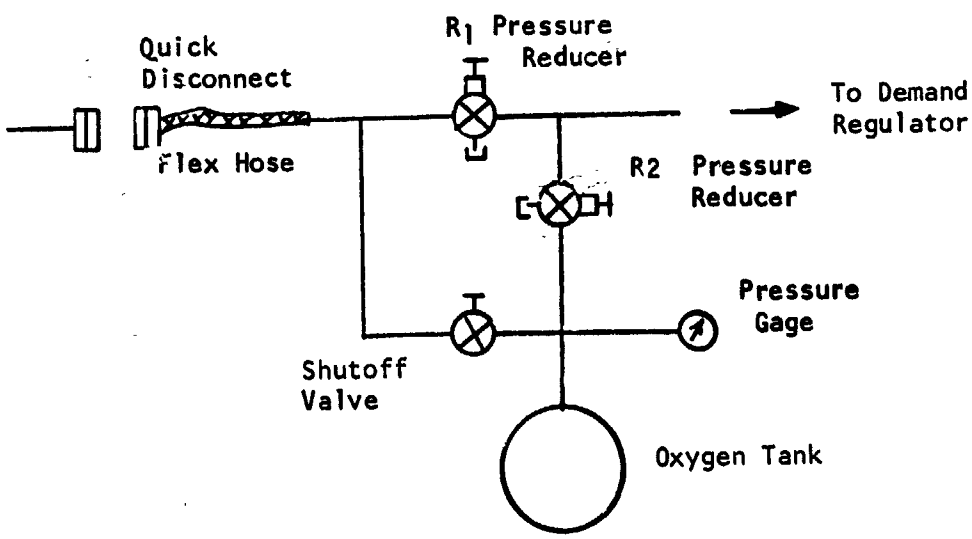

Figure 2-2. Redesigned Oxygen Supply Subsystem

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1. Orifice and regulator tolerances become critical. Reduced oxygen flow caused by contamination or calibration shift could cause pressurization problems in the PRS.

2. The 10 minute denitrogenation time is extended as shown in Figure 2-3. The 0.14 kg/hr (0.3 lb/hr) flow rate fails to meet the 5 volume percent concentration 5.065 KPa (38 mm Hg abs) in 10 minutes.

Oxygen flow rates higher than 0.41 kg/hr (0.9 lb/hr) were rejected early in the study because of the associated high launch weight penalties.

Figure 2-4 shows the oxygen launch weight and volume penalty, exclusive of hardware, for the three POS operational modes: prebreathing prior to EVA, contaminated cabin, and EVA rescue for a 4-man crew. It was assumed that two EVA's had occurred prior to each of the three modes shown. Figure 2-5 shows the same information for a seven man crew. Except for the contaminated cabin operational mode, the oxygen dumped into the cabin from POS internal storage is also used for metabolic consumption and cabin leakage makeup (providing cabin relief valve operating pressure is not reached). Therefore, under some conditions, a net reduction (negative oxygen penalty), in Orbiter cryogenic oxygen use results.

To select the optimum oxygen flow rate to meet Orbiter requirements, the LiOH bed/heat sink characteristics were evaluated and then combined with results of the oxygen flow analysis.

LiOH BED/HEAT EXCHANGER EVALUATION

During POS operation, the moisture- and CO_2-laden exhaled breath is directed through the LiOH bed where carbon dioxide is absorbed and heat is generated. This moisture and heat must be removed from the breathing loop before the gas is directed to the mask. A portion of this heat must be removed in the LiOH bed to maintain a bed temperature conducive to good LiOH utilization. A heat exchanger is placed downstream of the LiOH bed to provide sufficient heat rejection and condensation removal to maintain the mask inlet temperature at 43.3°C (110°F) maximum and dewpoint at 37.8°C (100°F) maximum.

The various heat rejection concepts listed in Table 2-2 were evaluated for use in the heat exchanger and LiOH bed. These concepts are described in the paragraphs that follow.

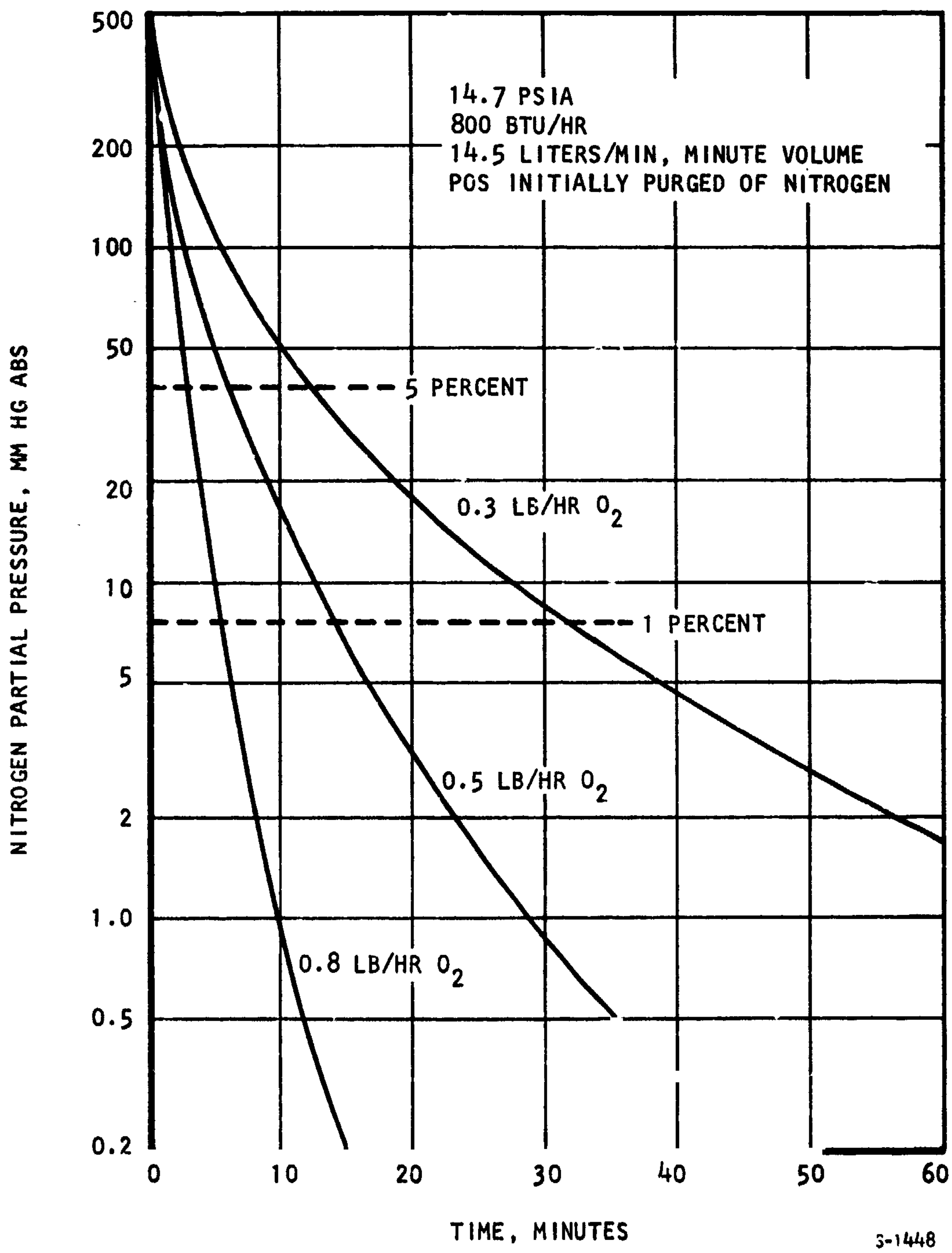

Figure 2-3. Denitrogenation Performance

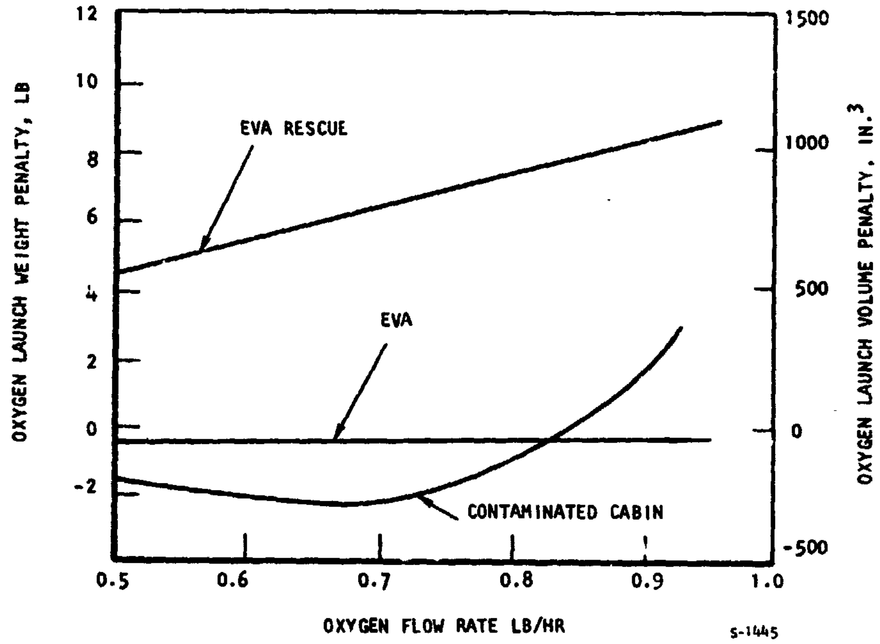

Figure 2-4. Launch Weight and Volume Penalty for Four-Man Crew

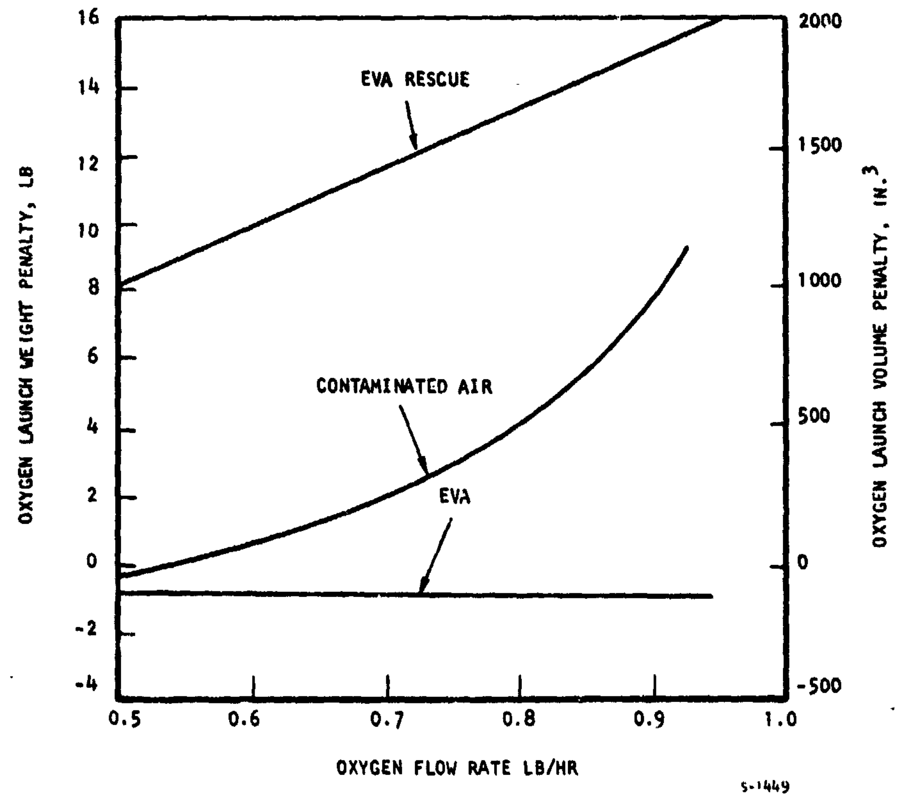

Figure 2-5. Launch Weight and Volume Penalty for Seven-Man Crew

TABLE 2-2

CANDIDATE HEAT SINK CONCEPTS

1.	Thermal Energy Storage (Phase Change Material)
2.	Gas to Gas Heat Exchanger a. Cold Side Flow Provided by Breathing Bag b. Evaporator on Cold Side c. Cold Side Flow Provided by Turbofan

THERMAL ENERGY STORAGE

Thermal energy storage by solid crystalline materials that undergo a structural transformation at temperatures above 26.7°C (80°F) can be used as the heat sink for the POS. These materials will remain solid when stored in the Orbiter environment. As the POS is used, the material temperature is increased to its melting point, absorbing the amount of heat equivalent to it's heat of fusion. These materials can be reconstituted by reducing their temperature to less than the melting temperature. An investigation showed that dibasic sodium phosphate dodecahydrate was a good candidate phase change material because:

1. It is nontoxic.

2. It is a nonorganic salt and is therefore not flammable.

3. It's melting point is compatible with POS operation and Orbiter storage.

It's properties are:

Melting Point: 32.2°C (90°F)

Heat of Fusion: 240 KJ/kg (103 Btu/lb)

Figure 2-6 shows a schematic using a phase change heat sink for thermal energy storage.

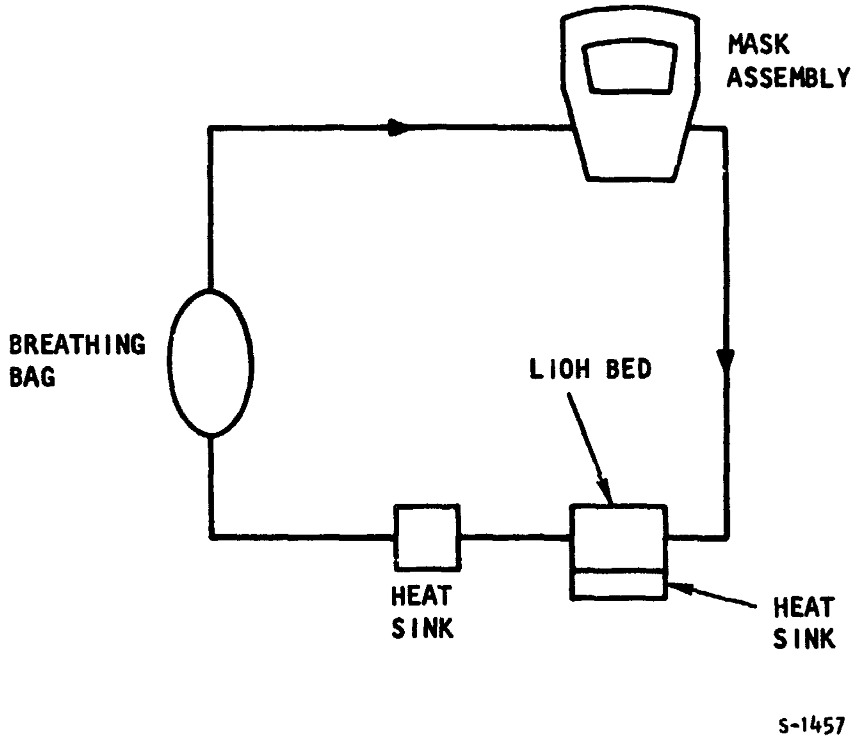

Figure 2-6. Phase Change Heat Sink Schematic

GAS TO GAS HEAT EXCHANGER

A gas to gas heat exchanger can be used to provide the cooling required for both the heat sink and the LiOH bed. The cold-side gas is cabin air or PRS air. Two methods of providing cold-side gas flow were investigated: (1) breathing bag induced flow and (2) turbofan induced flow.

1. Breathing Bag Induced Flow

The breathing bag can be made to pump cabin air by surrounding it with a rigid enclosure containing flow directional check valves. This concept is shown schematically in Figure 2-7. As the breathing bag expands and contracts with the breathing cycle, cabin air will be pumped through the heat exchanger. The volume of air pumped will match the user's minute volume. The heat capacity of this concept can be increased by providing water-holding wicks to the cold side of the heat exchanger. These wicks would be precharged with water prior to use. As the system is used, this water is evaporated into the cold side air flow, providing additional cooling.

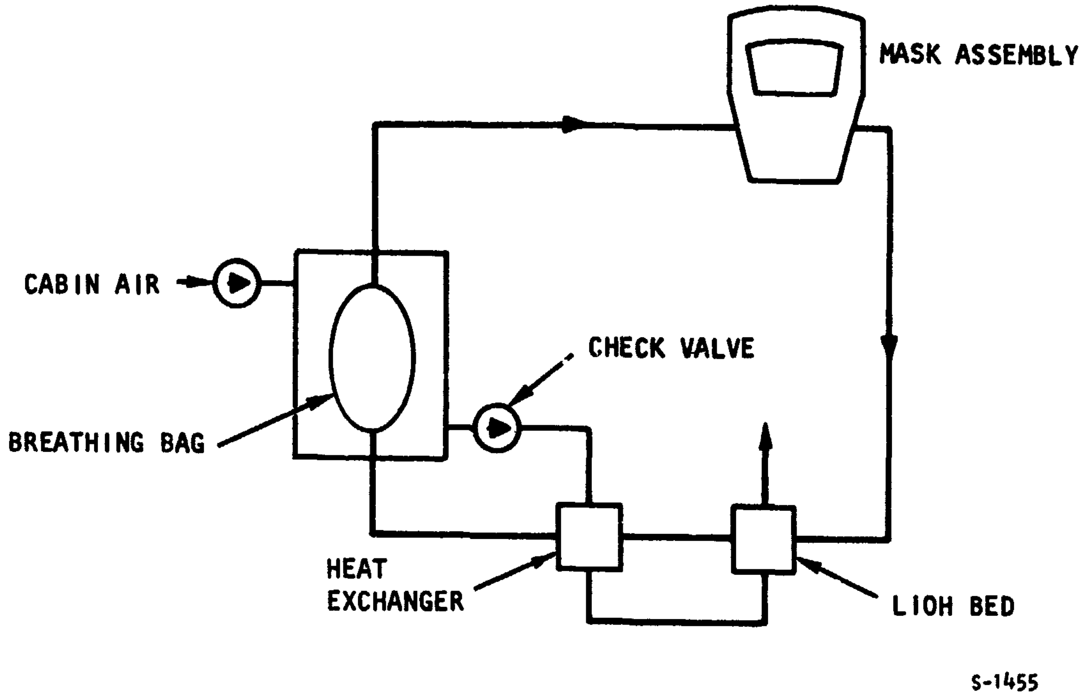

Figure 2-7. Breathing Bag Induced Cooling Flow Schematic

2. <u>Turbofan-Induced Flow</u>

Figure 2-8 shows a schematic with a turbofan used to provide the cold side gas flow. In this concept, the energy that is normally lost when the delivery gas is throttled through an orifice is directed to a turbine. The turbine drives a fan that forces cabin air through the heat exchanger. Again, the cooling capacity of this concept can be increased by providing water holding wicks to the cold side of the heat exchanger.

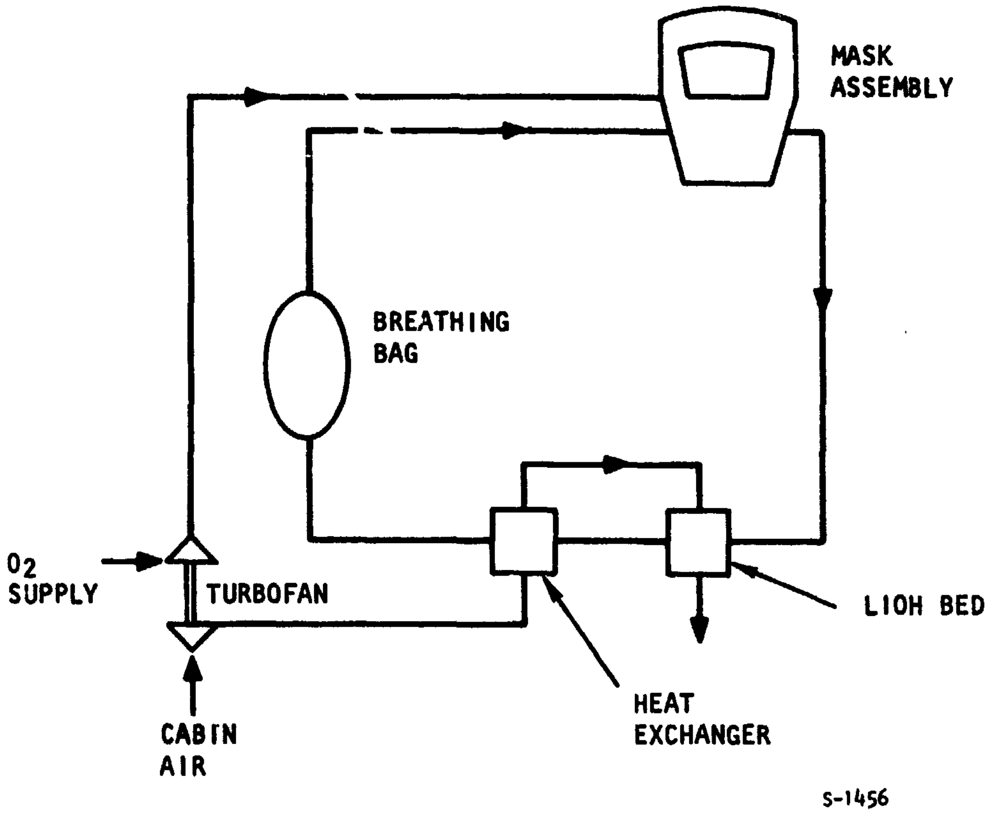

Figure 2-8. Turbofan Induced Cooling Flow Schematic

Various LiOH/heat exchanger combinations will provide the required mask inlet conditions. The analytical method used to size the units was to determine the loop parameters using the system performance computer program with the LiOH bed subroutine to determine LiOH performance with various heat sink, LiOH bed, and oxygen flow combinations.

Total heat rejection varies with the oxygen flow rate into the breathing loop. Advantages and disadvantages of each concept is shown in Table 2-3.

TABLE 2-3

COMPARISON OF HEAT REJECTION CONCEPTS

	Advantages	Disadvantages
Phase Change Material	1. Static device. Heat capacity and melting temperature are well known.	1. No acceptable method of reconstituting in Orbiter; therefore, concept limited to replacement, which increases weight and volume penalties for multiple POS usage. 2. Heat rejection rate must be carefully controlled to prevent heat rejection capacity from being exceeded before end of mission.
Gas-to-Gas Heat Exchanger Breathing Bag Induced Flow (Without Evaporation)	1. Simple, low cost approach. 2. Lightweight concept. Is not time dependent 3. No recharge of expendables required.	1. Limited heat rejection capacity
Breathing Bag Induced Flow (With Evaporation)	1. Increased heat rejection capacity.	1. Requires servicing of wicks with water. 2. High development risk. Unit would have to be built and tested to predict performance. 3. Heavier and more costly than heat exchanger without evaporation.
Turbofan Induced Flow	1. High heat rejection. 2. Lightweight concept. It not time dependent. 3. Low risk.	1. Hardware cost more than phase change material and breathing bag induced flow.

The heat rejection needed to meet mask inlet requirements as a function of oxygen inflow is shown in Figure 2-9.

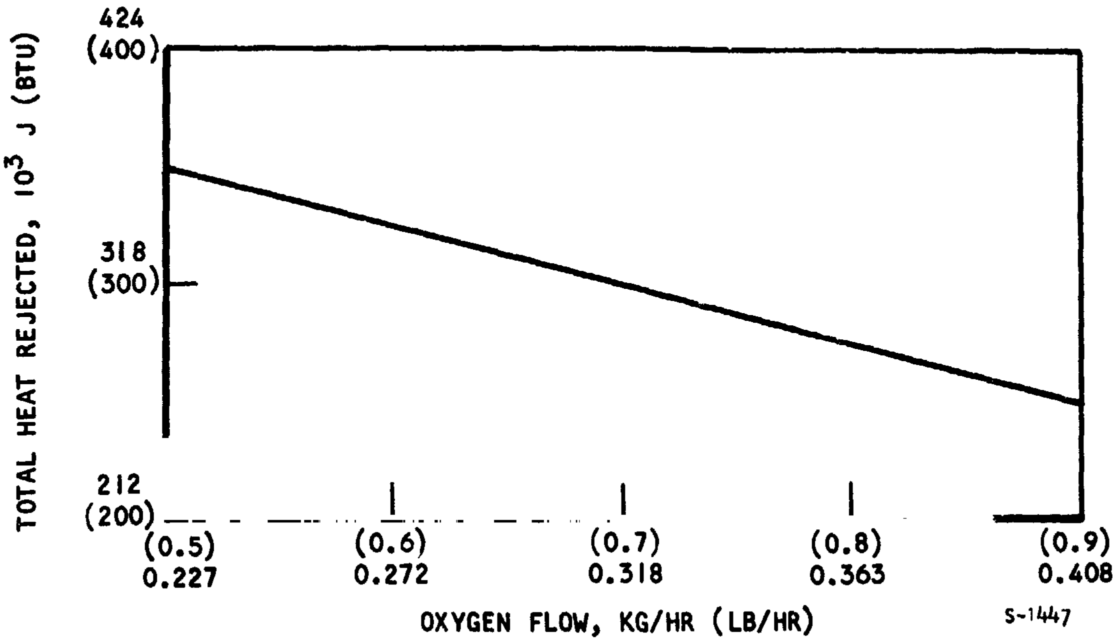

Figure 2-9. Total Heat Rejection in Oxygen Flow

The portion of heat that must be rejected in the LiOH bed varies with the quant y of LiOH in the bed. Figure 2-10 shows how heat rejection in the LiOH bed varies with the quantity of LiOH for two oxygen inflow rates.

