NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 6

RELATED SYSTEMS EVALUATION

VOLUME III

COMMAND AND SERVICE MODULE

MAY 1970

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 6

RELATED SYSTEMS EVALUATION

Volume III

Command and Service Module

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1.0 INTRODUCTION

Apollo 13 was launched from Cape Kennedy, Florida, on April 11, 1970. Approximately 56 hours into the mission, it was aborted due to a massive failure of the cryo O_2 system of the SM. An investigation team was established to determine the cause of this failure and define an appropriate course of action to be followed by the Manned Spacecraft Center to allow a timely continuation of manned exploration of the moon and space.

The Apollo 13 investigation team was made up of several panels. This report is the result of a part of the investigation conducted by Panel 6 and is limited to consideration of Command and Service Module hardware only. Other reports are being prepared for that part of the Panel 6 investigation which pertains to LM hardware, GFE hardware and GSE hardware.

This report contains the results of an evaluation of systems other than the cryo O_2 tank portion of the EPS which might possess the potential for the same general class of failures.

The following general outline was used for this report:

1.0 Introduction

2.0 CSM Pressure Vessel Summary

3.0 Subsystem Assessment

- 3.1 Environmental Control Subsystem
- 3.2 Electrical Power Subsystem
- 3.3 CM Reaction Control Subsystem
- 3.4 SM Reaction Control Subsystem
- 3.5 Service Propulsion Subsystem
- 3.6 Mechanical Subsystem

4.0 Assessment of Damage Potential

5.0 Conclusions

6.0 Recommendations

2.0 CSM PRESSURE VESSEL SUMMARY

Table 2.0 - APOLLO COMMAND AND SERVICE MODULE PRESSURE VESSELS, identifies the pressure vessels of the CSM used for storage of consumable fluids. In addition, the SM fuel cell pressure shell is included in this list even though it is not a storage vessel. The CM entry and pyro batteries, while not included in this summary table, are considered as pressure vessels and were given the same review that all of the listed vessels were given. They are included as part of the EPS and are covered in Section 3.2.4.

TABLE 2.0.— APOLLO COMMAND SERVICE MODULE PRESSURE VESSELS

SYSTEM	PRESSURE VESSEL	PART NUMBER	QUANTITY REQUIRED	VESSEL DIMENSIONS	VESSEL MATERIAL	DESIGN PRESSURES			NORMAL OPER. PRESS	F/SAFETY *		QUAL. BURST	TNT ** EQUIVALENCE	MANUFACTURER
						LIMIT	PROOF	BURST		ACTUAL	THEO.			
CM RCS	PRESSURE TANK HELIUM	282-0002	2	8.92 DIAMETER 0.102	TITANIUM 6A1-4V	5000	6667	7500	4240	1.7	1.5	8600		MENASCO
	PROPELLANT TANK OXIDIZER	282-0006	2	19.907 X 12.6 0.022	TITANIUM 6A1-4V	360	480	710	295	2.5	2.0	885		BELL/AIRITE
	PROPELLANT TANK FUEL	282-0007	2	17.32 X 12.6 0.022	TITANIUM 6A1-4V	360	480	710	295	2.9	2.0	1040		BELL/AIRITE
SM RCS	PRESSURE TANK HELIUM	282-0051	4	12.0 DIAMETER 0.132	TITANIUM 6A1-4V	4500	5985	7000	4240	1.6	1.55	7310		AIRITE (GAC DESIGN)
	PROPELLANT TANK PRIMARY OXIDIZER	282-0004	4	27.563 X 12.6 0.017	TITANIUM 6A1-4V	248	331	460	192	2.3	1.5	567		BELL/AIRITE
	PROPELLANT TANK PRIMARY FUEL	282-0008	4	22.722 X 12.6 0.017	TITANIUM 6A1-4V	248	331	460	192	2.4	1.5	603		BELL/AIRITE
	PROPELLANT TANK SECONDARY OXIDIZER	282-0006	4	19.907 X 12.6 0.022	TITANIUM 6A1-4V	248	480	710	192	2.0	1.5	885		BELL/AIRITE
	PROPELLANT TANK SECONDARY FUEL	282-0007	4	17.32 X 12.6 0.022	TITANIUM 6A1-4V	248	480	710	192	4.2	1.5	1040		BELL/AIRITE

* FACTOR OF SAFETY, ACTUAL = $\frac{\text{LOWEST ACTUAL TEST BURST PRESSURE}}{\text{DESIGN LIMIT PRESSURE}}$

THEORETICAL = $\frac{\text{DESIGN BURST PRESSURE}}{\text{DESIGN LIMIT PRESSURE}}$

** SEE SECTION 4.

TABLE 2.0. APOLLO COMMAND AND SERVICE MODULE PRESSURE VESSELS (CONT)

SYSTEM	PRESSURE VESSEL	PART NUMBER	QUANTITY REQUIRED	VESSEL DIMENSIONS	VESSEL MATERIAL	DESIGN PRESSURES			NORMAL OPER. PRESS	F/SAFETY		QUAL BURST	TNT EQUIVALENCE	MANUFACTURER
						LIMIT	PROOF	BURST		ACTUAL	THEO.			
SPS (SM)	PRESSURE TANK HELIUM	V37-347102	2	40.52 DIAMETER 0.366	TITANIUM 6A1-4V	3685	4910	5530	3585	1.7	1.5	6250		AIRITE
	PROPELLANT TANK OXIDIZER STORAGE	V37-343101	1	153.05 X 45 0.047/0.025	TITANIUM 6A1-4V	225	300	337.5	182		1.5	*		ALLISON
	PROPELLANT TANK FUEL STORAGE	V37-343101	1	153.05 X 45 0.047/0.025	TITANIUM 6A1-4V	225	300	337.5	182		1.5	*		ALLISON
	PROPELLANT TANK OXIDIZER SUMP	V37-342101	1	152.30 X 51 0.054/0.028	TITANIUM 6A1-4V	225	300	337.5	182	1.8	1.5	413		ALLISON
	PROPELLANT TANK FUEL SUMP	V37-342101	1	152.38 X 51 0.054/0.028	TITANIUM 6A1-4V	225	300	337.5	182	1.8	1.5	413		ALLISON
	PRESSURE TANK GN_2	1119578	2	9.16 X 4.64 0.130	STAINLESS STEEL AM 350	2900	5000	7500	2550	3.4	2.5	9820		AEROJET
EPS	CRYOGENIC TANK SM H_2	282-0047	2/ 3"J"	28.24 DIAMETER 0.044	TITANIUM 5A1-2.5 SN	285	379	450 (CRYO) 400 (AMB)	255	4.8 (CRYO) 2.7 (AMB)	1.5	1382 (CRYO) 771 (AMB)		BEECH
	PRESSURE TANK FUEL CELL GN_2	607434	3	6.1 DIAMETER 0.075	TITANIUM AMS4910	1730	3000	5780 @ 70°	1500	5.5	2.9	9400		
	FUEL CELL SM	ME464-0007-1002	3	15.938 DIA. 19.750 DIA.	TITANIUM	57.75	85-95	295-300	54					
	FUEL CELL ACCUMULATOR	607122	3	.017 TO .023 THKD 29.02 DIA. X 9.085 LONG. .032 ± .002	AL 6061	57.75	85-95	291	54					

* DUE TO SIMILARITY TO BLOCK I, ONLY ONE BLOCK II SPS PROPELLANT TANK WAS QUALIFICATION TESTED (51 IN. DIAMETER SUMP TANK).

TABLE 2.0. APOLLO COMMAND AND SERVICE MODULE PRESSURE VESSELS (CONT)

SYSTEM	PRESSURE VESSEL	PART NUMBER	QUANTITY REQUIRED	VESSEL DIMENSIONS	VESSEL MATERIALS	DESIGN PRESSURES			NORMAL OPER. PRESS	F/SAFETY		QUAL BURST	TNT EQUIV.	MANUFACT.
						LIMIT	PROOF	BURST		ACTUAL	THEO.			
ECS	SURGE TANK O_2	V-16-613059	1	14.00 X 13.00 0.033/0.078	INCONEL 718	1020	1356	1530	910	2.1	1.5	2150		
ECS	CABIN REPRESS. O_2	282-0048	3	12.62 X 6.92 0.028/0.045	INCONEL 718	1210	1600	1800	910	2.3	1.5	2767		AIRITE
ECS	RESERVOIR GLYCOL	282-0049	1		6061-T6	60WG 270_2	90WG 400_2	150	50WG $18\text{-}270_2$	7.0	2.5	420		
ECS	WATER TANK POTABLE	812373			6061-T6	$48H_2O$ 270_2	$64H_2O$ 400_2	$100H_2O$ 1000_2	$18\text{-}22H_2O$ $18\text{-}270_2$	2.1				
ECS	WATER TANK WASTE	812260			6061-T6	$40H_2O$ 270_2	$64H_2O$ 400_2	$100H_2O$ 1000_2	$18H_2O$ $18\text{-}270_2$	$3.2H_2O$ 4.00_2	$2.5H_2O$ 3.70_2	$130H_2O$ 1100_2		
MECHANICAL SYSTEM	FIRE EXTINGUISHER (CM)	ME280-0010-0003	1	5.0 DIAMETER X 7.5 0.062	STAINLESS STEEL 304	250	400	1000	85			1860		
MECHANICAL SYSTEM	PRESSURE TANK HATCH GN_2 (CM)	ME282-0052 -0005	2	1.0 DIAMETER X 8.0	INCONEL 718	5000	10500	14000	5000			19100 20400		
MECHANICAL SYSTEM	PRESSURE TANK DOCKING PROBE GN_2 (CM)	ME901-0697 -0005	4	1.0 DIAMETER X 8.0	INCONEL 718	5000	10500	14000	5000			19100 20400		
MECHANICAL SYSTEM	PRESSURE TANK PAN CAMERA GN_2 (SM)	ME282-0051	1	12.0 DIAMETER 0.135	TITANIUM 6A1-4V	4500	5985	7000	4000			7800		AIRITE

3.0 SUBSYSTEM ASSESSMENT

3.1 ENVIRONMENTAL CONTROL SUBSYSTEM (ECS)

This section pertains to the O_2 portion of the ECS and is restricted to those components which interface with 20 psia or greater (normally after a single failure). Those components which interface with less than 20 psia O_2 were and will be verified acceptable by the non-metallic material task which is the responsibility of PD9/J. Craig.

A schematic is provided in Figure 3.1-1. For ease of reference, the familiar ECS schematic number for each component is shown and this number is then used in the text.

The ECS components are divided into 2 parts, mechanical components (9 pressure vessels, and 22 line components), electrical components (8 components). Briefly, the findings of the CM, ECS, Apollo 13 related study indicated the following areas requiring additional effort:

a) Potable and waste quantity gaging systems for effect of electrical short.

b) Exposed non-metallics (after a single failure) which have been accepted by similarity for acceptance by MSC.

c) O_2 control panel and ECU 100 and 900 psi aluminum lines for adjacent electrical sources.

d) Cyclic accumulator control valve (1.36), O_2 flow transducer (9.2) and 100 psi system pressure transducer (9.8) for completion of review -- Engineering drawings were not available at time of this writing.

For summary and recommendations, see beginning of each section and for details see the individual component.

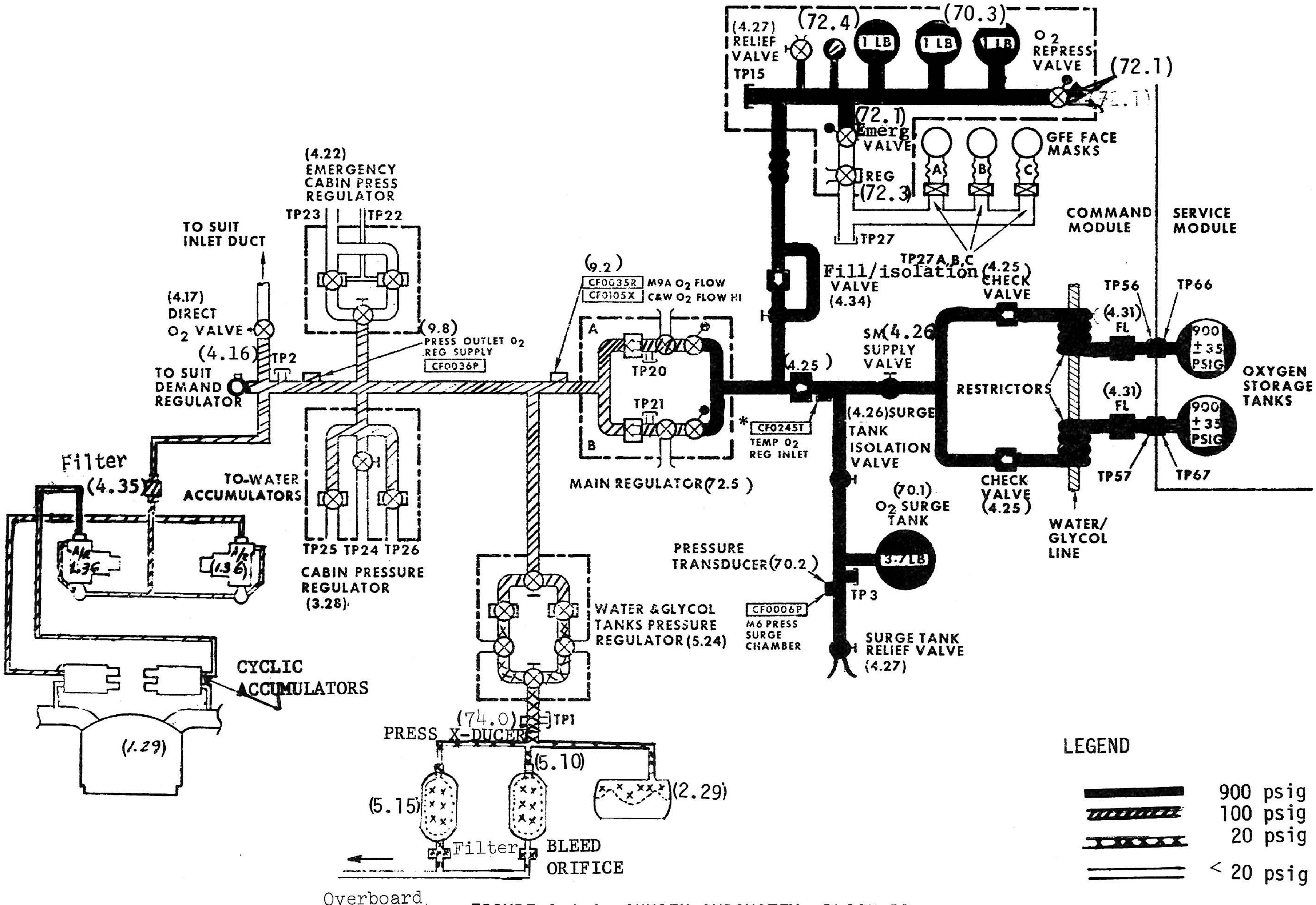


FIGURE 3.1-1. OXYGEN SUBSYSTEM, BLOCK II

3.1.1 Mechanical Components

3.1.1.1 Pressure Vessels

Listed below in Table 3.1.1.1-1 are the pressure vessels and a summary of this study. The table shows that the only area of concern are the two water tanks. The concern is the quantity gaging electronics in the potable and waste tanks which are exposed to 25 psia oxygen in flight and 35 psia on the ground along with the anomalies of the gaging system experienced on CSM 103, 108, and 109. It is possible with a short in the gaging system to cause ignition with probable loss of the gaging system and possibly, but less probable, the loss of the tank. Both these tanks are outside the cabin in the aft compartment and loss of the tank would probably not damage any other equipment. The power input to the O_2 exposed electronics is 10 amp, 28 VDC supplied through two 5 amp circuit breakers. Loss of potable tank requires termination of mission. The mission may be continued for loss of waste tank.

It is recommended that the water quantity gaging system be tested for effect of electrical short and redesigned or deleted depending on results of test and trade-off studies.

Table 3.1.1.1-1. ECS Pressure Vessel Summary

Item		Non Metallics			Electrical		
		Static or Sliding	Impact	Exposed After Single Failure	In Stream	After Single Failure	Failure* Trends
Surge Tank	(70.1)	OK	-	OK	-	-	-
Repress tanks	(70.3)	OK	-	OK	-	-	-
Glycol Reservoir	(2.29)	OK	-	-	-	-	-
Potable Tank	(5.10)	OK	-	OK	Yes	-	Yes
Waste Tank	(5.15)	OK	-	OK	Yes	-	Yes**
Cyclic Accumulator	(1.29)	OK	-	-	-	-	-

Note: (-) indicates not applicable
*Failure trends relative to pressure increases or excessive thermal environments
**Yes, by similarity with potable tank.

The detail information for the individual pressure vessels follows.

3.1.1.1.1

MECHANICAL COMPONENTS

Subsystem: Environmental Control

Component: O_2 Surge Tank 70.1

Quanity: 1

Part No. V16-613034, Figure 3.1.1.1.1-2 &-3

Location: Left Hand Equipment Bay. Figure 3.1.1.1.1-1

Description and Function

The Surge Tank stores approximately 3.7 lbs of O_2 at 900 psig for use during entry, and for augmenting the SM supply when the operational demand exceeds the flow capacity of the inlet restrictors, and is redundant with the repress tanks for these functions.

Pressure Control Components

The surge tank incorporates the following components which are located in line in the high pressure supply line:

1. Relief Provisions: Surge Tank relieves through the pressure relief valve (item 4.27) which operates at 1045 $\pm$ 25 psig. The pressure relief flow is 3.4 lbs/hr minimum at 1070 psig.

2. Surge tank shutoff valve (item 4.26) which provides a means for shutting off the O_2 flow.

3. A pressure transducer item (70.2) which puts out a signal proportional to surge tank pressure for telemetry and for display to the crew.

Internal Parts and Materials: See Table 3.1.1.1.1-1

Effect of Component Loss

Continue mission, all phases, isolate surge tank through surge tank S/O valve (item 4.26). Place repress package valve to fill.

Burst Damage Effect: See Section 4

Structural Assembly

Dimension: 14.0" x 13.0"
Size: .742 cu.ft.
Manufacturer: Marquardt

Tank is made up of two forgings and each forging is machined. The two machined halves are welded in the middle for a width of 1.0" forming the tank.

Failure Mode

Four (4) O_2 Surge tanks S/NO^s 001, 002, 003 and 004 were subjected to hydrostatic test by Associated Engineering Test Laboratories. The demonstrated burst pressures on the 1st three (3) tanks were 2340, 2150 and 2280 psig respectively. No burst pressure was conducted on tank S/N 004.

Photographs of the test speciment after burst (see fig. 3.1.1.1.1-4) indicated that the rupture was located near the proximity of the machined inlets/outlets and not by the weld.

Although no fragmentation can be detected from this test, since it is a hydrostatic test, yet the tank will fragment at material/stress combination at these burst pressures.

The design burst pressure is 1520 psig and the nominal operating pressure is 900 psig. The safety factors are: 1.5 design and 2.1 to 2.29 actual.

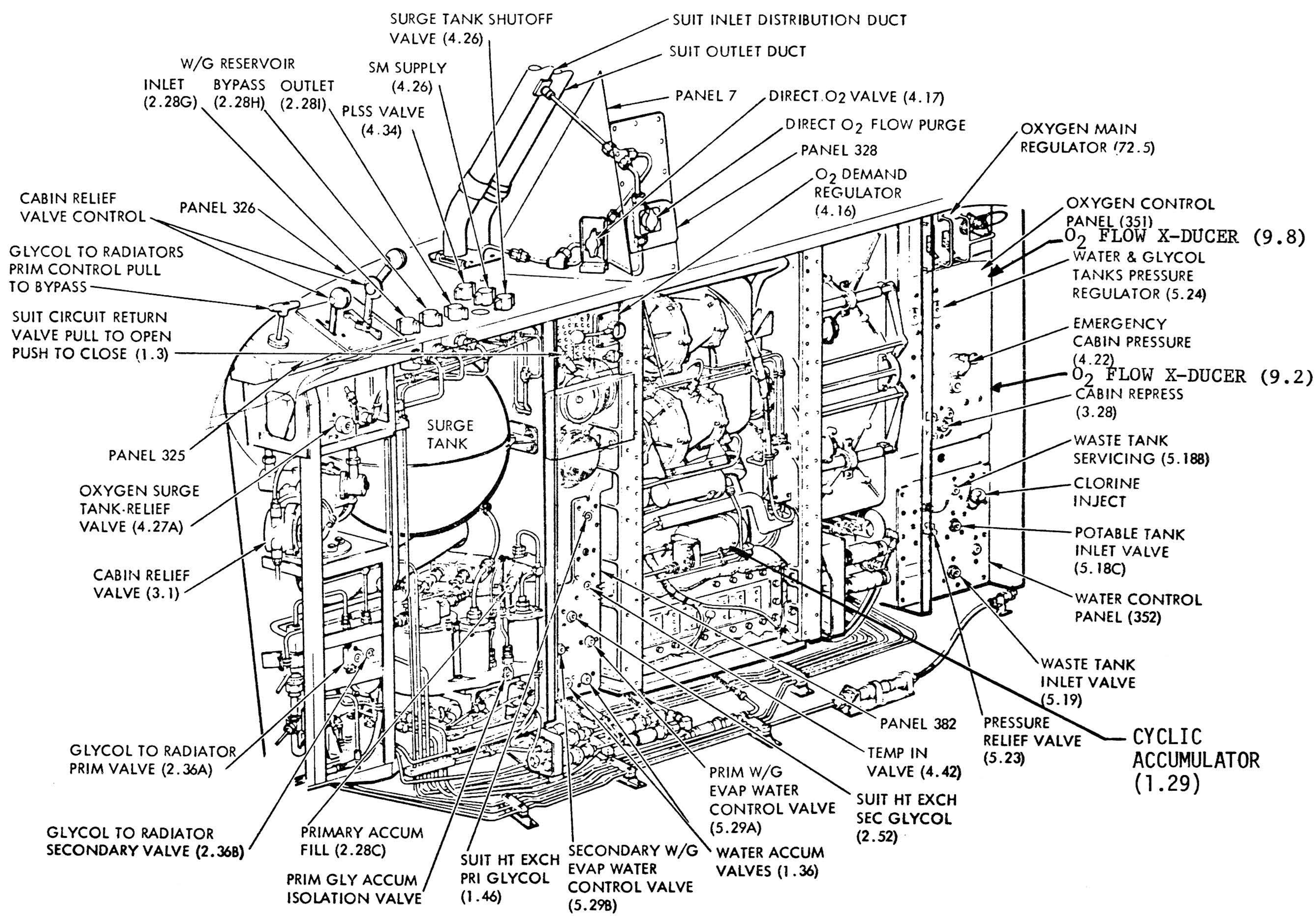


FIGURE 3.1.1.1.1-1. INSIDE ECS INSTALLATION

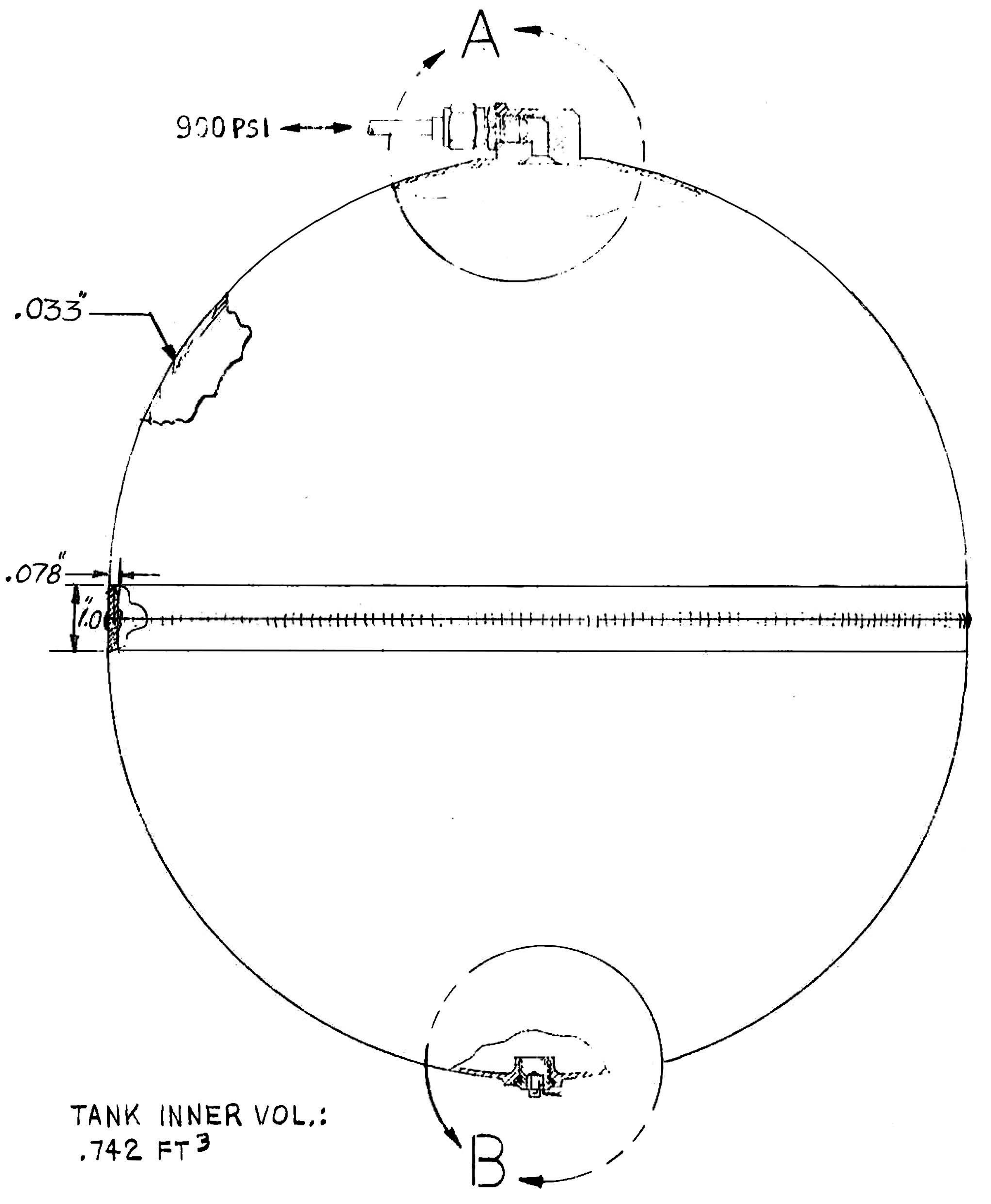
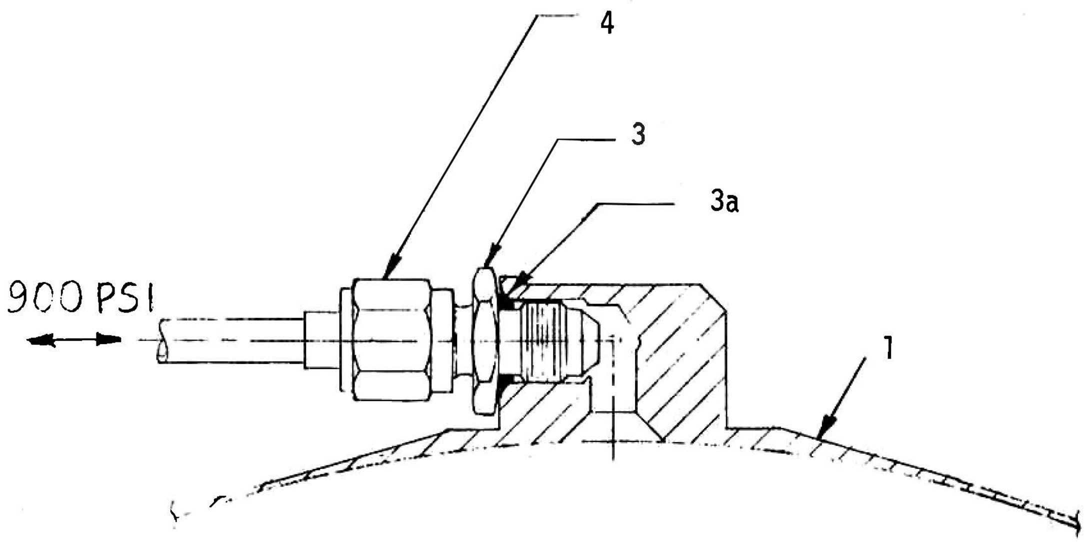
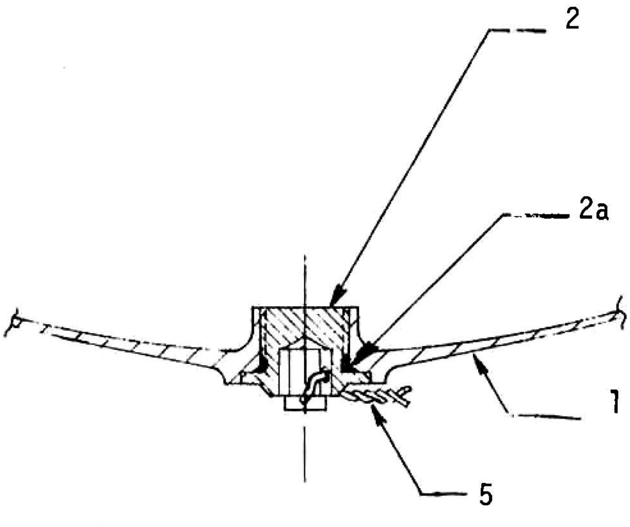


FIGURE 3.1.1.1.1-2 SURGE TANK INTERFACES - 70.1



DETAIL A (SCALE: 1/1)



DETAIL B (SCALE: 1/1)

FIGURE 3.1.1.1.1-3 SURGE TANK INTERFACES - 70.1

SURGE TANK 70.1
MATERIALS

METALLIC

ITEM	PART NAME	MATERIAL
1	Tank Assembly	Inconel 718
2	Plug	Same
a	Seal	304 cres - AMS5639
3	Fitting	Cres Per QQ-S-763(300 Series)
4	Tubing	304 L Cres.
5	Wire (Safety)	MA0101-005 (Inconel per QQ-W-390)

NON-METALLIC

Maximum PSIA	°F Temp.	Use-age Cat.	Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Sliding	Impact
1086.5	160	D	C	Lubeco 905	N	N	X		
		B		Epon 828/Vers 115	N	0.04			
		B		Lam. Shim Stock "O" Ring Butyl	N	N			

Table3.1.1.1.1-1 Surge Tank Materials

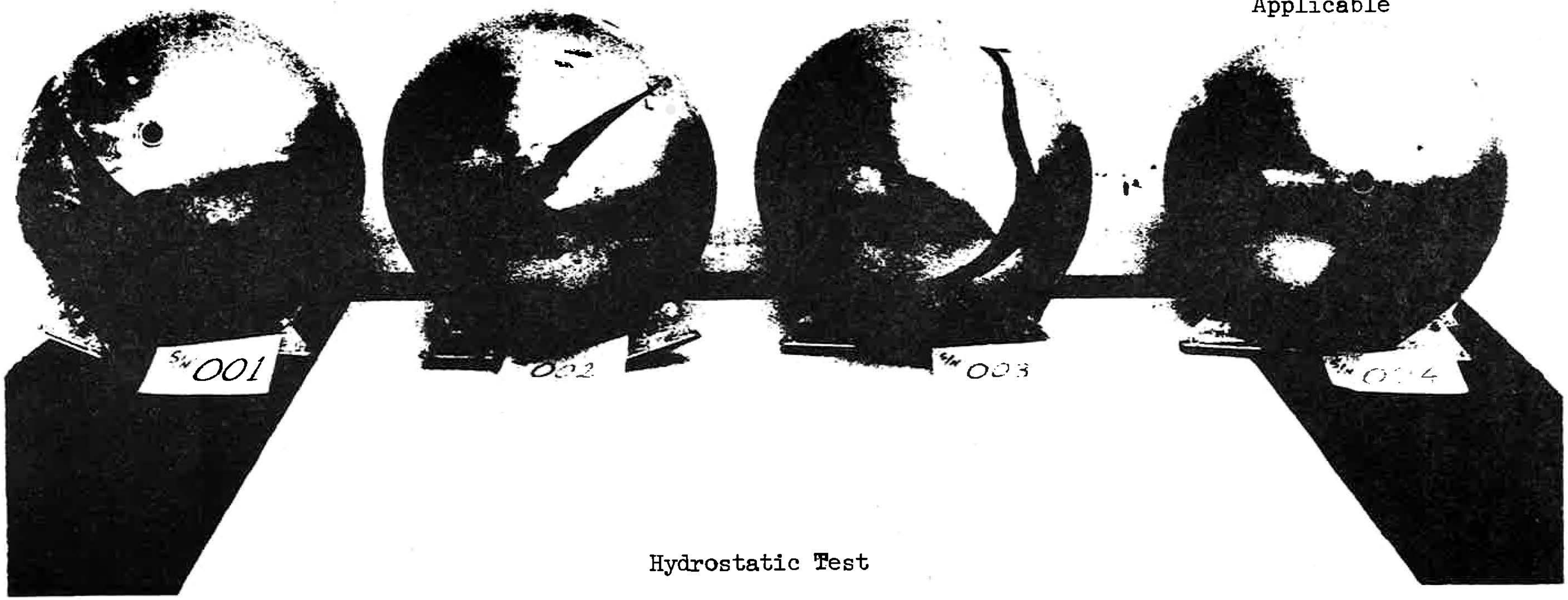


Figure 3.1.1.1.1-4 SURGE TANK HYDROSTATIC TEST

3.1.1.1.2 MECHANICAL COMPONENTS

Subsystem: Environmental Control

Component: O_2 Repress Tanks

Quantity: 3

Part No.: ME282-0048 See Figure 3.1.1.1.2-1 & 2.

Location: Below hatch. See Figure 3.1.1.1.2-3.

Description and Function:

Each repress tank (connected to common manifold) contains 1 lb of O_2 at 900 psig for use during entry and for augumenting the SM supply when the operational demand exceeds the flow capacity of the inlet restrictors and is redundant with the surge tank for these functions. In addition, it provides Direct O_2 for the emergency face masks.

Pressure Control Components:

1. Relief Provisions: The repress tanks relieve through the pressure relief valve (item 72.3) which can be isolated by a manual valve (item 72.1). The relief valve operates at 1045 $\pm$ 25 psig with a pressure relief flow of 3.4 lbs/hr minimum at 1070 psig.

2. A check valve is located downstream for isolation and a valve for manual isolation and fill around the check valve.

3. A direct reading pressure gage (item 72.4) is available to the crew.

Internal Parts and Materials: See Table 3.1.1.1.2-1.

Effect of Component Loss:

Continue mission all phases. Isolate repress tanks with fill/isolation valve (item 4.34).

Burst Damage Effect: See Section 4

Structural Assembly

Dimension: 12.5" x 7.0"
Size: .22 cu. ft.
Manufacturer: Airite

Tank is made up of two forgings and each forging is machined. The two machined halves are welded in the middle for a width of 1.0" forming the tank.

Failure Mode

Two (2) Repress tanks S/NO^S 0009 and 0010 were subjected to hydrostatic test by Durkee Environmental Laboratories, Inc.

The demonstrated burst pressures were 3437 and 3406 psig respectively. Photographs of the test specimen after burst are shown in Figure 3.1.1.1-4.

Although no fragmentation can be detected from this test, since it is a hydrostatic test, yet the tank will fragment at material/stress combination at these burst pressures and will leak with no fragmentation at the limit pressure.

The design burst pressure is 1800 psig, the nominal operating pressure is 900 psig and the limit is 1210 psig. The safety factors are: 1.5 design and 2.8 actual.

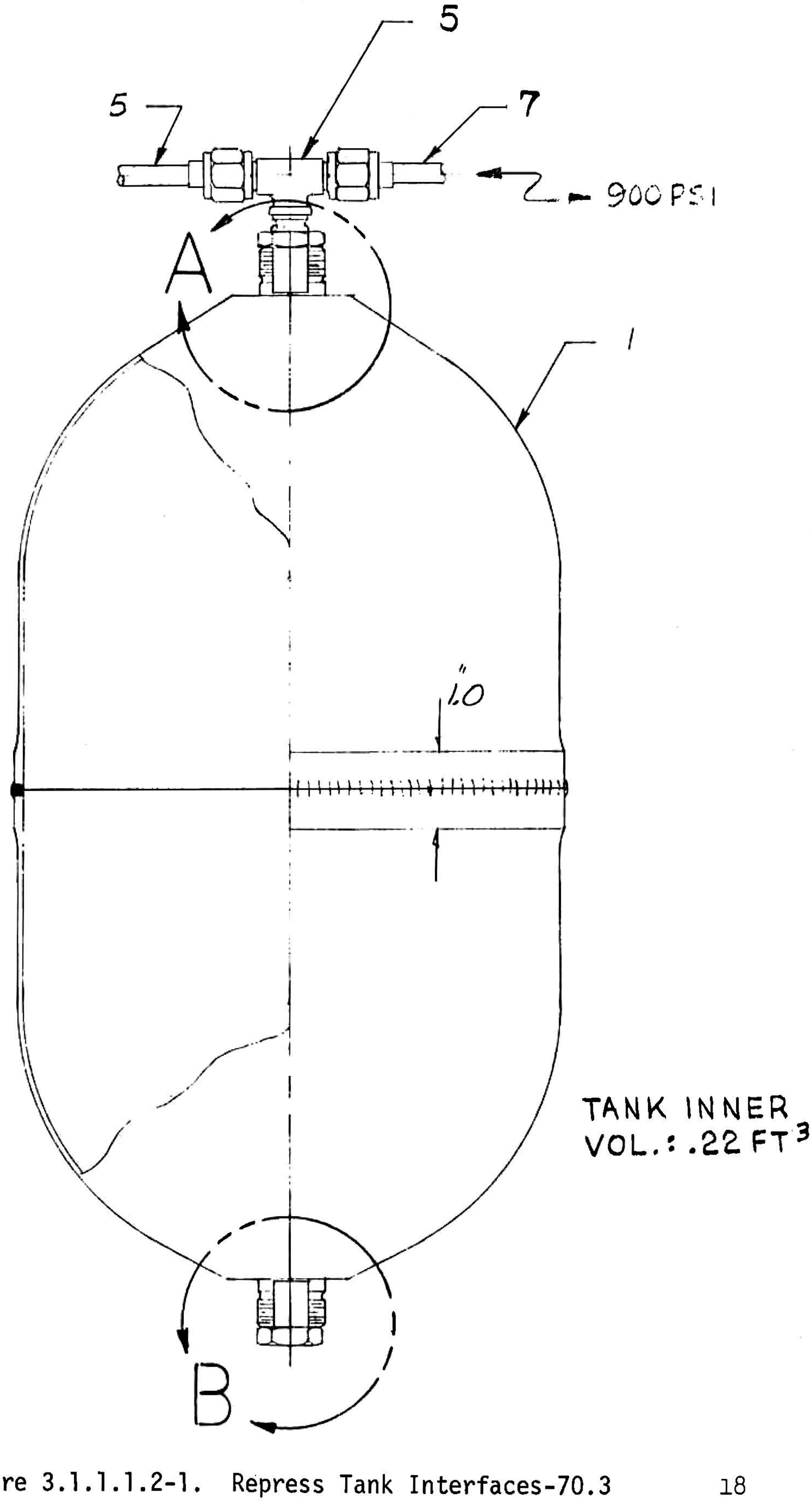
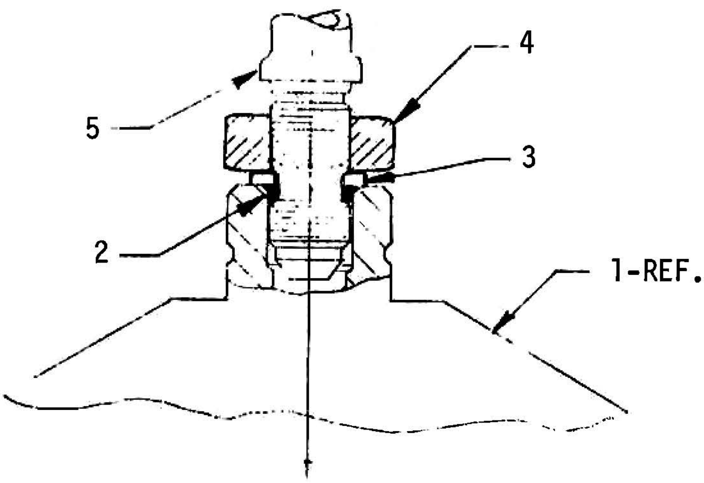
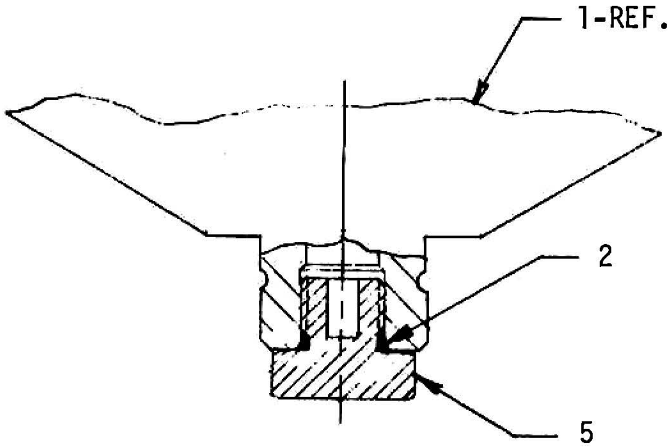


Figure 3.1.1.1.2-1. Repress Tank Interfaces-70.3



DETAIL A (SCALE: 1/1)



DETAIL B (SCALE: 1/1)

FIGURE 3.1.1.1.2-2 REPRESS TANK INTERFACES - 70-3

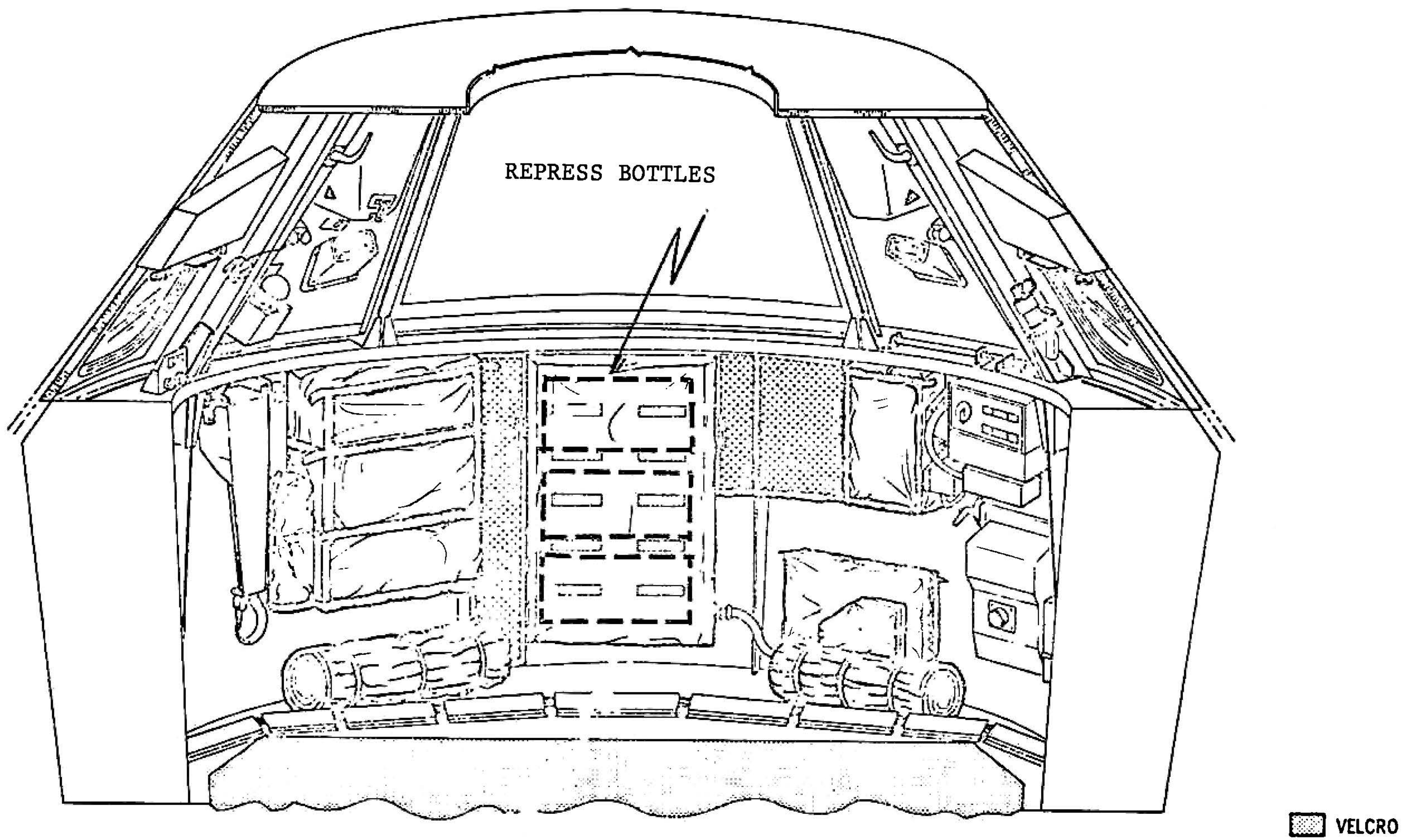


Figure 3.1.1.1.2-3. Apollo CM Interior VEB (Sidewall) & Hatch

REPRESS BOTTLES 70.3
MATERIALS

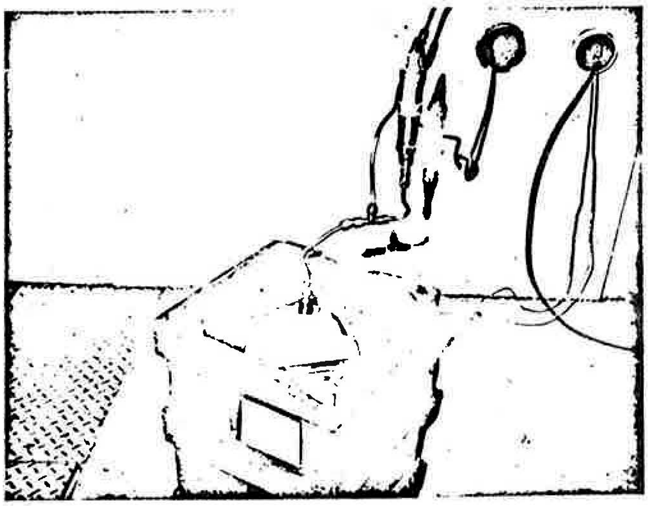
METALLIC

ITEM	PART NAME	MATERIAL
1	Bottles (3)	Inconel 718
2	Seal	
3	Retainer	MS28773-04
4	Fittings	304 Cres. - AMS 5639
5	Fittings	304 Cres. - AMS 5639
6	Lub. Thd. Fittings	MB0140-005
7	Tubing & Fittings	304 L Cres.

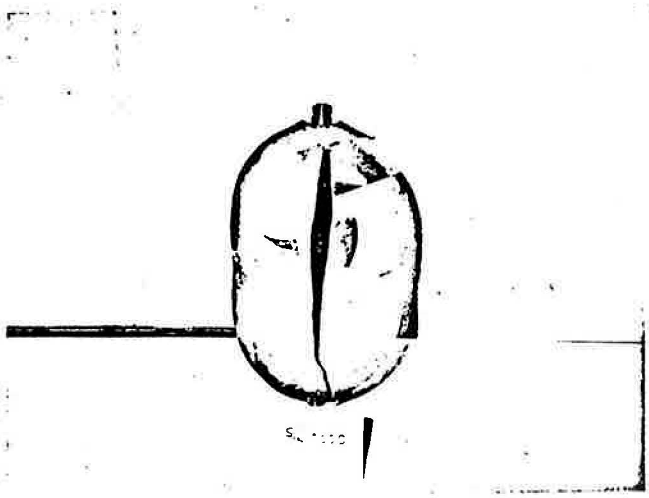
NON-METALLIC

"O" Ring - Material - Butyl Per MB0130-028

Table 3.1.1.1.2-1 Repress Bottles Materials



BURST TEST



	Burst Level
S/N 9	3437 psig
S/N 10	3406 psig

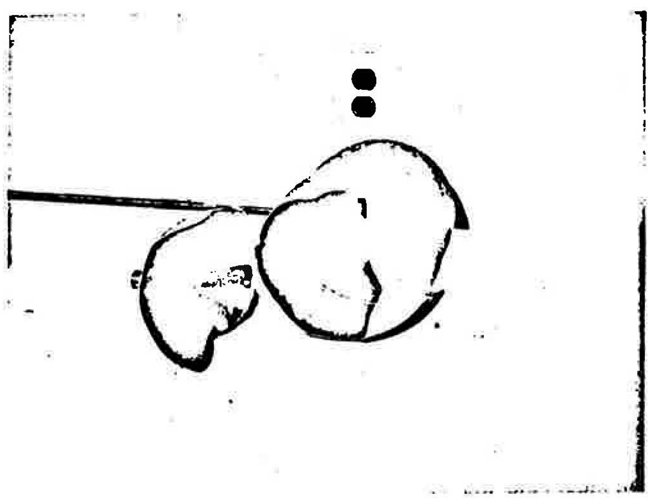


Figure 3.1.1.1.2-4 REPRESS BOTTLES BURST TEST

3.1.1.1.3

Subsystem: Environmental Control
Component: Water Glycol Reservoir
Quantity: 1
Part No.: ME 282-0049, See Figure 3.1.1.1.3-1
Location: Left Hand Equipment Bay

Description and Function:

The Glycol reservoir contains approximately 8.2 lbs of water glycol at 70°F, it contains reserve supply of W/G and substitutes for failed accumulator. O_2 is used to pressurize the bladder for W/G expulsion at zero G.

Pressure Control Components:

1. Relief Provisions: The (2) water and glycol tanks pressure regulators (item 5.24) provides relief to the reservoir. The full relief flow is 9 lbs/hr @ 27 psig.
2. Two isolation valves inlet and outlet items 2.28 are incorporated in the system to isolate W/G. There is no isolation provision for the O_2 side.
3. O_2 Pressure x-ducer (item 74.0) to measure the outlet pressure of the water and glycol tanks regulator.

Internal Parts and Materials: See Table 3.1.1.1.3-1.

Effect of Component Loss:

External Leakage O_2 and/or Water Glycol

Mission termination due to loss of all tank pressurization capability and free fluid hazard which has toxic effect on crew.

LM environment (if available) may be used for earth return.

Structural Assembly

Dimension: 12.07" x 4.72" x 5.82"
Size: 210 cu. in.
Manufacturer: AiResearch

The tank is made up of two (2) shells having a thickness of .08 to .10 with an expulsion bladder in the middle. The two halves are bolted together.

Failure Mode

One tank S/NO 46-102 was subjected to hydrostatic test by AiResearch Manufacturing Division. The demonstrated burst pressure was 420 psig. The results of the CTR Data indicated that one bolt at end of tank broke and caused the tank halves to separate. The separation caused the bladder to blow out. In addition, all bolts and tank flange were bent.

Two more tests on another speciment were conducted, the tests were for package level dynamic test and mission life test.

However, aside from a premature tank failure the system exhibited failure mode for overpressurization is not the water glycol reservoir. With the reservoir isolated overpressurization causes either of the water tanks to fail ($\approx$ 110 psig) prior to the reservoir (420 psig). With the reservoir not isolated it is also possible that the glycol accumulator may fail. (250 psig from failure on CSM 104 due to procedural error)

The design burst pressures is 150 psig and the nominal operating pressure is 18-27 psig. The safety factors are 2.5 design and 7.0 actual.

