NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 6

Get DRA

RELATED SYSTEMS EVALUATION

VOLUME IV
GOVERNMENT FURNISHED EQUIPMENT
AND
GROUND SUPPORT EQUIPMENT

MAY 1970

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

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Volume IV

Government Furnished Equipment
and
Ground Support Equipment

CONTENTS

1.0 INTRODUCTION

This volume presents the results of the Panel 6 (Related Systems Evaluation) review of the Government Furnished Equipment (GFE) and Ground Support Equipment (GSE).

Organization of the material in this volume is as follows:

2.0 Government-Furnished Equipment (GFE)

Apollo Flight GFE was reviewed during the activities of Panel 6C, MSC Apollo 13 GFE Investigation Team to identify all high pressure vessels and oxygen systems included in the various GFE end items. The purposes of this document are to summarize the data which were used to assess the adequacy of the design and testing programs, and present the results of this assessment for the pressure vessel and related O_2 systems listed below.

PLSS (Portable Life Support System O_2 Bottle)

OPS (Oxygen Purge System) O_2 Bottles

Life Raft CO_2 Cylinders

Life Vest CO_2 Cartridges

RTG (Radioisotope Thermal Generator) Capsule

LGEC (Lunar Geological Exploration Camera) Gas Bottles

PSE (Passive Seismic Experiment) Caging System

2.1 Portable Life Support System (PLSS)

2.1.1 Description

The total PLSS O_2 Flow Schematic is shown in Figures 2.1-1 and 2.1-2. In use, O_2 is circulated through the Pressure Garment Assembly (Space Suit), Contaminant Control Assembly (LiOH Canister), sublimator, and Water Separator by the PLSS Fan. The supply regulator permits automatic make-up from the supply bottle of O_2 lost through metabolism or leakage. Figure 2.1-3 presents a fully assembled view of the PLSS with the OPS installed on top. Figures 2.1-4 and 2.1-5 show the location of the PLSS O_2 bottle inside the PLSS case and the 1/32" aluminum protective shield. The case is made from 1/4" aluminum honeycomb with fiberglass facing plates.

Two PLSS Units are assigned to each mission, with one stowed on the LM floor and one on the aft bulkhead, as shown in Figures 2.1-6 and 2.1-7, during translunar flight. The units are checked in the LM prior to each Extra-Vehicular Activity excursion (EVA) and are worn as back-packs for life support during the EVA. The primary oxygen supply bottles are recharged with O_2 from the LM system between EVA's and are normally off-loaded to the lunar surface prior to LM lift-off. The location of the units during recharge is shown in Figure 2.1-8.

The components of the PLSS system which are subjected to the highest potential pressure of 1110 psig are restricted to those above the ball and stem valve closure of the regulator which is shown in Figure 2.1-9 and 2.1-10. The portions downstream from the valve seat,

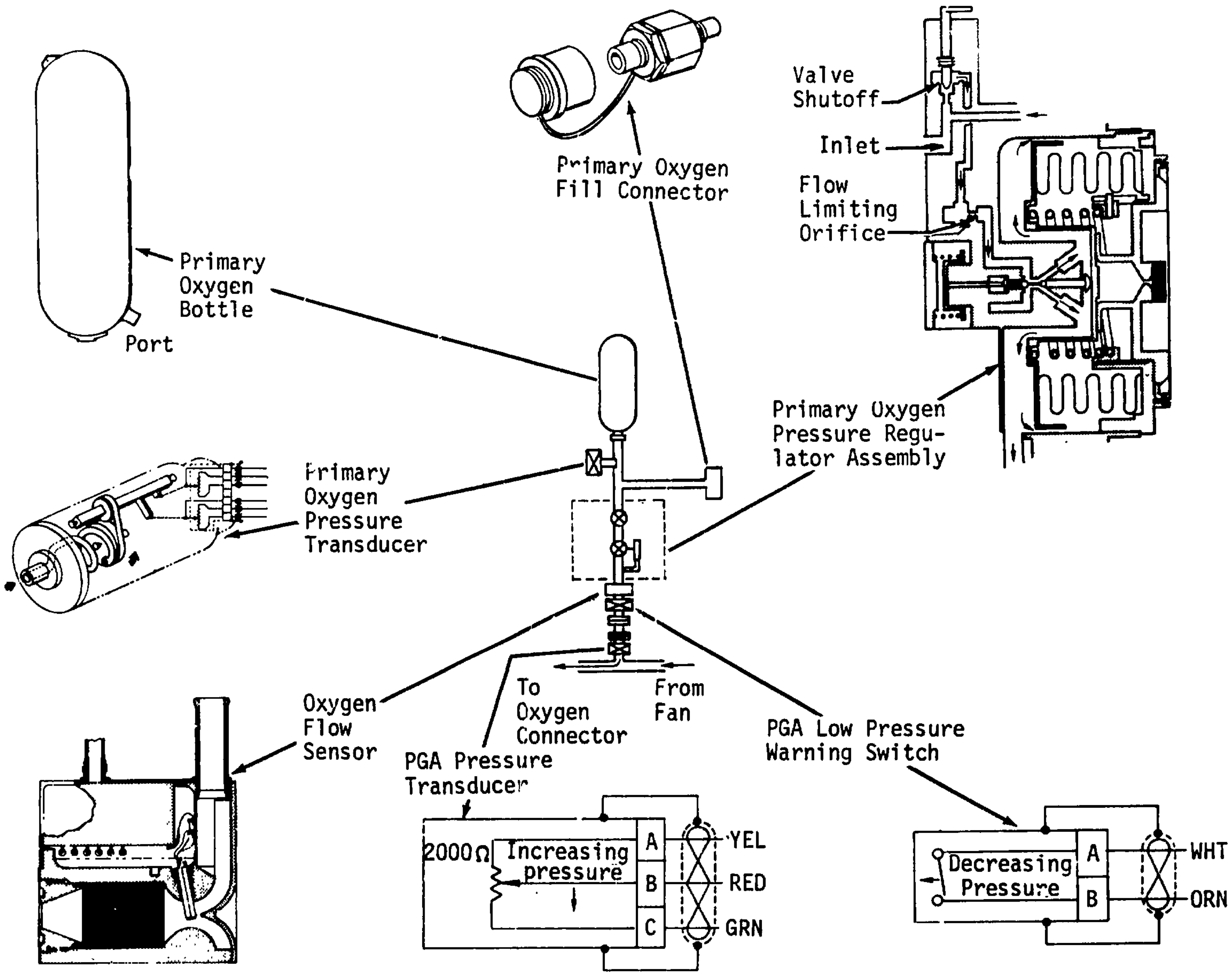

Figure 2.1-1. PLSS Primary Oxygen Subsystem Schematic

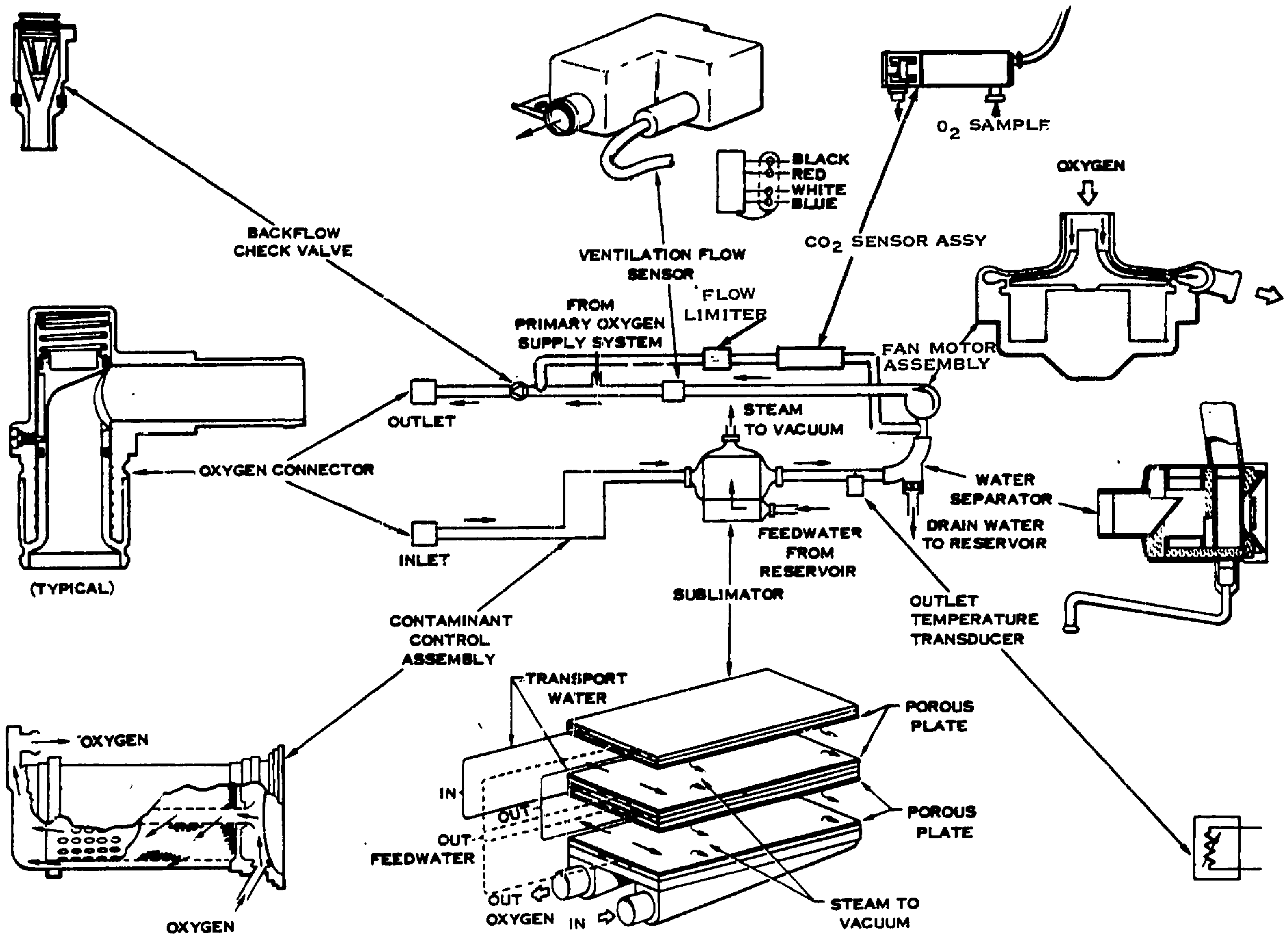

Figure 2.1-2. PLSS Oxygen Ventilating Circuit Schematic.

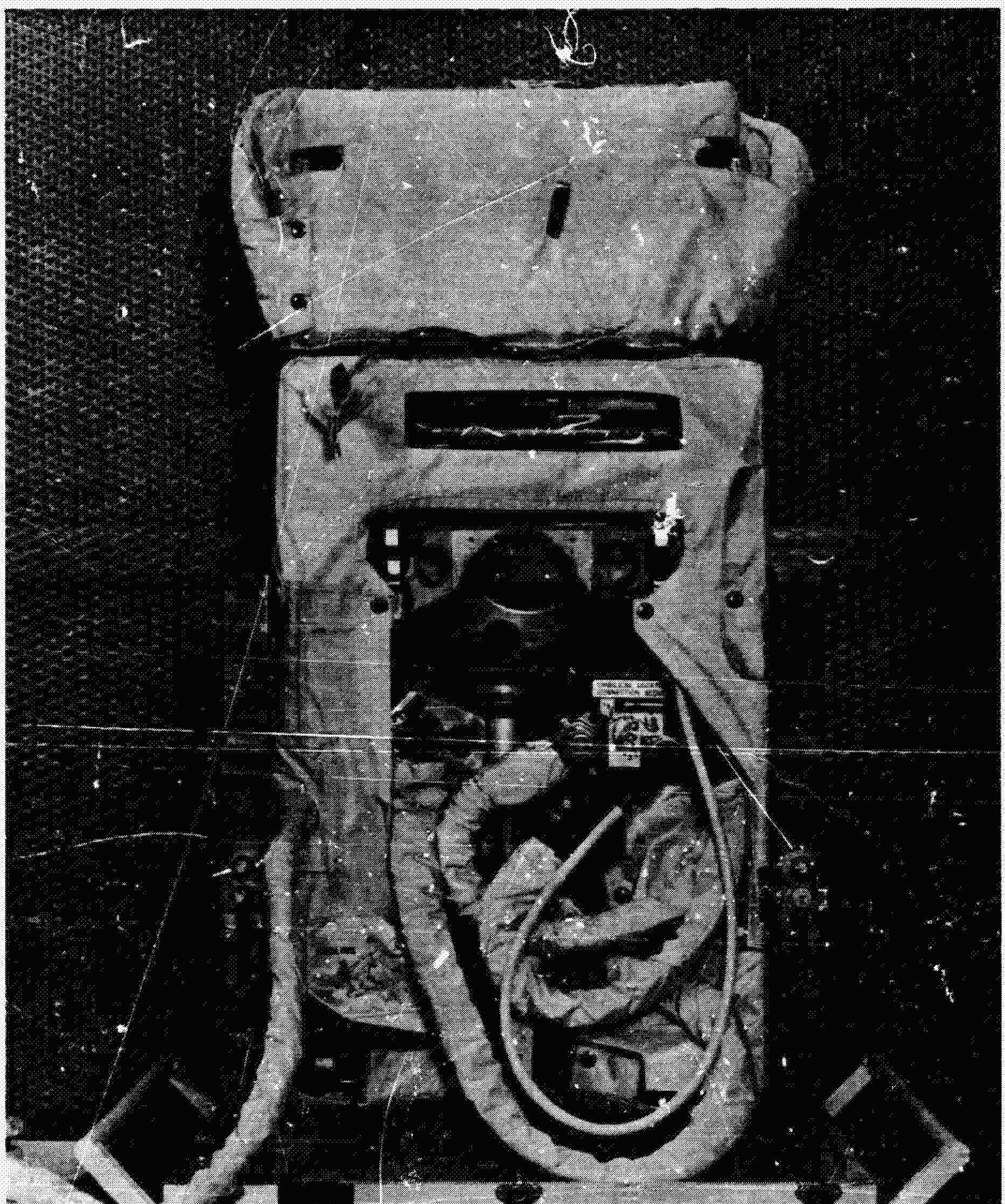

Figure 2.1-3

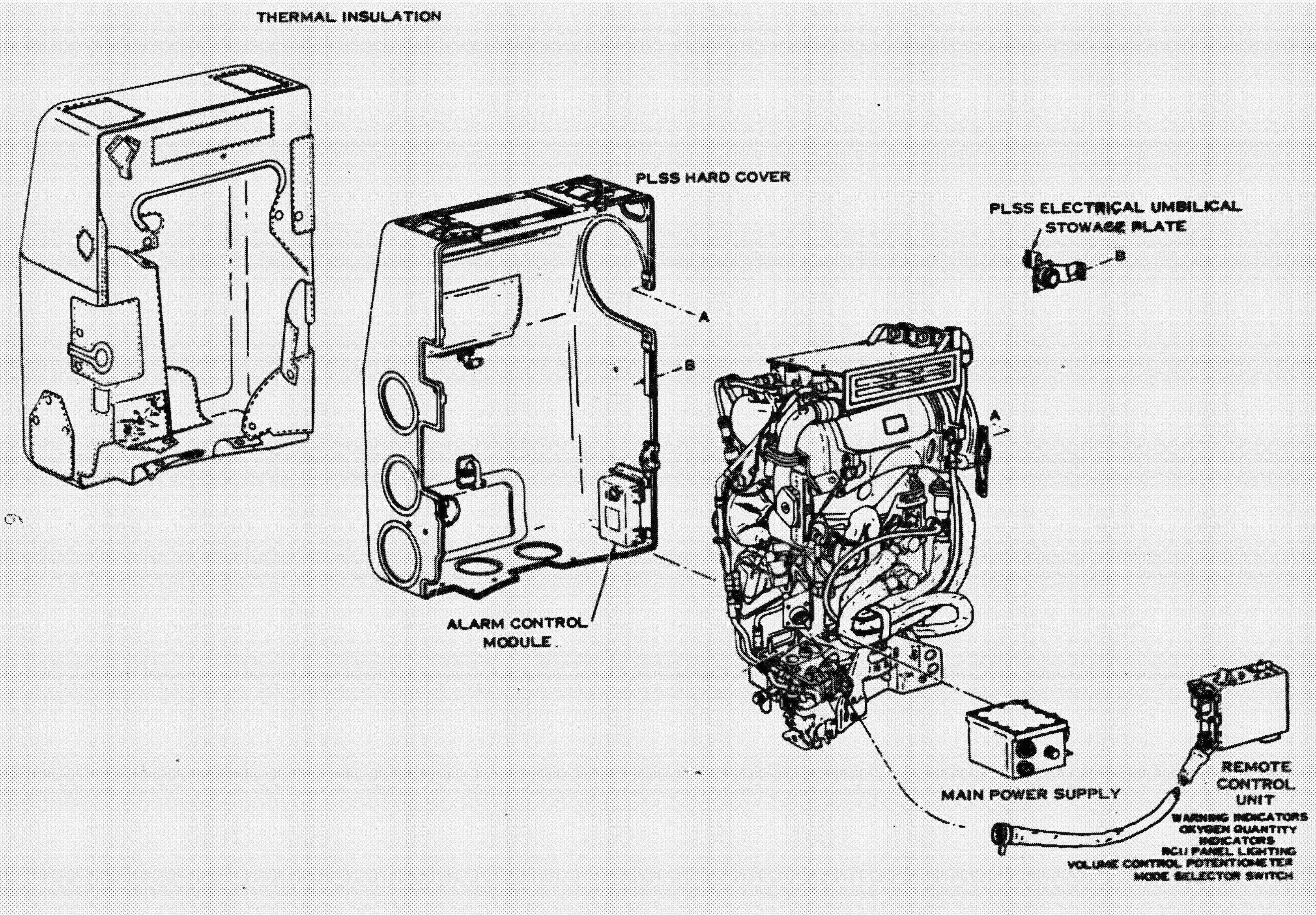

Figure 2.1-4. Portable Life Support System (PLSS)

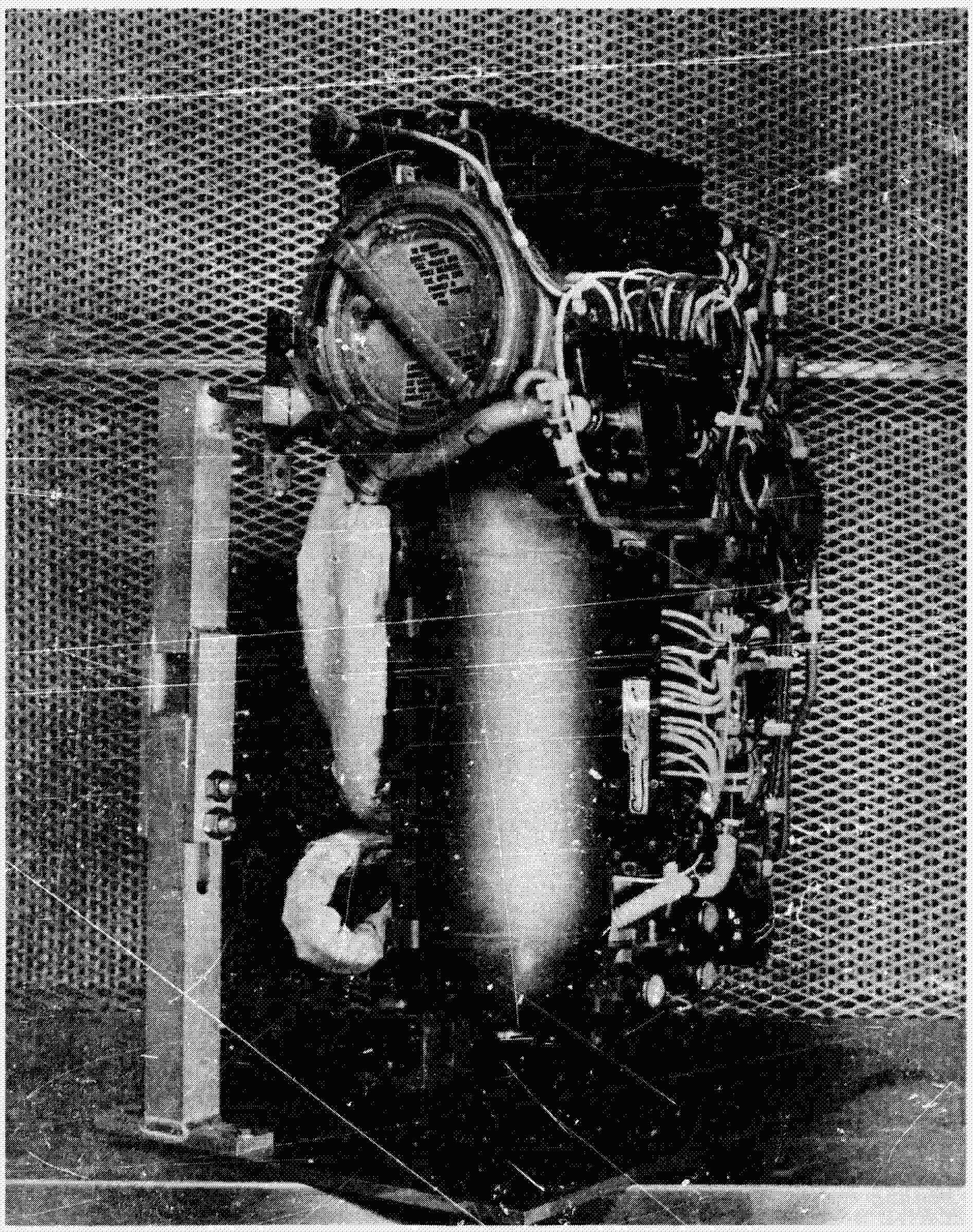

Figure 2.1-5

Figure 2.1-6

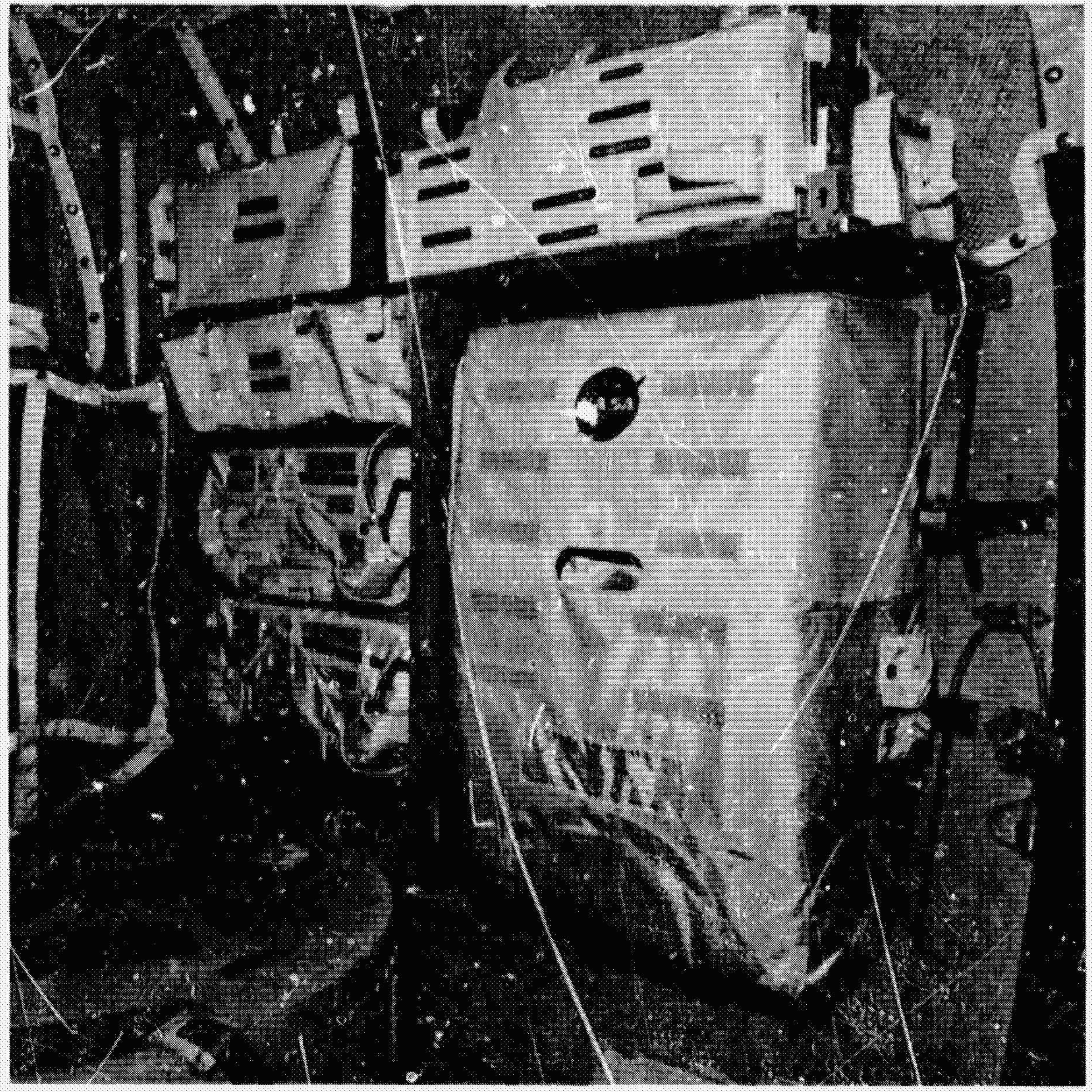

Figure 2.1-7

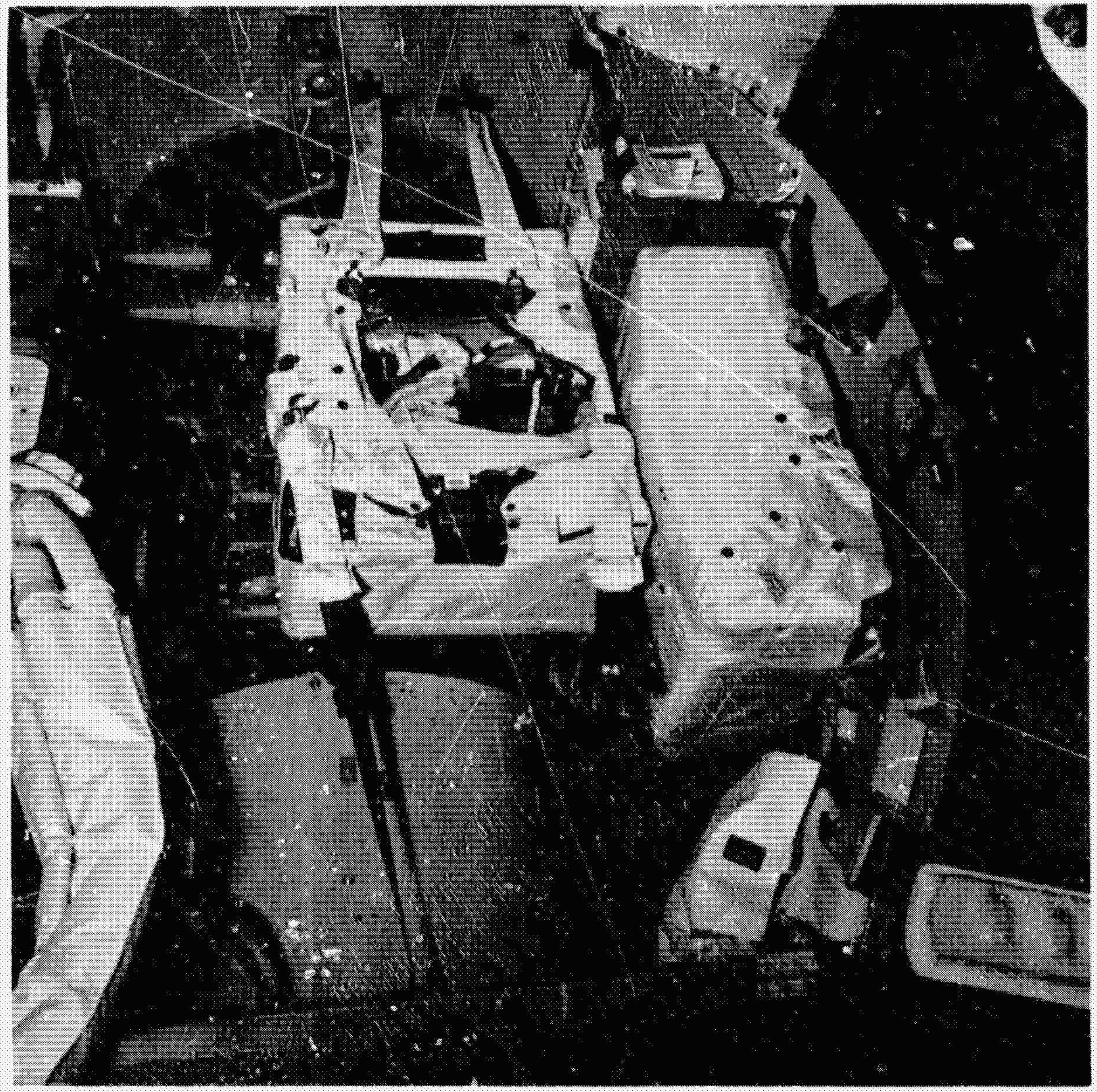

Figure 2.1-8

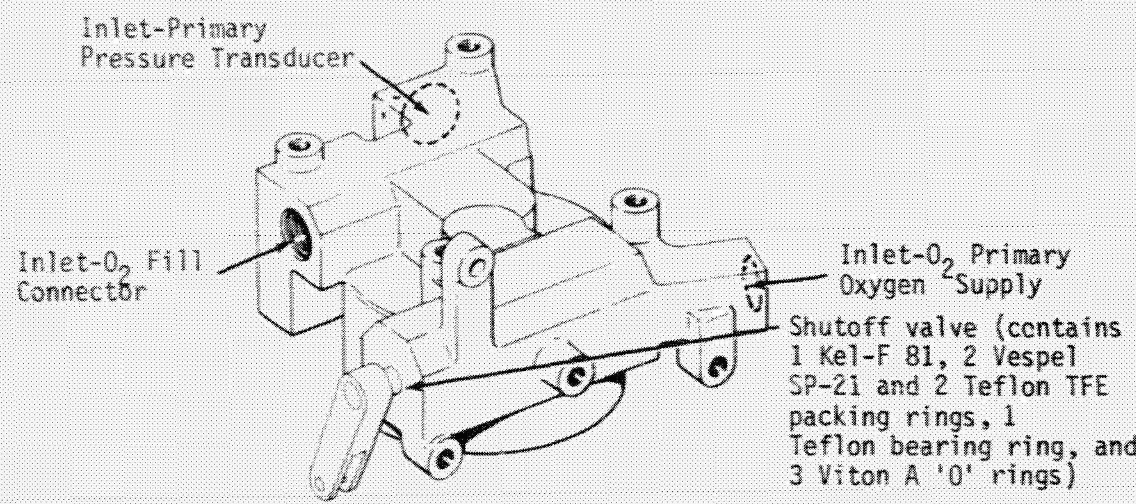

Figure 2.1-9. Primary Oxygen Regulator Assembly.