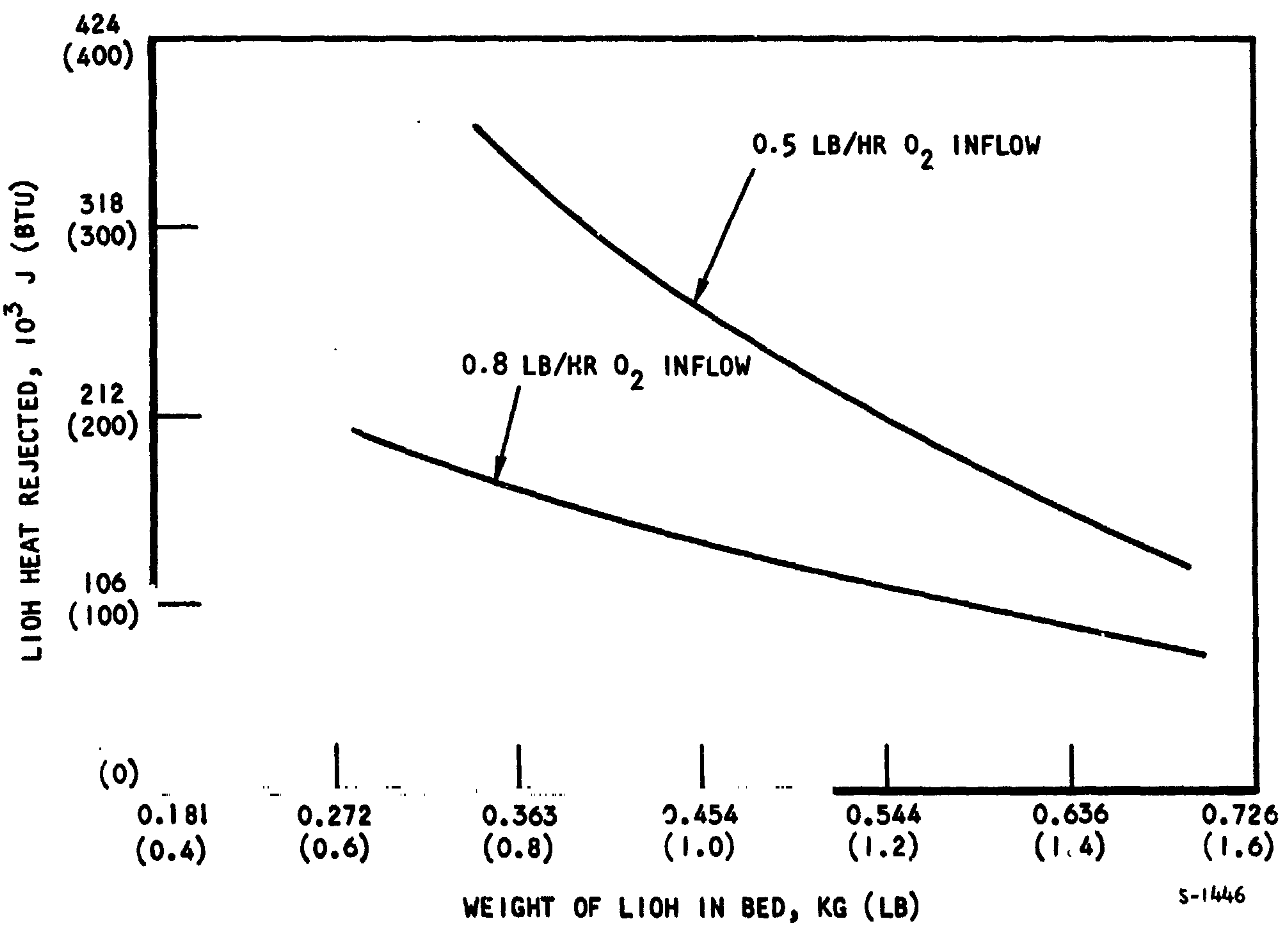

Figure 2-10. Heat Rejection in LiOH Bed

After a preliminary evaluation, some of the concepts were rejected from further consideration for the reasons stated on Table 2-4.

TABLE 2-4

EVALUATION OF HEAT SINK CONCEPTS

Concept	Use as LiOH Bed Heat Sink	Use as Heat Exchanger Heat Sink
Phase change material	Selected for further evaluation with breathing bag induced flow for heat exchanger heat sink.	Excessive weight and volume penalty for multiple POS usage.
Breathing Bag Induced Flow (Without Evaporation)	Has insufficient heat rejection capacity	Selected for further evaluation.
Breathing Bag Induced Flow (With Evaporation)	Weight and volume and cost penalties and development risks are higher than for phase change material.	Water servicing required. Has high development risk.
Turbofan Induced Flow (Without Evaporation)	Selected for further evaluation.	Selected for further evaluation.
Turbofan Induced Flow (With Evaporation)	Evaporator not required with turbofan--sufficient heat rejection provided by sensible cooling.	Evaporator not required with turbofan--sufficient heat rejection provided by sensible cooling.

The concepts selected for further consideration as LiOH bed and heat exchanger heat sinks were then evaluated to determine the optimum combination of LiOH weight, heat rejection, and oxygen flow. The two best heat sink combinations are compared in Table 2-1 with respect to launch weight and volume penalties.

TABLE 2-5

LAUNCH WEIGHT AND VOLUME PENALTIES
FOR TWO BEST HEAT SINK CONCEPTS

Penalty*	Fusable Salt LiOH Bed Cooling Breathing Bag Heat Exchanger	Turbofan-Cooled LiOH Bed and Heat Exchanger
Oxygen Flow	0.36 Kg/hr (0.8 lb/hr)	0.32 kg/hr (0.7 lb/hr)
LiOH Weight	0.32 kg (0.7 lb)	0.36 kg (0.8 lb)
<u>4 Man Crew Penalties</u>		
Weight Penalty	14.06 kg (31.0 lb)	11.88 kg (.2 lb)
Volumn Penalty	0.0148 m^3 (900 $in.^3$)	0.0164 m^3 (1000 $in.^3$)
<u>7 Man Crew Penalties</u>		
Weight Penalty	17.96 kg (39.6 lb)	17.06 kg (37.6 lb)
Oxygen Penalty (EVA Rescue)	6.03 kg (13.3 lb)	5.31 kg (11.7 lb)
Total Weight Penalty	24 kg (52.9 lb)	22.4 kg (49.3 lb)
Volume Penalty	0.019 m^3 (1200 $in.^3$)	0.0213 m^3 (1300 $in.^3$)

*NOTE: Weight and volume penalties shown are for expendables only. Weight and volume for the remainder of the system, such as valves, lines, and frame, are fixed and are identical for both concepts. The evaluation therefore can be made without considering these items.

CONCEPT SELECTION

Of the alternates considered for further evaluation, the turbofan concept was selected as the method of providing cooling for the LiOH bed and heat exchanger for the following reasons:

1. It has a smaller launch weight penalty. The launch volume penalty is comparable.

2. It has the heat rejection capacity to provide a large design margin for meeting mask inlet conditions easily. System development should therefore pose no risk. The alternate concept (breathing bag induced flow with phase change LiOH bed heat sink) is, by comparison, marginally acceptable and would result in a high development risk.

3. There is no reliability advantage for either concept.

4. It increases mission flexibility. The turbofan concept is insensitive to metabolic rate and duration variations.

5. Total costs for development, fabrication, and maintenance are less for the turbofan concept.

6. The turbofan concept is a low risk approach, because the design is based on the miniaturization techniques AiResearch has used in cryogenic turboexpanders and in other applications described below.

Components of a miniature cryogenic turbogenerator utilizing foil gas bearing technology are shown in Figure 2-11. The turbine wheel shown on the far left is 0.013 m (0.5 in.) in diameter.

The rotor of a miniature heart turbopump utilizing double conical foil gas bearings is shown in Figure 2-12. The pump impeller is only 0.003 m (0.125 in.) in diameter, and the turbine is 0.013 m (0.5 in.) in diameter, which is near in size to the selected POS turbofan. This rotor and its bearing are currently operating unattended in ambient air in an endurance test setup. As of December 9, 1975, the rotor had completed 12,908 hours of virtually continuous operation at 200,000 rpm, with no servicing whatsoever.

A computer analysis of the selected concept was performed to verify POS operation under all conditions and to determine component requirements. A detailed description of the POS transient operation computer program used for this analysis follows.

Figure 2-11. Components of Miniature Turbogenerator

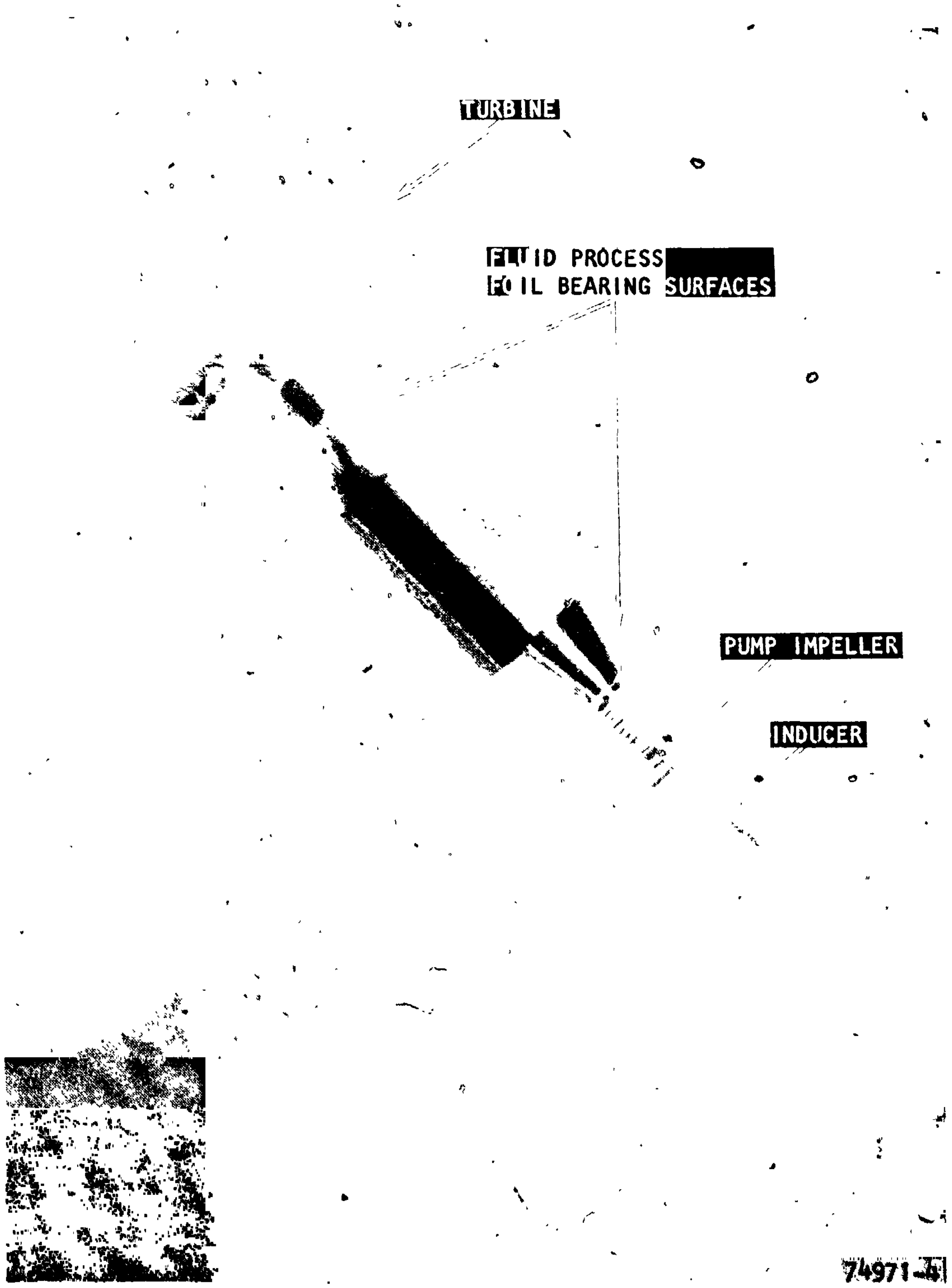

Figure 2-12. Turbopump Rotor for Artificial Heart

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The POS transient performance prediction program, S0970, was written in Fortran V for the Univac 1108 digital computer. A finite-difference technique was used to simulate system performance. This same technique was used in the transient performance prediction program, S0110, for LiOH. This program was coverted into a subroutine for the POS program. The computer program has been revised to conform with the final POS configuration shown in Figure 1-1.

The body metabolic processes are supplied to the computer program in the form of equations or tables to represent the oxygen consumption rate, the carbon dioxide production rate, the volumetric rate of change in the lungs as a function of time, and the nitrogen release rate shown in Figure 2-13. The rate of water diffusion into the lungs was assumed to be adequate to maintain a saturated condition of 6.267 kPa (47 mm Hg) partial pressure, from a total capacity of 5.97 liters and a residual lung volume of 1.19 liters. A different lung volumetric rate-of-change curve (Figure 2-14) is given for each metabolic rate. The area under each curve corresponds to the lung tidal volume, either for the inspiration and expiration portions of the curves.

These breathing curves form the basis of the POS analysis because this system is lung-powered. Should breathing characteristics of the crewmen deviate greatly from this normalized curve, their breathing curve data could be fed into the computer program to evaluate system performance.

The breathing curves are divided into equal time increments, up to a maximum of 50 each for the inhalation and exhalation portions of the curve, to determine the lung volumetric displacement for each time increment. The area under the lung volumetric rate-of-change curve, multiplied by the time increment, corresponds to the incremental lung volume from the previous time increment.

Current runs use 5 increments for the inhalation portion of the curves and 7 increments for the exhalation portion of the curves. This results in reasonable accuracy for calculating transient performance variation.

The turbine and fan of the turbofan assembly were assumed to have fixed efficiencies of 20 percent at the flow rates and pressure ratios specified. The condenser was assumed to have a constant hot-side effectiveness, which was determined from system test data. The LiOH bed heat sink was approximated by varying the film conductance to the heat sink, which was part of the original S0110 computer program.

The program has been written to accommodate five step changes in any combination of metabolic beat rates, or oxygen feed rates, for the four characteristic curves shown in Figure 2-14. Because these curves start on the inhalation mode the computer program also must start on the inhalation mode; it ends on the exhalation mode to the nearest integer number of breaths for the time period desired.

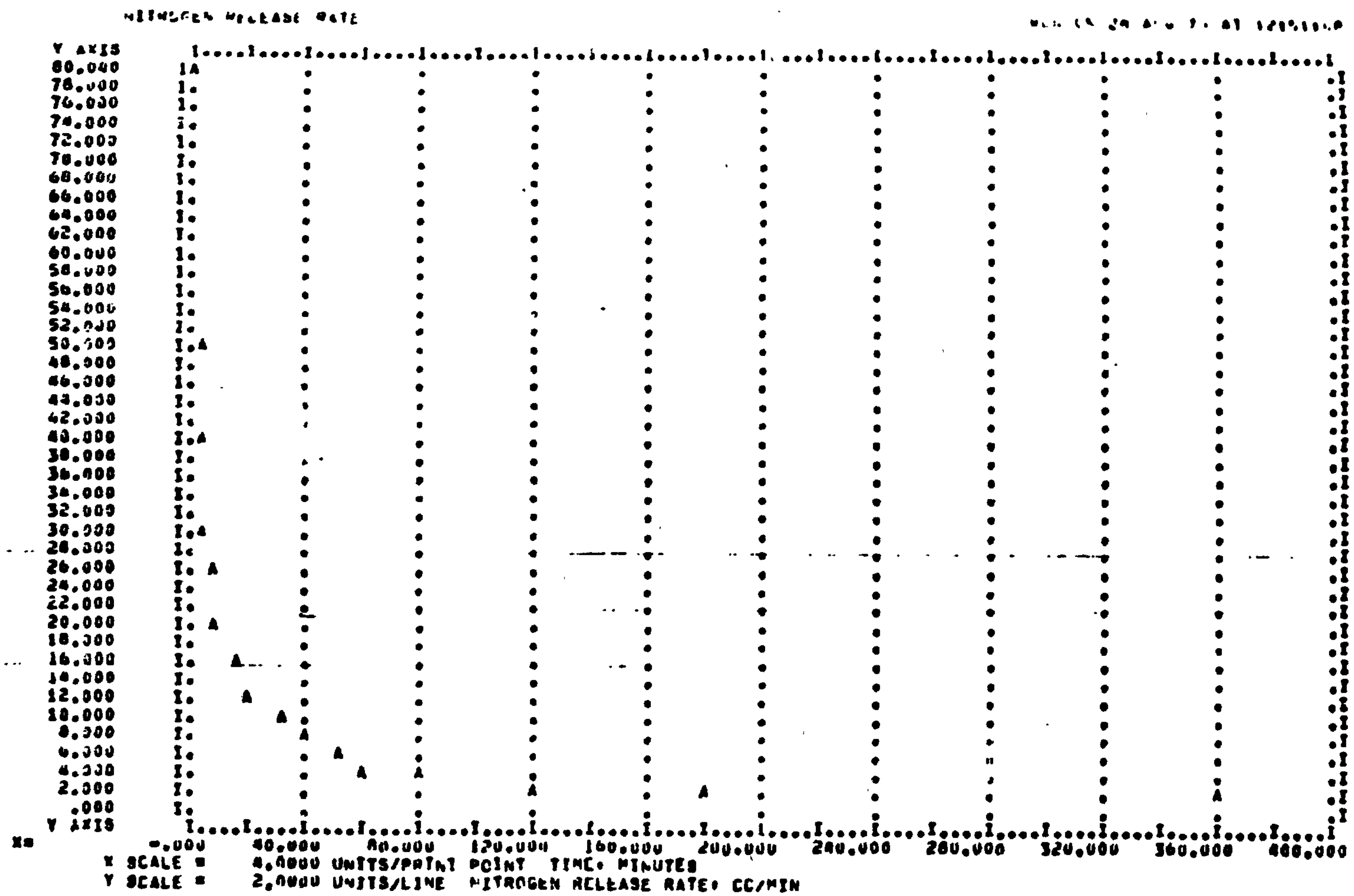

Figure 2-13. Nitrogen Release Rate

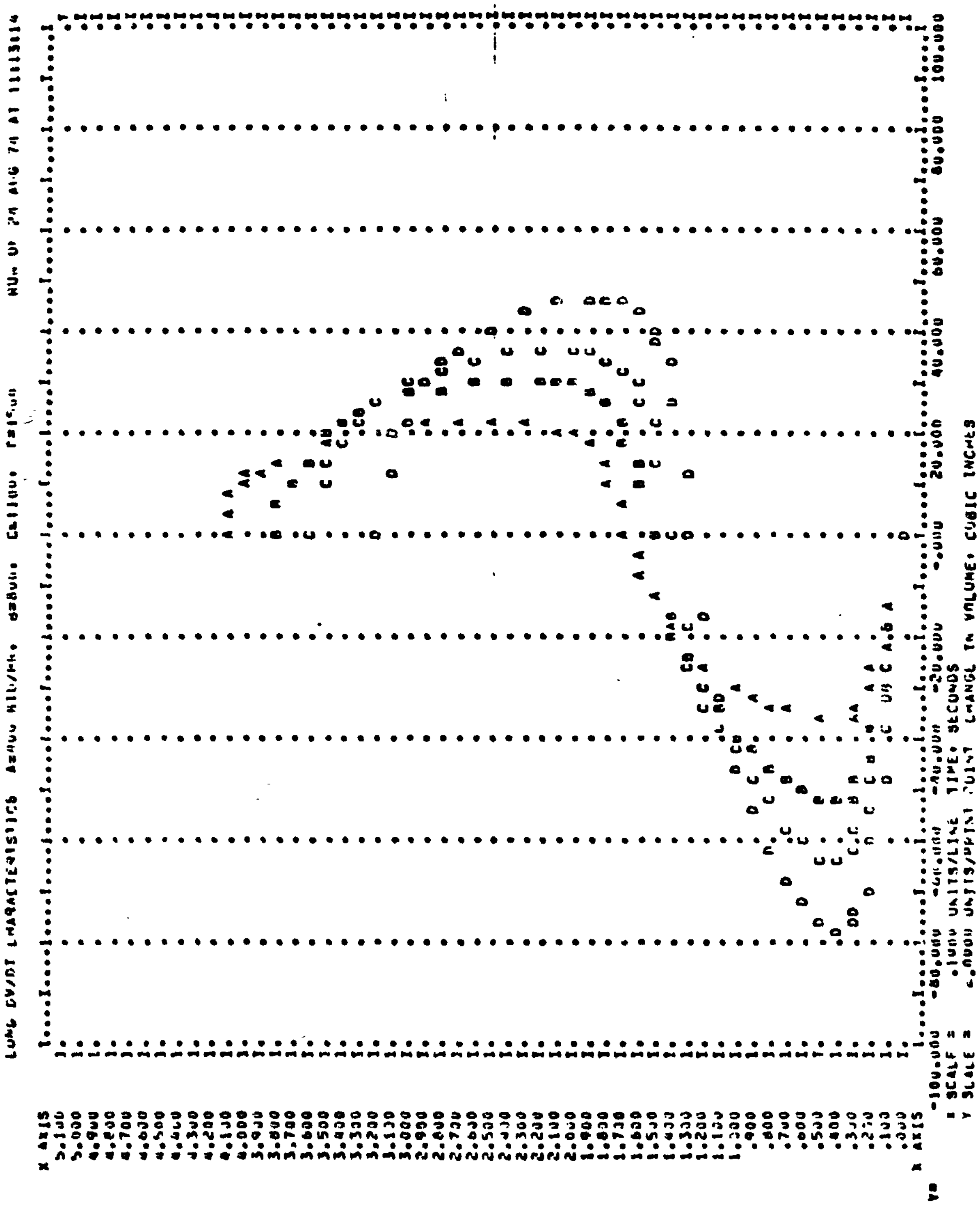

Figure 2-14. Lung Volume Rate-of-Change

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The program input consisted of available data on specific heat, viscosity, and thermal conductivity for oxygen, nitrogen, carbon dioxide, water vapor, and air, plus the data shown in Figures 2-13 and 2-14. In addition, the physical characteristics of the system, such as equivalent duct internal diameter, wall thickness, length, thermal conductivity, ambient and sink temperatures, and outside air velocities were included for each component so that external heat transfer calculations could be made. The bag maximum volume and pressure-volume characteristic, as well as the relief valve crack and flow characteristics, also are program inputs.

For the system start, the initial bag volume, the initial starting pressure for the system, and the initial gas composition were inputed. Computer runs were started with the POS and mask having 100 percent oxygen and lung gas partial pressures as follows:

1. 15.47 kPa (116 mm Hg) of oxygen
2. 758.7 kPa (569 mm Hg) of nitrogen
3. 3.867 kPa (29 mm Hg) of carbon dioxide
4. 6.267 kPa (47 mm Hg) of water vapor

NAMELIST input data was used to specify the initial starting conditions and physical parameters for transient LiOH bed calculations. Since three pages of computer printout are generated for each complete breathing cycle, the NPRINT parameter in the NAMELIST data allows the program user to print as much material as desired. Every 16th cycle is approximately one minute or every 32nd cycle. Approximately two minutes has been found to be a reasonable time for following system performance.