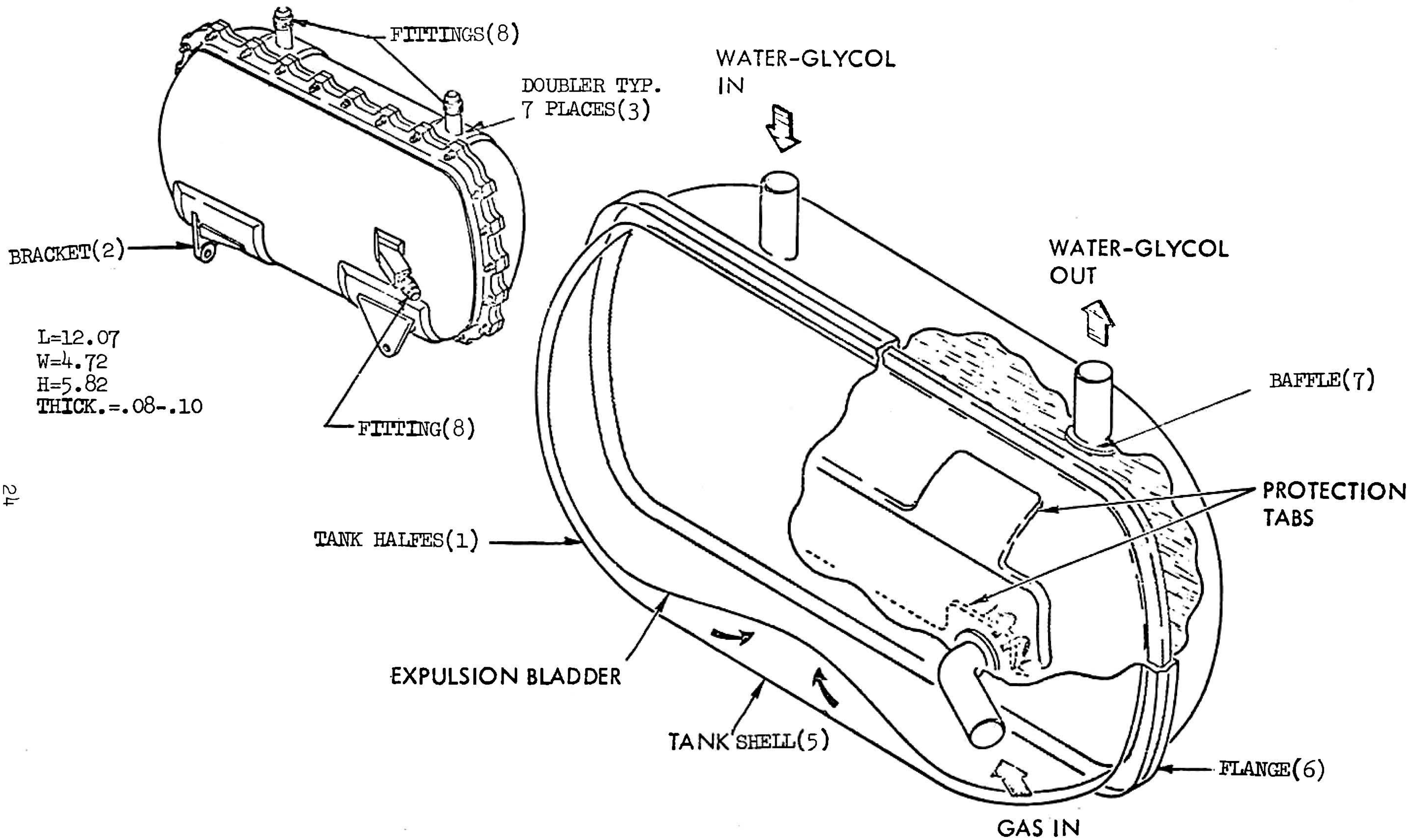


Figure 3.1.1.1.3-1 Water Glycol Reservoir

Water Glycol Reservoir Material

Metallic

Item	Part Name	Material
A	W/G Reservoir Assy	
1	Tank Halves	H.T. to T.6 per MIL-H-6088 & Anodize per MIL-A-8625, Type 1
2	Bracket	AL.Aly 6061-T6,QQA-327
3	Doubler	AL.Aly 6061-0,QQ-A-327
4	Button	AL.Aly 6061-T6,QQ-A-327
5	Shell	AL.Aly 6061-0,QQ-A-327
6	Flange	AL.Aly 6061-T6,QQ-A-367
7	Baffle	AL.Aly 6061-0,QQ-A-367
8	Fitting	AL.Aly 6061-T6,QQ-A-325 AL.Aly 6061-T6,QQ-A-327

Non Metallic

Maximum PSIA	°F TEMP.	Use-age Cat.	Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Sliding	Impact
43.5	89	B		EC 583	.001	.06			
		B		Scotchcal 3650	Neg.	.03			
		B		Dry Film Lube	Neg.	13			
		D	C	Polyisopreme Rubber	.3	110	X		
		D	B	L-9	.003	.06	X		
		F		Polyisopreme Rubber	.3	110			

Table-3.1.1.1.3-1 Water Glycol Reservoir Material

3.1.1.1.4

Subsystem: Environmental Control
Component: Potable and waste water tank (5.10 & 5.15)
Quantity: One (1) each
Part No.: ME192-0036-Potable; ME192-0008-Waste Figure 3.1.1.1.4-2
Location: Aft Compartment. See Figure 3.1.1.1.4-1

Description and Function:

The potable and waste water tanks are cylindrical in shape with pressurized bladder. The potable contains 39 lbs of H_2O and is used primarily for metabolic purposes. The waste contains 59 pounds of water and is used primarily for storage of water for cooling. The bladders are pressurized with 25 psig O_2 thru a common manifold which pressurizes the potable, the waste and the glycol reservoir. The common manifold has no provisions to isolate a tank.

Pressure Control Components:

1. Relief Provisions: The (2) water and glycol tanks pressure regulators (item 5.24) provides relief to the tanks. The full relief flow is 9 lbs/hr @ 27 psig.

2. O_2 Bleed orific down stream each tank filter provides overboard relief.

3. O_2 pressure X-ducer (item 74.0) to measure the outlet pressure of the water and glycol tanks regulator.

Internal Parts and Material: See Figures 3.1.1.1.4-2 & 3.1.1.1.4-3

Note: A rotary potentiometer quantity transducer is located on each tank on the O_2 side of the bladder.

The water quantity is measured by the amount the bladder is displaced from the center. This is done as shown in Figure 3.1.1.1.4-3. Callout 23 in this figure contains the signal conditioner and the variable resistor. The signal conditioner is supplied 28 VDC (Fig. 3.1.1.1.4-5) through two 5 amp circuit breakers. Both circuit breakers are closed for all phases of countdown and flight. Normal power consumption is 40 ma for each transducer. There is no fusing for the Apollo vehicles, however, the Skylab CM is incorporating a 1/4 amp fuse. The transducer is open to the O_2 pressure through a 0.095 inch diameter hole less the teflon coated wire running through it of 0.021 inch diameter. This leaves an area of 0.0067 sq. in.

Three ignition tests were performed, 11/6/67 due to the exposure of the electronics to the O_2 pressure. The test was performed at 20 psia O_2 and the isnition source was tissue paper wrapped around nichrome wire. See Figure 3.1.1.1.4-4. The three tests were similar except the ignition location was varied. See below.

LOCATION OF IGN SOURCE	MATERIAL AND USE	RESULTS
Contract with RTV 90	RTV 90 sealant for wire lead thru	Surface burn
	EPON 828 Encapsultation for signal cond.	25% of surface burn
	Glass-filled Epoxy Helipot	No damage
Contact with Helipot at wire lead thru	RTV	No damage
	EPON 828	No damage
	Sleeve at feed thru	Consumed
	Teflon insul. wire	Partially burned in immediate vicinity
Contact with EPON 828	EPON 828	50% surface burn No other apparent damage

The results of the above tests indicate that the fire is self extinguishing and would not terminate the mission nor compromise crew safety. However, the test was performed at a pressure of 20 psia, whereas the actual configuration pressure would be 35 to 37 psia during the countdown and 25 psia during flight. In addition, a nichrome wire wrapped with tissue papper was the ignition source whereas the actual situation a short in wiring would be the ignition source. If detailed analysis of the quantity gaging system ignition test and the theoretical failure analysis indicates a marginal factor of safety, then consideration should be given to repeating the ignition test to a better fidelity.

Effect of Component Loss:

Potable

Mission termination due to drinking water, food preparation and fire extinguishing capabilities are lost. However LM water (if available) may be used to supplement CSM.

Waste

Continue mission. LM system (if available) may be used to supplement CSM. Although no water will be abailable for cooling, some power down may be required for Lunar Orbit. Thermal studies indicated that reentry can be accomplished without cooling.

Burst Damage Effect:

There would be no outside damage if the tank were to burst prematurely at limit pressure. For pressure increase above limit pressure the failure mode is deformation of the end plate allowing O_2 and water to escape. See Failure Mode Section following.

Structural Assembly

Dimension:	Potable - 12.25 x 9.9
	Waste - 12.25 x 16.0
Size:	Potable - 0.640 ft 3
	Waste - 0.962 ft 3
Manufacture:	AiResearch

Tank is made up of seven major parts

1. Cylindrical portion
2. Two end caps welded to (1)
3. Bladder assembly
4. Two end plates which holds and seals the bladder.
5. Quantity gaging system

Failure Mode

The CTR burst tests and over pressurization accident on S/C 020 indicated the failure mode to be stripping of the center bolt on the end plates. See Figure 3.1.1.1.4-2. This allows both the O_2 and the water to escape. Thus a failure of this type would also cause the loss of O_2 pressure from the other two tanks which are tied to the common O_2 manifold.

CTR Burst Test Data*		H_2O Side Psig	O_2 Side Psig
Limit Pressure		48	27
Design Burst		100	100
Actual Burst		130	110
Safety Factor			
	Design	2.1	3.7
	Demonstrated	2.7	4.0

*Above data based on test with waste tank. No burst test was performed on potable tank. It was approved by similarity.

TABLE 3.1.1.1.4-1 POTABLE & WASTE WATER TANKS
METALLIC MATERIALS

ITEM		PART NAME	MATERIAL
1		TANK ASSY	
2		CLAMP	CRES TYPE 304 MIL-T-8506
3		FRAME ASSY	AL ALLOY: 6061-T6; QQ-A-327 WW-T-789
4	SUB ASSY		
5		TUBE	AL ALLOY: 6061-T6, WW-T-789
6		BLOCK	AL ALLOY: 6061-T6, QQ-A-327
7		ROD	AL ALLOY: 6061-T6, QQ-A-270
8		TUBE ASSY	AL ALLOY: 6061-T6, WW-T-789 QQ-A-270
9	(SEE NON-METALLIC TABLE)		
10	(SEE NON-METALLIC TABLE)		
11		COVER	AL ALLOY: 6061-T6, QQ-A-327
12	SUB ASSYS		
13		CAP	AL ALLOY: 6061-0, QQ-A-327
14		END	AL ALLOY: 6061-T6, QQ-A-327
15		BOSS	AL ALLOY: 6061-T6, QQ-A-325
16		GUSSET	AL ALLOY: 6061-T6, QQ-A-327
17		DOUBLER	AL ALLOY: 6061-0, QQ-A-327
18		SHELL	AL ALLOY: 6061-T6, QQ-A-327
19		RING	AL ALLOY: 6061-T6, QQ-A-327
20		DRAIN TUBE	AL ALLOY: 6061-0, WW-T-789
20(a)		PIN	AL ALLOY: 6061-T6, Per QQ-A-325
21		INSERTS	NAS 1394C-4
22	(SEE NON-METALLIC TABLE)		
23	(SEE NON-METALLIC TABLE)		
24		GUARD	AL ALLOY: 6061-T6
		COVER ASSY	AL ALLOY: 6061-T6, QQ-A-327
		o INSERT	MS35914-145
25		FITTING ASSY	(O_2 BLEED ORIFICE)
		FITTING	CRES 304, QQ-S-763
		RESTRICTOR	CRES 347, QQ-S-763
		TUBE	CRES 304 PER MIL-T-8504
26	(SEE NON-METALLIC TABLE)		
27	(SEE NON-METALLIC TABLE)		
27(a)		FILTER	CRES 300 SERIES (15 μMESH)
27(b)		RETAINING RING	MS16629-4025
		LABEL (OXYGEN)	----
		LABEL (GSE)	----
		LABEL (WATER)	----
28	(SEE NON-METALLIC TABLE)		
29	(SEE NON-METALLIC TABLE)		
30	(SEE NON-METALLIC TABLE)		
31		SEAL	1/2 HARD AL.
		NUT	CRES; 300 SERIES
32		LABEL, IDENT	----
33		NUT	AL ALLOY: QQ-A-225/4; 225/6; QQ-A-367

TABLE 3.1.1.1.4-1 POTABLE & WASTE WATER TANKS
METALLIC MATERIALS (Continued)

ITEM	PART NAME	MATERIAL
33(CONTINUED)	UNION	AL ALLOY: 17-ST, QQ-A-351 CONDT 24-ST, QQ-A-267 CONDT
	WASHER	CRES MIL-S-5059/6721
	WASHER	AL ALLOY: QQ-A-20515 (T3/T4)
	SCREW	
	SCREW	
	LOCKWIRE	
	SCREW	
	NUT	CRES - AMS 5735/7 or 5525
	IDENT PLATE	
	DECAL	----

TABLE 3.1.1.1.4-2 POTABLE & WASTE WATER TANKS

NON-METALLIC MATERIALS

ITEM	Use-age Cat.	Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area $In.^2$	Applicat. Static	Sliding	Impact	Remarks
23	F		RTV 102	Neg.	.57				
32	F		Loctite GRH	Neg.	.04				In Screw Threads
23	F		Locquie Primer	Neg.	.01				
--	F		XCQ-H125/H9-3469	Neg.	.03				Adhesive
22	B		Dry Film Lube	Neg.	2.0				
22	B		DC-510	.001	2.2				
23	F		Microseal Bearing Lube	Neg.	.79				
22	F		Polyisoprene Rubber	.45	300				
22	D	C	Polyisoprene Rubber	.45	300	X			
28	B		Silicone Rubber EMS323	.003	3.02				
23	F		S418-6	Neg.	.33				
30	F		EPR Rubber	.001	.46				
26	D	B	EPR Rubber	.001	1.76	X			
--	F		Zytel 101	Neg.	.08				Screw Lock
28	F		Teflon	.005	3.82				
23	F		Fiberglass Tape	Neg.	.04				
10, 29	F		Turcon, Filled TFE	.021	3.4				
23	F		Epon 828 Deta	.027	8.45				
23	F		RTV 90/Therm 12	.007	.37				
23	F		Scotch Cast XR5068	.001	.69				
23	F		Textalite	.002	1.5				
27	D	B	EPR Elastamer	Neg.	.07	X			

LEGEND

- o Usage catagory for non-metallics
  - A - On component but not exposed to high pressure O_2 (major used mat.)
  - B - On component but not exposed to high pressure O_2 (minor used mat.)
  - C - < 20 PSIA - Suit Loop
  - D - > 20 PSIA
  - E - Hermetically Sealed Box
  - F - Vented Box - to cabin
- o Cat. D Evaluation
  - A - NASA Test
  - B - AiResearch Test
  - C - Accepted by similarity

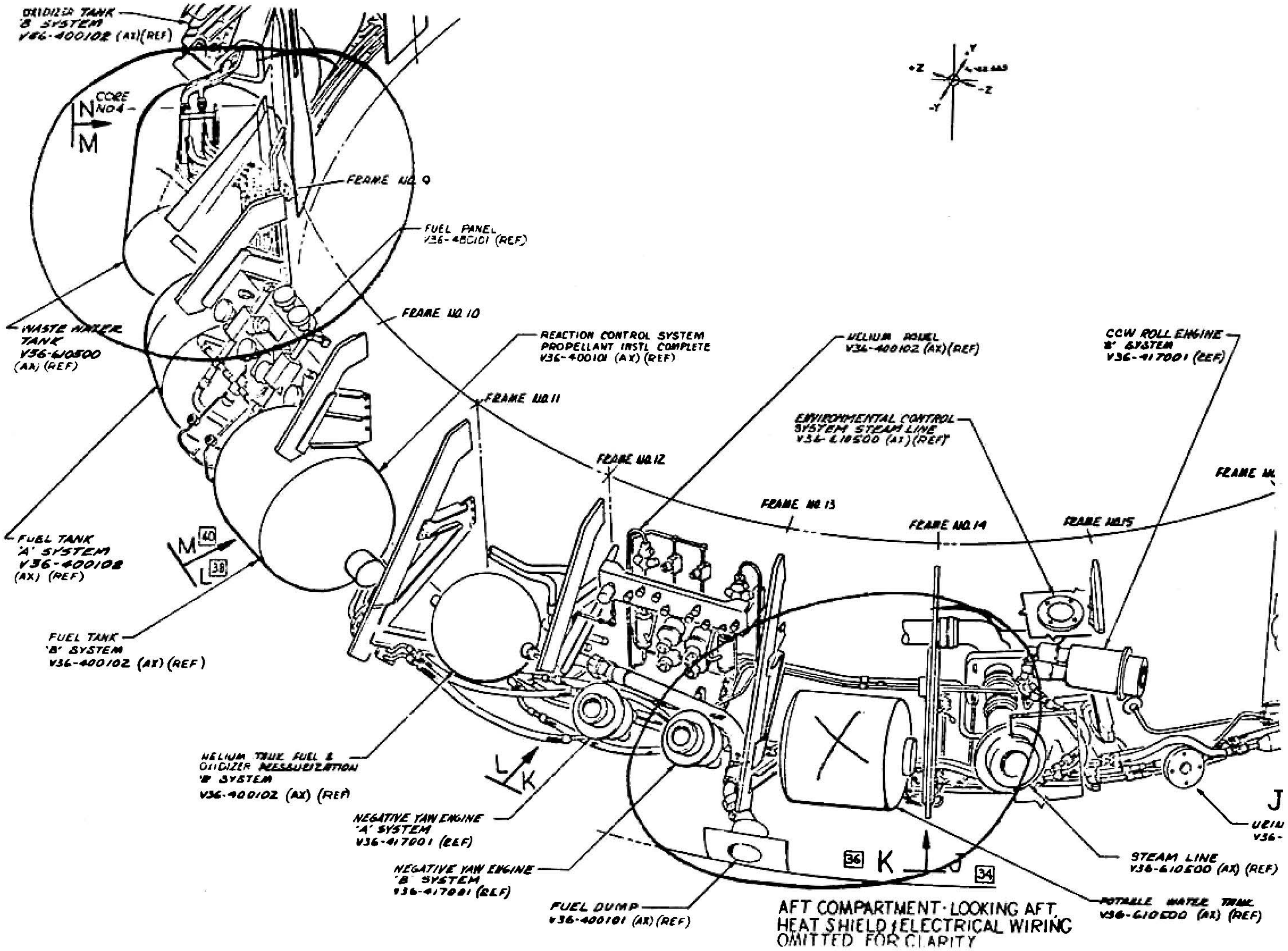


Figure 3.1.1.1.4-1. Potable and Waste Location

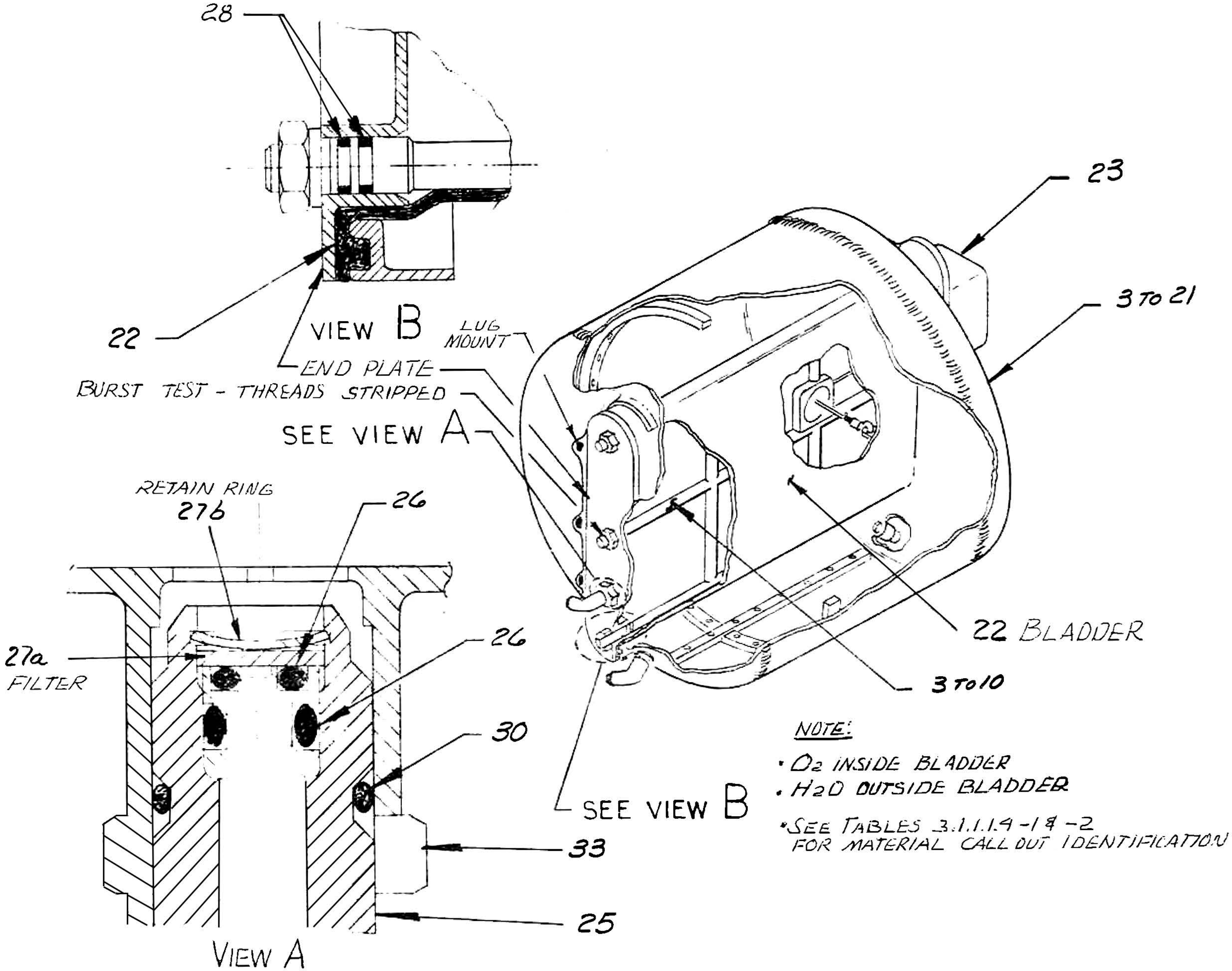


Figure 3.1.1.1.4-2. Potable and Waste Water Tanks (5.10 & 5.15)

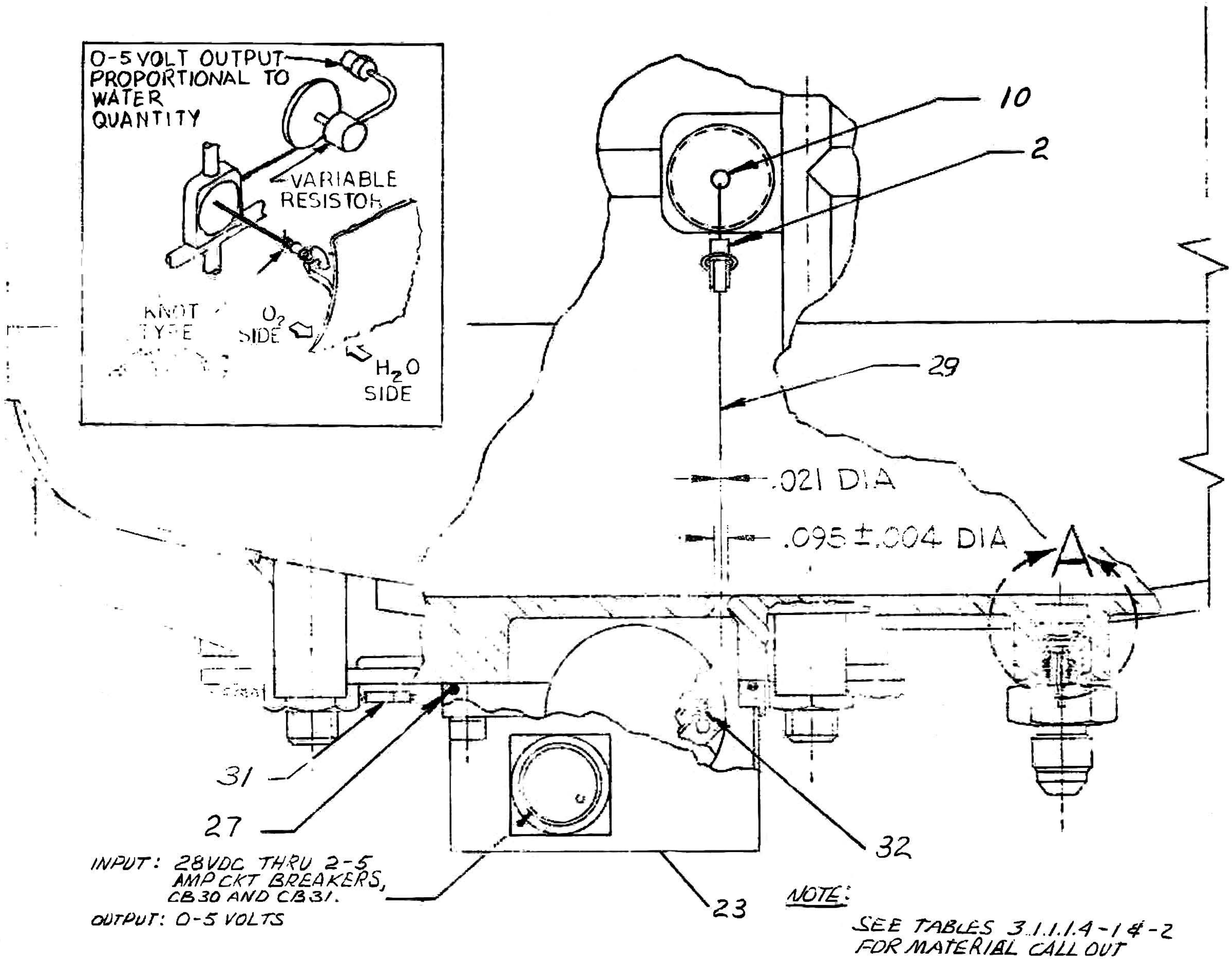


Figure 3.1.1.1.4-3. Potable and Waste Tanks - Quantity Transducer End

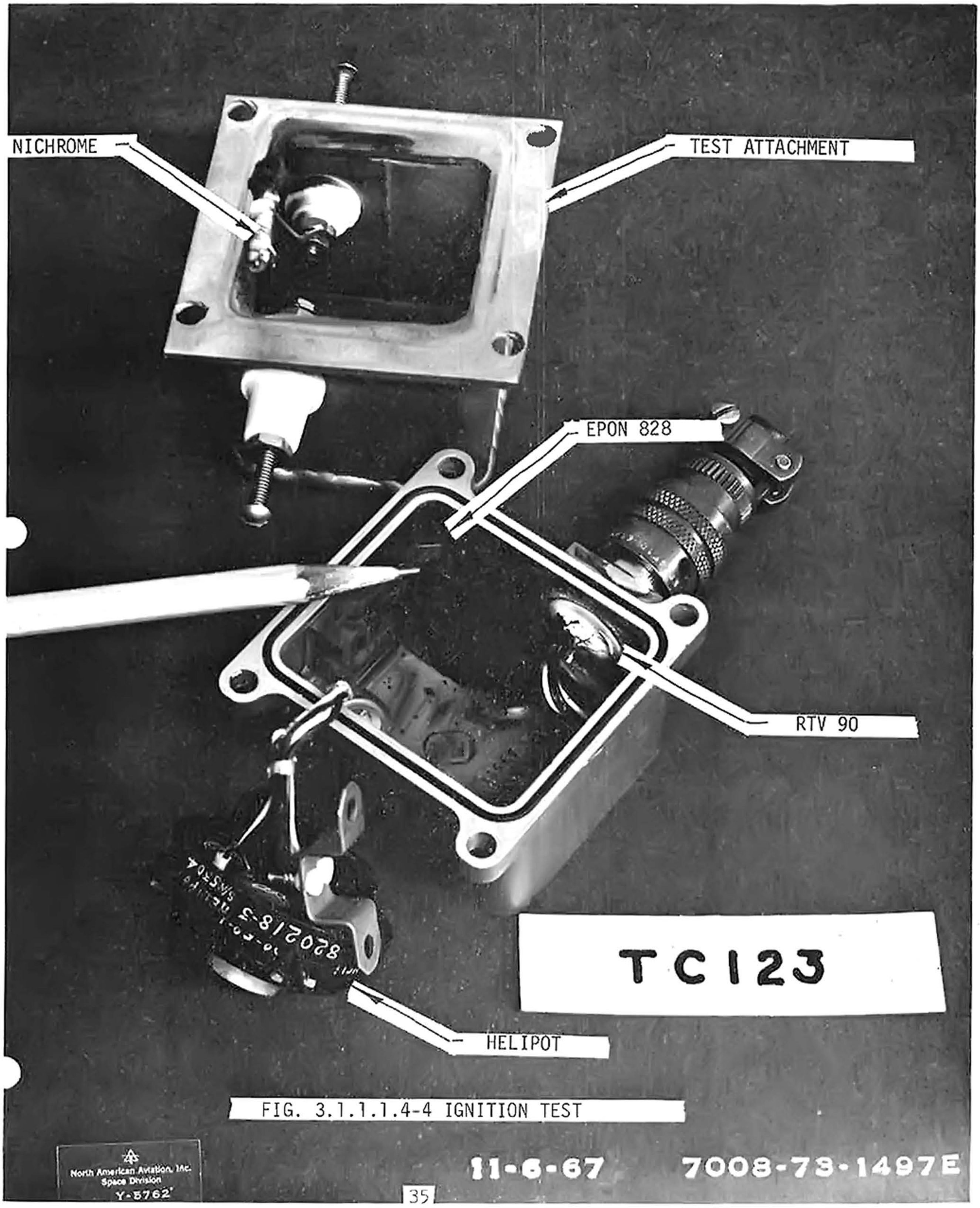


FIG. 3.1.1.1.4-4 IGNITION TEST

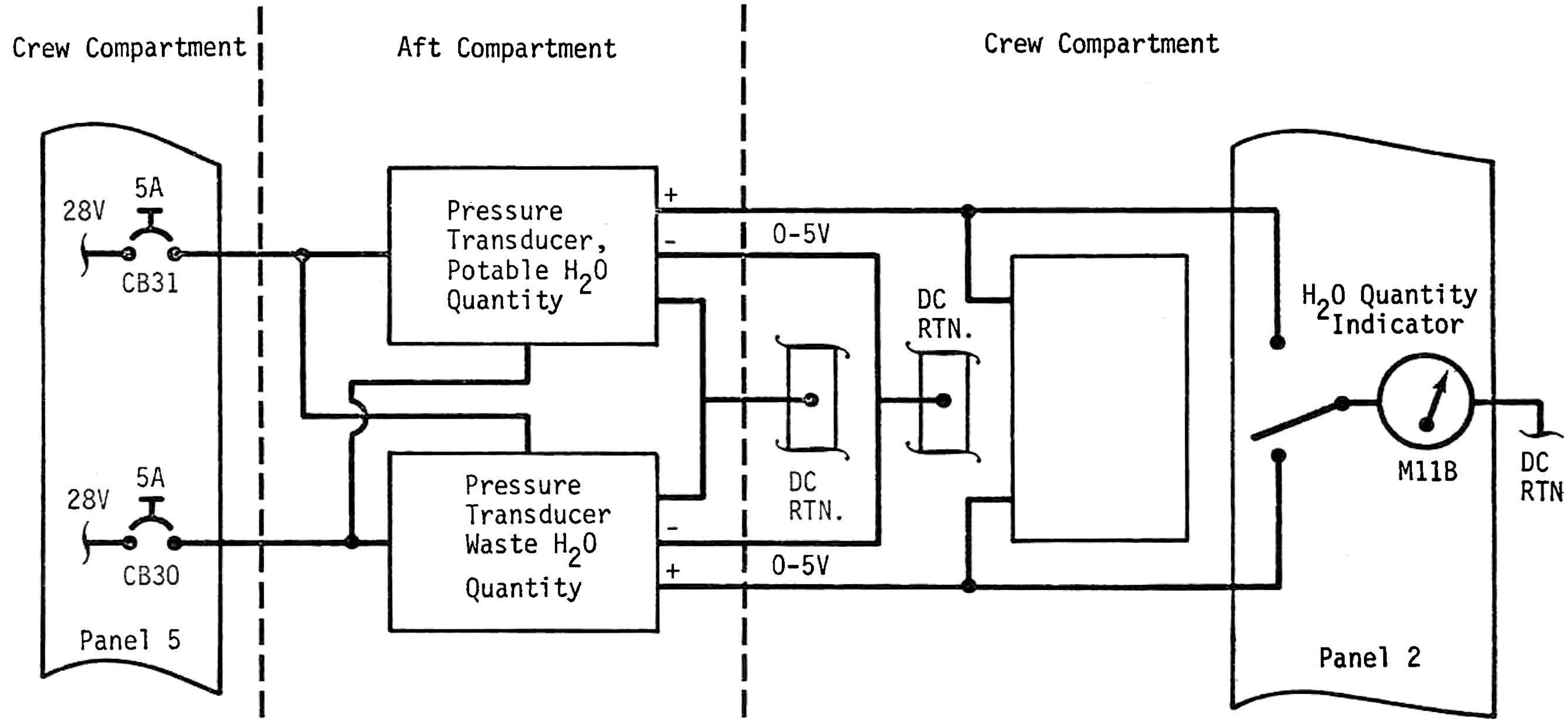


Figure 3.1.1.1.4-5 Electrical Schematic, Potable And Waste H_2O Quantity Sensors

3.1.1.1.5 MECHANICAL COMPONENTS

Subsystem: Environmental Control

Component: Cyclic Water Accumulators (1.29)

Quantity: 2

Part No: ME901-0737 Fig. 3.1.1.1.5-1

Location: Left Hand Equipment Bay in the ECU. See Fig. 3.1.1.1.1-1

Description and Function

The cyclic water accumulators are part of the suit heat exchanger. They are redundant system and piston-type pumps, which are actuated by a common manifold with O_2 pressure of 100 psig on the discharge stroke, and by a return spring for the suction stroke. The O_2 flow is controlled by the two water accumulator selector valves. Each valve contains a selector for auto, manual or off control. The auto position allows the solenoid valve to actuate the cyclic accumulator. The solenoid valve can be controlled automatically by signals from the timing equipment which will cause one of the accumulators to complete a cycle every 10 minutes. The purpose of the accumulators is to remove excess water to control humidity. During mission,one accumulator is operable.

Pressure Control Components:

1. Relief provision: Bleed orifice to the suit heat exchanger in each accumulator.
2. Two solenoid control valves with a manual over ride, Item 1.36, to shut off O_2 flow to the accumulators.
3. Water accumulator controller Item 1.38 to control solenoid valves 1.36.

Internal Parts and Material

EPR Elastomer RS-142
Dacron D400 cloth

These parts are diaphragm parts and passed AiResearch Static test.

Effect of Component Loss:

All phases. Continue mission with one accumulator loss.
Two accumulators loss. Propable mission termination.

Burst Damage Effect:

Analysis indicates burst tank at limit pressure will not cause damage other than loss of cyclic accumulation which can be isolated. The failure mode of excessive pressure is through the diaphragm.

Structural Assembly

Dimension: Length = 4.74 in, I.D. = 2.536 in, Thickness = 0.03 in

Size: 8 cu in

Manufacturer: AiResearch

The cyclic accumulators are made of two (2) halves bolted together with a piston/diaphragm to isolate the O_2 from the water. The water inlet and outlet check valves and the O_2 bleed orifice are incorporated in the tank.

Failure Mode

Only one cyclic accumulator burst test was accomplished for the flight configuration version. There were four previous tests using a block II configuration except for the diaphragm material which was changed from Viton A to EPR. The failure mode, assuming the O_2 side is overpressurized, is rupture of the diaphragm.

Below is the design and test pressures:

	H_2O	H_2O
Limit (psig)	NA*	140
Burst (psig)	100	350
CTR Test (psig)	210/290**	640
Safety Factor		
Design	1.5*	2.5
Demonstrated	3.1/4.3*	5.3

*No limit design is indicated in specification to determine safety factor. Burst divided by 150% is assumed (67 psig).

**The CTR burst test for the H_2O side was not accomplished since it was approved by similarity.

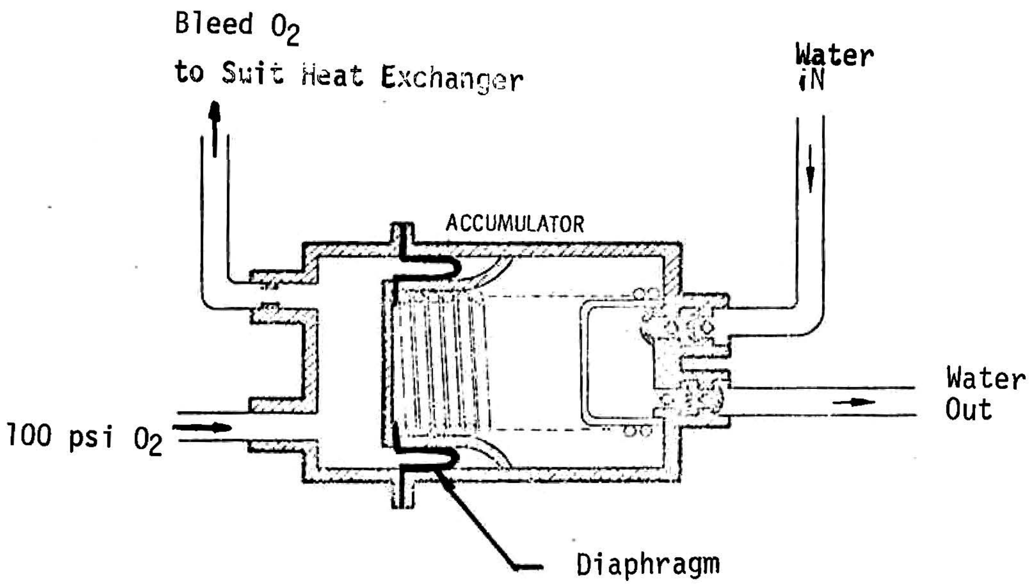


Fig. 3.1.1.1.5-1 CYCLIC ACCUMULATOR

3.1.1.2 Line Components

Listed below in Table 3.1.1.2-1 are the line components reviewed and a summary of the findings. The primary area of concern as shown by a "yes" in the last column is related to the acceptance of non metallic materials exposed to greater than 20 psi oxygen. NR has reviewed the non metallics on these components and many were accepted by similarity. MSC has not yet concurred on the NR acceptance. The non metallics referred to here are those non metallics not in the high pressure oxygen stream but are on the component. It is recommended that these non metallics which NR has accepted by similarity be reviewed by MSC. If any non metalic materials are unacceptable by MSC, a detail review of those components that contain the non metallic be accomplished to determine if a single failure can expose that particular non metallic to the high pressure oxygen.

The concern on the aluminum lines is the possibility of an external thermal source which could weaken the lines, specifically a shorted electrical source. It is recommended that a visual inspection be made to ensure that there are no electrical sources immediately adjacent to the aluminum lines.

The non metallics were reviewed for each component to determine if they were acceptable for high pressure oxygen (plus impact if applicable) use. Since all non metallics were acceptable or of insignificant amount, no single failure analysis was accomplished for the mechanical components -- pending the aforementioned review.

All impact application non metallic materials are presently acceptable. Because of the uncertainty of the adequacy of the impact test, a re-review of these materials may be required as indicated by any new test standard. The material type and its application and acceptance is shown in Table 3.1.1.2-2.

Table 3.1.1.2-1 ECS Line Components Summary

NON - METALLICS

COMPONENT	STATIC OR SLIDING	IMPACT	EXPOSED AFTER SINGLE FAILURE	FAILURE TRENDS	OTHER CONCERNS
900 PSI					
Check Valve (4.25)	OK	OK	OK	--	YES*
Shutoff Valve (4.26)	OK	OK	OK	--	YES*
Filter (4.31)	OK	--	--	--	YES*
Surge Tank Relf. Vlv. (4.27)	OK	OK	OK	--	YES*
Repress Pkg. Vlv. (4.34)	OK	OK	OK	--	--
Valve (72.1)	OK	--	OK	--	YES*
Repress Regulator (72.3)	--	--	--	--	YES*
Repress Press. Gage (72.4)	--	--	OK	--	YES*
O_2 Main Reg. (72.5)	OK	OK	OK	--	YES*
100 PSI					
Emergency Cabin (4.22) Pressure Reg.	OK	--	OK	--	YES*
Cabin Pressure (3.28) Regulator	OK	OK	OK	--	YES*
Direct O_2 Valve (4.17)	OK	--	OK*	--	YES*
Oxygen Filter (4.35)	--	--	OK	--	YES*
Demand Pressure (4.16) Regulator	OK	OK	OK	--	YES*
Tank Pressure Reg. (5.24) and Relief Valve	OK	OK	OK	--	YES*
25 PSI					
Potable and Waste Filters	--	--	--	--	--
Aluminun Lines	--	--	--	--	YES**

Note: (--) indicates not applicable.

* Non-metallics accepted by similarity
** Aluminum lines with pressure greater than 100 psig

TABLE 3.1.1.2-2 ECS Line Components

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	Use-age Cat.	Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
4.25 828280-2 Check Valves	1086.5	150	B		EC 583	N	.04			
			D	B	L-9 Lube	N	.40	X		
			D	B	EPR Elastomer	N	.28			X
			D	B	EMS 342 Sil. Rub.	N	.35	X		
4.26 ME 284-0191	1086	150	B		EC 583	Neg.	.02			
-0041			D	B	L-9 Lube	.001	3.2	X	X	
-0021			D	B	EPR Elastomer	.006	2.52			X
Valve, Shut Off			B		Kel-F	Neg.	.02			
			B		Zytel 101	Neg.	Neg.			
			B		Teflon TFE	.001	.38			
			D	A	Teflon TFE	.01	.02		X	
			B		Teflon FEP	Neg.	.15			
			B		L-9 Lube	.001	1.75			
4.31 ME 286-0034	1026	150	D	A	Teflon TFE	.002	.08			
-0002 Oxygen Filter			D	A	Teflon TFE	Neg.	.03			

LEGEND

- o Usage catagory for non-metallics
  - A - On component but not exposed to high pressure O_2 (major used mat.)
  - B - On component but not exposed to high pressure O_2 (minor used mat.)
  - C - 20 PSIA - Suit Loop
  - D - 20 PSIA
  - E - Hermetically Sealed Box
  - F - Vented Box - to cabin
- o Cat. D Evaluation
  - A - NASA Test
  - B - AiResearch Test
  - C - Accepted by similarity

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area $In.^2$	Applicat. Static	Applicat. Sliding	Applicat. Impact
4.27 ME 284-0192-0021 Relief Valve	1086	150	B		EC 583	Neg.	.01			
			D	A	Luctite	Neg.	2.2	X		
			D	B	L-9 Lube	.003	8.1	X	X	
			D	B	Nylon	Neg.	Neg.	X		
			D	B	Polyurethane	Neg.	.01			X
			D	B	EMS 342 Silicone	.02	2.39	X	X	
			D	B	EPR Rubber	Neg.	.17		X	
			B		Zytel 101	Neg.	Neg.			
			D	A	Teflon TFE	Neg.	.13	X		
			D	A	Teflon TFE	Neg.	.66		X	
			D	A	Teflon TFE	.007	1.3		X	
			B		Loctite	Neg.	.02			
4.34 ME 284-0298 -0011 Repress Pkg. Valve	1086	150	B		EC 583	Neg.	.03			
			B		Loctite	Neg.	.01			
			D	B	L-9 Lube	.001	3.20	X	X	
			D	B	EPR E Lastomer	.002	2.45			X
			D	B	EMS 342 Silicone	.001	.87	X		
			D	A	Teflon TFE	.030	4.30	X	X	
			B		Nylon	Neg.	Neg.			
			D	A	Teflon TFE	.001	.61		X	

* See first page of this table for LEGEND

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
72.1 ME 284-0360-0001 Shut Off Valve Carlton	1086.5	160	D	B	E515-8 (EPR)	.002	1.43	X	X	
			D	B	EMS 342 Silicone	Neg.	.52	X		
			D	A	Kel-F	Neg.	.41	X		
			B		Teflon TFE	Neg.	.90			
			D	B	Krytox 240 AC	Neg.	Neg.	X		
			B		Zytel 101	Neg.	Neg.			
			D	B	E515-8 (EPR)	.002	.59		X	
			D	C	11199 Silicone	Neg.	.11	X		
			D	B	Krytox 240 AC	Neg.	Neg.	X		
			B		Epoxy Glass/Lam	Neg.	.71			
			D	A	Kel-F	.001	.34	X		
			D	C	SE 555 Silicone	Neg.	.05		X	
			D	C	PRP 1235-80 Silicone	Neg.	.05	X		
72.4 V36-613574 Repress Press. Gage	NA	NA	B		465 Transfer Tape	.001	.01			
			B		Krytox 240 AC	.010	.02			

* See first page of this table for LEGEND

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area $In.^2$	Applicat. Static	Applicat. Sliding	Applicat. Impact
72.5 ME 284-0359			D	B	E515-8	.004	4.18	X		
-0001			D	B	EPR Rubber	Neg.	.45	X	X	
-0002			D	C	4404 U Silicone	.1	.71			X
Regulator Carlton			D	C	11199 Silicone	Neg.	.06	X	X	
			B		Zytel 101	Neg.	.41			
			B		Epoxy/Glass Lam.	Neg.	1.41			
			D	C	SE 555 Silicone	Neg.	.18	X		
			B		Teflon	Neg.	1.79			
			D	B	Krytox 240 AC	Neg.	Neg.	X		
			D		Kel-F 81	.002	.76	X		

* See first page of this table for LEGEND

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Number Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
4.22B			B		EC 583	N	.04			
828510-5	156.5	160	B		A4000 Sil. Adh.	N	1.32			
EMERGENCY CABIN PRESSURE REGULATOR			D	A	Loctite	N	N	X		
			B		Loctite	N	.34			
			D	C	DC 731	N	.12	X		
			B		EMS 242 Dry Lube	N	1.5			
			B		Dry Film Lube	N	2.0			
			D	B	L-9 Lube	.003	7.6	X		
			D	C	SE 550 Sil.	N	.78	X	X	
			D	B	EMS 342 Sil. Rub	.005	5.5	X		
			D	B	EPR	N	.34	X		
			B		5224-1000-Mol. CPD	N	.2			
			B		Nylon	.024	3.06			
			B		Nylon	N	N			
			D	A	Teflon, TFE	.001	1.84		X	
			D	A	Teflon, TFE	.012	2.13		X	
			B		SE 550 Sil.	.007	9.97			
			B		EMS 342, Sil. Rub.	.002	2.23			
			B		L-9 Lube	.001	4.07			
3.28C			B		EC 583	N	.035			
810230-3	'56.5	160	B		Loctite GR HV	N	.002			
CABIN PRESSURE REGULATOR			B		Locquic Primer	N	.002			
			B		DC 33 Light	.005	8.00			
			D	B	L-9 Lube	.001	4.00	X		
			D	B	EMS 342 Sil. Rub.	N	.06	X		X
			D	A	Viton A	.002	1.48	X		
			B		Biton A	.005	4.20			
			B		L-9 Lube	.001	2.0			

* See first page of this table for LEGEND

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
4.17	156	200	B		EC 583	Neg.	.01			
			B		Loctite Gr H	Neg.	.77			
828560 Direct O_2 Valve			D	A	Invelco 33F	Neg.	.80	X		
			D	B	Th1076 Silicone	Neg.	.04	X		
			D	B	EMS 342 Silicone	.001	.63	X		
			B		Teflon FEP	.001	1.97			
			B		Kel-F	Neg.	Neg.			
			B		Zytel 101	.02	1.11			
			B		Loctite Grade C	Neg.	.02			
			B		Locquic Primer	Neg.	.02			
			B		Dry Film Lube	Neg.	2.97			
			B		EMS 342 Silicone	Neg.	.26			
			B		Invelco 33	Neg.	.80			
4.35 848353-2 OXYGEN FILTER	NA	NA	B		EC 583	N	.032			

* See first page of this table for LEGEND

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	Use-age Cat.*	Cat.* D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
4.16			B		EC 583	N	.35			
828730-9			D	A	A-2/Cat A Epoxy	N	.2	X		
DEMAND PRESSURE REGULATOR	156.5	160	C		A-2/Cat E	N	.01			
			B		Epon 123/Hard 931	N	.1			
			D	C	DC 140	N	.2	X		
			C		Loctite	N	.01			
			B		Loctite	N	.06			
			D	C	DC 731	N	.12	X		
			D	A	EMS 242 Dry Lube	N	1.0	X		
			B		Invelco 33F	N	.75			
			D	B	L-9 Lube	.003	9.4	X		
			D	B	EMS 342 Sil. Rub.	.011	5.17	X		
			C		DC 6508 Elast.	.001	.45			
			D	C	SE 550 Elast.	.036	11.5	X		
			D	B	EMS 342 Sil. Rub.	.005	5.5	X		
			D	B	EPR Elast.	.002	2.62		X	
			C		Fluoroloy Bear.	.001	.01			
			B		Polypropylene	N	.25			
			B		Nylon	N	N			
			B		Teflon, TFE	.001	2.16			
			D	A	Teflon, TFE	.051	10.7	X	X	
			B		FEP, Teflon	.006	5.83			
			C		A-2/Cat A Epoxy	N	.06			
			D	A	Loctite	N	.008	X		
			B		L-9 Lube	N	1.0			
			C		L-9 Lube	.001	3.0			
			C		EMS 342 Sil. Rub.	N	.81			
			B		SE 550	.03	4.65			
			C		SE 550	.005	5.7			
			B		EMS 342 Sil. Rub.	.001	1.05			
			C		EMS 342 Sil. Rub.	.003	3.69			

* See first page of this table for LEGEND

TABLE 3.1.1.2-2 ECS Line Components (Continued)

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	* Use-age Cat.	* Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
5.24 ME 284-0368 -0001 OXYGEN REGULATOR	156	160	B		EC 583	Neg.	.04			
			D	A	Epibond 123?931	.001	1.57	X		
			D	C	Epi Re2 510	Neg.	.25	X		
			D			Neg.	.38			
			D	A	Loctite	Neg.	.01	X		
			B		DC-510	Neg.	.34			
			D	B	L-9 Lube	.002	5.6	X	X	
			D	B	EMS 308 si/Dacron	.041	2.08			X
			D	B	Th 1076 Silicone	Neg.	.07			X
			D	C	8164 Silastic	.001	.34			X
			D	B	EMS 342 Silicone	.001	.97	X		
			D	B	EPR Elastometer	.002	2.6	X	X	
			D	A	Teflon TFE	.017	4.2	X		
			D	C	Red Fiber Sheet	Neg.	1.17	X		
			D	B	15004/1 Dacron Fab.	.002	20.8			X

* See first page of this table for LEGEND

3.1.2 Electrical Components

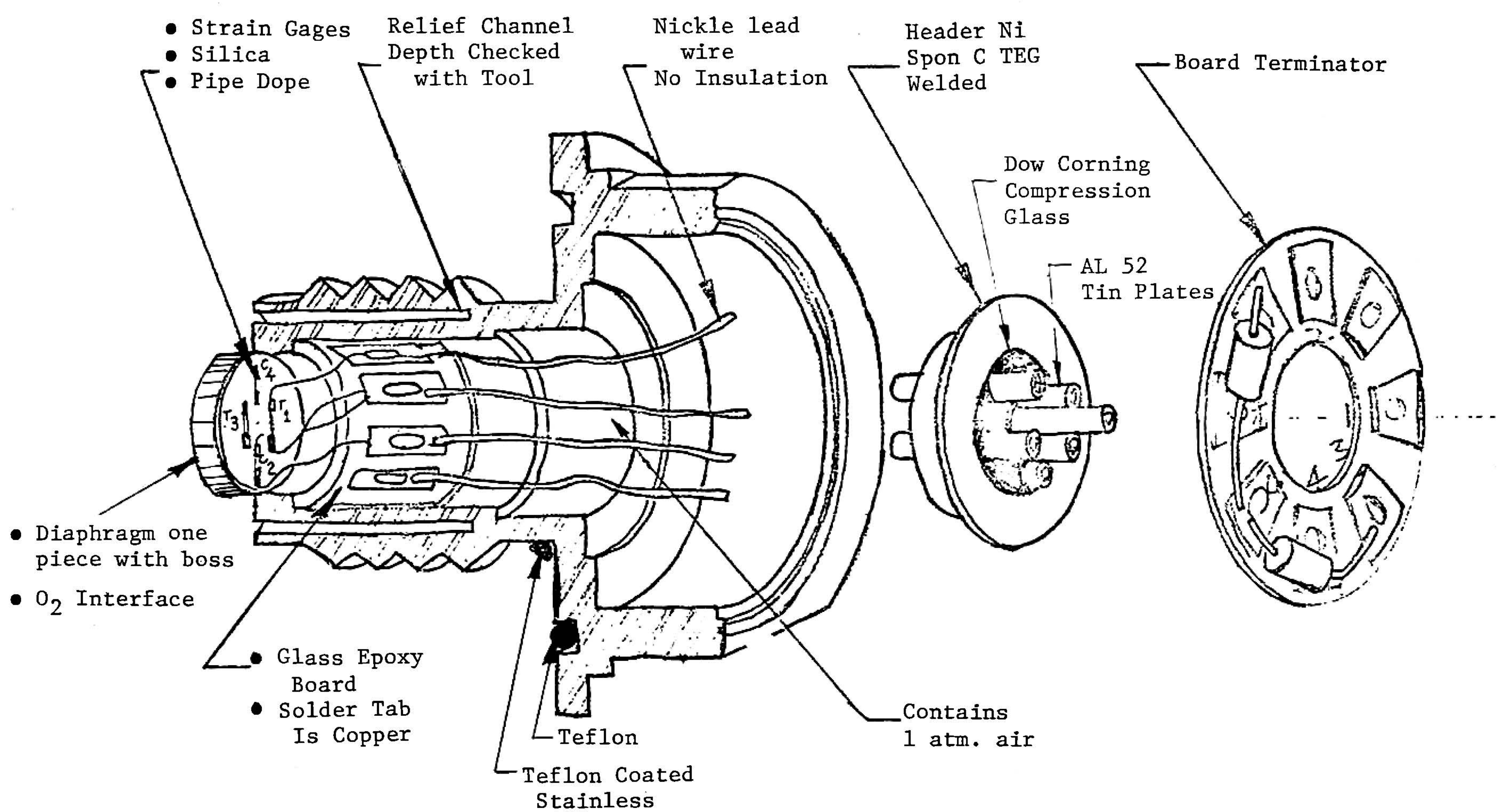
Listed below in Table 3.1.2-1 are the electrical components reviewed and a summary of the findings. Note that the review for items 1.36, 9.2, and 9.8 have not been completed, and the potable and waste tank quantity gaging systems are covered in Section 3.1.1.1.4 Pressure Vessels, since they are integral with the tanks. As can be seen by Table 3.1.2-1, the only area of concern is the exposure of electronics to high pressure oxygen after a single failure for items 70.2 and 74.0. Because of the design, however, the transducers are accepted as is. The transducers are similar in design, see Figure 3.1.2-1 and have a safety factor of greater than 10. Note, that the threaded fiting and the sense diaphragm is machined from a single stock. In addition, the signal conditioner is current limited by a 1/4 amp fuse, see Figure 3.1.2-2. Also, the electronics that would be exposed after a single failure is further current limited by the signal conditioner.