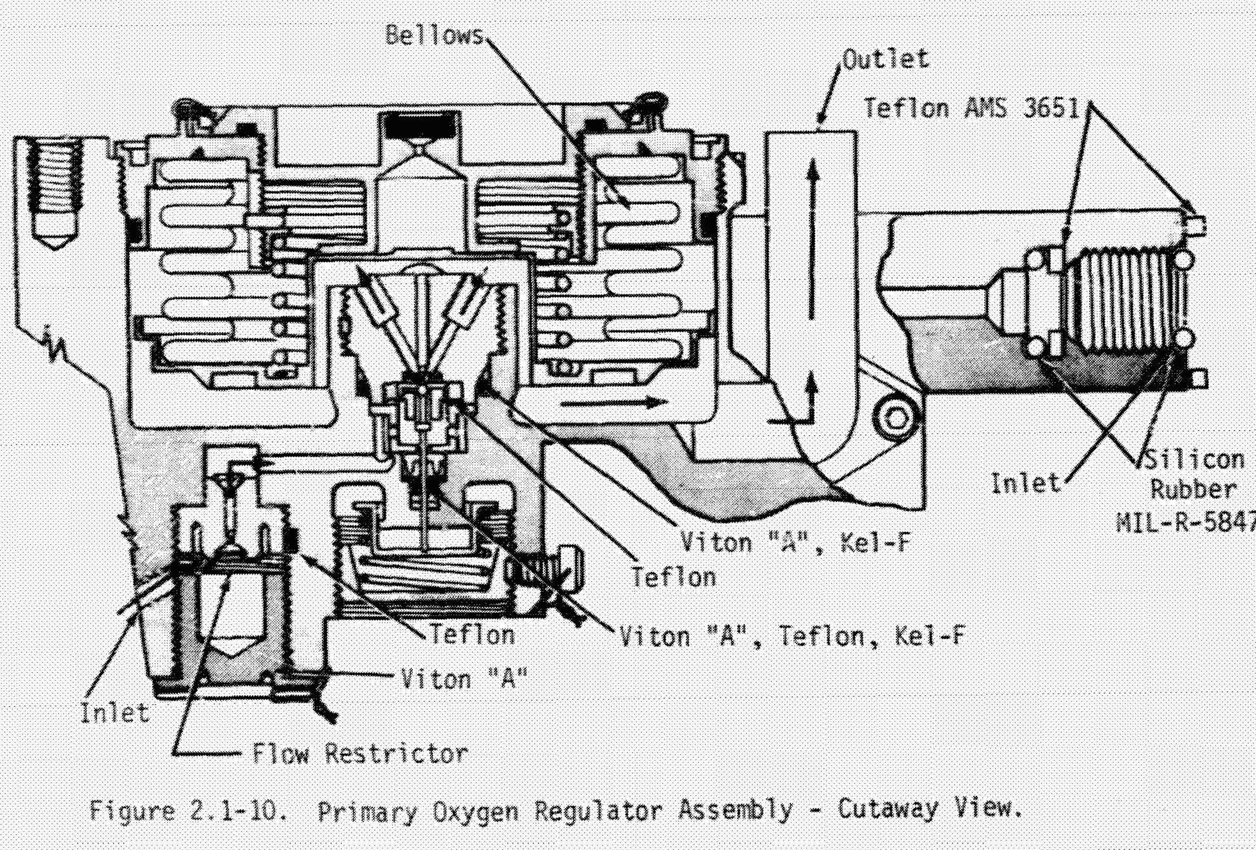

Figure 2.1-10. Primary Oxygen Regulator Assembly - Cutaway View.

including the bellows, are subjected normally to $3.85 \pm .15$ psig. This may increase to 5.5 psig in the event of total failure of the regulator. In this case the space suit relief valve is sized to permit maximum flow through the regulator flow limiting orifice and maintain suit pressure at 5.5 psig maximum.

2.1.2 Discussion

The characteristics of the PLSS O_2 bottle are shown in Table 2.1-1, which includes the safety factor of 2.1 derived from qualification test results summarized in Table 2.1-2. The bottles, which are made from .028 mil 301 cryoformed steel, and the forgings are dye penetrant, x-ray, and ultrasonically checked both in process and after fabrication to detect manufacturing defects. The bottles have no internal electrical or non-metallic components. The boss mounting for the tank prevents the stress corrosion that would be encountered with a mounting strap. External sources for pressure increase include increases in LM cabin temperature due to a general LM cabin fire, or simultaneous failure of the LM dual pressure regulators, relief valve and burst disc during O_2 recharge. The PLSS bottle shield and insulation prevent local hot spots on the tank. The shield and PLSS structure minimize the potential for mechanical damage to the tank during stowage or PLSS operation. The O_2 bottle is protected from pressure surges from the low pressure loop by the regulator and the fact that the umbilical outlets provide a ready path for pressure decay.

The characteristics of all PLSS O_2 System components that are subjected to high pressures and all electrically interfacing components are summarized in Table 2.1-3. Figures 2.1-10 through 2.1-14 show cross-sections with the location of non-metallic materials in the components of the high pressure system. Note that the primary O_2 pressure transducer is the only electrical component exposed to high pressure. The PLSS shut off valve is normally turned off except for EVA and in EVA operation all parts of the pressure regulator downstream of the ball/stem valve closure are exposed to low pressure only. High pressure impact applications are the ball/stem valve, shut off valve, and O_2 fill connector. Of these, the fill connector alone involves non-metallic materials (see Figure 2.1-14). The connector contains an internal seal which could be impacted under a maximum pressure of 1110 psi. Liquid Oxygen (LOX) tests at Marshall Space Flight Center and Gaseous Oxygen (GOX) impact testing up to 2000 psi at MSC and White Sands indicate no problems should be anticipated in the application.

Off limit testing of selected PLSS system components was conducted to determine their ignition potential. Included were the Primary O_2 Pressure Transducer, the Fan/Motor Assembly and the O_2 Fill Connector. Results are summarized in Table 2.1-4. All tests simulated worst case conditions except the Primary O_2 Pressure Transducer, which could be subjected to 1110 psi O_2 if the transducer bourdon tube (see Figure 2.1-11) failed. Since this component has been tested to 13,500 psi without leakage, corresponding to a safety factor of 12, this failure mode is considered remote. The component to battery circuit for the transducer

GFE - PRESSURE VESSEL DATA

PRESSURE VESSEL (MANUFACTURER)	PART NUMBER	QUANTITY REQUIRED	VESSEL DIMENSIONS	VESSEL MATERIAL	NORMAL OPERATING PRESSURE (PSIA)	DESIGN PRESSURE (PSIA) LIMIT	PROOF	BURST	FACTOR SAFETY THEO.	ACTUAL	QUAL. BURST PRESS. (PSIA)	TNT EQUIV./LBS.	FAILURE MODE
PLSS O_2 Bottle (Arde' Inc.)	SV713010	2	Cylindrical Diam. - 6.062" O.D. Height - 16.03" Max Wall Thick. - 0.028"Min Volume - 378 in^3	AISI 301 Unaged Cryoformed Steel	1020 ± 10	1110	1665	2220	2.0	2.1	2345 to 2450 10 Bottles Tested to Burst	0.050	Leakage No Mechanical Damage
OPS - O_2 Bottle (Fansteel Metallurgical Corp.)	SV730103	4	Spherical 7.04" ± .03" O.D. Wall Thick. - 0.130"Min Volume - 163 in^3	AMS Inconel 718	5880 ± 80	6750	10130	13500	2.0	2.2	14,700 to 15,200 5 Bottles Tested to Burst	0.182	Leakage No Mechanical Damage
Three-Man Liferaft Cylinders (Arde' Inc.)	SEB 40100064-203	2	Cylindrical 11" Long x 2" Thickness-.022 in.Min. Volume - 336 in^3	301 Stainless Steel	1000	1500	4600	5600	3.7	5.0	7500 - 7800	0.027	Leakage No Mechanical Damage
Dual Life Vest Pressure Assy.Cylinders (Knapp-Monarch)	SDB 40100179-001	2 per Vest	Cylindrical 3" long x .075" dia. Thickness-.036 in. Min. Volume - 1.7 in^3	Nickel Plated Steel	800 - 1000	N/A	N/A	7000	7.0 Min.	7.0 Min	N/A	Negligible	Leakage No Mechanical Damage
Goerz Gas Bottle Assy.	Goerz	1 per Magazine	Cylindrical 1.81" long 1.35" diam. Thickness-0.45 in.Min. Volume - 1.0 in^3	1061-T6 Aluminum	500	--	760	N/A	2+	2+	N/A	73.8×10^{-6} of TNT	Leakage No Mechanical Damage
Passive Seismic Experiment Caging Assembly	Bendix	1 per Unit	Manifold of Bellows and lines Volume - 1.6 in^3	Bellows - AM350 Steel Thickness-.002" Lines Stainless Thin Wall Tubing .04 Diam.	333	--	650	--	2+	2+	N/A	77.5×10^{-6} of TNT	Leakage No Mechanical Damage
RTG-SNAP 27 Fuel Capsule	AEE	1	Cylindrical 16" long 2-1/2" diam. 60 Mills and .20 Mills Thick.	Super Alloy Haynes 25 double walled	400-700	--	1400 (Ductile Weld)	1400	2+	2+	N/A	Negligible	Leakage No Mechanical Damage

TABLE 2.1-1

- EMU PRIMARY OXYGEN BOTTLE QUALIFICATION TEST RESULTS
Test Plan No. SS-4023A

Test	Vessel S/N	Environmental and/or Mission Simulation Tests	Total Operating Cycles @ 1130+20 psig 1000 Cycles Minimum Required Prior to Rupture	Total Proof Cycles @ 1685+20 psig 10 Cycles Minimum Required prior to Rupture	Static Burst Pressure 2220psig Min. Req.
Proof & Operating Pressure Cycles	31		1002	12	2370
	42		1002	12	2350
	43		1002	12	
Operating Pressure Cycles to Failure	18		8726*	12	----
	23		8281*	12	----
Proof Pressure Cycles to Failure	26		1	2811*	----
	27		2	1219*	----
Acc. Vibr. & Impact	35	20g's for 100 sec.	1	1	2350
	44	Two 78g saw tooth pulses 10-15ms rise time & 0-1ms delay time - all 3 along 3 orth axes.	1	1	2390
Humidity	29	100% rel. humidity for 10 temp. cycles 84° to 160°F 24 hrs/cycle 1 hr. @ 0°F.	2	3	2345
Salt Spray	30	1% NaCl by weight 95°F 48 hrs.	3	2	2350
Burst	13		1	3	2400
	4		1	1	2450
	41		1	1	2380

*Cycles to failure

Table 2.1-2

COMPONENT	FUNCTION	NORMAL OPERATING ELECTRICAL CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		SUMMARY DESCRIPTION OF ELECTRICAL COMPONENT OR NON-METALLIC MATERIAL TO FLUID INTERFACE
		VOLTS	AMPS	PRESSURE PSI	TEMP. °F	
O_2 Fill and Recharge Conn.	O_2 Fill and inflight recharge		NO ELECT INTER-FACE	1110	0-160	For non-metallics see Figure 2.1-10
O_2 Regulator	Pressure regulation		NO ELECT INTER-FACE	1110	0-160	For non-metallics see Figure 2.1-10
Flow Restrictor	Backup to PLSS regula-tor		NO ELECT INTER-FACE	1110 (-7 PLSS, 1500)	0-160	See Figure 2.1-10
O_2 Bottle	Primary oxygen supply		NO ELECT INTER-FACE	1110 (-7 PLSS, 1500)	0-160	No non-metallics in bottle Connector See Figures 2.1-12 & 2.1-13 for connector non-metallics
O_2 Shut Off Valve	PLSS O_2 Flow Shut Off		NO ELECT INTER-FACE	1110 (-7 PLSS, 1500)	0-160	See Figure 2.1-9 for a listing of non-metallics

Table 2.1-3
LINE COMPONENT SUMMARY FOR
PLSS SUBSYSTEM (oxygen)

COMPONENT	FUNCTION	NORMAL OPERATING ELECTRICAL CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		SUMMARY DESCRIPTION OF ELECTRICAL COMPONENT OR NON-METALLIC MATERIAL TO FLUID INTERFACE
		VOLTS	AMPS	PRESSURE PSI	TEMP. °F	
Primary O_2 press transducer	Sense PLSS primary O_2 bottle pressure	5.025 max	7.7 ma max	1110 (-7 PLSS, 1500)	0-160 (-7 PLSS, 0-130)	Leak of Bourdon Tube would expose electronic components and following non-metallics (TFE, Epoxy lite 5302). For non-metallics normally exposed, see Figure 2.1-11.
CO_2 Sensor	PLSS CO_2 level sensing	10.025 max	100 ma max	3.1 - 4.2	35-120	Failure of Dimethyl Silicone Rubber and FEP Teflon sensing element would expose O_2 to Glass, Ag and AgCl electrode. Other normally exposed non-metallics include ethylene propylene rubber, FEP Teflon and Penton (chlorinated polyester).
Ventilation Flow Sensor	Sense O_2 Flow Rate	20.5 max	25 ma max	3.1 - 4.2	35-90	O_2 flows around capacitor plates (Kovar alloy - Fe, Co, Ni) one of which is insulated with Dow Corning 7025 glass.
PGA Diff. press transducer	Sense PGA inlet pressure	5.025 max	2.5 ma max	3.4 - 4.1	45-85	Leak in transducer bellows would expose electrical components with following non-metallics (eccostock R-19, Infinitron, My calex #400, Versilube F-50, Stycast 2762 FF)
PGA Diff. press switch	Trip low pressure warning signal	10.0 max.	0.5 ma max.	3.4 to 4.1	40-85	Leak in bellows would expose elect components with following non-metallics (Eccostock R-19, My calex #400, Versilube F-50, Stycast 2762 FF)
Oxygen Flow Sensor	Sensor O_2 Flow Rate	20.5 max	25 ma max	3.4 - 4.1	40-85	The flow sensor is totally enclosed in a stainless steel housing.
Fan/Motor Assy	O_2 circulation	16.5 normal	5.75 max	3.1 - 4.2	35-90	O_2 flows into motor cavity over the Krytox bearing lubricant and around the EC1663 potting around the stator.

Table 2.1-3
LINE COMPONENT SUMMARY FOR
PLSS SUBSYSTEM (oxygen)

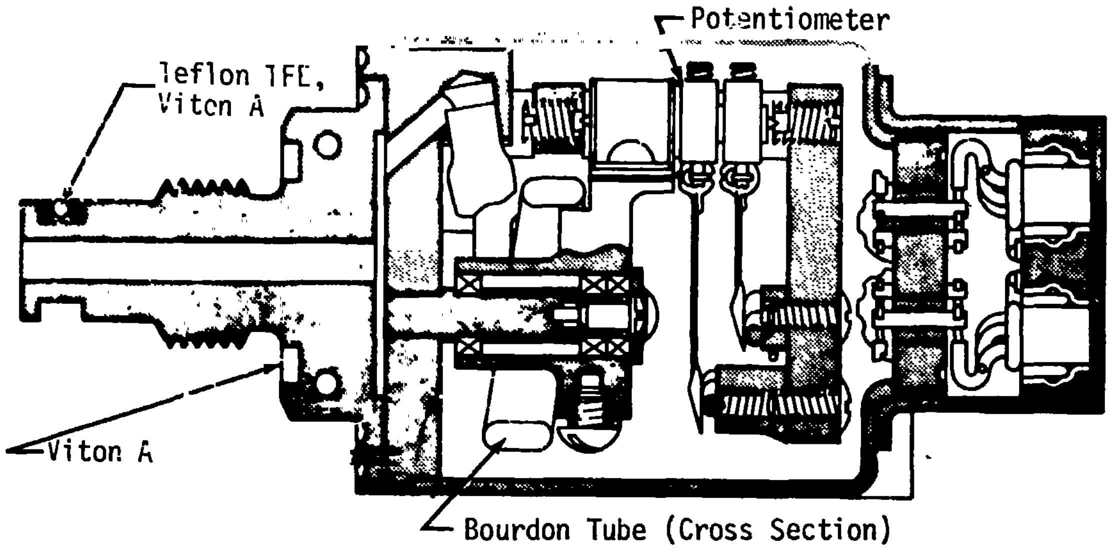

Figure 2.1-11. Primary Oxygen Pressure Transducer

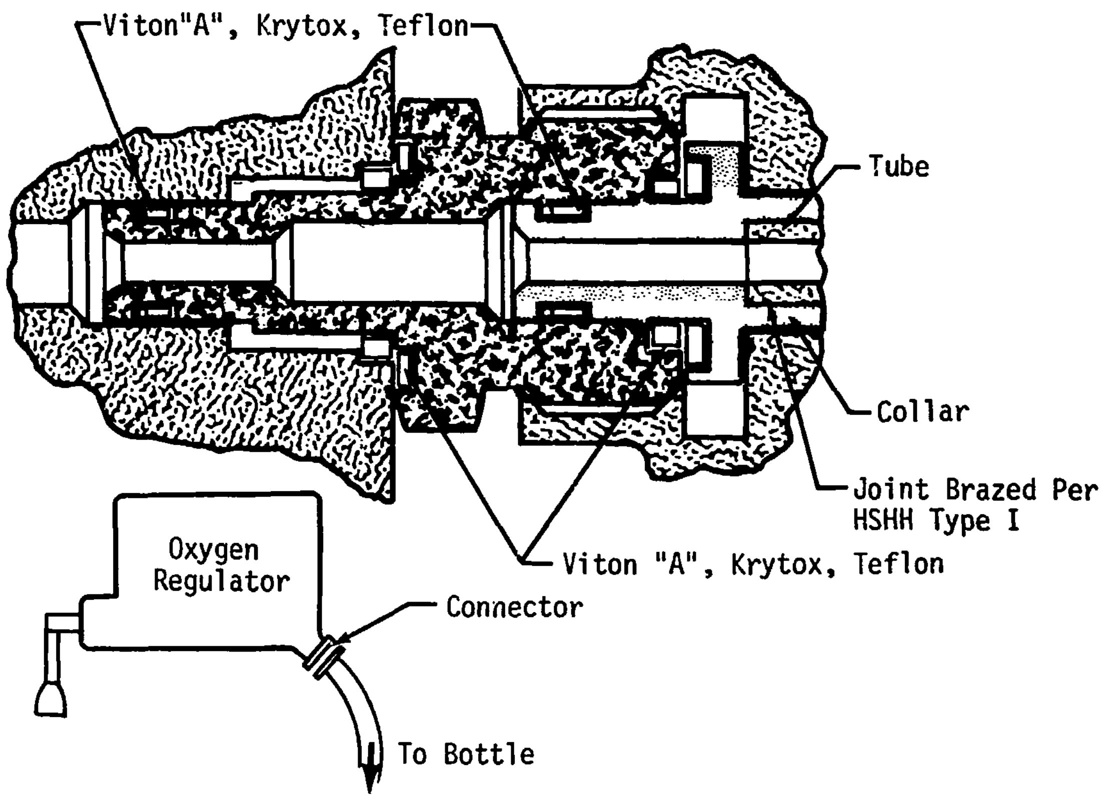

Figure 2.1-12. Regulator/Oxygen Line Connector

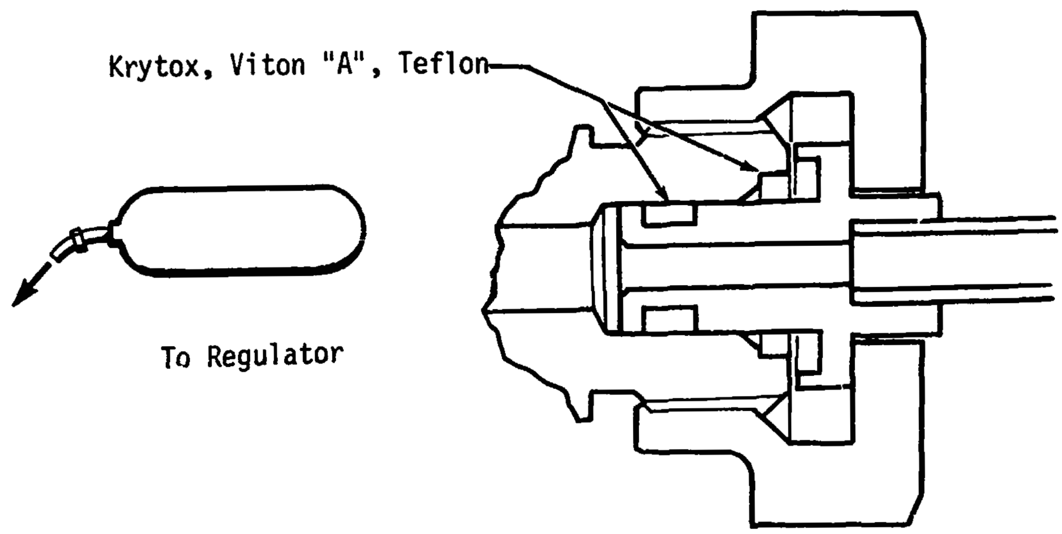

Figure 2.1-13. Bottle/Oxygen Line Connector.

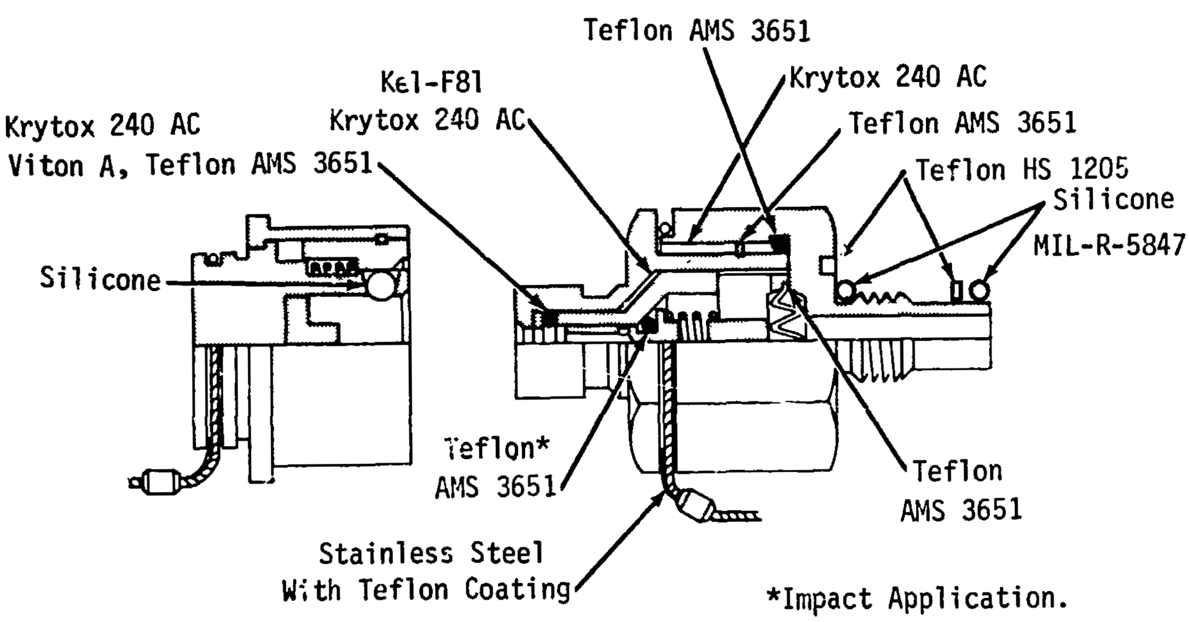

Figure 2.1-14. Primary Oxygen Fill Connector Cutaway View.

is shown in Figure 2.1-16. The Fan Assy(Fig 2.1-15)was selected as the test subject from the Low Pressure portion of the O_2 system because it represented the worst case regarding voltage/amperage maximum potentials. Non-metallic materials in the high pressure system have been selected according to the guidelines of Document MSC-PA-D-67-13, Apollo Spacecraft Non-metallics Materials Requirements. Material acceptability has been verified by the tests noted in Table 2.1-4, LOX impact test results and in the case of silicone seals, special GOX testing in which the material was subjected to momentary pressure surges of several thousand psi. The documents containing the latter test data are referenced in Table 2.1-5. In addition Hamilton Standard document SVSHER 4395A contains a complete analysis of the non-metallic materials selection rationale by examination of potential failure modes for all components in the PLSS system. System level certification tests have recorded additional application experience and no failures have been noted relative to non-metallic materials ignition.

The predicted -6 O_2 tank failure mode is to leak and not cause mechanical damage.* The TNT equivalent is 0.050 lbs. Since the OPS provides a secondary oxygen supply, tank failure would result in abort of the EVA portion of the mission. For Apollo 16 and subsequent flights the -7 PLSS, was to use an O_2 pressure vessel manufactured by the Arde cryoform process using an aged modified 301 stainless steel. Best estimate fracture toughness data in standard MSC/Apollo pressure vessel procedures indicates that this design may have a catastrophic fracture rather than a leakage failure mode at maximum design operating pressure. Inconel -718 material is recommended for this application based on analysis by Structure and Mechanics Division.