Figures 2-15 through 2-17 show typical computer program output data at the end of approximately 20 minutes of system time. The integers printed on the extreme right-hand side of Figures 2-15 and 2-16 show the relationship of the 12 increment breathing curves with sequence numbers 1 through 6 showing the inhalation phase and 6 through 13 showing the exhalation phase. Vertical columns below the arrowheads, headed by the following: LUNG, MASK, BAG, LiOH, HEAT SINK, and DUMP GAS, are printed for the gas partial pressure, the total pressure, the component pressure differential to ambient (or component pressure drop), the inlet, dewpoint, and exit temperatures, the flow increment and flow rate, the accumulated condensed water, lung and bag volumes, and the accumulated total and latent rejected. Figure 2-17 shows the transient status of the LiOH bed.

```
AIRESEARCH PORTABLE OXYGEN LAB TEST CORRELATION STUDY

         RUN ON 18 DEC 75 AT 11:36:30                                                  PAGE =  56

METABOLIC RATE= 800. BTU/HR        MINUTE VOLUME=16.0 LITERS/MIN        OXYGEN FEED=.700 LB/HR       HEAT EX EFF=.730
TURBINE EFF.  = .200               FAN AIR FLOW =15.0 LB/HR             FAN EFF.   = .200

TIME             <<<     LUNG         >>> <<<      MASK        >>> <<<       BAG         >>> <<<    LIOH      >>> < HEAT SINK > << DUMP GAS >>
MIN. GAS          O2      N2  CO2  H2O     O2      N2  CO2  H2O     O2      N2  CO2  H2O CO2I CO2O H2OI H2OO                  DELTA       SUM

19.2 PP, MM HGA 676.1     .8 38.2 48.7 709.2     .6 25.7 28.4 745.8     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 763.9              .86   761.8             .86   761.1           1.00  761.1           .00           .19
     T IN/OP/OUT  98.6            98.6    89.1   89.1   89.1      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .9879-02/ 1.5339     .1914-03/ 2.3039        .6378-03/ .0000          .5157-03/-2.5762 .489-03/ -2.58   .1914-03   .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    3.580                                         2.000                                         18.62/12.21                 1

19.2 PP, MM HGA 674.8     .8 37.4 48.0 748.1     .6  1.7 10.6 745.8     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 761.0              .47   761.0             .47   761.0            .47  761.0           .00           .19
     T IN/OP/OUT  98.6            98.6    75.0   75.0   75.0      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .1027-01/ 4.5831     .3794-03/ 4.5525        .3169-03/ 3.8525         .5157-03/-2.5762 .489-03/ -2.58   .0000      .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    3.718                                         1.890                                         18.62/12.21                 2

19.3 PP, MM HGA 676.4     .8 35.5 48.1 746.8     .7  1.9 11.6 745.7     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 760.9              .41   760.9             .41   760.9            .41  760.9           .00           .19
     T IN/OP/OUT  98.6            98.6    75.0   75.0   75.0      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .1104-01/ 9.0598     .7474-03/ 8.9692       -.3722-03/ 8.2692         .5157-03/-2.5762 .489-03/ -2.58   .0000      .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    3.993                                         1.655                                         18.62/12.21                 3

19.3 PP, MM HGA 677.7     .8 34.1 48.2 746.8     .7  1.8 11.5 745.6     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 760.8              .36   760.8             .36   760.8            .36  760.8           .00           .19
     T IN/OP/OUT  98.6            98.6    75.0   75.0   75.0      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .1175-01/ 8.3049     .6846-03/ 8.2153       -.9985-03/ 7.5153         .5157-03/-2.5762 .489-03/ -2.58   .0000      .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    4.245                                         1.441                                         18.62/12.21                 4

19.3 PP, MM HGA 678.5     .8 33.3 48.2 747.1     .6  1.8 11.2 745.5     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 760.7              .32   760.7             .32   760.7            .32  760.7           .00           .19
     T IN/OP/OUT  98.6            98.6    75.0   75.0   75.0      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .1229-01/ 6.4277     .5293-03/ 6.3517       -.1465-02/ 5.6517         .5157-03/-2.5762 .489-03/ -2.58   .0000      .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    4.040                                         1.280                                         18.62/12.21                 5

19.3 PP, MM HGA 678.4     .8 33.3 48.3 749.6     .5  1.5  9.1 745.5     .7  2.0 12.5   .0   .0   .0   .0
     PT,MM DP,IN 760.7              .31   760.7             .31   760.7            .31  760.7           .00           .19
     T IN/OP/OUT  98.6            98.6    76.4   76.4   76.4      66.0   66.0   66.0   96.6           97.4    97.4  82.4
     W/HR LB/PPH   .1252-01/ 2.6132     .2137-03/ 2.5646       -.1625-02/ 1.8646         .5157-03/-2.5762 .489-03/ -2.58   .0000      .20
     COND H2O LB                               .1626-02                .5244-03                                 .8490-02
     VOL.L Q.BTU    4.520                                         1.227                                         18.62/12.21                 6
```

Figure 2-15. POS Inhalation Operation (Conditions 1 - 6)

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                    AIRESEARCH PORTABLE OXYGEN LAB TEST CORRELATION STUDY

            RUN ON 18 DEC 75 AT 11136131                                      PAGE =  57

     METABOLIC RATE= 800. BTU/HR      MINUTE VOLUME=16.0 LITERS/MIN      OXYGEN FEED=.700 LB/HR       HEAT EX EFF=.730
     TURBINE EFF.  = .200             FAN AIR FLOW =15.0 LB/HR           FAN EFF.   = .200

TIME            <<<     LUNG      >>> <<<      MASK       >>> <<<       BAG       >>> <<<     LTCH      >>> < HEAT SINK > << DUMP GAS >>
MIN. GAS            O2     N2  CO2  H2O     O2     N2  CO2  H2O     O2     N2  CO2  H2O CC2I CO2O H2CI H2OO              DELTA      SUM

19.3 PP, MM HGA 678.6      .8 34.0 48.3 700.5     .6 26.4 34.3 748.5     .7  2.4  9.0 26.4   .0 31.9 47.4
     PT,MM DP,IN 761.7             .86   761.7            .86   760.8            .35   760.7          .15          .06
     T IN/DP/OUT  98.6            98.6   98.6   87.5   87.5    82.4   62.5   62.5   93.2           97.2   97.2  82.4
     W/HR LB/PPH   .1230-01/ 2.3518     .2791-03/ 3.0518      -.1345-02/ 3.0518       .2791-03/ 3.0846 .269-03/  3.00  .0000     .20
     COND H2O LB                              .1627-02                 .5244-03                                .8494-02
     VOL.L Q.BTU     4.441                                           1.323                                   18.63/12.22             7

19.2 PP, MM HGA 679.8      .8 34.7 48.5 691.8     .7 30.7 40.7 759.7     .7  3.9 -3.5 30.7   .0 37.3 47.7
     PT,MM DP,IN 763.8            1.95   763.8           1.95   760.8            .37   761.3          .28          .20
     T IN/DP/OUT  98.6            98.6   98.6   92.8   92.8    82.4   50.6   50.6   96.3           97.4   97.4  82.4
     W/HR LB/PPH   .1184-01/ 5.0718     .5282-03/ 5.7714      -.8390-03/ 5.5206       .5282-03/ 5.7625 .502-03/  5.60  .0000     .20
     COND H2O LB                              .1628-02                 .5244-03                                .8501-02
     VOL.L Q.BTU     4.272                                           1.494                                   18.64/12.22             8

19.3 PP, MM HGA 679.7      .8 35.5 48.5 691.0     .7 31.6 41.1 814.2     .7 11.4-65.4 31.6   .0 37.8 47.9
     PT,MM DP,IN 764.5            2.31   764.5           2.31   760.9            .42   761.8          .30          .22
     T IN/DP/OUT  98.6            98.6   98.6   93.1   93.1    82.5   -6.0   -6.0   96.8           97.5   97.5  82.5
     W/HR LB/PPH   .1135-01/ 5.4341     .5615-03/ 6.1341      -.3024-03/ 5.8540       .5615-03/ 6.1250 .533-03/  5.94  .0000     .20
     COND H2O LB                              .1629-02                 .5244-03                                .8509-02
     VOL.L Q.BTU     4.091                                           1.670                                   18.65/12.23             9

19.3 PP, MM HGA 678.6      .8 36.2 48.5 690.3     .7 32.1 41.0 631.7     .8-13.5142.0 32.1   .0 37.6 47.8
     PT,MM DP,IN 764.1            2.12   764.1           2.12   761.0            .45   761.5          .30          .21
     T IN/DP/OUT  98.6            98.6   98.6   93.0   93.0    82.4  202.8  202.8   96.8           97.5   97.5  82.4
     W/HR LB/PPH   .1086-01/ 5.3038     .5495-03/ 6.0038       .2224-03/ 5.7252       .5495-03/ 5.9947 .521-03/  5.81  .0000     .20
     COND H2O LB                              .1630-02                 .5244-03                                .8517-02
     VOL.L Q.BTU     3.915                                           1.818                                   18.66/12.24            10

19.3 PP, MM HGA 678.7      .8 37.0 48.6 691.4     .7 32.6 40.5 691.7     .8 -5.4 74.0 32.6   .0 37.1 47.8
     PT,MM DP,IN 763.5            1.80   763.5           1.80   762.0           1.00   761.1          .28          .19
     T IN/DP/OUT  98.6            98.6   98.6   92.7   92.7    82.4  128.0  128.0   96.6           97.5   97.5  82.4
     W/HR LB/PPH   .1041-01/ 4.9378     .5159-03/ 5.6378       .5876-03/ 3.9842       .5159-03/ 4.2395 .489-03/  4.06  .1113-03  .20
     COND H2O LB                              .1630-02                 .5244-03                                .8524-02
     VOL.L Q.BTU     3.751                                           2.000                                   18.68/12.25            11

19.3 PP, MM HGA 677.4      .8 37.8 48.5 693.4     .7 32.0 38.4 691.7     .8 -5.4 74.0 32.6   .0 37.1 47.8
     PT,MM DP,IN 762.8            1.44   762.8           1.44   761.1           1.00   761.1          .28          .19
     T IN/DP/OUT  98.6            98.6   98.6   91.0   91.0    82.4  128.0  128.0   96.6           97.5   97.5  82.4
     W/HR LB/PPH   .1007-01/ 3.7473     .4069-03/ 4.4473       .5876-03/  .0000       .5159-03/ 3.2335 .489-03/  3.23  .4069-03  .20
     COND H2O LB                              .1631-02                 .5244-03                                .8524-02
     VOL.L Q.BTU     3.626                                           2.000                                   18.69/12.25            12