Table 3.1.2-2 lists each electrical component along with its function, interface properties and electrical characteristics. Table 3.1.2-3 lists the non-metallic materials.

Table 3.1.2-1 ELECTRICAL COMPONENTS SUMMARY

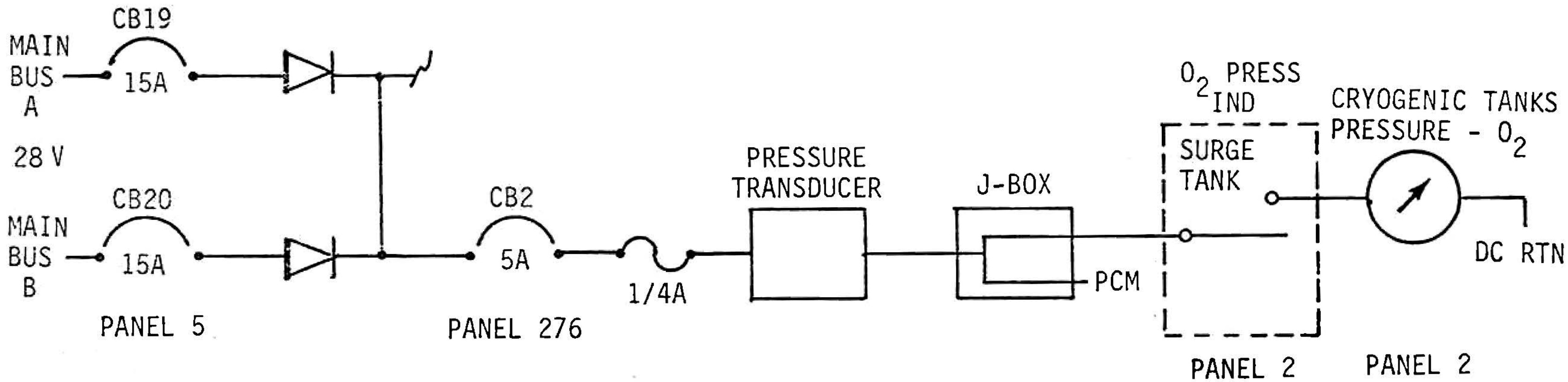
COMPONENT	EXPOSED NON-METALLICS			EXPOSED ELEC.		FAILURE TRENDS
	STATIC or SLIDING	IMPACT	AFTER SINGLE FAILURE	IN STREAM	SINGLE FAILURE	
O_2 Surge Tank Pressure X-Ducer (70.2)	OK	--	OK	--	YES	--
O_2 W/G & H_2O Tank Press. X-Ducer (74.0)	OK	--	OK	--	YES	--
Cyclic Accum. Control Vlv (1.36)	TBD	TBD	TBD	TBD	TBD	--
O_2 Flow X-Ducer (9.2)	TBD	TBD	TBD	TBD	TBD	--
O_2 Main Reg. Press X-Ducer (9.8)	TBD	TBD	TBD	TBD	TBD	--
Potable & Waste Quantity Gaging	SEE SECTION 3.1.1.1.4					

(--) None

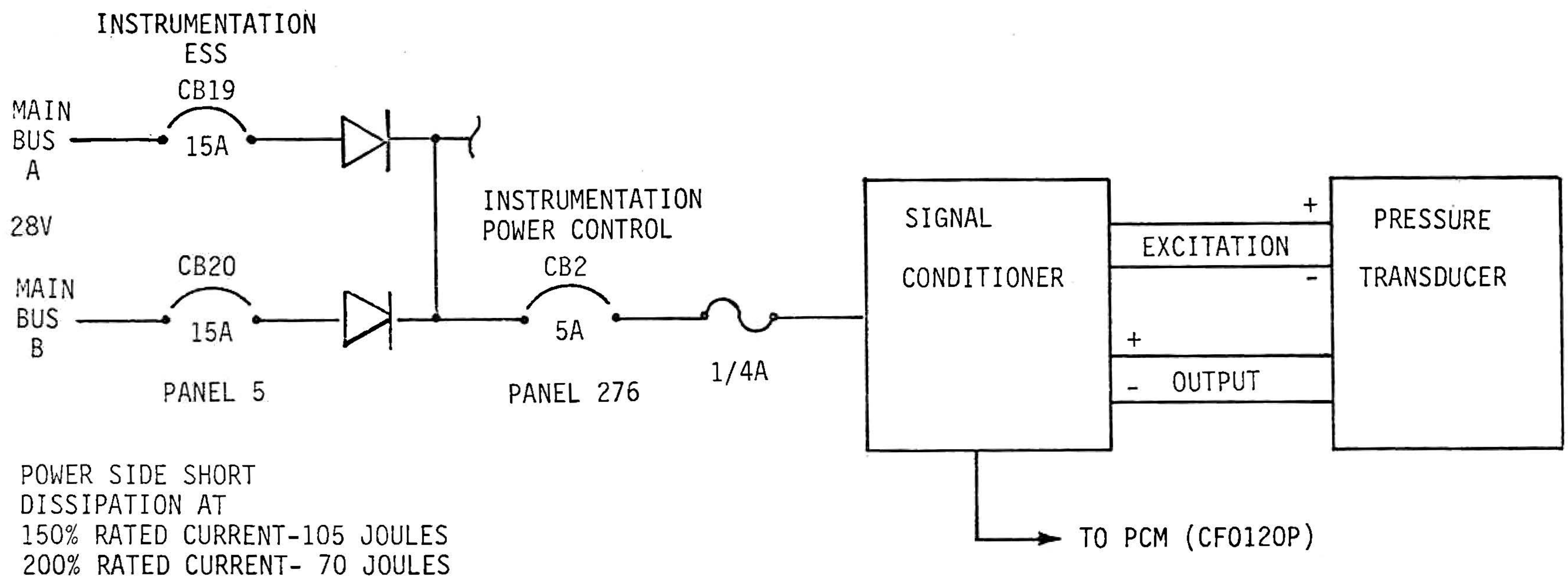


NOTE: A burst test with diaphragm thickness. Same as item 74.0 (0–50 psi) failed at 9000 psia. The diaphragm developed a small crack.

Fig. 3.1.2-1 O_2 Pressure Transducer (70.2 & 74.0)



PRESSURE, CM O_2 SURGE TANK (70.2)



CM, ECS WATER AND GLYCOL TANK PRESSURE (74.0)

Figure 3.1.2-2 Item 70.2 & 74.0 Electrical Line Schematic

TABLE 3.1.2-2 ELECTRICAL COMPONENTS

COMPONENT SCHEMATIC NO. / PART NUMBER / NAME	FUNCTION	MAXIMUM FLUID PROPERTIES AT COMPONENT		ELECT. COMPONENT TO FLUID INTERFACE	ELECTRICAL CHARACTERISTICS
		PRESS. PSI	TEMP. °F		
1.36 / ME 90-0737 / Control Valve	To control the activation of the cyclic accumulator, by supplying 100 psi oxygen pressure to cyclic accumulator thru a solinoid operated valve. Open/close one for each accumulator.	156.5	160	TBD	TBD
9.2 / ME 449-0129 / O_2 Flow X-Ducer	To measure oxygen flow down stream of O_2 main regulators. Used for PCM, onboard readout and C&W input.	156.5	160	TBD	TBD
9.8 / ME 181-0133 / O_2 Pressure X-Ducer	To measure main regulator outlet pressure used for PCM only.	156.5	150	TBD	TBD

TABLE 3.1.2-2 ELECTRICAL COMPONENTS (CONT'D.)

COMPONENT SCHEMATIC NO. / PART NUMBER / NAME	FUNCTION	MAXIMUM FLUID PROPERTIES AT COMPONENT PRESS. PSI	TEMP. °F	ELECT. COMPONENT TO FLUID INTERFACE	ELECTRICAL CHARACTERISTICS
70.2 / ME 449-0055 / O_2 Pressure X-Ducer	To measure pressure surge tank up to 1050 psig. Used for PCM and on-board display.	1086.5	150	There is no interface of electronics to the high pressure O_2. A failure of a one piece x-ducer threaded fitting and the sense diaphragm must fail. Safety factor >10.0. See Fig. 3.1.2-1.	Signal conditioner current limited by 1/4 amp fuse. See Figure 3.1.2-2. X-ducer further current limited by signal conditioner
74.0 / ME 449-0052 / O_2 Pressure X-Ducer	To measure the water and glycol tanks regulation outlet pressure.	43.5	89	Same as Item 70.2	Same as Item 70.2
5.10 / ME 192-0036 / Potable H_2O Tank Quantity	To measure the quantity of H_2O in potable tank. Used for PCM and onboard display.	43.5	130	The details for these x-ducers are covered under Section 3.1.1.1.4 since x-ducer is integral with tank.	
5.15 / ME 192-0008 / Waste H_2O Tank Quantity	To measure the quantity of H_2O in the waste tank. Used for PCM and onboard display.	43.5	130		

* Steady state conditions:
Downstream cryo tanks (in CM) 900 psia and 70°F
Downstream main regulators (item 72.5) 100 psia and 70°F
Downstream H_2O glycol tank regulators (item 5.24) 25 psia and 70°F

Table 3.1.2-3 ECS Electrical Components

Item No. Part Name	Maximum PSIA	Maximum °F Temp.	Use-age Cat.	Cat. D Eval.	Nonmetallic Material Name	Wt. Lbs.	Surface Area In.^{2}	Applicat. Static	Applicat. Sliding	Applicat. Impact
74.0 ME 449-0052 -1102 -1104 Pressure Transducer	43.5	89	A		Penntube II	.009	4.20			
			B		DC 651	.001	.10			
			B		Strycast 1090/Cat 9	.012	.52			
			A		FEP Teflon	.329	410			
70.2 ME 449-0055 -1001 and -1043 Pressure and Temperature Transducer	1086.5	150	B		DC 651	Neg.	.02			
			B		S418-6	Neg.	.02			

3.2 ELECTRICAL POWER SUBSYSTEM

The portion of electrical power subsystem included in this evaluation consists of the cryo H_2 storage tanks, the oxygen distribution provision, the fuel cells provision, entry and pyro batteries.

3.2.1 HYDROGEN TANK

Installation of the H_2 storage tank in the SM is shown in Figure 3.2.1.1. The hydrogen tank contains the following:

Internal Components

a. Temperature sensor
b. Density sensor probe
c. Two heaters
d. Two fans
e. Filter
f. Support tube

External Components (mounted)

a. Signal conditioner (temperature and density)
b. Electrical connector
c. Fill and vent disconnect
d. Vac-ion pump

Drawings of the above items are shown in Figure 3.2.1.2 through 3.2.1.6. Table 3.2.1.1 is a list of materials contained in the H_2 tank assembly.

The storage tank consists of two concentric spherical shells. The annular space between them is evacuated and contains the thermal insulation material, pressure vessel support, fluid lines and the electrical conduit. The inner shell, or pressure vessel is made from forged and machined hemispheres. The pressure vessel support is built up on the pressure vessel from subassemblies and transmits pressure vessel loads to the support assembly.

Each storage tank contains a forced convection pressurization and destratification unit. Each unit consists of the following:

a. A 2.0 inch diameter support tube approximately 3/4 the tank in diameter in length.

b. Two heaters.

c. Two fan motors.

d. Two thermostats. Eliminated for H_2 on CSM 113 and subsequent CSMs.

The motors are three phase, four wire, 200 volts A.C. line to line, 400 cycles miniature induction type with a centrifugal flow impeller.

The heaters are a nichrome resistance type, each contained in a thin stainless steel tube insulated with powered magnesium oxide. The heaters are designed for operation at 28 volts DC during flight or 65 volts DC for GSE operation. The heaters are spiralled and brazed along the outer surface of the tube.

The thermostats are a bimetal type unit developed for cryogenic service. They are in series with the heaters and mounted inside the heater tube with a high conducting mounting bracket arranged so that the terminals protrude through the tube wall.

Each storage tank contains a density sensor consisting of two concentric tubes which serve as capacitor plates, with the operating media acting as the dielectric between the two. The density of the fluid is directly proportional to the dielectric constant and therefore probe capacitance. A four-wire platinum resistance temperature sensing element is mounted on the density sensor. It is a single point sensor encased in an Inconel sheath which dissipates only 1.5 millivolts of power per square inch to minimize self-heating errors.

Materials used in the H_2 tank assembly have been investigated and no known incompatibility has been found with the metallic materials. However, there are two alloys, solder and brass, which in themselves are not known to be incompatible with H_2, but which contain lead and zinc, respectively, which are known to be individually incompatible with hydrogen. Testing is required to resolve this issue. The nonmetallic materials in the hydrogen tank has been evaluated and no known incompatibility with hydrogen has been found unless heat is present such as would be the case in the event of an electrical short. In this case, it is suspected that a potential reaction of teflon, aluminum and H_2 exists. Testing is required to resolve this issue and has been initiated.

The potential for hydrogen embrittlement of the metals in the H_2 tank has been reviewed. The metals used in H_2 tanks are not embrittled by hydrogen.

Evaluation of the detailed design of the H_2 tank electrical element indicate that the same type of design has been used in H_2 tank as is used in the O_2 tank which failed (these components are not subjected to AVT during acceptance). Therefore, the H_2 tank must be assumed to have the potential of producing electrical short circuits. Short circuits in the hydrogen tank will result in mission aborts if:

a. The shorts produce a reaction that subsequently ruptures the pressure vessel or

b. The shorts cause a failure of both heaters and a single fan thereby greatly reducing the flow rate available from the tank.

It will be necessary to conduct special tests to determine whether the above abort situations can result from electrical short circuits in the hydrogen tank. Two test requests have been submitted to initiate the required testing.

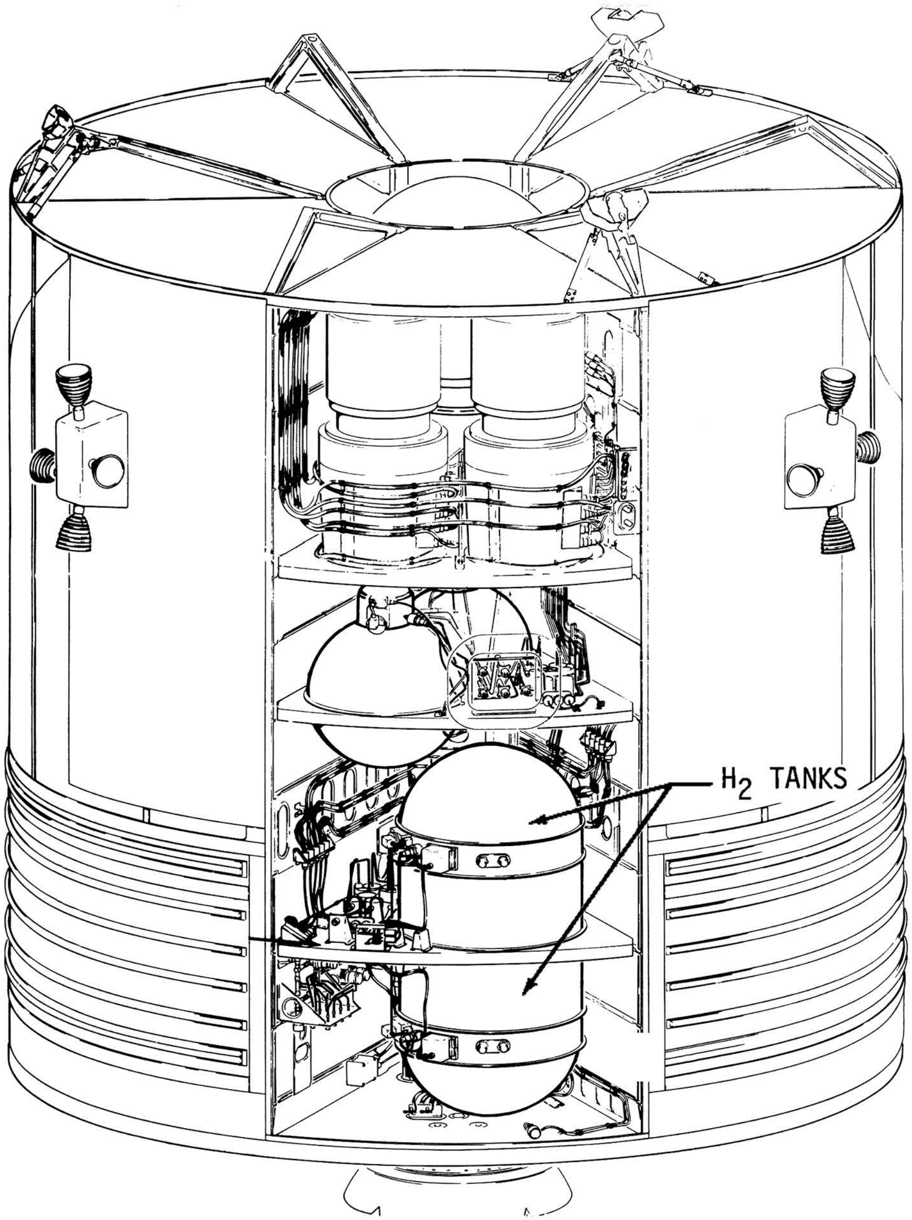


FIGURE 3.2.1.1. H_2 TANK INSTALLATION IN SM.

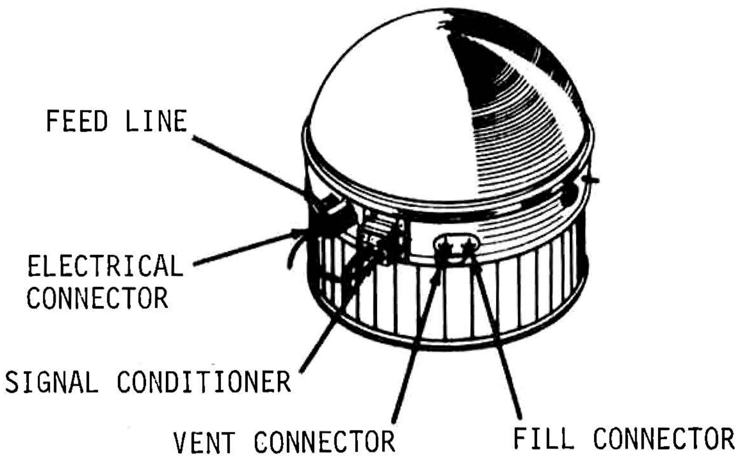


FIGURE 3.2.1.2. H_2 STORAGE TANK

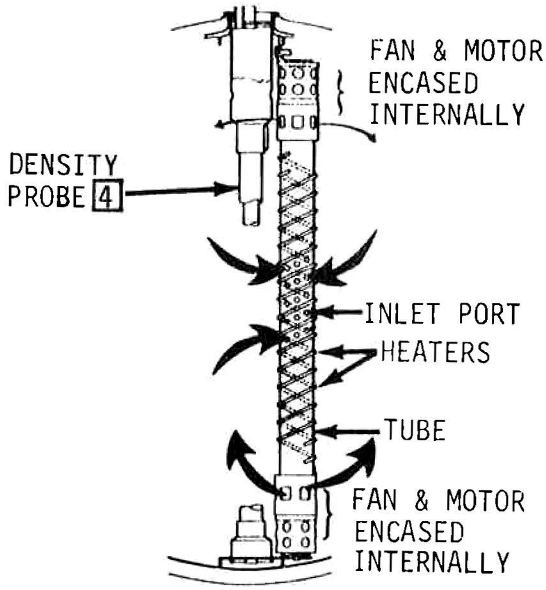


FIGURE 3.2.1.3. H_2 TANK PRESSURIZATION AND DESTRATIFICATION UNIT

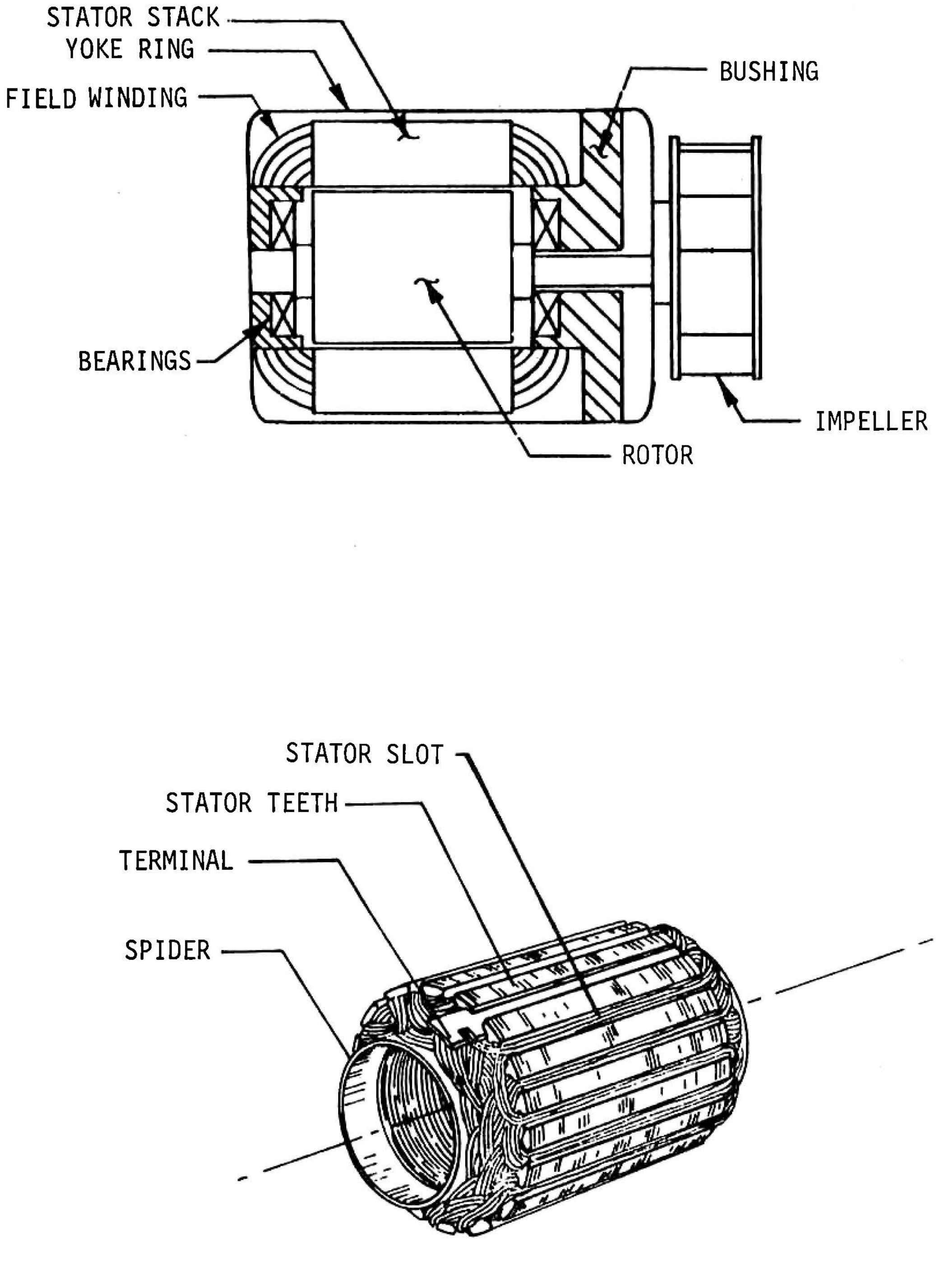


FIGURE 3.2.1.4. H_2 TANK FAN MOTORS.

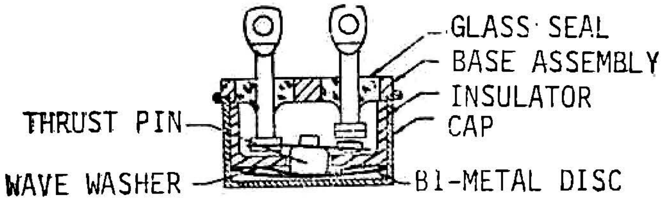


FIGURE 3.2.1.5. H_2 TANK TEMPERATURE CONTROL SWITCH

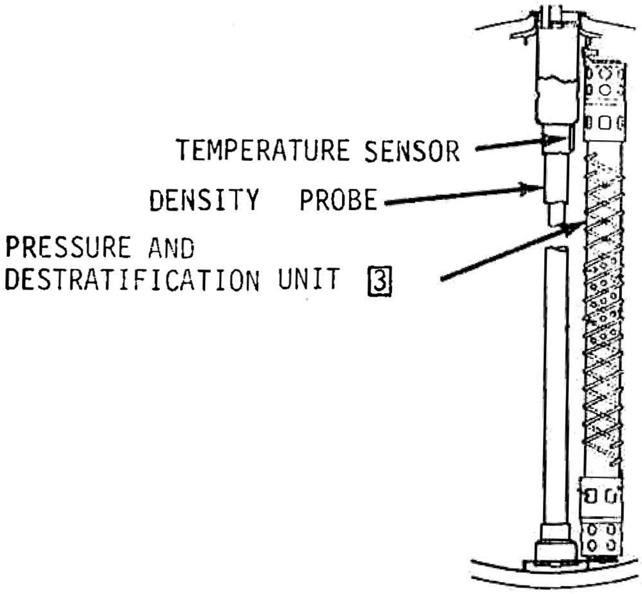


FIGURE 3.2.1.6. H_2 TANK DENSITY PROBE.

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST (ME282-0047)

Part Name	Part Number	Material
Skirt Assy, H_2 Tank	13532-1503	
Angle	13532-3543	AL ALY 7075-T6 QQ-A-250/12
Tee-Attachment	13532-3542	AL ALY 7075-T6 QQ-A-250/12
Skirt Beaded	13532-3545	AL ALY 2024-0 QQ-A-250/5
Plate Reinf.	13532-3544	ALSH QQ-A-250/12 7075-T6
Plate-Ident	13532-3557	ALPL QQ-A-250/12 7075-T6
Tank Assy-H_2	13532-1502	
Ring Assy	13532-2806-3	
Ring Assy	13532-2807-9	
Ring Mount		
Girth	13532-3515-7	5Al-2.5Sn Titanium (BS13869)
Tube Assy	13532-3519-3	5Al-2.5Sn Eli Titanium (BS13769)
	-5	AST21 8-5 Copper T. Loc.
Valve Assy	13532-2510-1	
Adapter Assy		
Vent Disconnect	13532-2809-3	
Coupling-Weld	13532-3506-5	304L Cres MB0160-020 (BAR)
	-7	
Tube Feed Inlet	13532-3517-3	304L Cres Tube MB0160-007
Fitting-Feedline	13532-3808-1	304L Cres MB0160-020 (BAR)
Adapter Assy		
Bi-Met. Vent Disc.	13532-2814-1	
Adpt. Flange	13532-3813-1	5Al-2.5Sn Eli Titanium (BS13769)
Jt.-Transition	13532-3811-3	5Al-2.5Sn Titanium (BS13769)
	-5	304L Cres MB0160-020 (BAR)
Adpt. Vent & Fill	13532-3812-1	304L Cres MB0160-020 (BAR)

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Tube-Vent	13532-3531-3	ASTM-B-338-611 Titanium GR-2
Body Fill Disc.	13532-3533-3	Cres 304L Annealed MB0160-020
Poppet-Disc.	13532-3534-3	5Al-2.5Sn Eli Titanium (BS3769)
Spring-Poppet	13532-3535-1	302 Cres QQ-W-423 Form I Cond B
Cap-Disc.	13532-3536-3	Cres 304L Annealed MB0160-020
Ferrule-Cable	13532-3540-1	Cres Tube Mil-T-8504
Seal-Disc.	13532-4070-1	
Valve Assy.		
Fill Disc.	13532-2811-1	
Adpt Assy-Fill	13532-2808	
Tube-Fill	13532-3530-3	Cres 304L MB0160-007
Adpt-Assy Fill	13532-2815-1	
Flange-Adpt	13532-3814-1	5Al-2.5Sn Eli Titanium (BS13769)
Diaph-Press-Relief	13532-4036	AL 1100-0 QQ-A-561
Brkt Assy (Sig. Con)	13532-2513	6061-T6 Al ALY QQ-A-250/11 QQ-A-200/8
		Cres 304L MB0160-020
Transition Jt.	13532-3805-1	5Al 2.5Sn Eli Titanium (BS13769)
Sleeve-Elect.	13532-3806-1	Cres 304L MB0160-020
		Shell Matl: Cres 304L
Conn.-Elect.	13532-4702-1	Glass Bead Insulators
To Ring	13532-3548-1	Cres QQ-S-766 CL 302 Cond A
		.0005 Cold Coated Kapton
Insl.-H_2 Tank	13532-3523	Type H Film
Press Vess. Assy	13532-2501-1	
Tank Hemis. Upper	13532-3500-1	MB0170-010 5Al-2.5Sn Eli Ti
Tank Hemis. Inner	13532-3120-9	MB0170-010 5Al-2.5Sn Eli Ti
Bolt Hook	13532-3133-1	Cres 302 Cond B
Spt Sen. & Heater	13532-3132-1	2.5Sn Eli Titanium (BS13769)
Washer-Flat	13532-3086-3	Cres 302 MIL-S-50157
Plate-Disc.	13532-2514	5Al-2.5Sn Eli Ti (B1S168)

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST (ME282-0047)- Continued

Part Name	Part Number	Material
Nut-Self Lock	13532-4052-3	Elastic Stop Nut P/N 1803-02
Clamp-Heater	13532-3134-1 Assy	5Al-2.5Sn Eli Ti Alloy (BS13769))
	-5	
	-9	
Insert-Screw	13532-3141-1	Cres 302 or 304 (Same as MS21209)
Screw-Cap	13532-3139-1	302 or 304 Cond A QQ-S-763 or as specified in NAS 1351
Wire-Safety	13532-3110-1	Cres 304 Form I Cond A QQ-W-423
Insl. Instl.	13532-2800-1	
Beam Assy No. 1	13532-2505-1	
Strap Assy.-Tens	13532-2512-1	
Strap Tens	13532-3509-1	6Al 4V Eli Ti Type III
	-3509-2	Cond. C Annealed MIL-T-9046
Fast. Tens-Strap	13532-3521-3	7075-T651 Al ALY QQ-A-225/9
Strap Inner-Tank	13532-3510-1	Unalloyed Ti Ams 4900
		6Al 4V Eli Ti Type III Cond D
Strap Intmed.	13532-3511-	Annealed Mil-T-9046
Insul.-Strap	13532-3512-1	Type E Glass Fiber & Type 700
	-3-5	Binder (BS14463)
Ret. Pre-Load	13532-3528	Cres 304 Cond A QQ-S-763
		QQ-S-766
Fast-Ann. Threaded	118707	Cres 304, 304L, 316, 321 or 347 QQ-S-763
Shield Assy No. 1	13532-2803-3	
Tube-Vapor No. 1	13532-3508-3	Cres 304L Annealed MB0160-007
Clip-Tube	13532-3550-1-3	
	-5-7	See Sht 10
Shield Girth	13532-3563	
Clip-Shield	13532-3561-1	Ams 4900 Coml Pure Titanium
		.0005 Gold Coated Kapton

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Insl-Spider	13532-3567	Type H Film
Shim-Pump	13532-3572	Al Aly 6061-T6 QQ-A-250/11
Shield Vapor Cool.	13532-3507-1-3 -5-7	Al Aly 3003-0 QQ-A 250-2
Shield Assy No. 2	13532-2804-1 -3	

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Wash. Rad. Shield	118708-1	Dupont "Vespel" SP-1 Polymide Resin
Shield Assy No 3	13432-2805-1	
	-3	
Tube Vapor Cooled	13532-3514-3	Cres 304L Annealed MB0160-007
Spider Assy Beam	13532-3524-1	Alaly 2014 7351 AMS4014
	-3	
	-1-3	
Insl. Shield	13532-3539-1-3	Type E Glass Fiber & Type 700 Binder (Owens-Corning)
	-1-5	
Spacer Tens:Strap	13532-3547-1	Alaly 7075-T6 QQ-A-250/12
Probe & Heater	13532-2801-1	
Probe Assy	13532-2802-1	
	-3	
Tube Vent	13532-3502-3	Cres 304L Annealed MB0160-007
Conduit-Wire	13532-3503-3	Cres 304L Annealed MB0160-007
Adpt Assy Press-Ves	135321-2813-1	
Adpt Plate	13532-3809-1	Cres 304L Annealed MB0160-020
Adpt Flange	13532-3810-1	5AL-2.5 SN ELI-Titanium (BS13768)
Jt-Trans Cres-Tit.	13532-3205-5	Cres 304L Annealed SST MB0160-020
	-7	SAL-2.5 SN ELI TI ALY (BS13769)
Plate Mount Elect	13532-3802-1	Cres 304L Annealed MB0160-020
Tube Fill Line	13532-3522-3	Cres 304L Annealed MB0160-007
Filter Element	13532-4504-11	See Page 11
Wash.-Teflon	13532-3520-1	Teflon Rod MIL-P-19468
Adpt.-Teflon	13532-3525-1	Teflon Rod MIL-P-19468 GPS
	-3	
Tube-Fill to QTY Sensor	13532-3526-3	Cres 304L Annealed MB0160-007
Probe Qty & Sensor See Sheets No. 5, 6, & 7	13532-4502-3	

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Heater Assy Fan	13532-2515-1	Same Matl as O_2 Except as in TLD on Fan Assy-Motor 13532-4505
Heater Assy Fan	13532-2052-5	Cres SH MIL-S-6721 Comp. Tl.
	-7	Cres SH MIL-S-6721 Comp. Tl.
	-9	Copper Tinned SH QQ-C-576 Soft Annealed Cold Rolled
	-11	Teflon Rod MIL-P-19468
	-45	Teflon TFE

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Simmonds Probe		
Tubing	398269	Titanium 5AL-2.5 SN BS13769 BS13768
Wire	398262	Grade "A" Spring Phosphor Bronze MIL-W-16602
Wire	398261	Grade "A" Spring Phosphor Bronze MIL-W-16602
Rivet Semi-Tubular	398254	1100-H14 Alum-QQ-A-430
Solder	398274	60 SN-40PB Alloy QQ-A-571
Teflon, Bar Stock	398386	25% Glass Fibre Filled TFE Teflon
Terminal-400 Cycle	398203	1100-H14 Alum Alloy ASTM MB3178-55T
Support Sleeve Assy-Bottom	398194	
Plug, Inner Tube	398387	25% Glass Fibre Filled Teflon TFE
Terminal, Coax	398202	Brass Half Hard Comp 1 QQ-B-6136
Cable 4 Conductor	398562	MIL-W-16878
Cable 2 Conductor	398563	Type E
Inner Tube Assy	398210-03009	
Outer Tube Assy	466004	
Tube-Outer	398206-03009	Alum Alloy 6064-T6 WW-T-70016 d
Sleeve Support-Top	466011	Cres 304L-M105-4043
Sleeve Insulator-Bottom	398184	25% Glass Fibre Filled TFE Teflon

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Bracket, Strain Relief	398217	Alum-3003-0 QQA359
Sensor, Temperature Resistance Type	466001	
Transmitter-Density Sensor-Supercritical	391093-03009	
Rivet, Solid Universal Head, Modified	398193-002	Alum 1100-MS2024-70A3-4
Tubing, Alum	398189	Alum ASTM 3210-59T 6061-T832
Tubing-Teflon	398157	25% Glass Fibre Filled TFE Teflon
Rivet, Semi-Tubular	398167	Alum-3003-0-QQA-359
Tubing	466012	304L Cres M105-4043
Eyelet, Flat Flanged	398171	1100-H14 Alum Alloy ASTM MB3178-55T
Tubing, Alum	398188	6061-T6 Al Aly-WW-T-70016d
Spacer, Sleeve	398173	25% Glass Filled Fibre Filled TFE Teflon
Spacer	398172	
Rod, Teflon	398155	
Rod, Teflon	398161	
Rivet, Semi-Tubular	398166	3003-0 Alum QQ-A-359
Rod, Teflon	398192	25% Glass Fibre Filled TFE Teflon
Rivet, Solid Universal Head Modified	398204	2117 Al Aly MS20470A02-3

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047) - Continued

Part Name	Part Number	Material
Sheet, Brass	398271	Brass, Half Hard Comp 1 QQ-B-6136
Wire, Rivet, Alum	398268	1100-H14 Al Aly QQ-A-430
Sheet, Alum	398270	3003-0 Alum. QQ-A-357
Grommet	398218-001 -002	25% Glass Fibre Filled TFE Teflon
Solder	398263	60 SN - 40 PB Aly Core 66 Flux 44 Resin
Sleeve	398283	ASTM Size D Thin Wall TFE Extruded Teflon Sleeving-MIL-I-22129
Flux-Resin	398288	Rosin Base Type-A MIL-I-14256

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part name	Part number	Material
Tube assy fan	13532-2516-1	
Element heater	13532-4510-1	Same mat'l as element in the O_2 tank
Nozzle assy heater	13532-2054-1	Assembly
Nozzle	-2054-3	Cres SH MIL-S-6721 comp T1
Sleeve	-2054-5	Cres tube 321 MIL-T-8808 type I
Tube motor case	13532-3136-1	Cres 321 AMS5645
	-3136-3	Cres 321 AMS5645
Support motor lwr	13532-3137-1	Cres 302 MIL-S-7720 cond A (C)
Support motor upr	13532-3138-3	Cres 302 MIL-S-7720 cond A (C)
Tube heater	13532-3529-1	Cres 321 MIL-T-8808 type I
Tube fan htr	13532-2053-15	Cres 321 MIL-T-8808 type I
Support	-2053-21	Cres SH MIL-S-6721 comp T1
Tube assy	-2053-29	(Consists of -15 & -21 above)
Blind rivet	13532-3091-1	Al aly comp 2117 QQ-A-430
	-3091-3	Al aly comp 2117 QQ-A-430
Screw machine	13532-3099-1	Cres 302 cond A QQ-S-763
	-3099-3	Cres 302 cond A QQ-S-763
Bolt	13532-3104-9	Cres 302 cond A QQ-S-763 or as specified in NAS501
Wire safety	13532-3110-1	Cres 304 form I cond A QQ-W-423
Rivet 100° csk	13532-3119-1	Al aly comp 2117-T4 QQ-A-430
Screw cap	13532-3139-3	302 or 304 cond A QQ-S-763 or as specified in NA51351
Doubler thermo.	13532-3162-2	Al aly fed QQ-A-327 T6
Nut self lock	13532-4052-1	Elastic stop nut P/N 1803-40
	-4052-3	Elastic stop nut P/N 1803-02
Fan assy-motor	13532-4505-1	H_2 motor same as O_2 except stator assy has RML wire
Thermostat H_2 and O_2	13532-4506-1	Same mat'l as O_2

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST (ME282-0047)- Continued

Part name	Part number	Material
Shell-outer	13532-2501-1	Cameron Forging P/N 61598-1
		Titanium (SAL 2.5 SN?) (BS13869)
Cap pinchoff tube	13532-3551-1	Assy.
Body	-3551-3	6061T6 Alum
Cap	-3551-5	6061T6 Alum
Disconnect fill & purge	13532-4009-	Assy
Plate ident.	13532-3168-	8015 Minnesota Mine Mfg.
Placard	118703-	
Pump assy vac-ion	13532-2527-1-3	304 cres. ASTM-A-269
	-5-9	
Detail parts	13532-3569-1	Cres. 304L annealed SST MB0160-020
	-3	5AL-2.5 SN Eli Ti alloy BS13769
Brkt assy vac-ion	13532-2528-1	Assembly
	-3	6061-T6 Al QQ-A-250/11
	-5	6061-T6 Al QQ-A-250/11
	Sub-assy -7	
	-9	6061-T6 Al QQ-A-250/11
Vac-ion pump append	13532-4072-5	Purchased from Varian Associates Palo Alto, Calif. — Mat'l same as O_2
	-15	
	-21	
Converter-volt	13532-4074-7	Purchased from Transformer Electronics Co., Boulder, Colo. (Mat'l same as O_2)
Case assy-potting	13532-2706-3	Cres. 304L QQ-S-766 cond A
	-5	Cres. 304L QQ-S-766 cond A
	-9	Cres. 304L QQ-S-766 cond A
	Sub-assy -13	
	Sub-assy -19	
	-21	Cres. 304L QQ-S-766 cond A

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part name	Part number	Material
Clip tube	13532-3550-1	Al 6061-T6 QQ-A-250/11
	-3	Al 6061-T6 QQ-A-250/11
	-5	Al 1100-0 QQ-A-250/1
	-7	ASTM-B-338 61T GR2 soft annealed titanium
Shield assy-heat	13532-2523-7	Titanium annealed AMS4901
	-9	Titanium annealed AMS4901
	-11	Titanium ASTM B-338 61T GRII
	-13	Titanium ASTM B-338 61T GRII
	-15	Titanium annealed AMS4901
	-17	Coml pure titanium AMS 4900
	-18	Coml pure titanium AMS 4900
	-19	Titanium annealed AMS 4901
Ring.	13532-2707-3	Mat'l same as O_2
Harness assy	13532-2704-5	
Plug-elect	13532-4509	Purchased from Physical Science Corp. Arcadia, Calif. P/N 5573 or 61

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part name	Part Number		Material
	BAC P/N	VACCO P/N	
VACCO filter BAC P/N 13532-4504			
Loading Mandrel-filter	13532-4504-1	81436	300 series cres
Disc & sleeve assy		61148	304 cres
Disc-compressor	13532-4504-3	61141	304 cres
Seal	13532-4504-5	61140	Teflon
Compressor washer	13532-4504-7	61142	304 cres
Element tube	13532-4504-1	62080	304 cres

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number		Material
Wiring Harness	13532-2709	(A)	Teflon TFE Type E AWG # 14 Ht. Shrink, Tubing.
		(B)	Wire AWG # 22 Teflon Coated MIL-W-16878 Type E, E Modified
		(C)	Plug - Make From PTS06A-14 915 (Bendix Corp. Sidney, N. Y.)
		(D)	Terminal - Make From 328472 Post insulated AWG # 20 Stud Size No. 10 (American Pancor Inc., Havertown, Penn.)
		(E)	Placard CP 1000 (Transformer Electronics Boulder, Colo.)
		(F)	Weld Wire MIL-R-5031 Class 16 ER308ELC
		(G)	Potting Boot for Shell Size 8 Recept. Nylon Threaded (Bendix Corp., Sidney, N. Y.)
		(H)	Shielding 1/8 in. Braided Tinned Copper (P/N1390 Consolidated Wire & Associate Co. Chicago, Ill.)
		(I)	AN735-4 Clamp AN735-12 Clamp
		(J)	AN3C-3A Screw
		(K)	79NTM-02 Nut
		(L)	Volseal (Johns-Manville Chicago, Ill.)
		(M)	Apiezon m (Johns-Manville Chicago, Ill.)

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
Wiring Harness	13532-2709 cont. (N)	MS21044C06 Nut
	(O)	AN960C67 Washer
	(P)	NAS 1593-114 O-Ring
	(Q)	AN960C10L Washer
	(R)	RTV 108 Potting (G.E. Waterford, N. J.)
		General Notes:
		Solder per B514244 Solder per MIL-S-6872 Use Matl per FED QQ-S-571 Comp. SN60, type S
MS20995-C20	Lockwire	
CL-2-C-120	Cable	
7649-6	Terminal	
MS20426AD3	Rivet	
NAS1068C3	Nut Plate	
MS27039-C1	Screw	
NAS1022	Nut	
LB0170-126CL. II	Weld Wire	
QQ-R-566A-4043	Weld Wire	
NAS1351C3H8	Screw	

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
QQ-S-571 SN60	Solder	
MIL-F14256	Flux	
MS204335F3	Rivet	
10-285909-143	Ring Potting Boot	
10-150913-14	Potting Boot	
2850 FT	Stycast	
24LV	Catalyst	
D-103	Solder Sleeve	
1390	Shielding Copper	
LB0170-126CL.I	Weld Wire	
MIL-R-5031CL.16	Weld Wire	
MS21209-F1-20	Insert	
C12043-BE-12-27	Speed Nut	
C12043-BE-012-27	Speed Nut	
1000-X17-BC	Snap Ring	
MS20470A3	Rivet	
MF-1031-3	Anchor Nut	

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Continued

Part Name	Part Number	Material
TA731TH	Clamp Tubing	
MS21288-1.6	Bolt	
NAS1351	Screw Cap	
NAS1291	Nut, Self-Locking	
NAS1633	Screw	
S11214-111	O-Ring	
FED-Q-F-499	Flux	
FEDQQ-S-561 CL. II	Braze Matl. Silver Braze	
MIL-R-5031B Type 2	Weld Wire	
MIL-E-19933A	Weld Wire	
NAS560-CK3-2	Screw	
TF552TSS-3T	Clamp	
MIL-W-16878M - Pure ni Type E	Wire Teflon	
Type E #12 Clear	Tubing Heat Shrink	
Type E #14 White	Tubing Heat Shrink	
FEDQQ-S-571 Type AR	Solder	
MMS-N306A Type 822	Drilube	
MS17821-4-9	Tie, Self Locking	
QQ-571-SN60-WARPZ	Solder	
MIL-F-14256	Flux	
MS27039-C1-08	Screw	
TA716WT-D-4T	Clamp	
MIL-L-7178 #509	Lacquer, Red	
MS51045-19	Set Screw	

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047) - Continued

Part Name	Part Number	Material
Miscellaneous Material & Applicable Specs other than the detail parts description		
H_2 Tank Assy	13532-1504	Clean Per Bac Spec BS13879
		Clean Per Bac Spec BS13779
Shield Assy	13532-2523	Clean Per Bac Spec BS13879
Tube Assy	13532-3519	Bac BS13879
Valve Assy Disc.	13532-2810	
Adpt Assy Vent. Disc.	13532-2814	Clean Per BS13779
		Clean Per BS13779
Adpt Assy Fill Disc.	13532-2808	Clean Per BS13879
Insl Instl H_2 Tank	13532-2800	Bac 13879
		Bac 13879
Shield Assy No. 2	13532-2804	Bac 13779
		Bac 13879
Shield Assy No. 3	13532-2805	Bac 13779
Probe & Heater Instl.	13532-2801	Drilube as Reqd See Page 14
		Bac 13779 & 13879
Heater Assy Fan Mtr	13532-2052	Bac 13779, Drilube See Page 14
		Silver Braze See Page 14
Tube Assy Fan Mtr	13532-2053	Bac 13779
		Silver Braze See Page 14

TABLE 3.2.1.1 H_2 TANK ASSY MATERIALS LIST(ME282-0047)- Concluded

Part Name	Part Number	Material
Ring Assy	13532-2807	Clean Surfaces in contact with H_2 Per BS13779. Vacuum Clean BS13879
Adapter Assy	13532-2809	Vacuum Clean BS13879 H_2 Surfaces clean BS13779
Valve Assy	13532-2811	H_2 Surfaces Clean BS13779 Vacuum Clean BS13879
Press Vessel Assy	13532-2501	H_2 Surfaces Clean BS13779
Beam Assy #1	13532-2505	Vacuum Clean BS13879
Strap Assy	13532-2512	Vacuum Clean BS13879
Heater Assy Fan	13532-2515	Solder Wire to Terminals Per NPC200-4 Suppl'td by MSC-ASPO-56A & NAA Attachment O_2 & H_2 Surfaces Clean Per BS13779 Solder Per MIL-5-6872
Tube Assy Fan	13532-2516	O_2 & H_2 Surfaces Clean Per BS13779 Braze per MIL-B-7883
Pump Assy Vac-Ion	13532-2527	Vacuum Clean BS13879
Shield Assy Heat	13532-2523	Vacuum Clean BS13879
Converter Volt	13532-4074	Coating Per MIL-C-5541 Type II, Grade C, Class I
Tank Hemis Inner	13532-3120	H_2 Surfaces Clean BS13779

3.2.2 FUEL CELLS

The fuel cells contain three pressure vessels: the gaseous nitrogen (GN_2) supply bottle, the fuel cell pressure shell which contains the reactant element and individual cells, and the glycol accumulation. Figure 3.2.2.1 is a simplified schematic of the fuel cell and GN_2 supply.