2.1.3 Results

2.1.3.1 The -7 PLSS O_2 pressure vessel should not use aged Arde material since the predicted failure mode is a catastrophic fracture rather than leakage.

2.1.3.2 The -6 PLSS O_2 bottle design parameters provide an actual worst case safety factor against burst of 2.0 and the predicted failure mode is to leak without mechanical damage.

2.1.3.3 There are no electrical circuits in or on the O_2 bottle.

2.1.3.4 Tests indicate that the only electrical component in the high pressure system, the Primary O_2 Pressure Transducer, will not ignite when current loaded to burn out with the hermetic seal ruptured and the internal parts exposed to O_2 at 6.2 psia.

2.1.3.5 Pressurization to 13,500 psi has indicated a minimum safety factor of 12 against exposure of the Primary O_2 Pressure Transducer internal electronics to the high O_2 flow stream.

*At maximum design operating pressure

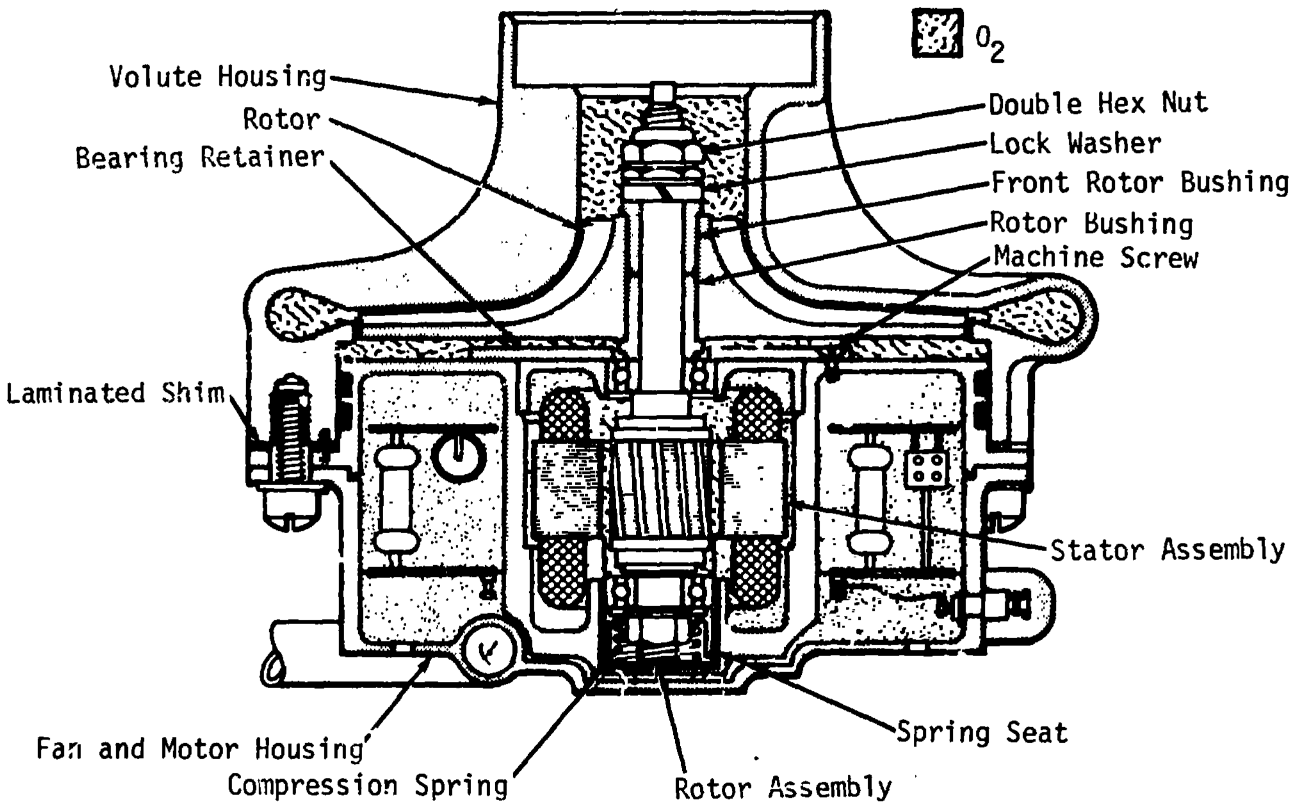

Figure 2.1-15. PLSS Fan Motor Assembly Sectional View.

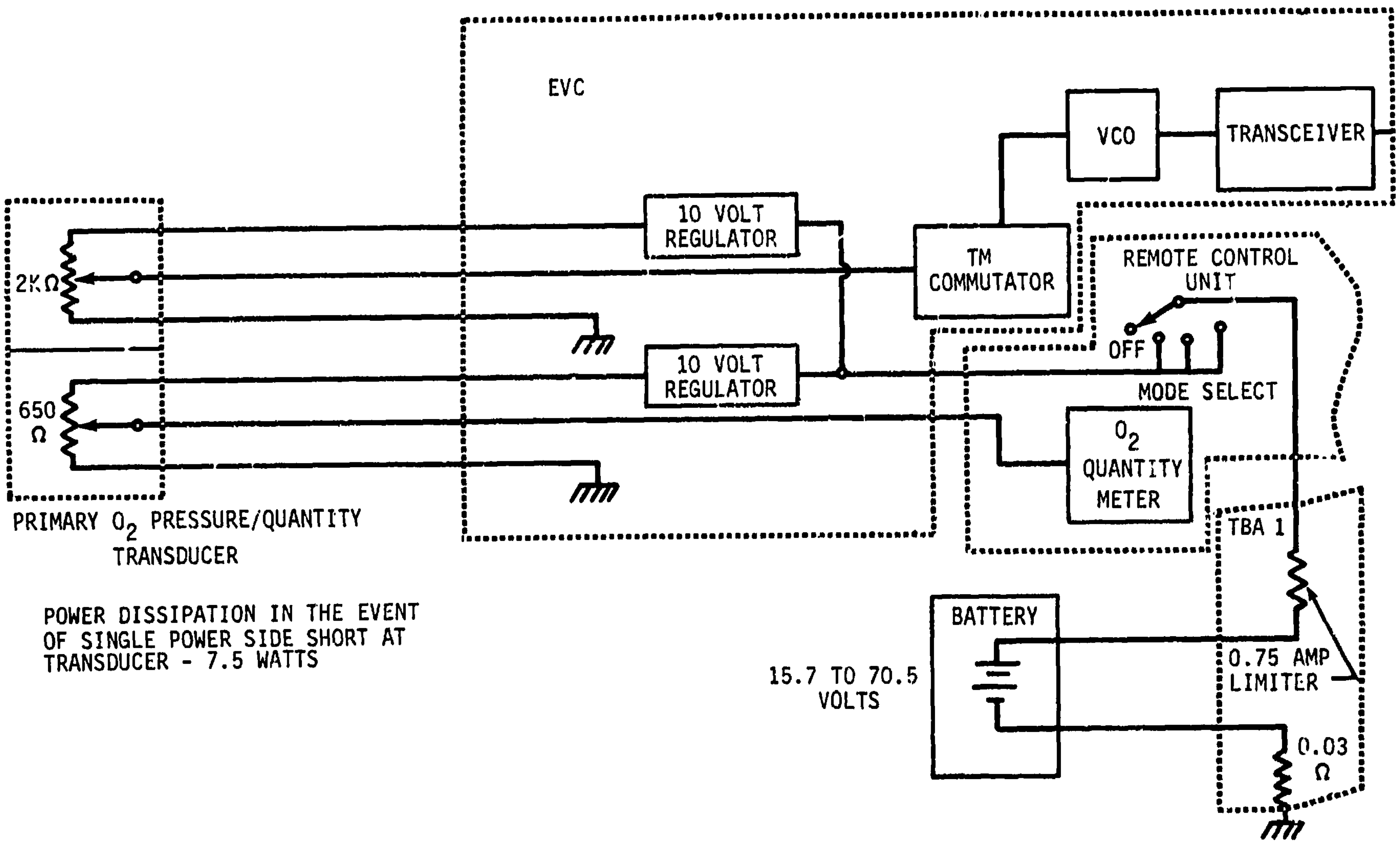

FIGURE 2.1-16. PLSS O_2 PRESSURE AND QUANTITY MONITOR CIRCUIT SCHEMATIC.

PLSS COMPONENTS IGNITION TEST SUMMARY

PLSS COMPONENT	TEST PURPOSE	TEST CONDITION	TEST RESULTS
O_2 Fill Connector	Determine ignition potential from gas flow	Worst case simulation by loosening connector cap probe, removing Teflon backup ring and pressurizing to proof pressure (1680 psi)	No ignition
Primary Pressure Transducer	Determine ignition potential from current overload	Most probable worst case simulation by step loading to burn-out after rupture of hermatic case seal and exposure to 6.2 psia O_2	No ignition; no outgassing detected from monitoring test chamber pressures
PLSS Ventilation Fan/Motor Assembly	Determine ignition potential from current overload	Worst case simulation by exposing fan/motor assy to 6.2 psia O_2 environment while increasing volt/amps in steps from 16.0 VDC minimum to 40 VDC/60 amps at burn-out	No ignition; no outgassing detected from monitoring test chamber pressures

TABLE 2.1-4

NONMETALLIC MATERIALS TEST RATIONALE (PLSS)

MATERIALS	APPLICATION	TEST RATIONALE (TEST RESULTS)
MIL-R-25897 SILICONE RUBBER	SILICONE RUBBER 'O' RING	EM NA-SS-3552
MIL-P-14078 TFE	COMPRESSION RING	MTP-P&VE-M-63-14 HS 7-006-SVHSER 3784-65L
MIL-P-22242 TFE	TFE BACKUP RING	MTP-P&VE-M-63-14 HS 7-006 SVHSER 3784-65L
74-545 VITON A	VITON A 'O' RING	MTP-P&VE-M-63-14 HS 8-104 SVHSER-4326
514AD VITON A	VITON A QUAD SEAL	MTP-P&VE-M-63-14 HS 8-104-SVHSER-4326
2Z-R-765 SILICONE RUBBER	SILICONE RUBBER 'O' RING	EM NA-SS-3552 HS 8-106

Table 2.1-5

NONMETALLIC MATERIALS TEST RATIONALE (PLSS) (CONT)

MATERIALS	APPLICATION	TEST RATIONALE (TEST RESULTS)
KRYTOX PR 240 AC GREASE	GREASE	MSC/EP TEST DATA
HS 1205 GR A TFE	TFE RECTANGULAR SEAL	MTP-P&VE-M-63-14 SVHSER 3784-65L
KEL-F-81 GR 3 PLASTIC	PLASTIC	MTP-P&VE-M-63-14 7EER 560072
KRYTOX 240 AC GREASE	GREASE	MSC/EP TEST DATA HS 7-022
AMS 3651 TFE	SEAL	MTP-P&VE-M-63-14 HS 7-006 SVHSER 3784-65L
MIL-P-19468 TFE	BACKUP RING	MTP-P&VE-M-63-14 SVHSER 3784-65L HS 7-006
VESPEL SP-21 PLASTIC	PLASTIC	M9-0399, PRELIMINARY WSTF TEST PASSED 2000 PSIA

Table 2.1-5 (cont)

2.1.3.6 Material sensitivity tests have been accomplished to develop the rationale for acceptance of all non-metallic materials applications in the high pressure O_2 system (see Table 2.1-5).

2.1.3.7 Bottle over pressuration from external sources is limited to a general LM cabin fire.

2.1.3.8 The bottle is protected from handling damage by the PLSS structure and integral bottle shield.

2.1.3.9 Component testing of the worst case component (fan/motor assy) has been conducted to verify the low potential for ignition sources in the low pressure O_2 system.

2.1.3.10 The high pressure system is protected from any pressures surges originating in the low pressure system by the PLSS pressure regulator.

2.1.3.11 The low pressure system is protected from exposure to high pressures in case of regulator failure by a regulator flow limiter and the Space Suit pressure relief valve.

2.1.4 Conclusions

Changes to the -6 PLSS are not required. The -7 PLSS O_2 pressure vessel should not use aged Arde material.

2.2 Oxygen Purge System (OPS)

2.2.1 Description

The OPS Oxygen flow schematic is shown in Figure 2.2-1. The OPS is actuated by the crewman in case of PLSS failure to provide an O_2 flow into the helmet, throught the Space Suit, and out through the sized orifice, the Oxygen Purge Valve, to ambient. The maximum flow rate through the system is 8.16 lbs. per hour at a pressure of 3.7 $\pm$ 0.3 psig. The case, which is made from 1/4" aluminum honeycomb with figerglass face plates, Figure 2.2-2, protects the OPS bottles from damage during stowage and operations.

Two OPS units are assigned to each Apollo mission. The units are stowed on the LM aft bulkhead next to the PLSS until EVA (Figure 2.2-3) The units are returned to the LM after EVA, if not depleted, for use during contingency LM/CM EVA transfer. They are stowed on the LM floor for Lunar launch (see Figure 2.2-4)

The OPS is normally turned off except for emergency uses. When the oxygen shut off valve is turned on, the portions of the system that are normally subjected to the maximum O_2 pressure of 6750 psig are those upstream from the ball and stem of the regulator. All parts of the system would be subjected to high pressures in the event the regulator failed open, but this would have an immediate catastrophic effect on the

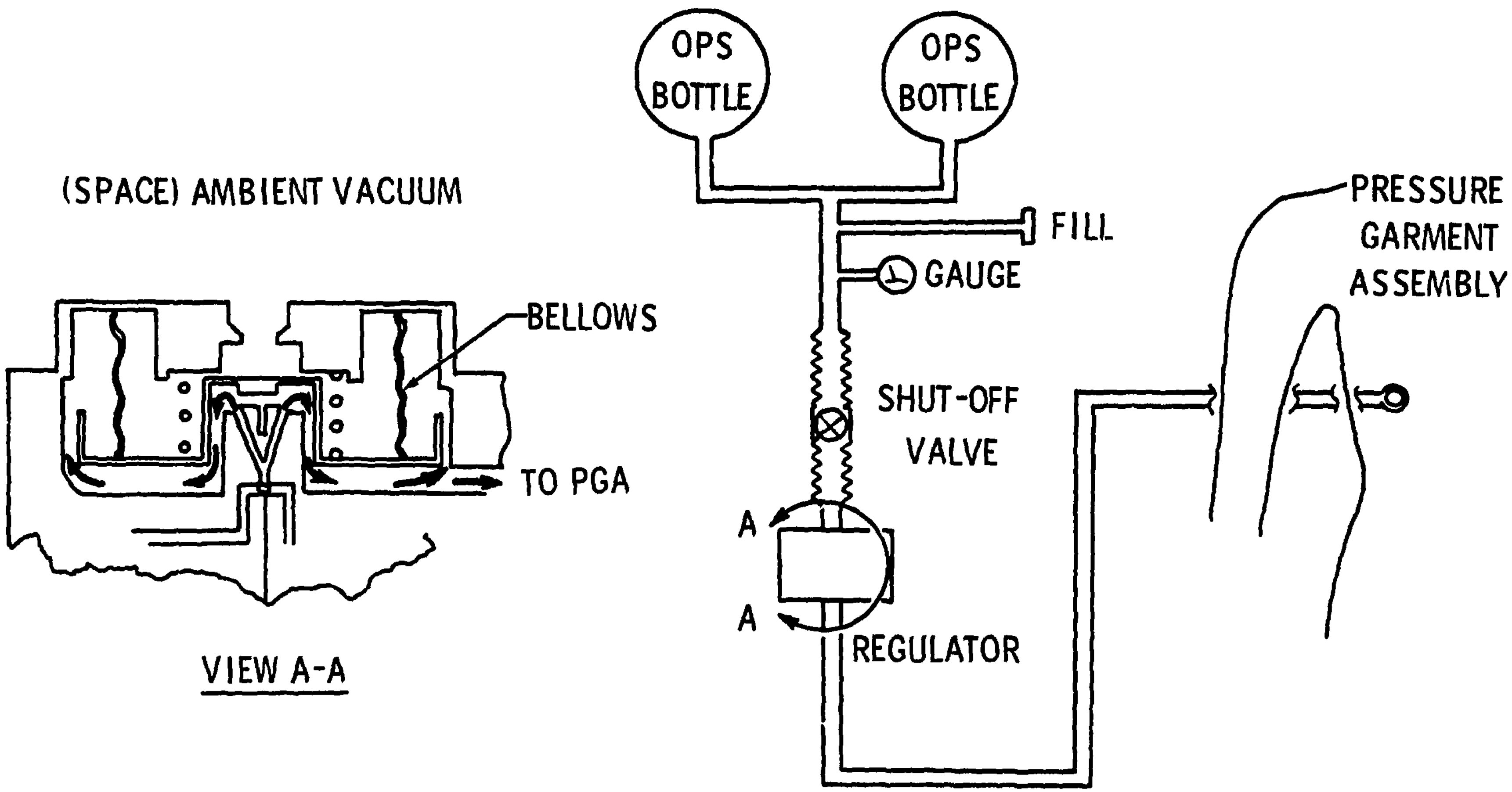

Figure 2.2-1. OPS Flow schematic

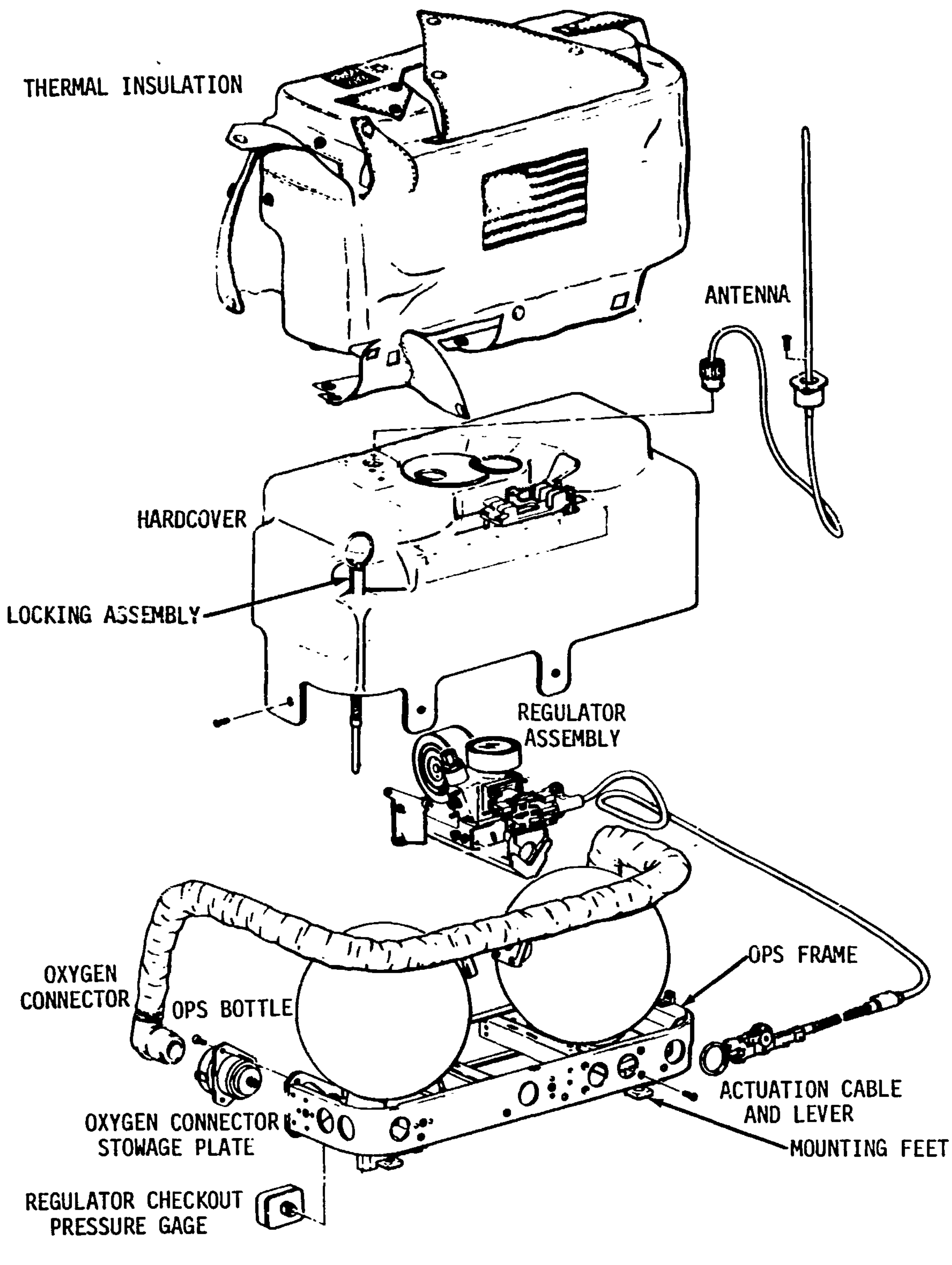

Figure 2.2-2. Oxygen Purge System-Major Components

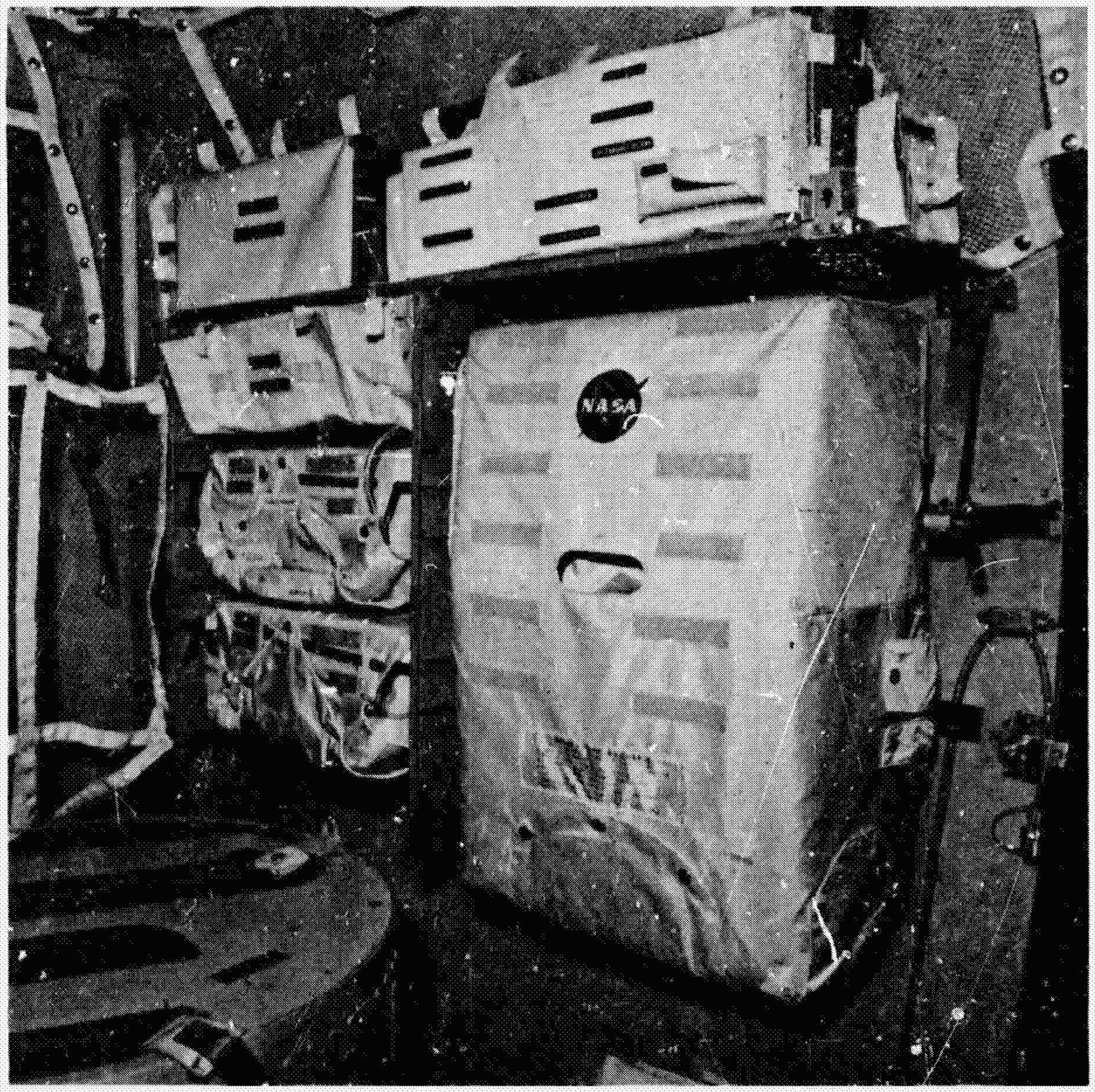

Figure 2.2-3.

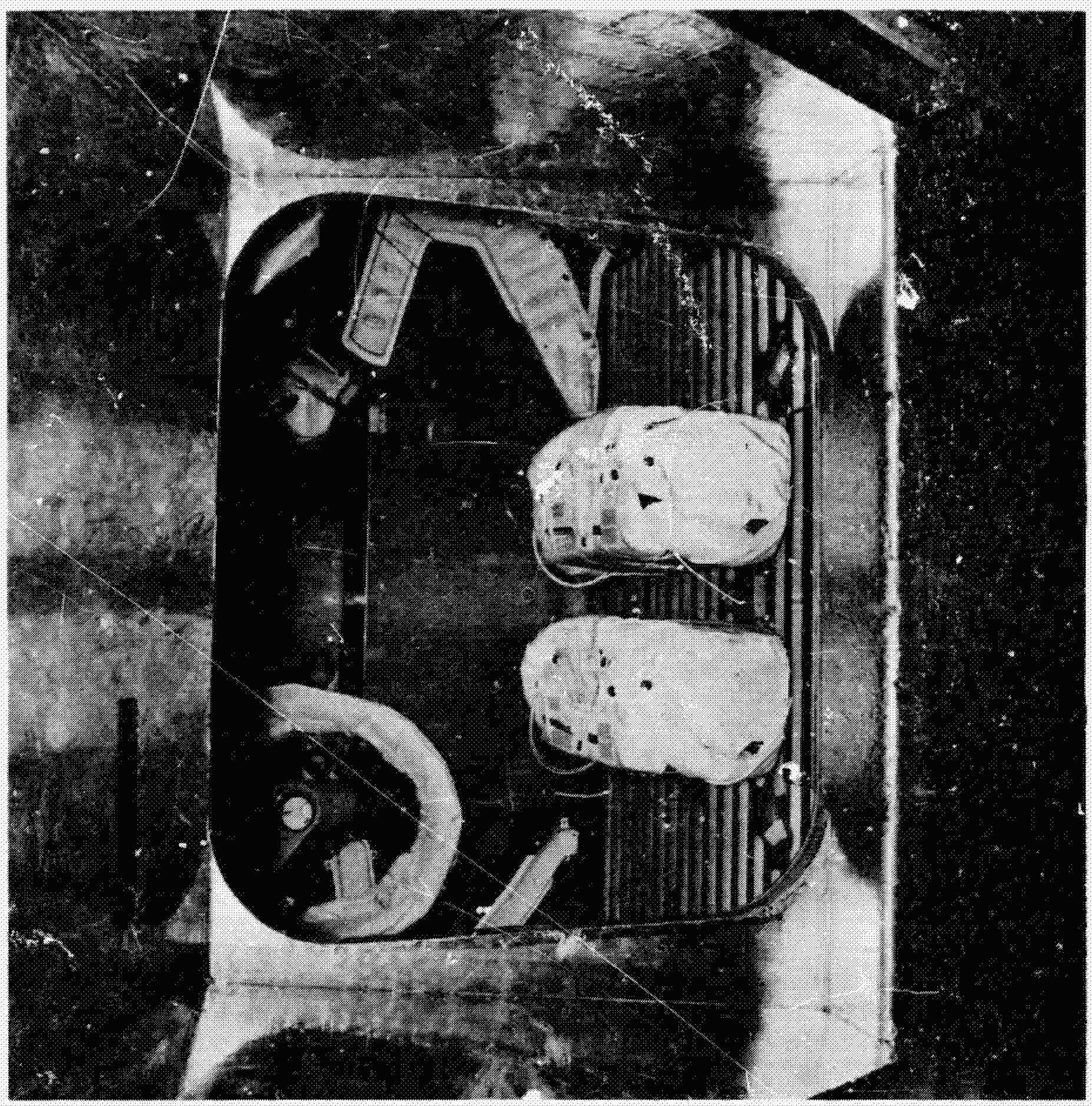

Figure 2.2-4

Space Suit. High pressure impact applications are the ball/stem valve, the shut off valve and the fill connector which do not involve non-metallic materials.