19.3 PP, MM HGA 676.0      .8 38.6 48.5 709.0     .5 25.9 28.4 691.7     .8 -5.4 74.0 32.6   .0 37.1 47.8
     PT,MM DP,IN 741.8             .86   761.8            .86   761.1           1.00   761.1          .28          .19
     T IN/DP/OUT  98.6            98.6   98.6   81.7   81.7    82.4  128.0  128.0   96.6           97.5   97.5  82.4
     W/HR LB/PPH   .8947-02/ 1.3949     .1914-03/ 2.0949       .5876-03/  .0000       .5159-03/-2.3435 .489-03/ -2.34  .1914-03  .20
     COND H2O LB                              .1632-02                 .5244-03                                .8524-02
     VOL.L Q.BTU     3.560                                           2.000                                   18.70/12.26            13
```

Figure 2-16. POS Exhalation Operation (Conditions 7 - 13)

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AIRESEARCH PORTABLE OXYGEN LAB TEST CORRELATION STUDY   PAGE 58

APOLLO GRADE LIOH   DENSITY=31.4 LB/CU FT

TOTAL VOLUME OF LIOH BED, CU FT	=	.0223
TOTAL WEIGHT OF LIOH BED, LBS	=	.700
TOTAL VOLUME OF S.G. BED, CU FT	=	.0000
TOTAL WEIGHT OF S.G. BED, LBS	=	.000
INLET CO2 PARTIAL PRESSURE, MM HG	=	32.621
INLET H2O PARTIAL PRESSURE, MM HG	=	37.127
INLET GAS TEMPERATURE, DEG F	=	96.61
TOTAL GAS FLOW RATE, LB/HR	=	5.629
TOTAL GAS PRESSURE, MM HG	=	762.72

SYSTEM TIME= .32173 HR   19.304 MIN   BED TIME= .13997 HR   8.398 MIN   TIME INCREMENT= .00009 HR

NODE NO	PCO2 MM HG ABS	PH2O MM HG ABS	GAS TEMP DEG F	LIOH TEMP DEG F	CO2 LOADING LB/LB	H2O LOADING LB/LB	COOLING RATE BTU/HR	COOLING LOAD BTU	SINK TEMP DEG F
1	.0008	79.7463	97.5022	96.9257	.0031	.0040	20.38	.00	83.68
2	.0052	68.7617	115.0736	114.5753	.0033	.0020	11.14	.00	83.68
3	.0328	68.7214	130.2639	129.7707	.0041	.0014	16.63	.00	83.68
4	.2136	68.5490	145.3001	144.8193	.0092	.0010	22.06	.00	83.68
5	1.3581	64.5490	159.9551	159.6459	.0376	.0018	27.40	.00	83.68
6	7.0074	59.3175	169.3792	169.4864	.1262	.0046	30.95	.00	83.68
7	19.2226	48.3303	166.1122	168.3922	.2533	.0091	30.56	.00	83.68
INLET	32.6206	37.1269	96.6146						

AVG CO2 LOADING IN LIOH BED = .6240-01 LB/LB
TIME AVG CO2 ABSORPTION RATE= .1290 LB/HR
INST CO2 REMOVAL RATE = .3328 LB/HR
AVG LIOH BED EFFICIENCY = .0680
ACCUMULATED COOLING LOAD = 23.6792 BTU

AVG H2O LOADING IN LIOH BED = .3401-02 LB/LB
TIME AVG H2O ABSORPTION RATE= .1057-01 LB/HR

Figure 2-17. LiOH Bed Transit Status

SECTION 3

DESIGN AND CONSTRUCTION

DESCRIPTION

All POS components are mounted to an aluminum alloy, load-carrying, flat backpan and to a lower baseplate, which is attached to the backpan. Because the POS package is only 0.23 m (9 in.) wide, it is not necessary to curve the backpan to fit snugly to the crewman's chest. The backpan/base plate assembly is shown in Figures 3-1 and 3-2. The LiOH bed/heat exchanger assembly, shown in Figure 3-3, is attached to the baseplate with two over-center latches. Gas sealing of the ports is accomplished by elastomeric gaskets, located on the upper plenum of the LiOH bed/heat exchanger assembly, which bears against the sealing surfaces located on the baseplate.

Extensive use was made of manifolding to: (1) reduce the number of tubes required, (2) simplify sealing requirements, (3) reduce package volume, and (4) reduce assembly time. Figure 3-4 shows the separate oxygen supply manifolds with valves installed, Figure 3-5 shows the oxygen supply manifolds assembled together, and Figure 3-6 shows the oxygen tank assembled to the manifold assembly. These items, with the breathing bag and miscellaneous tubing, are shown assembled together in Figure 3-7. A protective cover encloses this assembly. Figure 3-8 shows the completed POS assembly with the flexible hose and mask assembly stowed within the POS.

The POS is worn on the chest of the crewman. As shown in Figure 3-9, it is attached by one strap that loops around the neck, and another strap that goes around the waist.

The turbofan design is shown in the cross-section diagram of Figure 3-10. Excluding turbine and fan outlet connections, the turbofan is 0.045 m (1.75 in.) in diameter and 0.064 m (2.50 in.) long. One special design feature is that there is no contamination of air leakage into the oxygen flow driving the turbine. This is made possible by designing the turbine to discharge oxygen toward the shaft seal, at a pressure slightly above fan pressure, allowing a small leak of oxygen into the air side. Lubricant contamination is obviated by using the conical foil air bearings described in the following paragraph.

As shown in the Figure 3-10 cross-section diagram, the rotor assembly consists of the shaft (item 1), the fan (item 2), and the turbine (item 3). The rotor assembly is supported on two conical foil air bearings (item 4). The resilient pads of the air bearings always maintain a spring preload on the shaft through elastic deformation, insuring stability at zero-g conditions. As the shaft speed increases at start, a film pressure develops between the conical journals and foils, cuasing deflection of the resilient pads. The foils are inserted in conical retainers (item 5), which are separated by a shimmed spacer that controls the preload of the foils. The features of this proven-type bearing arrangement are shown in Figure 3-11.

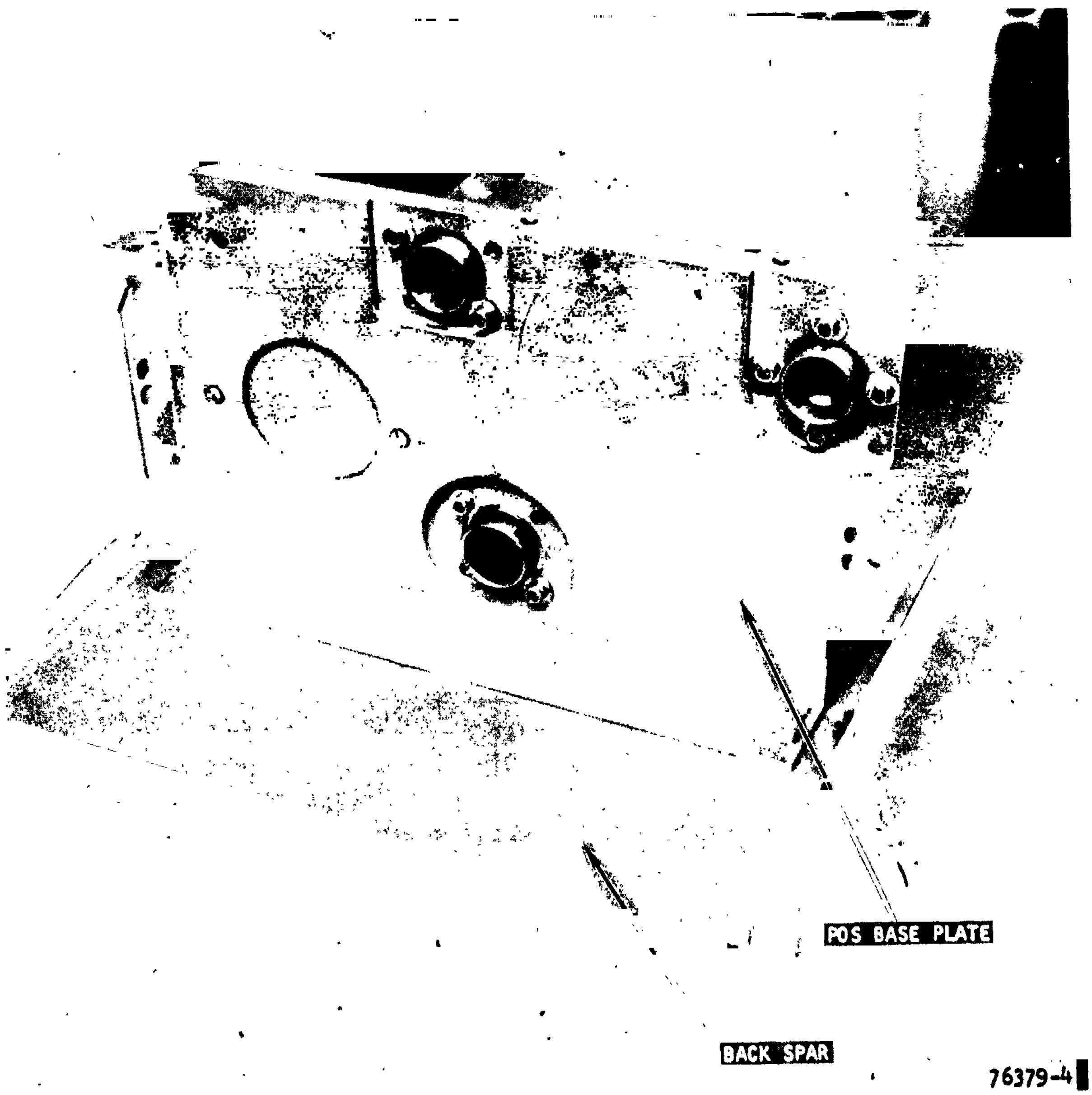

Figure 3-1. Backpan/Baseplate Assembly Botton View

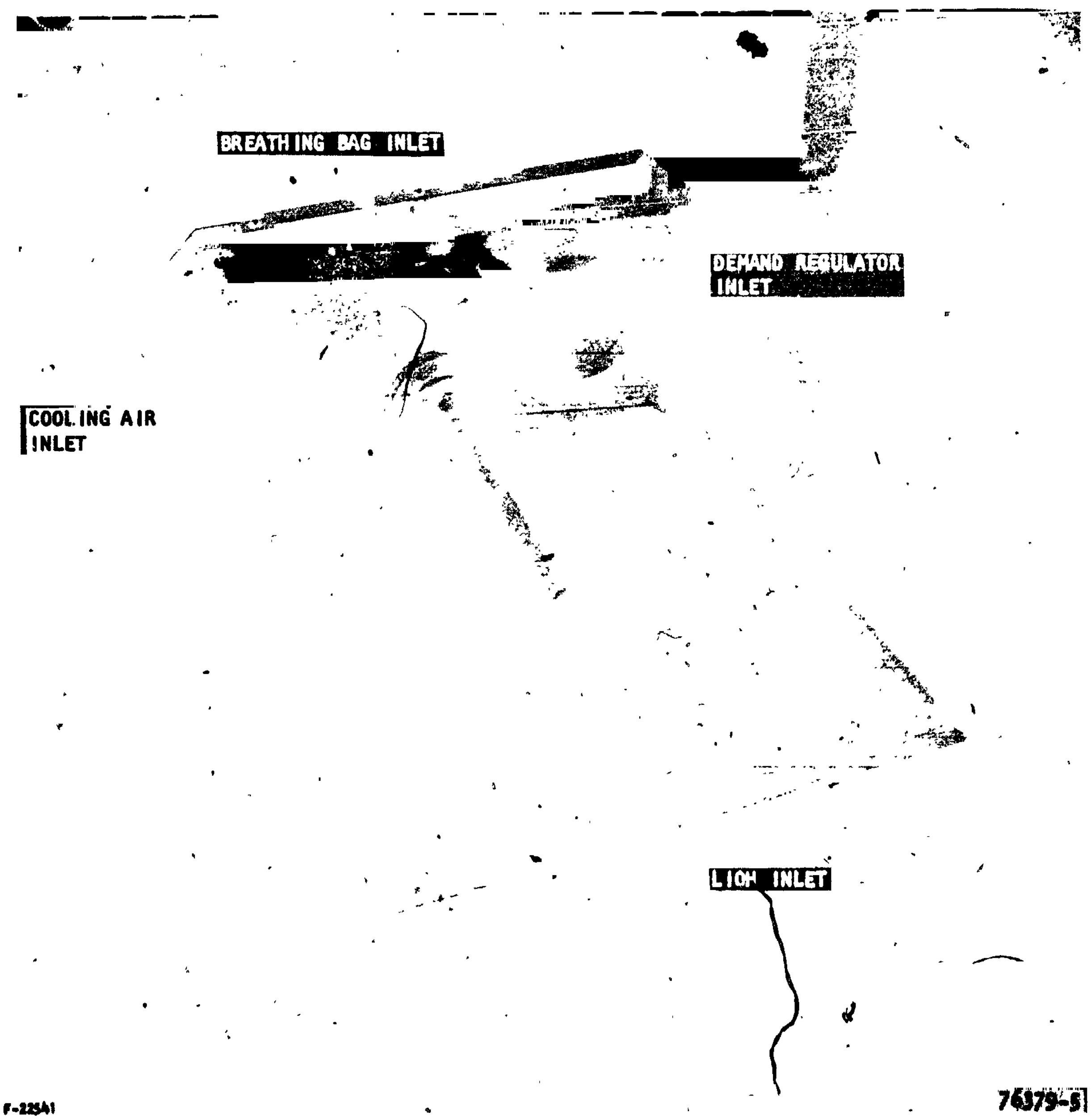

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Figure 3-2. Backpan/Baseplate Assembly Top View

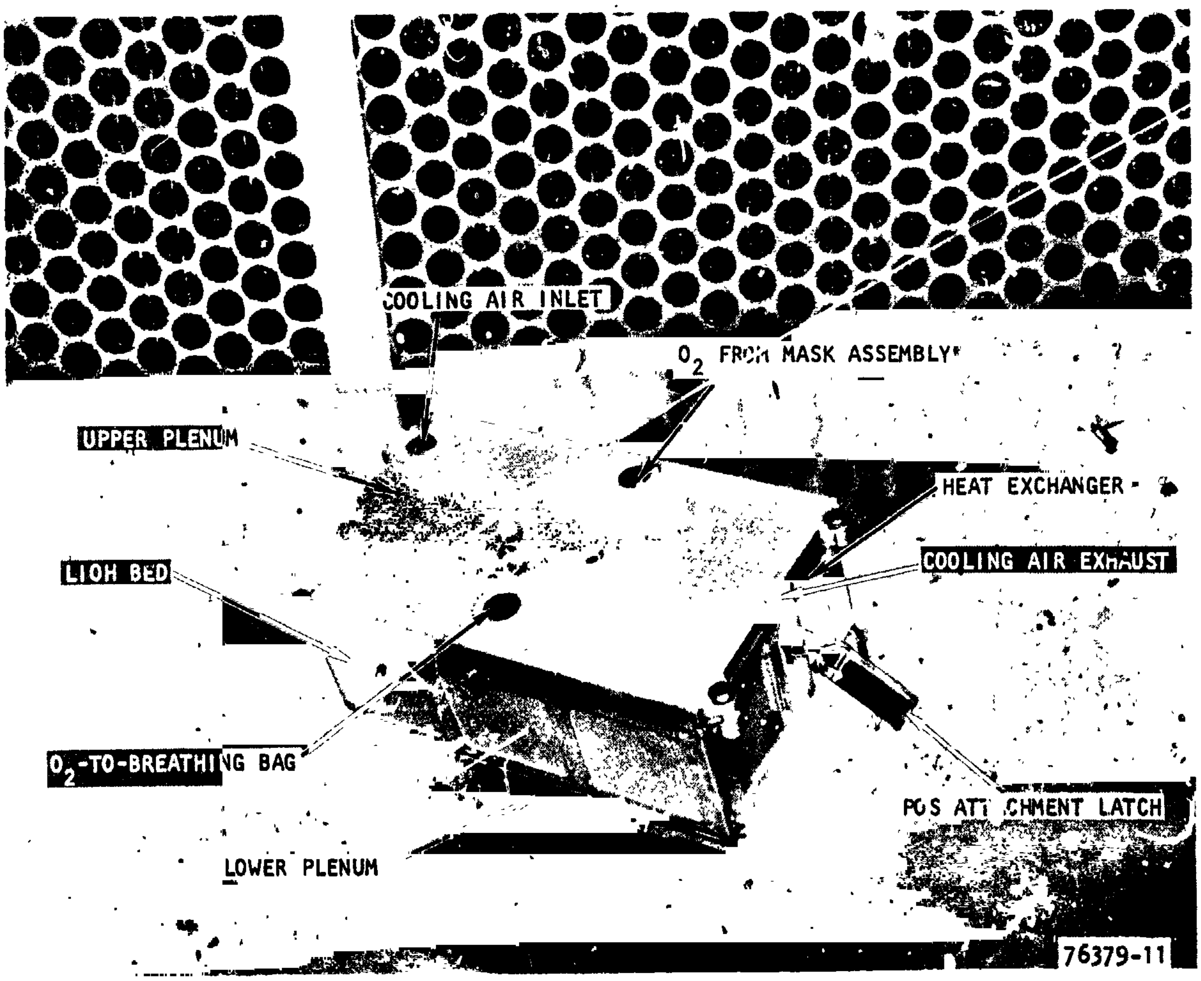

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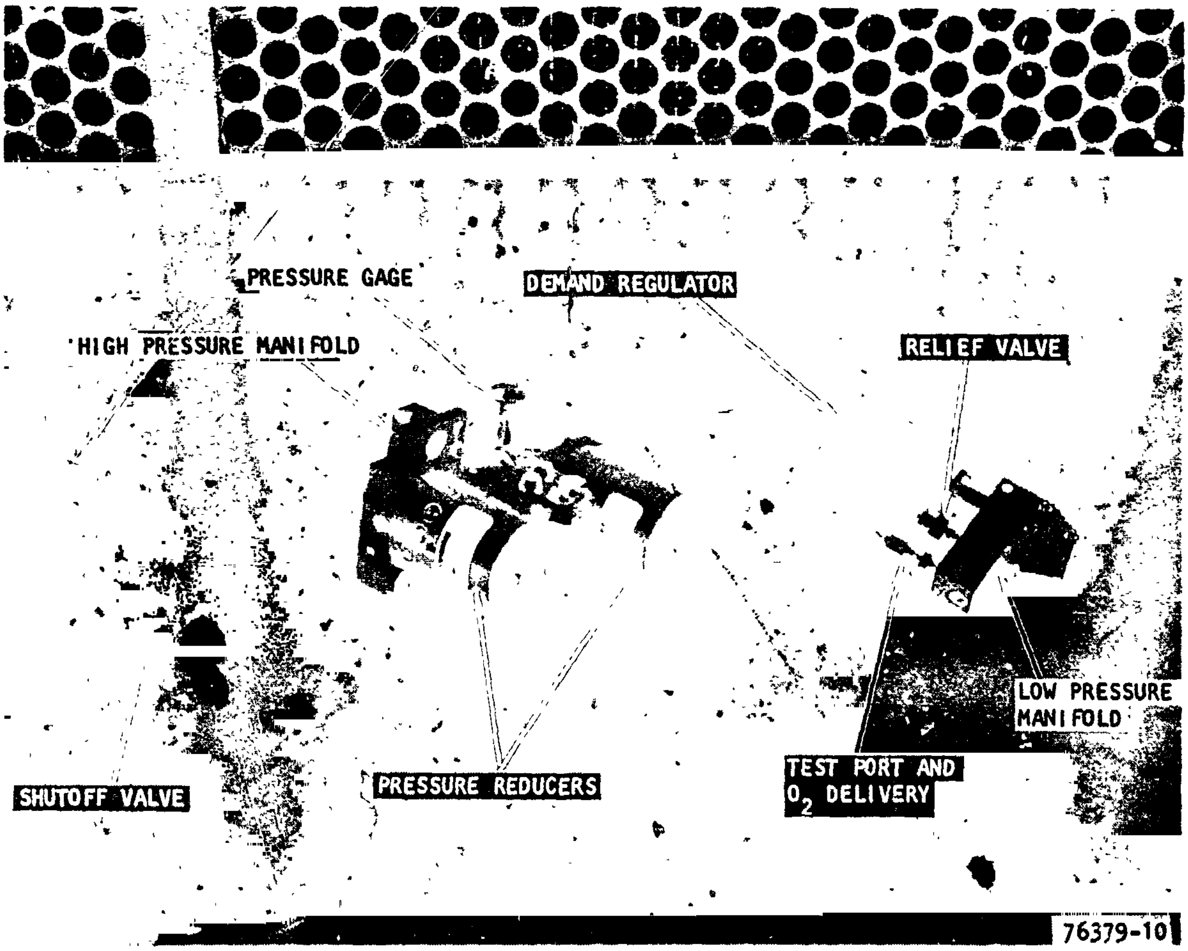
Figure 3-3. LiOH Bed/Heat Exchanger Assembly



F-22432

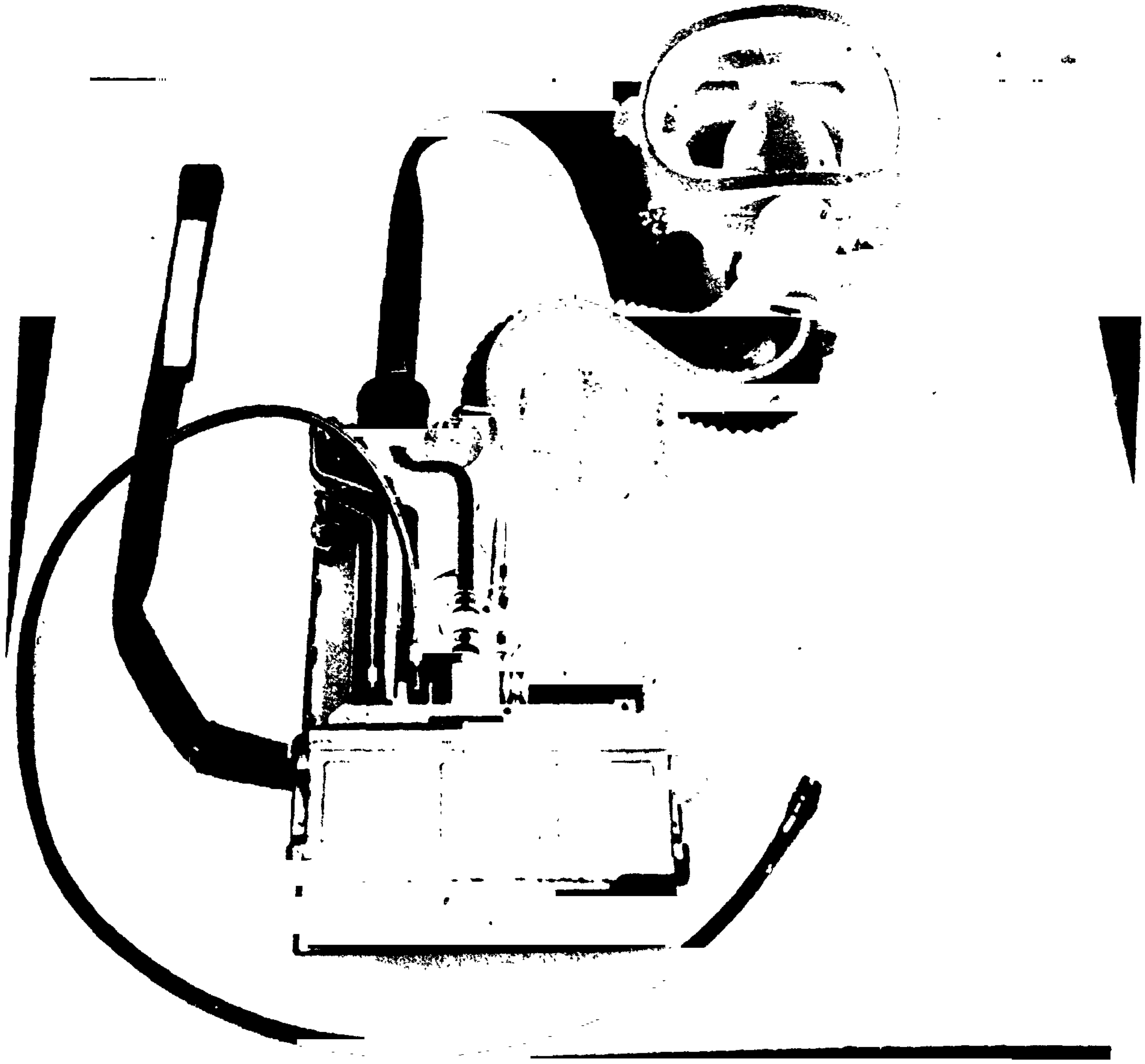
Figure 3-4. Oxygen Supply Manifolds with Valves Installed

F-22433

Figure 3-5. Assembled Oxygen Supply Manifolds

F-22434

Figure 3-6. Oxygen Tank and Supply Manifold Assembly



76515-4

Figure 3-7. Internal Components Assembly

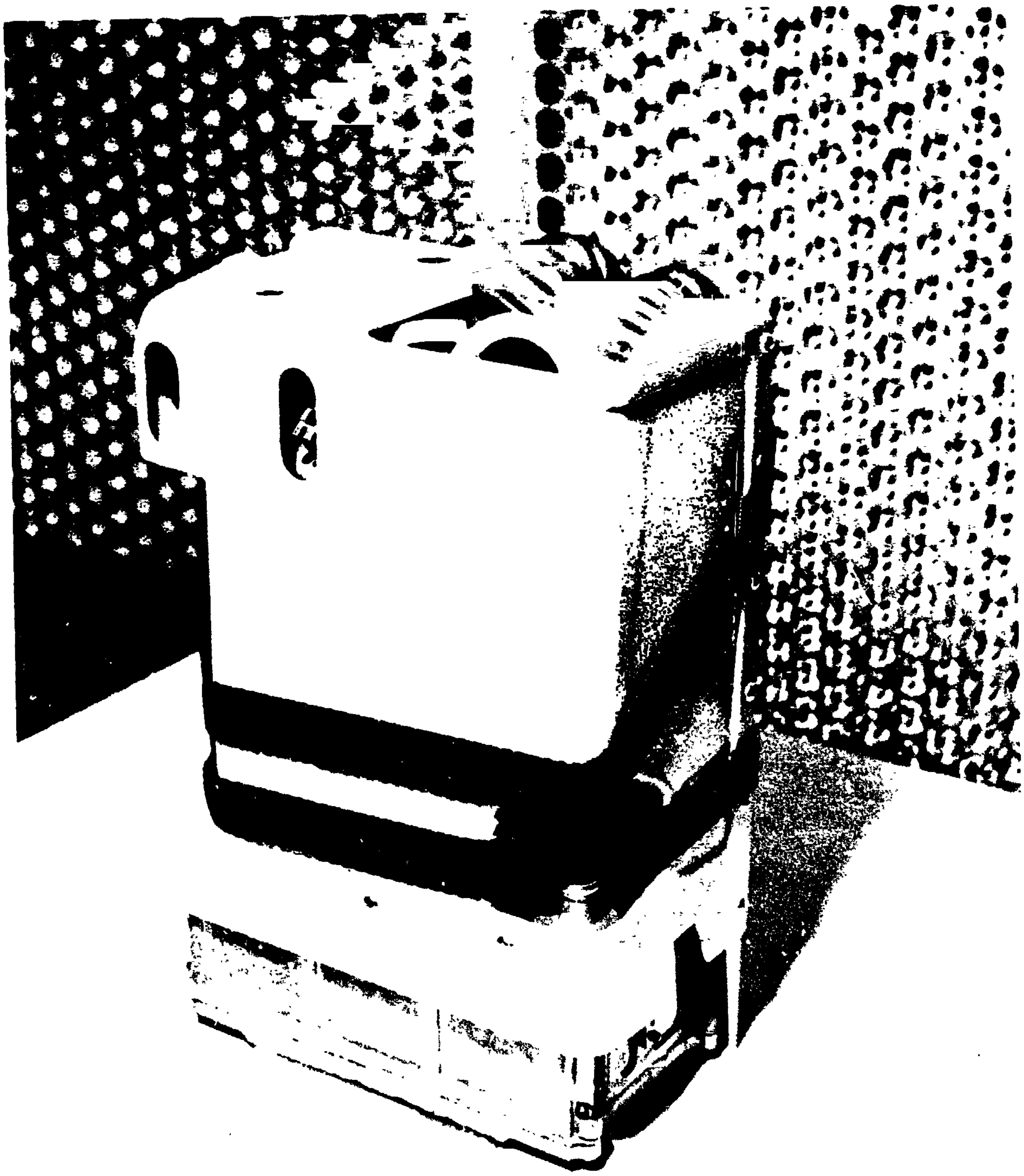


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Figure 3-8. Comp'eted POS Assembly


76515-8

Figure 3-9. Mounted POS Assembly

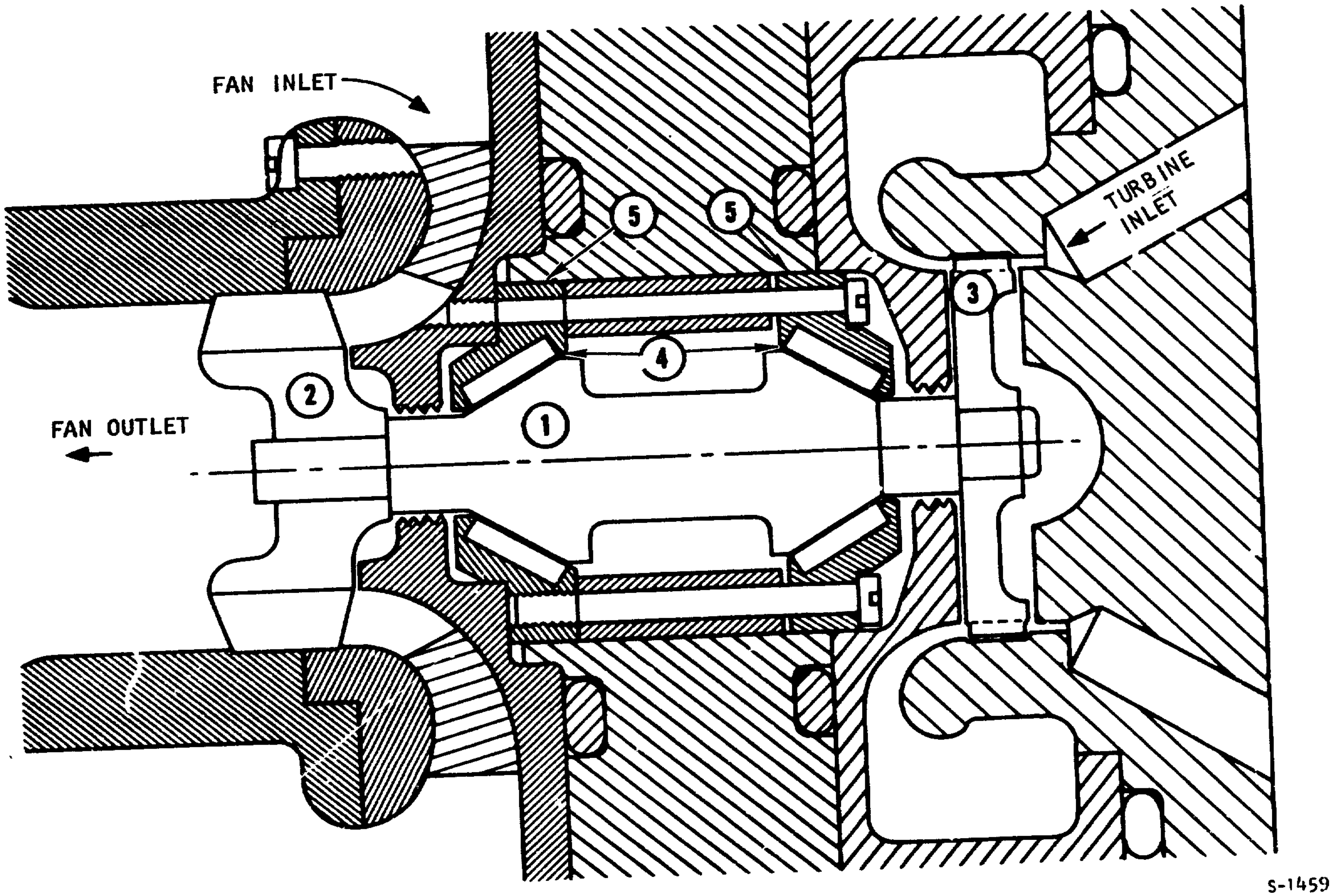


Figure 3-10. Cross-Sectional Diagram of POS Turbofan

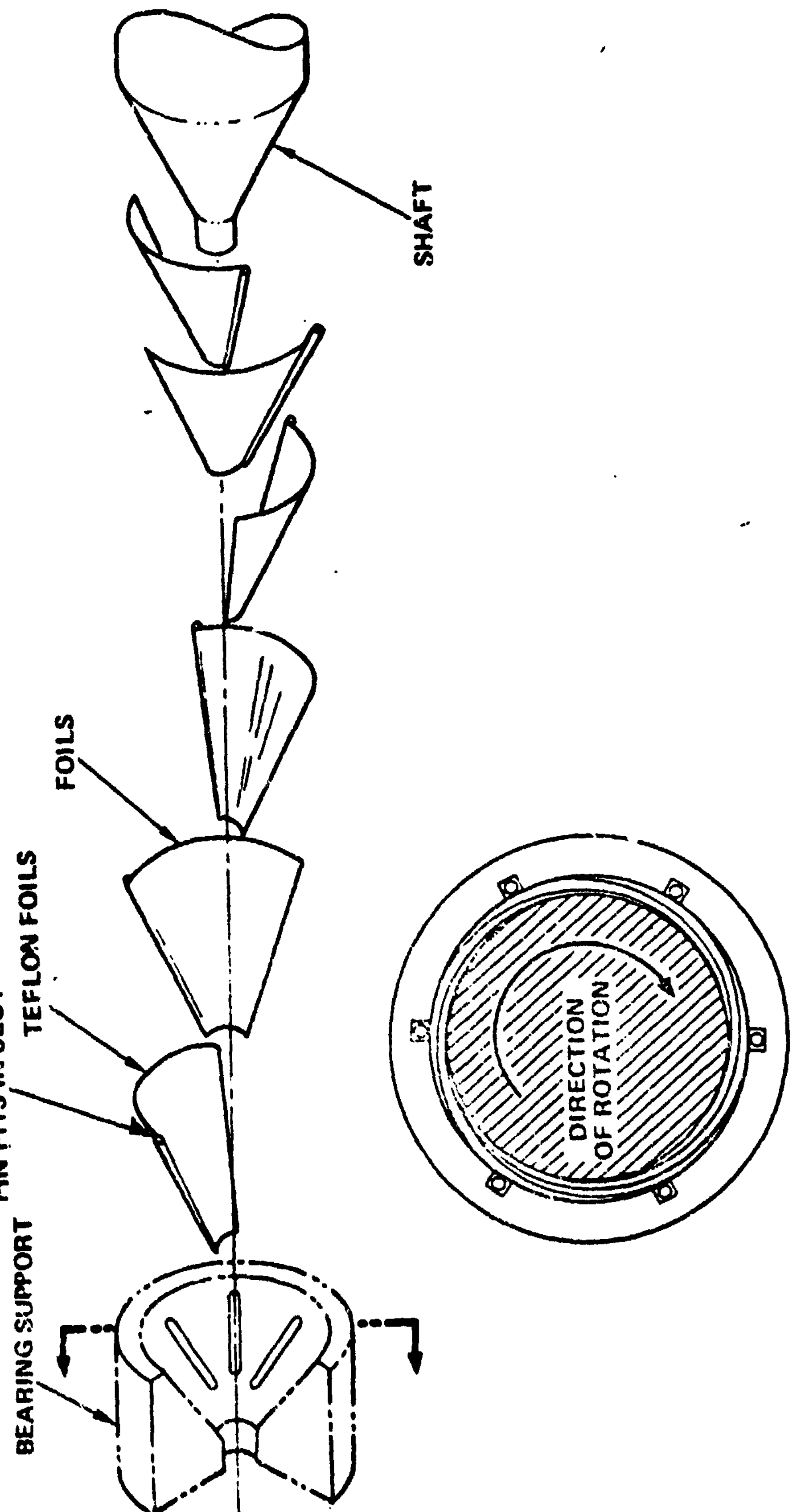


Figure 3-11. Turbofan Bearing Arrangement

OPERATION

Referring to the system schematic shown in Figure 1-1 and the POS package arrangement shown on Figure 3-12, system operation is described in the following pages. For this program, the turbofan was simulated by laboratory equipment.

During in-cabin operations, oxygen normally is supplied at 6.205 MPa (900 psig) from the Orbiter through a flexible hose located on the side of the POS. Oxygen flows through a pressure reducer (PR1) where the pressure is reduced to 379 kPa (55 psig). This reducer incorporates a manual override, which is set in the closed position for pack storage. When oxygen inflow into the breathing loop is desired, the manual override is opened. The regulated oxygen supply then enters the turbine inlet of the turbofan, which controls the flow to 0.32 kg/hr (0.7 lb/hr) with a 101 kPa (14.7 psia) ambient pressure. The turbine is driven at 130,000 rpm by the constant 0.32 kg/hr (0.7 lb/hr) oxygen flow into the breathing loop. The turbine drives the fan, producing 6.8 kg/hr (15 lb/hr) cabin airflow. This airflow is directed through the heat exchanger and then around the LiOH bed to satisfy all the cooling requirements. Additional oxygen cooling occurs by the oxygen expansion through the turbine as energy is extracted to drive the fan.

The partial admission turbine is of the axial impulse type, with two convergent-divergent nozzles of two-dimensional cross section. Two auxiliary nozzles are used, when starting, to develop the torque necessary to overcome the bearing preload. When the crewman dons the POS, he depresses the PURGE button on the demand regulator to purge the breathing loop of contaminant gases. A portion of this purge flow will be directed to the turbofan to provide the added startup flow.

The vaneaxial fan has four twisted blades, an annular inlet with stators, and a conical diffuser. Like the turbine, the fan is of proven design.

Turbine discharge oxygen flow is directed to the facepiece of the mask assembly to provide facial cooling, to prevent visor fogging, and to purge the facepiece of contaminant gases. The oxygen flow then enters the breathing loop through check valves mounted in the oral-nasal cup assembly.

Paralleling the oxygen flow entering the turbine, regulated oxygen also is directed to the demand regulator mounted at the top of the pack. The regulator is placed on the pack so that the SAFETY PRESSURE button can be depressed by the crewman while the POS is being worn. After the POS is donned, this button is immediately depressed to fill the breathing bag and to purge the breathing loop of contaminant gases. Additionally, if the bag should collapse for any reason, such as the user taking a deep breath, the demand regulator will automatically open and allow sufficient oxygen to enter the breathing loop to maintain uninterrupted breathing.