The GN_2 supply tank contains nitrogen at 1500 psi. It is used to supply nitrogen to the fuel cell pressure shell where a 53 psi atmosphere is maintained. This is accomplished through a regulator in the feed line. The regulator controls the pressure in the fuel cell pressure shell by either providing more nitrogen from the supply tank or by venting the fuel cell pressure shell as required.

The GN_2 tank is a spherical tank 6.1 inches in diameter made of 0.075 inch Titanium AMS4910. The tank is mounted on the fuel cell frame above the fuel cell pressure shell. This tank has no internal or external components. The characteristics of this tank are given in Table 2.0.

The fuel cell pressure shell is a cylindrical vessel with dished and flanged ends. It is 14.6 inches in diameter and 24 inches long. It is made of Al-10 Titanium with walls of 0.022 inches and ends of 0.015 inches. This pressure shell is designed to a burst pressure of 265 psi. An N_2 regulator failure would dump the entire GN_2 tank and result in a pressure of 160 psi which is not high enough to burst the fuel cell pressure shell. This pressure shell is covered with gold mylar insulation and has no external components. It contains the 31 electricity-producing reactant cells and a hydrogen by-pass valve and regenerator. Figure 3.2.2.2 is a drawing of the fuel cell module showing the pressure shell.

The fuel cell glycol accumulator is a cylindrical tank with a nominal operating pressure of 53 psia. It contains a butyl rubber bladder to separate the water glycol mixture from the nitrogen which is used as a reference pressure. Figure 3.2.2.3 is a drawing of the glycol accumulator. There are no electrical components in or on the glycol accumulator tank.

All of these pressure vessels are acceptable for their present applications as they have an adequate factor of safety and there are no significant sources of pressure increase except to the fuel cell shell. A failed open O_2 regulator (discussed in 3.2.3.2.4) will result in an overpressure condition which causes the gasket in the shell joint to fail resulting in loss of the fuel cell due to leakage. This is considered acceptable as discussed in 3.2.3.2.4.

3.2.3 EPS O_2 LINE COMPONENTS

Evaluations of the EPS O_2 line components considered the following items:

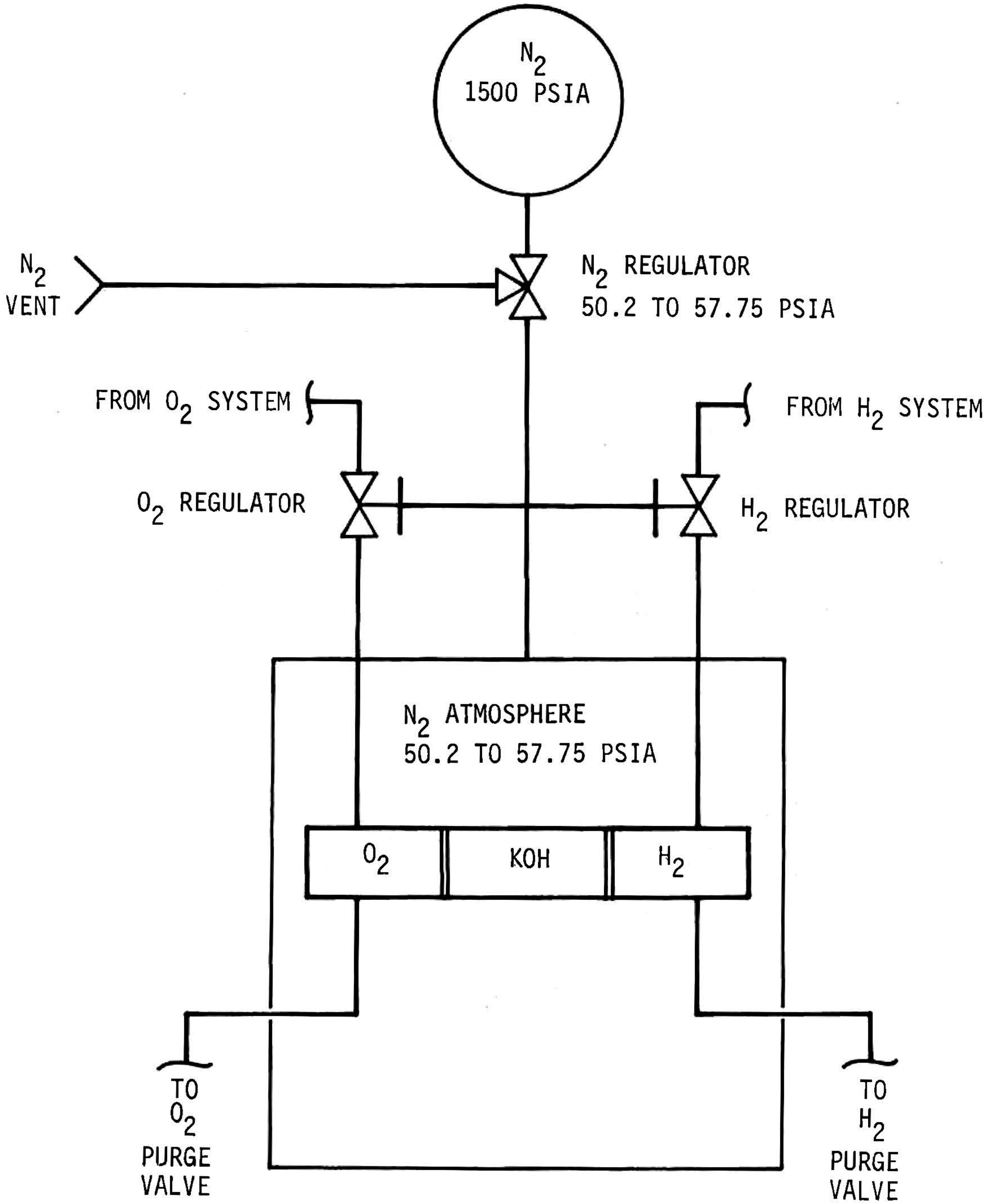


FIGURE 3.2.2.1. FUEL CELL SCHEMATIC.

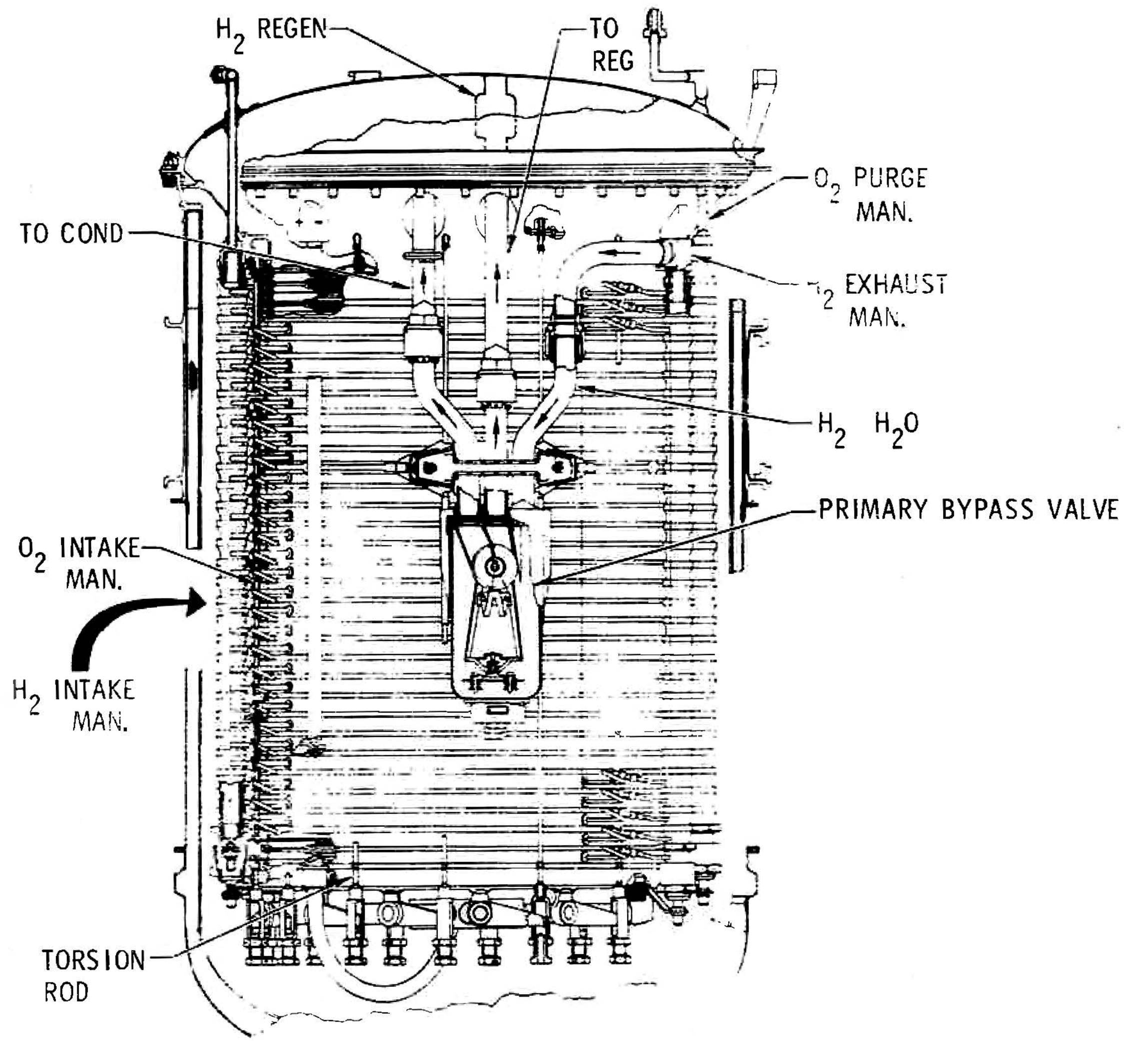


FIGURE 8.3.2.2. FUEL CELL MODULE

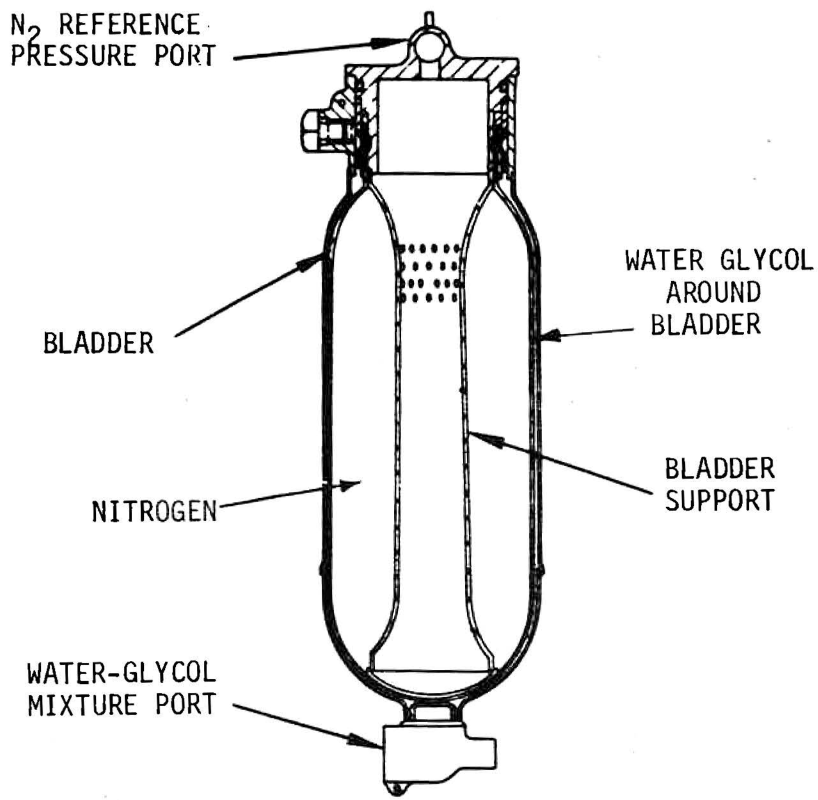


FIGURE 3.2.2.3. FUEL CELL GLYCOL ACCUMULATOR.

a. O_2 System Valve Module (ME 284-0290-001) which contains 2 relief valves, 1 check valve, 2 pressure transducers and 2 pressure switches.

b. Inline Filter (ME 286-0036-0002).

c. Fuel Cell Valve Module (ME 284-0289-001) which contains 3 solenoid valves and 2 check valves.

d. O_2 Flow Sensor (ME 449-0015).

e. Fuel Cell Reactant Pressure Transfucer.

f. O_2 Reactant Pressure Regulator.

g. O_2 Purge Valve.

The fluid schematic for these components is shown in Figure 3.2.3.1. The invidivual components are described in the following sections.

3.2.3.1 Materials

The materials used for the EPS O_2 line components are listed by component in Table 3.2.3.1. The following components were found to have nonmetallic materials in the indicated application in contact with the O_2:

a. Fuel Cell Valve Module - Solenoid Valves - Teflon and KEL-F are used in direct contact with the high pressure O_2. Teflon is used as wire insulation, heat shrink tubing, and tape to form insulation for the armature coil. KEL-F is used as a ball and adapter for actuation of a micro switch. (Micro-switch is a purchased part and its composition was not available.) The check valves in this module do not use any nonmetallic parts.

b. O_2 Purge Valve - "Vitron" is used as "O" rings and red silicone rubber is used as a seat.

c. O_2 Reactant Pressure Regulator - Fluoro carbon and silicone rubber are used as "O" rings and fluoro carbon rubber is used as a poppet.

Impact applications of nonmetallics were found as follows:

a. Fuel Cell Valve Module - Impact of KEL-F ball on KEL-F adapter and impact of stainless steel armature plunger on KEL-F ball. Both of these occur in high pressure O_2.

b. O_2 Reactant Pressure Regulator - Impact of fluoro carbon rubber poppet on stainless steel seat on both the inlet and vent ports. Both of these occur in high pressure O_2.

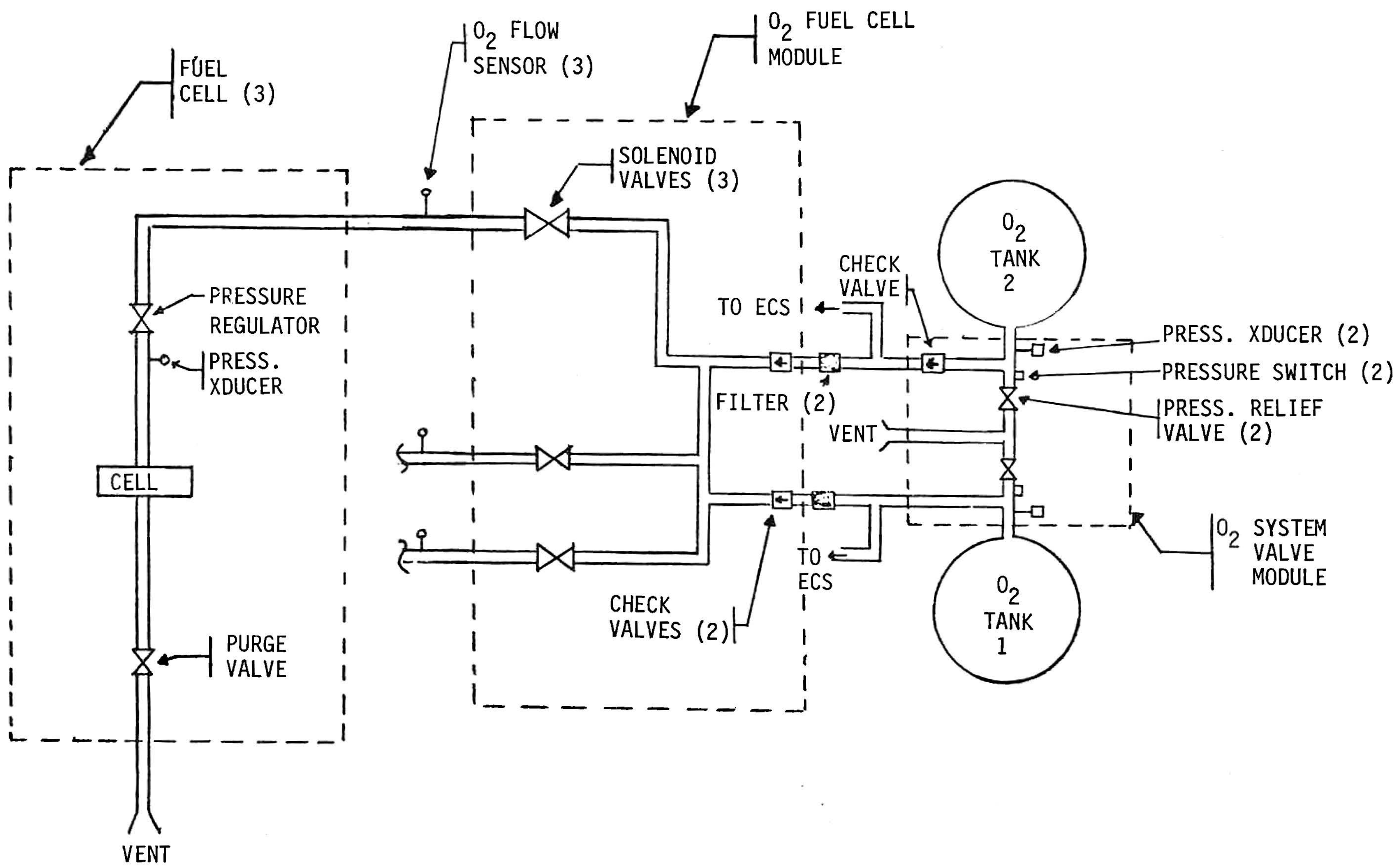


FIGURE 3.2.3.1. EPS O_2 LINE COMPONENTS FLUID SCHEMATIC.

TABLE 3.2.3.1 - EPS O_2 LINE COMPONENTS MATERIALS LIST

O_2 SYSTEM VALVE MODULE (PARKER)
(ME 284-0290-001)

PART NAME	VENDOR PART NUMBER	MATERIAL
O_2 Sys Valve Mod	5630061M5	
O_2 Sys Valve & Module Assy	5631030	
Mounting Lug, Relief Valve	5661031	2024-T351
Mounting Lug S.O.V.	5661020	2024-T351
Mounting Lug P.T.	5661019	2024-T351
Mounting Lug P.S.	5661021	2024-T351
Strap	5631571-1	304L-CRES
Spring, Tubular	5631510	A286-CRES
Spring, Tubular	5631511	A286-CRES
Tension Device	5631795	17-4-PH
Pin	5631812	302-CRES
Spring Supt Ring	5631790	17-4-PH
Spring, Inner	5632167	RS-120-Ti
Spring, Outer	5631791	RS-120-Ti
Saddle, Lower	5631559-1	321-CRES
Saddle, Upper	5631559-2	321-CRES
Nut, Lock	FN1216-1032	Vendor Item
Insulator	5641116	Mylar-Type A
Saddle Screw	5631574-1	17-4-PH
Locking, Device	5631576	303-CRES
Expander, Saddle	5631575	17-4-PH
Shim, Manifold	5631805-1 thru 4	301/302-CRES
Name Plate	5661034	2024-T3
Saddle, Upper	5631550-1	2024-T351
Rivet	AN442A2-4	321-CRES
Clamp	MS21919H5	
Lock Wire	MS20995C32	
Tape		471 Teflon
Saddle, Lower	5631559-2	321-CRES
Wire		16GA MIL-W-16878 Nickel Plated Conductor Teflon Coated Skylastic, Dow Corning
Potting		KTV-601
Primer	SS-4101	G.E. SS-4101
Spring, Positioner	5661205	Mylar Type A
O_2 Relief Valve Assy	5661032-1	
Spring, Poppet	5631319	301-CRES
Shim Poppet Seat	5631338-1 thru 3	301/302-CRES
Spring	5631381	302-CRES
Washer	5631342	Mylar Type A

TABLE 3.2.3.1 (Continued)

Washer	NAS620C6	
Screw	MS35275-28	
Support Main	5631343	17-4-PH
Support, Diaphram	5631322	302/304-CRES
Compensator	5631345	2024-T4
Compensator	5631346	1NVAR
Support	5661036	17-4-PH
Shim	5661064	300-CRES
Stop	5661038	2024-T351
Guide	5661039	17-4-PH
Spring	5631352	17-4-PH
Support	5661040	17-4-PH
Shim	5661062-1 thru 7	301/302-CRES
Cap	5661009	2024-T351
Spring	5631356	17-4-PH
Ring	UR-2625	Vendor Part
Shim	5661041-1 thru 6	301/302-CRES
Support	5661063	17-4-PH
Spring	5631359	17-4-PH Dry Film Lube
Shim	5631361	301/302-CRES
Support	5631362	17-4-PH
Support	5631363	17-4-PH
Support	5631364	17-4-PH
Insulator	5631365	17-4-PH
Lock Wire	MS20995C32	
Guide	5631376	17-4-PH
Spacer	5631726	17-4-PH
Spacer	5631727	17-4-PH
Ring, Retainer	5661077	2024-T4/T351
Screw	MS35275-13	
Washer	MS15795-303	
Guide	5632169	Mylar Type A
Spacer	5631806	2024T
Screw	MS35275-33	
Shim	5631279-1 thru 3	301/302-CRES
Spring	5631286	17-7-PH Dry Film Lube
Spring	5631295	17-7-PH Dry Film Lube
<u>Seat & Poppet Assy</u>	5661033-1	
Tube Assy Outlet	5661013	
Tube	5661013-1	304L-CRES
Sleeve	MS20819-4C	
Nut	AN818-4C	
Tube, Inlet	5661035	304L-CRES
Seat	5661333	A286-CRES
<u>Body & Check Valve Assy</u>	5661027	
Tube	5661027-1	304L-CRES
Tube, Inlet	5661082-2	304L-CRES

TABLE 3.2.3.1 (Continued)

Seat	5661088	A286-CRES
Poppet	5661463	A286-CRES
Spring	5631218	302-CRES
Body Manifold Assy	5661079	
Tube	5661079-1	304L-CRES
Sleeve	MS20819-4C	
Nut	AN818-4C	
Manifold, Inlet Assy	5631328	
Manifold	5631328-1	321-CRES
Insert	MS21209F1-15	
Nut	AN818-4C	
Sleeve	AN819-4C	
Plug	5641444	321-CRES
Guide	5661261	301-CRES
*Pressure Switch Assy	5641715	Vendor
Body		304L-CRES
Tube, Inlet		304L-CRES
Diaphragm		17-7-PH
*Pressure Transducer Assy	5630034-3	Vendor
Body		NISPAN "C"
Tube, Inlet		304L-CRES

* ONLY COMPONENTS LISTED ARE THOSE IN CONTACT WITH SYSTEM FLUIDS

O_2 Relief Valve Assy	5661032-2	
Seat Assy	5661033-2**	
Tube	5661013-1	304L-CRES
Nut		
Tube, Inlet	5661035	304L-CRES

** ALL REMAINING PARTS SAME AS 5661032-1 ASSY

Body Assy	5661045	
Body	5661045-1	
Body	5661010	347-CRES
Bellows Assy	5661045-2	
Bellows Assy	5661047	
Bellows	5641310	321-CRES
Seat, Poppet Link	5641311	347-CRES
Shim	5631341	301/302-CRES
Body Assy	5661029	
Body	5661028	321-CRES
Tube, Outlet	5661029-1	304L-CRES
Tube, Inlet	5661082-1	304L-CRES
Nut	AN818-4C	
Sleeve	AN819-4C	
Plug	5641414	321-CRES

TABLE 3.2.3.1 (Continued)

INLINE FILTER (VACCO VALVE CO)
(ME 286-0036-000 2)

Body		304L-CRES
Filter Disc.		304L-CRES

O_2 FUEL CELL VALVE MODULE (PARKER)
(ME 284-0289-001)

Fuel Cell Module Assy Instl	5630046M2	
Fuel Cell Module Assy	5661048	
Shim	5631224	302-CRES
Shim	5631330	301/302-CRES
Spacer	5631329	300 Series CRES
Nut	5661052	321-CRES
Grommet	5631235	Teflon
Shim	5641430	301/302-CRES
Spring	5631211	301-CRES
Poppet	5641463	A286-CRES
Adhesive Tape	471	3M Co.
Potting	123 & 931	EPIBOND 99384
Solder		Sn 30
Wire	5631269-9	MIL-W-16878/4 Nickel Plate
	5631269-10	
	5631269-11	
	5631269-12	
	5631269-13	
	5631269-14	
	5631269-15	
	5631269-16	
	5631269-17	
	5631269-18	
	5631269-19	
	5631269-20	
	5631269-23	
	5631269-24	
Wire	5631269-25	MIL-W-16878/4 Nickel Plate
Body Assy	5661060	
Weldment	5661060-1	
Body	5661060-2	321-CRES
Clip L. H.	5661060-4	321-CRES
Clip R. H.	5661060-5	321-CRES
Sleeve	5661060-6	303-CRES
Forging	5631799	321-CRES
Solenoid Assy	5661053	
Sleeve	5661065	2024-T351
Shell	5641394	Armco Ingot Magnetic

TABLE 3.2.3.1 (Continued)

Spacer	5631492	2024-T351
Connector	5631558	321-CRES
Clip	5661073	301-CRES
Spring	5631237	301-CRES
Tubing HT Shrinkable	FEP 18	Teflon
Tubing HT Shrinkable	FEP 20	Teflon
Solder		Sn 30
Coil Assy	5661072	
Bobbin Assy	5661066	
Bobbin	5661072-1	316-CRES
Teflon		FEP Teflon
Washer	5631434	Sintered Teflon
Solder		Silver
Magnet Wire	30 AWG	Copper
Magnet Wire	26 AWG	Copper
Tape	P-411	Teflon
Tape	FEP 2000 Type A	Teflon
Tubing, HT Shrink	FEP 22	Teflon
Armature & Switch Assy	5661059	
Ball	5631440	KEL-F
Shell	5641398	Armco Ingot Magnetic
Adapter	5631438	KEL-F
Switch	6SM7	Vendor
Shim	5661080	301-CRES
Screw	AN500 AD2-6	
Screw	AN500 AD2-7	
Washer	AN960C2-1	
Washer	AN960C2	
Lock Wire	M520995C-20	
Solder	Easy Flow 45	Silver
Lead Wire	26 AWG Type E	Copper
Tubing HT Shrink	FEP 20	Teflon
Pin, Terminal	R01-040-0565	NIRON
Solder		Sn 30
Gasket	5631439	Teflon
Armature Assy	5661074	
Armature, Close	5641400	416-CRES
Armature, Open	5641401	416-CRES
Spacer	5631230	A286-CRES
Spring	5631218	302-CRES
Spring	5631229	Berylco 25
Rivet	MS206152CU5	
Tube Assy	5661049	
Seat	5661049-1	
Seat	5661051	A286-CRES
Tube	5661049-2	
Tube	5661050	304L-CRES
Sleeve	MS20819-4C	
Nut	AN818-4C	

TABLE 3.2.3.1 (Continued)

Cap Assy	566;081	
Cap	5661075	A286-CRES
Tube	5661050	304L-CRES
Sleeve	MS20819-4C	
Nut	AN818-4C	
Diaphram	5641427	301/302-CRES
Washer	5641428	301-CRES
Seat Assy	5661076	
Poppet	5641426	A286-CRES
Seat	5661037	A286-CRES
	O_2 FLOW SENSOR (ROSEMONT) (ME 449-0015)	
Case Assy	124-80	
Nut, Hex	S-5786	Steel
	S-2192	Loctite
	S-5412	Mylar
	S-2413	Hysol
	S-2414	Hysol
Case	124-151	304-CRES
Plate	124-153	3003-H14
Bracket	124-115	304-CRES
Base	124-60	304-CRES
End Cap & Tube Assy	124-72	
	X-5609	CRES Screen
Tube	124-74	304-CRES
End Cap	124-68	304-CRES
Diffuser Assy	124-71	
Filter	S-4835	
Ring	124-73	304-CRES
Diffuser	124-49	304-CRES
Shunt Tube Assy	124-418	
	X-509	Silver solder 45
	X5815	304-CRES
Tube	124-434	304-CRES
Convection Shield Assy	124-66 & 53	
	S-628	Silvalay 355
	S-94	Cement PBX
	S-828	Ceramic
Convection Shield	124-191	446-CRES
Bell and	124-55	303/304-CRES
Wire	S-334	.0004 Platinum
Wire	S-60	.002 PT
	S-4804	446-CRES
Elbow, Lead	124-150	304-CRES
Lead Tube	124-109	304-CRES

TABLE 3.2.3.1 (Continued)

Heat Link Assy	124-384	
Outlet	124-45	304/321-CRES
Inlet	124-110	304-CRES
Lead Assy	124-111	
Wire	X-59	24K Gold
	X-2484	Ceramic
Wire	X-262	.0125 PT
Insert	X-1273	Ceramic
Tube Assy	510-167	304-CRES
Ring	90082-9 & -19	304-CRES
Bushing, Elbow	124-152	304-CRES
Tube (By-Pass)	124-56	304-CRES

O_2 REACTANT PRESSURE REGULATOR (P&W)

Regulator Assy	607117	
Screw	600024	303-CRES
Spring	600030	302-CRES
Screw	600043	303-CRES
Seat	600026	347-CRES
Lock	600047	321-CRES
Washer	600052	302-CRES
Spring	600029	302-CRES
Tube	600064	321-CRES
Bellows	600950	321-CRES
Bellow Flange	600951	321-CRES
Packing	601591	Fluoro Carbon Rubber
Packing	601604	Silicone Rubber
Molding	603738	Fluoro Carbon Rubber
Rod	603736	303-CRES
Pin	602892	302-CRES
Spring	603243	17-7-PH
Rod	603730	303-CRES
Seat	604560	17-4-PH
Spring	604188	302-CRES
Packing	604566	Fluoro Carbon Rubber
Packing	604567	Fluoro Carbon Rubber
Washer	605205	321-CRES
Nut	605274	A-286-CRES
Stud	605330	AMS 5735
Pin	605331	AMS 5625
Seat	605625	AMS 5445
Filter	605675	Stainless Steel
Collar	605674	321-CRES
Housing	606136	6061-T4
Seat	606155	17-7-PH
Adapter	606413	C120AV T:
Housing	607269	6061-T4
Bellows Flange	607272	AMS 5747

TABLE 3.2.3.1 (Continued)

FUEL CELL REACTANT PRESSURE TRANSDUCER (P&W)
(Complete materials list not available)

Case	Steel
Diaphragm	347-CRES
Wire	Teflon Coated X30-738
Curing Agent	Slygard 182

O_2 PURGE VALVE (P&W)

The purge valve contains the following types of materials:

302, 303, 304, 304L, 321, 347, 430 and 440 CRES Steels
2024-T4 Aluminum Alloy
Red Silicone Rubber (Seat)
Viton (O-rings)
Teflon Coated Wire (MIL-W-16878/48)
Solenoid Coil Contains the following:
  Tape-Permacil P-211
  Varnish GE 220
  Fiberglas Yarn - Huse Liberty EPC 450½
  Sleeving - Bently Harris #20 extra flex
  Wire SML #35 Anaconda
  O-Ring MIC-R-25897
  Diode Potting Compound Dicast 2762

c. O_2 Purge Valve - Impact of stainless steel ball on red silicone rubber seat occurs in the O_2 downstream of the fuel cells (60 psi).

No sliding application occurs in these components. All other usages of nonmetallics in contact with the O_2 are static.

Table 3.2.3.2 provides a summary of the nonmetallic materials used in the O_2 line components and the rationale for acceptance of these applications. MSFC LOX impact data have been considered and MSC is in process of developing the capability to perform impact testing. When MSC data become available, it will be used to support these conclusions. If discrepancies exist, the issue will be reopened at the time the data become available. All of the nonmetallic materials applications listed above are considered conditionally acceptable except for the fuel cell valve module solenoid valves.

3.2.3.2 Mechanical Components

The following components are strictly mechanical:

a. O_2 system valve module relief valves and check valves.

b. Inline filter.

c. Fuel cell valve module check valve.

d. O_2 reactant pressure regulator.

3.2.3.2.1 O_2 System Valve Module

3.2.3.2.1.1 Relief Valves - Parker part number 5661032-1

Figure 3.2.3.2 shows an overall view of the O_2 valve module with relief valves installed. Figure 3.2.3.3 is a cutaway drawing of the relief valve. The relief valve is a differential type designed to be unaffected by back pressure in the downstream plumbing. The valve has temperature compensation and a self-aligning valve seat. The valve consists of an ambient pressure sensing bellows preloaded with a belleville spring, which operates a poppet valve. Full flow pressure is 1010 psig maximum and reseat pressure is 965 psig minimum. The bellows is a potential single point failure which, if failed, would allow the venting of the contents of one of the O_2 tanks. This failure is judged to have a low probability of occurrence since the bellows was development tested for 10,000 cycles at 1000 psi, stroking from 1.129" to 1.114" and back as a component. The relief valve was qualification tested by applying 199 cycles of pressure from 30 to 982 psi and one cycle to crack pressure ($>$ 983 psig), full flow ($<$ 1010 psig) and reseat pressure ($>$ 965 psig). This sequence was repeated until 2400 cycles were applied. Each valve is proofed as a component at 2030 psi and after installation into the

TABLE 3.2.3.2 EPS O_2 LINE COMPONENTS - MATERIALS NORMALLY EXPOSED

SPACECRAFT COMPONENT	EXPOSED MATERIAL	APPLICATION	OXYGEN COMPATIBILITY	RATIONALE	REMARKS
Oxygen System Valve Module					
Pressure Relief Valve	No Nonmetallics exposed				One failure will expose Mylar
Pressure Transducer	No Nonmetallics exposed				One failure will expose additional nonmetallics
Pressure Switch	No Nonmetallics exposed				One failure will expose additional nonmetallics
Check Valve	No Nonmetallics exposed				—
Oxygen Fuel Cell Module					
Check Valve	No Nonmetallics exposed				
Solenoid Valve	Teflon Insulation	Wire Insulation	G	MSC/WSTF Test	These materials associated with electrical current.
	Teflon	Heat Shrink Tube	G	MSC/WSTF Test	
	Teflon FED 2000 Tape	Covers Coils	G	MSC data on teflon	
	Teflon Coating	Coil Coating	G	MSC/WSTF Test	
	P-471 Teflon Tape	Covers Coils	G	MSC Teflon Data	
	Kel-F Seat	Seat	G	MSC/EP	
Fuel Cell					
Pressure Regulator	Viton A	Seat	G	MSC/WSTF	
	Viton A	Seal	G	MSC/WSTF	
	Viton A	Seal	G	MSC/WSTF	
	Viton A	O-Ring	G	MSC/WSTF	
	Silicone Rubber	Packing	G	MSC/WSTF	

*G - Good, P - Poor, U - Unknown Data

TABLE 3.2.3.2 EPS O_2 LINE COMPONENTS - MATERIALS NORMALLY EXPOSED - Concluded

SPACECRAFT COMPONENT	EXPOSED MATERIAL	APPLICATION	OXYGEN COMPATIBILITY	RATIONALE	REMARKS
	TFE Teflon	Gasket	G	MSC/WSTF	
Oxygen Purge Valve	Viton	O-Ring	G	MSC/WSTF	
	Silicone Rubber AMS 3304	Seat	G	DTD 149	
Transducer	No Nonmetallic Materials				
<u>Oxygen Flow Sensor</u>	No Nonmetallic Materials				
<u>Inline Filter</u>	No Nonmetallic Materials				

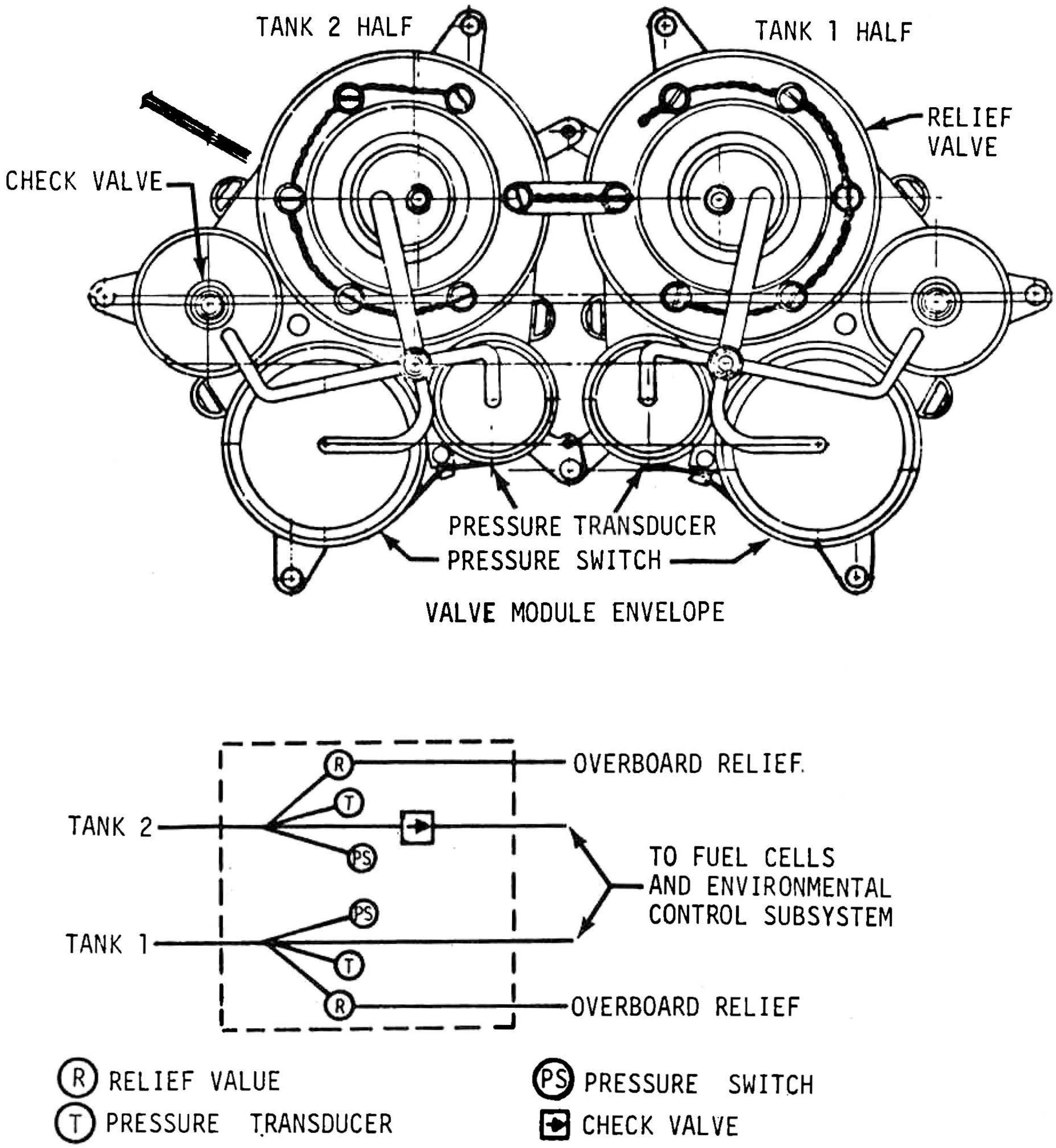


FIGURE 3.2.3.2. O_2 SYSTEM VALVE MODULE

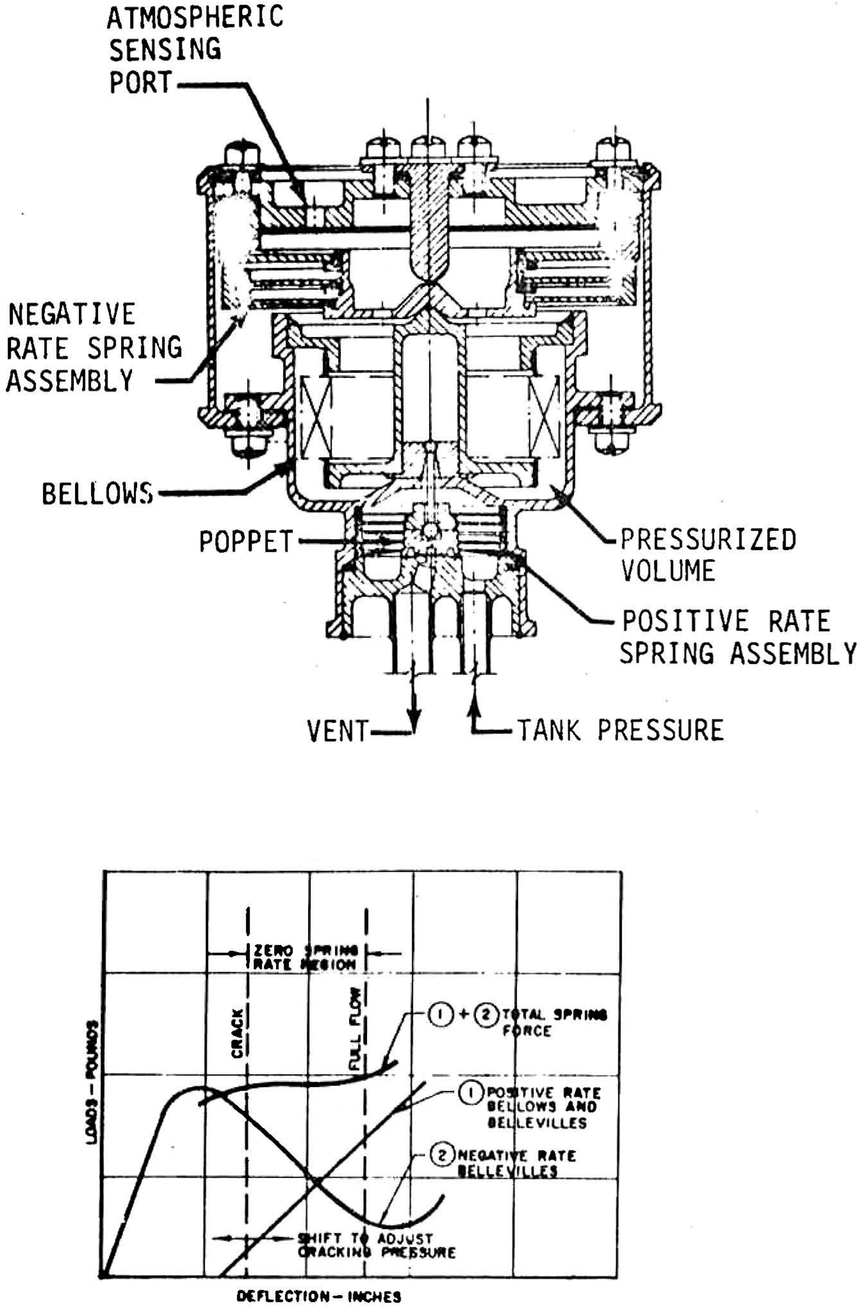


FIGURE 3.2.3.3. O_2 RELIEF VALVE.

system at 1260 to 1310 psi. Because of the test history of this valve and lack of problems associated with its usage, this is considered to be an acceptable single point failure.

3.2.3.2.1.2 Check Valves - Parker part number 5661027-1

Figure 3.2.3.4 is a cutaway drawing at the check valve. The check valve is designed to open at a differential pressure of approximately 1 psia. It has an all stainless steel welded body and a single, spring loaded, poppet with metal to metal seats. It uses no nonmetallic materials.

3.2.3.2.2 Inline filter - (ME 286-0036-002)

The filter consists of a stack of chemically etched discs mounted on a mandrel-like cartridge. The body is welded 304L CRES and the element is 304L CRES. It uses no nonmetallic materials and has no moving parts.

3.2.3.2.3 Fuel Cell Module Check Valve (Parker part number 5661076)

Figure 3.2.3.5 is a cutaway drawing of the check valve. The check valve is designed to open at a differential pressure of approximately 1 psia. The valve contains a main and an auxiliary seat which are spring loaded such that at low flows the auxiliary seat is barely open and catches contaminant particles. During full flow both seats open fully and the high flow velocities carry particles through the valve. The valve contains no nonmetallics and uses metal to metal seats.

3.2.3.2.4 O_2 Reactant Pressure Regulator (P&W part number 607117)

Figure 3.2.3.6 is a cutaway drawing of the regulator. The O_2 reactant regulator is a bellows operated, lever actuated unit which maintains O_2 pressure at a constant prescribed level above the fuel cell nitrogen reference pressure over the full range of gas consumption from zero flow to full power operation plus purge flow. The bellows assembly is composed of two bellows for increased unit reliability. The lever arm is friction damped and actuates a supply and vent valve. The regulator regulates pressure by pressure sensed at the bellows, balanced against spring and regulated N_2 pressure. Error in regulated pressure causes bellows to compress or extend, opening vent or supply valves, respectively, causing regulated pressure to decrease or increase, restoring balance. The regulator characteristics are as follows:

Set Pressure	6.7 to 12.2 (6.2 to 11.7)* psi above reference
Dead Band	0.2 - 0.7 psid
Capacity	2.6 lbs/hr
Upstream Pressure	150 psia (min.)
	1020 psia (max.)

*Applies to power plants P650769 and up

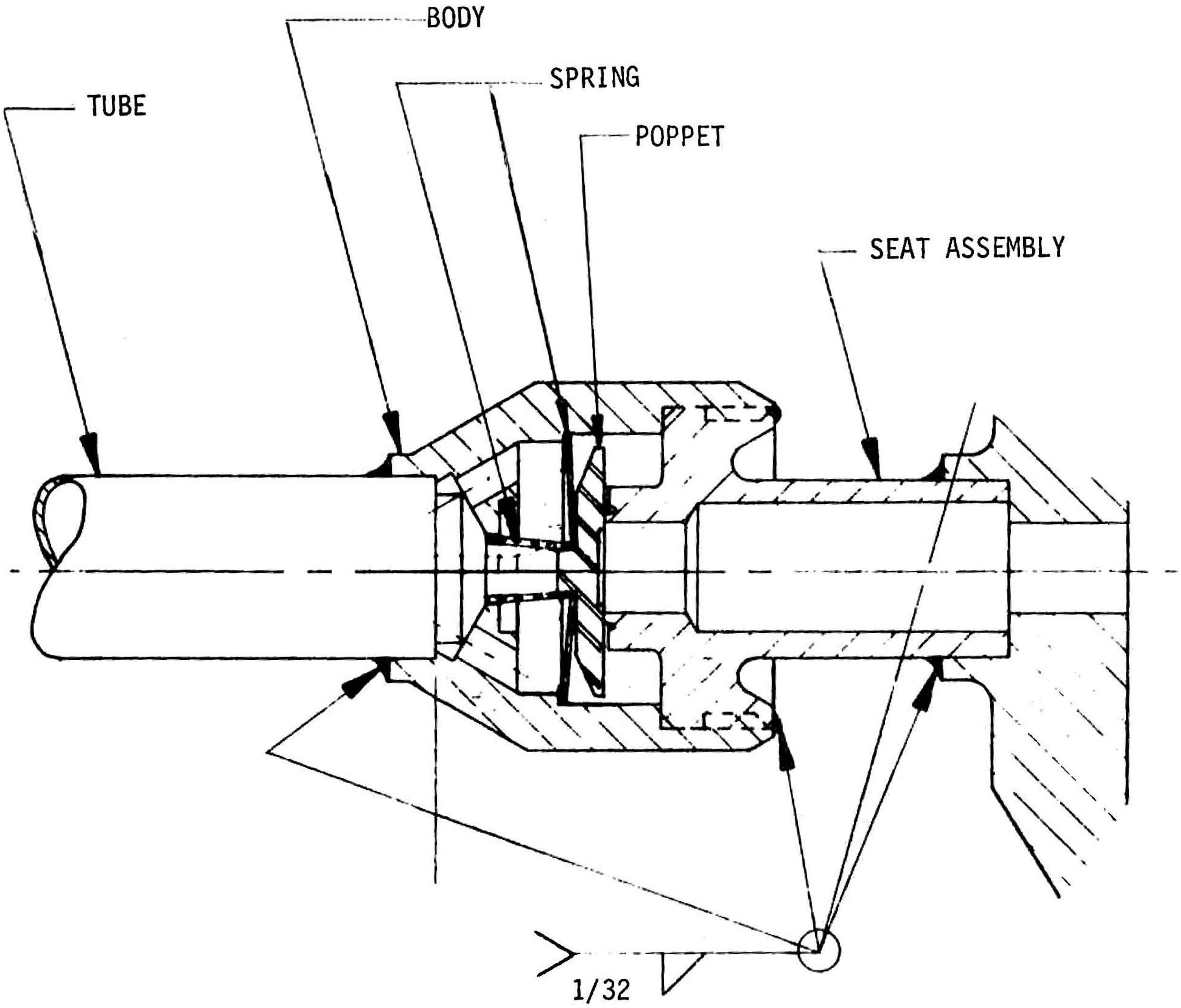
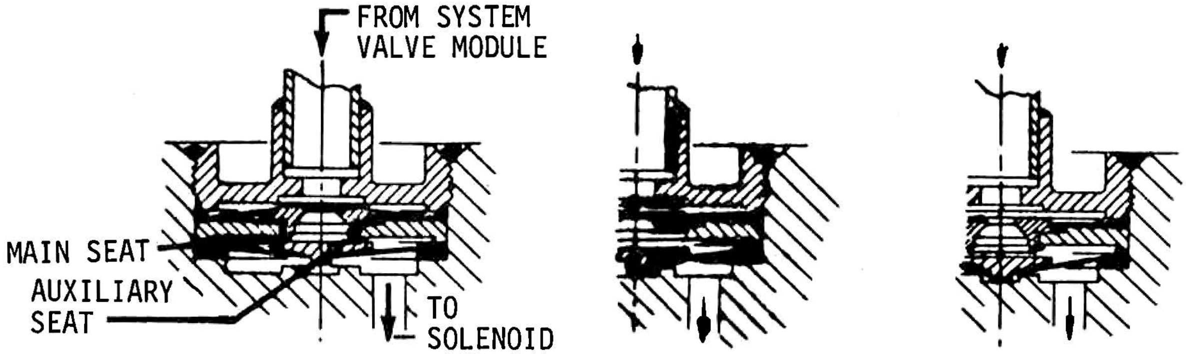


FIGURE 3.2.3.4. O_2 CHECK VALVE.