2.2.2 Discussion

The characteristics of the OPS O_2 bottles are shown in Table 2.2-1. The actual bottle safety factor of 2.1 was obtained from the qualification test restuls shown in Table 2.2-2. The bottles are fusion welded from 0.130 minimum thickness Inconel-718 forgings with an Inconel-600 tube braced to the inside diameter for reasons of heat transfer. The forgings are ultrasoncially checked and the total assemblies are x-ray and dye checked after manfucature. The bottles are flange mounted to an aluminum AA-2217 regulator and 6 AL-4V titanium bracket. There are no electrical or chemical sources for tank or system failure through out the OPS system. Inconel-718 is not susceptible to stress corrosion at OPS operating temperature, and tests have shown no significant material degradation occurance at temperatures of several hundred degrees Farenheit. The only potential external heat source would be extreme temperatures caused by a general LM fire. The bottles are protected from mechanical failure by the OPS structure. The only other OPS components in the high pressure system are the regulator, O_2 fill connector, pressure gauge and tank inspection port plug (see Table 2.2-3) Locations of the non-metallic materials in all components are shown in Figures 2.2-5 through 2.2-12. The OPS regulator and its non-metallics are essentially the same as the PLSS except for the lack of a flow limiter and the use of a silicon O-ring at the ball/stem seal. Silicon was selected for this application because of the tendency for viton degradation under high O_2 pressure cycling.

The guidelines of Document MSC-PA-D-67-13, Apollo Spacecraft Non-metallic Materials Requirements, were used in the specification of OPS non-metallic materials. Rationale for acceptance for all non-metallic materials in the OPS high pressure components has been established by materials sensitivity tests (reference Table 2.2-4). System level certification tests have provided additional application assurance.

All OPS high pressure system components have been burst tested. The regulator withstood 22,000 psi before burst and the pressure gauge withstood 30,000 psi with no rupture. The fill connectors saw pressures of 27,250 and 28,500 psi during bottle testing. The inspection port plug was tested during OPS bottle testing. These results indicate a minimum safety factor for high pressure components substantially higher than for the bottles.

The OPS bottle failure mode is predicted to be leakage with no mechanical damage. The TNT equivalent is 0.182 lbs. Tank failure would cause cancellation of the EVA portion of the mission, since mission rules dictate the requirement for OPS backup for the PLSS for all EVA operations.

GFE - PRESSURE VESSEL DATA

PRESSURE VESSEL (MANUFACTURER)	PART NUMBER	QUANTITY REQUIRED	VESSEL DIMENSIONS	VESSEL MATERIAL	NORMAL OPERATING PRESSURE (PSIA)	DESIGN PRESSURE (PSIA) LIMIT	PROOF	BURST	FACTOR SAFETY THEO.	ACTUAL	QUAL. BURST PRESS. (PSIA)	TNT EQUIV./LBS.	FAILURE MODE
PLSS O_2 Bottle (Arde' Inc.)	SV713010	2	Cylindrical Diam. - 6.082" O.D. Height - 16.03" Max Wall Thick. - 0.028" Min Volume - 378 in^3	AISI 301 Unaged Cryoformed Steel	1020 ± 10	1110	1665	2220	2.0	2.1	2345 to 2450 10 Bottles Tested to Burst	0.050	Leakage No Mechanical Damage
OPS - O_2 Bottle (Fansteel Metallurgical Corp.)	SV730103	4	Spherical 7.04" ± .03" O.D. Wall Thick. - 0.130" Min Volume - 163 in^3	AMS Inconel 718	5880 ± 80	6750	10130	13500	2.0	2.2	14,700 to 15,200 5 Bottles Tested to Burst	0.182	Leakage No Mechanical Damage
Three-Man Liferaft Cylinders (Arde' Inc.)	SEB 40100064-203	2	Cylindrical 11" Long x 2" Thickness-.022 in.Min. Volume - 336 in^3	301 Stainless Steel	1000	1500	4600	5600	3.7	5.0	7500 - 7800	0.027	Leakage No Mechanical Damage
Dual Life Vest Pressure Assy.Cylinders (Knapp-Monarch)	SDB 4C100179-001	2 per Vest	Cylindrical 3" long x .075" dia. Thickness-.036 in. Min. Volume - 1.7 in^3	Nickel Plated Steel	800 - 1000	N/A	N/A	7000	7.0 Min.	7.0 Min	N/A	Negligible	Leakage No Mechanical Damage
Goerz Gas Bottle Assy.	Goerz	1 per Maga-zine	Cylindrical 1.81" long 1.35" diam. Thickness-0.45 in.Min. Volume - 1.0 in^3	1061-T6 Aluminum	500	--	760	N/A	2+	2+	N/A	3.8×10^{-6} of TNT	Leakage No Mechanical Damage
Passive Seismic Experiment Caging Assembly	Bendix	1 per Unit	Manifold of Bellows and lines Volume - 1.6 in^3	Bellows - AM350 Steel Thickness-.002" Lines Stainless Thin Wall Tubing .04 Diam.	333	--	650	--	2+	2+	N/A	7.5×10^{-6} of TNT	Leakage No Mechanical Damage
RTG-SNAP 27 Fuel Capsule	AEE	1	Cylindrical 16" long 2-1/2" diam. 60 Mills and 20 Mills Thick.	Super Alloy Haynes 25 double walled	400-700	--	1400 (Ductile Weld)	1400	2+	2+	N/A	Negligible	Leakage No Mechanical Damage

TABLE 2.2-1

EMU OPS BOTTLE QUALIFICATION TEST RESULTS

Test Plan No. SSP3052

TEST	VESSEL S/N	SIMULATION	TOTAL OPERATING CYCLES	TOTAL PROOF CYCLES	STATIC BURST PRESSURE
Burst	16		1	1	15,200
Operating Cycles	11		59,364 *		
Procf Cycles	17		1	7,736*	
Proof Cycles	21		1	4,485*	
Environ-mental	24	Salt Fog, Humidity	2	1	15,200
Structural	13	Vibration, Acceleration, Shock	2	1	14,8000
Structural	15	Vibration, Acceleration, Shock	2	1	14,7000

* cycles to failure

Table 2.2-2

COMPONENT	FUNCTION	CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		SUMMARY DESCRIPTION OF ELECTRICAL COMPONENT TO FLUID INTERFACE
		VOLTS	AMPS	PRESSURE PSI	TEMP. °F	
O_2 Bottle	O_2 supply	NO ELECTRICAL COMPONENTS		0-5880	-200 to +130	See Figures 2.2-12 and 2.2-11 for non-metallics at the bottle/regulator and tank inspection port interfaces.
Fill Fitting	Ground Servicing	NON-ELECTRICAL		0-5880	-200 to +130	See Figure 2.2-9 for non-metallics.
Shut-off Valve	O_2 Shut-off	NON-ELECTRICAL		0-5880	-200 to +130	See Figure 2.2-7 for non-metallics.
Gauge	Bottle Pressure Readout	NON-ELECTRICAL		0-5880	-200 to +130	See Figure 2.2-8 for non-metallics.
Regulator	Pressure Regulator	NON-ELECTRICAL		0-5880	-200 to +130	See Figure 2.2-10 for non-metallic.

NOTE: Following components that are in the O_2 low pressure distribution system have no electrical interface.
Gas connector stowage plate
Gauge, Regulator Checkout
Umbilical Connector
Oxygen Hose (umbilical)

Table
TIME COMPONENT SUMMARY FOR
OPS SUBSYSTEM (oxygen)

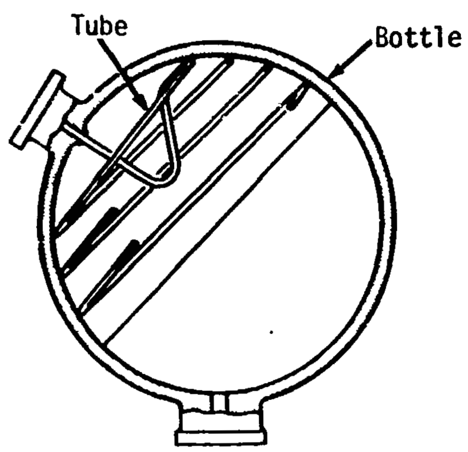

Figure 2.2-5. OPS Bottle Cutaway View

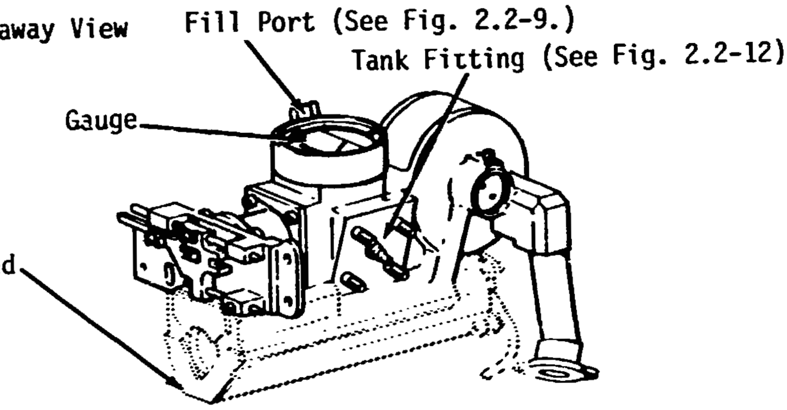

Figure 2.2-6. Regulator Assembly

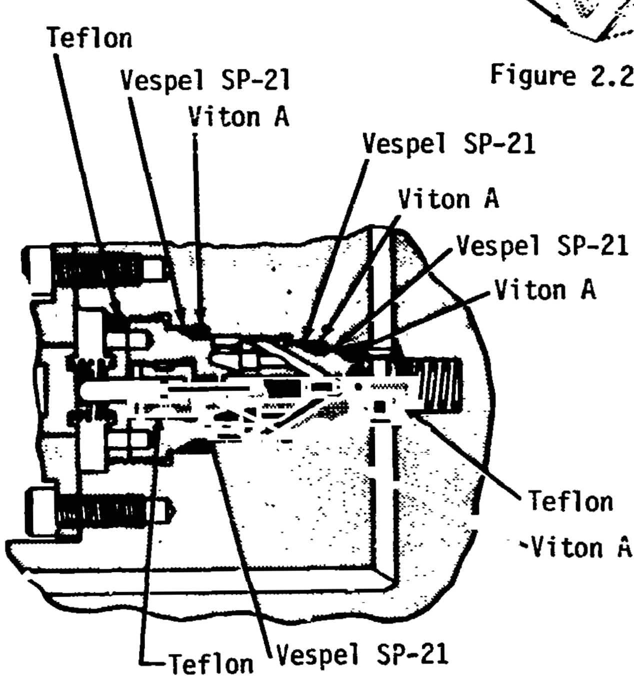

Figure 2.2-7. Regulator Shutoff Valve

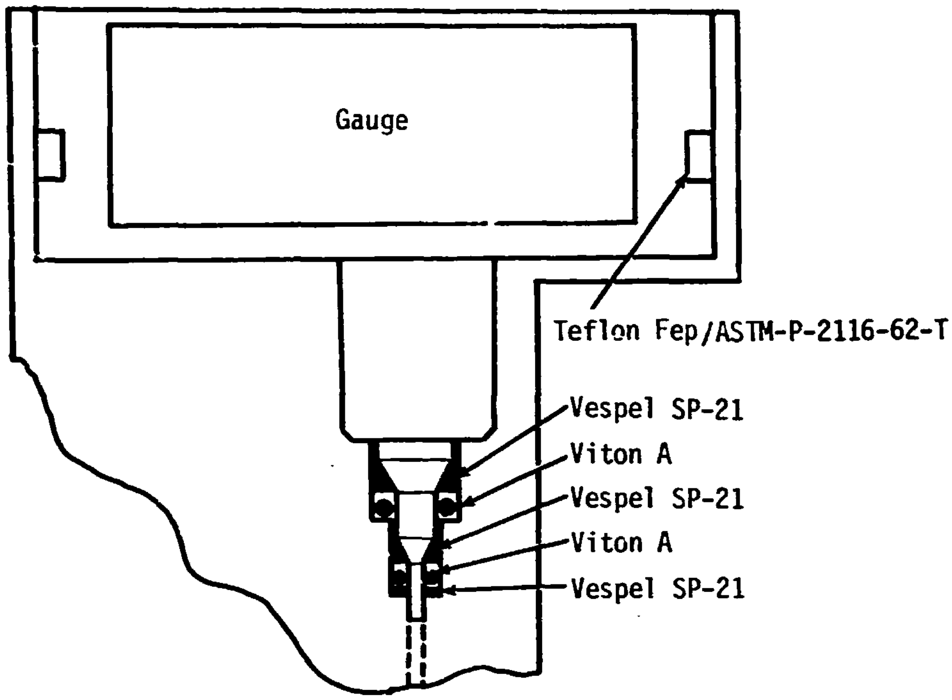

Figure 2.2-8. High Pressure Gauge Sealing

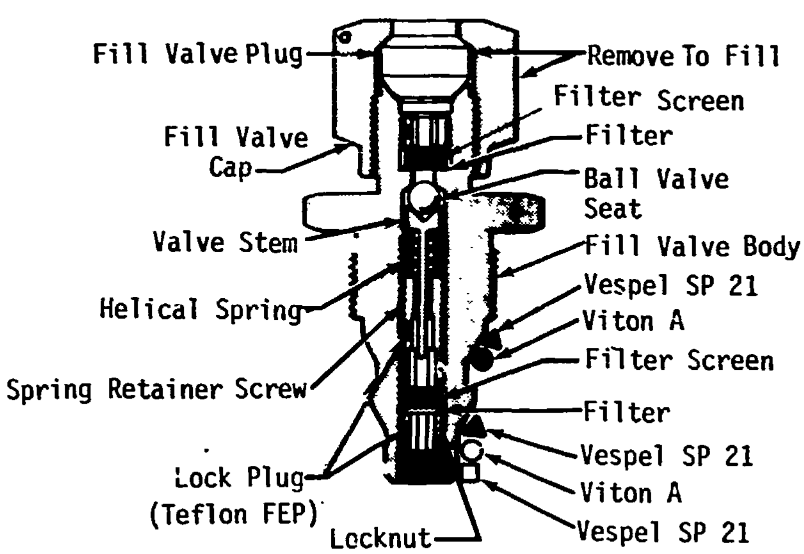

Figure 2.2-9. OPS Fill Fitting

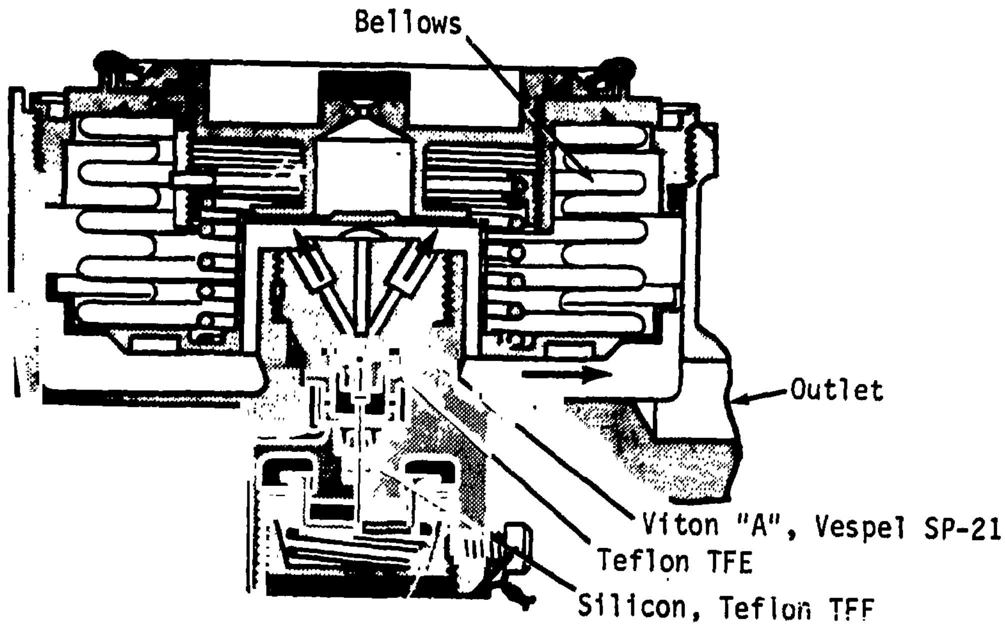

Figure 2.2-10. OPS Oxygen Regulator Assembly - Cutaway View.

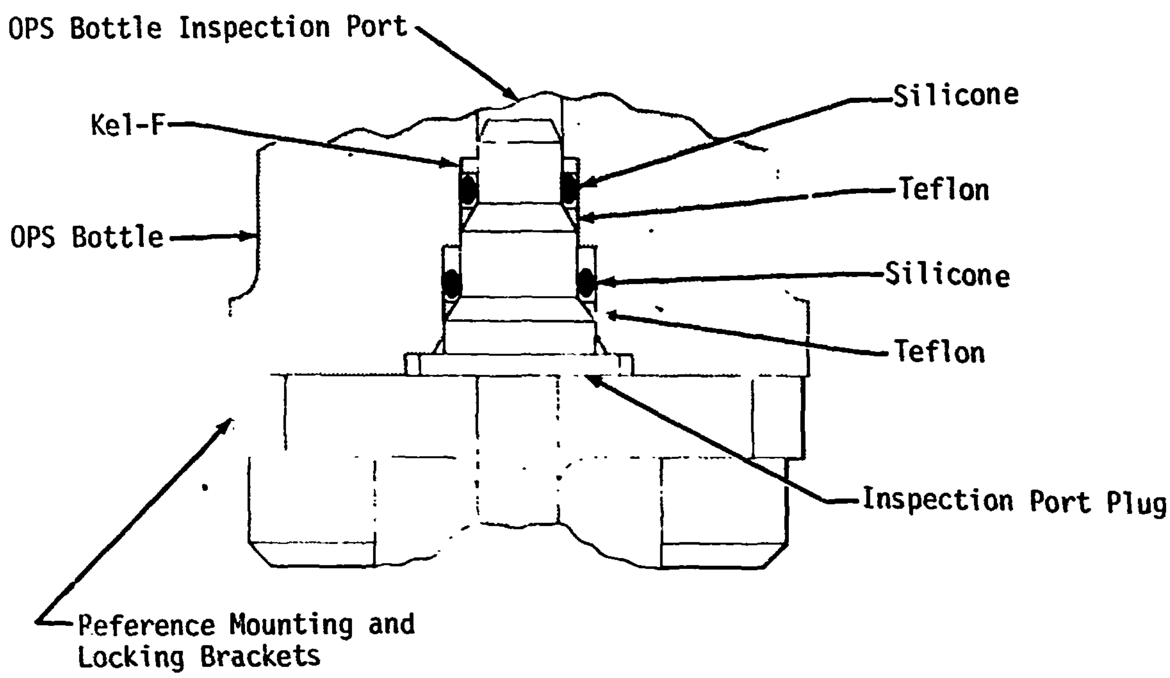

Figure 2.2-11.
Installation of Seals and Packings of
OPS Bottle Inspection Port

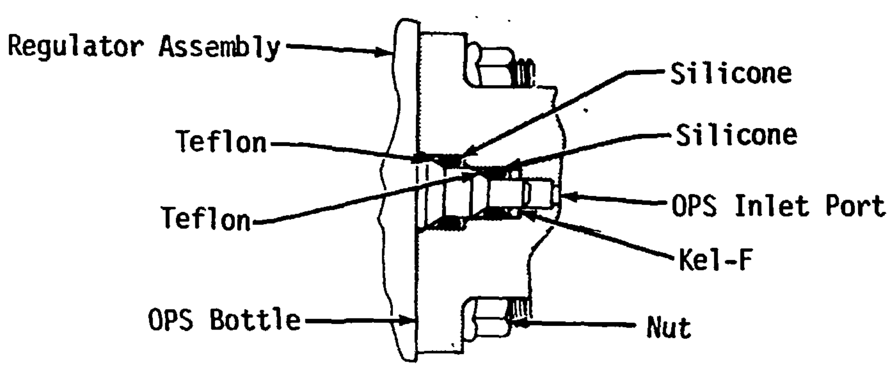

Figure 2.2-12.
Installation of Seals and Packings of OPS Inlet Port.

NONMETALLIC MATERIALS TEST RATIONALE (OPS)

MATERIALS	APPLICATION	TEST RATIONALE (TEST RESULTS)
S-614-8 SILICONE RUBBER	SILICONE 'O' RING	EM NA-SS-3552
FEP TEFLON	LOCK PLUG	HS 7-006 MTP-P&VE-M-63-14 SVHSER 3784-65L
KRYTOX 240 AB/EC1101	GREASE	MSC/EP TEST DATA
VESPEL SP-21 PLASTIC WASHER	PLASTIC WASHER	M9-0390, PRELIM WSTF TEST PASSED 2000 PSIA, TESTING TO BE CONTIN-UED TO 10,000 PSIA
77-545 VITON A	VITON RUBBER 'O' SEAL	MTP-P&VE-M-63-14 HS 8-104, SVHSER-4326
MIL-P-19468 TFE	SEAL RING (TEFLON)	MTP-P&VE-M-63-14 SVHSER 3784-65L HS 7-006
MIL-P-46036 KEL-F PLASTIC	PLASTIC	MTP-P&VE-M-63-14 7EER560072

Table 2.2-4.

2.2.3 Results

2.2.3.1 OPS O_2 bottle design parameters provide an actual worst case safety factor against burst of 2.1 and the predicted failure mode is to leak without mechanical damage.

2.2.3.2 There are no electrical circuits in the OPS system.

2.2.3.3 The safety factor against burst for high pressure system components has been determined by test to be substantially greater than that for the O_2 bottles.

2.2.3.4 Acceptance rationale for all non-metallic materials in the high pressure system has been developed from material sensitivity testing.

2.2.3.5 Bottle overpressurization from external sources is limited to heat from a LM cabin general fire.

2.2.3.6 The OPS structure protects the O_2 bottle from damage during storage or operations.

2.2.4 Conclusion

No changes to the OPS design are required.

2.3 THREE-MAN LIFE RAFT INFLATION SYSTEM

2.3 DESCRIPTION

The three man life raft (Fig 2.3-1)is stowed in section R-4(Fig 2.3-2 & 2.3-3) of the CSM until required at splashdown. The raft is then inflated by actuating two CO_2 cylinders. The cylinders, manufactured by Arde, are 11" long by 2" in diameter - 301 stainless steel, wall thickness 0.022". (Fig 2.3-4).

The tanks are pressurized with 36 in ^{3} of CO_2 at 1000 psig and designed for the following pressures; limit 1500 psig, proof 4600 psig, burst 5600 psig (design). The actual burst pressure demonstrated during hydro burst testing (four vessels) ranged from 7500 psig to 7800 psig. All failures exhibited longitudinal fractures non-fragmenting. The safety factor is 4 plus. In addition to the tank safety factor, the cylinder is protected from over pressure by a 4175 psig burst disk.

2.3-2 DISCUSSION

The TNT equivalent of an air burst of the cylinders is 0.027 pounds per cylinder. The predicted failure mode is by leakage and is not considered to cause mechanical damage. The cylinders are enclosed within the folded life raft, stowed within the Survival Ruck Sack. (Figure 4-5)

A failed life raft inflation system would release approximately two pounds of CO_2 into the CSM.

The LiOH will completely scrub this amount of CO_2 in approximately ten minutes. Two pounds of CO_2 would raise the cabin partial pressure approximately 10 mm of Hg or raise the percentage of CO_2 from 3 to 6.5 per cent. This could result in minor changes in crew perceptivity for a few minutes if the CO_2 were dumped directly into the cabin.

2.3-3 RESULTS

The safety factor demonstrated through test is well above normal limits. the predicted failure mode is by leakage and the tank is protected by a burst disk. The CM ECS can handle a CO_2 discharge from a cylinder within compartment R-4 but the crew may have minor perceptive changes for a few minutes if the CO_2 is dumped directly into the cabin.

2.3-4 RECOMMENDATION

No further design, configuration changes, testing, or procedure changes are recommended for the life c CO_2 cylinders.

A more complete review of the effects of a life raft CO_2 cylinder discharge into the cabin is recommended.

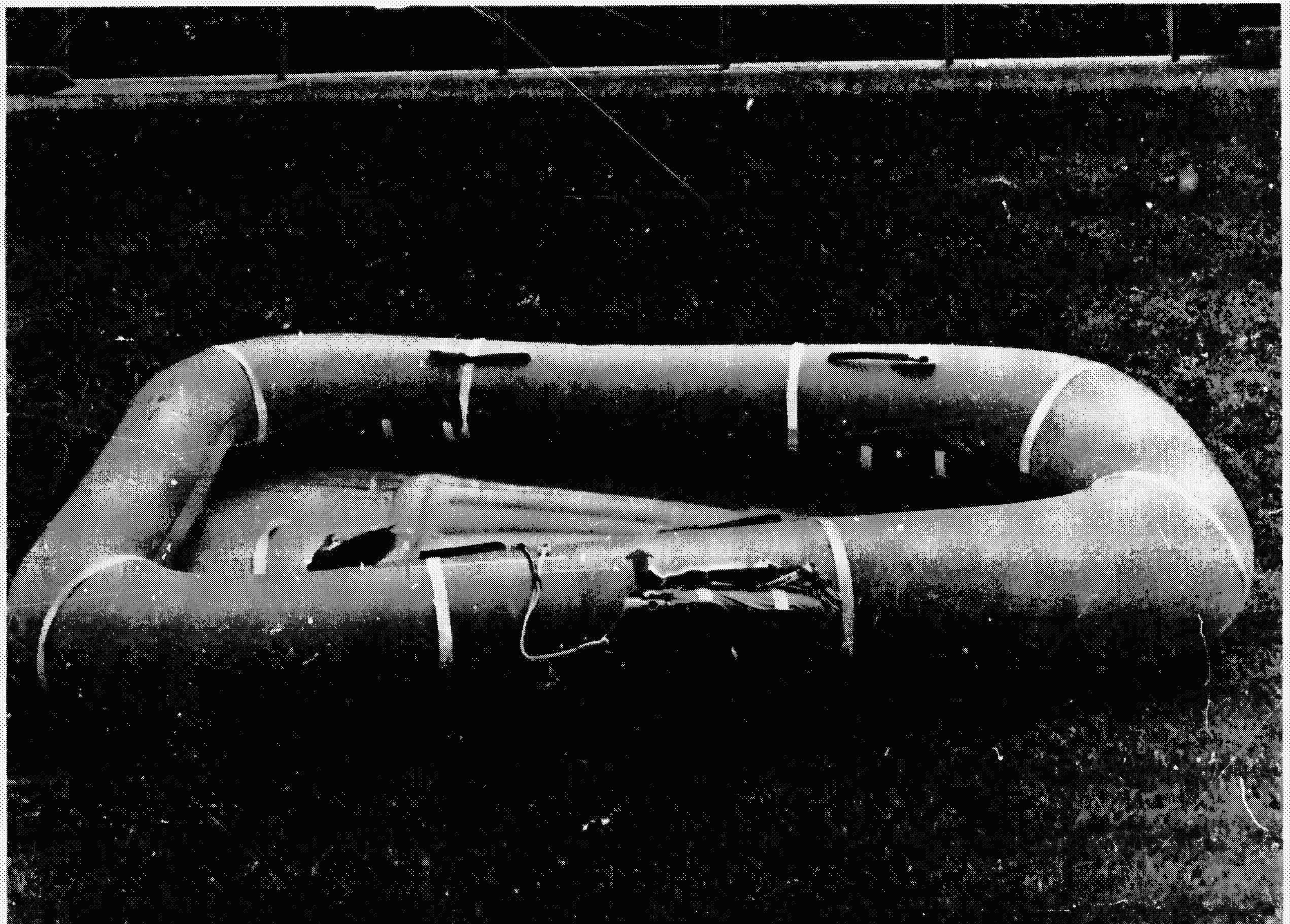

Figure 2.3-1. Three Man Life Raft

Figure 2.3-2.