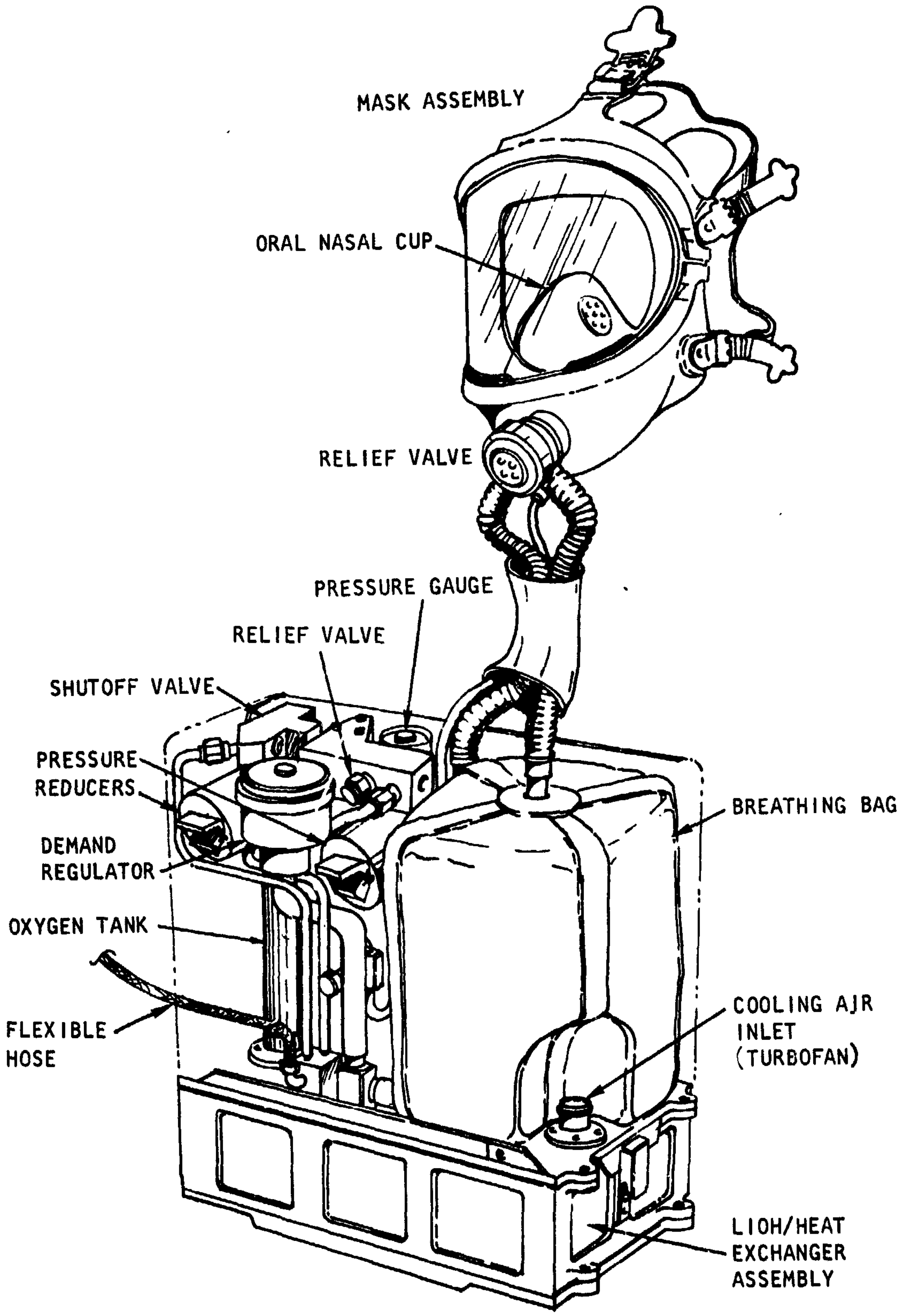


Figure 3-12. POS Package Arrangement

For independent POS operation, the oxygen tank stores 0.272 kg (0.6 lb) of usable oxygen (sufficient for one hour of operation in the PRS) at 16.89 MPa (2450 psig). The tank is charged through the flexible hose. After charging, the shutoff valve is closed to isolate the tank. Operation of the system is as described before, except that pressure reducer PR2 is manually opened. Operation of the breathing loop is described in the following paragraphs.

In the breathing loop, the exhaled gas is diverted to the LiOH bed by the check valve located in the mask assembly. As this gas flows through the LiOH bed, carbon dioxide is absorbed in a chemical reaction. This reaction produces heat and moisture, which are removed in the heat exchanger. The condensed moisture is retained in the heat exchanger by a water sorbent material. The cooled gas leaves the heat exchanger and fills the breathing bag. The breathing bag volume compensates for the change in lung volume during the breathing cycle, until it fills. As the pressure in the bag then increases above 0.373 kPa (1.5 in. of water), the relief valve that is mounted in the mask assembly opens and exhausts the remainder of the exhaled gases.

The advantages of placing the breathing bag downstream of the LiOH bed are as follows:

1. The breathing bag determines the breathing loop pressure level in relation to ambient, so that the negative pressure in the mask is reduced by the pressure drop of the LiOH bed and the heat sink. This greatly reduces the chances of introducing contaminants into the breathing loop due to mask leakage.

2. The total breathing resistance is reduced because the flow through the LiOH bed and heat exchanger occurs during exhalation instead of inhalation. The peak exhalation flow rate is approximately 40 percent less than the peak inhalation flow rate; hence, the pressure drop through LiOH bed and heat exchanger is significantly reduced.

As the crewman inhales, the pressure in the mask is reduced to 0.373 kPa (0.5 in. of water) below ambient. which causes gas to flow from the breathing bag to the mask assembly.

POS operation in the PRS is identical to that in the Orbiter, except that the oxygen inflow is sufficient to maintain the inspired cabin dioxide partial pressure below 2.667 kPa (20 mm Hg), without any carbon dioxide absorption by the LiOH bed.

WEIGHT

The POS total weight, as tested, was 6.90 kg (15.20 lb). Table 3-1 presents the component weight summary.

TABLE 3-1

POS COMPONENT WEIGHT SUMMARY

COMPONENT NAME	Weight	
	kg	lb
Quick Disconnect	0.023	0.05
Flexible Hose	0.209	0.46
Manual Shutoff Valve	0.064	0.14
Pressure Reducer (PR1)	0.281	0.62
Pressure Reducer (PR2)	0.281	0.62
Demand Regulator Including Relief Valve (RV1) and Pressure Gauge (PG)	0.177	0.39
OXYGEN TANK	1.315	2.90
LiOH Bed/Heat Exchanger Assembly (Including Plenums)	2.000	4.41
Breathing Bag	0.068	0.15
Mask Assembly	0.662	1.46
Hoses	0.091	0.20
Frame, tubing, fittings, etc.	1.723	3.48
Total Weight	5.894	15.20

SECTION 4

DEVELOPMENT TEST PROGRAM

TEST REQUIREMENTS

The POS was subjected to an acceptance test, three unmanned, and one manned development tests to verify that the unit met performance requirements of the Statement of Work. The tests performed and their specific objectives are listed in Table 4-1. Basic test requirements are described below:

1. During EVA preparation, the POS shall be capable of denitrogenizing a crew member to less than five volume percent of inspired gas in ten minutes and to less than three volume percent of inspired gas at the end of three hours operation. Denitrogenization shall be performed while operating from the Shuttle Orbiter 6.205 MPa (900 psia) oxygen supply.

2. Inspired carbon dioxide concentration shall be less than one volume percent at a metabolic rate of 234.4 watts (800 Btu/hr) and less than two percent at a metabolic rate of 322.2 watts (1100 Btu/hr).

3. The inspired dry bulb temperature shall be less than 43.3°C (110°F) and the dew point shall be less than 37.8°C (100°F).

4. All POS external parts shall have a temperature of less than 45°C (113°F) under all operating conditions.

TEST ITEM INFORMATION

Description of Test Item

The Portable Oxygen Subsystem (POS) is a multiple use system, which furnishes oxygen for breathing when the cabin atmosphere is contaminated, serves as a self-contained breathing system used by the crewman inside the Personnel Rescue System (PRS) during emergency EVA rescue transfer, and operationally, is used for pre-breathing prior to EVA. The subsystem contains a rebreather circuit to remove carbon dioxide and water vapor during use.

The subsystem can operate from 6.205 MPa (900 psia) spacecraft oxygen or from its independent tank. Independent operation time capability is ten minutes for walk around in the cabin and sixty minutes in the Personnel Rescue System. Makeup oxygen is added to the rebreather system at 0.318 Kg/hr (0.7 lb/hr) for metabolic consumption and nitrogen purge.

TABLE 4-1

DEVELOPMENT TESTS AND OBJECTIVES

Test No.	Description of Test	Test Objective
1	Assembly Verification	Verify POS is assembled properly and is acceptable for development testing.
2	Unmanned Performance	a. Test checkout b. Denitrogenization c. Overstress
3	Unmanned Performance	Statement of Work verification. High metabolic rates used at the end of the test.
4	Unmanned Performance	Statement of Work verification. Varied breathing pattern used. High metabolic rates used at the start of the test.
5	Manned Performance	Statement of Work verification.
6	Acceptance Test	Verify POS integrity prior to shipment to NASA.

The major subsystem components include a full face mask (including mask inlet and outlet flow check valves), relief valve, breathing bag with internal wick condensate collector, lithium hydroxide cartridge, heat sink, turbofan, purge and demand regulator, and a 6.205 MPa (900 psia) oxygen supply system with inlet check, pressure reducer (with manual shutoff valve), quick disconnect, and flex hose.

Test Item Configuration

The prototype subsystem, less turbofan and final configuration storage tank (which were simulated by shop air and tank machined from CRES bar, respectively) was utilized for the development tests described herein. The subsystem, as tested, consists of the components shown below:

	Quantity Per Subsystem
Flexible Hose	1
Shutoff Valve	1
Pressure Reducers	2
Relief Valve (Supply Side)	1
Demand Regulator	1
Breathing Bag	1
Mask Assembly	1
Exhalation Check Valve	1
Relief Valve (Breathing Side)	1
LiOH Cartridge	1
Heat Exchanger	1

Test Item Modifications

The development test hardware was modified to incorporate the following instrumentation for external monitoring. Instrumentation added to the POS was planned and installed such as not to affect either functional or dynamic performance of the hardware.

POS Instrumentation (See end of Section 4 for complete test instrumentation list.)

1. Temperatures

    Mask inlet and outlet
    LiOH Cartridge Inlet (Breathing Side)
    LiOH Cartridge Skin Temperature
    Heat Exchanger (Breathing Side)
    LiOH Cooling Air Outlet

2. Pressures

Mask Inlet

Mask Outlet

3. CO_2 Concentration

Mask Inlet

Mask Outlet

4. Dew Point Temperatures

Mask Inlet

Mask Outlet

The POS case and the hoses connecting the masks to the POS and to the LiOH cartridge assembly were insulated to reduce the heat transferred to ambient to essentially zero.

DISCUSSION OF TEST RESULTS

Test Data Evaluation

Because of test setup limitations, the actual mask inlet (crewman inhalation) conditions could not be measured directly. These conditions were calculated, using the procedure outlined below. The conditions noted as POS outlet are those measured in the hose connecting the breathing bag and the mask inlet.

The POS outlet conditions were corrected to the mask inlet conditions by making the following assumptions:

1. The gas mixture contained only oxygen, water vapor, and carbon dioxide.
2. The gas mixture was saturated with water vapor at the measured temperature.
3. The total pressure of the gas at the POS outlet and mask inlet is 14.7 psia.

These assumptions determine the volumetric gas compositions at the POS outlet and permit determination of the gas composition on a weight basis. The mask inlet gas has an additional 0.318 kg/hr (0.7 lb/hr) of dry oxygen added to the gas mixture.

The mass fraction of the gas composition was recalculated for the mask inlet with the addition of this 0.318 kg/hr (0.7 lb/hr) of oxygen, neglecting any possible water condensation in the ducting or mask, and the cooling effects of the colder temperature of the oxygen supply gas. This mass fraction of the gas composition was converted to a volumetric fraction, from which the gas partial pressures could be calculated.