SEATED - BOTH MAIN AND AUXILIARY SEATS ARE CLOSED

CRACKED - AT LOW FLOWS THE AUXILIARY SEAT IS BARELY OPEN AND CATCHES CONTAMINANT PARTICLES, THE MAIN SEAT IS WIDE OPEN OPEN AND PROTECTED FROM CONTAMINANTS

FULL FLOW - BOTH MAIN AND SECONDARY SEATS ARE WIDE OPEN; THE HIGH FLOW VELOCITIES CARRY PARTICLES THROUGH THE VALVE WITHOUT FOULING THE SEAT

FIGURE 3.2.3.5. FUEL CELL MODULE CHECK VALVE

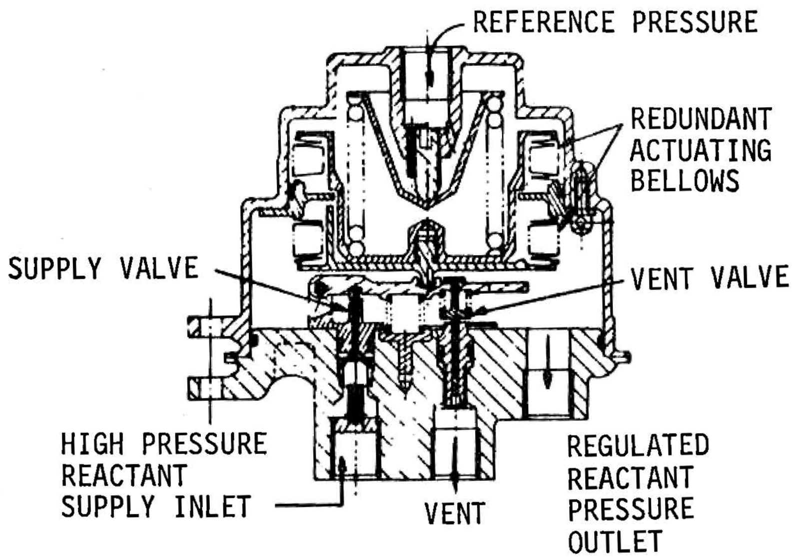


FIGURE 3.2.3.6. O_2 REACTANT PRESSURE REGULATOR.

TABLE 3.2.3.3. EPS O_2 LINE COMPONENTS SUMMARY OF ELECTRICAL CHARACTERISTICS.

COMPONENT		FUNCTION	NORMAL OPERATING ELECTRICAL CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		CIRCUIT PROTECTION PROVISIONS	INTERFACE OF ELECTRICAL ELEMENTS OF COMPONENT WITH FLUID
			VOLTS	AMPERES	PRESSURE (PSI)	TEMPERATURE, (°F)		
O_2 SYSTEM VALVE MODULE	PRESSURE TRANSDUCER	SENSES O_2 TANK PRESSURE	0-5 SIGNAL 28 POWER	0.05	935	0	1/4 AMPERE FUSE DIODED PARALLEL 5 AMPERES C.B. FROM BUSES A AND B	NONE
	PRESSURE SWITCH	ACTUATES MOTOR SWITCH TO CONTROL FANS AND HEATERS	28	5.0	935	0	DIODED PARALLEL 10 AMPERES FUSES FROM BUSES A AND B	NONE
O_2 FLOW TRANSDUCER		SENSES FLOW OF O_2 TO FUEL CELLS	0-5 SIGNAL 28 POWER	0.14	935	70	1/4 AMPERES FUSE DIODED PARALLEL 5 AMPERES C.B. FROM BUSES A AND B	NONE
FUEL CELL PRESSURE TRANSDUCER		SENSES F/C REACTANT PRESSURE	0-5 SIGNAL 28 POWER	0.05	61.5	70	1/4 AMPERES FUSE 5 AMPERES C.B. FROM BUSES A AND B	NONE
FUEL CELL PURGE VALVE		VENTS O_2 FROM F/C	28	0.22	61.5	70	DIODED PARALLEL 5 AMPERES C.B. FROM BUSES A AND B	NONE
FUEL CELL VALVE MODULE SOLENOID VALVE		PERMITS O_2 FLOW TO F/C	28	MAXIMUM -IN RUSH 10 STEADY STATE 2	935	0-70	10 AMPERES C.B.	SEE PARAGRAPH 3.2.3.3.2.

This regulator is single stage and is a potential single point failure which, if it occurred, would overpressurize the fuel cell causing it to fail. The possible failure modes of the regulator are a stuck open inlet poppet due to freezing or a binding in the lever pivot member. If this failure occurs, it will cause an overpressurization of a fuel cell causing its pressure shell to fail (failure history of the F/C shell indicates its failure mode to be a failed gasket which produces a leak) causing the loss of one fuel cell and partial contents of the storage system. This regulator has experienced 60,000 hours of operation during field operations, 120,000 hours of operation during development and in-house tests and 11,500 hours of component type tests. The postulated mode of failure has never occurred. This is considered to be very unlikely failure and therefore is an acceptable single point failure.

3.2.3.3 Electrical Components

The following components have both electrical and mechanical functions:

a. O_2 system valve module pressure switch and pressure transducer

b. Fuel cell valve module solenoid valves

c. O_2 flow sensor

d. Fuel cell reactant pressure transducer

e. O_2 purge valve

The electrical characteristics and circuit protection provision for these components are given in Table 3.2.3.3.

3.2.3.3.1 O_2 System Valve Module

3.2.3.3.1.1 Pressure Switch - Parker part number 5641715

Figure 3.2.3.7 is a cutaway drawing of the pressure switch. This part is purchased by Parker from Southwest, Ind. Its internal materials and detailed arrangement were not available. The pressure switch is a double pole, single throw absolute device. A positive reference pressure, typically between 4 to 10 psia, is used to trim the mechanical trip mechanism to obtain the required absolute switch actuation settings. A circular convoluted diaphragm senses tank pressure and actuates a toggle mechanism which provides switching to drive a motor switch. The motor driven switch controls power to both the tank heaters and destratification fans. Review of the information available on this switch indicates that a diaphragm failure will expose nonmetallic materials and the electrical elements of the switch to the high pressure O_2. Qualification testing of this component required exposure to 5000 on-off cycles. This switch has never experienced a disphragm failure. This

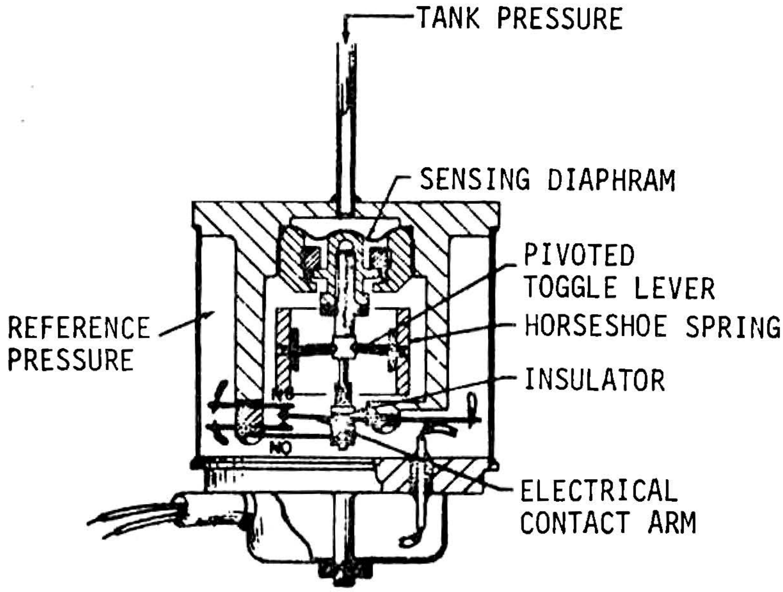


FIGURE 3.2.3.7. O_2 VALVE MODULE PRESSURE SWITCH.

structural failure mode is considered to have a low prabability of occurrence and therefore is acceptable. If the additional data to be provided by NR prove this conclusion to be invalid, the issue will be reopened at that time.

3.2.3.3.1.2 Pressure Transducer - Parker part number 5630034-3

Figure 3.2.3.8 is a drawing of the pressure transducer. This part is purchased by Parker from Dyna-Sciences, Inc. and its internal materials and detailed arrangement were not available. The pressure transducer is an absolute (vacuum reference) device. The transducer consists of a silicone pickup comprised of four sensors mounted on a damped edge diaphragm and an integral signal conditioner. The unit senses tank pressure through the discharge line from the tank. The signal conditioner output is a 0-5 VDC analog output which is linearly proportioned to tank pressure. Review of the information available on this transducer indicates that a diaphragm failure will expose nonmetallic materials and the electrical elements (sensors as a minimum) to the high pressure O_2. Since this failure is structural in nature and since the transducer is exposed to proof pressure during system proof testing, it is considered to have a low likelihood of occurrence and is an acceptable single point failure. If additional data to be provided by NR prove this conclusion to be invalid, the issue will be reopened at that time.

3.2.3.3.2 Fuel Cell Valve Module Solenoid Valves

Figure 3.2.3.9 is a cutaway drawing of the solenoid valve. The solenoid valve employs a poppet-seat arrangement. The poppet is actuated by a magnetic armature which is suspended on a belleville spring. One solenoid is used to open the valve; another to close it. A snap-over-center belleville spring guides the armatures and latches the valve open or closed. A switch to indicate valve closed position is incorporated. The valve opens against pressure and pressure helps seal the valve against leakage in the normal flow direction. The electrical elements of this valve and nonmetallic materials are in direct contact with the high pressure O_2. The solenoid coils are made on a 316 CRES bobbin which is coated on its inside with .0025 FEP teflon. Multi-teflon coated 30 gage cupron resistance wire and multi-teflon coated 30 gage copper magnet wire are wound on the bobbin to form the coil. The outside of the coil windings is covered with a layer of P-411 teflon tape and a layer of FEP 2000 type "A" teflon tape. Type E teflon coated 26 gage copper wire is spliced to the 30 gage wires to form the power leads for the coil The high pressure O_2 is in contact with these solenoid coils and their power leads. The position indicating parts of this valve consists of a KEL-F ball, a KEL-F adapter and a micro switch, all three of which are in direct contact with the high pressure O_2. The power leads for the solenoids and the leads for the position indication passes through the valve body via glass header type pass through. The joint of the lead to the pass-through stud is covered with heat shrinkable teflon tubing. This is also in contact with the O_2.

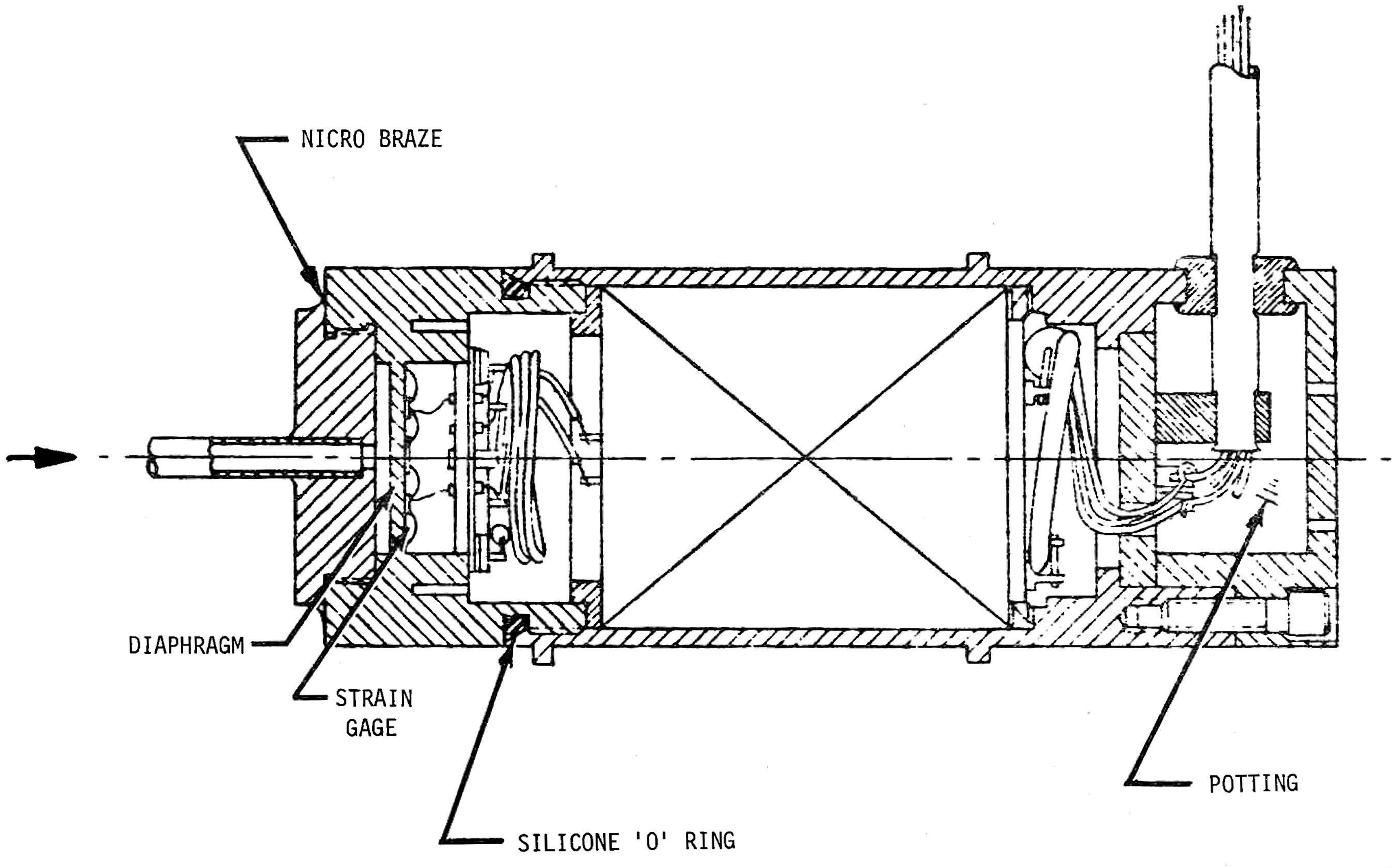


FIGURE 3.2.3.8. O_2 VALVE MODULE PRESSURE TRANSDUCER.

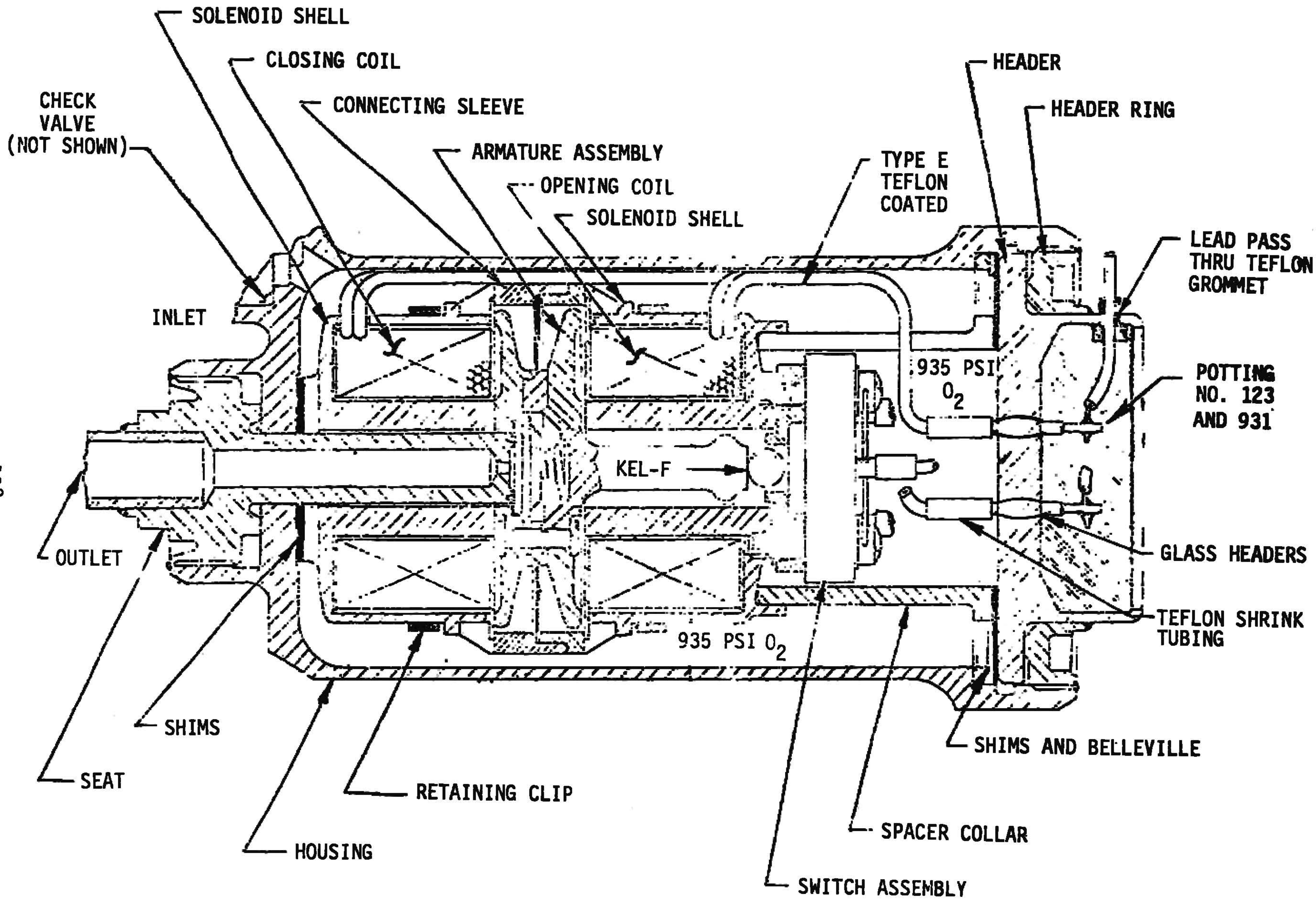


FIGURE 3.2.3.9. FUEL CELL VALVE MODULE SOLENOID VALVE.

Figure 3.2.3.10 is a circuit diagram for this valve. Power to maintain latching is applied to the solenoid during boost and other assigned times and is current limited to approximately .5 amps. Normal solenoid operations use a steady current of 2 amps with maximum in-rush current of 10 amps. Assuming a direct short, the energy available for 200% overload is (28 volts) (20 amps) (40 seconds) = 22800 joules and for a 600% overload is (28 volts) (60 amps) (1.75 seconds) = 2940 joules.

All of the elements are available within this valve to make it a potential **fire** hazard to the subsystem and spacecraft and therefore should be re-designed.

3.2.3.3.3 O_2 Flow Sensor (ME 449-0015)

Figure 3.2.3.11 is a drawing of the flow sensor. The flow sensor is a capillary tube hot wire anemometer. The only nonmetallics used on this component are on the outside of the case elements or in the signal conditioning. To expose any of them to the O_2 would require two structural failures.

3.2.3.3.4 Fuel Cell Reactant Pressure Transducer

Figure 3.2.3.12 is a drawing of the transducer. Complete identification of the internal materials and its detailed arrangement were not available. The transducer is an absolute device utilizing bonded strain gages on a beam assembly which is strained via link and piston attached to a diaphragm which interfaces with the pressurized fluid. Review of available information indicates that a diaphragm failure will expose nonmetallic materials and the electrical elements (strain gages as a minimum) to the O_2. During fuel cell operation, this transducer has experienced similar exposure as the regulator discussed in 3.2.3.2.4. This postulated failure mode is structural in nature and has never been experienced in usage. This is considered a very unlikely failure and therefore is an acceptable single point failure.

3.2.3.3.5 O_2 Purge Valve

Figure 3.2.3.13 is a cutaway drawing of this valve. This valve employs "O" rings of viton and red silicone rubber as the valve seat in direct contact with the O_2. Detailed engineering drawings of this valve were not available to allow assessment of postulated failures; however, Pratt & Whitney Aircraft was asked to make this determination. Their response indicates that two failures are required to introduce additional nonmetallic materials or electrical elements to the O_2. This valve is considered acceptable.

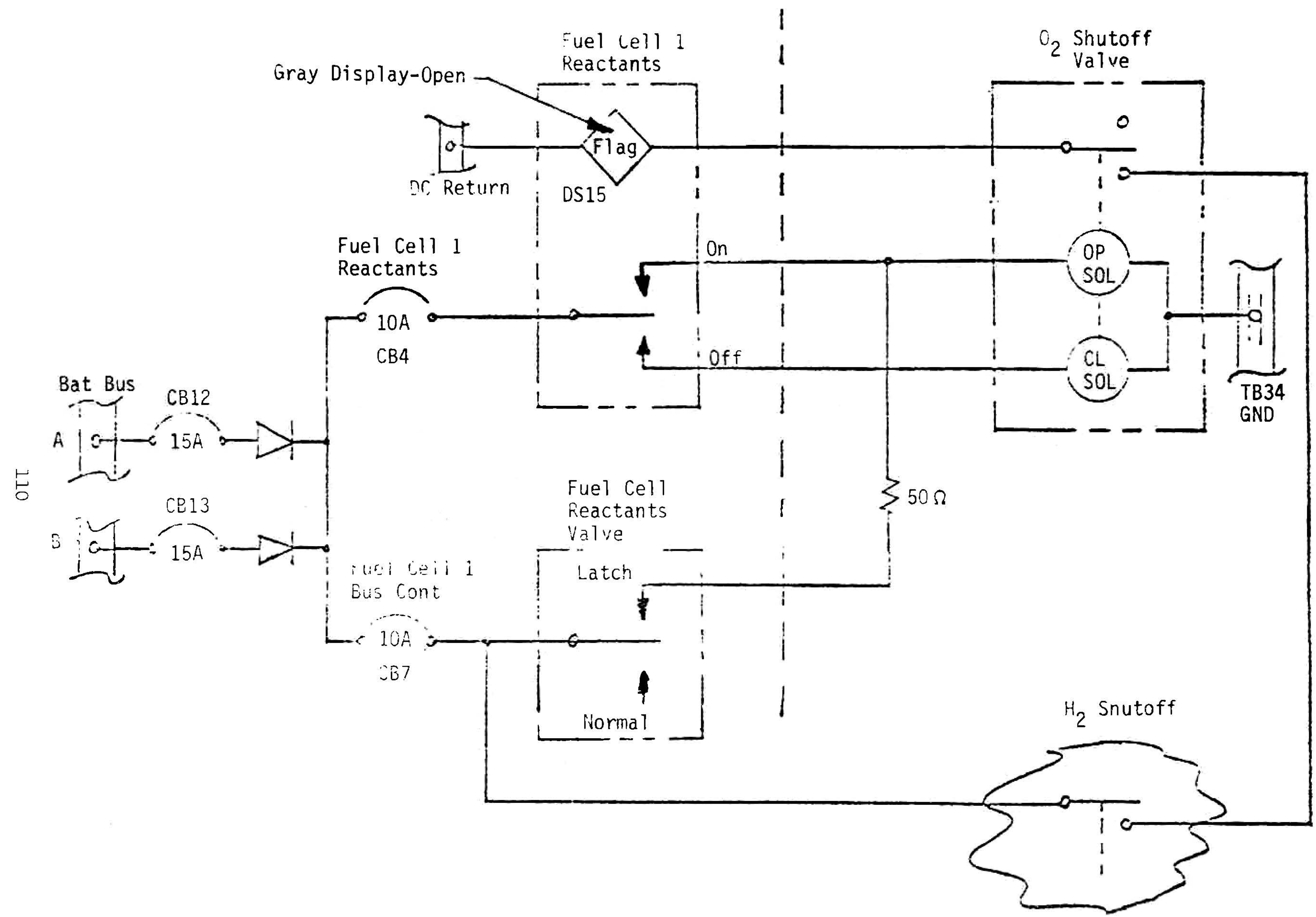


Figure 3.2.3.10. - Solenoid Valve Circuit Diagram

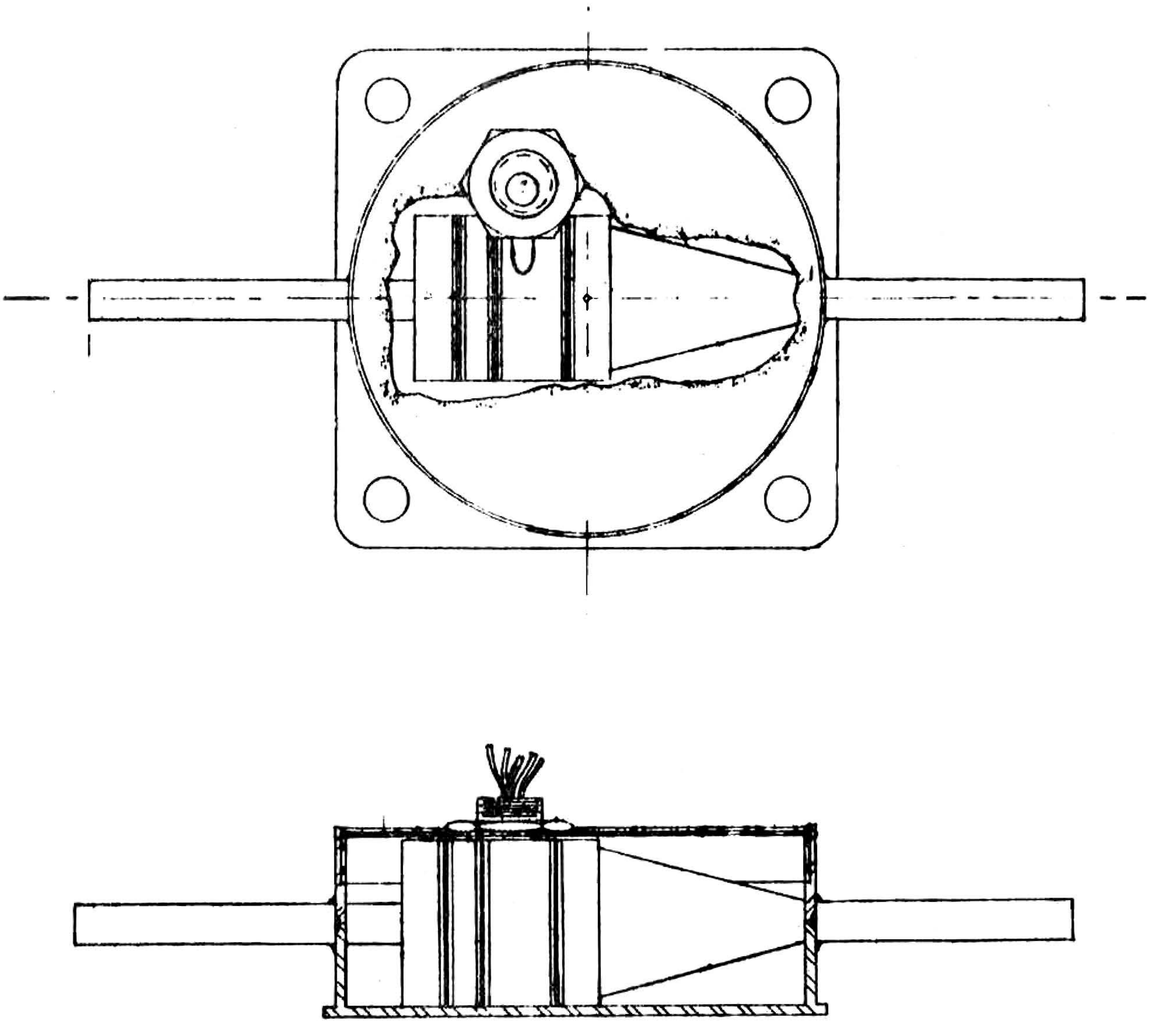


FIGURE 3.2.3.11. O_2 FLOW SENSOR.

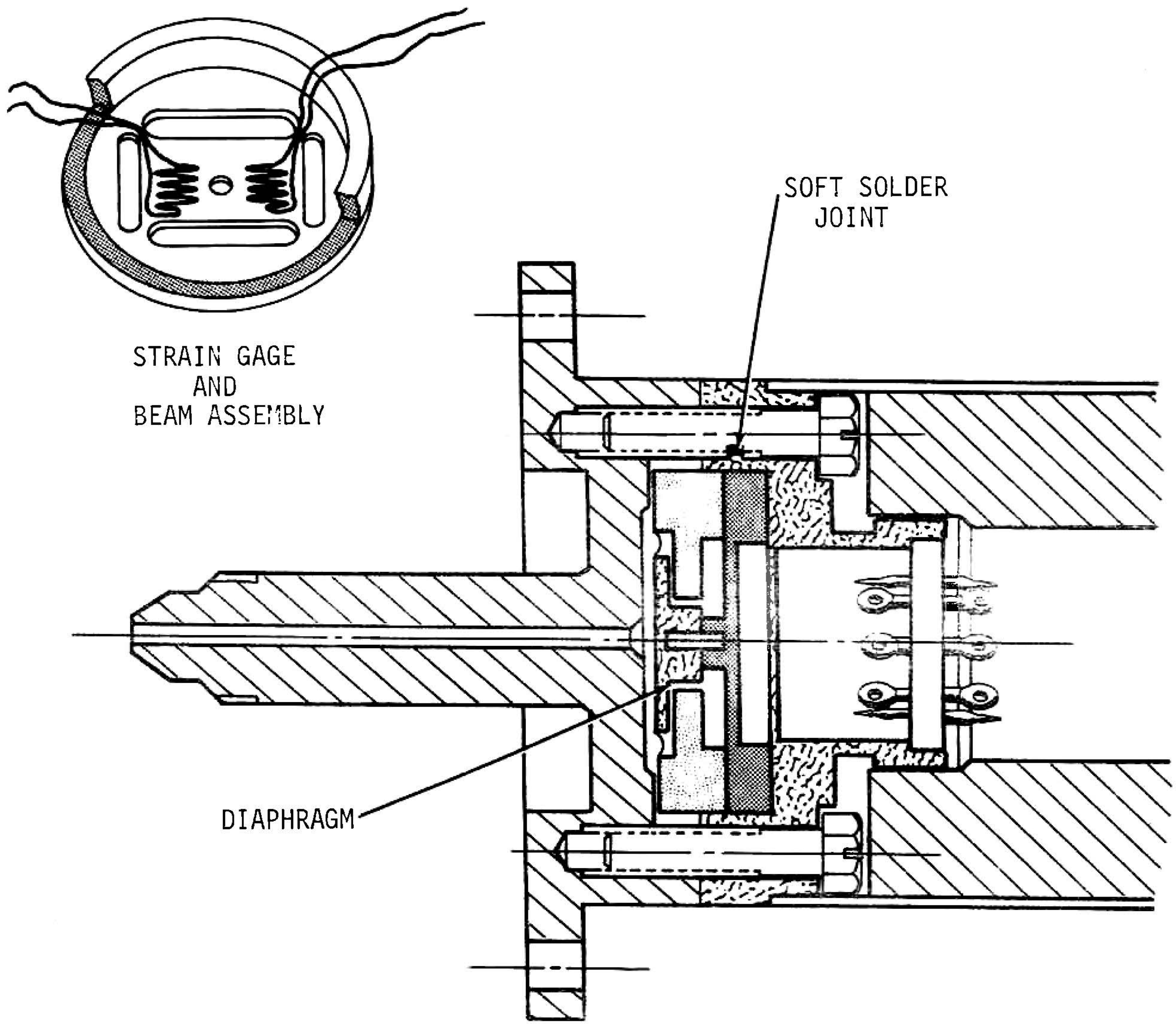


FIGURE 3.2.3.12. FUEL CELL REACTANT PRESSURE TRANSDUCER.

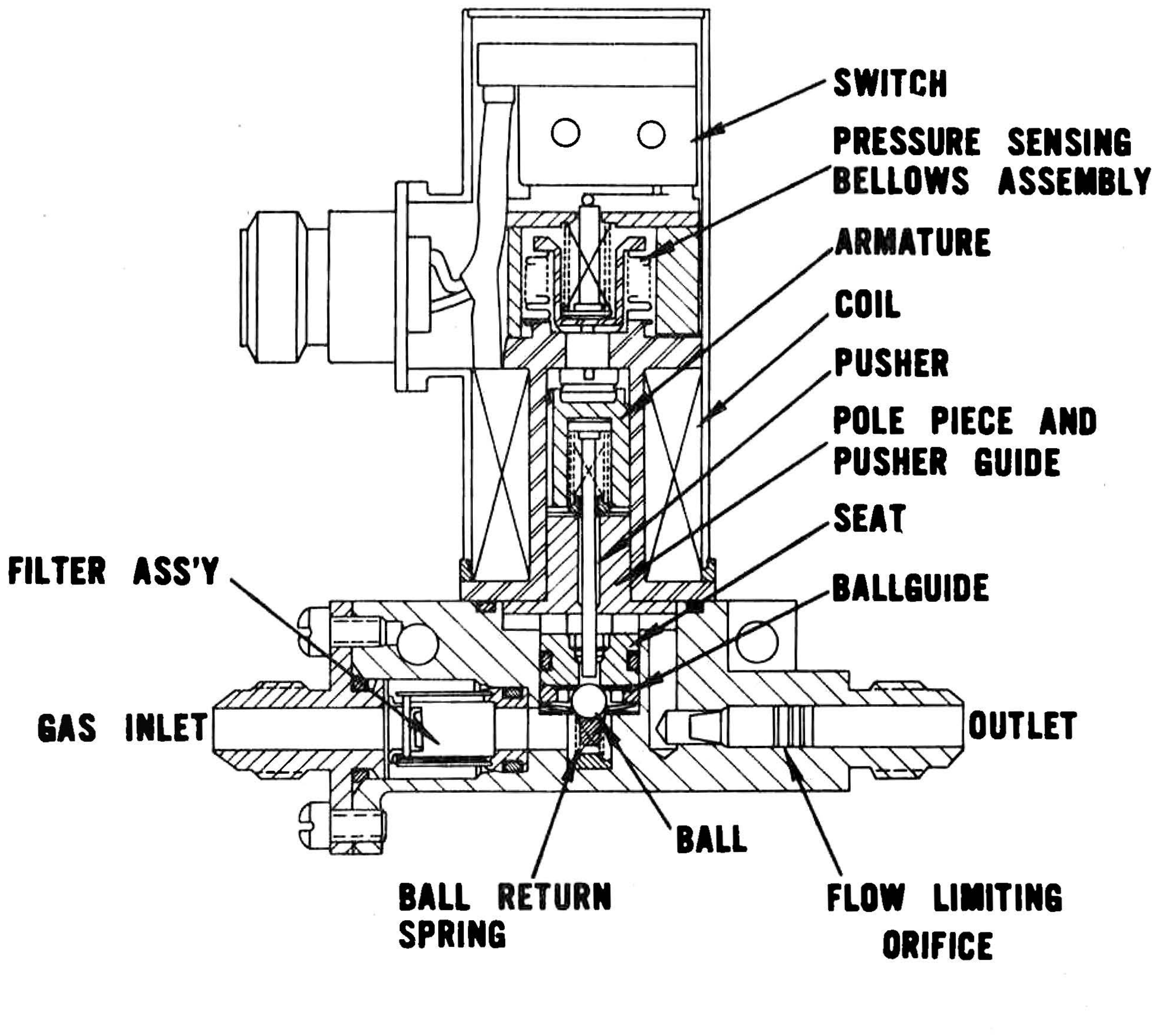


FIGURE 3.2.3.13. O_2 PURGE VALVE

3.2.4 COMMAND MODULE BATTERIES

The CM contains five silver oxide-zinc batteries. Three are rechargeable entry batteries and two are pyro batteries. They use an electrolyte of KOH in 40% solution.

3.2.4.1 ENTRY BATTERIES

The CM entry batteries are constructed of twenty individual cells with their own plastic case. These cells are encased in a plexiglass type case and wrapped with layers of resin impregnated fiberglass cloth.

The entry battery cells are each vented within the battery assembly which is in turn connected to a manifold. The manifold has instrumentation which can sense from 0 to 20 PSIA. This manifold can be manually vented to local ambient through the water overboard dump nozzle.

Each cell incorporates electrolyte entrapment provisions and gas (H_2) pressure relief valves which relieve at 30 ± 10 PSIG.

ENTRY BATTERY PERFORMANCE CHARACTERISTICS

Rated Capacity per Battery	Open Circuit Voltage	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
40 amp-hrs (25 ampere rate for 1 hr & 2A to 40 AH	37.2 VDC nom (37.1 VDC in flight)	29 VDC (25 amps load)	27 vdc (25 amps. load)	50° to $110^{\circ}F$

3.2.4.2 PYRO BATTERIES

The CM pyro batteries utilize a G-10 laminated glass epoxy case and cover.

The battery case has a relief valve which operates at 30 ± 5 PSI differential pressure. The battery cells each have relief valves which operate at about 0 to 2 psi differential pressure.

Each cell incorporates electrolyte entrapment, and the battery assembly vents directly into the lower equipment bay.

PYRO BATTERY PERFORMANCE CHARACTERISTICS

Rated Capacity per Battery	Open Circuit Voltage	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
0.75 amp-hrs (75 amps for 36 seconds)	37.2 vdc nom. (37.1 vdc in flight)	23 vdc (75 amps load)	20 vdc (75 amps load) (32 vdc open circuit)	30° to 110°F

3.2.4.3 SUBSYSTEM ASSESSMENT

Qualification tests of the entry batteries did not include a pressurization burst test of the battery case. Because the upper limit of the specified operation of the pressure relief valve is 40 psid, the case should be capable of withstanding that pressure with some additional margin of safety. Two individual cells were tested by the vendors. Failure pressures were in excess of 50 psid.

The procurement specification (MC 461-0012) requires the vendor to verify the function of each cell as to containment of pressure up to 30 ± 10 psid and relief of over pressure. The acceptance test procedures in ATP-202A, 2/12/69, are not completely responsive to this. They call out separate tests of the cell case at one atmosphere, and functional test of the relief valve. Each delivered cell case is not verified to be capable of containing 40 psi which is the highest pressure to be expected.

Qualification tests of the pyro batteries did not include a pressurization burst test of the battery case. The upper limit of the specified operation of the pressure relief valve is 35 psid, therefore the pyro battery case must be capable of withstanding that pressure with some margin of safety. The specification (MC 461-0007) requires the vendor to perform pressurization tests of each cell to operational specified pressures.

The vendor is also required to test the integrity of the seal to specified pressures prior to delivery to NR. This implies a test of the case to withstand pressures of 35 psid. The test procedures are similar to those of ATP-202A for the entry batteries, and do not require verification of pressure retention up to 30 ± 5 psid with subsequent relief.

The limited test history of these batteries indicates that there is little danger of explosive burst of the case, but that the case will split at a joint. The result of a CM battery failure would be to release H_2 gas into the CM cabin and provide a means of escape for free KOH. Each cell of the entry battery contains about 2cc and each cell of the pyro battery contain about 1/2 cc of KOH. The hazard of the H_2 released is small because the volume of the CM is large with respect to the amount of H_2 generated under normal conditions.

If KOH solution escapes into the cabin area, the effect would be equivalent to the presence of any caustic solution (as Lye) free to move about in a zero-G environment; i.e., physiological skin damage accompanied by stinging sensation and eye damage. However, this is very unlikely since the batteries are located behind a close out panel of the lower equipment bay which would impeed the movement of the KOH. Any leakage from a battery case could corrode the aluminum structure in this area.

E&D has been requested to perform burst test of entry and pyro batteries to determine the capability of the design to perform its intended function and determine capability to subject each individual battery to a proof pressure test to insure required manufacturing perfection is being obtained.

Proof pressure testing to 1.33 times maximum relief valve setting of all batteries is desirable, but if the burst test show the batteries do not have this capability, then the relief valves should be adjusted within the necessary operational limits to allow a minimum proof of 1.1 times maximum relief valve setting.

3.3 CM RCS

3.3.1 FLUID SYSTEM DESCRIPTION

The CM/RCS provides the impulse for attitude control to maintain the required CM entry attitude after separation from the SM. During entry the CM/RCS provides impulse to control roll attitude and to damp roll, pitch, and yaw rates. During aborts, the CM/RCS provides the impulse for three-axis rotation and/or rate damping as required to control CM attitude. Propellant depletion is accomplished prior to CM touchdown for all mission modes. The CM/RCS consists of two independent pulse-modulated, helium-pressure-fed, positive-propellant-expulsion, rocket propulsion systems as shown schematically in Figure 3.3.1. Earth storable hypergolic fuel and oxidizer are used as the propellants. Each subsystem (designated Assembly 1 and Assembly 2) consists of the following:

a. Helium pressurization subassembly

b. Propellant supply and distribution subassembly

c. Six reaction control rocket engines

d. Monitor and control provisions

e. Propellant burn/dump provisions

f. Servicing provisions

The engines are mounted internally, with the engine nozzle extensions scarfed to match the CM heat shield mold line. Figure 3.3.2 shows the arrangement of the system in the CM.

3.3.2 CM RCS MATERIALS

The materials of construction of the components in the CM RCS are listed, by component, below. Table 3.3.1 defines the compatibility of materials used in the ozidizer system and the rationale for their acceptance. Table 3.3.2 defines the compatibility of materials which may be contacted by the oxidizer in the event of a single failure, spill, or leakage. Table 3.3.3 defines the compatibility of materials used in the fuel system and the rationale for their acceptance. Table 3.3.4 defines the compatibility of materials which may be contacted by the fuel in the event of a single failure, spill, or leakage.

3.3.2.1 Oxidizer System

a. Oxidizer tank: titanium, aluminum (6061), stainless steel (304, 304L, 347, A286), TEFLON (TFE, FEP).

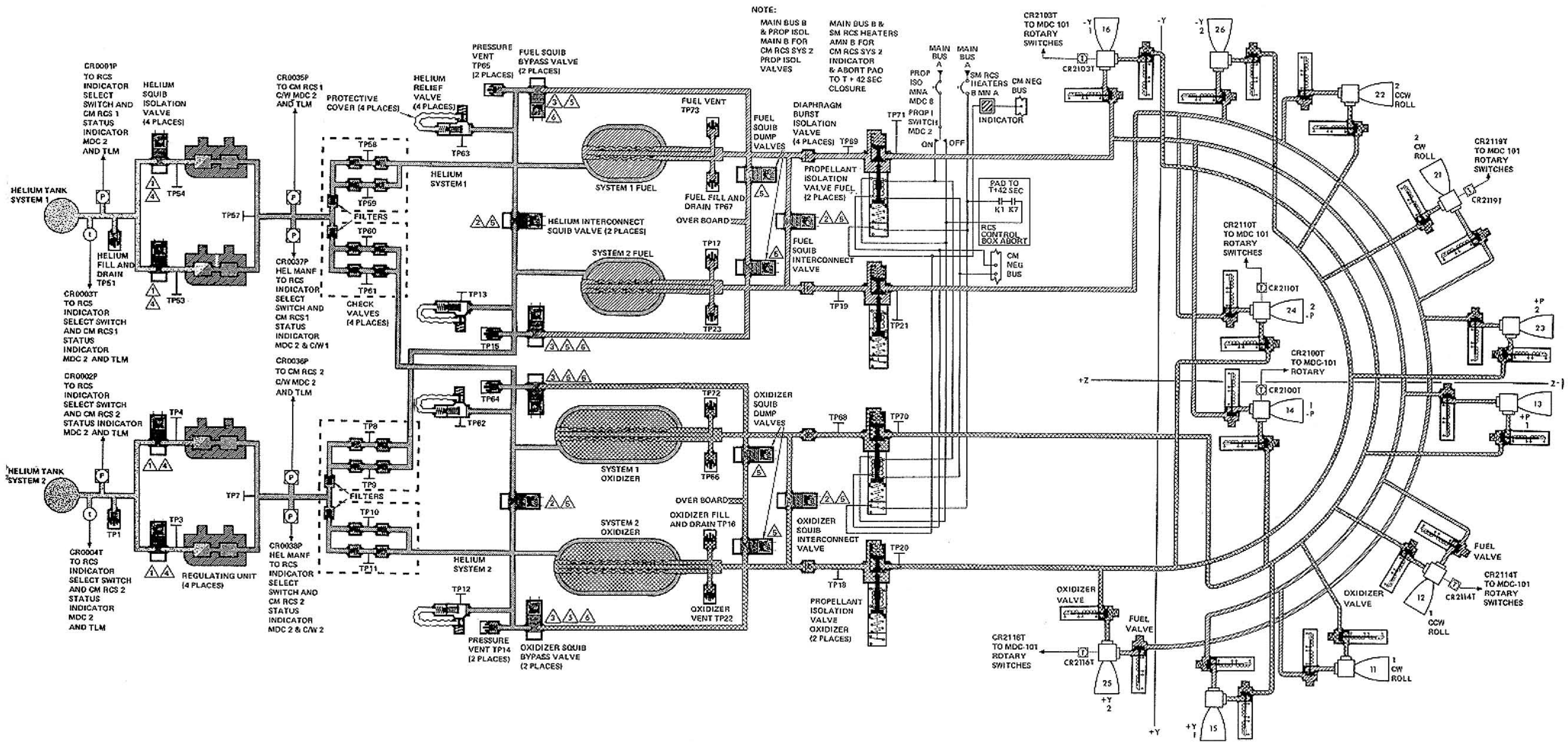


FIGURE 3.3.1. CM RCS FUNCTIONAL FLOW DIAGRAM.

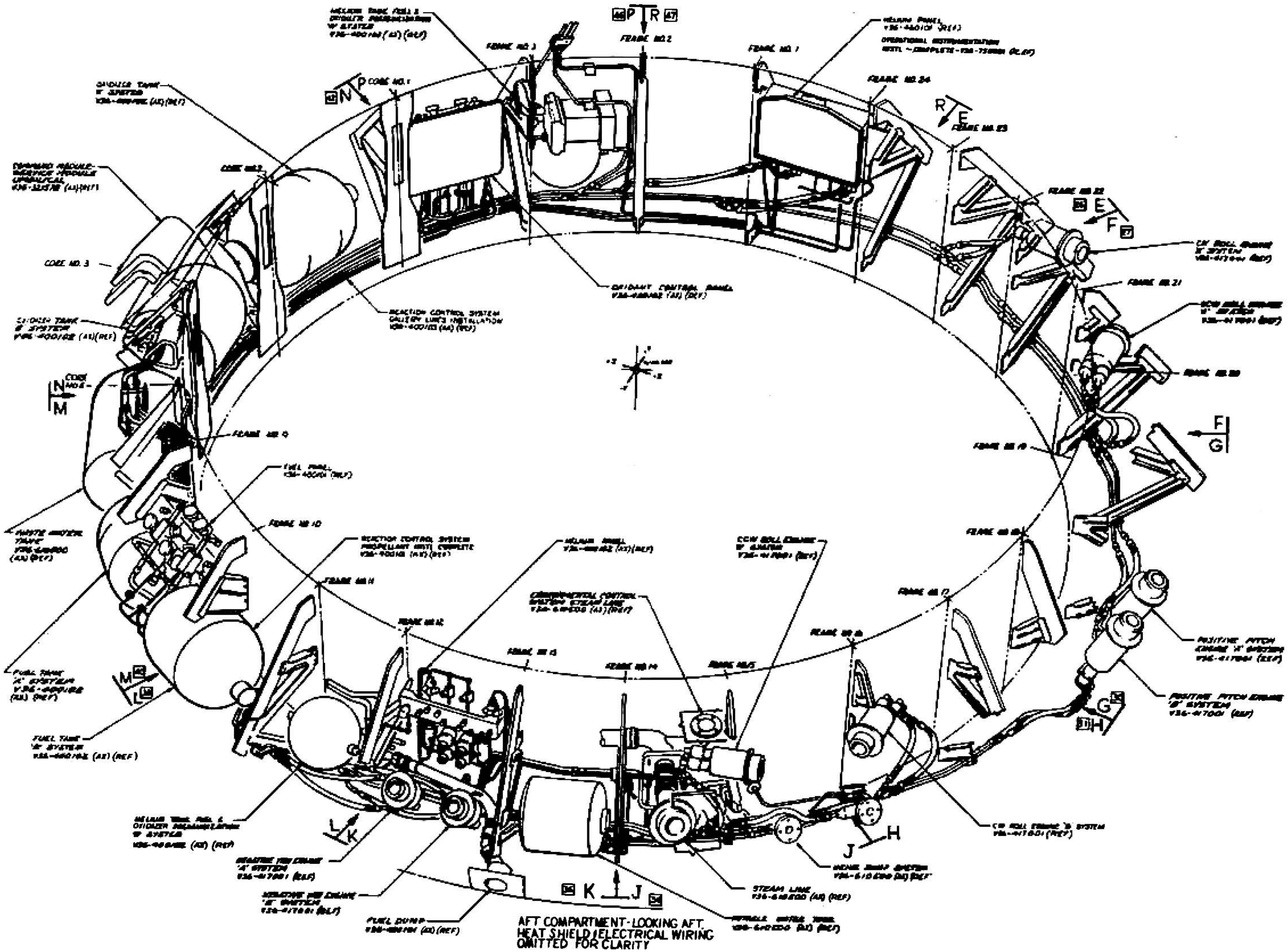


FIGURE 3.3.2. CM AFT COMPARTMENT EQUIPMENT.

TABLE 3.3.1 COMPATIBILITY OF CM RCS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING*	REFERENCE/ PAGE NO. **	REMARKS
Tank		Titanium		G	2/28	
Tank Probe		Cress Steel		G	2/28	
		Titanium		G	2/28	
		Aluminum		G	2/28	
		Teflon TFE/FEP	Blotter	G	2/28	
		Teflon TFE	Gasket	G	2/28	
		Teflon TFE	Vent Cord	G	2/28	
		Teflon TFE	Pad	G	2/28	
		Teflon TFE/FEP	Pad	G	2/28	
Propellant Explosive Valve		Cress Steel		G	2/28	
		Viton	Seal	P	1/77	Acceptable for this application since this is a secondary seal.
Propellant Latching Solenoid Valve		Cress Steel		G	2/28	
		Stainless Steel		G	2/28	Acceptable for this application since failure is required for exposure.
		Alinco V		U		
		Iron		G	2/28	
		Teflon	Valve Seats	G	2/28	
		Silicone Rubber	Potting	P	1/55	Exposed only after 1 failure, therefore acceptable in this application.

* G - Good
P - Poor
U - Unknown

TABLE 3.3.1 COMPATIBILITY OF CM RCS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE - Continued

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING*	REFERENCE/ PAGE NO.**	REMARKS
Injector Valve		Cres Steel		G	2/28	
		Stellite Steel		G	2/28	
		Nickel Coated Wire		G	2/28	
		FEP Teflon	Valve Seat	G	2/28	
Burst Diaphram		Cres Steel		G	2/28	
Isolation Valve		Aluminum		G	2/28	
		CNR (Resistazine 88)	Seal	G	1/38	
		Teflon	Seal	G	2/28	
Propellant Disconnect Coupling		Cres Steel		G	2/28	
		Kynar	Seat	G	3 & 4	
Check Valve		Cres Steel		G	2/28	
		CNR (Resistazine 88)	Valve Seat	G	1/38	
		Kynar	Seat	G	3 & 4	
Test Point Disconnect Coupling		Cress Stainless		G		
		Kynar	Valve Seat	G		

TABLE 3.3.1 COMPATIBILITY OF CM RCS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE - Concluded

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING*	REFERENCE/ PAGE NO. **	REMARKS
Propellant Filter		Cres Steel		G	2/28	

** References:

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey

2. **Compatibility of Materials with Rocket Propellants and Oxidizers**, January **1965; Battelle Memorial Institute.**

3. Pennsalt Chemical Bulletin VF 2R-62

4. NR Report SD69-459-1 & 2 dated July 1969

TABLE 3.3.2 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO NITROGEN TETROXIDE

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE/** PAGE NO.	REMARKS
Aluminum	Structure and/or Tubing	Indefinite	G	2/28	In moisture downgrade to class 4
Aluminum	Name Plates	Indefinite	G	2/28	In moisture downgrade to class 4
Aluminum/Silicone	Tape				No data
Aluminum/Epoxy	Honeycomb	15 days	P	2 and 1/28 and 16	Epoxy will fail first
Aluminized Mylar/H-Film	Thermal Insulation	7 days	P	1/24 and 36	Crumbles
Anodized Aluminum	Structures (gold, blue, and brown)				No data
Epoxy/Fiberglas	Circuit Boards	15 days	P	1/16	Electrical properties will change before visible effects
Fiberglas	Spot Ties	No failure	G	4/13-1	
H-Film (polyimide)	Wire Insulation	7 days	P	1/36	Crumbles. Copper wire is also a class 4 material.
Kynar (polyvinylidene chloride)	ID Sleeves and Heat-Shrink Tubing	Indefinite	G	1/34	
Neoprene/Fiberglas	Bandaids	4 hours	P	1/38	Decomposes
Nomex (aromatic nylon)	Spot Ties	4 hours	P	1/39	Disintegrates
Nylon	Velcro Fasteners	1 day	P	1/39	Decomposes
Nylon	Parachute System	1 day	P	1/39	Decomposes
Phenolic/Fiberglas	Paints (red, yellow, and black)	Several hours	P	4/13-1	Paints will first bleach and then dissolve.