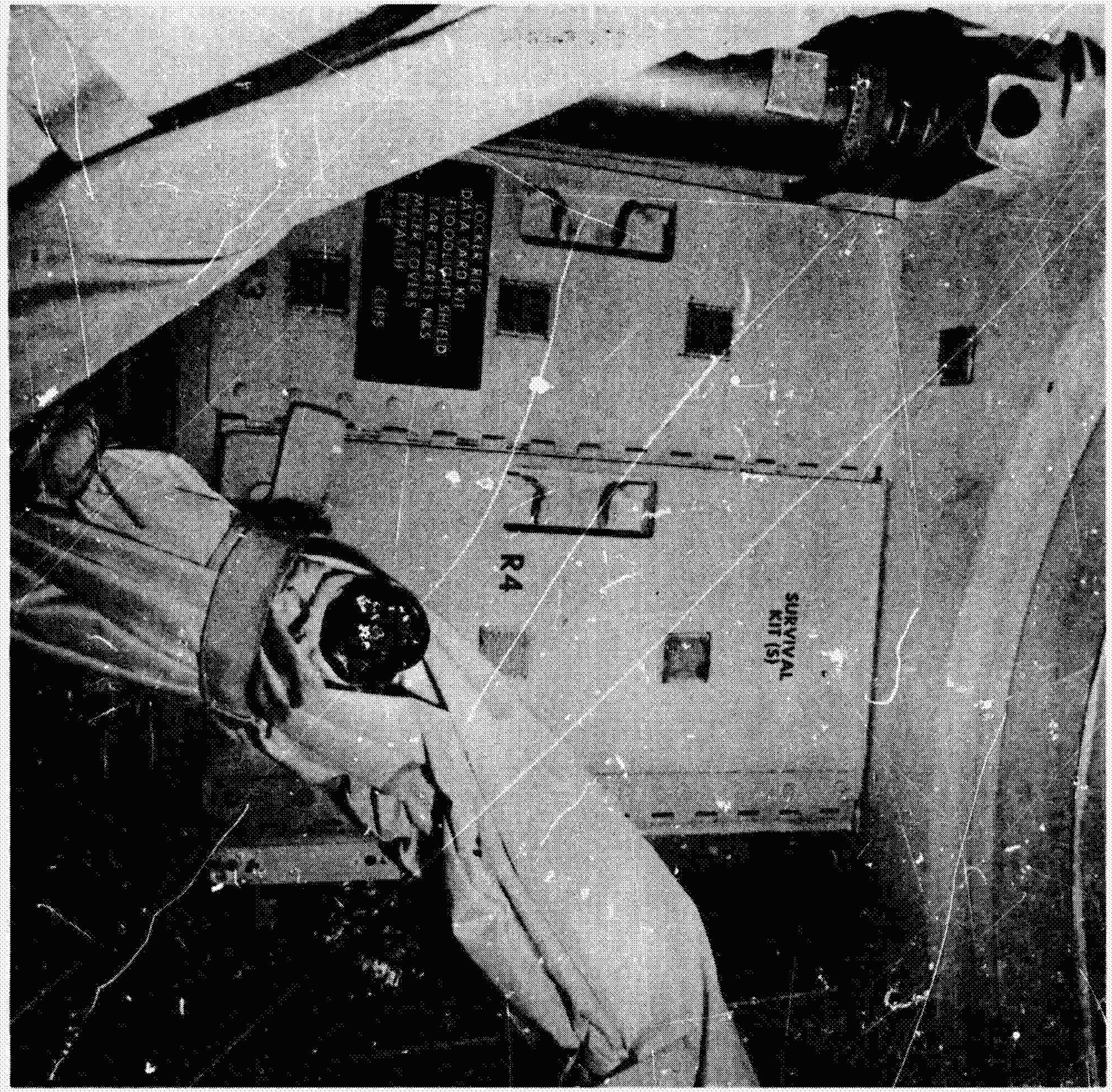

Figure 2.3-3.

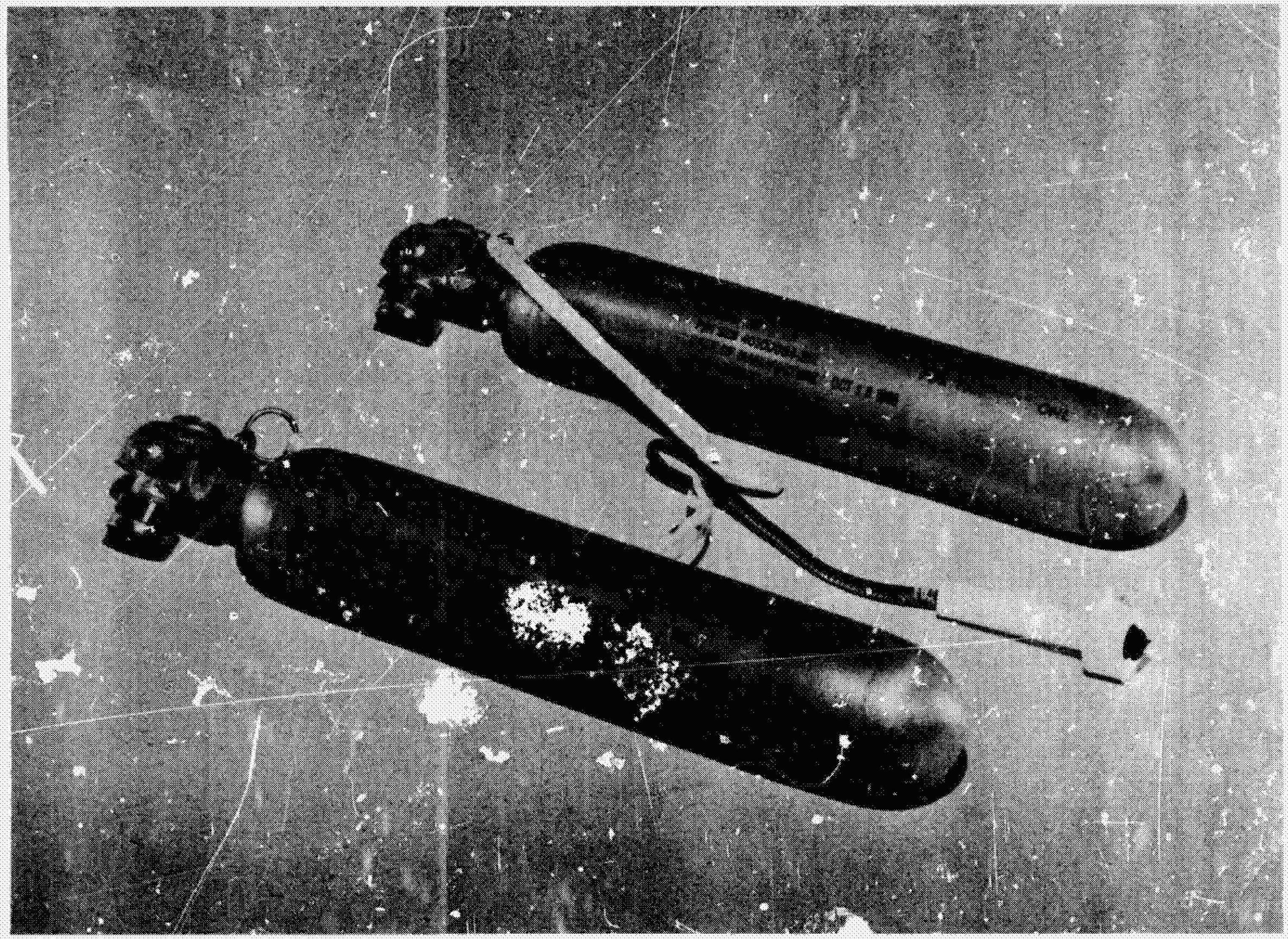

Figure 2.3-4.

2.4 DUAL LIFE VEST INFLATION SYSTEM

2.4.1 DESC ION

The life vests are worn during launch then are stowed in PGA containers in section R-4 of the CSM until required for reentry. Each vest is inflated by actuating two CO_2 cylinders. The cylinders are 3.480" long by .865" in diameter - carbon steel, wall thickness .036". Fig 2.4-1 presents the inflated life vest and Fig 2.4-2 the stowage configuration.

The cylinders are pressurized with 1.7 in^3 CO_2 to 1000 psig and designed for the following pressures: normal 1000 psig, proof 7000 psig, and burst 8500 psig. The cylinders are fabricated in accordance with Mil-C-601F, with an elevated temperature burst test on the filled cylinders conducted at 300°F minimum.

2.4.2 DISCUSSION

The normal failure mode of the cylinders is leakage - which would result in little or no damage to the vest or surrounding equipment. A failure of the cylinders would be a loss of flotation capability of the vest.

2.4.3 RESULTS

The safety factor demonstrated through test and years of demonstrated use of the cylinders is well above acceptable limits. The predicted failure mode is by leakage with little or no likelihood of burst and no mechanical damage.

2.4.4 RECOMMENDATION

No further design, configuration changes testing, or procedure changes are recommended for the life vest CO_2 cylinders.

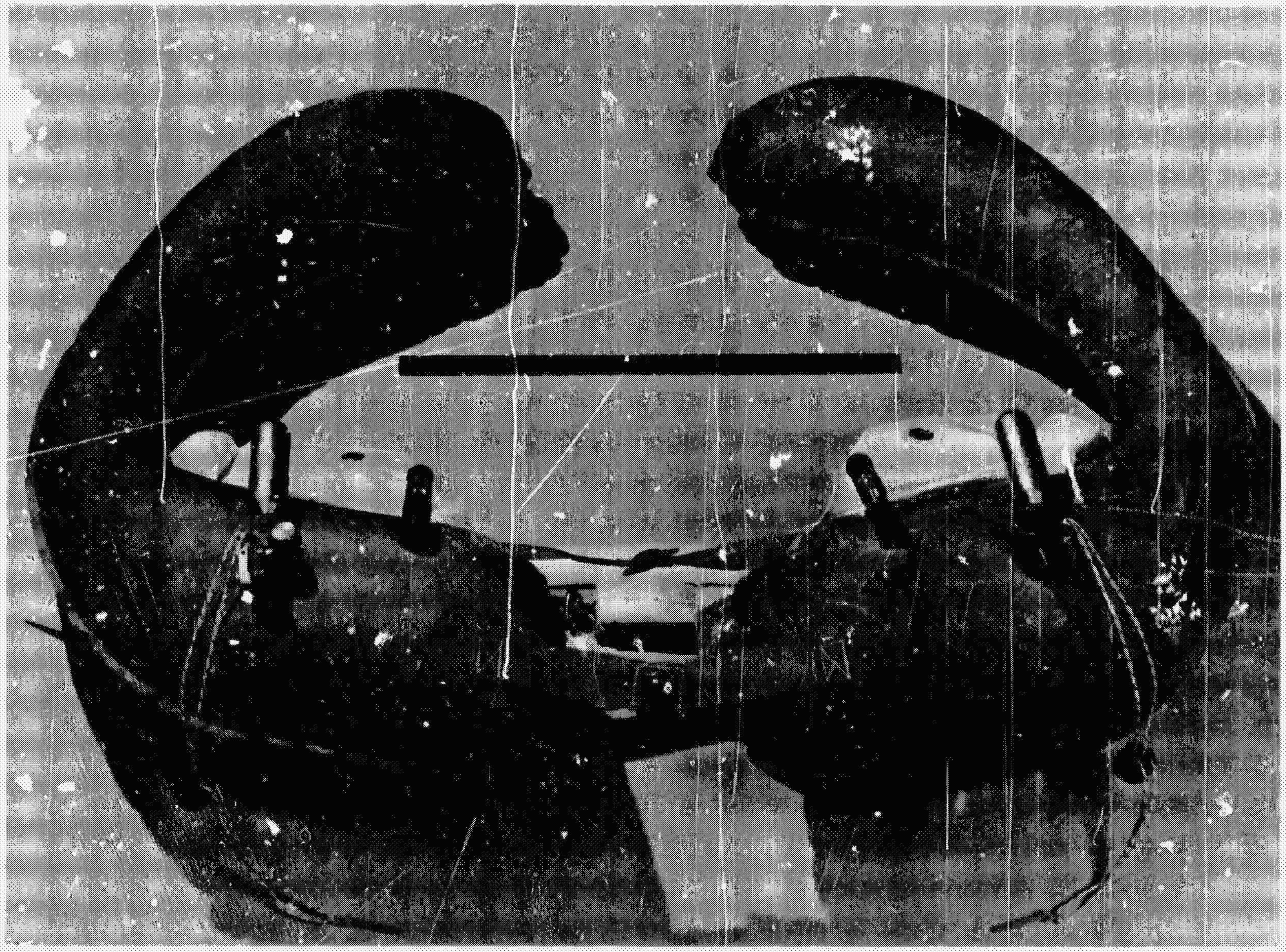

Figure 2.4-1. Dual Life Vest

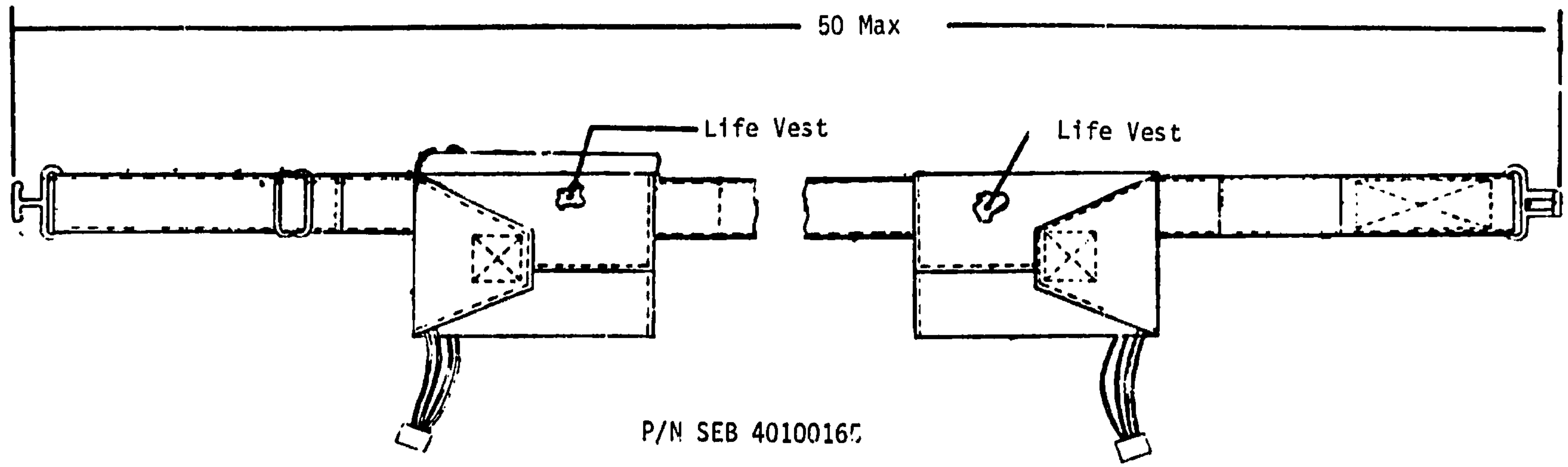

Figure 2.4-2. Dual Life Vest

2.5 RADIOISOTOPE THEMOELECTRIC GENERATOR

Snap-27 'l Capsule

2.5.1 DESCRIPTION

The RTG is provided to supply electrical power for the Apollo Lunar Surface Experiment Package (ALSEP). The fuel capsule assembly is stowed in a Graphite LM Fuel Cask (GLFC) installed on the exterior of the LM adjacent to the MESA. (Fig 2.5-1)

The fuel capsule is a cylinder 16" long 2 1/2" in diameter of super alloy Haynes 25 double walled, 60 and 20 mills thick. The fuel is inserted between the walls, and chambers are provided for the helium gas. (Fig 2.5-2

The helium gas is a by-product of the plutonium fuel radioactive decay. Internal capsule helium pressure builds up as a function of time (see (Fig 2.5-3). Normal pressures are 400-700 psig depending upon the time of flight relative to the encapsulation of the fuel. For the flight dates shown, the safety factor is in excess of 2 for helium pressure failure. The capsules are designed with a center section weld machined for a ductile failure at 1400 psig which corresponds to eight years from the fueling - encapsulation of the capsule.

2.5.2 DISCUSSION

The capsule has no internal components and is protected externally by enclosure in the (GFLC) consisting of a 1/4" graphite laminated pyrolite layer and 1/2" beryllium sheath inside layer. (Fig 2.5-4) The cask with capsule enclosed are designed to withstand Saturn pad explosion, and after-fire, S-IVB fragmentation, suborbital and earth orbital reentry and subsequent impact at 300 ft/sec into solid granite.

Extensive testing has been performed using gas pressure and rapid heating to 2100°F to demonstrate that the capsule ruptures in a ductile manner at the machined rupture groove (as designed) permitting the gas to vent with no fragmentation and no emission of the fuel. The ductile failure demonstrated assures that a pressure build up capsule failure would be none catastrophic and would not effect adjacent equipment, crew safety, or mission success. The non emission of the fuel demonstrated during the pressure tests assures that the fuel capsule performance would not be impared as a result of a Helium pressure rupture.

2.5.3 RESULTS

The Snap-27 tanks have very low potential for helium pressure build up to failure pressures. In the event of a pressure failure there would be no damage to surrounding equipment, effect upon crew safety or mission success. The fuel capsule power generation would be unaffected by helium vent.

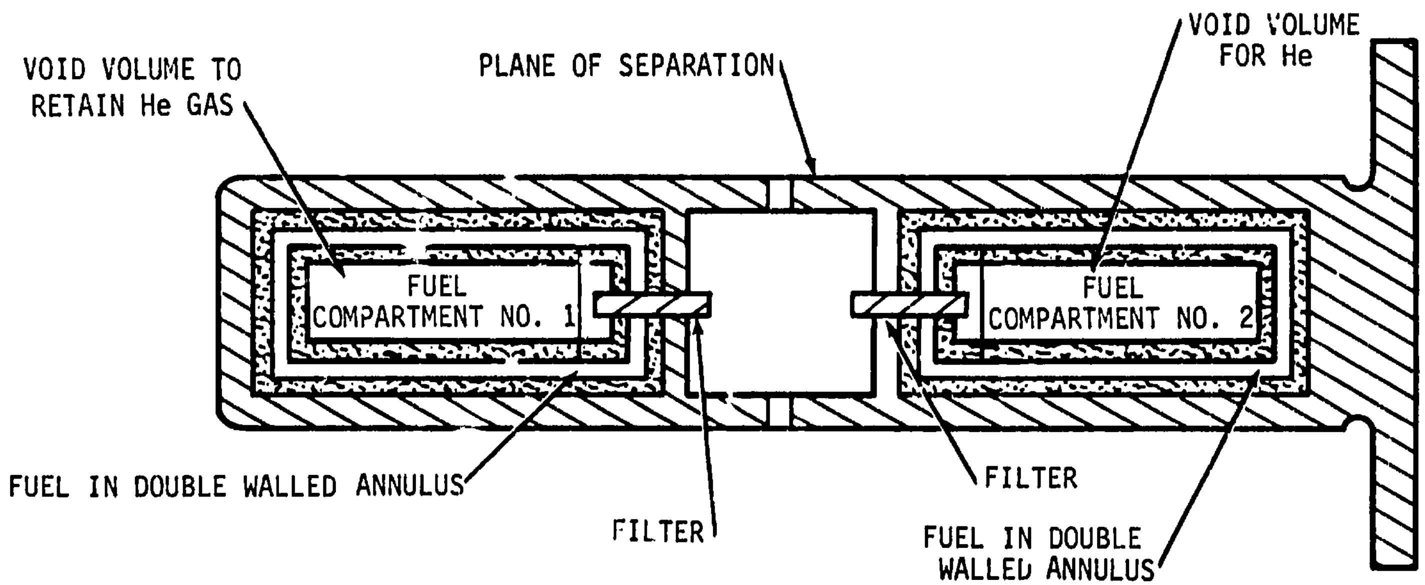

FIGURE 2.5-2. FUEL CAPSULE ASSEMBLY DESIGN FEATURES.

2.5.4 RECOMMENDATION

The fuel capsule should be accepted as non hazardous, with no procedural, design, or testing changes recommended.

STRESS RUPTURE LIFE OF THE SNAP 27 FCA

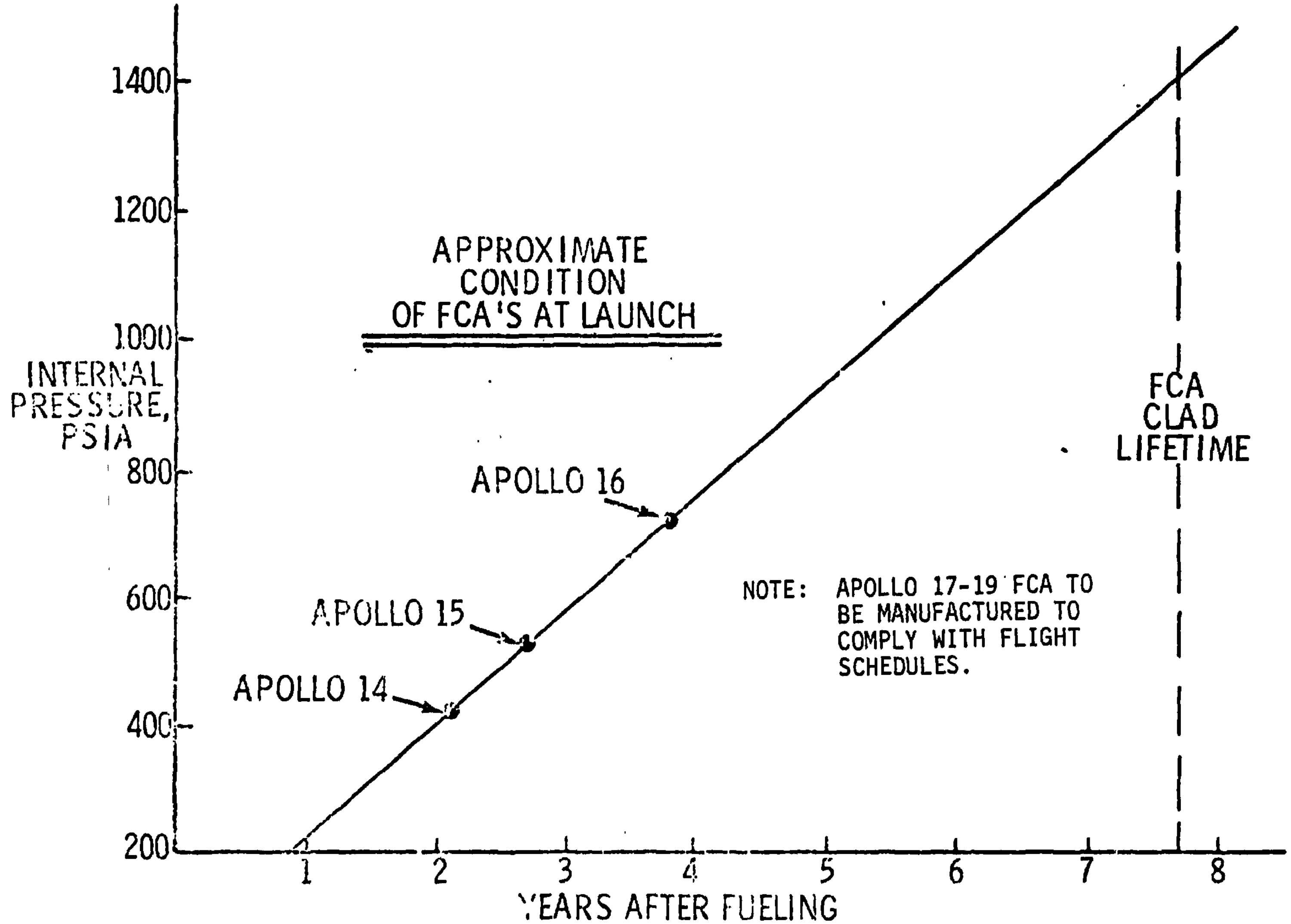

FIGURE 2.5-3.

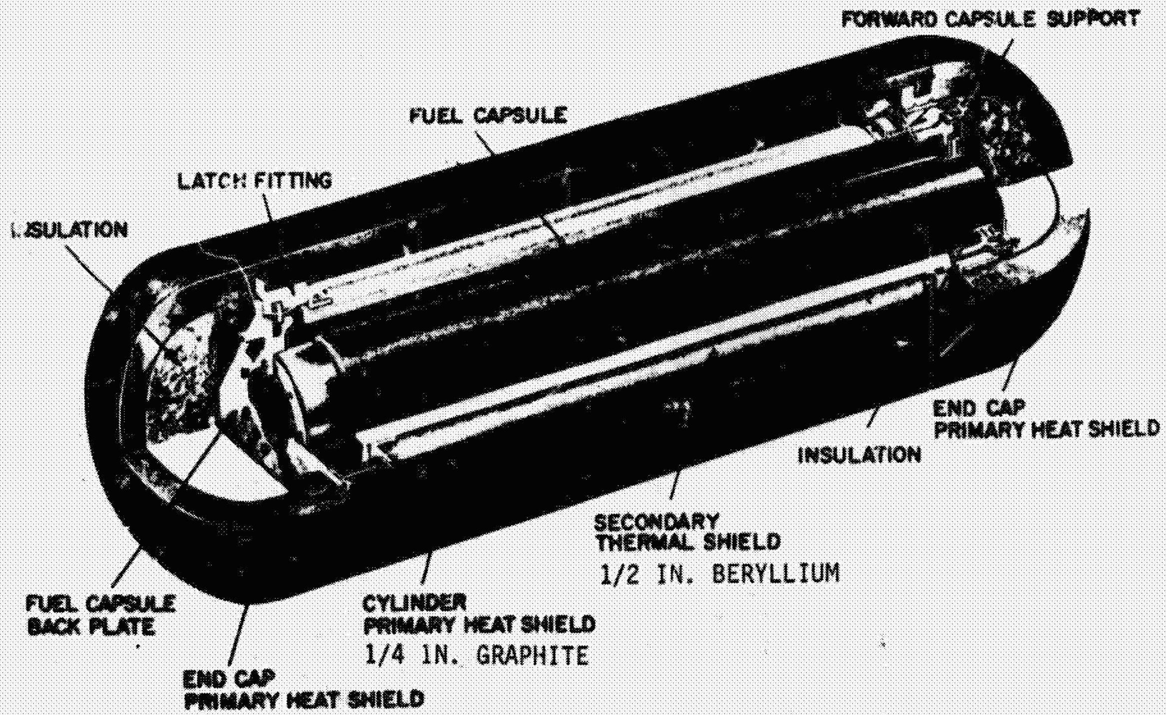

FIGURE 2.5-4. . G.L.F.C.