NOTE: The mask inlet gas is saturated. A thermocouple was included in the oral-nasal cup assembly for tests Numbers 3 and 4. Therefore, for these two tests, the mask inlet dry bulb and dewpoint temperatures were measured directly.

Test No. 1 - Assembly Verification

This acceptance test was performed to verify that the POS was assembled properly, and that the subsystem is acceptable to be used for development testing. The tests performed were:

Proof pressure of high pressure loop.

External leakage of high pressure loop.

Proof pressure of low pressure loop.

Breathing resistance.

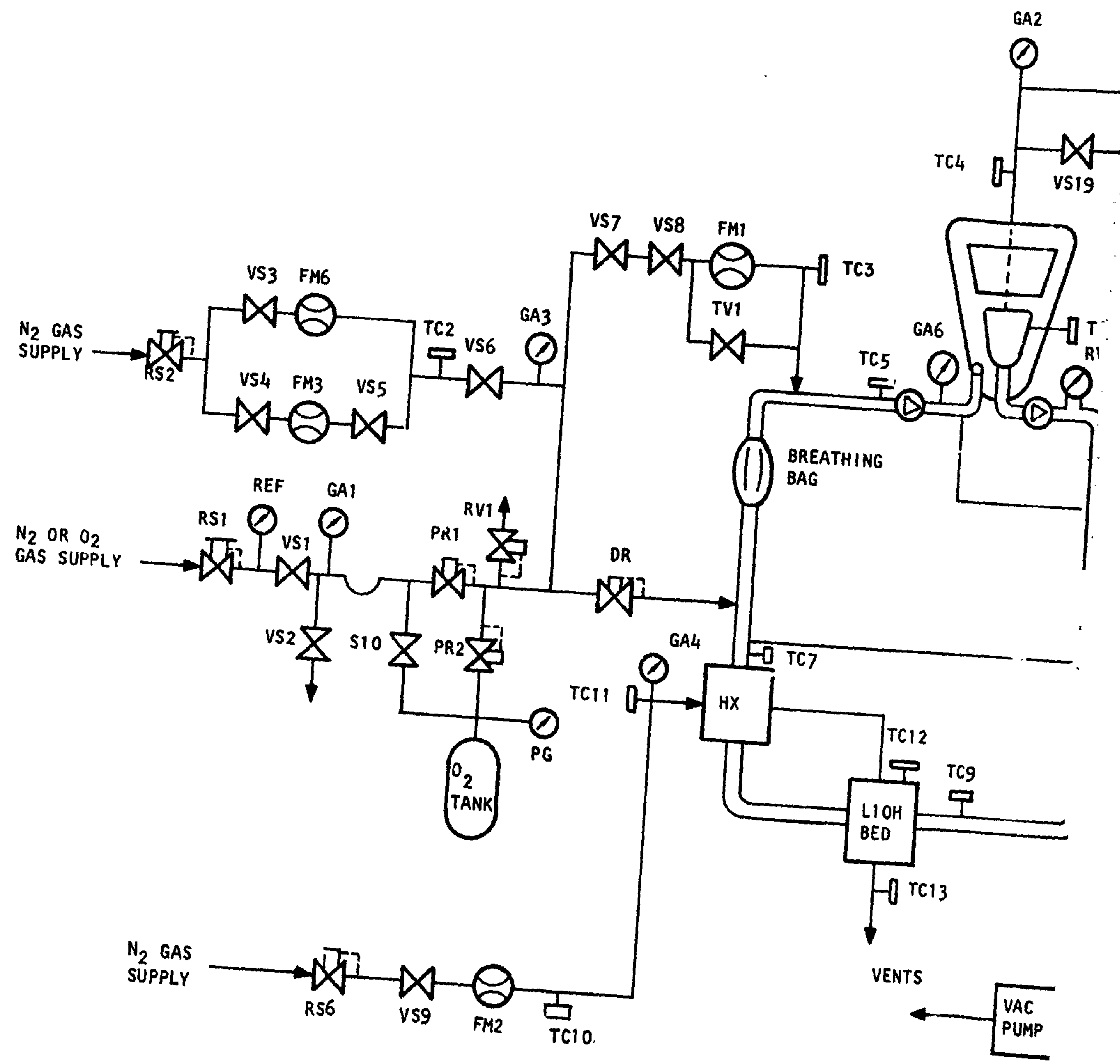
All tests were completed satisfactorily.

Test No. 2 - Unmanned Performance

1. Test Objective and Test Setup

This test was performed primarily to verify that the test setup was operating properly and to allow the test operators to familiarize themselves with the POS operation. Originally, the data was not intended to be used for anything other than test setup verification. However, because of an instrumentation error, the metabolic rate simulated was higher than planned. The test data for this test, therefore, is included to provide POS operating characteristics at off-design conditions.

The test schematic and POS configuration used for this test is shown in Figure 4-1. The constant oxygen bleed was placed in the hose connecting the breathing bag and the mask inlet. These conditions could not be recorded directly in the oral-nasal area, because the lung simulations (moisture and steam) were injected in this area. To prevent moisture from condensing in the hoses connecting the mask with the breathing bag, the hose was heated to a temperature above 100°F. LiOH inlet temperature was maintained by heating the hose connecting the LiOH bed inlet with the mask outlet. The POS was insulated so that there would be no heat transfer between it and ambient, except at the breathing bag.



FOLDOUT FRAME 1

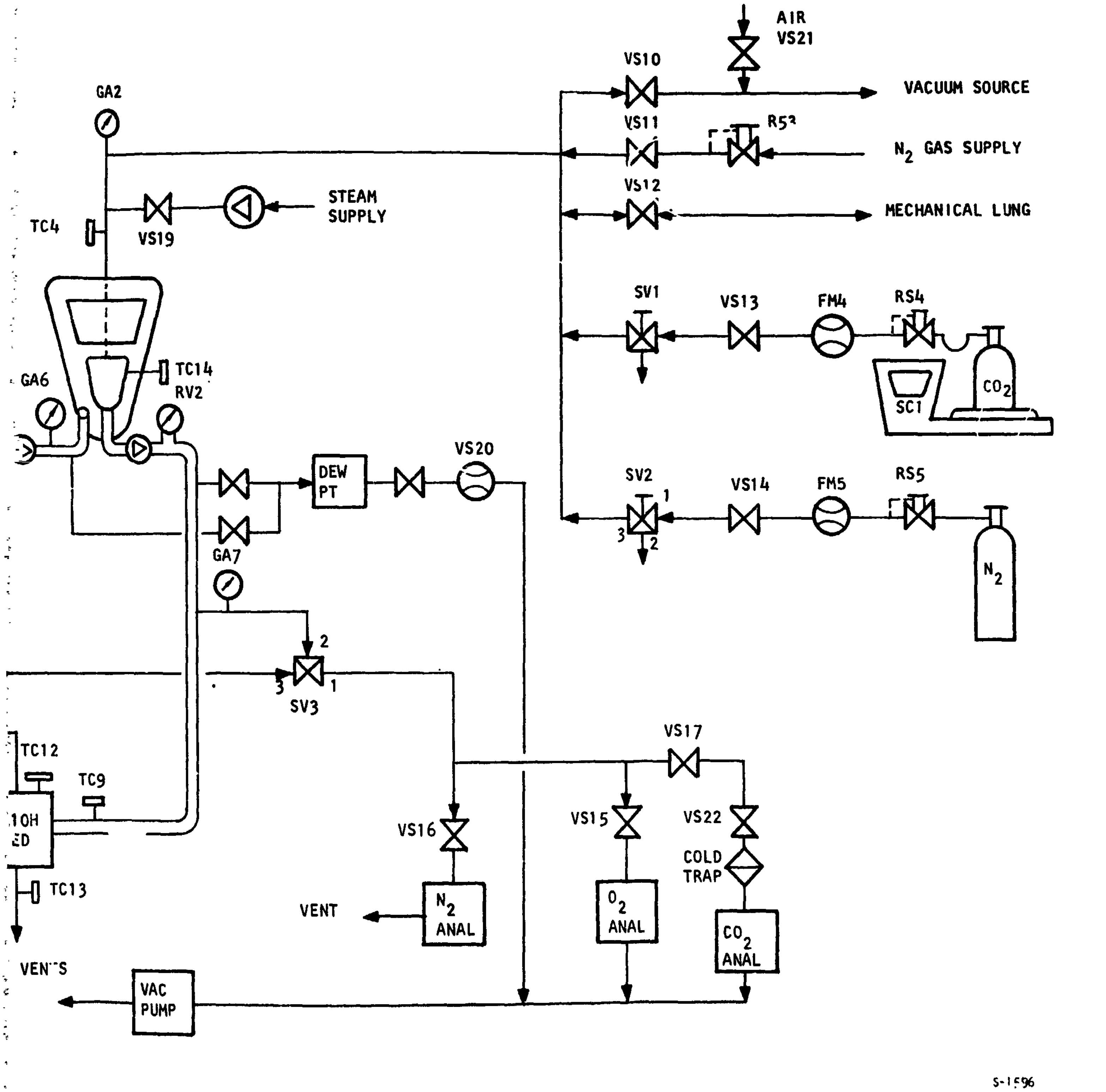


Figure 4-1. POS Configuration and Schematic for Unmanned Performance Test (No. 2)

2. Test Procedure

Oxygen was supplied to the flexible hose, pressure reducer PRI was opened, and the PURGE button on the demand regulator was depressed to purge the breathing loop. The purge was continued until the oxygen analyzer indicated 98 percent oxygen minimum.

The following conditions were established prior to the start of the test.

Cooling air flow:	6.805 kg/hr (15 lb/hr)
Cooling air temperature:	23.9°C (75°F)
Breathing machine cycle rate:	16 cycles/min
Breathing machine volume/cycle:	1.12 liters
Oxygen flow into the breathing loop:	0.318 Kg/hr (0.7 lb/hr)
Mask outlet dew point:	32.2°C (90°F)
CO_2 flow into breathing loop:	0.085 kg/hr (0.186 lb/hr)
N_2 flow into the breathing loop:	62 scc/min
Metabolic rate simulation:	275.5 watts (940 Btu/hr)

Test time of zero (start of the test) was recorded at the time that carbon dioxide and nitrogen flow was initiated.

Nitrogen flow was metered into the breathing loop as shown in Figure 4-2. At 165 minutes after the start of the test, the metabolic simulation was increased to 375.2 watts (1280 Btu/hr). The following new conditions were then established:

Breathing machine cycle rate:	17 cycles/min
Breathing machine volume/cycle:	1.23 liters
CO_2 flow into the breathing loop:	0.117 kg/hr (0.258 lb/hr)

At 180 minutes after the start of the test, the metabolic simulation was increased to 498.3 watts (1700 Btu/hr). The following new conditions were then established:

Breathing machine cycle rate:	18 cycles/min
Breathing machine volume/cycles:	1.36 liters
CO_2 flow into the breathing loop:	0.16 kg/hr (0.354 lb/hr)

At 184 minutes after the start of the test, the metabolic simulation was decreased to that imposed at the start of the test. The test was terminated at the end of 230 minutes.

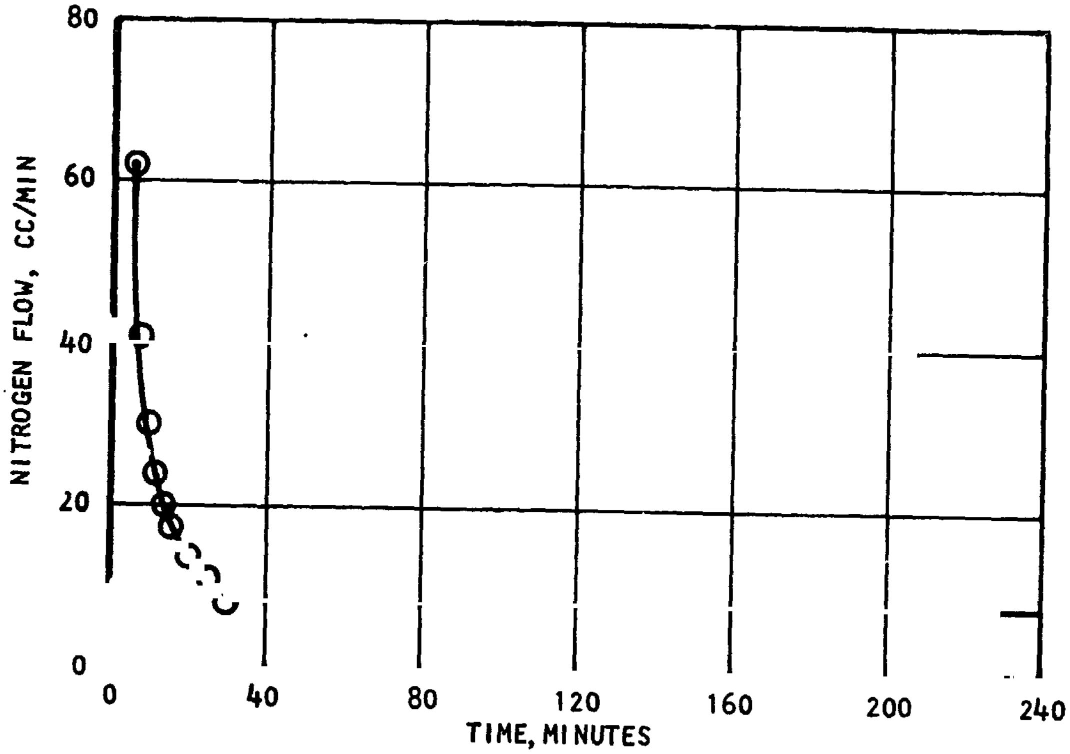


Figure 4-2. Nitrogen Flow History for Unmanned Performance Test (No. 2)

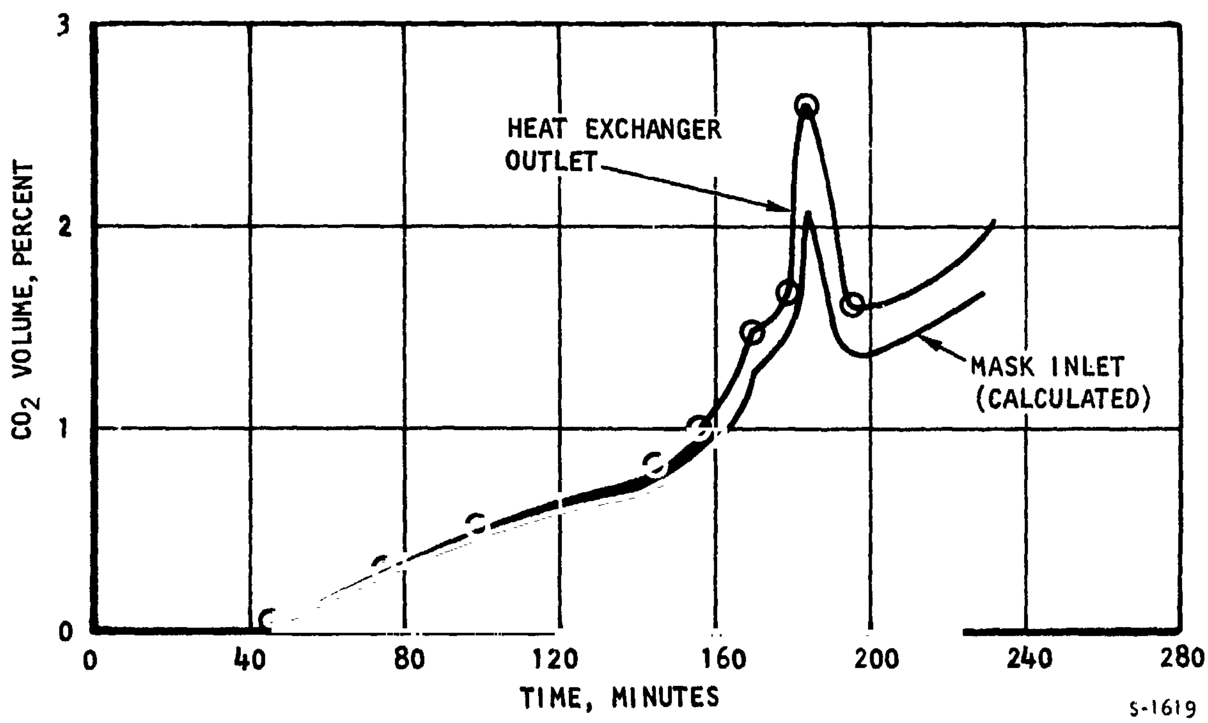


Figure 4-3. Carbon Dioxide Concentration History for Unmanned Performance Test (No. 2)

3. Test Results

a. Denitrogenization

The inspired nitrogen volume was 1.5 percent at the end of 22 minutes and was then reduced to 0.8 percent at the end of 75 minutes. It remained at 0.8 percent for the rest of the test.

b. Inspired Carbon Dioxide Concentration

The carbon dioxide concentration was measured at the heat exchanger outlet. This measured value and the calculated mask inlet values are shown in Figure 4-3.

c. Heat Exchanger Outlet and Mask Inlet Temperatures

Figure 4-4 shows the measured dry bulb and dew point temperatures at the heat exchanger outlet and the calculated mask inlet dry bulb and dew point temperatures.

d. Structural Temperature

The highest structural temperature in the POS was found on the side of the LiOH bed, next to the cooling air exhaust. This temperature is shown in Figure 4-5.

Additional test results are shown in Table 4-2.

Test No. 3 - Unmanned Performance

1. Test Objective and Test Setup

This test was performed to verify that the POS meets Statement of Work requirements.

The test setup was modified from that used for Test No. 2 to allow better systems monitoring. Figure 4-6 shows the test setup and POS configuration used for this test. The test setup is shown pictorially in Figures 4-7 and 4-8. The changes from the prior test setup are noted below:

a. The steam injection location was moved from the simulated oral-nasal area to the mask outlet to prevent condensation in the head and tubing and to allow direct oral-nasal temperature measurement.

b. The 0.318 kg/hr (0.7 lb/hr) oxygen inflow point was placed in the mask to exactly simulate the POS as it will be delivered.

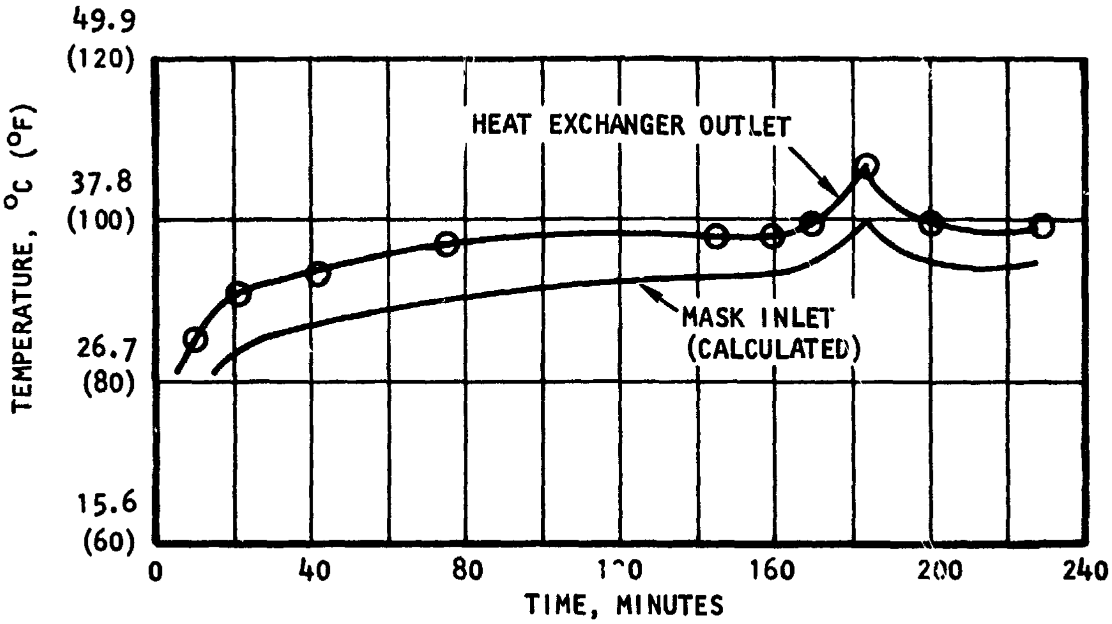


Figure 4-4. Heat Exchanger Outlet and Mask Inlet Temperature History for Unmanned Performance Test (No. 2)

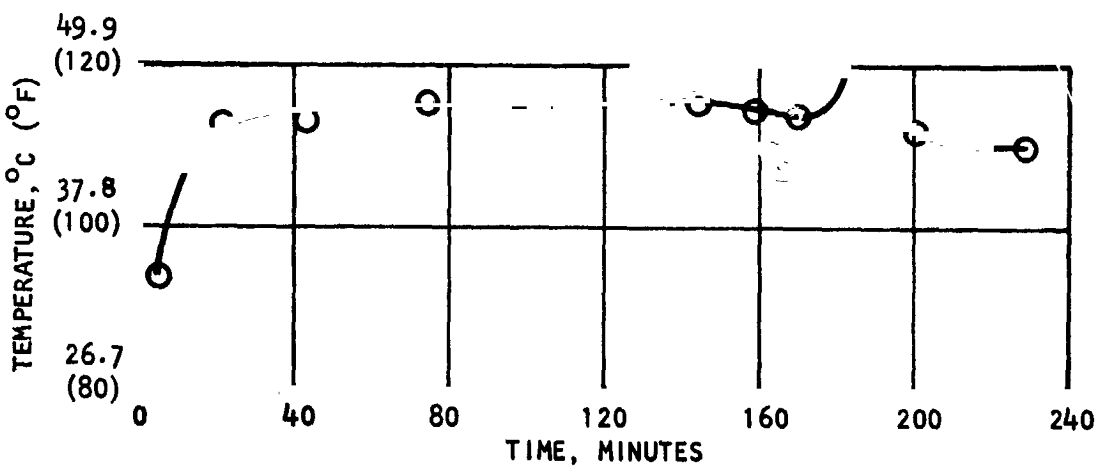


Figure 4-5. Structural Temperature History for Unmanned Performance Test (No. 2)

S-1613

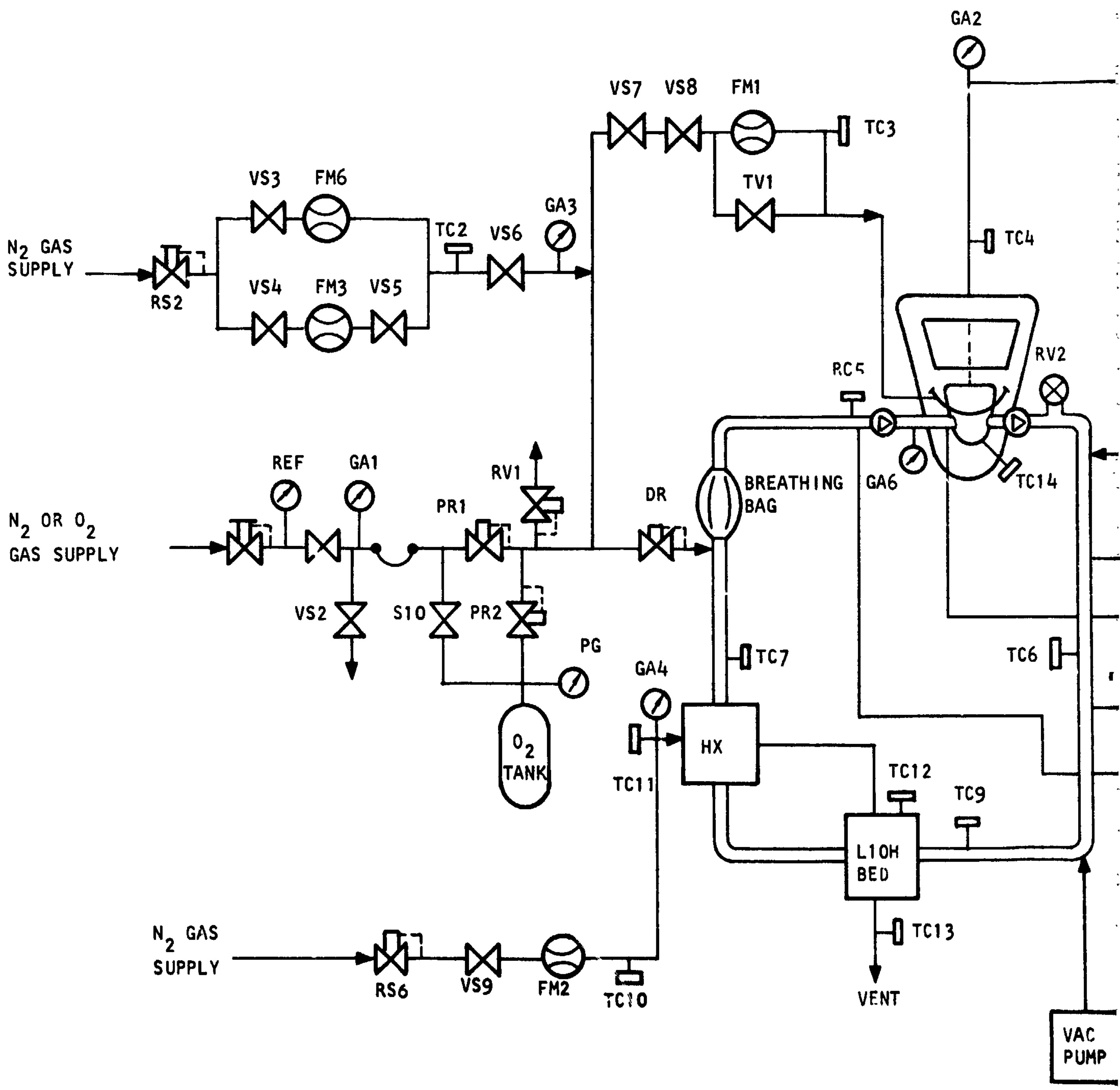
TABLE 4-2

RESULTS OF UNMANNED PERFORMANCE TEST (NO. 2)

Elapsed Time, Minutes	Demand Regulator Inlet Pressure (GA3), kPa (psig)	Mask Pressure (GA2), kPa (in. H_2O)	Dew Point Outlet Temp., °C (°F)	POS Inlet Temp. (TC9), °C (°F)
5	389.6 (56.5)	-0.10/+0.62 (-0.8/+2.5)	31.1 (88)	37.2 (99.0)
23	379.2 (55.0)	-0.17/+0.69 (-0.7/+2.8)	32.2 (90)	38.6 (101.5)
45	379.2 (55.0)	-0.14/+0.92 (-0.6/+3.7)	30.0 (86)	36.7 (98.0)
75	379.2 (55.0)	-0.24/+0.92 (-1.0/+3.7)	31.7 (89)	39.7 (103.5)
145	386.1 (56.0)	-0.22/+0.79 (-0.9/+3.2)	33.3 (92)	40.8 (105.5)
155	386.1 (56.0)	-0.14/+0.67 (-0.6/+2.7)	30.0 (86)	41.4 (106.5)
170	386.1 (56.0)	-0.24/+0.77 (-1.0/+3.1)	32.2 (90)	41.7 (107.0)
200	389.6 (56.5)	-0.27/+0.57 (-1.1/+2.3)	32.8 (91)	42.5 (108.5)
230	NR (NR)	-0.27/+0.57 (-1.1/+2.3)	32.2 (90)	42.5 (108.5)

Elapsed Time, Minutes	Cooling Air Temp. (TC11), °C (°F)	LiOH Skin Temp. (TC12), °C (°F)	Volume Percent			
			N_2 In	O_2 Out	CO_2 In	CO_2 Out
5	26.1 (79)	34.4 (94)	1.0	NR	0.00	NR
23	23.3 (74)	45.0 (113)	1.5	90.5	0.00	5.95
45	25.0 (77)	45.3 (113.5)	1.2	90.0	0.05	5.95
75	24.4 (76)	46.1 (115)	1.0	92.5	0.30	4.85
145	24.4 (76)	46.4 (115.5)	1.0	91.0	0.80	5.90
155	23.9 (75)	45.8 (114.5)	1.0	90.0	1.00	5.90
170	23.9 (75)	48.6 (119.5)	1.0	NR	1.48	NR
200	23.6 (74.5)	44.4 (112)	1.0	91.5	1.60	5.35
230	25.8 (78.5)	43.3 (110)	0.75	NR	2.00	NR

NR = Not recorded.



FOLDOUT FRAME /

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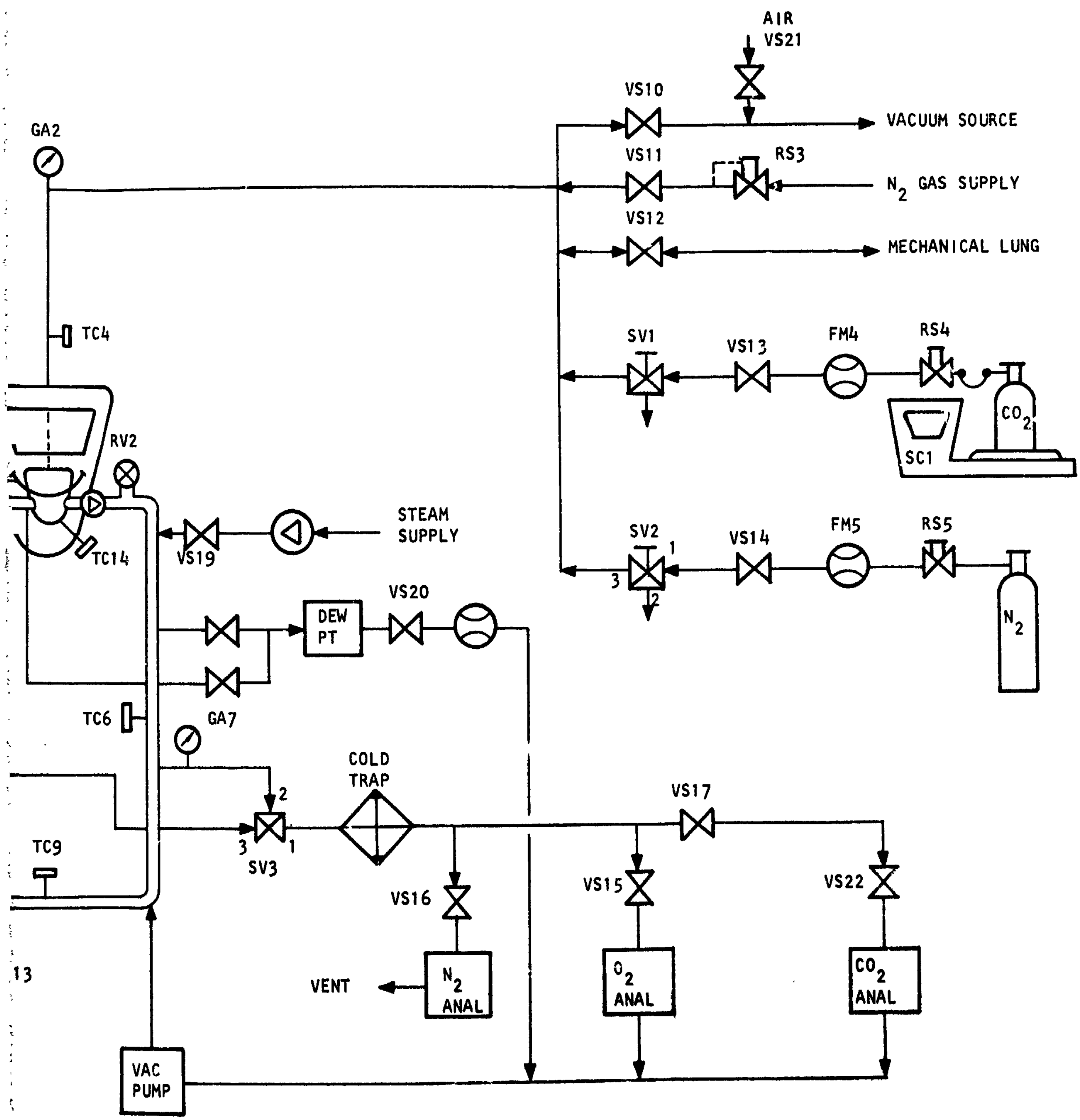

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Figure 4-6. POS Configuration and Schematic for Unmanned Performance Test (No. 3)

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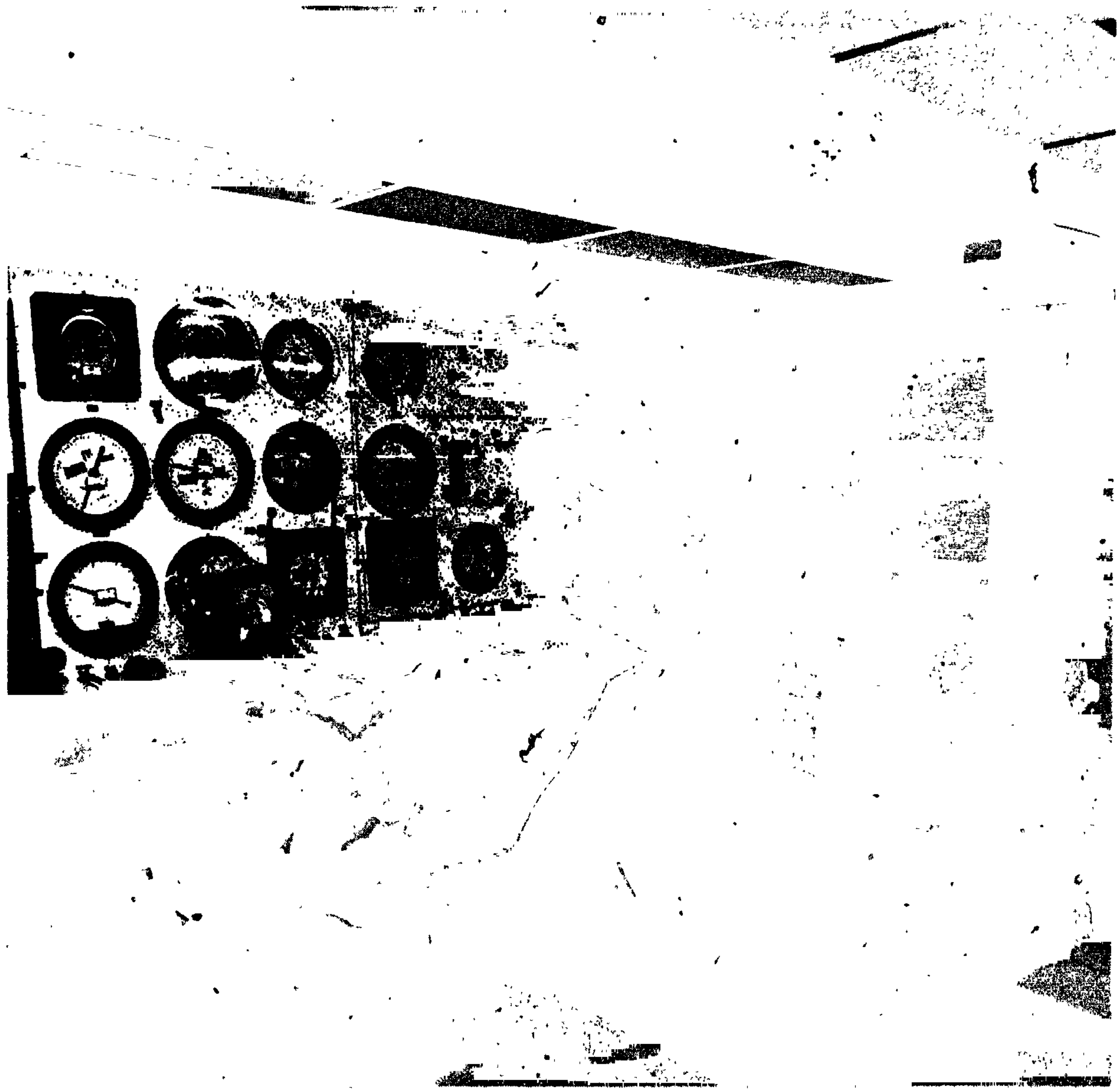

Figure 4-7. Setup for Unmanned Performance Test (No. 3)

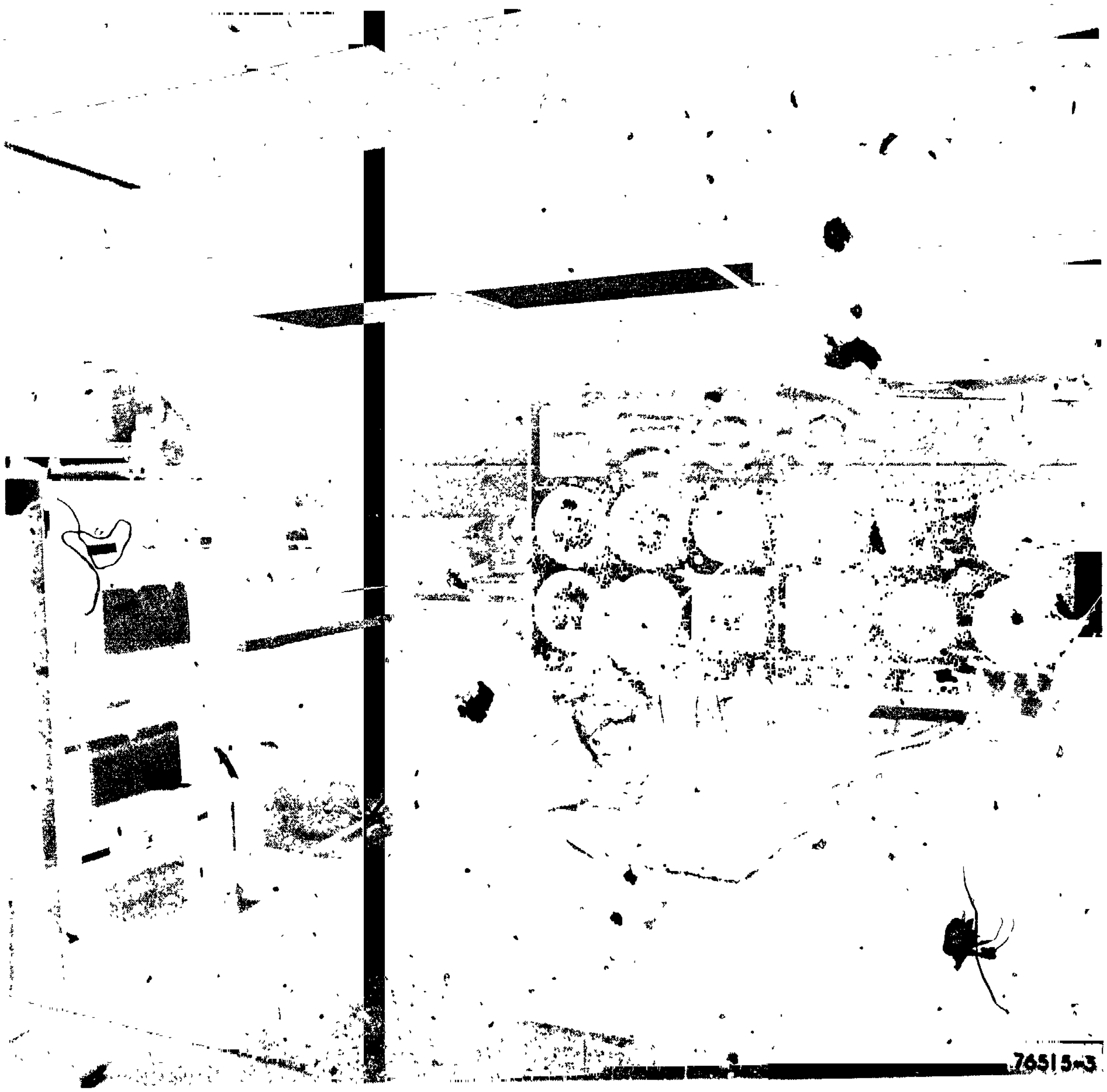

Figure 4-8. Other View of Setup for Unmanned Performance Test (No. 3)

c. The hose connecting the breating bag with the mask was not heated, but was insulated. This configuration change allows direct mask inlet monitoring and prvoides an accurate simulation of POS operation.

d. The oxygen, carbon dioxide, and dew point sample gases were returned to the breathing loop.

2. <u>Test Procedure</u>

Oxygen was supplied to the flexible hose, pressure reducer PRI was opened, and the PURGE button on the demand regulator was depressed to purge the breathing loop. The purge was continued until the oxygen analyzer indicated 98 percent oxygen minimum.

The following conditions were established prior to the start of the test.

Cooling air flow:	6.805 kg/hr (15 lb/hr)
Cooling air temperature:	23.9°C (75°F)
Breathing machine cycle rate:	16 cycles/min
Breathing machine volume/cycle:	1.12 liters
Oxygen flow into the breathing loop:	0.318 kg/hr (0.7 lb/hr)
Mask outlet dew point:	32.2°C (90°F)
CO_2 flow into breathing loop:	0.073 kg/hr (0.159 lb/hr)
Metabolic rate simulation:	234.5 watts (800 Btu/hr)