*G - Good
P - Poor
U - Unknown

TABLE 3.3.2 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO NITROGEN TETROXIDE - Continued

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE/** PAGE NO.	REMARKS
Phenolic/Fiberglas	Pipe Standoff	24+ hours	P	3/42	Bleeds in 4 hours. No more change until 24 hours.
Polyimide/Teflon TFE	Wire Insulation	4 days	P	1/24	Crumbles. Copper wire is also a class 4 material.
Polyolefin	Heat-Shrink Tubing	7 days	P	1/52	Cracks
Silicone Rubber - RTV 102	Potting Compound	Probably 1 day	P	1/55 and 62	No data, but RTV 20 dissolves in 1 day at 80°F.
Silicone Rubber - RTV 560/577	Potting Compound	Probably 1 day	P	1/55 and 62	No data, but RTV 20 dissolves in 1 day at 80°F.
Silicone Rubber - LASR 5000	Cable Clamps	Probably 1 day	P	1/55 and 62	No data, but RTV 20 dissolves in 1 day at 80°F.
Silicone Rubber - AMS 3245	Inserts and Connectors	Probably 1 day	P	1/55 and 62	No data, but RTV 20 dissolves in 1 day at 80°F.
Stainless Steel	Tubing	Indefinite	G	2/28	Possible downgrade in presence of moisture.
Teflon TFE/Silicone	Tape				No data
Teflon TFE	Wire Insulation	Indefinite	G	1/68	
Teflon TFE	Wire Wrap	Indefinite	G	1/68	
Teflon TFE	Strain Relief Guard	Indefinite	G	1/68	
Teflon TFE	ID Tags	Indefinite	G	1/68	

TABLE 3.3.2 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO NITROGEN TETROXIDE - Concluded

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE/** PAGE NO.	REMARKS
Teflon TFE/FEP	Heat-Shrink Tubing	Indefinite	G	1/68	
TG-15000 Fiberglas	Thermal Insulation				No data
Paint	Torque Stripe Paint	Several Hours	P	4/13-1	Paint will first bleach and then dissolve.
73-X	Marking Ink	A few minutes	P	4/13-1	Bleaches
Avcoat II	Heatshield Material	A few minutes	P	4/4-3	Bubbles and reacts with oxidizer fumes. Destroyed.

**REFERENCES

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey

2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965; Battelle Memorial Institute

3. NASA Contributions to Advanced Valve Technology, NASA SP-5019, 1967; National Aeronautics and Space Administration, Office of Technology Utilization, Washington, D.C.

4. Hypergolic Propellant Materials Compatibility, No. CR 64-88; Martin Company

TABLE 3.3.3 COMPATIBILITY OF CMRCS FUEL SYSTEM MATERIALS

NORMALLY EXPOSED TO MONOMETHYLHYDRAZINE

SPACECRAFT COMPONET	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATIBILITY RATING*	REFERENCE/** PAGE NO.	REMARKS
Injector Valve		Cres Steel		G	2/18	
		Stellite Steel		G	2/18	
		Nickel Coated Wire		G	2/18	
		FEP Teflon	Valve Seat	G	2/18	
Burst Diaphragm		Cres Steel		G	2/18	
Isolation Valve		Aluminum		G	2/18	
		EPR (Parker B496-7)		G		
		Teflon	Seal	G	1/68	
Propellant Disconnect Coupling		Cres Steel		G	2/18	
		Kynar	Seat	G	3 & 4	
Check Valve		Cres Steel		G	2/18	
		EPR	Valve Seat	G		
		Kynar	Seat	G	3 & 4	Requires Test
Test Point Disconnect Coupling		Cress Stainless		G	2/18	
		Kynar	Valve Seat	G	3 & 4	Requires Test

**REFERENCES

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey

2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965; Battelle Memorial Institute

3. Pennsalt Chemical Bulletin VF2R-62

4. NR Report SD69-459-1 & -2 dated July 1969

TABLE 3.3.3 COMPATIBILITY OF CMRCS FUEL SYSTEM MATERIALS

NORMALLY EXPOSED TO MONOMETHYLHYDRAZINE - Concluded

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATIBILITY RATING*	REFERENCE/** PAGE NO.	REMARKS
Tank		Titanium		G	2/18	
Tank Probe		Cress Steel		G	2/18	
		Titanium		G	2/18	
		Aluminum		G	2/18	
		Teflon TFE/FEP	Blatter	G	1/68	
		Teflon TFE	Gasket	G	1/68	
		Teflon TFE	Vent Cord	G	1/68	
		Teflon TFE	Pad	G	1/68	
		Teflon TFE	Pad	G	1/68	
Propellant Explosive Valve		Cress Steel		G	2/18	
		Viton	Seal	U	1/16	Acceptable for this application since this is a secondary seal.
Propellant Latching Solenoid		Cres Steel		G	2/18	
		Stainless Steel		G	2/18	
		Alinco V		U		Exposed only after one failure. Therefore, acceptable for this application.
Valve		Iron		G	2/18	
		Teflon	Valve Seats	G	1/68	
		Silicone Rubber	Potting	U	2/18	Exposed only after one failure. Therefore, acceptable for this application.

*G - Good
P - Poor
U - Unknown Data

TABLE 3.3.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO MONOMETHYLHYDRAZINE

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE**/ PAGE NO.	REMARKS
Aluminum	Structure and/or Tubing	Indefinite	G	2/19	
Aluminum	Name Plates		U	2/19	Similar to R-7001.
Aluminum/Silicone	Tape		U	2/19	Silimar to R-7001.
Aluminum/Epoxy	Honeycomb		P	2/19	Epoxies as class - poor
Aluminized Mylar/H-Film	Thermal Insulation		P	2/19	H-Film - poor
Anodized Aluminum	Structures (gold, blue and brown)		G	2/19	Anodized aluminum probably all good
Cork	Door Sealant		U	3	
Epoxy/Fiberglas	Circuit Boards		P	2/19	Similar to Spun VI, 828.
Fiberglas	Spot Ties		P	4	Similar to Armalon
H-Film (polyimide)	Wire Insulation		P	2/19	
Kynar (polyvinylidene chloride)	ID Sleeves and Heat-Shrink Tubing		P	2/19	
Neoprene/Fiberglas	Bandaids		P	1/37	
Nomex (Aromatic Nylon)	Spot Ties		U	1/39	
Nylon	Velcro Fasteners		G	1/39	
Nylon	Parachute System		G	1/39	
	Paints (red, yellow, and black)		P	4	Bleaches

* G - Good U - Unknown
P - Poor

TABLE 3.3.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO MONOMETHYLHYDRAZINE - Continued

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE**/ PAGE NO.	REMARKS
Phenolic/Fiberglas	Pipe Standoff		P	3/19	
Polyimide/Teflon TFE	Wire Insulation		P	2/19	
Polyolefin	Heat-Shrink Tubing		P	2/19	Good to fair - depends upon class
Silicone Rubber RTV 102	Potting Compound		P	2/19	Similar to R-7001.
Silicone Rubber RTV 560/577	Potting Compound		P	2/19	Similar to R-7001.
Silicone Rubber LASR 5000	Cable Clamps		P	2/19	Similar to R-7001.
Silicone Rubber AMS 3245	Inserts and Connectors		P	2/19	Similar to R-7001.
Stainless Steel	Tubing	Indefinite	G	2/19	
Teflon TFE/Silicone	Tape		P	2/19	Similar to R-7001.
Teflon TFE	Wire Insulation		P	1/68	
Teflon TFE	Wire Wrap		G	2/19	
Teflon TFE	Strain Relief Guard		G	2/19	
Teflon TFE	ID Tags		G	2/19	
Teflon TFE/FEP	Heat-Shrink Tubing		G	2/19	

TABLE 3.3.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO MONOMETHYLHYDRAZINE - Concluded

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE**/ PAGE NO.	REMARKS
TG-15000 Fiberglas	Thermal Insulation		U		
Paint	Torque Stripe Paint		U	4	Bleaches/Washes out
Vinyl (polyvinylchloride)	Wire Insulation		P	2/18	
73-X	Marking Ink		U		Bleaches/Washes out
Unidentified	Sleeve (black and yellow)		U		
Unidentified	Lanyard Cover (green)		U		
Unidentified	Potting Compounds (blue and brown)		U		

**REFERENCES

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey.

2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965; Battelle Memorial Institute

3. NASA Contributions to Advanced Valve Technology, NASA SP-5019, 1967; National Aeronautics and Space Administration, Office of Technology Utilization, Washington, D.C.

4. Hypergolic Propellant Materials Compatibility, No. CR 64-88; Martin Company

b. Purge valve: stainless steel (304L, 17-7PH), VITON (fluororubber)

c. Dump valve: See (b) above.

d. Interconnect valve: See (b) above.

e. Isolation valve: Stainless steel (304L, 347, 321, AM350), Alnico V, Armco ingot iron, aluminum (2024), TEFLON, silicone rubber, epoxy A14.

f. Engine injector valve: stainless steel (304L, 321, 347, 430F, 17-7PH), stellite, TEFLON (FEP), silicone rubber.

g. Fill and vent coupling: stainless steel (302, 303, 304, 304L, 316, 17-7PH), KYNAR.

h. Burst disc assembly: stainless steel (303, 304, 304L, 17-4), aluminum (6061) TEFLON, Resistazine 88.

i. Test point disconnect coupling: stainless steel (303, 304, 310, 321, 17-7PH), KYNAR.

j. Check valve: stainless steel (304, 304L, 321, 17-4PH, 17-7), KYNAR, Resistazine 88.

3.3.2.2 Fuel System

The components used in the fuel system are the same as those used in the oxidizer system, with the same materials used, except in the check valve. The fuel-side check valve materials are: stainless steel (304, 304L, 321, 17-4PH, 17-7) and EPR (ethylene propylene rubber).

3.3.2.3 Helium Pressurization System

a. Helium tank: titanium, stainless steel, TEFLON, butyl rubber.

b. Regulator: stainless steel (302, 304L, 347, AM 350, 440C, 17-4PH), steel (SAE 9524), aluminum (2024, 6061, 7075), bimetal, TEFLON (TFE), KYNAR, rubber (SR634-70).

c. Isolation valve: stainless steel (304L, 17-4PH), aluminum (6061), VITON.

d. Check valve: stainless steel (304, 304L, 321, 17-4PH, 17-7), KYNAR and Resistazine 88 in oxidizer system and EPR (ethylene propylene rubber) in the fuel system.

e. Interconnect valve: stainless steel (304, 17-4PH), VITON.

f. Relief valve: stainless steel (301, 303, 304, 304L, 17-4PH), aluminum (1145), TEFLON.

g. Fill coupling: stainless steel (303, 304, 304L, A286, 17-4PH, 17-7PH), aluminum (2024, 7075), KYNAR, KEL-F81.

h. Test point coupling: stainless steel (303, 304, 310, 321, 17-7PH), KYNAR.

3.3.3 CM RCS MECHANICAL COMPONENTS

3.3.3.1 Oxidizer System

a. Oxidizer tank: Figure 3.3-3.

The oxidizer tanks are in the CM aft compartment between Frames 1 and 2 and 3 and 4. The CM RCS oxidizer is inhibited N_2O_4. Each tank is loaded with 78.3 ±1.6 lb. oxidizer under a pressure of 100 ±5 psia with helium. The system is not pressurized for operation (291 ±4 psia) until one hour before re-entry. There are no electrical sources on or in the tank. Should the tank bladder leak, a double check valve failure must occur before oxidizer could get into the fuel system and cause a reaction. The oxidizer tanks are considered acceptable in their present application. Pressure regulation is redundant as discussed in paragraph 3.3.3.3 and there are no electrical interfaces to provide an ignition source for the tank bladders (teflon). Risk associated with these tanks is minimized by the limited pressurized operations (entry only).

b. Fill and vent coupling: Figure 3.3-4.

The coupling mechanism is backed up by a closure cap after loading. The coupling is acceptable in its present application as a single failure does not cause leakage.

c. Burst disc assembly: Figure 3.3-5.

Component failure would result in premature exposure of the gallery lines to the oxidizer and does not impair crew safety. The disk assembly is acceptable.

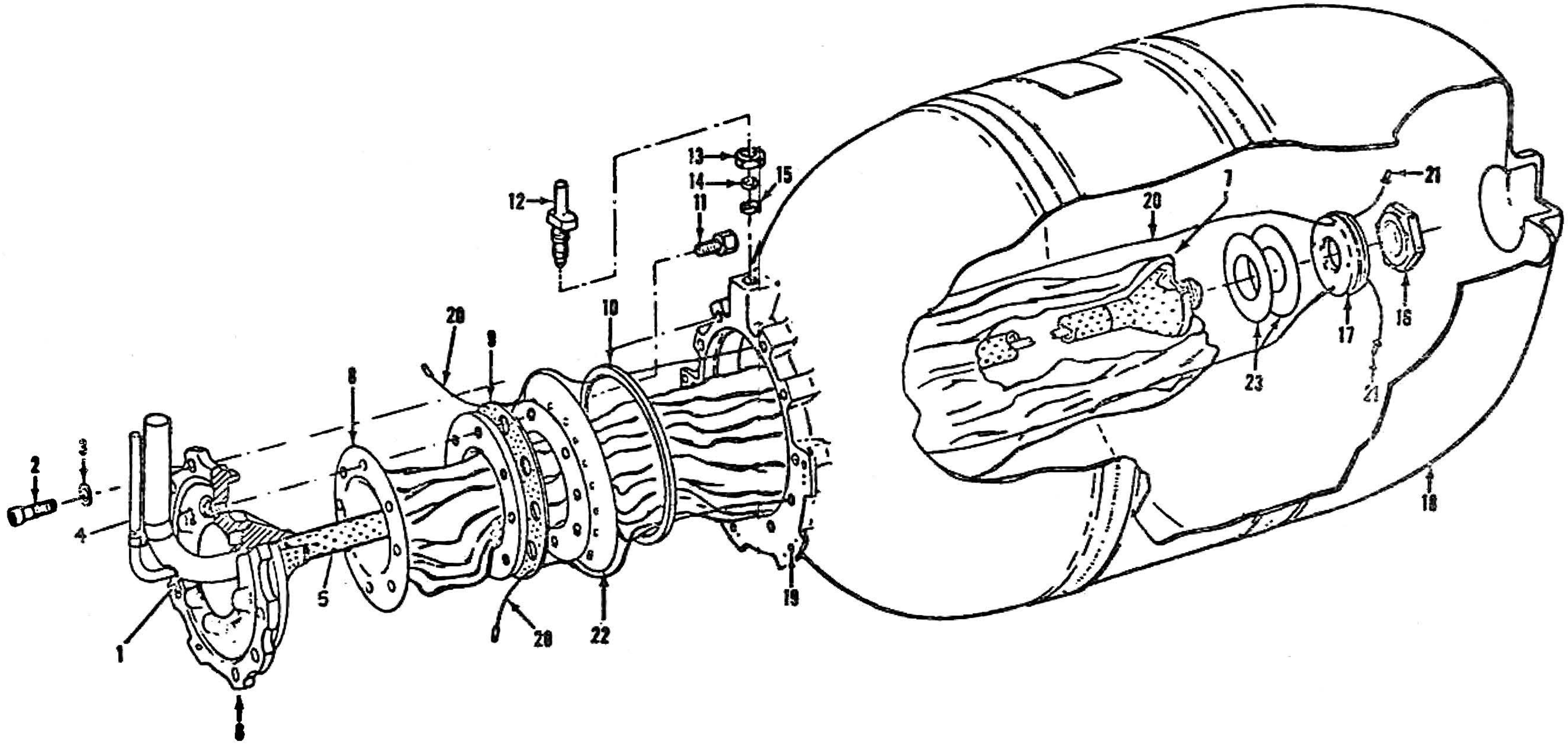
d. Test point disconnect coupling: Figure 3.3-6.

Same as (b) above.

3.3.3.2 Fuel System

a. Fuel tank: Figure 3.3-3.

The fuel tanks are in the CM aft compartment at Frames 9 and 10. The CM RCS fuel is MMH. Each tank is loaded with 44.2 ± 0.9 lb. fuel under a pressure of 100 ±5 psia with helium. The system is not pressurized for operation (291 ±4 psia) until one hour



1.	OUTLET TUBE	(347 CRES)	9.	RING	(6061 Al)	17.	WASHER	(6061-T6 Al)
2.	BOLT	(TITANIUM)	10.	GASKET	(TEFLON TFE)	18.	SHELL	(TITANIUM)
3.	WASHER	(347 CRES)	11.	BOLT	(347 CRES)	19.	NUT PLATE	(A286 CRES)
4.	LSV TUBE	(347 CRES)	12.	FITTING	(304L CRES)	20.	VENT CORD	(TEFLON TFE)
5.	DIFFUSER TUBE	(6061 Al)	13.	NUT	(347 CRES)	21.	FLANGED EYELET	(304 CRES)
6.	FLANGE	(6061 Al)	14.	GASKET	(TEFLON TFE)	22.	PAD	(TEFLON TFE/FEP)
7.	RETAINER	(6061-T6 Al)	15.	GASKET	(TEFLON TFE)	23.	PAD	(TEFLON TFE)
8.	BLADDER	(TEFLON TFE/FEP)	16.	NUT	(347 CRES)			

FIGURE 3.3.3. PROPELLANT TANK

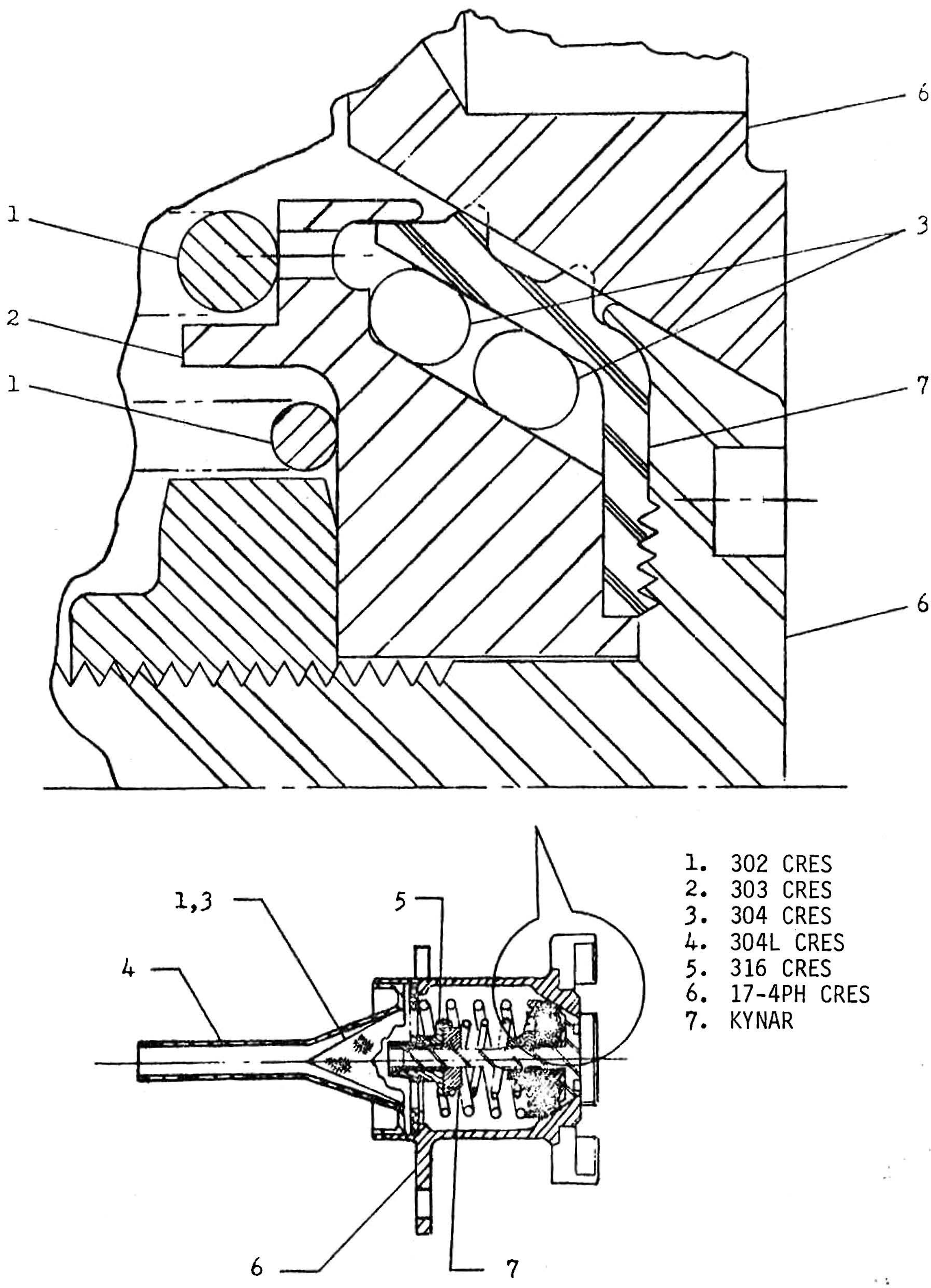
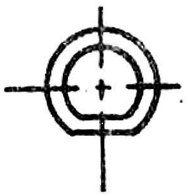
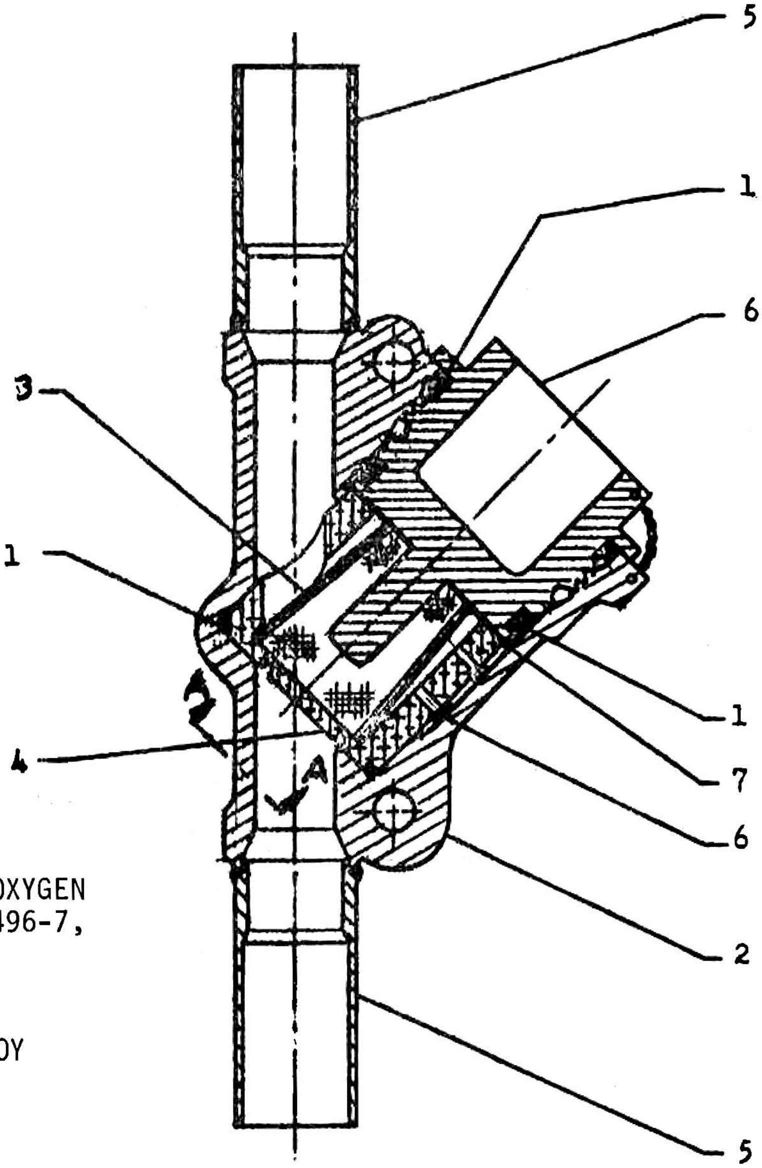


FIGURE 3.3.4. AIRBORNE HALF OF THE PROPELLANT DISCONNECT COUPLING.



VIEW A-A

(END VIEW OF THE
BURST DIAPHRAGM
'V' GROOVE)



1. RESISTAZINE 88, OXYGEN VALVE; PARKER B496-7, FUEL VALVE
2. 17-4 CRES
3. 304 CRES
4. 6061-T651 Al ALLOY
5. 304L CRES
6. 303 CRES
7. TEFLON

FIGURE 3.3.5. BURST DIAPHRAGM ISOLATION VALVE

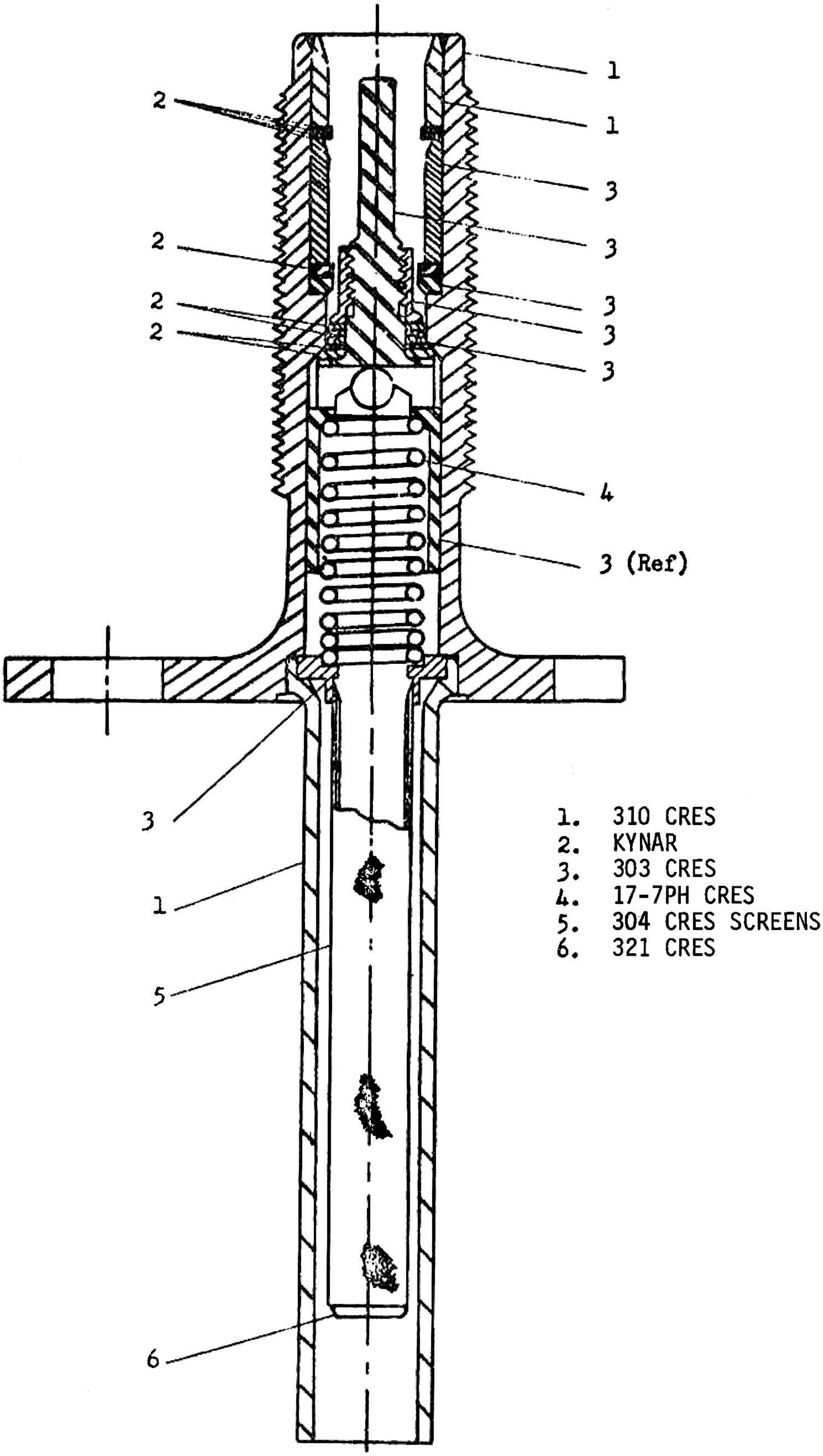


FIGURE 3.3.6. AIRBORNE HALF OF THE TEST POINT DISCONNECT COUPLING

before re-entry. There are no electrical sources on or in the tanks. Should the tank bladder leak, a double check valve failure must occur before fuel could get into the oxidizer system and cause a reaction. The fuel tanks are considered acceptable in their present application. Pressure regulation is redundant as discussed in paragraph 3.3.3.3 and there are no internal sources of tank pressure increase. The limited pressurized operation (entry) by these tanks further reduces any risks.

b. Fill and vent coupling: Figure 3.3-4.

Same remarks as for oxidizer.

c. Burst disc assembly: Figure 3.3-5.

Same remarks as for oxidizer.

d. Test point disconnect coupling: Figure 3.3-6

Same remarks as for oxidizer.

3.3.3.3 Helium System

a. Helium tank: Figure 3.3-7.

The two helium tanks are located approximately diametrically on the +Y and -Y sides of the aft compartment between Frames 2 and 3 and between Frames 11 and 12. Each tank is loaded with 0.57 lb. helium at 4150 $\pm$50 psia at 70 $\pm5^{\circ}$F. There are no electrical sources on or in the tank. There are no significant external sources of tank pressure or temperature increases. The tanks are acceptable in their present application as they have an adequate factor of safety and no mechanisms for tank pressure or temperature increase.

b. Regulator: Figure 3.3-8.

The regulators are series-parallel redundant for each propellant system. Loss of a single regulator would have no effect on fuel or oxidizer tank pressure. If both regulators of a unit in series failed open after system activation, then the propellant tanks of that system would rupture as the failed open regulator flow exceedes the relief valve capability.

c. Relief valve: Figure 3.3-9.

The helium relief valve contains a diaphragm which ruptures at 340 $\pm$8 psig. The valve relieves at 346 $\pm$14 psig and reseats at 327 psig minimum. There is a relief valve for each

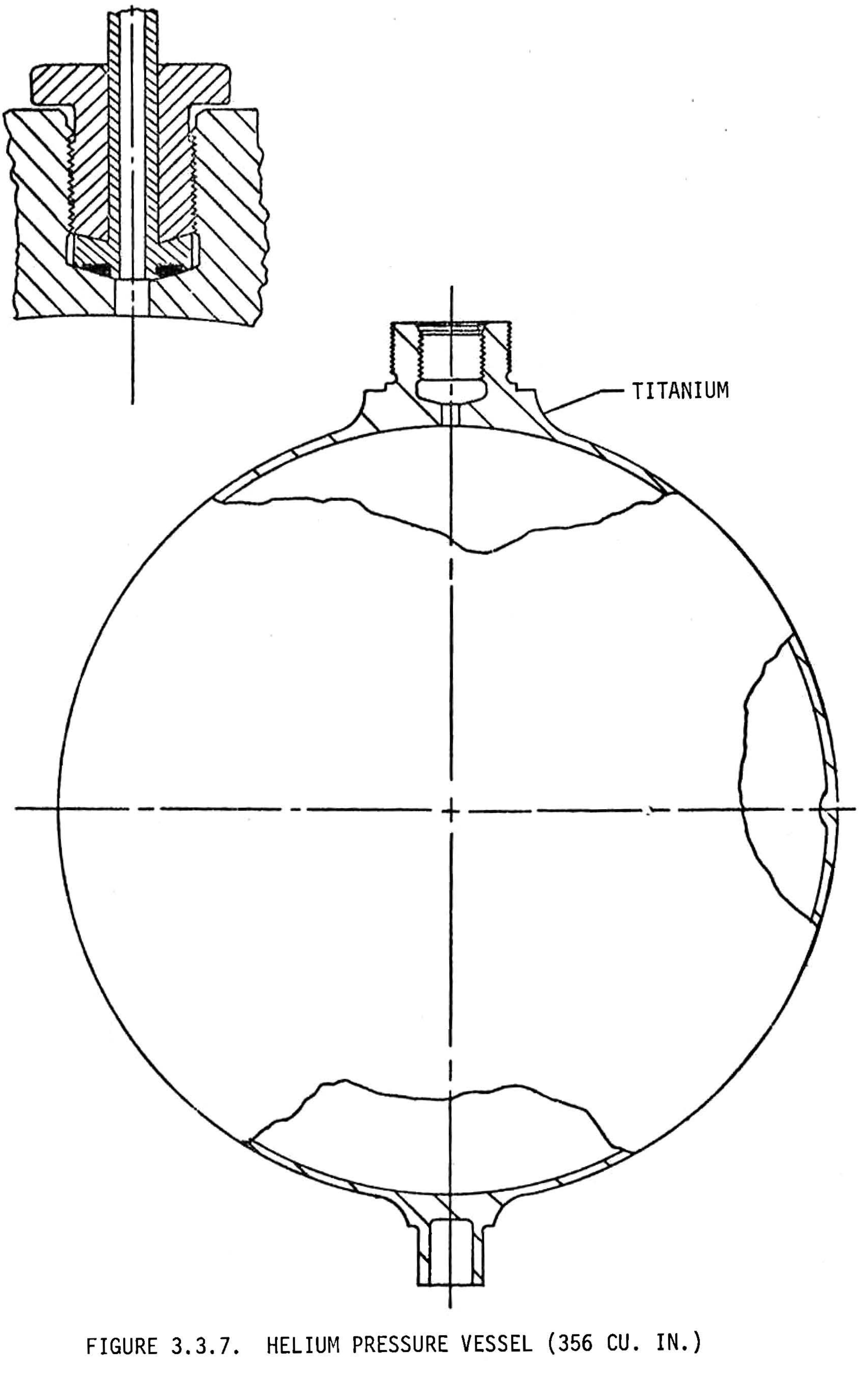


FIGURE 3.3.7. HELIUM PRESSURE VESSEL (356 CU. IN.)

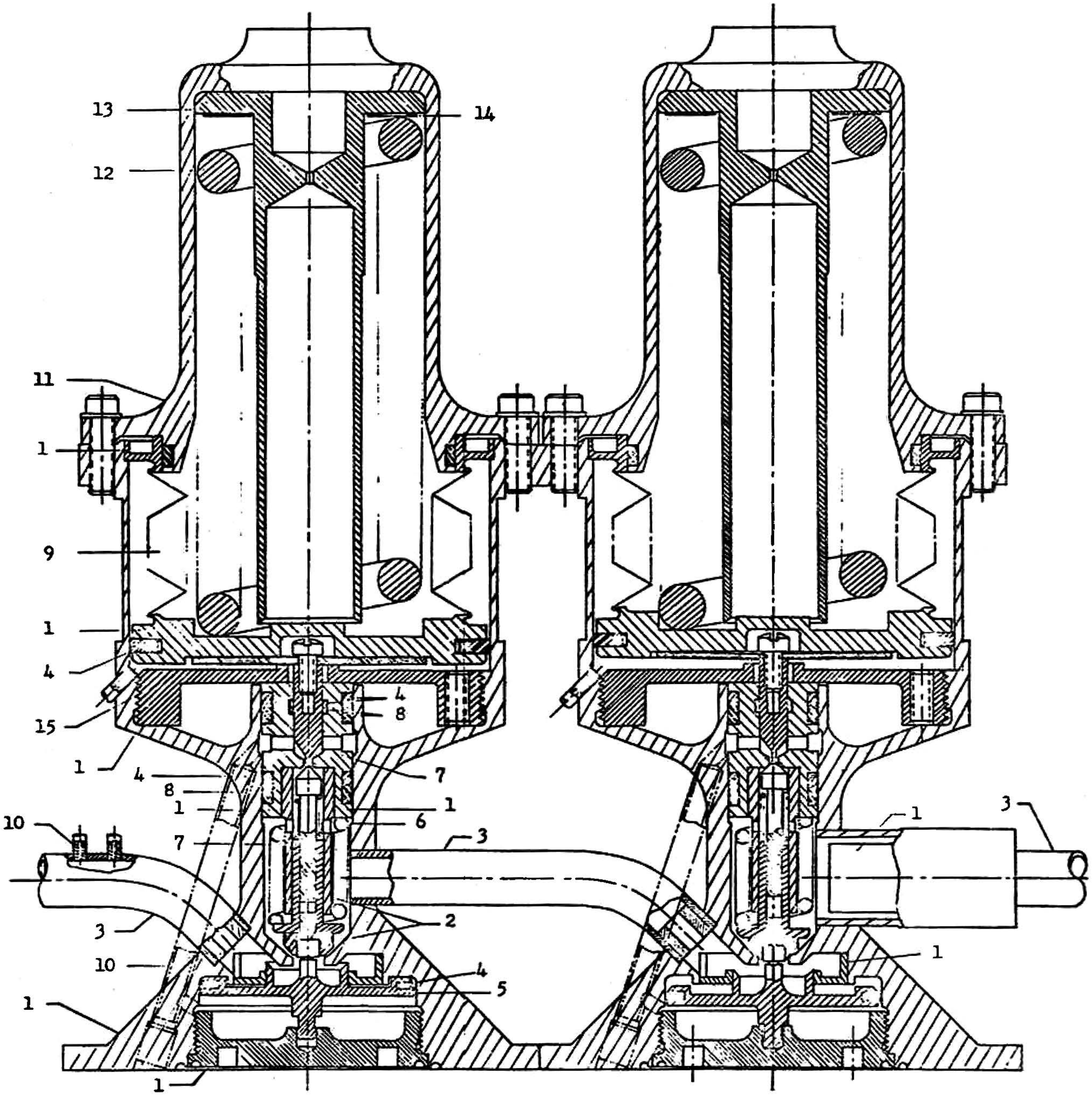


FIGURE 3.3.8. HELIUM PRESSURE REGULATOR UNIT.

1. 17-4PH CRES
2. Kynar
3. 304L
4. Teflon TFE
5. 7075-T6 Al
6. 17-7PH CRES
7. 440C CRES
8. "O" Ring SR634-70
9. AH350 CRES
10. 347 CRES
11. 2024-T4 Al
12. SAE 9254
13. 6061-T6 Al
14. 302 CRES
15. Bimetal

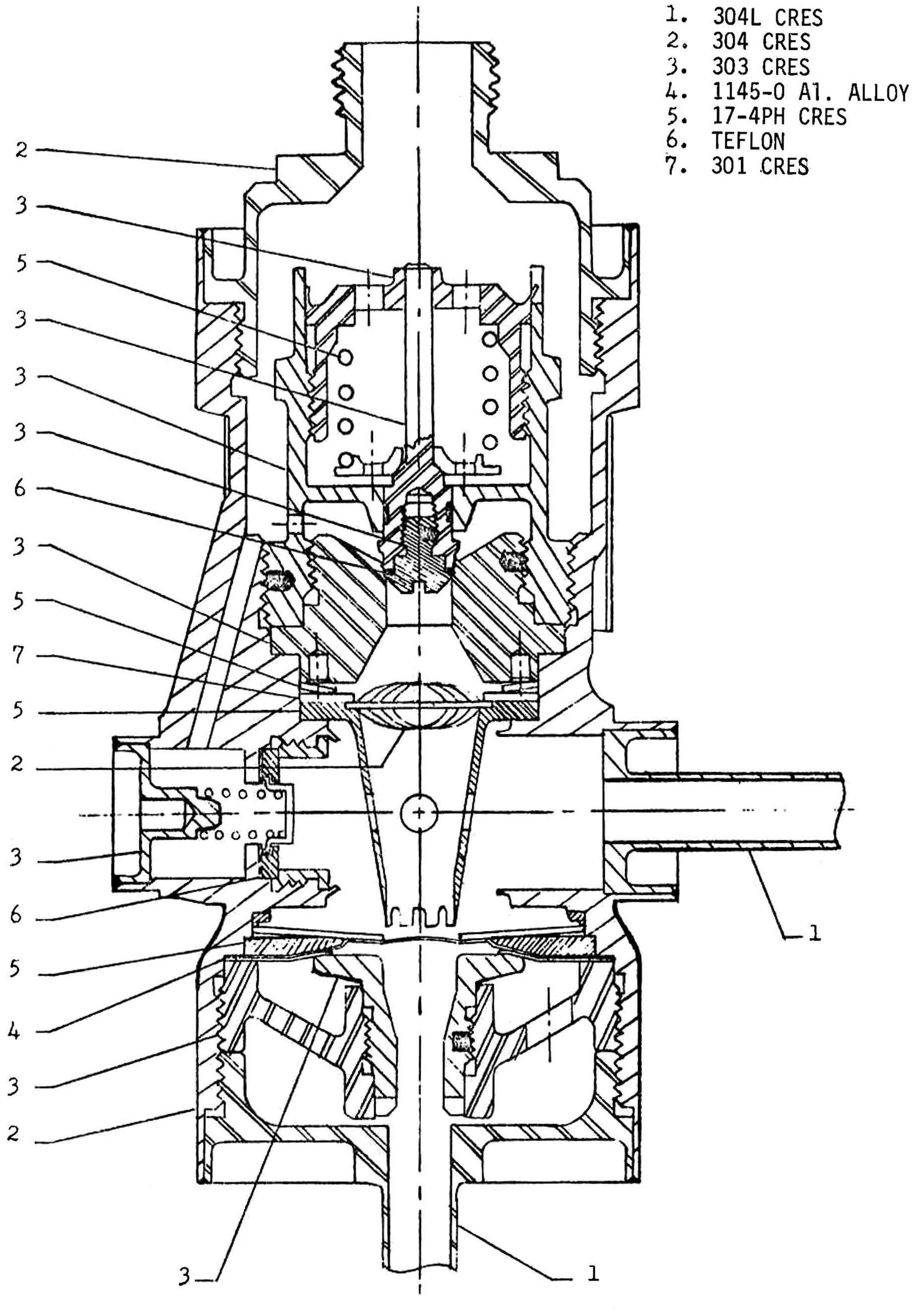


FIGURE 3.3.9 . CM RCS HELIUM PRESSURE RELIEF VALVE.

propellant tank. These valves are sized to accommodate temperature or pressure increases such as entry heating but do not accommodate dual regulator failures.

d. Fill and drain coupling: Figure 3.3-10.

The coupling mechanism is backed up by closure cap after loading. They are acceptable as a single failure does not cause excessive leakage.

e. Check valve: Figure 3.3-11.

The check valves are series-paralled redundant and any single failure does not result in fuel and oxidizer mixing or loss of pressurization. They are considered acceptable.

f. Test point disconnect coupling: Figure 3.3-6.

See (d) above.

3.3.4 CM RCS ELECTRICAL COMPONENTS

3.3.4.1 Oxidizer System

The salient characteristics of the electrical components in the oxidizer system are given in Table 3.3-5. A discussion of the hazard potential and effect of component failure are discussed below.

a. Purge valve: Figure 3.3-12.

As shown in Figure 3.3-12, machined fittings are brazed to the tubing forming a complete metallic end closure. Leakage of an unactuated valve is remote. A metal-to-metal seal is formed after actuation with a redundant VITON seal. These valves are actuated only after completion of RCS control for system dump and purge. They are acceptable for their present applications.

b. Dump valve: Figure 3.3-12.

Same as (a) above.

c. Interconnect valve: Figure 3.3-12.

Same as (a) above.

d. Isolation valve: Figure 3.3-13.

Propellant isolation valves are normally in the open condition and are not normally cycled during flight. Therefore, failures due to cycle life are insignificant. A single failure of the

1. A286 CRES
2. 303 CRES
3. 304 CRES
4. 304L CRES
5. 17-4PH CRES
6. 17-7PH CRES
7. 2024-T4 Al Al
8. 7075-T6 Al Al
9. KYNAR
10. KEL-F81

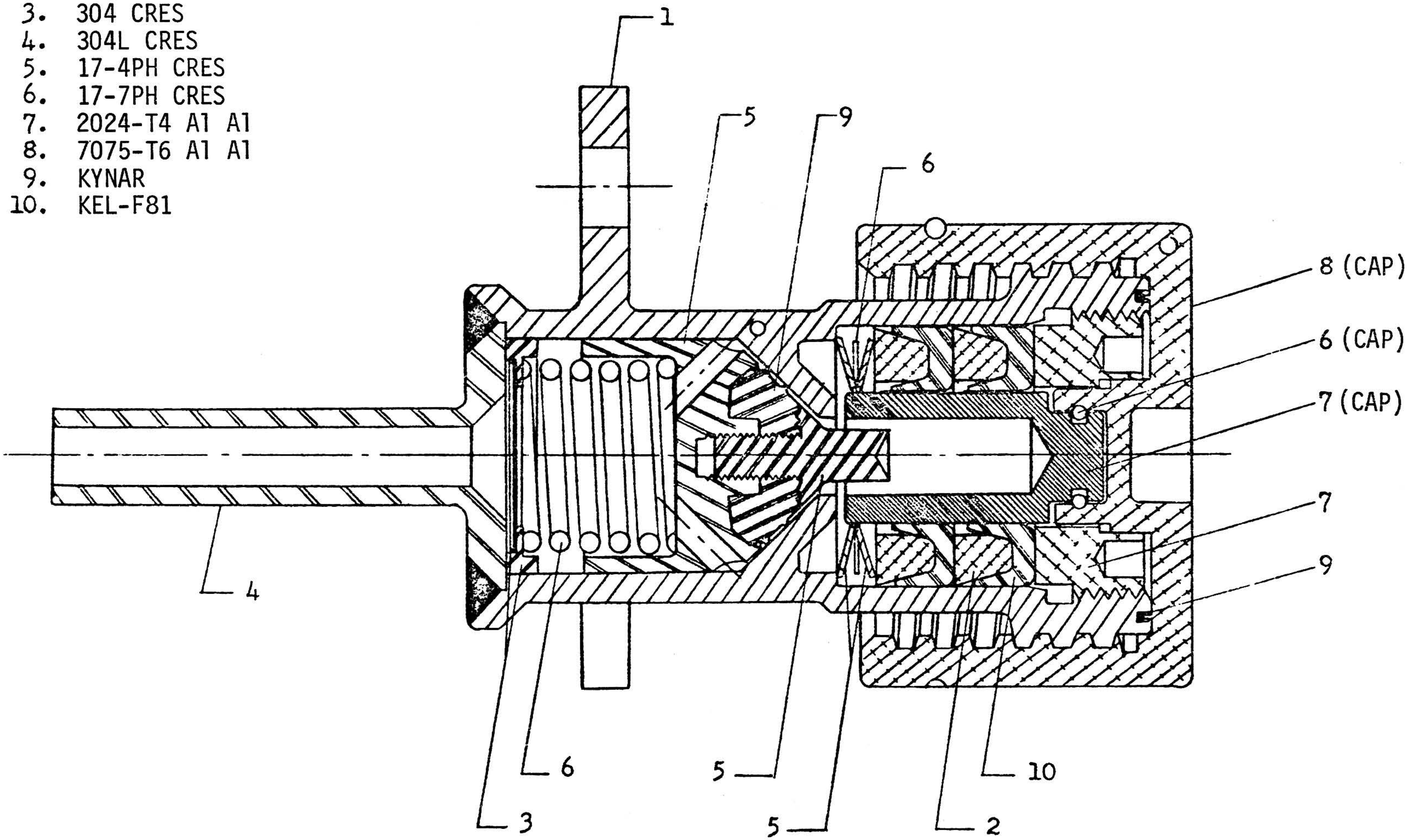
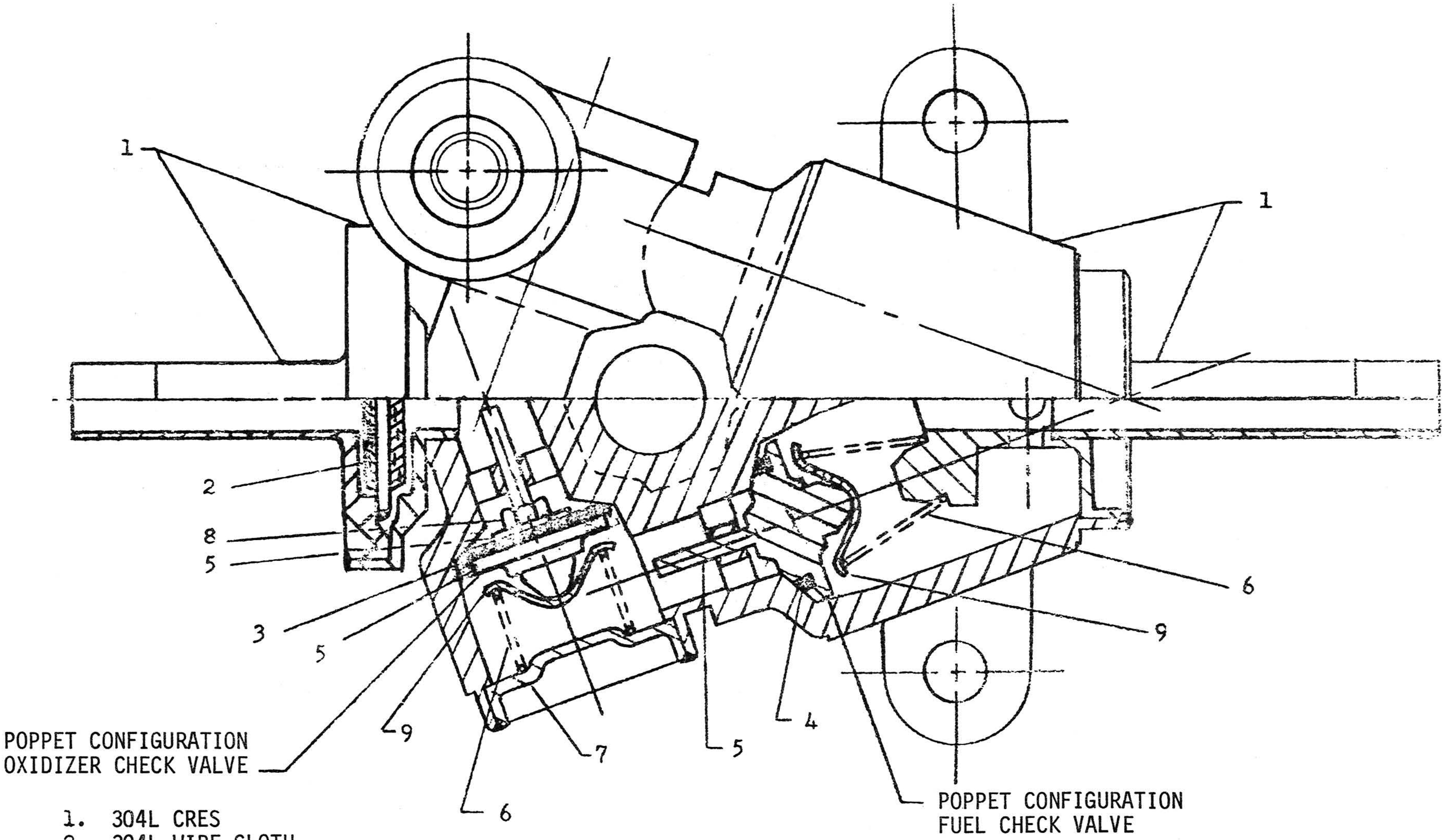


FIGURE 3.3.10. AIRBORNE HALF OF THE HELIUM-FILL DISCONNECT COUPLING



1. 304L CRES
2. 304L WIRE CLOTH
3. RESISTAZINE 88
4. EPR
5. 17-4 PH
6. 17-7
7. 321
8. KYNAR
9. 304 CRES

FIGURE 3.3.11 CHECK VALVE

TABLE 3.3.5. CM RCS OXIDIZER SYSTEM ELECTRICAL COMPONENTS

COMPONENT	FUNCTION	NORMAL OPERATING ELECTRICAL CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		SUMMARY DESCRIPTION OF ELECTRICAL COMPONENT TO FLUID INTERFACE
		VOLTS	AMPERES	PRESSURE (PSI)	TEMPERATURE (°F)	
PURGE VALVE	SQUIB VALVE TO PURGE OXIDIZER LINES AFTER DUMP.	28	3.5/5.0 10 MILLISECONDS/ 15 MILLISECONDS	291	70	P/N ME284-0019-0006. OXIDIZER FILLED LINE ON OUTLET SIDE OF VALVE. HELIUM ON INLET SIDE OF VALVE. ONE VALVE IN EACH SYSTEM.
PROPELLANT ISOLATION VALVE	SOLENOID VALVE TO ISOLATE OXIDIZER FROM ENGINE INJECTOR VALVE.	28	1.71 (ACCEPTANCE)	291	70	P/N ME284-0276-0001. OXIDIZER ON INLET SIDE ONLY AFTER BURST DISC RUPTURED IN SYSTEM ACTIVATION. OXIDIZER THROUGH VALVE AFTER ACTUATION. ONE VALVE IN EACH SYSTEM.
OXIDIZER VALVE	SQUIB VALVE TO CONNECT SYSTEM 1 AND SYSTEM 2.	28	3.5/5.0 10 MILLISECONDS/ 15 MILLISECONDS	291	70	P/N ME284-0130-0014. OXIDIZER ON BOTH SIDES OF VALVE FROM TIME OF SYSTEM LOADING. ONE VALVE FOR BOTH SYSTEMS.
OXIDIZER DUMP VALVE	SQUIB VALVE TO DUMP OXIDIZER OVERBOARD.	28	3.5/5.0 10 MILLISECONDS/ 15 MILLISECONDS	291	70	P/N ME284-0130-0002. OXIDIZER ON INLET OF SYSTEM LOADING. ONE VALVE IN EACH SYSTEM.
ENGINE INJECTOR VALVE						
DIRECT	SOLENOID FOR MANUAL ENGINEER CONTROL; HEATER.	28	1.74/1.86 ACCEPTANCE/ SPECIFICATION	291	70	SIX SOLENOIDS IN EACH SYSTEM: ONE PER ENGINE. OXIDIZER AGAINST VALVE ONLY AFTER SYSTEM ACTIVATION.
AUTOMATIC	SOLENOID FOR AUTOMATIC ENGINE CONTROL.	28	3.47/3.75 ACCEPTANCE/ SPECIFICATION	291	70	SIX SOLENOIDS IN EACH SYSTEM: ONE PER ENGINE OXIDIZER AGAINST VALVE ONLY AFTER SYSTEM ACTIVATION.
TEMPERATURE SENSOR	RESISTANCE ELEMENT TO MEASURE INJECTOR TEMPERATURE.	0.5	0.001	AMBIENT	70	ONE EACH MOUNTED ON INJECTORS OF ENGINES 12, 14, AND 16 OF SYSTEM 1 AND ENGINES 21, 24, AND 25 OF SYSTEM 2.