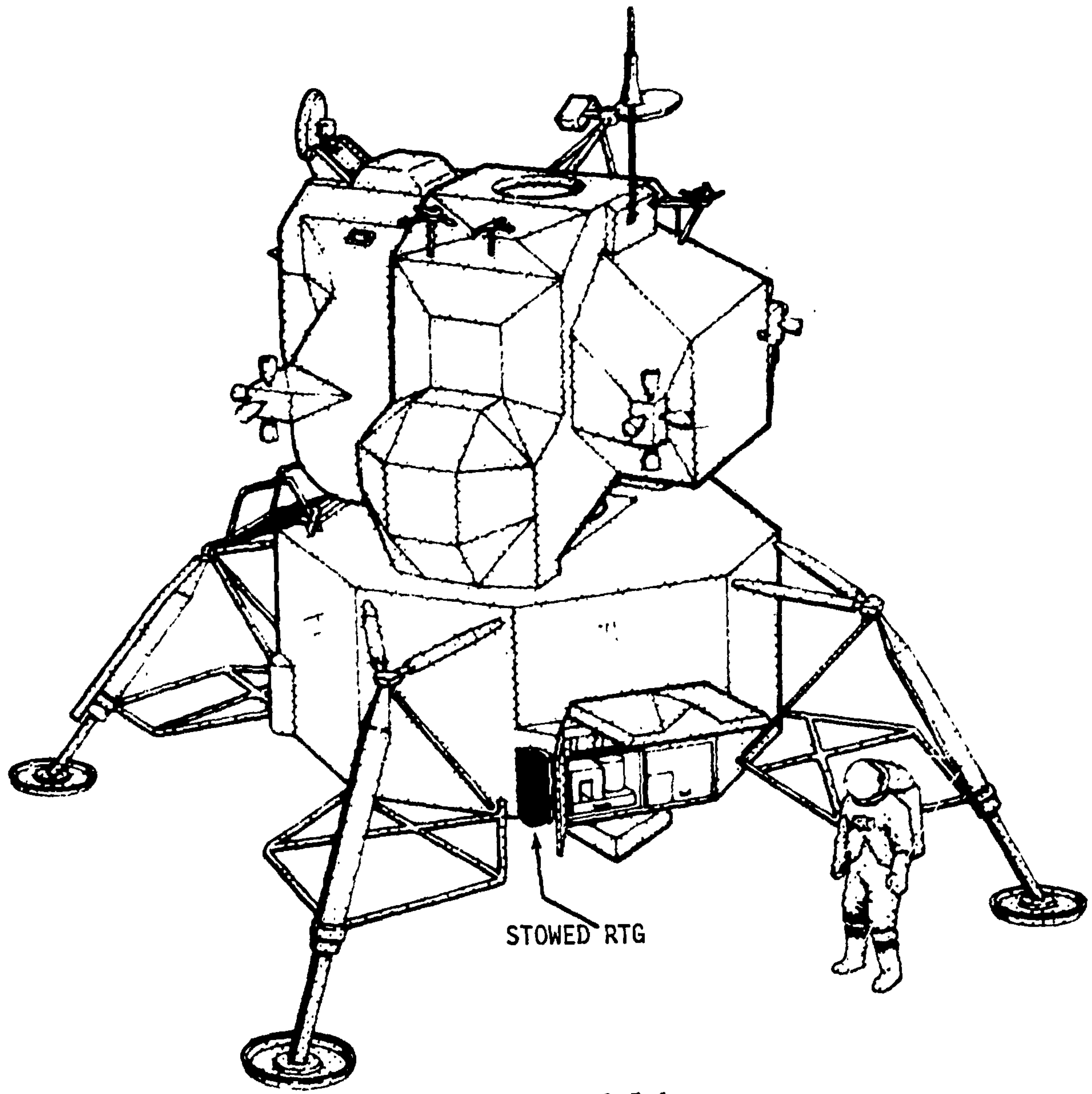

FIGURE 2.5-1.

2.6 LUNAR GEOLOGY EXPERIMENT CAMERA (GOERZ) GAS BOTTLE ASSEMBLY

2.6.1 DESCRIPTION

The gas bottle assembly is located in each film magazine provided for the Goerz Camera. The camera, with one magazine installed, and the magazine storage containers with spare magazines are stowed in the MESA until required for use on the lunar surface. The gas bottle provides the film magazine with an air environment maintaining 1.0 $\pm$ .5 pressure differential from ambient to protect the film from out gassing and insures proper film transport in the magazine.

The LGEC gas cylinder is 1.80" long by 1.35" in diameter with domed ends and includes two pressure compartments. The cylinder is 1061-T6 aluminum, .045" minimum thickness. See Fig 2.6-1.

The cylinder is charged with 500 psi of dry air, and designed for the following pressures; operating 500 psi, proof 760 psi. Theoretical factor of safety is 2+. Fig 2.6-2 through 5 present the Goerz camera and magazine with the gas bottle location in the magazine.

2.6.2 DISCUSSION

The camera is in the early production phase and qualification data which includes actual destructive burst pressure is not available. Apollo 14 & 15 are the first scheduled use of the camera and will carry one camera with magazine installed and one spare magazine in the storage container. Apollo 16 through 19 will have two spare magazines and one camera with magazine.

The volume of air, 1 cubic inch at 500 psi, has a TNT equivalent of 73.8×10^{-6} pounds of TNT. It is estimated that the explosive potential would be 1/20 of a dynamite blasting cap (1/2 gm TNT). The predicted failure mode is to leak and is not considered to cause mechanical damage.

Any potential damage to equipment or effect on crew safety is negligible as the bottle is contained within the magazine and within the storage container or camera (except during film magazine changes). The damage would be contained within the magazine and containers.

The qualification and acceptance testing will exercise the cylinder to proof limits of 760 psi and should obtain actual burst pressure data.

2.6.3 RESULTS

The Goerz gas bottle assembly is a small bottle designed to acceptable safety factor with a predicted failure mode resulting in leakage. The bottle is well protected within the magazine. In the event of rupture the damage would be contained within the camera or magazine container.

2.6.4 RECOMMENDATION

The gas bottle assembly should be accepted as non-hazardous with no procedural, design or testing changes recommended. The actual burst data should be obtained for file as soon as possible.

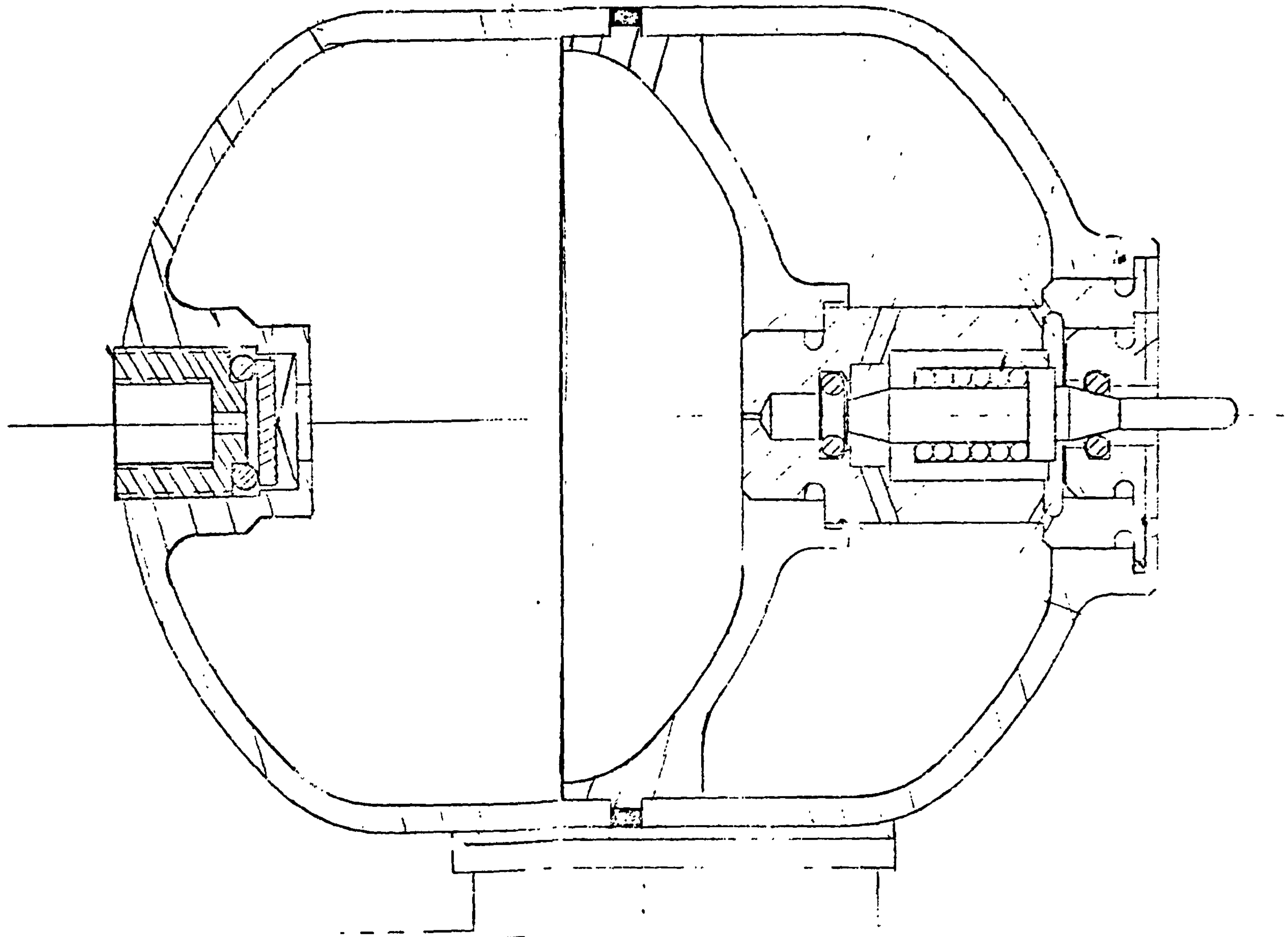

FIGURE 2.6-1. GOERZ GAS BOTTLE

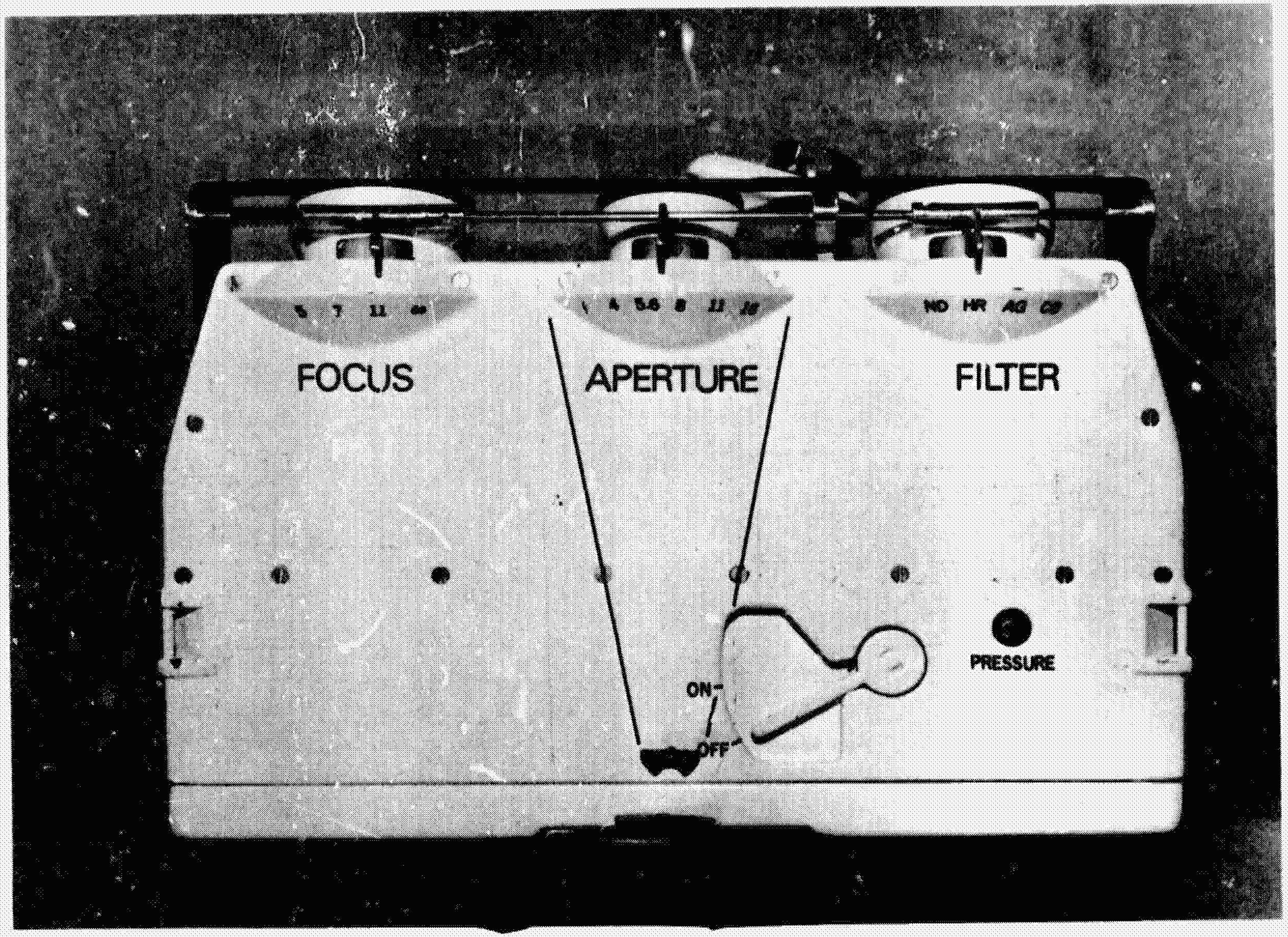

FIGURE 2.6-2.

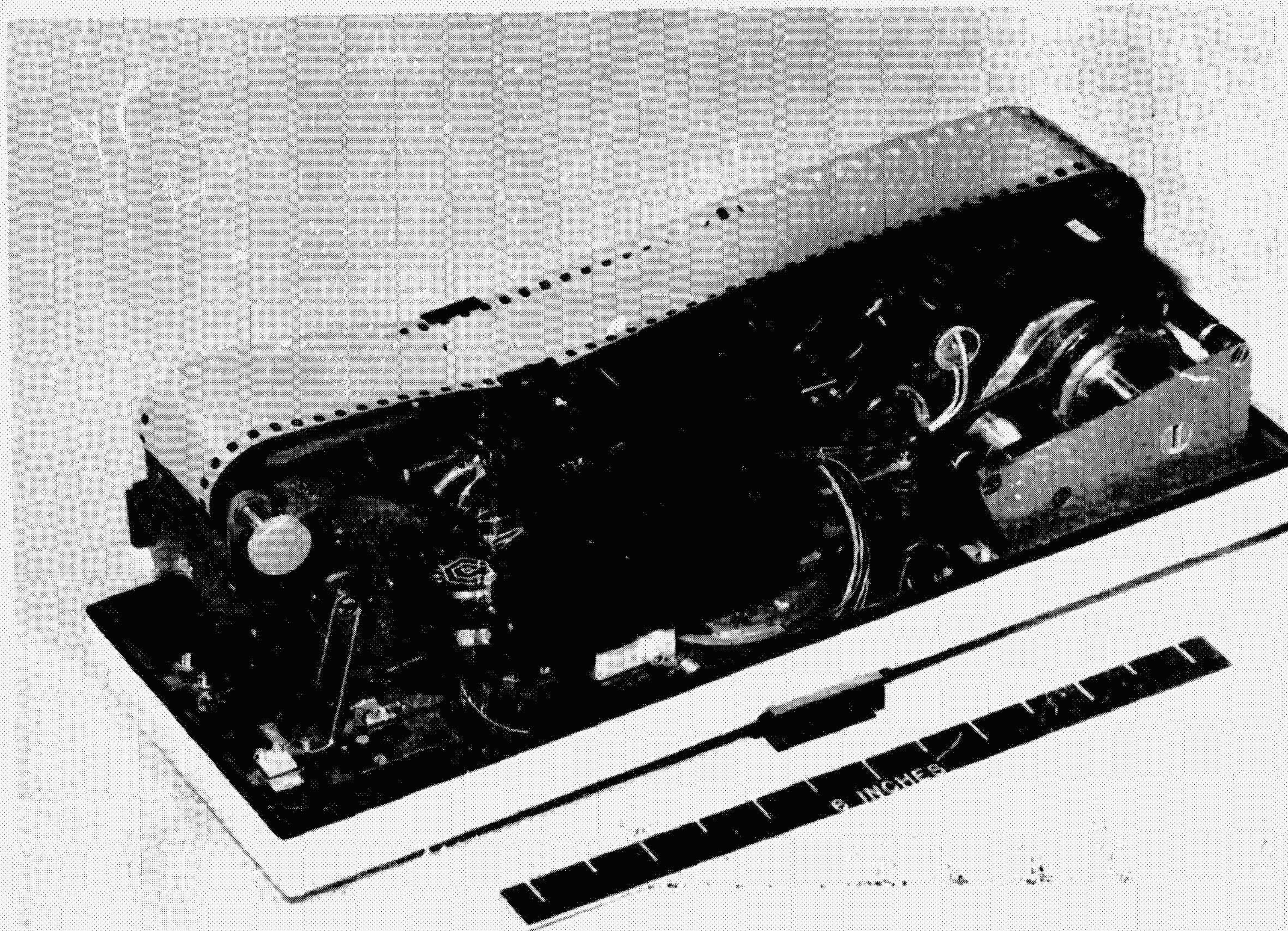

FIGURE 2.6-3.

Figure 2.6-4.

2.7 PASSIVE SEISMIC EXPERIMENT

PSE Caging Assembly

2.7.1 DESCRIPTION

The PSE inertial sensors are isolated through a pressurized bellows/manifold distribution assembly which cages the components for their trip to the lunar surface. The pressure system contains 1.6 cubic inches of 10% Helium and 90% Nitrogen at 333 PSI. On the lunar surface, the equipment is activated by ground command allowing the pressure to vent to vacuum and thus uncage the inertial sensors. There are eight 3/8" x 1/2" x .002" thick bellows, manifolded through .04" diameter stainless steel thin wall tubing which provide the isolation/caging forces. (Fig 2.7-1 & 2.7-2). The PSE is stowed in the ALSEP compartment. (Fig 2.7-3 and 2.7-4). Fig 2.7-5 pictures the internal components of the PSE and part of the shell, and shows part of the tubing and one of the bellows.

2.7.2 DISCUSSION

The loss of pressure during flight would cause uncaging of the inertial components and loss of the experiment. Any damage sustained to the experiment would be contained within the PSE soft spun aluminum shell. The shell is 6061 T-4 spun aluminum, 10.5" in diameter, 16.5" long and .02" thick. The shell is vented to ambient.

The operating and proof pressures are 333 and 650, respectively. The factor of safety is 2 +. The qualification program identified only a bellows slow leak problem corrected by going from a soft solder to a brazing process. The TNT equivalent for the system is 77.5 x 10^{-6} pounds TNT or approximately 1/16 of a dynamite blasting cap (1/2 gm TNT equivalent). The predicted failure mode is to leak and is not considered to cause mechanical damage.

2.7.3 RESULTS

The PSE pressure system has a very low explosive potential based on its low pressure, self containment, and high safety factor. Further, the predominant failure mode is to leak.

2.7.4 RECOMMENDATION

The PSE should be accepted as non-hazardous with no procedural, design or testing changes recommended.

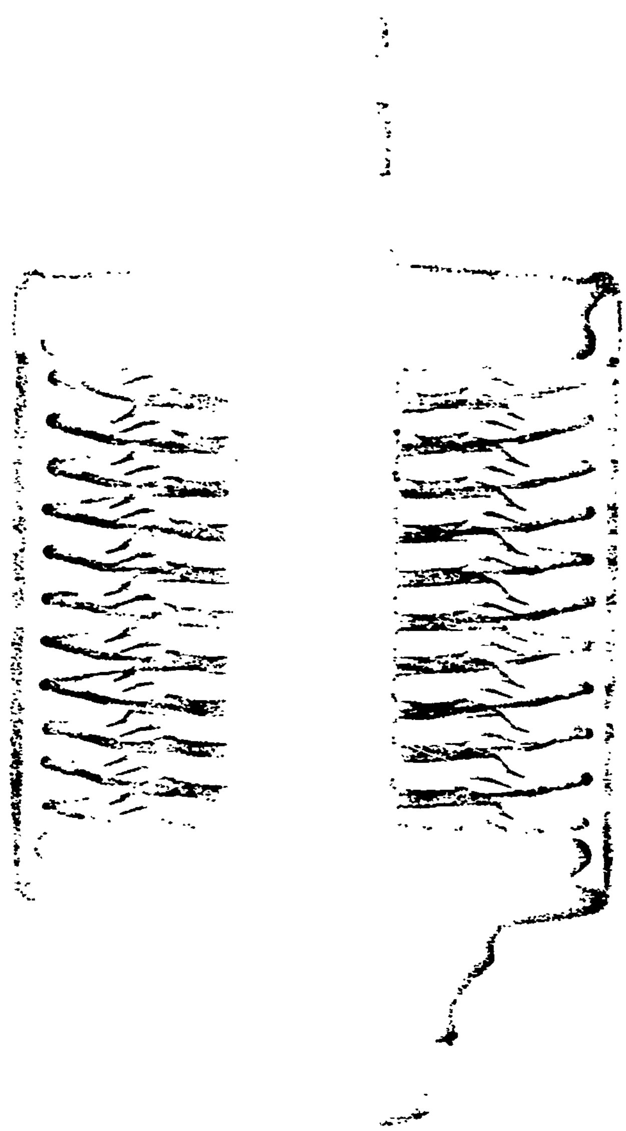

FIGURE 2.7-1. X-RAY OF TYPICAL PSE CAGING SYSTEM BELLOWS.

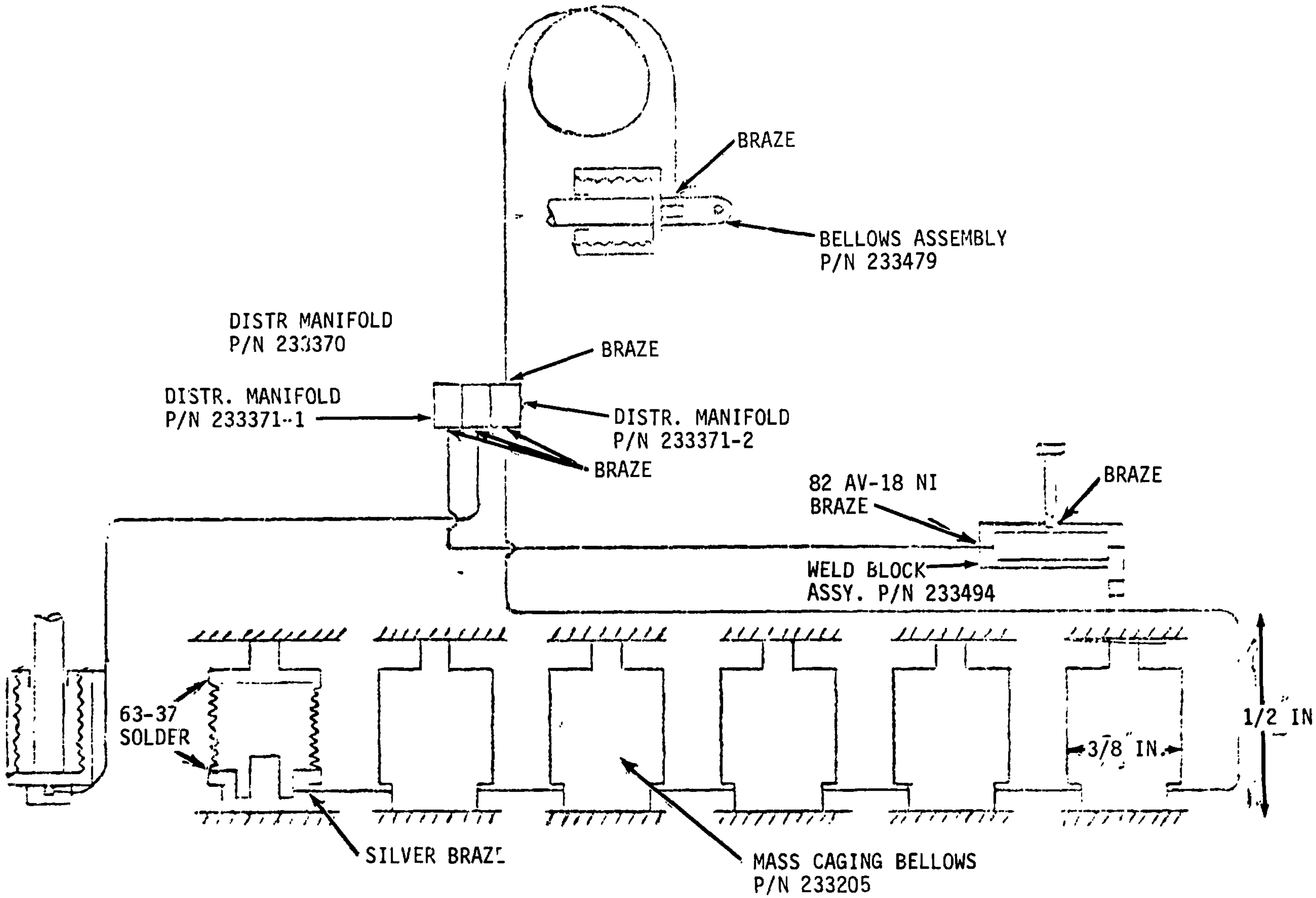

FIGURE 2.7-2. PSE CAGING SYSTEM SCHEMATIC

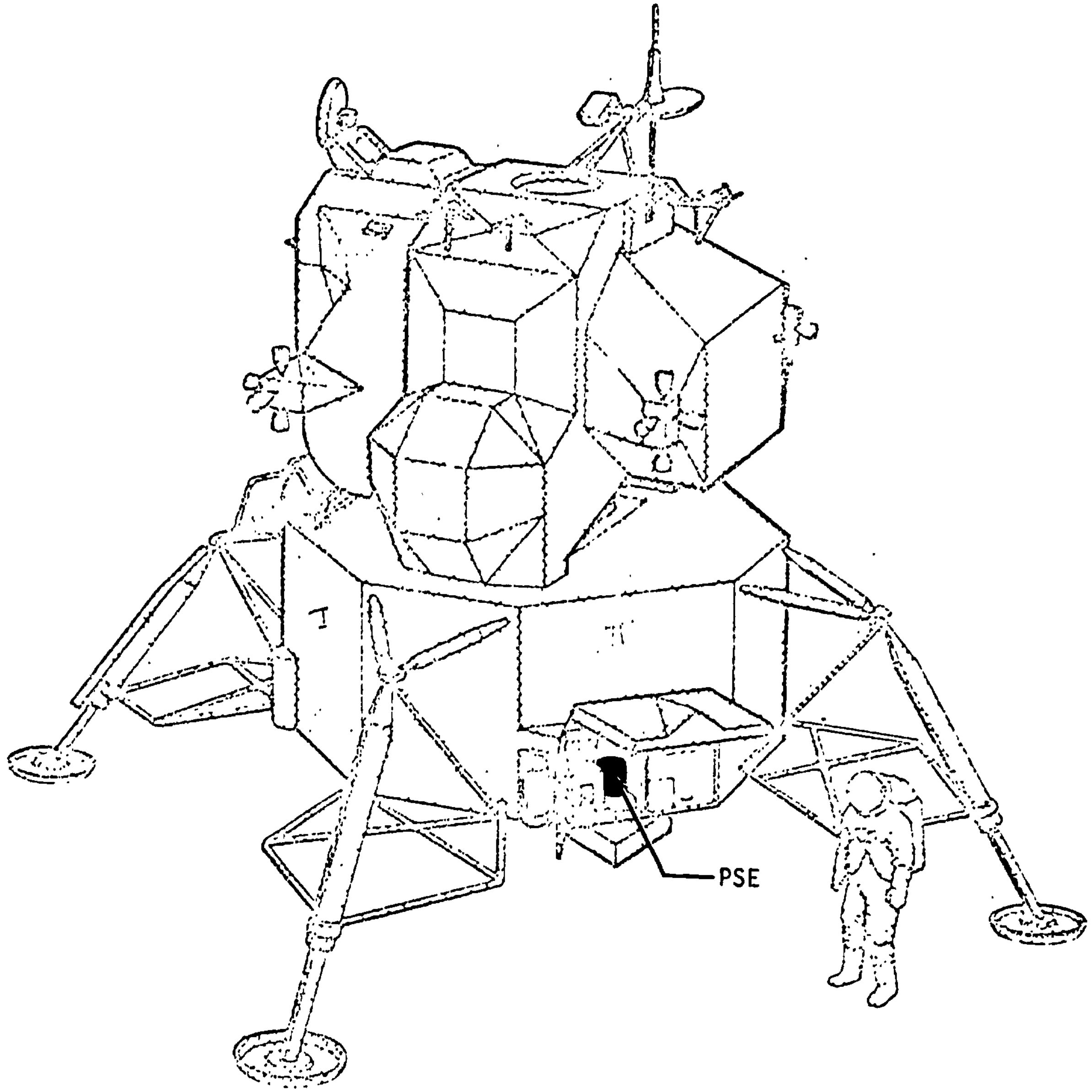

FIGURE 2.7-3.