Test time of zero (start of the test) was recorded at the time that carbon dioxide flow was initiated.

At 162 minutes after the start of the test the metabolic simulation was increased to 322.4 watts (1100 Btu/hr). The following new conditions were then established:

Breathing machine cycle rate:	17 cycles/min
CO_2 flow into the breathing loop:	0.099 kg/hr (0.219 lb/hr)

At 177 minutes after the start of the test, the metabolic simulation was increased to 439.7 watts (1500 Btu/hr). The following new conditions were then established:

Breathing machine cycle rate:	18 cycles/min
CO_2 flow into the breathing loop	0.135 kg/hr (0.298 lb/hr)

At 180 minutes after the start of the test, the metabolic simulation was decreased to that imposed at the start of the test. The test was terminated at the end of 291 minutes.

3. Test Results

a. Inspired Carbon Dioxide Concentration

The carbon dioxide concentration was measured at the POS outlet. This measured value and the calculated mask inlet values are shown in Figure 4-9.

b. Mask Inlet Temperature

Figure 4-10 shows the measured dry bulb and dew point temperatures at the mask inlet.

c. Structural Temperature

The highest structural temperature in the POS was found on the side of the LiOH bed next to the cooling air exhaust. This temperature is shown in Figure 4-11.

Additional test results are shown in Table 4-3.

Test No. 4 - Unmanned Performance

1. Test Objective and Test Setup

The primary purpose of this test was to determine the system operating characteristics when high metabolic loads were imposed at the start of the test. The test setup and POS configuration were identical to that described for Test No. 3.

2. Test Procedure

C[illegible]n was supplied to the flexible hose, pressure reducer PRI was opened, a[illegible]d t[illegible] JRGE button the demand regulator was depressed to purge the breathing loop. The purge was continued until the oxygen analyzer indicated 98 percent oxygen minimum.

The following conditions were established prior to the start of the test:

Cooling air flow:	6.805 kg/hr (15 lb/hr)
Cooling air temperature:	26.7°C (80°F)
Breathing machine cycle rate:	18 cycles/min
Breathing machine volume/cycle:	1.23 liters
Oxygen flow into the breathing loop:	0.7 lb/hr
Mask outlet dew point:	32.2°C (90°F)
CO_2 flow into breathing loop:	0.135 kg/hr (0.298 lb/hr)
Metabolic rate simulation:	439.7 watts (1500 Btu/hr)

Test time of zero (start of the test) was recorded at the time that carbon dioxide flow was initiated.

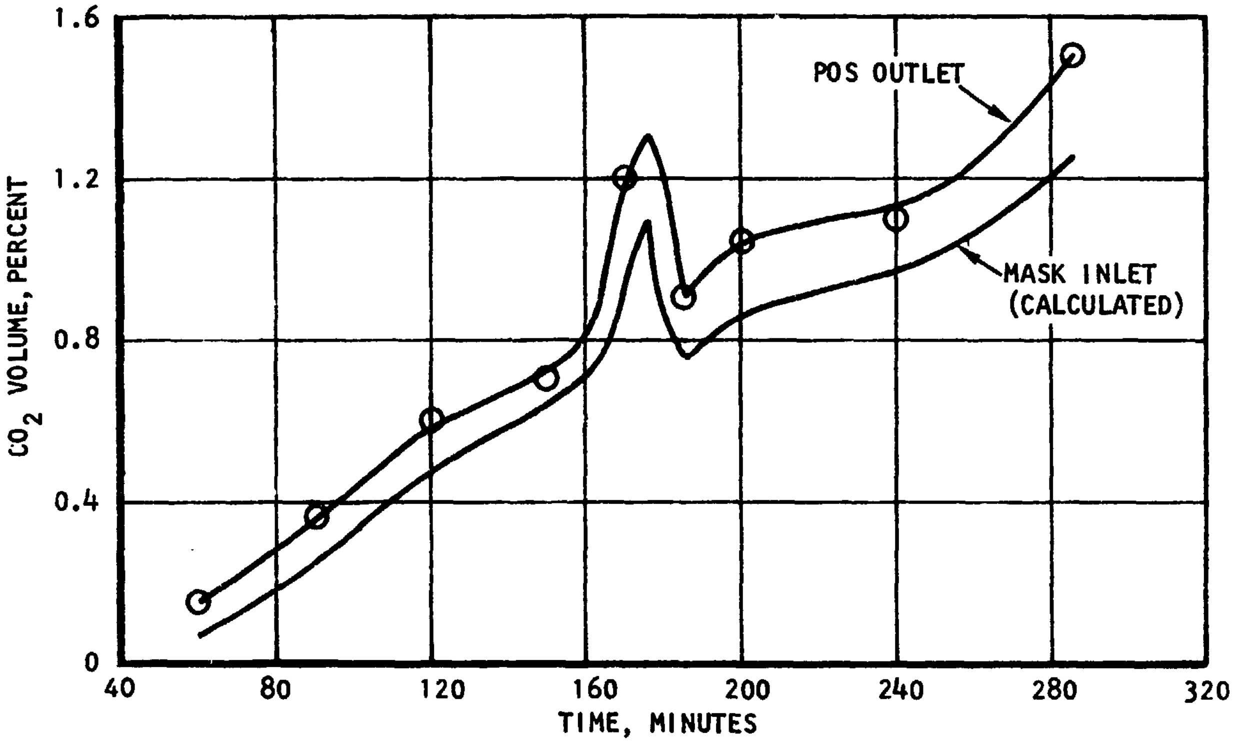

Figure 4-9. Carbon Dioxide Concentration History for Unmanned Performance Test (No. 3)

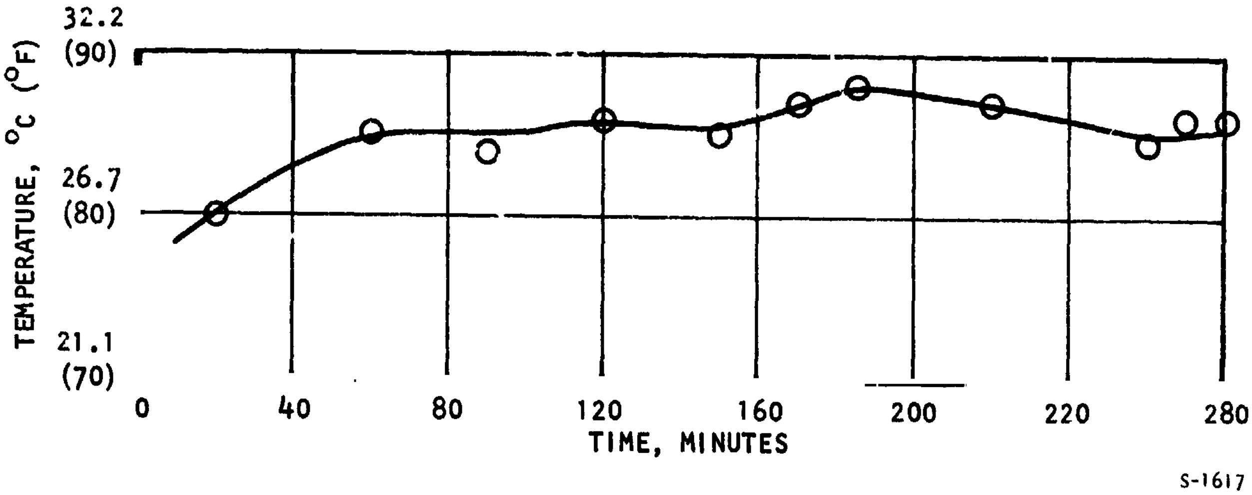

Figure 4-10. Mask Inlet Temperature History for Unmanned Performance Test (No. 3)

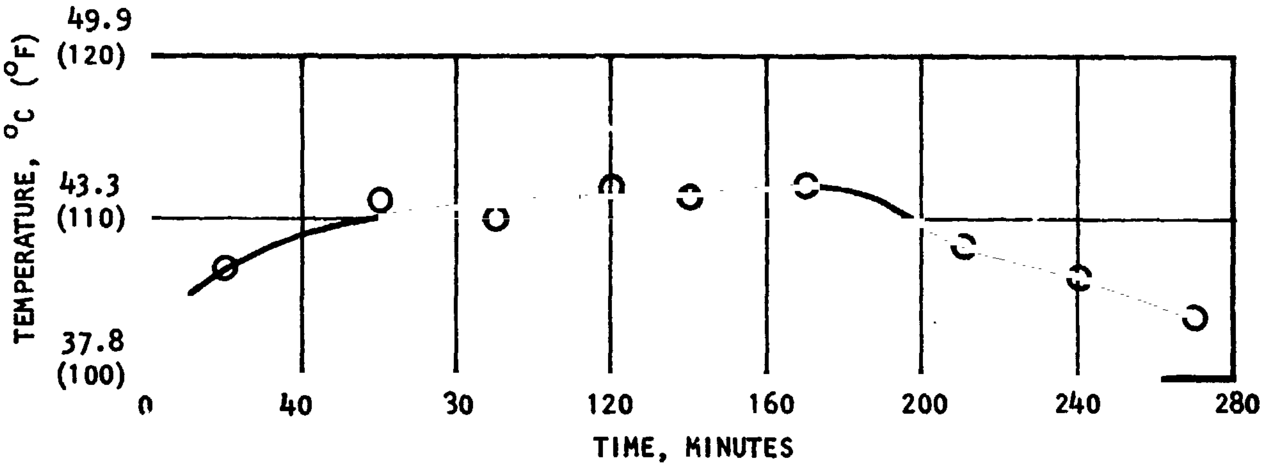

Figure 4-11. Structural Temperature History for Unmanned Performance Test (No. 3)

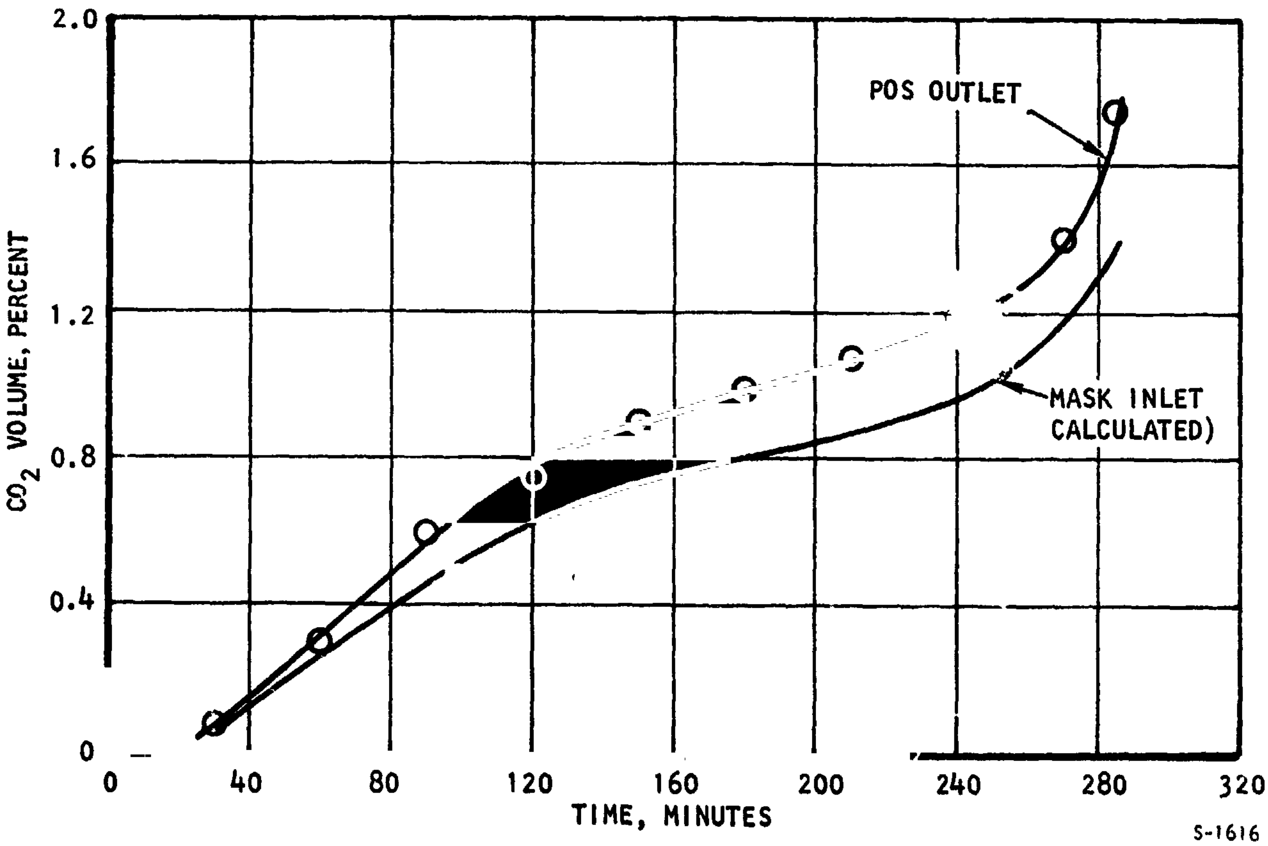

Figure 4-12. Carbon Dioxide Concentration History for Unmanned Performance Test (No. 4)

TABLE 4-3

RESULTS OF UNMANNED PERFORMANCE TEST (NO. 3)

Elapsed Time, Minutes	Demand Regulator Inlet Pressure, (GA3), kPa (psig)		Mask Inlet Pressure (GA6), kPa (in. H_2O)		Dew Point Outlet Temp., °C (°F)		POS Inlet Temp. (TC9), °C (°F)	
20	382.7	(55.5)	-0.09/+0.49	(-0.4/+2.0)	31.1	(88)	28.9	(84)
60	372.3	(54.0)	-0.01/+0.49	(-0.05/+2.0)	31.7	(89)	32.8	(91)
90	372.3	(54.0)	-0.02/+0.52	(-0.1/+2.1)	32.2	(90)	32.8	(91)
120	372.3	(54.0)	-0.02/+0.54	(-0.1/+2.2)	31.7	(89)	32.8	(91)
150	375.8	(54.5)	-0.02/+0.64	(-0.1/+2.6)	32.2	(90)	32.8	(91)
170	375.8	(54.5)	-0.02/+0.49	(-0.1/+2.0)	32.2	(90)	33.9	(93)
185	372.3	(54.0)	0/+0.49	(0/+2.0)	32.2	(90)	35.0	(95)
210	379.2	(55.0)	0/+0.52	(0/+2.1)	31.1	(88)	32.8	(91)
240	386.1	(56.0)	0/+0.49	(0/+2.0)	32.2	(90)	31.7	(89)
270	396.4	(57.5)	0/+0.42	(0/+1.7)	31.1	(88)	31.1	(88)
285	399.9	(58.0)	0/+0.44	(0/+1.8)	30.0	(86)	31.1	(88)

Elapsed Time, Minutes	POS Outlet Temp. (TC5), °C (°F)		Cooling Air Temp. (TC11), °C (°F)		LiOH Skin Temp. (TC12), °C (°F)		Mask Inlet Temp. (TC14), °C (°F)		Volume Percent		
									O_2 Out	CO_2 In	CO_2 Out
20	34.4	(94)	22.8	(73)	41.7	(107)	26.7	(80)	96.5	NR	3.80
60	36.7	(98)	22.8	(73)	43.9	(111)	29.4	(85)	97.0	0.15	3.80
90	37.2	(99)	22.8	(73)	43.3	(110)	28.9	(84)	97.0	0.36	3.80
120	37.2	(99)	23.3	(74)	44.4	(112)	30.0	(86)	96.2	0.60	3.92
150	37.8	(100)	23.3	(74)	42.8	(109)	29.4	(85)	96.0	0.70	4.00
170	38.9	(102)	23.3	(74)	44.7	(112.5)	30.6	(87)	NR	1.20	NR
185	40.0	(104)	23.9	(75)	45.8	(114.5)	31.1	(88)	NR	0.90	NR
210	36.7	(98)	23.6	(74.5)	42.2	(108)	30.6	(87)	NR	1.05	NR
240	35.6	(96)	23.3	(74)	41.1	(106)	29.1	(84.5)	NR	1.10	NR
270	33.9	(93)	23.3	(74)	39.7	(103.5)	30.0	(86)	NR	NR	NR
285	35.0	(95)	23.3	(74)	38.9	(102)	30.0	(86)	NR	1.50	4.70

NR = Not recorded.

At 3 minutes after the start of the test, the metabolic simulation was decreased to 322.4 watts (1100 Btu/hr). The following new conditions were established:

Breathing machine cycle rate:	17 cycles/min
CO_2 flow into the breathing loop:	0.099 kg/hr (0.219 lb/hr)

At 18 minutes after the start of the test, the metabolic simulation was decreased to 234.5 watts (800 Btu/hr). The following new conditions were then established:

Breathing machine cycle rate:	18 cycles/min
Breathing machine volume/cycles:	1.0 liters
CO_2 flow into the breathing loop:	0.072 kg/hr (0.159 lb/hr)

The test was terminated at the end of 287 minutes.

3. Test Results

a. Inspired Carbon Dioxide Concentration

The carbon dioxide concentration was measured at the POS outlet. This measured value and the calculated mask inlet values are shown in Figure 4-12.

b. Mask Inlet Temperature

Figure 4-13 shows the measured dry bulb and dew point temperatures at the mask inlet.

c. Structural Temperature

The highest structural temperature in the POS was found on the side of the LiOH bed next to the cooling air exhaust. This temperature is shown in Figure 4-14.

Additional test results are shown in Table 4-4.

Test No. 5 - Manned Performance

1. Test Objective and Test Setup

The manned test was performed to verify that the system would operate in a manner similar to unmanned operation. The test was performed in the same setup used for unmanned performance tests, numbers 3 and 4, except that the metabolic simulation equipment was not attached. This test setup is shown pictorially in Figure 4-15.

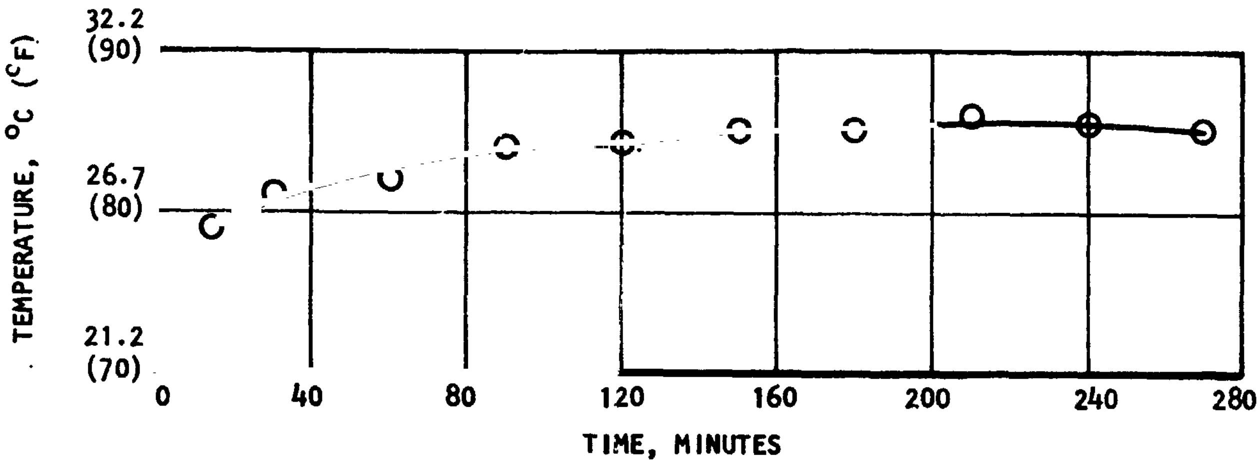

Figure 4-13. Mask Inlet Temperature History for Unmanned Performance Test (No. 4)

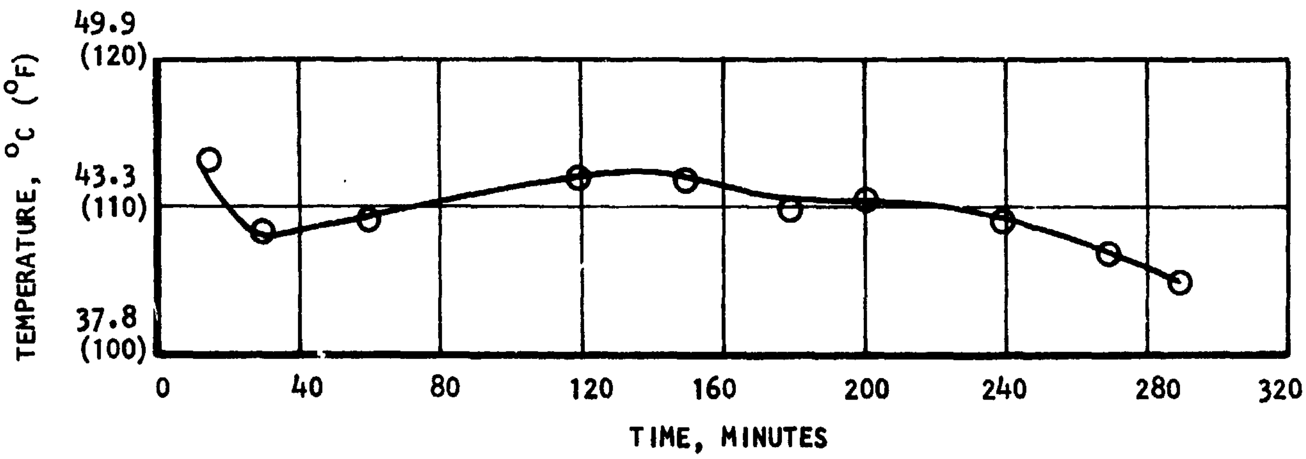

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Figure 4-14. Structural Temperature History for Unmanned Performance Test (No. 4)

TABLE 4-4

RESULTS OF UNMANNED PERFORMANCE TEST (NO. 4)

Elapsed Time, Minutes	Demand Regulator Inlet Pressure (GA3), kPa (psig)	Mask Inlet Pressure (GA6), kPa (in. H_2O)	Dew Point Outlet Temp., °C (°D)	POS Inlet Temp. (TC9), °C (°F)
15	379.2 (55.0)	0/+0.54 (0/+2.2)	33.3 (92)	34.4 (94)
30	375.8 (54.5)	0/+0.57 (0/+2.3)	31.1 (88)	36.7 (98)
60	372.3 (54.0)	-0.04/+0.49 (-0.2/+2.0)	32.2 (90)	37.2 (99)
90	372.3 (54.0)	-0.04/+0.49 (-0.2/+2.0)	32.5 (90.5)	37.2 (99)
120	372.3 (54.0)	-0.04/+0.62 (-0.2/+2.5)	32.8 (91)	36.9 (98.5)
150	386.1 (56.0)	-0.04/+0/62 (-0.2/+2.5)	32.2 (90)	36.7 (98)
180	379.2 (55.0)	-0.04/+0.62 (-0.2/+2.0)	33.3 (92)	36.7 (98)
210	389.6 (56.5)	-0.04/+0.62 (-0.2/+2.0)	32.2 (90)	36.7 (98)
240	389.6 (56.5)	-0.04/+0.67 (-0.2/+2.7)	32.2 (90)	36.1 (97)
270	393.0 (57.0)	-0.14/+0.54 (-0.6/+2.2)	31.1 (88)	35.6 (96)
285	NR (NR)	NR (NR)	31.1 (89)	NR (NR)

Elapsed Time, Minutes	POS Outlet Temp. (TC5), °C (°F)	Cooling Air Temp. (TC11), °C (°F)	LiOH Skin Temp. (TC12), °C (°F)	Mask Inlet Temp. (TC14), °C (°F)	Volume Percent		
					O_2 Out	CO_2 In	CO_2 Out
15	30.6 (87)	28.9 (84)	45.0 (113)	26.1 (79)	NR	0	NR
30	31.7 (89)	18.3 (65)	42.2 (108)	27.2 (81)	94	0.08	4.4
60	32.8 (91)	25.0 (77)	42.8 (109)	27.8 (82)	94	0.30	4.4
90	32.8 (91)	26.1 (79)	37.2 (99)	28.9 (84)	93.5	0.60	4.7
120	32.8 (91)	26.1 (79)	44.4 (112)	28.9 (84)	94.5	0.75	4.8
150	32.2 (90)	26.4 (79.5)	44.4 (112)	29.4 (85)	93.5	0.93	4.8
180	32.2 (90)	26.1 (79)	43.3 (110)	29.4 (85)	94	1.00	4.9
210	32.2 (90)	26.1 (79)	43.6 (110.5)	30.0 (86)	95	1.09	4.9
240	32.2 (90)	26.1 (79)	42.8 (109)	30.3 (85.5)	95	1.20	5.0
270	31.7 (89)	26.1 (79)	41.7 (107)	29.4 (85.0)	95	1.40	5.0
285	NR (NR)	26.1 (79)	40.6 (105)	29.4 (85.0)	95	1.75	5.1

NR = Not recorded.

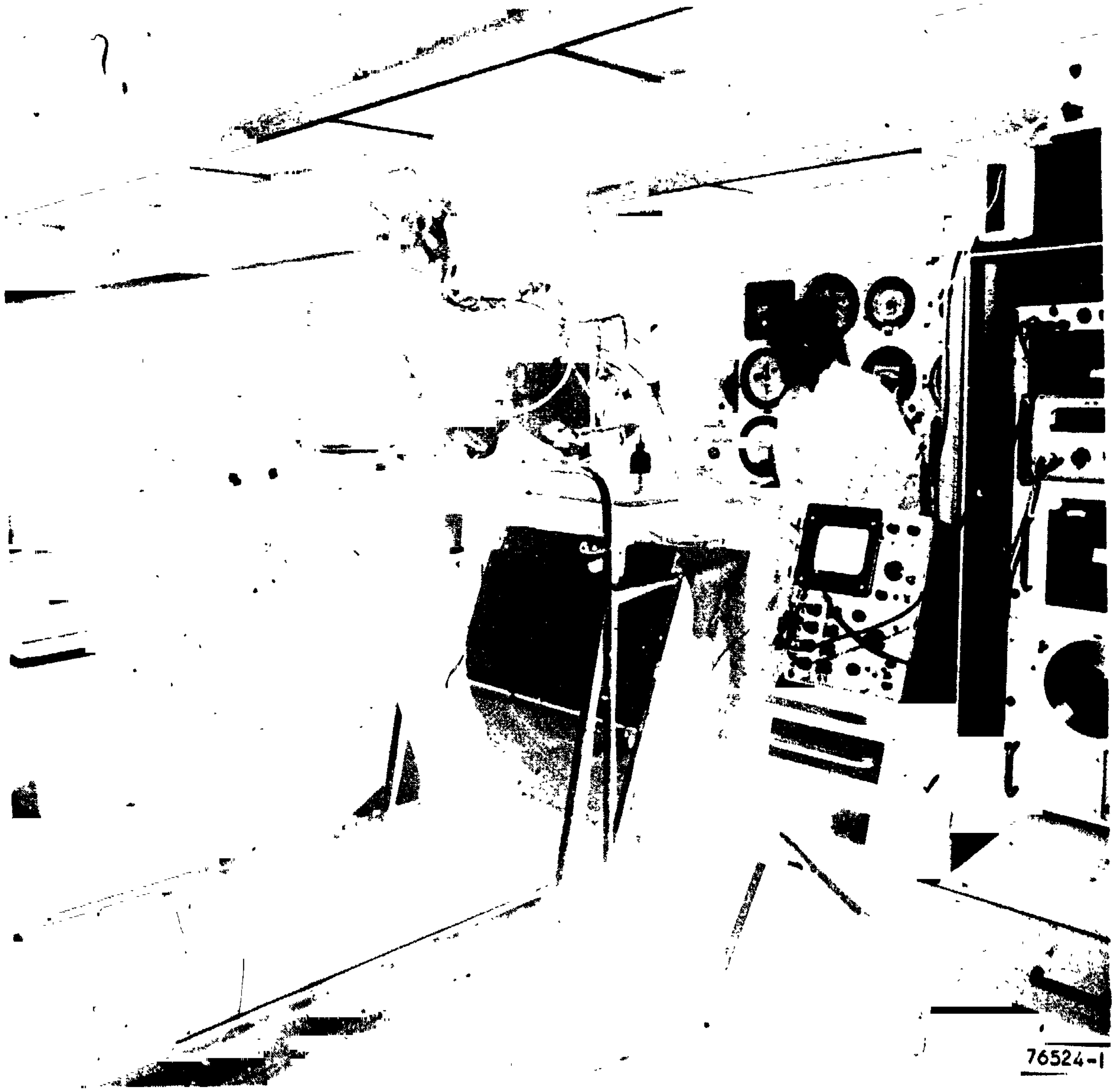

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Figure 4-15. Setup for Manned Performance Test (No. 5)

An accurate calibration of the manned test subject could not be obtained. However, based on past treadmill testing performed at AiResearch, a treadmill speed profile was established that closely approximated the desired values.

2. Test Procedure