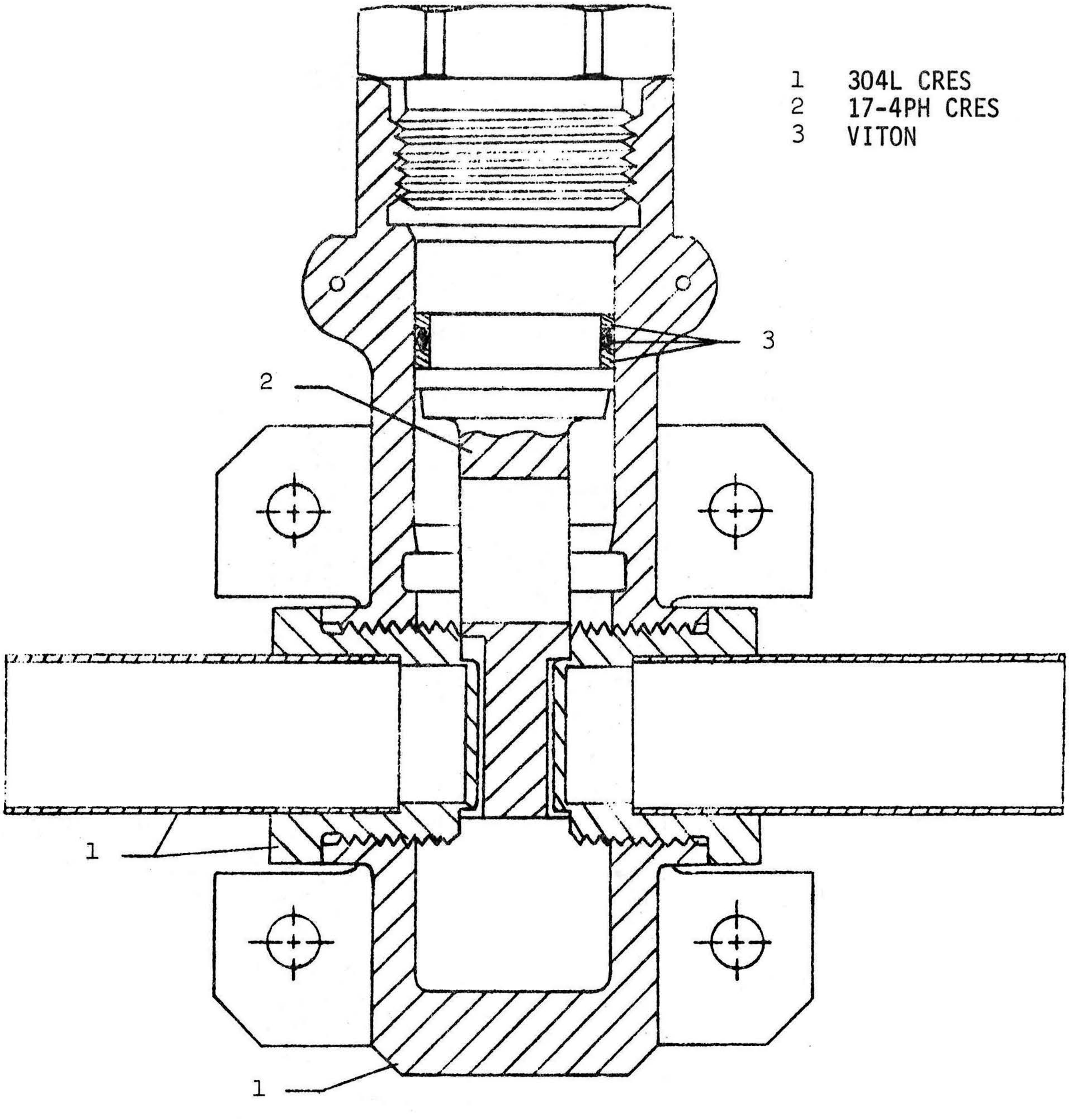


FIGURE 3.3.12. PROPELLANT EXPLOSIVE VALVE.

1. 304L
2. 347
3. AM350
4. AM355
5. ALNICO V
6. TEFLON
7. ARMCO INGOT IRON
8. SILICON RUBBER
9. 321 CRES
10. 2024-T4 A1
11. EPOXY A14

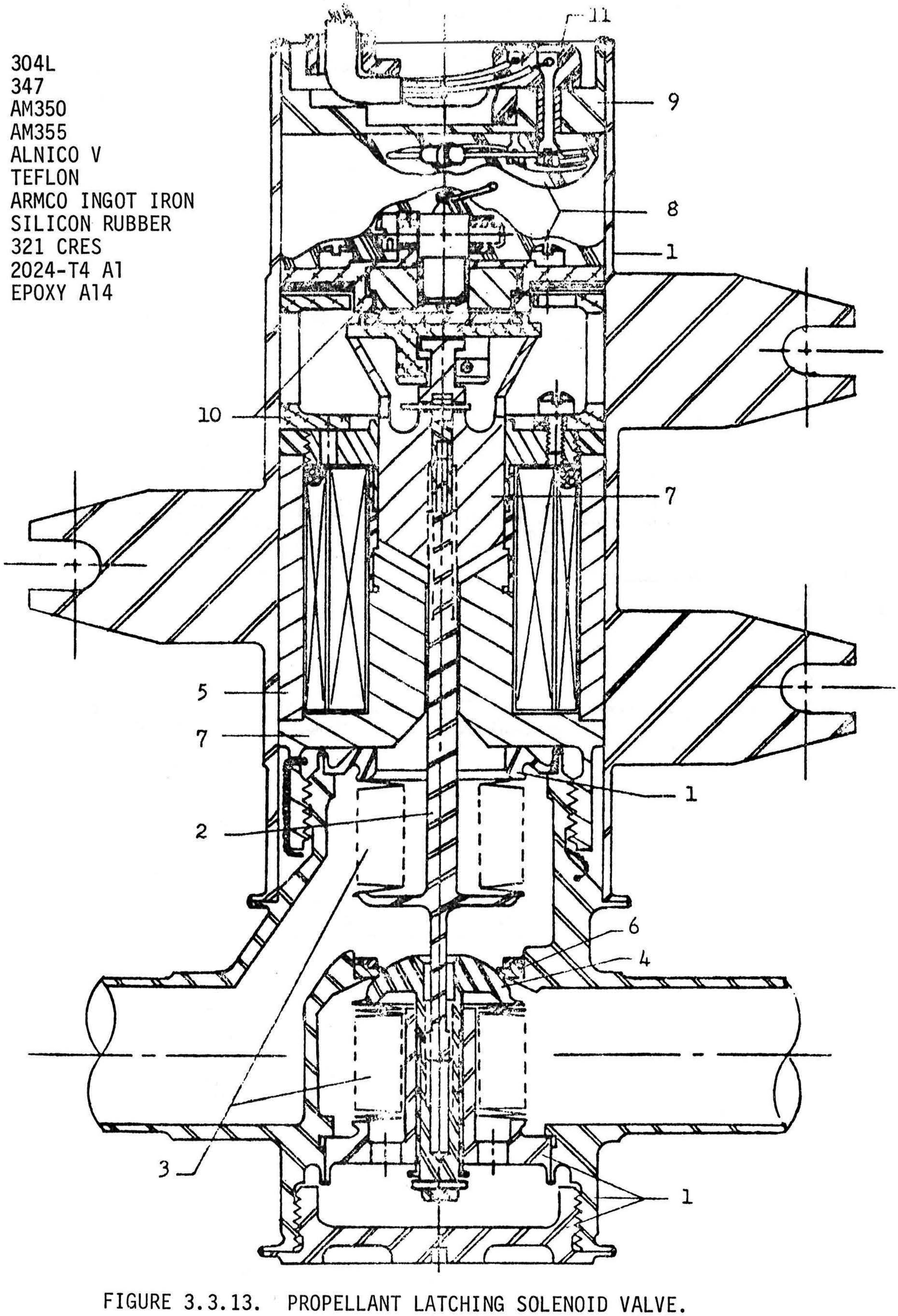


FIGURE 3.3.13. PROPELLANT LATCHING SOLENOID VALVE.

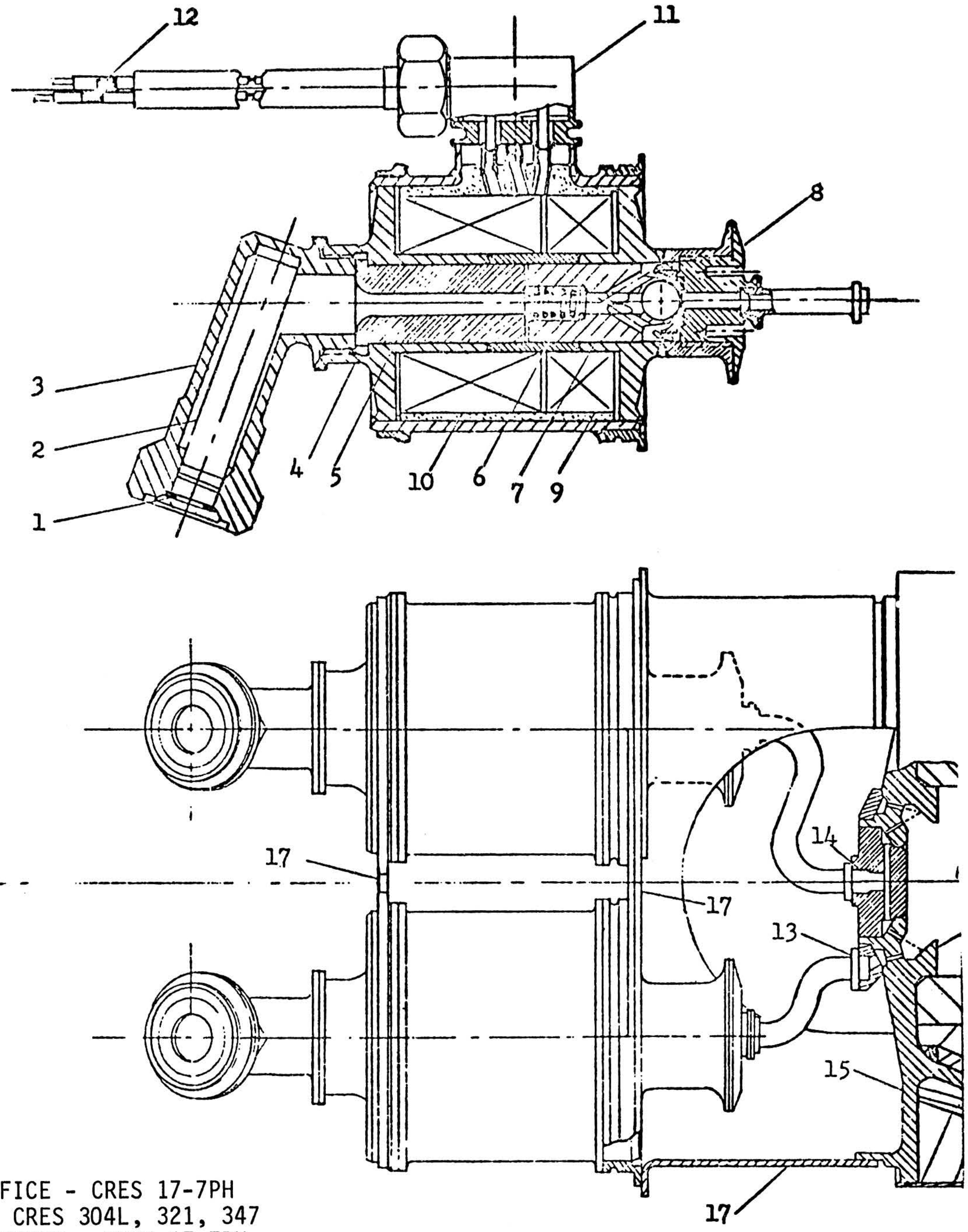
bellows would allow the propellants to come in contact with silicon rubber (a non-compatible material) and the instrumentation position switch and wiring (a possible ignition source). The bellows has been pressure tested to 3000 psi before failure. This is well above the burst capability of the propellant tanks. The bellows design has satisfactorily passed operational tests of 4000 cycles. The probability of a bellows failure under present operating conditions (not more than one operating cycle or abnormal pressure transients) is extremely small. The propellant isolation valves are considered acceptable because of the extremely low probability of exposing nonmetallic material to the propellants. In addition to certification testing these valves have shown compatibility during the propellant compatibility test. Figure 3.3-13 shows the isolation valve and lists the material of its components.

e. Engine injector valve: 3.3-14.

Each valve has two coils as shown in Figure 3.3-14. These coils are external to a welded tube which is considered very reliable. There are no single failures, other than tube leakage, which would expose the coils or other nonmetallic materials to the propellants. The operating history and qualification of the valves demonstrate their acceptability.

3.3.4.2 Fuel System

The fuel system electrical components are the same as the oxidizer system, and the same remarks apply. See (a) through (e) above.



1. TRIM ORIFICE - CRES 17-7PH
2. FILTER - CRES 304L, 321, 347
3. INLET HOUSING - CRES 17-7PH
4. VALVE BODY (BOBBIN) - CRES 321, 430F
5. CORE - CRES 430F
6. SPRING - CRES 17-7PH
7. ARMATURE - CRES 430F W/STELLITE BALL
8. VALVE SEAT ASSEMBLY - CRES 321, 17-7PH W/FEP TEFLON SEAL
9. AUTOMATIC COIL
10. DIRECT COIL
11. LEADWIRE HOUSING - CRES 347
12. LEADWIRES - AWG 20, MIL-W-16878 TYPE EE 19 STRAND NICKEL COATED

FIGURE 3.3.14. CM ROCKET ENGINE INJECTOR VALVE.

3.4 SM/RCS SUBSYSTEM

3.4.1 FLUID SYSTEM DESCRIPTION

The SM/RCS subsystem is composed of individual installations in four bays of the SM. Figure 3.4.1 is a typical schematic of one of these installations. The SM/RCS system is mounted on door panels and are located around the service module as shown in Figure 3.4.2 and Figure 3.4.3.

In each installation a single helium tank supplies ullage pressure to the primary and secondary oxidizer and fuel tanks. Helium flow to the pressure regulators may be shut off (if required) by helium isolation valves. The pressure regulators are two sets of parallel regulators with each set containing two regulators in series with the primary regulator set to operate at 181 $\pm$ 3 psia. Helium flows from the regulated helium manifold through 2 parallel sets of 2 check valves in series to the oxidizer tanks and through an identical check valve configuration to the fuel tanks. The helium ullage is isolated from the fluid propellant by a teflon bladder. A relief valve is installed in each fuel and oxidizer tank helium inlet system to allow the systems to start venting at 225 psia. However, it should be noted that the secondary fuel tank has an isolation valve in the system between the tank and fuel relief and check valves.

Isolation valves are located between each propellant tank and the engine valves of the quad. A pressure transducer is installed between the primary tanks and the isolation valves. Four engines form a cluster for each RCS unit. Figures 3.4.4 and 3.4.5 show the location of the SM/RCS on typical panel assemblies.

Table 3.4.1 defines the compatibility of materials used in the oxidizer system and the rationale for their acceptance. Refer to tables 3.3.2, 3.3.3, and 3.3.4, of the CM RCS section for the compatibility assessment of materials not normally exposed to oxidizer, normally exposed to fuel, and not normally exposed to fuel, respectively.

3.4.2 MECHANICAL AND NON-ELECTRICAL COMPONENTS

3.4.2.1 Helium Tanks

The helium is an inert gas, therefore, there is no compatibility problem for internal materials. Helium pressure vessel (ME282-0051) internal componenets and materials are listed in Table 3.4.2. The 6Al-4V titanium helium tank was demonstrated to be acceptable by certification testing. Hydrostatic testing showed the actual burst pressure to be 8000 psia giving a 1.7 safety factor and to be better than the 7000 psia design burst pressure.

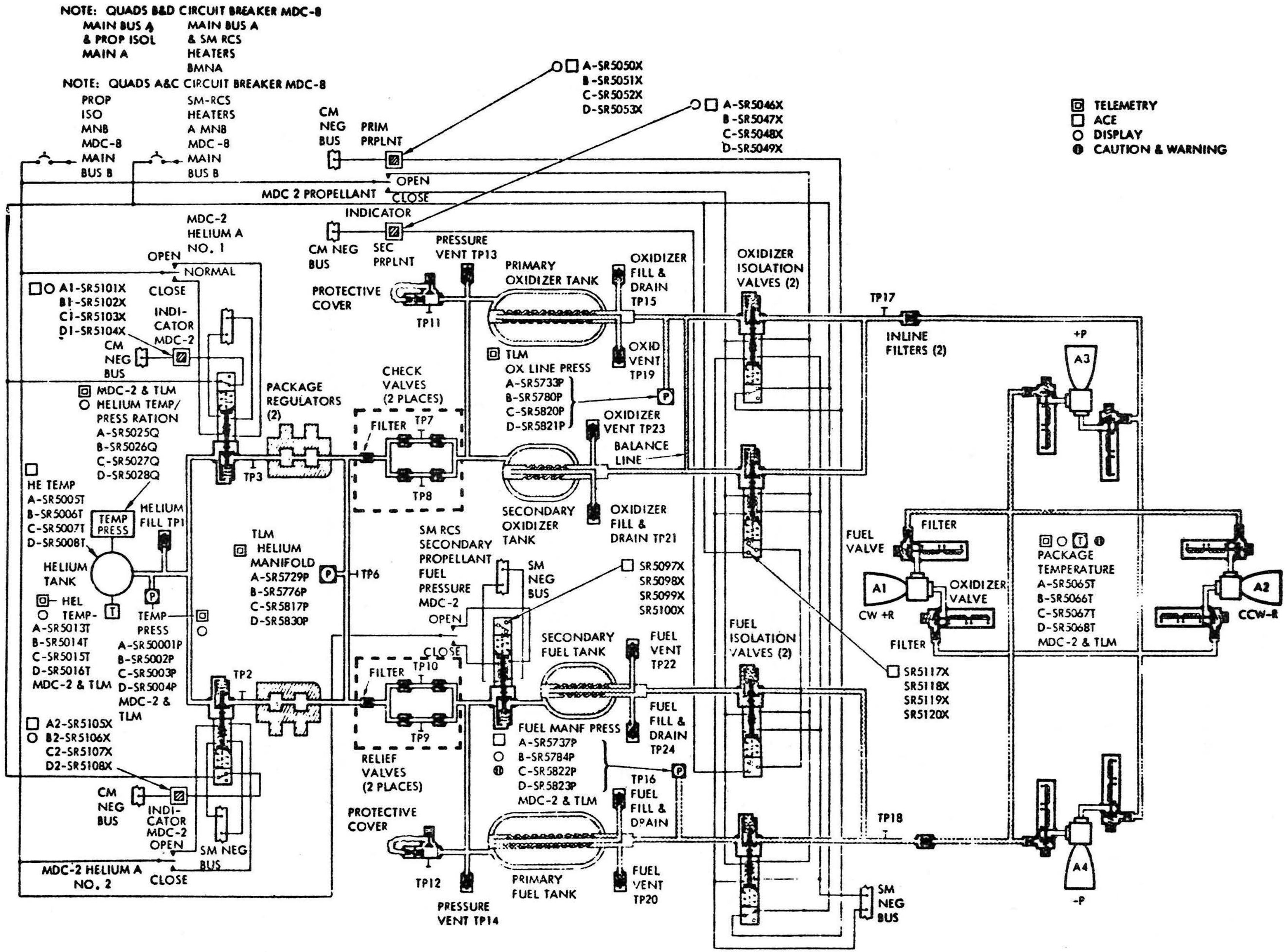


FIGURE 3.4.1. SM REACTION CONTROL SUBSYSTEM.

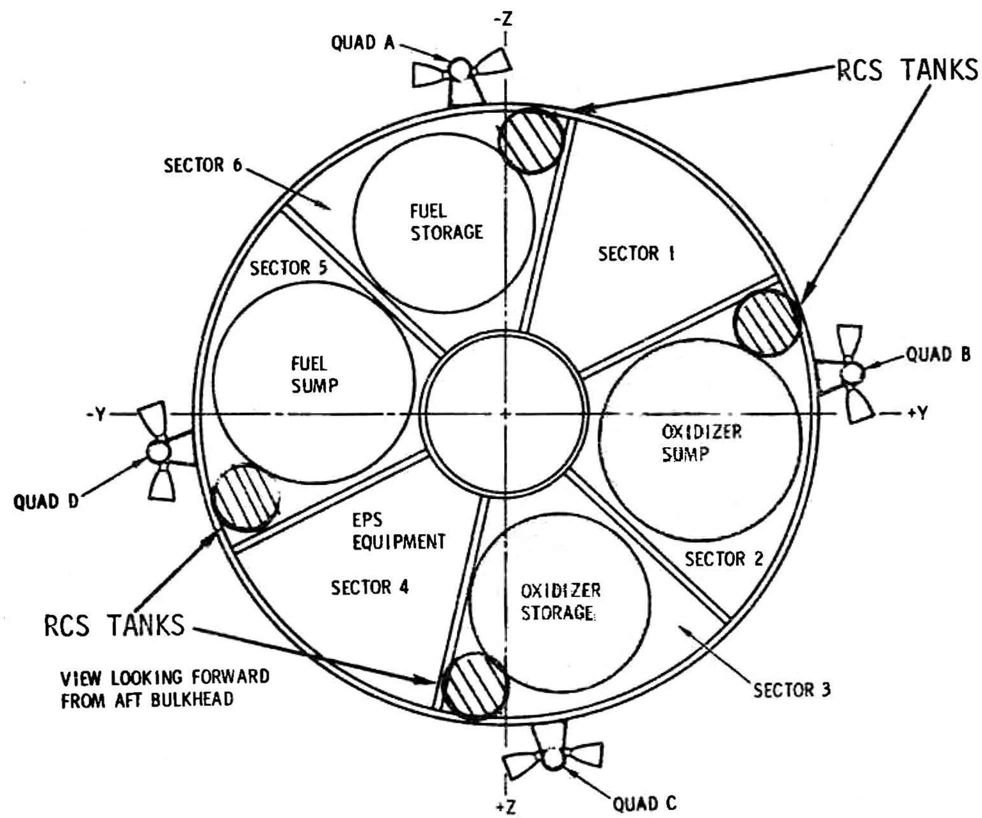


FIGURE 3.4.2. SM/RCS LOCATIONS

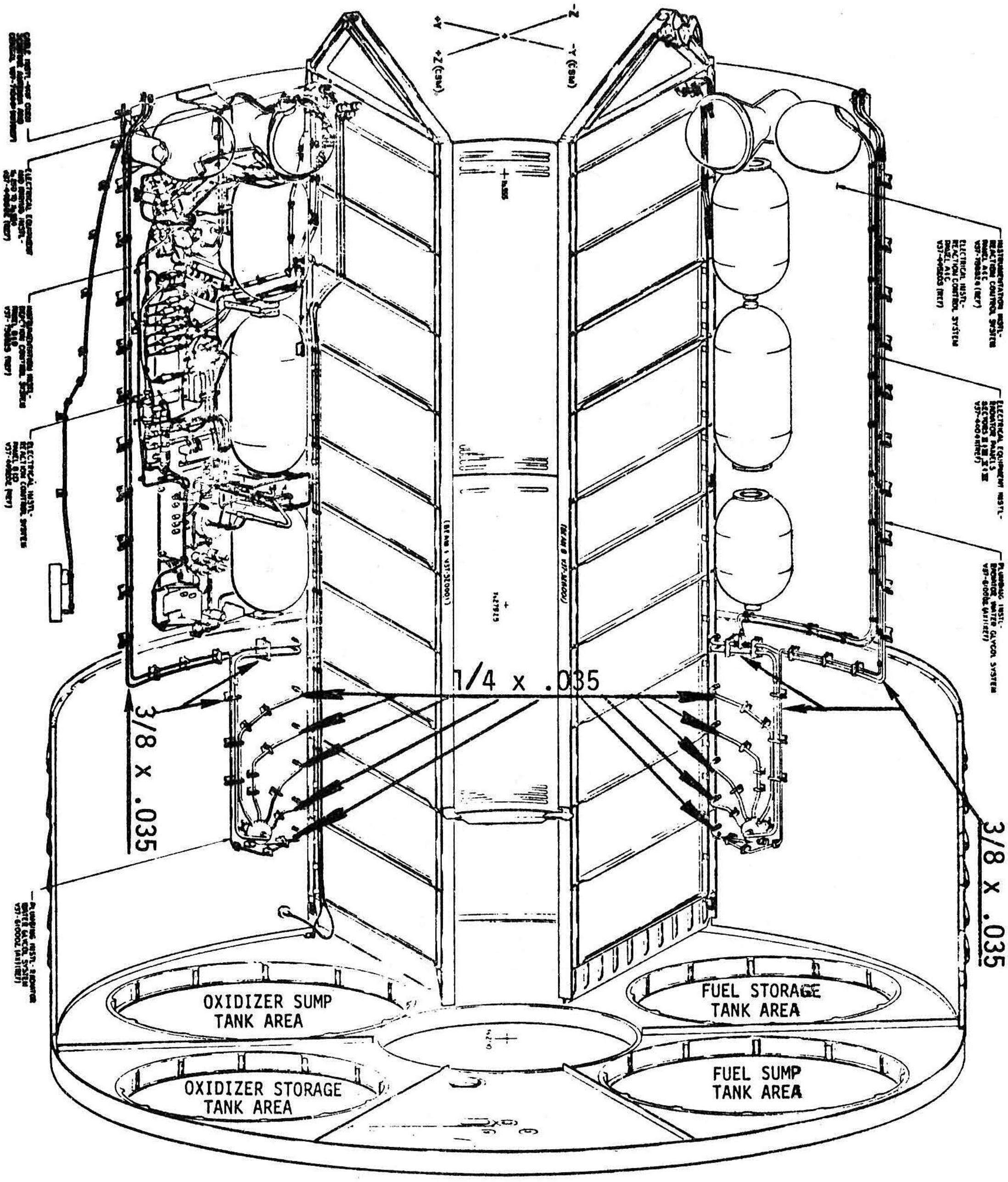


FIGURE 3.4.3. SM SUBSYSTEMS IN PROXIMITY OF RCS TANKS.

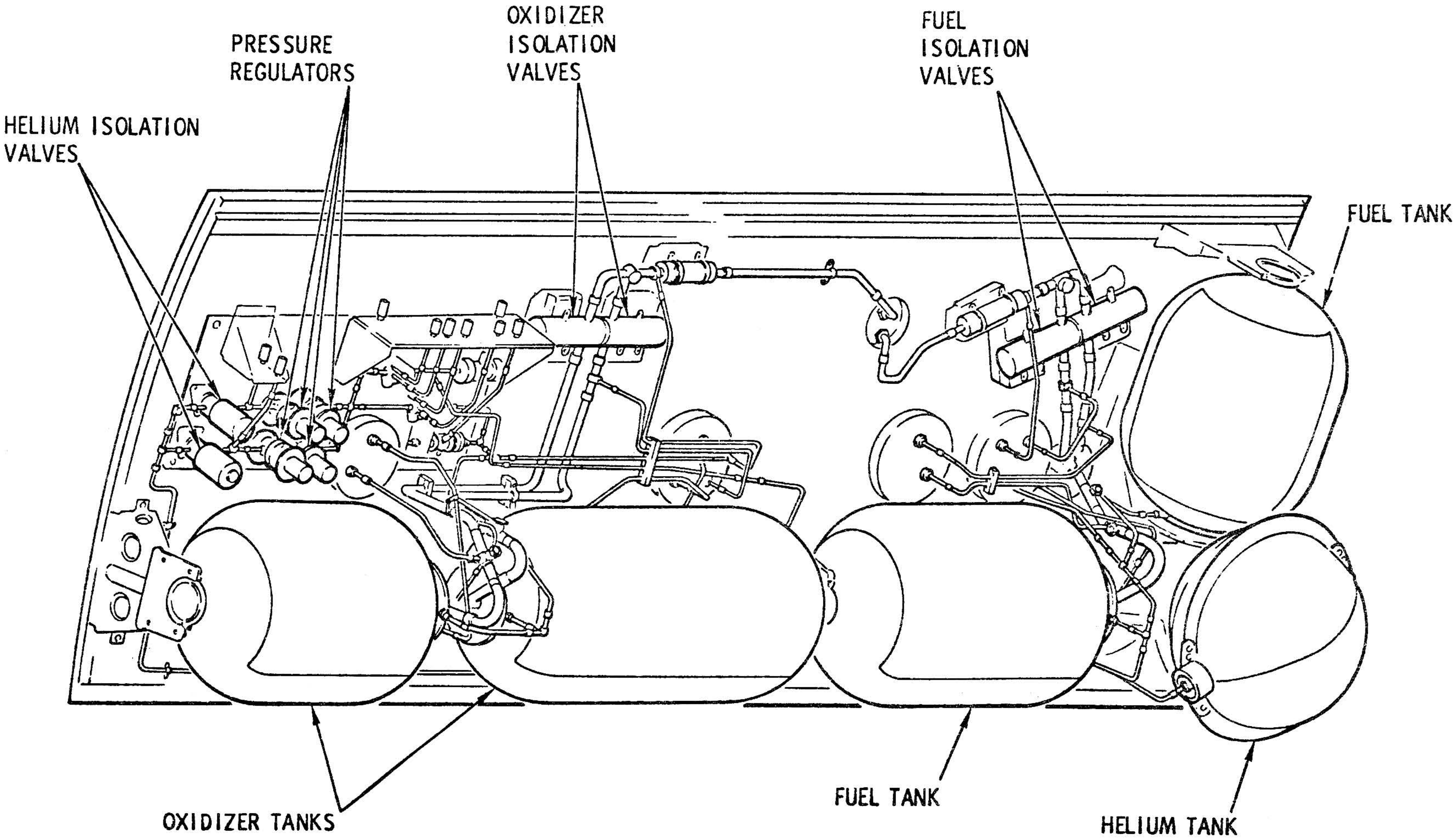


FIGURE 3.4.4. SM RCS PANEL ASSEMBLY QUADS B AND D.

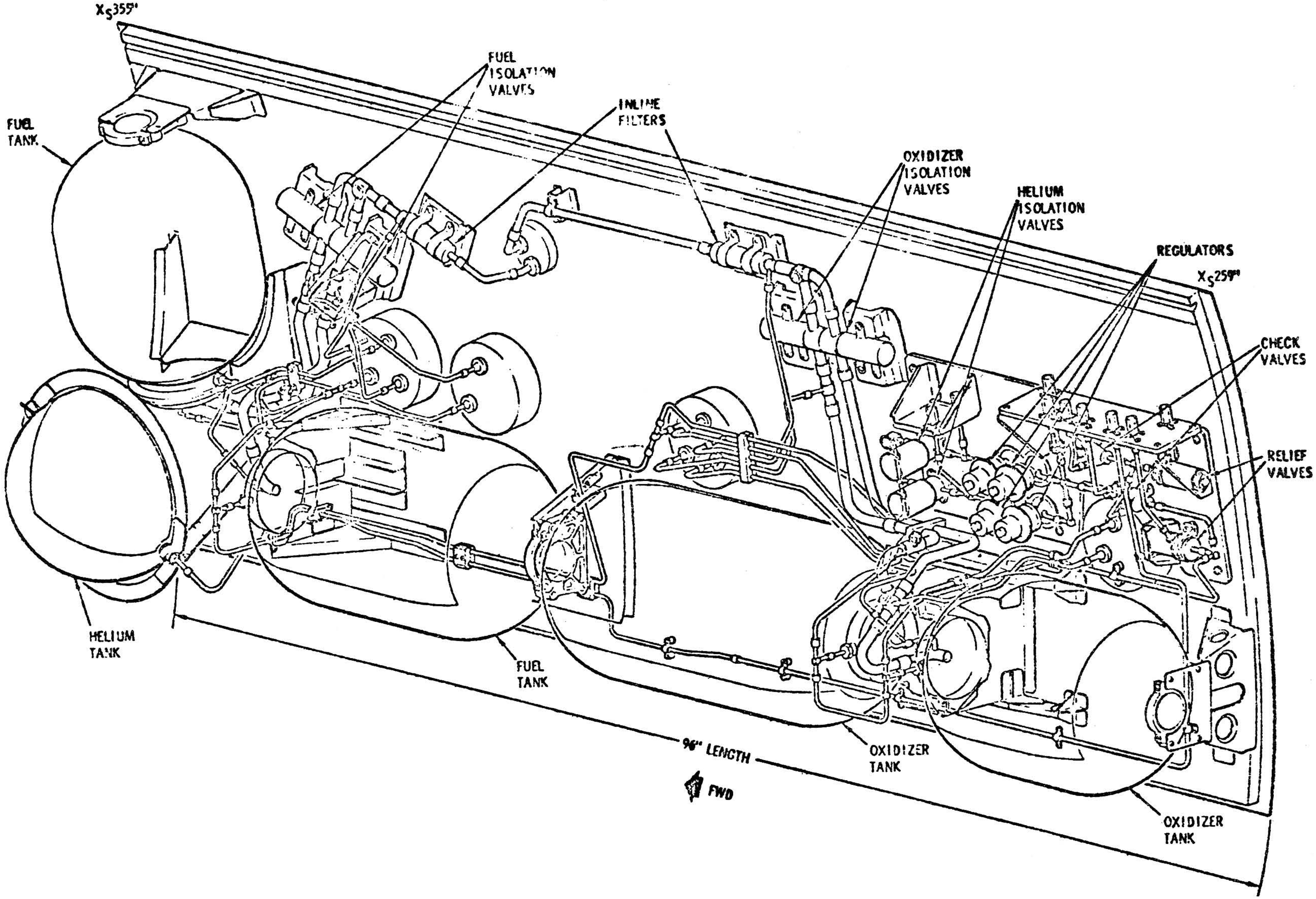


FIGURE 3.4.5. SM RCS PANEL ASSEMBLY QUADS A AND C.

TABLE 3.4.1. COMPATIBILITY OF SM RCS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE

SPACECRAFT COMPONENT	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATIBILITY RATING	REFERENCE/* PAGE NO.	REMARKS
TANK	TITANIUM		GOOD	2/28	
PROBE	STAINLESS STEEL		GOOD	2/28	
	TITANIUM		GOOD	2/28	
	ALUMINUM		GOOD	2/28	
	TEFLON TFE/FEP	BLADDER	GOOD	2/28	
	TEFLON TFE	GASKET	GOOD	2/28	
	TEFLON TFE	VENT PROBE	GOOD	2/28	
	TEFLON TFE	PAD	GOOD	2/28	
	TEFLON TFE	VENT LINE SPACER	GOOD	2/28	
ISOLATION VALVE	STAINLESS		GOOD	2/28	
	IRON		GOOD	2/28	
	ALUMINUM		GOOD	2/28	
	TEFLON	SEAT	GOOD	2/28	
	SILICONE RUBBER	POTTING	POOR	1/55	ACCEPTABLE FOR THIS APPLICATION SINCE ONE FAILURE IS REQUIRED FOR EXPOSURE.
OXIDIZER VALVE	CRES STEEL		GOOD	2/28	
	INCONEL		GOOD	2/28	
	TITANIUM		GOOD	2/28	
	ALUMINUM		GOOD	2/28	
	TEFLON	VALVE SEAT	GOOD	2/28	
PRESSURE TRANSDUCER					

*REFERENCES

1. COMPATIBILITY OF PLASTICS WITH LIQUID PROPELLANTS, FUELS AND OXIDIZERS, JANUARY,1969; PLASTICS TECHNICAL EVALUATION CENTER, PICATINNY ARSENAL, DOVER, NEW JERSEY.
2. COMPATIBILITY OF MATERIALS WITH ROCKET PROPELLANTS AND OXIDIZERS, JANUARY,1965; BATTELLE MEMORIAL INSTITUTE.

TABLE 3.4.2. HELIUM PRESSURE VESSEL (ME282-0051) INTERNAL COMPONENTS AND MATERIALS

PART NAME	PART NUMBER	MATERIAL
K SEAL	12100 PA4	17-4 PH GOLD PLATED
FITTING	V37-460106-3	304L
NUT	MC 174-C10W	CRES-316 CONDFF PASSIVATED
P/T SENSOR	ME449 0124-0002	N1-SPAN 6
SHELL - TIG WELD	6499-7	6A1-4V TI

- RATIONALE FOR ACCEPTABILITY
  - INERT GAS

3.4.2.2 Fuel and Oxidizer Tanks

All propellant tanks are made of 6Al-4V titanium. Primary and secondary tanks of both fuel and oxidizer systems are similar except for tank lengths. The secondary tanks are identical with those used in the command module. The internal tank components are shown and listed in Figure 3.4.6. The teflon bladder is the only non-metallic material within these tanks and is compatible with the propellant. Tank stress corrosion test resulted in the use of green (inhibited) N_2O_4 as the oxidizer. Titanium 6Al-4V is compatible with the propellants now in use.

3.4.2.3 Helium Regulators

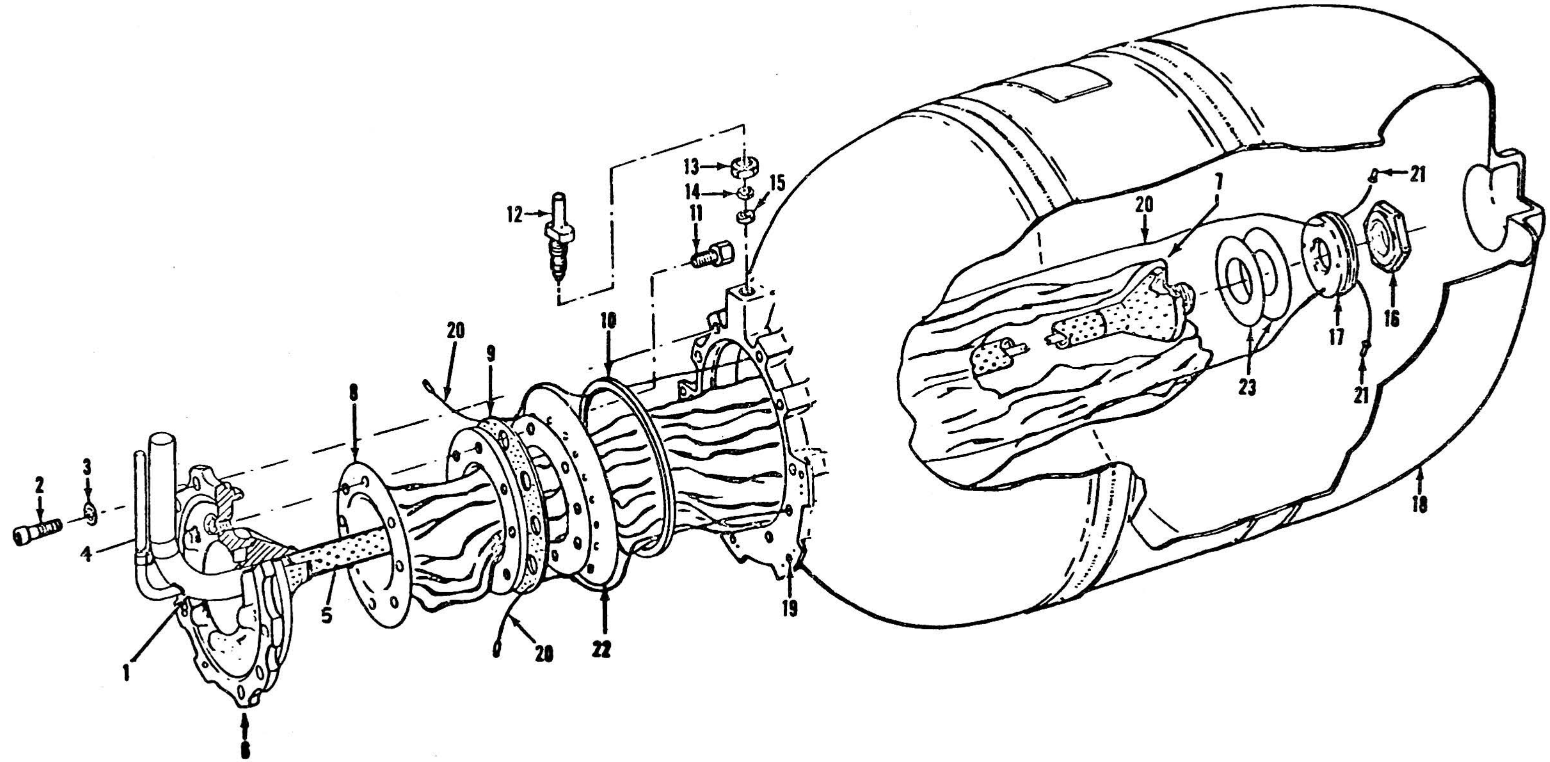
The helium regulators are two regulator sections coupled in series. Figure 3.4.7 shows a cutaway view and lists the materials. A dual failure in the full open position of the series regulators is the only failure mode that would result in over-pressurizing the propellant tank. The flow through the full open regulators exceeds the relief valve capability. The regulators are acceptable without change because the subject failure involves two regulators failing open, simultaneously and in the same series. No open failure has ever been reported for the regulator during development or during use. Details of the regulator failure study are given in the Apollo CSM Reaction Control System Series Regulator Study, SD-68-445, May 1968. Compatibility of materials exposed to oxidizer was demonstrated by the 90 day compatibility test. For details of the test see report "Ninety Day Propellant Compatibility Test CSM/RCS", SD-69-459, July 1969.

3.4.2.4 Check Valves

The check valves are arranged in a configuration to provide a parallel path. Each leg of the parallel path contains two check valves in series. The most common failure mode of a check valve is leakage in the reverse direction or a failure to close. The series/parallel arrangement requires a dual failure before the system is affected. During the 90 day compatability test the check valves were altered to allow leakage to penetrate upstream. At the end of the test the seals on the check valves had deteriorated and become gummy. However, the relief valves still functioned but required a slightly higher cracking pressure and leaked a little. For details of the test, see report "ninety Day Propellant Compatability Test CSM/RCS," SD-69-459, July 1969. A check valve and its list of materials is shown in Figure 3.4.8. Compatability of the exposed non-metallic material within the check valve is considered acceptable within the time constraints established by propellant compatability test.

3.4.2.5 Helium Relief Valve

A helium relief valve is located downstream of the check valves. The

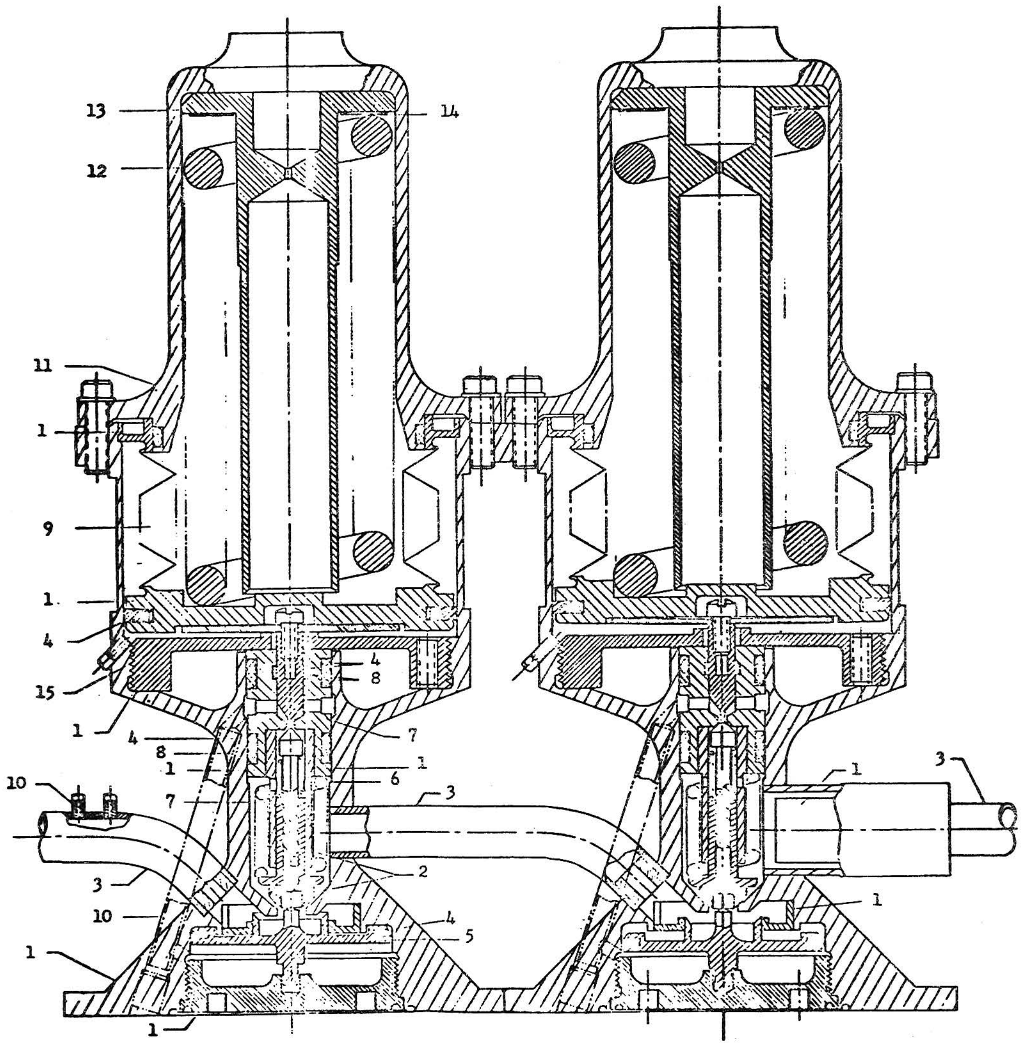


*Non-metallic material

1.	Outlet Tube	(347 CRES)	9.	Ring	(6061 Al)	17.	Washer	(6061-T6 Al)
2.	Bolt	(Titanium)	*10.	Gasket	(Teflon TFE)	18.	Shell	(Titanium)
3.	Washer	(347 CRES)	11.	Bolt	(347 CRES)	19.	Nut Plate	(A286 CRES)
4.	LSV Tube	(347 CRES)	12.	Fitting	(304L CRES)	*20.	Vent Cord	(Teflon TFE)
5.	Diffuser Tube	(6061 Al)	13.	Nut	(347 CRES)	21.	Flanged Eyelet	(304 CRES)
6.	Flange	(6061 Al)	*14.	Gasket	(Teflon TFE)	*22.	Pad	(Teflon TFE/FEP)
7.	Retainer	(6061-T6 Al)	*15.	Gasket	(Teflon TFE)	*23.	Pad	(Teflon TFE)
*8.	Bladder	(Teflon TFE/FEP)	16.	Nut	(347 CRES)			

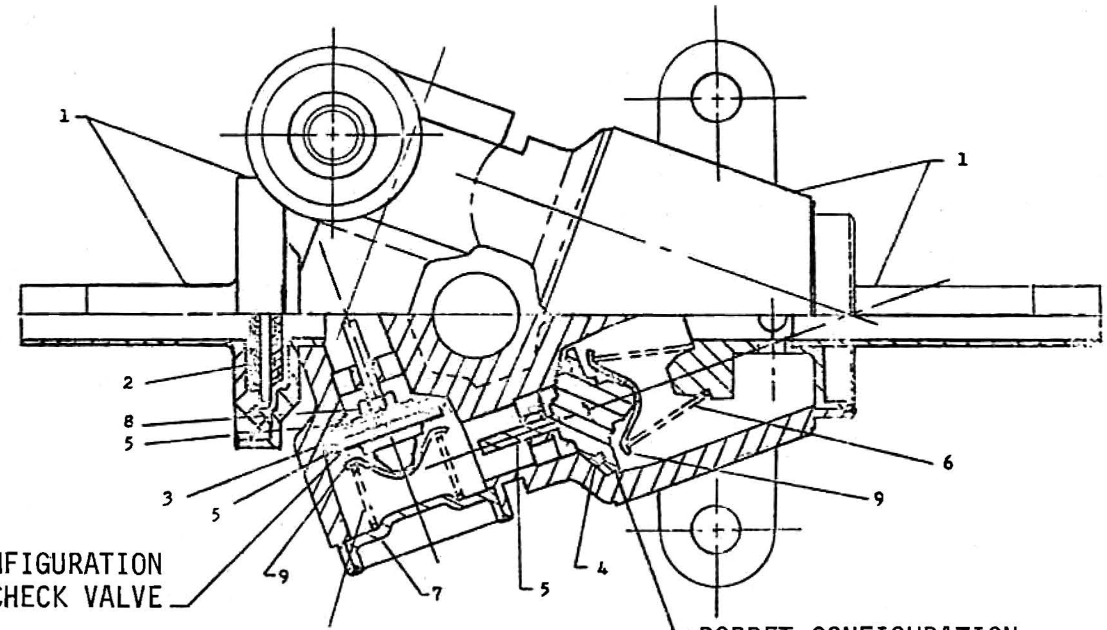
FIGURE 3.4.6. PROPELLANT TANK SCHEMATIC AND MATERIAL LIST.