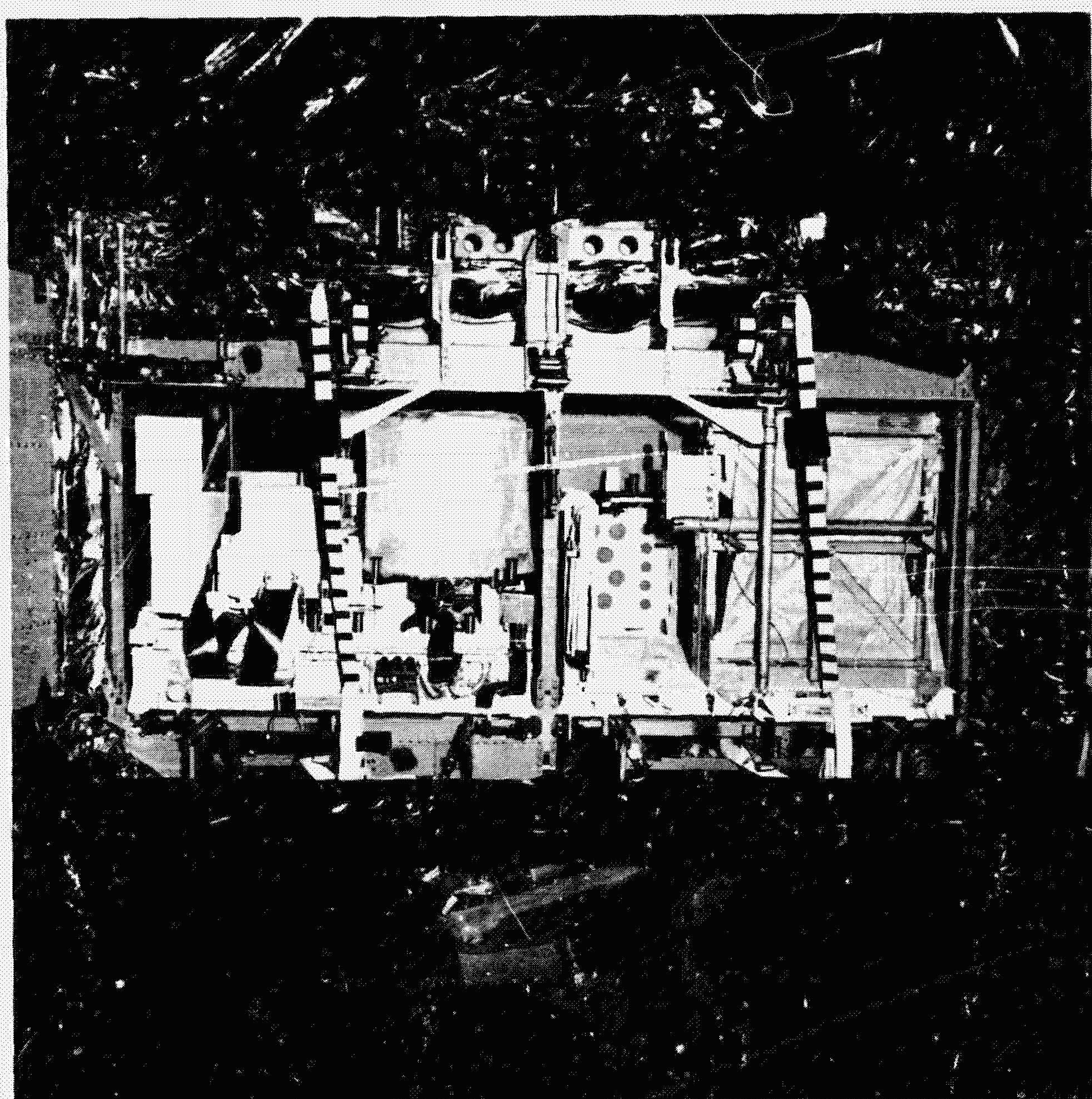

FIGURE 2.7-4.

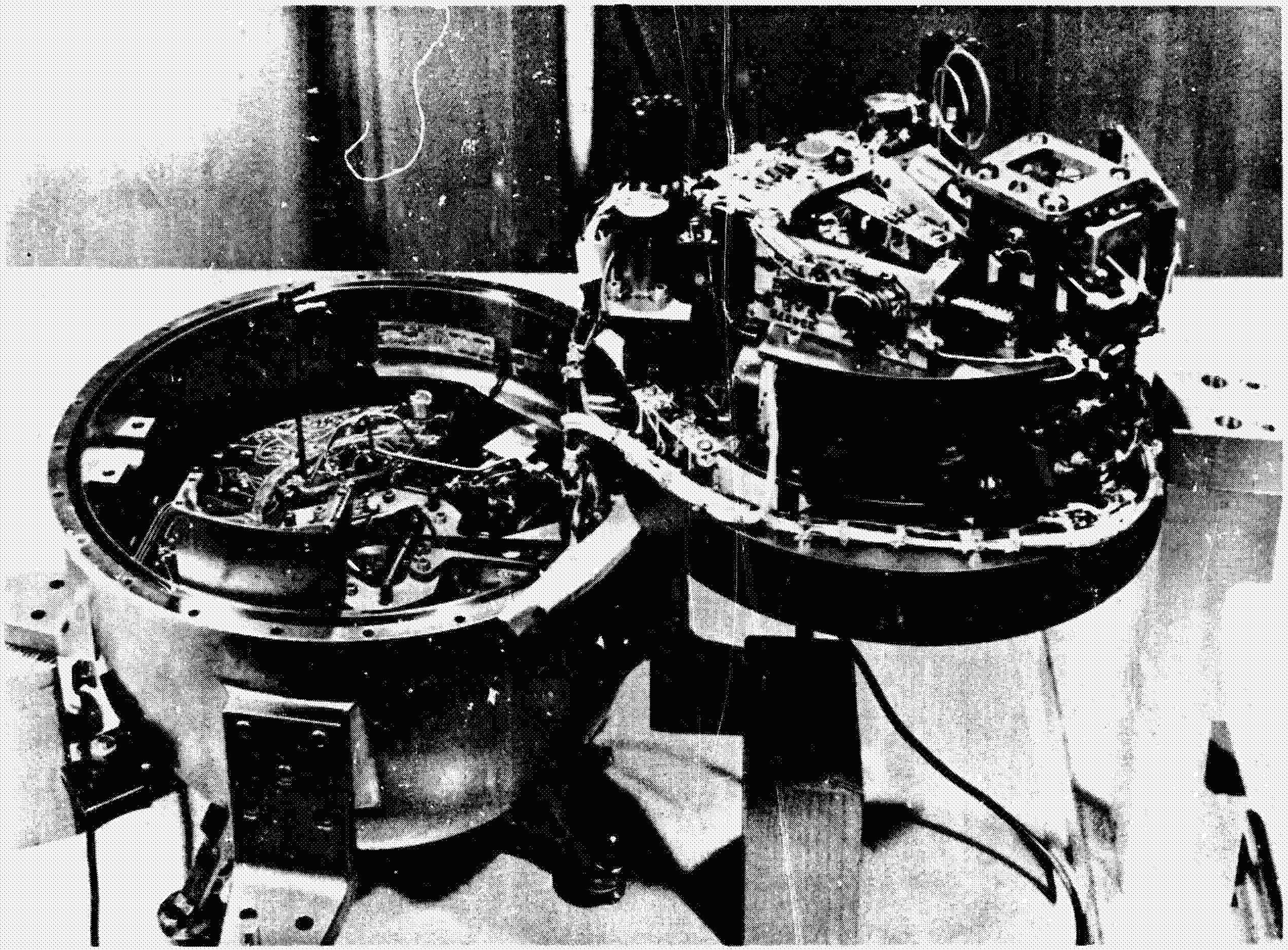

FIGURE 2.7-5.

3.0 GROUND SUPPORT EQUIPMENT (GSE)

The GSE (ground support equipment) investigation carried into the areas of pressure vessels, oxygen systems, and hypergolic systems. The tasks associated with these areas are outlined as follows:

- Pressure Vessels. - Due to the large number of pressure vessels contained in the GSE systems for both NR (North American Rockwell Corporation) and GAC (Grumman Aerospace Corporation), it was concluded to report only on those vessels that contained an ignition source, such as, a fan, heater, motor, etc., that could cause a reaction in the media being contained. After review of the GSE based on the above established criteria, only one vessel (liquid hydrogen dewar) qualified for the report (attachment 1).

- Oxygen System. - Two tasks (attachment 2) were assigned relative to the GSE investigation. All gas/liquid oxygen line components with electrical interfaces were to be identified and as many cross sectional views of these components provided as possible. Also, the identity was to be provided of all nonmetallic impact application materials, such as, valve seats.

- Hypergolic System. - One task was assigned concerning the hypergolic system. All oxidizer and fuel components with direct electrical fluid contact under nominal operations was to be identified. After review of the CSM and LM GSE hypergolic systems, it was determined that there are no components which have direct electrical contact with the propellants.

Several items related to all GSE hardware have been effected to provide a safe, reliable, efficient means of performing the operations necessary to support and launch a space vehicle.

- All GSE systems are functionally checked by performing a simulated checkout prior to acceptance of each vehicle for launch operations.

- Operational personnel provide continual surveillance in recognizing operational or hardware problems that may be hazardous to personnel or equipment. Immediate action is taken to effect safety changes. Also, changes to provide more efficient operations are initiated and reviewed for incorporation relative to necessity, technical adequacy, schedules, and cost.

- Many reviews of the GSE systems have been conducted to assure a successful vehicle checkout and launch operation. One such study, the Apollo Launch Availability Study, was conducted to investigate all components in each end item relative to redundancy, backup capability, and catastrophic failure. Also, for each new approved end item a failure mode effects analysis is conducted.

- Test procedures are continually being reviewed to provide optimum utilization of GSE equipment to perform a specific task.

- Experiences related to GSE have been and are being incorporated into followon designs of end item hardware.

- GSE reviews are conducted for each vehicle (FRR's).

- Close knit communications have been established among contractors, MSC, and KSC concerning GSE status.

- Components and end items have been modified during their usage period to the point that a design has been reached to provide streamlined operations and maximum safeguard from hazardous conditions or failures.

- Inspection and preventative maintenance plans are in existance for GSE end items.

- Adequate flushing techniques have been incorporated for those systems storing and transporting liquid or gases.

- All pressure vessels are acceptance-tested to a minimum of one and one-half times the working pressure. Also, functional test and component calibration data accompany each GSE end item when delivered.

In summary, it has been concluded from the investigation that:

(1) Action has been taken to incorporate maximum safety precautions, including design of hardware, for GSE during hazardous operations; (2) continued monitoring and usage of GSE hardware by operational personnel provide information that is acted upon immediately in the case of safety items; (3) although the GSE has caused test delays, the overall performance of GSE has been considered adequate and has never attributed to a scheduled launch delay; and (4) the validation tests, hardware reviews, and many studies performed are all attributes to the continual successful safe operation of the GSE.

3.1 GSE OXYGEN SYSTEMS

3.1.1 DISCUSSION

The GSE oxygen systems provided by NR and GAC were reviewed for materials compatibility and assessment of components with electrical/fluid interfaces. Table 3.1.1 lists the materials exposed to the high pressure oxygen in the ground support equipment. Table 3.1.2 lists the components in the oxygen system that have electrical interfaces. This information does not provide a sufficient basis for assessing the acceptability of the oxygen systems. The additional materials required have been requested from the contractors.

The original basis for acceptance of the nonmetallic materials application in the GSE was successful performance during actual operation. No failures have been experienced which can be attributed to impact sensivity of the nonmetallic materials in the system.

The contractors have indicated verbally that there are no components with direct contact between high pressure oxygen and electrical wiring of components. It is recommended that the necessary materials be assembled to complete review of the oxygen systems in the GSE to the same level as has been done in the spacecraft.

TABLE 3.1.1

(a) CSM GSE

O_2 NONMETALLIC MATERIAL EXPOSURE

ITEM	NOMENCLATURE	MATERIAL	REMARKS
S34-174 (O_2 Dewar)			
RV 1431	Relief Valve	Teflon	O-ring
MV 1430	Globe Valve	Kel-F, Teflon	Seat, Seal
MV 1429	" "	Kel-F	Seat
MV 1432	" "	No NMM	
MV 1433	" "	Viton	O-ring
MV 1437	" "	15% glass-filled Teflon	Packing Seat
RV 1435	Relief Valve	Teflon	O-ring
MV 1431	Manual Valve	Teflon	Seat and Packing
A34-329 (GO_2 Pressure Regulation Unit)			
RV 1	Relief Valve	Teflon	O-ring
MV 1	Manual Valve	Teflon, Penton, Buna N	Packing, Seat, Seal
PR 1	Pressure Regulator	Teflon, 15% graphite Teflon	Seat, Vent Valve Seat
FL 1	Filter	Teflon	Seal
S14-032 (Transfer Unit)			
FL 2	Filter	Teflon	Seal
PR 10	Pressure Regulator	Kel-F, Teflon, Buna N	Seat, Backup Ring, O-ring
PR 9	Pressure Regulator	Kel	Seat
PR 11	" "	Kel-F, Teflon, Buna N	Seat
PV 9, 10, 11, 12	Pressure Valves	Kel-F, Teflon	Seat. Packing
S14-132 (Fluid Distribution System)			
CV 1265, 1276	Check Valve	Viton	Seat
CV 3	" "	Teflon	Seat

TABLE 3.1.1 (Contd)

(a) CSM GSE

O_2 NONMETALLIC MATERIAL EXPOSURE

ITEM	NOMENCLATURE	MATERIAL	REMARKS
S14-132 (Fluid Distribution System, Cont'd)			
CV 1314, 2, 4, 5 6, 8	Check Valve	Viton A	Seat
CV 201, 202	" "	Viton	Seat
LV 12 thru 17, 18, 22	Solenoid Valve	Teflon	Seals
PV 11	Pilot Valve	-	Seat
PV 10	" "	-	Seat
PV 36	" "	-	Seat
PR 4, 5	Pressure Regulator	Teflon, 15% graphite Teflon	Seat, Vent Valve Seat
PR 202	" "	Delrin, Neoprene, Nylon	Spacer, Piston & Seat, O-ring, Work Screw
PR 1253, 201	" "	Teflon	Seat
MV 2, 1338, 1280	Manual Valve	Teflon	Seal and Seat
1281, 1254,	" "	"	"
1, 1255, 1257,	" "	"	"
1259	" "	"	"
203, 205, 204	" "	"	"
1438, 501, 601	" "	"	"
602, 603, 604	" "	"	"
RV 2, 3, 1262	Regulator Valve	-	Seat
FL 1247	Filter	Buna N	O-ring
FL 501, 502, 503	"	Teflon	Seal
PT 1, 3, 6, 8	Transducer	-	- -
PS 2	Pressure Switch	-	- -
TS 3, 4	Transducer	-	- -
PP 2	"	-	- -

TABLE 3.1.1 (Contd)

(b) LM GSE

O_2 NONMETALLIC MATERIAL EXPOSURE
ON MOBILE SERVICE STRUCTURE

ITEM	NOMENCLATURE	MATERIAL
430-54200 - Gaseous Oxygen Transfer Unit		
V18	Valve	Teflon, Kel-F
V16	"	Teflon
V13	"	Kel-F
V17	"	Teflon
V1	"	"
V2	"	"
V4	"	"
V3	"	"
R3	Regulator	Teflon, Kel-F
Con 1	Controller	Kel-F, Viton A
V19	Valve	Teflon
V20	"	"
V7	"	"
V11	"	Kel-F
V21	"	"
FL3	Filter	Viton A
Invelco	Lubricant	
430-54750 - Auxiliary Gaseous Oxygen Service Unit		
V1	Solenoid Valve	Teflon, Viton A, Kel-F
V2	" "	" " "
V3	" "	" " "
SOV-2	Shutoff Valve	Viton A
SOV-3	" "	" "
SOV-4	" "	" "
PT-1	Pressure Transducer	Viton A
PT-2	" "	" "
PT-3	" "	" "
RV-1	Relief Valve	Viton A
CV-1	Check Valve	Teflon
SOV-1	Shutoff Valve	Viton A
SOV-5	" "	Teflon

TABLE 3.1.2

(a) CSM GSE

O_2 COMPONENTS WITH ELECTRICAL INTERFACE

IDENTIFICATION	NOMENCLATURE	PART NUMBER	REMARKS
TS 3	Transducer	ME 449-8021-0033	Isolated from media
TS 4	" "	" "	" " "
PT 3	Transducer	ME 449-8012-2112	Isolated from fluid media
PT 6	" "	4390-0128-0165A	" " " "
PT 1	" "	ME 449-8023-0009	" " " "
PT 8	" "	360695-0100	" " " "
PP 2	Transducer	ME 449-8023-0108	Isolated from media
PS 2	Pressure Switch	ME 452-8017-0013	Sealed - Explosion-proof
FL 1	ΔP Switch	ME 286-8024-0007	Sealed - Explosion-proof
LV 12	Solenoid Valves	ME 284-8183-2101	Hermetically-sealed - isolated
LV 13	" "	" "	" " "
LV 14	" "	" "	" " "
LV 15	" "	" "	" " "
LV 16	" "	ME 284-8183-2105	" " "
LV 17	" "	ME 284-8183-2101	" " "
LV 18	" "	" "	" " "
LV 22	" "	ME 284-8077-1110	" " "

TABLE 3.1.2 (Contd)

(a) LM GSE

O_2 COMPONENTS WITH ELECTRICAL INTERFACE

IDENTIFICATION	NOMENCLATURE	REMARKS
SOL V-1	Solenoid Valve	Seal between electrical coil and fluid
SOL V-2	" "	" " "
SOL V-3	" "	" " "
PT-1	Pressure Transducer	Isolated in well
PT-2	" "	" "
PT-3	" "	" "
V11	Valve	Sealed

3.1.2 CONCLUSIONS

The available information on the GSE oxygen systems was not sufficient to verify the acceptability of the design with respect to:

a. Impact sensitivity of nonmetallic materials application.

b. Characteristics of electrical component interfaces with oxygen.

c. Accumulation of contaminants.

3.1.3 RECOMMENDATION

Obtain the necessary information to complete the evaluation of the oxygen systems.

3.2 HYDROGEN DEWAR TANK

3.2.1 DESCRIPTION

The liquid hydrogen dewar tank, part number S34-172, is a cylindrical-shaped, lightweight, vacuum-jacketed, superinsulated cryogenic container for storing liquid cryogenics with minimum losses due to heat leak during storage, transportation, or servicing. Dewar photograph, see Figure 3.2.1.

3.2.1.1 DIMENSIONS

	Diameter	Hemispherical Heads Total	Height of Cylinder
Inner Vessel	32"	17.98"	30.85"
Outer Vessel	36.25"	20.29"	31.25"

3.2.1.2 TANK MATERIAL AND THICKNESS

	Material	Thickness Cylinder	Thickness Dome
Inner Vessel	6061 aluminum T6	0.095	0.087
Outer Vessel	6061 aluminum T6	0.125	0.125

3.2.1.3 PRESSURES

Normal	Limit	Proof	Burst
20 psig	33 psig	45 psig	90 psig

3.2.1.4 INTERNAL COMPONENTS AND MATERIALS

Radial Resistors

Two groups of four carbon radial resistors separated by Teflon spacers are positioned in a perforated standpipe of 6061 aluminum welded at the top to 6061 aluminum vent line and resting on a Teflon guide at the bottom of the tank. The resistors are 1/8 watt, 270 ohm $\pm$ 5 percent, Type BB, made by Allan Bradley Company, Milwaukee, Wisconsin. The current to each resistor is 5 micro amps at liquid hydrogen temperature. Schematic of standpipe (probe), see Figure 3.2.2.

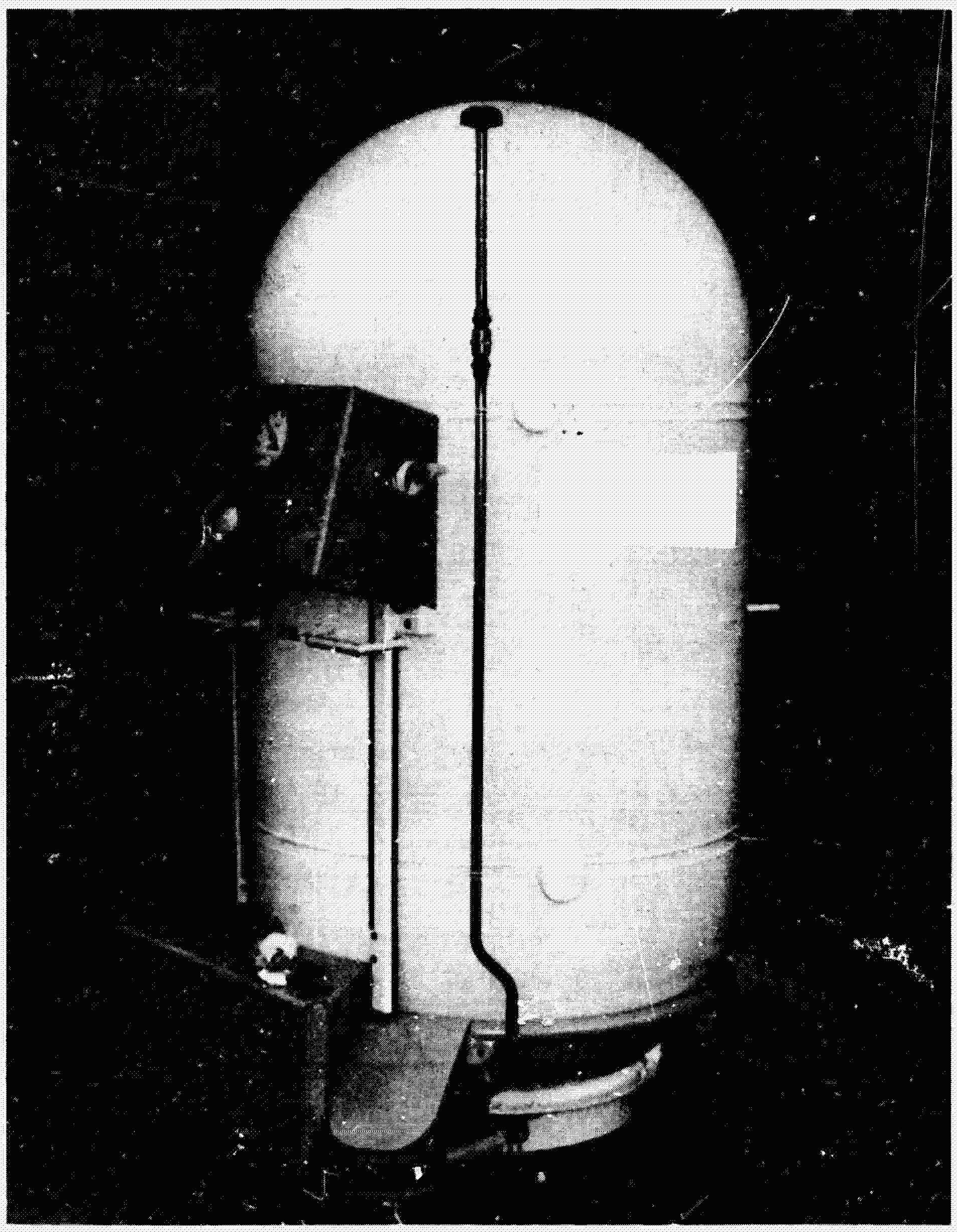

FIGURE 3.2.1 - HYDROGEN DEWAR TANK

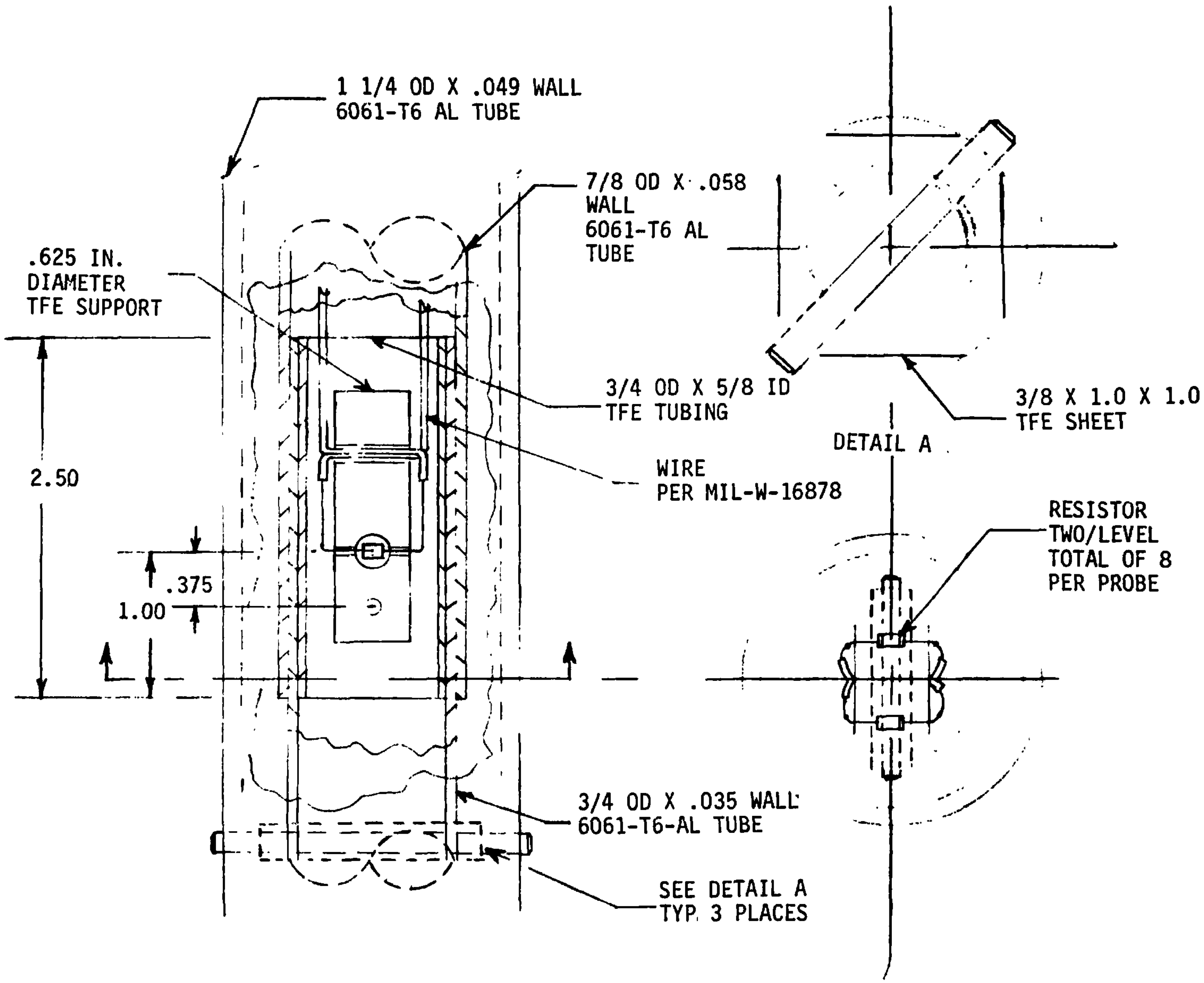

FIGURE 3.2.2. INSTALLATION CROSS SECTION OF CARBON RESISTOR IN LIQUID LEVEL PROBE
(TYP 4 PLACES)

Wire

Twenty-eight gage nickel conductor, Teflon-Coated wire per MIL-W-16878-4A, Type E28, is used in the inner vessel. There are two wires per resistor or a total of sixteen wires in standpipe.