Cooling air flow and temperature and oxygen flow was established as described for unmanned test No. 3. The manned test subject donned the mask and purged the breathing loop. Two minutes after the mask had been donned, the treadmill was started at a speed of 4.2 km/hr (2.5 miles/hr). At 162 minutes, the treadmill speed was increased to 5.3 km/hr (3.2 miles/hr). At 177 minutes, the treadmill speed was again increased to 6.6 km/hr (3.96 miles/hr). At 180 minutes, the treadmill speed was decreased to the starting value of 4.2 km/hr (2.5 miles/hr) for an additional 10 minutes.

3. Test Results

a. Denitrogenization

The mask outlet nitrogen concentration was 3.0 volume percent at the end of five minutes and 1.3 volume percent at the end of 30 minutes.

b. Inspired Carbon Dioxide Concentration

The carbon dioxide concentration was measured at the POS outlet. This measured value and the calculated mask inlet values are shown in Figure 4-16.

c. POS Outlet and Mask Inlet Temperatures

Figure 4-17 shows the measured dry bulb and dew point temperatures at the POS outlet and the calculated mask inlet dry bulb and dew point temperatures.

d. Structural Temperature

The LiOH skin temperature was not measured in this test.

Additional test results are shown in Table 4-5.

4. Test Data Evaluation

a. Metabolic Rate Determination

The amount of Li_2CO_3 was determined by performing a chemical analysis of the spent LiOH after the test was completed. The amount of CO_2 absorbed was then determined, using the chemical equation for LiOH absorption of CO_2. The amount of CO_2 vented (25.5 weight percent) from the breathing loop was taken as the average of that determined for the unmanned tests. The CO_2 production rate was calculated as shown in the following equation:

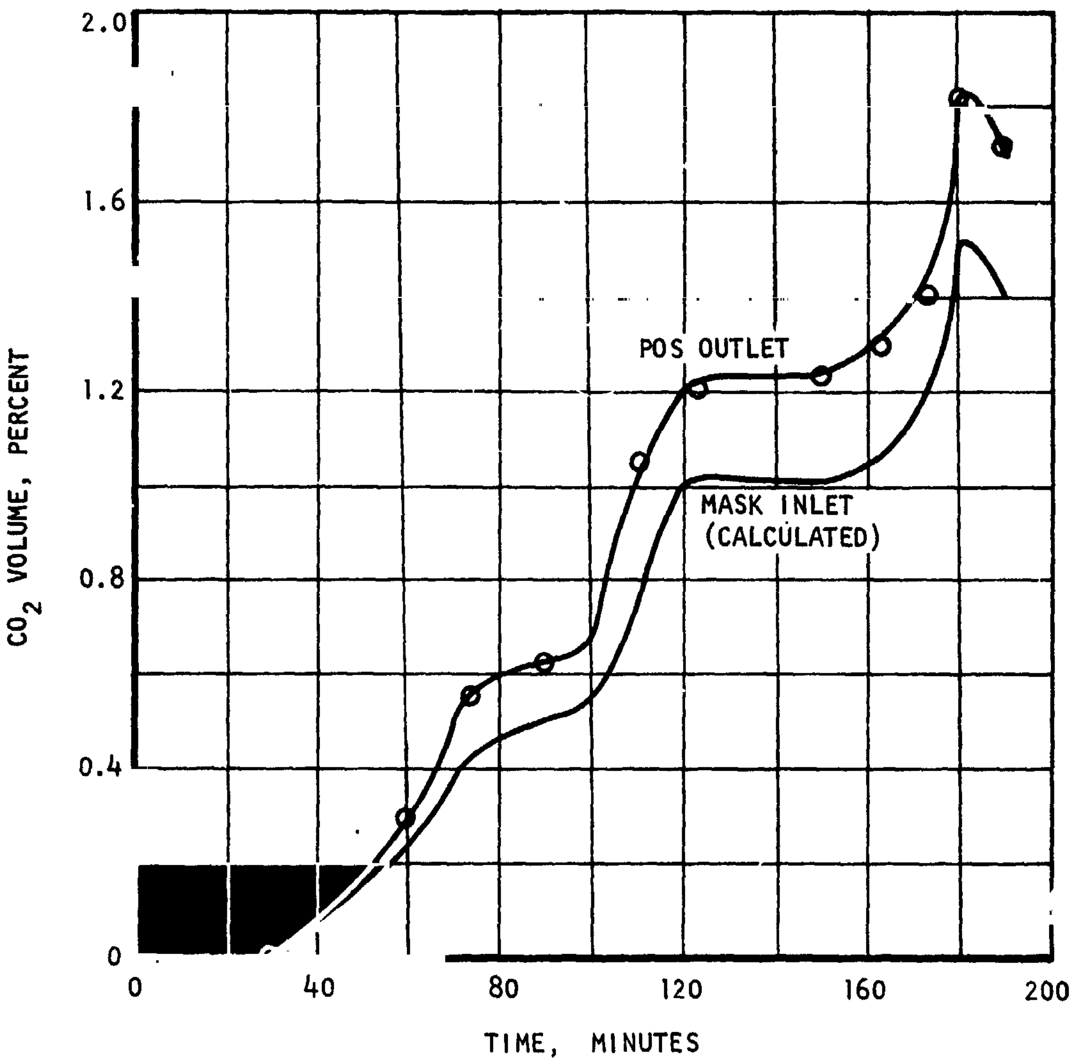

Figure 4-16. Carbon Dioxide Concentration History for Manned Performance Test (No. 5)

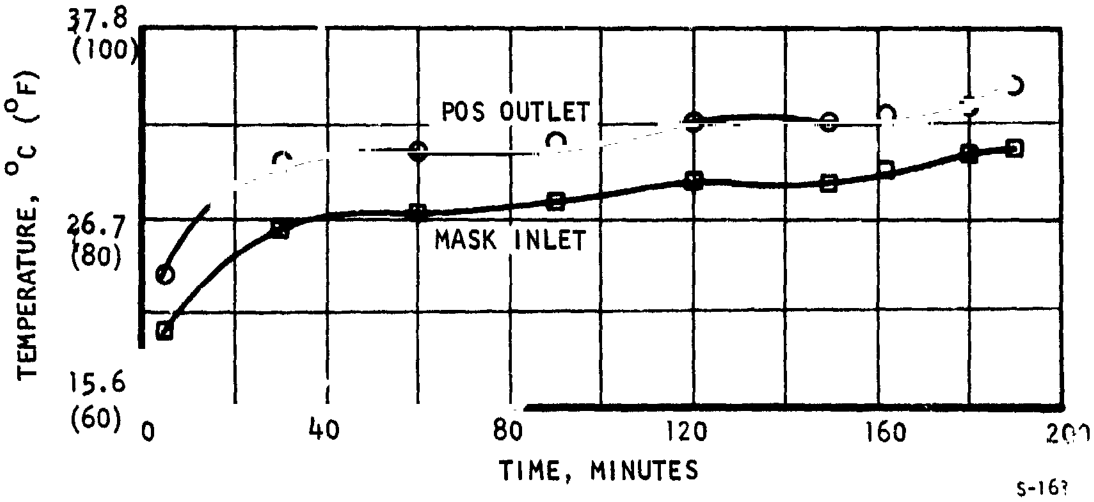

Figure 4-17. POS Outlet and Mask Inlet Temperature History for Manned Performance Test (No. 5)

TABLE 4-5

RESULTS OF MANNED PERFORMANCE TEST (NO. 5)

Elapsed Time, Minutes	Demand Regulator Inlet Pressure (GA3), kPa (psig)	Mask Outlet Pressure (GA6), kPa (in. H_2O)	Dew Point Outlet Temp., °C (°F)	POS Inlet Temp. (TC9), °C (°F)
5	399.9 (58)	-0.04/+0.62 (-0.2/+2.5)	27.8 (82)	23.9 (75)
30	406.8 (59)	-0.04/+0.79 (-0.2/+3.2)	31.9 (89.5)	33.0 (91.5)
60	410.3 (59.5)	-0.04/+0.64 (-0.2/+2.6)	32.2 (90.0)	33.6 (92.5)
90	410.3 (59.5)	-0.04/+0.52 (-0.2/+2.1)	32.8 (91.0)	33.9 (93.0)
120	410.3 (59.5)	-0.04/+0.74 (-0.2/+3.0)	33.3 (92.0)	33.9 (93.0)
150	410.3 (59.5)	-0.27/+0.79 (-1.1/+3.2)	33.3 (92.0)	34.1 (93.5)
162	410.3 (59.5)	-0.22/+0.64 (-0.9/+2.6)	33.3 (92.0)	34.1 (93.5)
180	413.7 (60.0)	-0.24/+0.67 (-1.0/+2.7)	34.4 (94.0)	35.0 (95.0)
190	417.1 (60.5)	-0.12/+0.77 (-0.5/+3.1)	NR (NR)	35.0 (95.0)

Elapsed Time, Minutes	POS Outlet Temp. (TC5), °C (°F)	Cooling Air Temp. (TC11), °C (°F)	Volume Percent			
			N_2 Out	O_2 Out	CO_2 In	CO_2 Out
5	23.3 (74)	21.7 (71)	3.0	89	NR	3.90
30	30.0 (86)	22.2 (72)	1.3	93	0.1	3.58
60	30.6 (87)	22.2 (72)	1.3	92	0.25	3.78
90	31.1 (88)	22.8 (73)	1.3	92	0.60	3.88
120	32.2 (90)	22.8 (73)	Off	92	1.14	4.10
150	33.3 (92)	22.2 (72)	Off	92.5	1.15	4.30
162	32.8 (91)	21.9 (71.5)	Off	91.5	1.30	5.10
180	33.3 (92)	22.2 (72)	NR	NR	2.0	5.10
190	34.4 (94)	22.2 (72)	NR	NR	1.9	NR

NR = Not recorded.

An accurate calibration of the manned test subject could not be obtained. However, based on past treadmill testing performed at AiResearch, a treadmill speed profile was established that closely approximated the desired values.

2. Test Procedure

Cooling air flow and temperature and oxygen flow was established as described for unmanned test No. 3. The manned test subject donned the mask and purged the breathing loop. Two minutes after the mask had been donned, the treadmill was started at a speed of 4.2 km/hr (2.5 miles/hr). At 162 minutes, the treadmill speed was increased to 5.3 km/hr (3.2 miles/hr). At 177 minutes, the treadmill speed was again increased to 6.6 km/hr (3.96 miles/hr). At 180 minutes, the treadmill speed was decreased to the starting value of 4.2 km/hr (2.5 miles/hr) for an additional 10 minutes.

3. Test Results

a. Denitrogenization

The mask outlet nitrogen concentration was 3.0 volume percent at the end of five minutes and 1.3 volume percent at the end of 30 minutes.

b. Inspired Carbon Dioxide Concentration

The carbon dioxide concentration was measured at the POS outlet. This measured value and the calculated mask inlet values are shown in Figure 4-16.

c. POS Outlet and Mask Inlet Temperatures

Figure 4-17 shows the measured dry bulb and dew point temperatures at the POS outlet and the calculated mask inlet dry bulb and dew point temperatures.

d. Structural Temperatures

The LiOH skin temperature was not measured in this test.

Additional test results are shown in Table 4-5.

4. Test Data Evaluation

a.

The amount of Li_2CO_3 was determined by performing a chemical analysis of the spend LiOH after the test was completed. The amount of CO_2 absorbed was then determined, using the chemical equation for LiOH absorption of CO_2. The amount of CO_2 vented (25.5 weight percent) from the breathing loop was taken as the average of that determined for the unmanned tests. The CO_2 production rate was then calculated. These analyses are shown below.

b. LiOH Bed Analysis After Test

Weight: 1.20 lb

Product Analysis:

LiOH	29.1 wt percent
Li_2CO_3	66.3 wt percent
H_2O	4.6 wt percent

$$\text{Weight of } CO_2 \text{ absorbed} = \frac{44}{74} \times 0.663 \times 1.2 = 0.473 \text{ lb}$$

c. CO_2 Production Rate

The average amount of CO_2 dumped overboard through the relief valve during the three unmanned tests was 25.5 percent. Assuming the percentage dumped during this test was the same, the total CO_2 produced was:

$$\dot{w}\, CO_2 = 1.255 \times 0.473 = 0.594 \text{ lb}$$

The CO_2 production rate at 2.5 miles/hr was determined as follows.

$$(\dot{w}\, CO_2 \times 172 \text{ min}) + (\frac{1100}{800}\ \dot{w}\, CO_2 \times 15 \text{ min}) + (\frac{1500}{800}\ \dot{w}\, CO_2 \times 3 \text{ min})$$

$$= (0.594 \times 60 \text{ min/hr})$$

$$\therefore \dot{w}\, CO_2 = 0.180 \text{ lb/hr}$$

The calculated CO_2 production rates and metabolic rates, assuming an R.Q. of 0.9, are listed in Table 4-6.

TABLE 4-6

CO_2 PRODUCTION AND METABOLIC RATES

Elapsed Time, minutes	CO_2 Production Rate, kg/hr (lb/hr)	Metabolic Rate, watts (Btu/hr)
0 to 162	0.082 (0.180)	260.9 (890)
162 to 177	0.112 (0.248)	360.5 (1230)
177 to 180	0.153 (0.338)	489.5 (1670)
180 to 190	0.082 (0.180)	260.9 (890)

TEST INSTRUMENTATION

The complete instrumentation used for the development tests, including that installed in the POS itself, is listed in Table 4-7.

TABLE 4-7

POS DEVELOPMENT TEST INSTRUMENTATION LIST

Instrumentation Designation	Range	Mfg./Type	Serial No.	Registration No.	Certification Period	DTP-75-11560 Smallest Readable Increment
GA1	0-1000 psig	Heise Gage	[illegible]	44N569	8-25-75 to 1-5-76	2 psi
GA2	10-0-10 in. H_2O	W&T Gage	GG07969	46K269-5	10-6-75 to 2-9-76	0.1 in. H_2O
GA3	0-200 psig	M&D Gage	2396	44Q482	9-8-75 to 1-12-76	0.5 psi
GA4	0-10 in. H_2O	W&T Gage	HHO[illegible] 2	44T028	10-6-75 to 2-9-76	0.05 psi
GA6	10-0-10 in. H_2O	W&T Gage	HH11118	231070192	10-6-75 to 2-9-76	0.1 in. H_2O
GA7	10-0-10 in. H_2O	W&T Gage	GG07970	46K265-9	10-6-75 to 2-9-76	0.1 in. H_2O
DX1	0-10 in. H_2O	Barton Gage	200-24186	44T029	10-6-75 to 2-9-76	0.1 in. H_2O
DX2	0-10 in. H_2O	Barton Gage	200-27141	44P377	[illegible]-6-75 to 2-9-76	0.05 in. H_2O
DX3-6	0-10 in. H_2O	Barton Gage	200-20396	46K265-19	[illegible] 75 to 2-9-76	0.1 in. H_2O
DX4	0-10 in. H_2O	Barton Gage	200-28895	44S030	10-[illegible]-75 to 2-9-76	0.05 in. H_2O
DX5	0-10 in. H_2O	Barton Gage	200-28896	44S031	1[illegible]-75 to 2-9-76	0.05 in. H_2O
P01	0-150 psia	W&T Gage	HH11710	46K400-5	10-6-75 to 2-9-76	0.2 psi
P02	0-50 psia	W&T Gage	GG09573	44N628	10-6-75 to 2-9-76	0.3 psi
P03-6	0-300 psia	M&D Gage	1306	44N518	10-6-75 to 2-9-76	0.05 psi
P04	0-50 psia	W&T Gage	LL02495	44P367	10-6-75 to 2-9-76	0.05 psi
P05	0-50 psia	W&T Gage	PP[illegible] 91	231110119	10-6-75 to 2-9-76	0.05 psi
FM1	0-.9 PPH at 60 psia	N.I.L. Flowmeter	2256	44D156	10-8-75 to 10-8-76	--
FM2	0-16 PPH at 30 psia	N.I.L. Flowmeter	3107	44C805	10-8-75 to 10-8-76	--
FM3	0-10 PPH at 115 psia	N.I.L. Flowmeter	3104	44C803	10-8-75 to 10-8-76	--
FM4	0-.3 PPH at 14.7 psia	N.I.L. Flowmeter	3102	44C798	4-17-75 to 4-17-76	--
FM5	0-150 sccm	N.I.L. Flowmeter	2377	44D198	10-8-75 to 10-8-76	--
FM6	0-.01 PPH at 60 psia	N.I.L. Flowmeter	3099	44C802	10-8-75 to 10-8-76	--
TC4	-100°F to +300°F	Honeywell Recorder	Q1176950001	43C258	10-21-75 to 1-23-76	--
TC5 & 6	-100°F to +300°F	Honeywell Recorder	U4709567001	2630100[illegible]	9-30-75 to 1-2-76	--
TC7 & 9	0°F to +200°F	Honeywell Recorder	F4670987003	43C173	--	--
Dew Pointer	-40°F to +120°F	EG&G Hygrometer	0816	235010031	10-24-75 to 4 23-76	1.0°F
CO_2 Analyzer	--	L&N Recorder	--	43C27[illegible]	10-21-75 to 1-23-76	--
O_2 Analyzer	0-100%	L&N Recorder	--	43C159	9-30-75 to 1-2-76	--
Temp. Pot.	-340°F to +230°F	L&N Temp. Pot.	No. 8692	43B159	7-24-75 to 1-22-76	1.0°F
SC1	0-101 LBS	Triner Scales	6711385	45B161	6-10-75 to 6-10-76	0.01 LB