Insulation

Sixteen layers of 0.00025 inch thickness aluminized Mylar NCR2 is used outside of the inner vessel.

3.2.1.5 EXTERNAL COMPONENTS AND MATERIALS ON TANK

Top Panel Box

Top panel box made from 6061 aluminum contains the following components:

Item	Identification Number
Filter	L130
Pressure Gage	102
Pressure Transducer	103
Manual Valve	126
Vacuum Gage	114
Converter (liquid lever)	
Circuit Breaker	
DC-DC Converter	
Power-On Light	
Three Electrical Connectors	
Power Receptical	
Descrete Receptical	
Analog Receptical	

The liquid/or gas-wetted area is exposed to stainless steel lines and components as well as aluminum. The soft goods contained in the components are Teflon, Deloren, Kel-F, and Viton.

Bottom Panel Box

Bottom panel box made from 6061 aluminum contains following components:

Item	Identification Number
Filter	L129
Pressure Regulator	101
Manual Valve	107
Burst Disc	108
Relief Valve	109
Manual Valve	104

Manual Valve	125
Relief Valve	111
Solenoid Valve	110
Vacuum Valve	106
Vacuum Transducer	105
Vacuum Transducer	123

The liquid/or gas-wetted area is exposed to stainless steel lines and components as well as aluminum. The soft good contained in the components are Teflon, Deloren, Kel-F, and Viton.

Lines

External plumbing of 304L stainless steel is sized as follows:

Transfer Lines	3/8 inch
Vent Lines	1/2 inch
Gas Lines	1/4 inch

3.2.1.6 OTHER INFORMATION

Liquid Hydrogen Dewar

The liquid hydrogen dewar was originally designed to be used with liquid helium in servicing the lunar module supercritical helium propulsion tanks. The dwar designed and built by Beech Aircraft for Grumman Aerospace Corporation was made common-use equipment and utilized by North American Rockwell Corporation to service command and service modules 103 with liquid hydrogen.

Prior to servicing command and service modules 103, the capability to completely fill the dewar with liquid hydrogen was verified by test at the Kennedy Space Center Cryogenic Number 2 Facility. Also, transportation of the dewar with liquid hydrogen up the mobile service structure elevators and installation on level 4A was verified by similarity based on tranrporting the dewars fully loaded with liquid helium (liquid helium heavier than liquid hydrogen 185 pounds versus 105 pounds full load).

General Design Criteria

Ground support equipment used for cryogenic fluids

Ground support equipment used for cryogenic fluids shall be designed to meet both cryogenic and ambient temperature conditions.

Provisions to prevent damage to fluid lines

Provisions shall be incorporated to prevent damage to fluid lines at temperature extremes due to expansion and contraction.

Construction of fluid systems

Fluid systems shall be constructed of material compatible with the fluids used.

Safety factors for fluid systems

	Pressures	
Lines/fittings	2XOP	4XOP
Pressure vessels	2XOP	4XOP
Operating pressure		

Lightweight metals compatible with pressure vessels

Lightweight metals compatible with pressure vessels shall be used in all lines and connecting fittings to tank.

Ground support equipment designed for use in hazardous gas

Ground support equipment designed for use in hazardous gas environment shall have components sealed.

Metals compatible with pressure vessels

Metals compatible with pressure vessels shall be used in all lines and connecting fittings to vessel.

Ground support equipment exposed to salt environment

Ground support equipment exposed to salt environment shall be designed to be compatible with environment either by the selection of the material or by a suitable coating.

Dewar design

The dewar design also included the following:

a. Smallest possible envelope

b. Mobility

c. Low heat leak

d. Manual or remote operation

Loading and Servicing

The dewars are loaded with liquid hydrogen prior to spacecraft servicing and stored in the cryogenic facility. During this time, the dewars are monitored and checked to verify nominal operation. When the spacecraft is ready for servicing, the dewars are topped off and transported to launch complex 39. One dewar is for backup and left at the base of the mobile service structure while the second dewar is positioned inplace on level 4A. After connections are made between facility, dewar, and spacecraft, the servicing is started and continues until approximately 90 percent is indicated on the spacecraft liquid hydrogen quantity gages. The spacecraft cryogenic tanks are allowed to cold soak followed by final loading until the spacecraft quantity gages indicate 100 percent. After servicing, the dewar is purged and inerted with a 1 psig pad pressure being maintained.

Venting

The venting of the liquid hydrogen dewar is accomplished as follows:

a. Cryogenic facility - The dewar venting is through the cryogenic facility vent system.

b. Transportation to pad - Dewars not vented.

c. Mobile service structure elevator - Dewar vent valve not opened but vent line attached to elevator vent as contingency provision.

d. Base of mobile service structure - Backup dewar at base of mobile service structure is vented into pad vent system.

e. Mobile service structure level 4A - Dewar servicing unit on level 4A is vented into pad vent system.

Schematic of Liquid Hydrogen Dewar

Schematic of liquid hydrogen dewar with critical component pressures (see Figure 3.2.3 - Liquid Hydrogen Dewar, S34-172).

3.2.2 POTENTIAL CAUSES OF TANK FAILURE

3.2.2.1 SOURCES INSIDE TANK

Electrical

Energy from electrical source is not considered sufficient to cause failure.

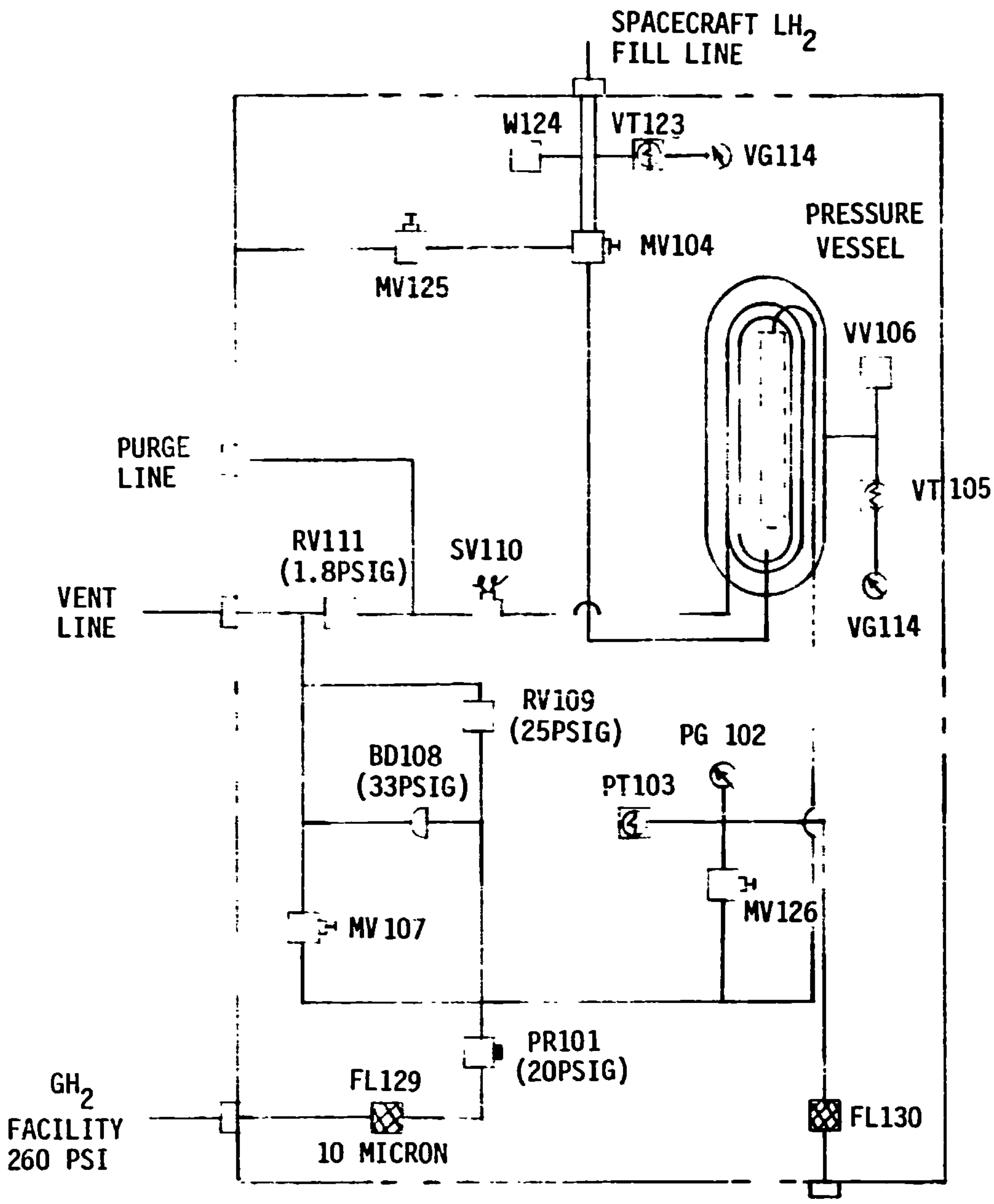

FIGURE 3.2.3. LIQUID HYDROGEN DEWAR (S34-172)

Chemicals (including contamination)

Shock-sensitive materials with liquid hydrogen have been detected in the system: iron, tin, sulfur, Butyl rubber, and zinc. These contaminants have been detected in small quantities - less than 1 mg/liter.

The following specifications are being utilized:

a. MA0610-017 - Cleanliness requirements and cleaning process for Apollo fluid systems.

b. MSC-SP-F-0021 - Apollo spacecraft fluid cleanliness specification.

- Particles

0	-	50	microns	UNL
50	-	140	microns	40
140	-	230	microns	10
230	-	320	microns	3
320	-	410	microns	2
410	-	500	microns	1
7500			microns	0

- Fibers

50	-	500	microns	10
500	-	1000	microns	1
71,000			microns	

- Nonvolatile residue - 1 mg/liter

No ground support equipment waivers for the liquid hydrogen dewar assembly have been experienced due to contamination.

Mechanical

Annulus - A leak into the vacuum-jacketed annulus of the dewar would result in rupture to outer or inner wall and subsequent gaseous hydrogen leakage that would form a flammable atmosphere. This condition is more likely to happen during transportation. A 2 psig blowout plug is part of the pressure vessel design to allow for contingency relief in case of leak into the annulus.

3.2.2.2 SOURCES EXTERNAL TO TANK OF PRESSURE INCREASE

Thermal

Not applicable

Mechanical

Not applicable

Other

Not applicable

3.2.2.3 REDUCTION OF TANK STRENGTH

Stress Corrosion

The hydrogen-containing shells of the liquid hydrogen dewar tanks, G37-84016, are fabricated from 6061 aluminum allow in the T6 condition. This alloy has an excellent history of hydrogen service with no known incompatibilities or sensitivities. The toughness of the alloy is relatively high, and a fracture mechanics analysis shows that the mode of failure at normal operating pressures is leakage rather than catastrophic rupture. This analysis does not include the possible effects of ignition of escaping gas. Should this occur, the vessel is protected by both a relief valve and a burst disc and has a minimum safety factor of 2.73 based on burst disc setting. The safety factor at normal operating pressure is 4.5. Materials reported inside the tank are aluminum, Teflon, nickel, and insulated composition resistors. There are no terminals or connections made inside the vessel. The evaluation of the vessel, its components, and environment does not show any condition or materials use which can be judged as potentially dangerous.

(The above coordinated with Materials Technology Branch, Structures and Mechanics Division, Engineering and Development Directorate, code ES8).

Local Hot Spots

There are no local hot spots.

Manufacturing Anomalies

There are no manufacturing anomalies.

Preventative Maintenance and Testing

Inspection of external unit for cleanliness

Inspect external unit for cleanliness. Remove all dirt, excess oil, water, or other foreign material. as required.

Inspection for evidence of rust or corrosion

Inspect for evidence of rust or corrosion. Remove, treat, prime, and touch-up finish, as required, where bare metal is exposed.

Inspection for obvious physical damage

Inspect unit for obvious physical damage, dents, cracks, loose, or missing hardware.

Inspection of piping and tubing for damage

Inspect piping and tubing for damage and clamps and connectors for security.

Inspection of gages

Inspect gages for broken lenses and bent or missing pointers.

Inspection of log book to verify minimum pressure in inner vessel

Inspect log book to verify a minimum of 1 psig pressure has been maintained in the inner vessel. Log book shall have a minimum of one entry every 7 days while not loaded and one entry every 72 hours while loaded.

Inspection of log book to verify annulus

Inspect log book to verify annulus vacuum reading has not exceeded 50 microns on VG 114. Log book shall have a minimum of one entry every 7 days while not loaded and one entry every 72 hours while loaded. Pump down vacuum as required.

3.2.3 DAMAGE POTENTIAL OF TANK

3.2.3.1 SURROUNDING EQUIPMENT CONFIGURATION

Surrounding equipment configuration which could be damaged on mobile service structure level 4A.

Nomenclature	Approximate Distance to Dewar in Feet
Spacecraft service module*	5
Electrical terminal distributor	10
Initiator stimuli unit	12
Liquid oxygen valve box	16
Service module-command module oxidizer valve box	5

* Command and service module service propulsion system fuel and oxidizer tanks are loaded at the time of liquid hydrogen servicing.

Service module-command module fuel valve box	10
Service propulsion system oxidizer valve box	17
Service propulsion system fuel valve box	22
Electrical power system vacuum systems service unit	25
Gaseous oxygen pressure regulation unit	12
100 amp electrical power distributor	9
Compressed gas cylinders (7 K bottles) gaseous nitrogen (outside enclosure)	20
Liquid hydrogen valve box	15

3.2.3.2 DAMAGE ESTIMATE

Failure Mode Exhibited in Test

No failure mode was exhibited.

TNT Equivalent

The following modes of tank failures must be considered:

a. Tank pressure exceeds burst pressure and a catastrophic failure occurs under pressure only.

b. A minimum 18 percent gaseous hydrogen/air mixture results from failure of tank or leak, and an explosion occurs.

Potential energy (pressure only)

The potential energy, under pressure is calculated using the following equation:

$$\text{Work} = \frac{P_1 V_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] = \text{ft-lbs}$$

One pound of TNT is equivalent to 1.08×10^6 ft-lbs of work. The actual energy produced by one pound of TNT is 1.62×10^6 ft-lbs, but 1/3 of this energy is given off as heat. The analysis shows that the liquid hydrogen dewar is equivalent to 0.185 pounds TNT under pressure only.

Potential energy (detonation) - Gaseous hydrogen has the following characteristics:

h	(heat of combustion	=	52,800 Btu/lb
			270 Btu/ft^3
w	(weight)	=	88.7 ft^3/lb
D_v	(detonation velocity)	=	9,000 ft/sec
I_t	(ignition temperature)	=	1,076°F
F_t	(flame temperature)	=	3,700°F
F_m	(flammable mixture)	=	4% to 74%

The following tank data is required to calculate the potential energy developed from an explosion:

v	(volume in tank)	=	118 gals
			11,200 ft^3
H	(heat value in tank)	=	3×10^6 Btu
H_t	(heat output in tank)	=	69 Btu/ft^3

Taking the tank heat value of 3×10^6 Btu and dividing by 2.1×10^3 Btu (Btu/lb TNT), an equivalent of 1,430 lbs TNT would be obtained. Due to the following, this value is less:

a. Rate of detonation of TNT is 14,800 ft/sec and of gaseous hydrogen is 9,000 ft/sec.

b. Gaseous hydrogen has a greater energy loss due to heat from combustion.

c. There is an energy loss due to mixing efficiency (35 percent)

The following three methods can be used to determine TNT equivalent energy in tank:

<u>Method 1</u>: 65 percent efficiency due to mixing and 33 percent energy loss due to heat

$$\text{Work} = (V_2)(.65)(.67)(h)(776) = \text{ft-lbs}$$

$$11 \times 10^3 \times .65 \times .67 \times 270 \times 776 = 10.5 \times 10^8 \text{ ft-lbs}$$

$$\text{TNT equivalent} = \frac{10.5 \times 10^8}{1.62 \times 10^6} = \underline{620 \text{ lbs-TNT}}$$

<u>Method 2</u>: Utilize (H_t) heat output of tank with 40 percent air-gas mixture

$$\text{Work} = (H_t)(776)(.65) =$$

$$69 \times 27.5 \times 10^3 \times 776 \times .65 = 960 \times 10^6 \text{ ft-lbs}$$

$$\text{TNT equivalent} = \frac{960 \times 10^6}{162 \times 10^6} = \underline{594 \text{ lbs-TNT}}$$

Method 3: Considers an 18 percent gaseous hydrogen-air mixture

TNT equivalent = WT GH_2-air x 1.3 x .65 = 584 lb-TNT

The three methods of determination give an average TNT equivalent of 596 pounds of TNT.

Gaseous hydrogen fire

If a gaseous hydrogen-air ignition occurred instead of an explosion, the result would be as follows:

a. Pressure within the combustible atmosphere would reach 120 psi.

b. Heat within the combustible atmosphere would reach 3,700°F.

Estimated Damage to Surrounding Equipment Due to Blast and Shrapnel

Damage to the surrounding area would result from the following:

a. Shock wave from an explosion

b. Heat damage from ignition

c. Shrapnel from an explosion

Damage from explosion

A catastrophic failure of the tank would transmit a shock wave with an overpressure (P_{so}) that would last for a time duration (t_d). This is calculated by the following equation:

$$P_{so} = \frac{4,120}{Z^3} - \frac{105}{Z^2} - \frac{39.5}{Z}$$

Where P_{so} = psi overpressure

$Z = \frac{R}{W^{1/3}}$

R = distance from blast

W = lbs TNT

$t_d = \frac{2I}{P_{so}}$ where: t_d = P_{so} time duration

$$I = \frac{.081W^{2/3}}{R}$$

The following table gives the overpressure (P_{so}) at distance (R) from blast for time duration (t_d). The distance (R) is from the center of the tank:

R(ft)	P_{so}(PSI)	t_d(MSCC)
6	10,955	0.174
8	4,705	0.31
10	2,368	0.42
12	1,394	0.69
14	881	0.94
16	589	1.23
20	291	1.99
30	95	4.0
40	37	7.8
60	15	[illegible].8
100	5	23.0

Equipment located adjacent to the liquid hydrogen dewar would receive extensive damage from the blast and from shrapnel. Damage to equipment and vehicle would be proportionate relative to distance from dewar.

Heat Damage

The gaseous hydrogen, when mixed with air, would form a flammable atmosphere that would cover an area of approximately 15 x 10^3 ft^3 to 274 x 10^3 ft^3. Heat produced from the flame could reach up to 3,700°F and pressures within the flame would reach 120 psig. Equipment located within the area would be damaged and there would be damage to the vehicle.

Personnel Hazard

Injury to personnel would result from burns, extreme pressures, shrapnel, and asphyxiation.

Heat effect

It requires 2 $coulomb^2$ of radiant flux to produce flesh burns and ignite certain combustible materials. Water vapor in the air greatly reduces the radiant heat effect from explosion; however, at distances up to 100 feet and with a gaseous hydrogen-TNT equivalent explosion of 600 pounds water vapor effect is minor. It can be assumed that personnel within 100 feet of the liquid hydrogen dewar will receive severe burns.

Asphyxiation and burns will also result from a gaseous hydrogen-air ignition fire referenced in paragraph entitled "Heat Damage" above.

3.2.4 SUMMARY OF CERTIFICATION TEST REQUIREMENTS

3.2.4.1 TESTS AT VENDOR FACILITY

Acceptance Tests

The acceptance tests shall include but not be limited to the following:

a. Visual examination

b. Leakage test

c. Functional test - To determine compliance with the assembly and component design criteria at the operating temperature extremes and humidity conditions specified.

d. Cleanliness tests

Special Tests

One unit from the production lot shall be tested to a simulated duty cycle of one and one-half times the period that the dewar assembly is in use during a launch countdown.

3.2.4.2 TESTS AT THE DELIVERED SITE

Acceptance Tests

The following acceptance tests shall be performed on all dewar assemblies:

a. Visual examination

b. Leakage test

c. Functional test

d. Cleanliness test

3.2.5 CONCLUSIONS

Review of the hydrogen dewar indicates that the design and procedures are acceptable with the following exceptions:

a. There is a possible presence in the system of shock sensitive materials. Accumulation of these materials over a period of time may cause quantities to exceed maximum allowable.

b. Component failures have occurred where external leakage of gaseous hydrogen was detected.

3.2.6 RECOMMENDATIONS

Perform a review of the system to determine any sources of contamination plus the constituents. This should include nonmetallic as well as metallic contamination. The intent is to assure the levels will not increase beyond the maximum allowable.

Investigate components that have demonstrated excessive failures in relation to incorporation of periodic change of soft goods or possible redesign.

3.3 PAD EMERGENCY AIR PACK

3.3.1 DESCRIPTION

The pad emergency air pack provides an air supply for emergency escape from the gantry in case of fire during flight preparation. There are three pad emergency air packs provided, mounted on the walls of the white room (CM level) in convenient locations. (See Figure 3.3.1)

The air pack consists of a manifold of five cylinders. The cylinders are 11" long by 2" diameter, 301 stainless steel of .035 minimum thickness. (Fig. 3.3.2)

The tanks are pressurized with air to 3600 psi, and designed for the following pressures; limit 4200 psi, proof 6000 psi, burst 9000 psi. The actual burst pressures demonstrated during hydro burst testing (7 cylinders) ranged from 10.600 to 11.600 psi, all failures exhibited longitudinal fractures and non-fragmenting. The actual safety factor is 2.5. The tank manifold is protected from overpressure via a 4200 psi relief valve.

3.3.2 DISCUSSION

The TNT equivalent of an air burst of the cylinders - 3600 psi x 29 $in.^3$ is 1.52×10^{-2} pounds per cylinder. The predicted failure mode for over pressure is relief at 4200 psi through the pressure relief valve.

In the event of a catastrophic failure (Blast & Fragmentation) CSM exterior penetration could occur but there is no critical equipment located in close proximity to the air pack stowage location. A failed emergency air pack would reduce by 1/3 the suited pad abort capability using the Launch Umbilical Tower.

The safety factor demonstrated by test is well above normal limits, the tanks are further protected by a 4200 psi relief valve in the manifold. The predicted failure mode from over pressure is pressure relief through the manifold relief valve.

3.3.3 CONCLUSION

The pressure vessels are acceptable and no further testing, configuration changes or procedural changes are required.

FIGURE 3.3.1. LOCATION OF THE PAD EMERGENCY AIR PACK IN THE WHITE ROOM RELATIVE TO HATCH

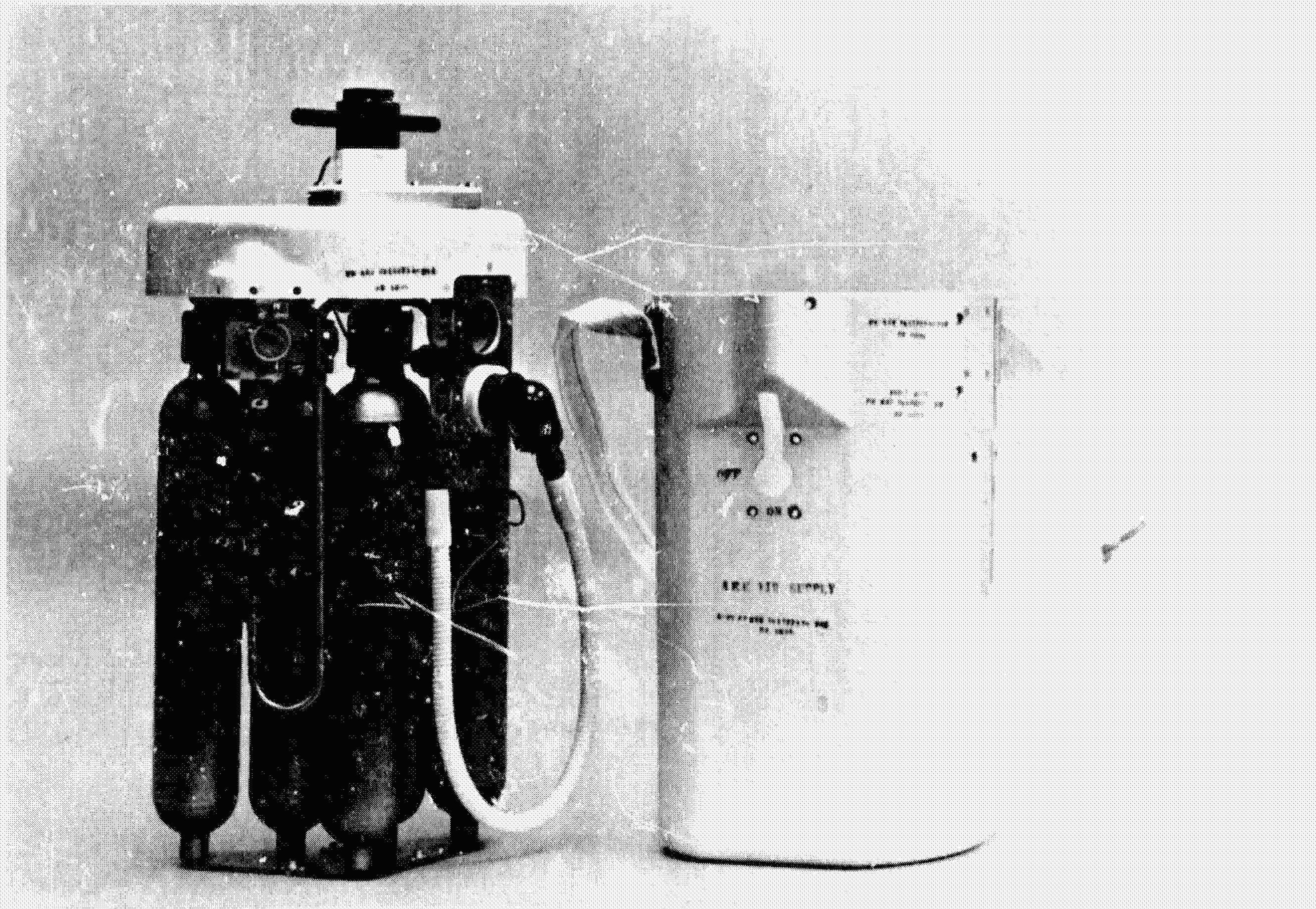

FIGURE 3.3.2. PAD EMERGENCY AIR PACK

4.0 CONCLUSIONS

4.1 GOVERNMENT FURNISHED EQUIPMENT (GFE)

All GFE pressure vessels and oxygen systems are considered satisfactory with the following exception:

> The -7 PLSS O_2 bottle should not use aged Arde material since the predicted failure mode at maximum design operating pressure is by fracture rather than by leakage, as in the -6 PLSS.

4.2 GROUND SUPPORT EQUIPMENT (GSE)

Oxygen Systems

The available information on the GSE oxygen systems was not sufficient to verify the acceptability of the design with respect to:

a. Impact sensitivity of nonmetallic materials application.

b. Characteristics of electrical component interfaces with oxygen.

c. Accumulation of contaminants.

Hydrogen Dewar

Review of the hydrogen dewar indicates that the design and procedures are acceptable with the following exceptions:

a. The possible presence in the system of shock sensitive materials. Accumulation of these materials over a period of time may cause quantities to exceed the maximum allowable.

b. Component failures have occurred where external leakage of gaseous hydrogen was detected.

5.0 RECOMMENDATIONS

5.1 GOVERNMENT FURNISHED EQUIPMENT (GFE)

a. The material in the -7 PLSS O_2 pressure vessel should be changed to one having a failure mode of leakage rather than fracture at maximum design operating pressure.

b. Analysis should be made of the effect of releasing the contents of the life raft CO_2 bottle into the CM cabin.

5.2 GROUND SUPPORT EQUIPMENT (GSE)

a. Obtain the necessary information to complete the evaluation of the GSE oxygen systems.

b. Perform a review of the hydrogen dewar system to determine any sources of contamination and the constituents. This study should include metallic as well as nonmetallic contamination and should investigate the accumulation of contaminants over a period of time.

c. Investigate components in the hydrogen dewar system that have demonstrated excessive failures to determine the necessity of periodic change of soft goods or possible redesign.