1. 17-4PH CRES
2. Kynar
3. 304L
4. Teflon TFE
5. 7075-T6 Al
6. 17-7PH CRES
7. 440C CRES
*8. "O" Ring SR634-70
9. AM350 CRES
10. 347 CRES
11. 2024-T4 Al
12. SAE 9254
13. 6061-T6 Al
14. 302 CRES
15. Bimetal



*Non-metallic material

FIGURE 3.4.7. HELIUM PRESSURE REGULATOR.



POPPET CONFIGURATION
OXIDIZER CHECK VALVE

POPPET CONFIGURATION
FUEL CHECK VALVE

1 304L CRES
2 304L WIRE CLOTH
3 *RESISTAZINE 88
4 *EPR
5 17-4 PH
6 17-7
7 321
8 KYNAR
9 304 CRES

*NON-METALLIC MATERIAL

FIGURE 3.4.8. CHECK VALVE

most common failure of a relief valve is leakage. A burst diaphragm is in each relief valve ahead of the valve portion to prevent leakage through the relief valve prior to its use. A low rate bleed vent is provided between the diaphragm and the valve to provide the correct differential pressure across the diaphragm. The system is operated in a manner that the relief valve is not functioned without a failure or an abnormal temperature rise of the propellant tanks. The failure of the relief valve in the closed position (low probability) would therefore be the second of two failures required to over-pressurize a tank. Figure 3.4.9 shows the helium relief valve and lists the material of its components. Teflon is the only non-metallic material in the relief valve and is compatible with the oxidizer and fuel.

3.4.2.6 Filters

The filters used in both the helium and propellant systems contain only metallic materials. The filters have no potential failure modes that would be different from ordinary lines. Figure 3.4.10 shows the filter and lists the material of its components.

3.4.3 ELECTRICAL COMPONENTS IN OR ON HELIUM AND PROPELLANT SYSTEMS

Electrical operating characteristic and interface of propellant components are listed in Table 3.4.3. Hazard potential is listed in Table 3.4.4.

3.4.3.1 Helium Temperature and Pressure Transducers

The temperature and pressure transducers in the helium system are compatible with the inert helium gas. The instrumentation signal conditioner provides current limiting and in the event of an internal failure the heat generated is insignificant.

3.4.3.2 Propellant Pressure Transducers

Propellant pressure transducers are located downstream of the primary oxidizer and fuel tanks. The interface with the propellant is a diaphragm whose burst press is approximately 9000 psi and is well over the tank burst pressure of 600 psi.

A single failure of the diaphragm will expose the stain gages (bridge network), wiring, feed through terminals and glass seal to the propellant.

There are no known failures of the diaphragm. Figure 3.4.11 shows the transducer. This transducer is acceptable due to the low probability of a ruptured diaphragm. In addition to the burst test during certification testing these transducers have also shown compatability during the propellant compatability test.

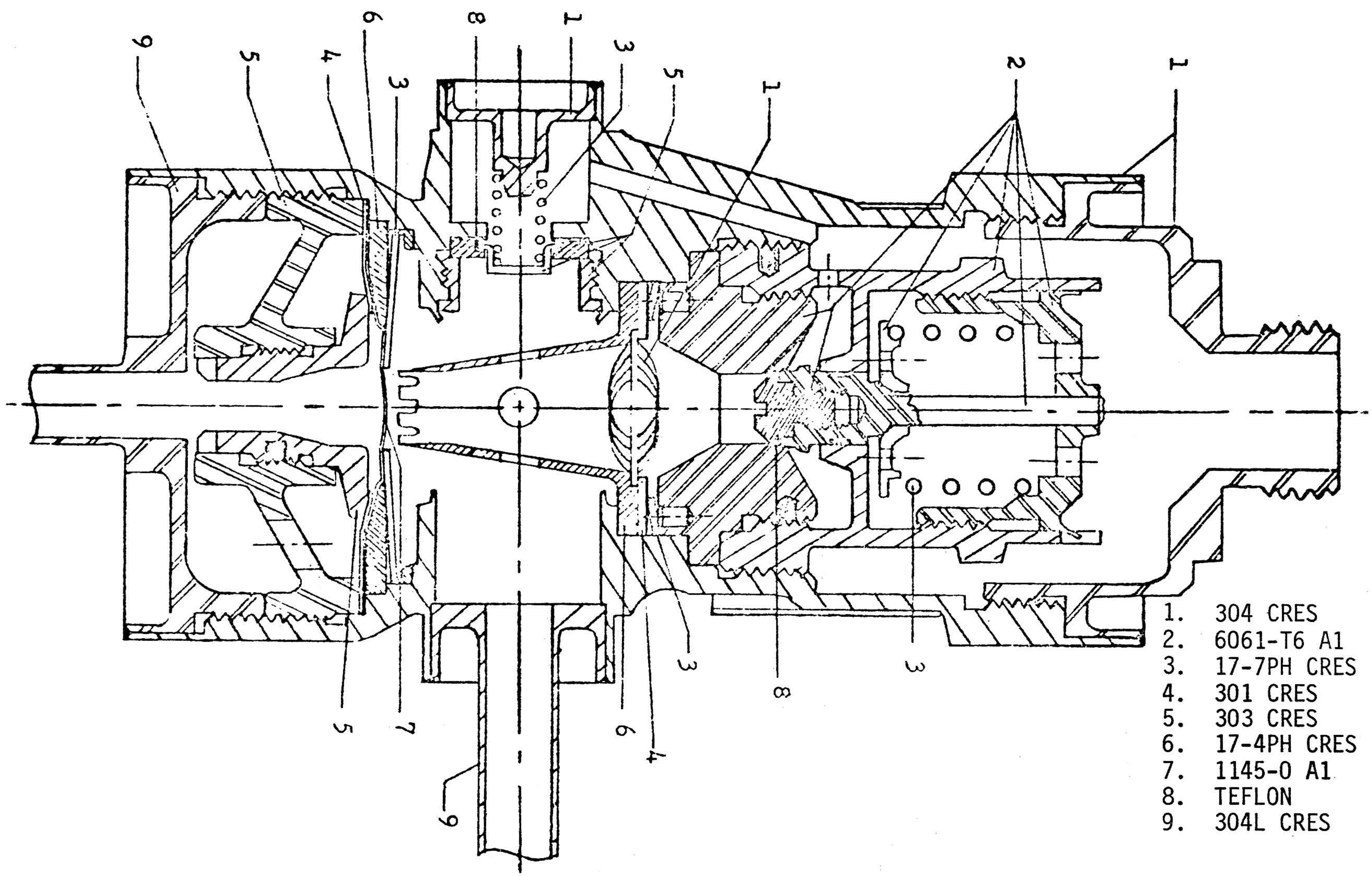
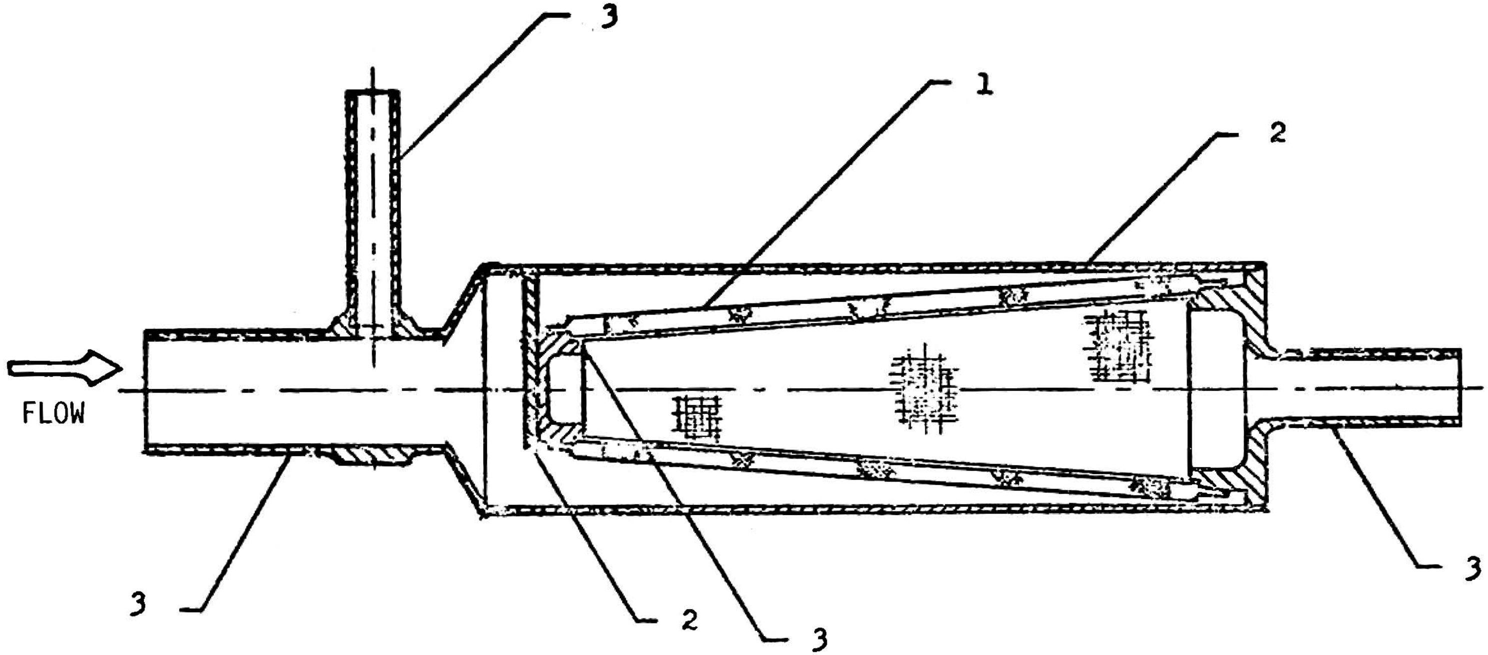


FIGURE 3.4.9. SM RCS HELIUM PRESSURE RELIEF VALVE.



1. 304L CRES WIRE
2. 321 CRES
3. 304L CRES

FIGURE 3.4.10. PROPELLANT FILTER.

TABLE 3.4.3. ELECTRICAL COMPONENTS IN OR ON OXIDIZER AND FUEL LINES

COMPONENT	FUNCTION	NORMAL OPERATING ELECTRICAL CHARACTERISTICS		NORMAL FLUID PROPERTIES AT COMPONENT		SUMMARY DESCRIPTION OF ELECTRICAL COMPONENT TO FLUID INTERFACE	CURRENT LIMITING (AMPS)
		VOLTS	AMPERES	PRESSURE PSI	TEMPERATURE °F		
ISOLATION VALVES ME284-0276-0001-2-7-8	CONTROL PROPELLANT FLOW FROM PRIMARY AND SECONDARY OXIDIZER TANKS	28	1.8 TO OPEN 1.3 TO CLOSE	180	70	SOLENOID ACTUATED LATCHING TYPE VALVES. IN LINE CONTACT WITH FLUID (MECHANICAL VALVE PORTION). MOMENTARY APPLICATION OF POWER REQUIRED TO ACTUATE VALVE. TEFLON ONLY NONMETALLIC MATERIAL NORMALLY IN CONTACT WITH PROPELLANT.	10
PRESSURE TRANSDUCERS ME449-0052-1129 ME449-0052-1131	MEASURE PROPELLANT PRESSURES	4	10 MILLIAMPERES	180	70	NO NONMETALLIC MATERIAL IS USED IN DIRECT CONTACT WITH THE OXIDIZER FLUID.	0.25
OXIDIZER PRESSURE SIGNAL CONDITIONER ME901-0289-1129 ME901-0289-1131	CONDITIONS PRESSURE TRANSDUCER SIGNAL FOR TELEMETRY SYSTEM	28	100 MILLIAMPERES	N/A	N/A	MOUNTED ON CHASSIS NOT IN CONTACT WITH FLUID.	0.25
TEMPERATURE SENSOR ME449-0030-9048	MEASURES QUAD PACKAGE TEMPERATURE	1/2	1 MILLIAMPERE	N/A	N/A	NO DIRECT CONTACT WITH FLUID.	0.25
SIGNAL CONDITIONER ME901-0291-9048	CONDITIONS PACKAGE TEMPERATURE SENSOR INPUT FOR TELEMETRY	28	100 MILLIAMPERES	N/A	N/A	NO DIRECT CONTACT WITH FLUID.	0.25
ENGINE ACTUATOR VALVE	CONTROL PROPELLANT	28	4 AMPERES AUTOMATIC 1 AMPERE DIRECT	185	70	DIRECT INLINE CONTROL OF PROPELLANT FLOWS TO ENGINE COMBUSTION CHAMBER. TEFLON IS ONLY NONMETALLIC MATERIAL NORMALLY IN CONTACT WITH PROPELLANT.	15
HEATERS AND THERMAL SWITCHES	THERMAL CONTROL OF ENGINE VALVES	28	1.4	N/A	N/A	NO DIRECT CONTACT WITHFLUID.	7.5

TABLE 3.4.4.— HAZARD POTENTIAL TO PROPELLANT SYSTEM

SOURCE	ABNORMAL OPERATING CONDITION	REMARKS
ELECTRICAL OPERATION OF ISOLATION VALVES	EXTERNAL OR INTERNAL SHORT OF VALVE AND SWITCH DEPRESSED OR FAILED CLOSED (DOUBLE FAILURE)	PROTECTED BY 10 AMP CIRCUIT BREAKER THEREFORE ALLOWING ONLY MOMENTARY 300 WATT HEAT SOURCE FOR DOUBLE FAILURE OR DEPRESSED SWITCH AND VALVE SHORT.
	BELLOWS FAILURE	A BELLOWS FAILURE WOULD ALLOW THE PROPELLANT TO CONTACT A NON-COMPATIBLE SILICON RUBBER MATERIAL. THIS WOULD EXPOSE SWITCH WIRING AND PRESENT A POTENTIAL IGNITION SOURCE
ELECTRICAL OPERATION OF ENGINE HEATERS	HEATER REMAINS ON OR SHORTS INTERNAL OR EXTERNAL	HEAT OUTSIDE OF SM WOULD NOT RESULT IN A NOTICEABLE HEAT INFLUX. SHORTED WIRING INTERNAL TO SM COULD CREATE UP TO 225 WATTS UNTIL 7.5 AMP BREAKER OPENS.
ELECTRICAL OPERATION OF MANUAL ENGINE ACTUATORS	INTERNAL OR EXTERNAL SHORT	POWER IS ON ONLY DURING SHORT DURATION OPERATION OF HAND CONTROLLER.
ELECTRICAL OPERATION OF AUTO RCS ACTUATOR	INTERNAL OR EXTERNAL SHORT	POWER IS ON WHEN AUTO RCS OPERATION IS ENABLED. A CONTINUOUS HEAT SOURCE OF UP TO 450 WATTS MAY EXIST UNTIL THE 15 AMP BREAKER OPENS. THIS HEAT SOURCE EXTERNAL TO A SM BAY HAS VERY SMALL EFFECT INTERNAL TO THE BAY.

TABLE 3.4.4. HAZARD POTENTIAL TO PROPELLANT SYSTEM (CONT)

SOURCE	ABNORMAL OPERATING CONDITION	REMARKS
SENSOR, PRESSURE AND TEMPERATURE	INTERNAL SENSOR SHORT	CURRENT IS LIMITED TO 250 M.A. SENSOR IS NOT CONSIDERED A POTENTIAL HEAT SOURCE.

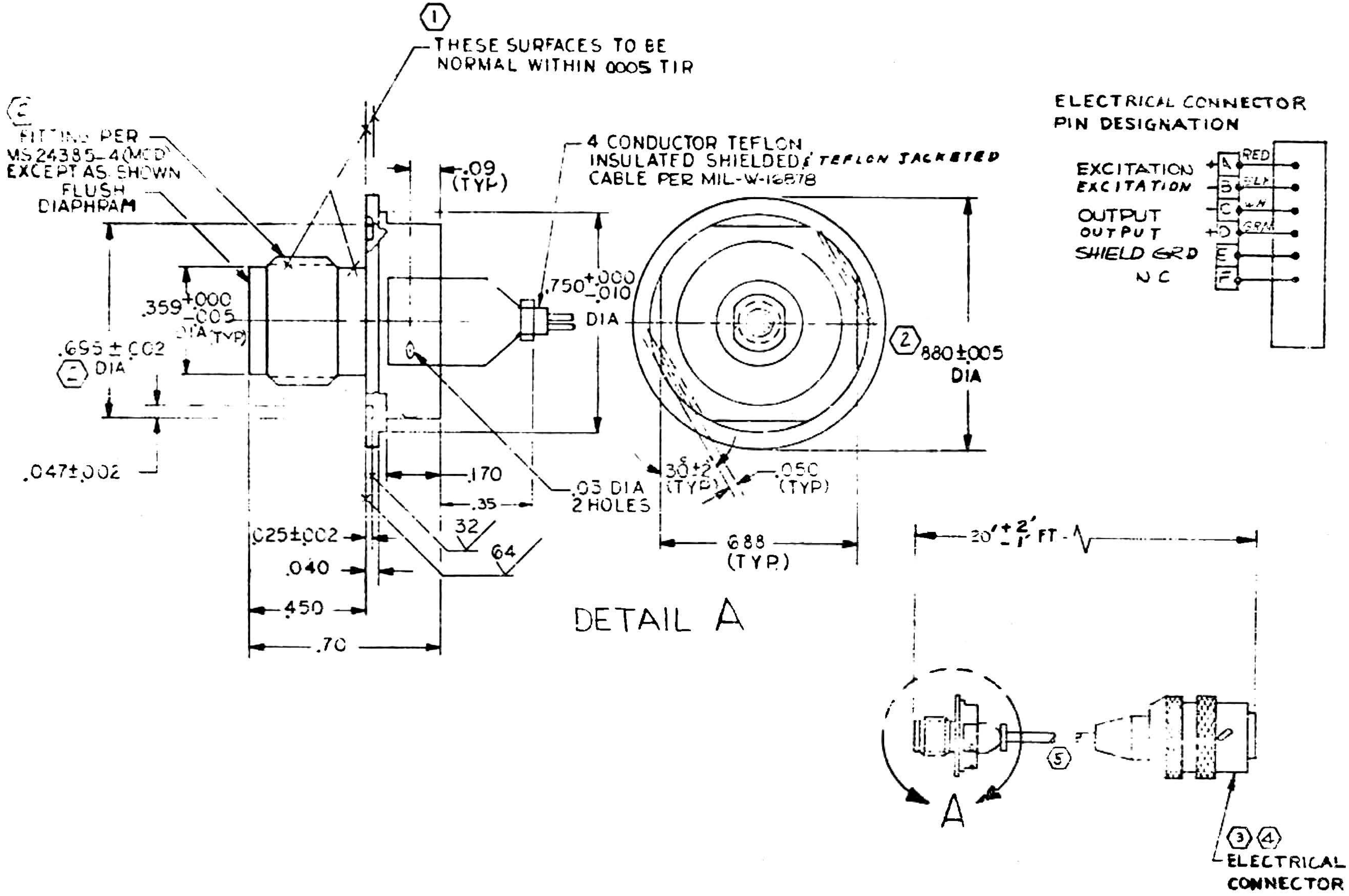


FIGURE 3.4.11. TRANSDUCER, PRESSURE

3.4.3.3 Propellant Isolation Valve

Propellant isolation valves are normally in the open condition and are not normally cycled during flight. Therefore, failures due to cycle life are insignificant. A single failure of the bellows would allow the propellants to come in contact with silicon rubber (a non-compatible material) and the instrumentation postion switch and wiring (a possible ignition source). The bellows has been pressure tested to 3000 psi before failure. This is well above the burst capability of the propellant tanks. The bellows design has satisfactorily passed operational tests of 400 cycles. The probability of a bellows failure under present operating conditions (not more than one operating cycle or abnoraml pressure transients) is extremely small. The propellant isolation valves are considered acceptable because of the extremely low probability of exposing non-metallic material to the propellants. In addition to certification testing these valves have shown compatability during the propellant compatability test. Figure 3.4.12 shows the isolation valve and lists the material of its components.

3.4.3.4 Engine Valves

Each engine has two actuator valves (one oxidizer and one fuel). Each valve has two coils (one auto and one manual). A single failure mode does not exist that would expose additional non-metallic material. Engine valves have been exposed to a broad range of temperatures without failures. In the event heat is induced by the electrical power to the coils or by the strip heaters the resulting temperatures are acceptable. Operating history and propellant compatability test also demonstrate the acceptability of the engine valves. Figure 3.4.13 shows the SM/RCS engine and lists the material of its components.

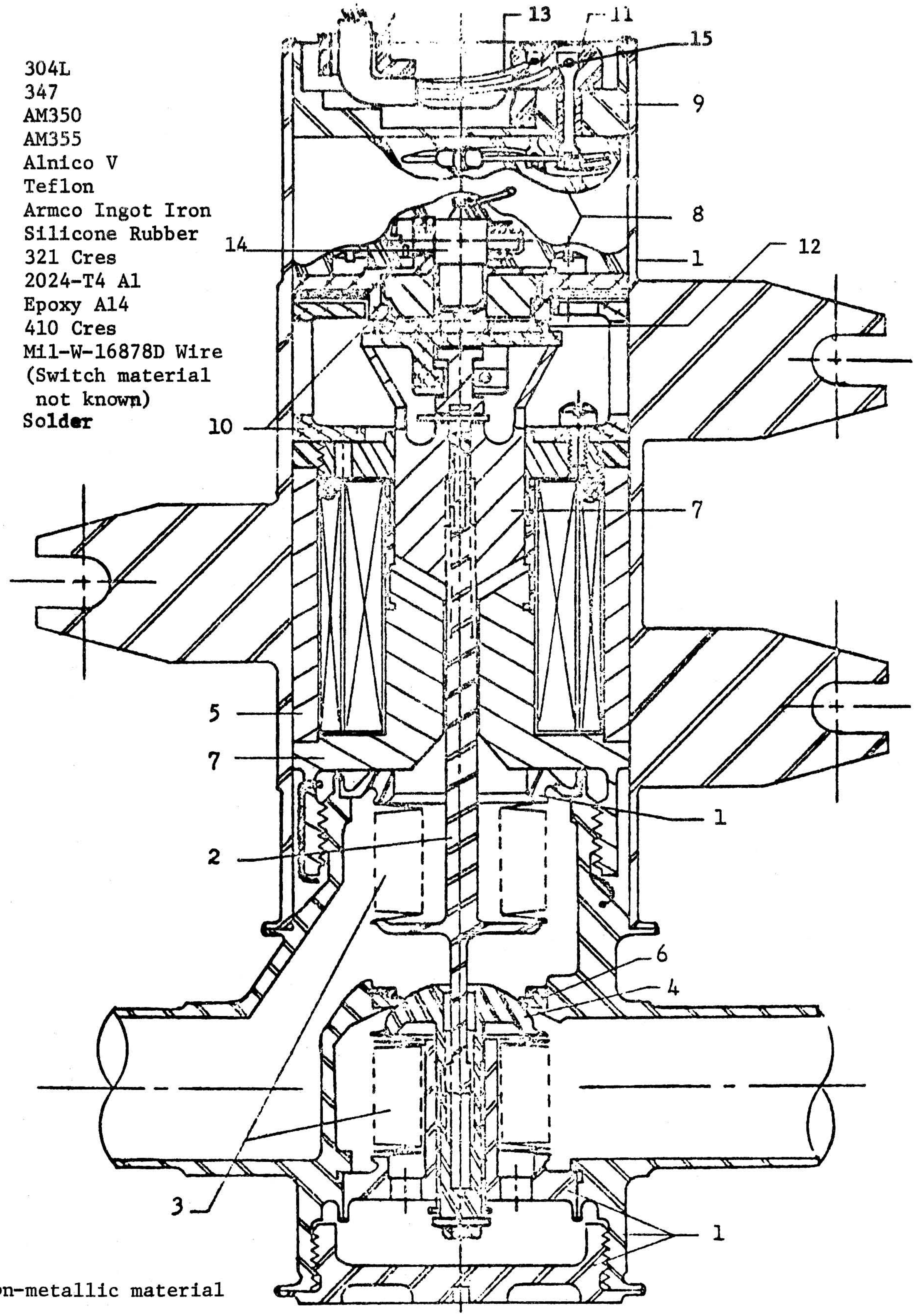
3.4.3.5 Heater, Thermo Switches and Temperature Transducer

The SM/RCS heaters are mounted in manner to prevent contact with the propellants. Figure 3.4.14 shows the SM/RCS engine housing, location of heaters, location of thermo switches and location of package temperature measurement.

3.4.4 SUMMARY OF UNRESOLVED ISSUES

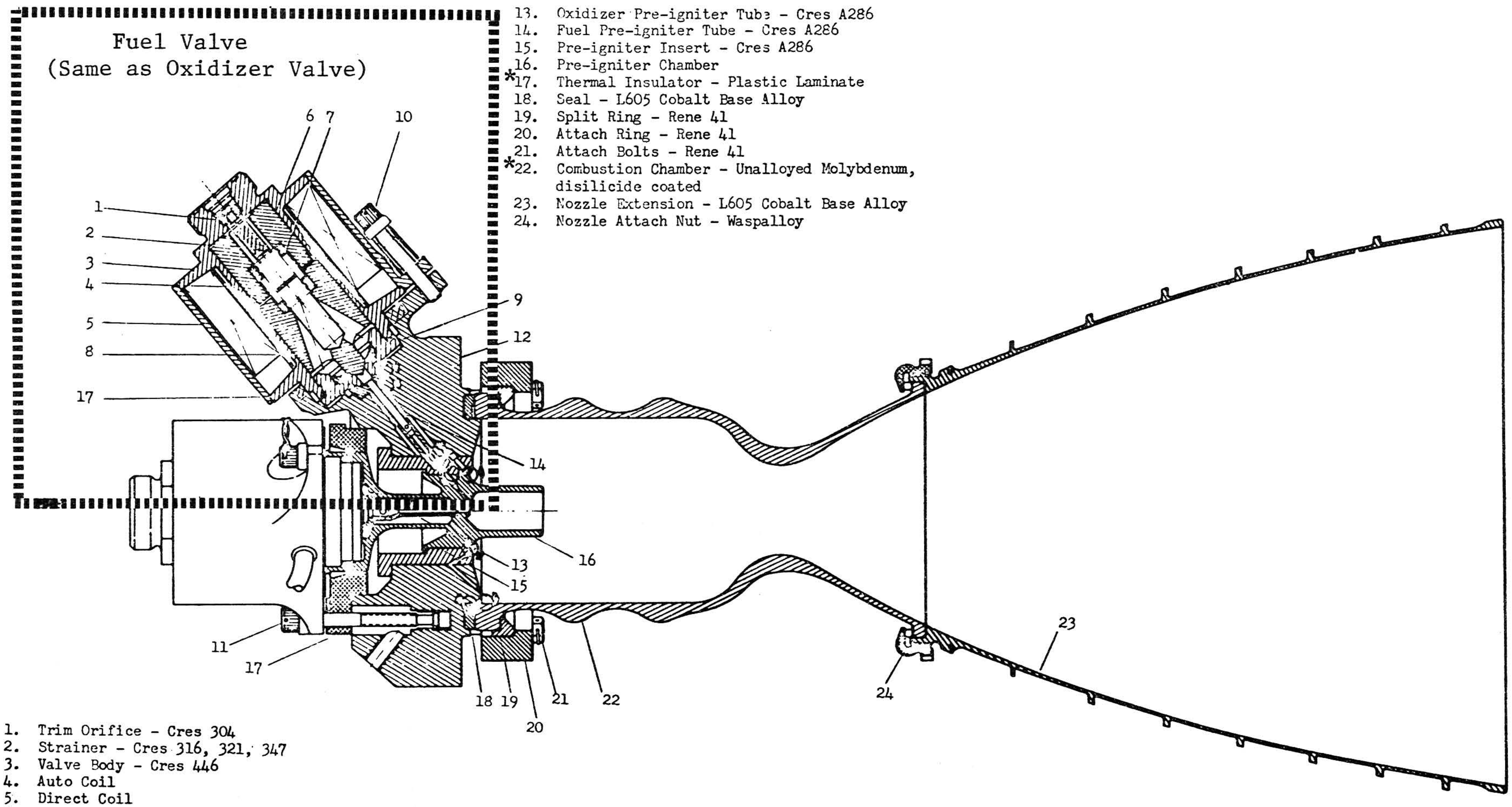
The affect of propellants upon silicon rubber under 180 psia pressure with an ignition source present is not known. This is not considered a problem since test data indicates that, even though a single point failure mode exists that could bring propellant in contact with the silicon rubber, the safety factor of the component is high.

1. 304L
2. 347
3. AM350
4. AM355
5. Alnico V
*6. Teflon
7. Armco Ingot Iron
*8. Silicone Rubber
9. 321 Cres
10. 2024-T4 A1
*11. Epoxy A14
12. 410 Cres
13. Mil-W-16878D Wire
*14. (Switch material not known)
15. Solder



*Non-metallic material

FIGURE 3.4.12. SM RCS ISOLATION VALVE.



13. Oxidizer Pre-igniter Tube - Cres A286
14. Fuel Pre-igniter Tube - Cres A286
15. Pre-igniter Insert - Cres A286
16. Pre-igniter Chamber
*17. Thermal Insulator - Plastic Laminate
18. Seal - L605 Cobalt Base Alloy
19. Split Ring - Rene 41
20. Attach Ring - Rene 41
21. Attach Bolts - Rene 41
*22. Combustion Chamber - Unalloyed Molybdenum, disilicide coated
23. Nozzle Extension - L605 Cobalt Base Alloy
24. Nozzle Attach Nut - Waspalloy

1. Trim Orifice - Cres 304
2. Strainer - Cres 316, 321, 347
3. Valve Body - Cres 446
4. Auto Coil
5. Direct Coil
6. Plug - Cres 446
7. Spring - Inconel X
8. Armature - Cres 446
*9. Valve Seat Assy - AM 355 w/TFE teflon seal
10. Fuel Valve Attach Bolts - 6AL-4V Titanium
11. Oxidizer Valve Attach Bolts - Cres A286
12. Injector Housing - 6061T6 Aluminum

*Non-metallic material

FIGURE 3.4.13. ROCKET ENGINE

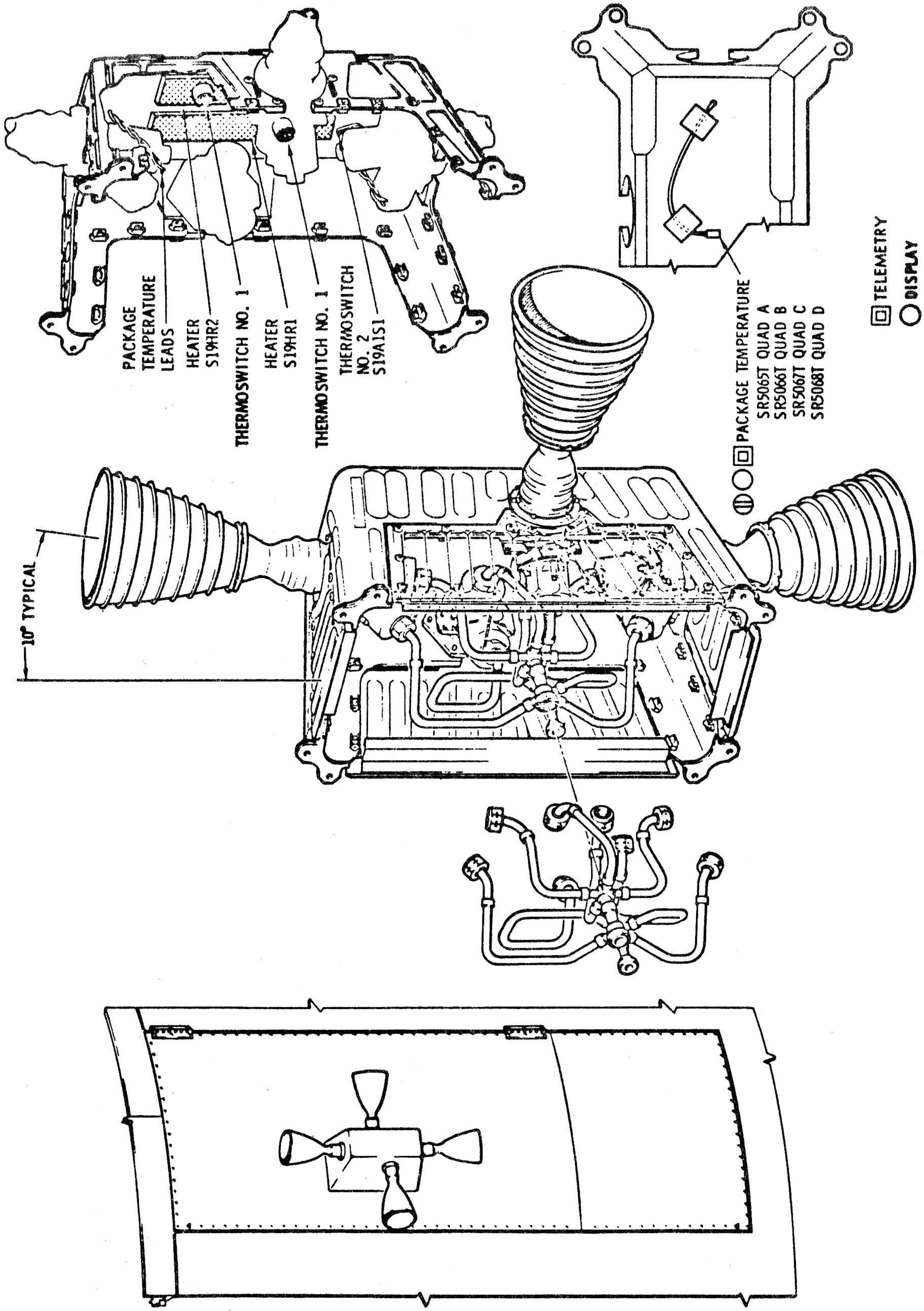


FIGURE 3.4.14. SM RCS ENGINE HOUSING.

3.5 SERVICE PROPULSION SYSTEM (SPS)

3.5.1 FUNCTIONAL DESCRIPTION

The SPS consists of a helium pressurization system, a propellant feed system, a propellant gauging and utilization system, and a rocket engine. The fuel is aerozine -50 (A-50) and the oxidizer is inhibited nitrogen tetroxide (N_2O_4). The pressurizing gas is helium. Figure 3.5.1 is a functional flow diagram of the SPS.

3.5.2 MATERIALS

Table 3.5.1 is a listing of the tank and fluid component materials used in the SPS. This listing includes materials which are wetted by the N_2O_4 and A-50 in normal operation and following a single seal or bellows failure. Table 3.5.2 defines the compatibility of material used in the oxidizer system and the rationale for their acceptance. Refer to table 3.3.2 of the CM RCS section for the compatibility of materials which may be contacted by the oxidizer in the event of a single failure, spill or leakage. Table 3.5.3 defines the compatibility of materials used in the fuel system and the rationale for their acceptance. Table 3.5.4 defines the compatibility of materials which may be contacted by the fuel in the event of a single failure, spill or leakage. Necessary data on the following materials are not available and testing has been initiated.

a. A-50/Kovar reaction (29% nickel, 17% cobalt and 54% iron)

b. A-50/Ni-Span-c reaction

c. N_2O_4/Teflon flammability

d. N_2O_4/Solder flammability (96.5% Sn, 3.5% Ag and QQ-S-571)

3.5.3 MECHANICAL COMPONENTS AND TANKS

3.5.3.1 PRESSURE REGULATOR ASSEMBLIES

Pressure for the SPS fuel and oxidizer tanks is provided by the helium pressurization subsystem. Tank pressure is controlled by redundant two-stage regulators. Failure of a primary stage of a regulator results in a regulated pressure increase from approximately 186 to 191 PSI. Failure of a secondary stage would not increase tank pressure. Failure of both stages open could result in tank rupture as the relief valve capacity is less than the flow rate through the failed regulators. The failure of both stages open is considered remote.

3.5.3.2 RELIEF VALVES

The pressure relief valves consist of a relief valve, a burst diaphram and a filter. Diaphram rupture pressure is 219 $\pm$ 6 PSIG and the relief valve relieves at 212 PSIG minimum and 225 PSIG maximum pressure. During normal system operation, the burst diaphram provides additional protection against

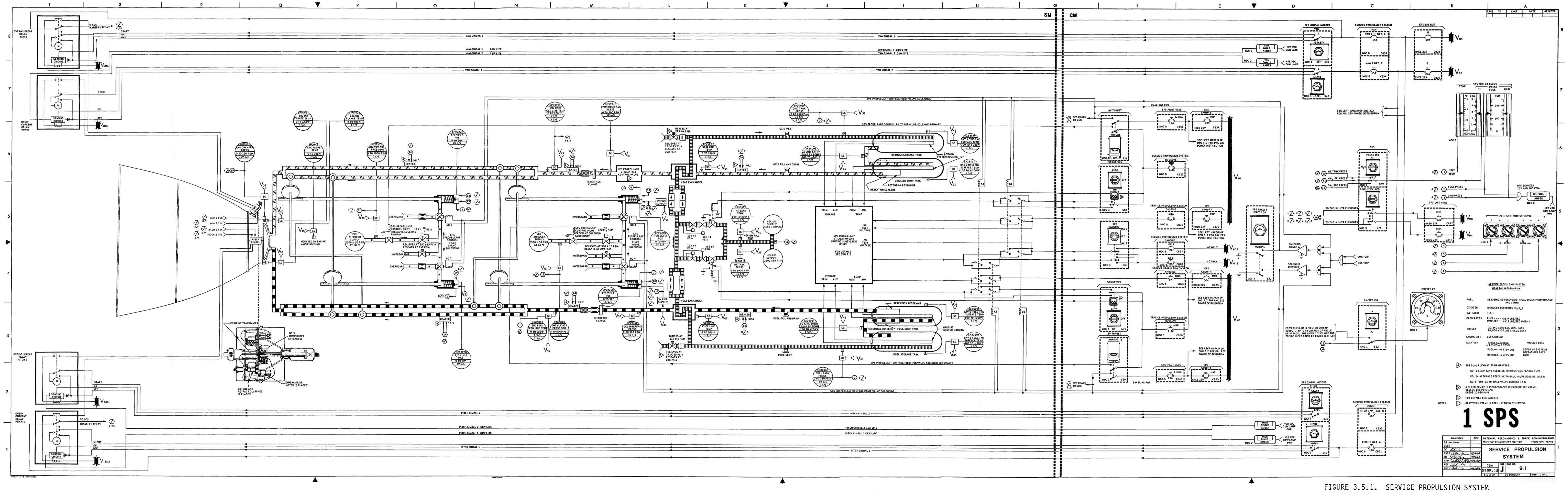


FIGURE 3.5.1. SERVICE PROPULSION SYSTEM

Table 3.5.1, a, SPS MATERIALS

PART NAME	PART NUMBER	MATERIALS
Helium tank	V37-347108	6AL-4v titanium
Sump tank (Fuel & oxidizer)	V37-342102	6AL-4v titanium
Retention res:	V37-342102	6061 AL alloy & Cres honeycomb
Door assy	V37-470204	Titanium & Cres tubing
Screen assy	V17-470451	Teflon-AMS-3651 Cres & 6061 AL alloy
Storage tank (Fuel oxidizer)	V37-343102	6 AL-4V Titanium
Door assy	V37-470203	Titanium & Cres tubing
O-ring	MD261-0001-254 & 258 V17-480217-9 & 7	MB 0130-027 (Butyl)
Seal	10059-16-505 10059-5-705	RAYCO Seal (Teflon)
GN_2 tank	119578 (Aerojet)	AM 350 stainless steel

Table 3.5.1, b, SPS MATERIALS

PART NAME	PART NUMBER	MATERIALS	
SPS OXIDIZER PROBE			
Flange base	389660, 389661	6061-T6 AL	
Tube tower	389653	6061-T6 AL	
Terminal Assy's	384055, 386964 & 389685	302, 303 Cres	
Compensator	386548	Teflon, TFE MIL-P-2296	
Ring support	386380	Teflon, TFE MIL-P2296	
C-ring outer	386381	302 Cres	$\frac{1}{2}$ hard, per
C-ring intermediate	386379	302 Cres	QQ-S, Class
C-ring inner	386526	302 Cres	302 Cond-C
Bracket R&th	389048-1, 389047-1	302 Cres	Passivate
		per MIL-F 14072, finish E 300	
Ground tube assy	38709		
Tube ground	389707	6061-T6	
Bracket	389079	"	
Inner Tube Assy	389669		
Tube, lower	389665	3003-A-18 WW-T-700/2	
Tube, inner	389697	3003 H-18 WW-T-700/2	
Tube, Upper	389666	3003-H-18 WW-T-700/2	
Sleeve, Upper	386426	6061- T651	
Sleeve, Lower	388974	6061 - T651	
Sleeve, Center	388975	6061 - T651	
Solder	QQ-S-571	SN100	
Washer Insulator	389679	Teflon-TFE Type 2, Class "E"	
Bushing, split	389650		
Spacer Grd Shld	389683	Teflon TFE Type 2	
Spacer collar 389682	389682	Class G	
Sleeve	389678		
Clamp hold down	389686		
Outer tube	389659	6061-T6	
Temp tube & plug		6061-T6	

Table 3.5.1, c, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS OXIDIZER PROBE (continued)		
PT sensor support assy	389690	
Mount ring	389695, 389696	Teflon-FEP
Support	389101	AL alloy per MIL-A-21110 Alloy No. A 356 Class 2 A grade "C"
Clamp assy	386989	
Band clamp	386857	301 Cres
Buckle clamp	386858	302 Cres
Collar insulated	89682	Teflon FEP
Half collar	389681	Teflon FEP
Clamp spacer	388681	301 Cres
Spacer	1389703-1 thru 9	6061 T651
Cap scuff	386432	Teflon FEP
Pin Lock	386941	Teflon - TFE
Tie bar	389046	302 Cres
Sensor ring	386419	6061 T6
Terminal	389330	
Solder		96.5 S/N 3.5 AG
Bushing, spacer	386517	
Spacer	386328	
Stand off	386322	
Brackett	386402	
Screws	MS35275-14-17-48 45 -47	
Washer	MS-15795-807	
Lug terminal	388231	

Table 3.5.1, d, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS Oxidizer Probe (cont'd)		
Pin lock	386941	
Wire lock	M520995-C20	
Cable clamp	M5213221	
Lug solder	386564	
Ins shoulder washer	398830	
Ins. tubing	12A006-MIL-E-22129	Teflon
Wire	389291-2 and -1 389291-1	
Insulator	389713	
SPS Fuel Probe		
Flange base	389470,339471	6061-T6
Tube, tower	389468,389469	6061-T6
Bushing	389180	QQ-5-763 347 CRES
Ferrule	389281	Kovar 52-460 Westinghouse
Primary sensor glass tube	339460,389459	Glass Pyrex Teflon -FEP
Temp tube & plug Lug	389680 389651	6061T6 2024
Clamp ring	388118	Teflon-TFE GROUP A MIL-P-19468
Clamp hold down	386549	2022-T35
Rod spacer	389450-1,389483-1 389455-1,-2,-3,-4	2024-T4

Table 3.5.1, e, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS FUEL PROBE (continued)		
Clamp assy	386989	
Band clamp	386857	301 Cres
Buckel clamp	386858	302 Cres
Collar insulated	389682	Teflon-FEP
Spacer collar	386757	
Clamp spacer	388681	Teflon-FEP
Point sensor support	339486, 389101	MIL=A-21180 A356 Class A grade
Mount, ring	389695, 389696	Teflon-FEP
Plate	389103	5052 - H34-QQ-A-318
Ring sensor	386795	6061-T6
Terminal Assy	339331	Kovar & Glass
Pin lock	388941	Teflon TFE
Point sensor & Tube Assy		
Tube conduit	389476, 389475	3003 AL alloy - H14
Snobber	389006	Teflon TFE
Insulator tube	389474	Teflon SEP
Point sensor Comp assy	389213	
PCD's	389201, 389197,	Epoxy/laminate Type FL-GB-062C2/2 MIL-P-13949

Table 3.5.1, f, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
PRESSURE TRANSDUCER (Wetted components)		
Body	ME 449-0052	NI-SPAN
Seal	ME 261-0011	Teflon
Seal	ME 261-0010	Teflon coated V-ring
PROPELLANT UTILIZATION VALVE (Wetted components)		
Valve body & actuator assy	483704	AMS 5362 D CRES, 347, 304, 440, & 304 CRES
Bellows		AMS 5548 CRES
Gate assy	483723	304, 347 & 410 CRES Teflon TFE
Lubrication	Dixon 95-1	Flora-Carbon LUB
SPS ENGINE ASSY		
Propellant line	AGC 112196-11	CRES 321
Bleed line	AGC 112906	Teflon & CRES 3046, 321 or 347
Filter, Screen	AGC 712135-5	CRES 347, 321, 3046 QQ-S-763
Filter seal	A 58040 E1-235	Teflon
Filter discharge	V37-470-231	CRES 3046

Table 3.5.1, g, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS ENGINE ASSY		
Pressure port plug		
Filter discharge	ME 261-0011-0035	Teflon
Pressure port seal	ME 261-0010-0001	Teflon
Propellant Line	RACO seal	
To S/C interface seals	11900-3.860 & MD261-0001-0155	Teflon on spring steel Butyl "O" ring
Propellant line	RACO seals	Teflon on spring steel
To valve seals	10053-1 & -3	
Orifice plate	710100-13	CRES 321 or AL AL 606-1T651
Filter snap ring	MS 16631-4334	
Bipropellant valve AGC 1155050-8		
Spacer	1154672-1	CRES 304 Cond A QQ-S-763
Spring	1133790-1	CRES 17-7PH AMS 5673
Ball seal	1154272-4	Cres 17-7PH MIC-S=25043
Spacer	1154033-12	AL all 606100-A-200/E 25 -11, Anodize MIL-A-8625 T
Ball seal cage	1154034-2	"
Bearing	1132998-11	Teflon on Arm alon
Seal	1132997-3	Teflon AGC 44087
Ball shaft	1154506-6	CRES 17- PH AMS 5643
Valve ball	1153975-4	Cres 17-7PH AMS 5644
Shaft seal(RACO seal)	Coml prod 10066-1-684	
Washer	1155111-1	CRES 307 QQ-S 763
		Polytetra (teflon) AGC 44087
Washer	1154291-1	Fluoroethylene or AMS 3651
Spacer	1155110-1	CRES 302 QQ-S-763 cond A

Table 3.5.1, h, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS ENGINE ASSY (continued)		
Bipropellant valve (continued)		
Nut	1153900-2	CRES 304L QQ-S-763
Washer tab	1154219-4	CRES 301 MIL-S-5059
Shim	1131971	CRES 301 or 302 MIL-S-5059
Expander	703873	CRES 347 QQ-S-763
Seal spring	1133788-1	CRES 17-7PH AMS 5673
Cage Omniseal	Coml prod AR10105-235 A2N	
Cage body	1133795-5	CRES 17-7 AMS 5644
Spring holder	1133792-5	CRES 304 QQ-S-763
Seal	1154272-4	CRES 17-7 PH MIL-S-25043
Shim	1131971-62	CRES 521 or 347 MIL-T-6737 or 6845
Cage screw	A54476-632-10	CRES
Washer	NAS62006	CRES
Safety wire	MS20995C20	CRES
Ball Cage	1154035-1	AL 6061-T6 anodize MIL-A-8625,Type I, CL I option alodine MIL-C-5541, Cl I,grade optional
Plug	1133037-1	
Seal retainer body	1153883-3	CRES 17-7PH AMS 5644
Helical spring	1118955-1	CRES 17-7PH AMS 5673
CAF screw	1154289-1	CRES from AS 4476-63275
Valve cord	0894-94	AL alloy 356-T6

Table 3.5.1, i, SPS MATERIALS

PART NAME	PART NUMBER	MATERIAL
SPS ENGINE ASSY (continued)		
Injector's header	711525-17	Inj AL alloy 50834113 Header Al 356-76
Valve to injector	10053-3	Teflon over spring steel
RACO seals	10054-3.931	
Injector purge plug	1121387-1	CRES 347 QQ-5 -763
Injector purge		
Plug seals	Packing AS8040	Teflon
Lubricant		FS 1281
Combustion chamber liner	AGC 1123011	Elastomer modified Phenyl-silane impregnated in silica fabric
Combustion chamber	1122981-1	Silicone Rubber
To injector gasket		
Combustion Chamber to injector "O" ring	1121358-1	Silicone Rubber

TABLE 3.5.2 COMPATIBILITY OF SPS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING*	REFERENCE/ PAGE NO.**	REMARKS
Tanks		Titanium		G	2/28	
Screen Assembly		SS		G	2/28	
		Teflon	Sec. 1	G	2/28	
Door Assembly		Titanium		G	2/28	
		Cress		G	2/28	
		Teflon	Sec. 1	G	2/28	
		Butyl 1	O-Ring	P	1/8	Acceptable for this application since it is a secondary seal.
Oxidizer Probe		Aluminum		G	2/28	
		Stainless Steel		G	2/28	
		Solder QQ-S-571		U		Test required.
		Solder 96.5SN/3.5AG		U		Test required.
		Teflon TFE	Compensator Ring	G	2/28	
		Teflon TFE	Washer	G	2/28	
		Teflon TFE	Bushing	G	2/28	
		Teflon TFE	Spacer	G	2/28	
		Teflon TFE	Cap	G	2/28	
		Teflon TFE	Pin	G	2/28	
		Teflon FEP	Pin	G	2/28	
		Teflon FEP	Ring	G	2/28	
		Teflon FEP	Collar	G	2/28	
		Teflon FEP	Insulation	G	2/28	
Pressure Transducer		NI Span C		G	2/28	
		Teflon V-Ring seal	Seal	G	2/28	

*G - Good, P - Poor, U - Unknown.

**References:

1. Compatibility of Plastics with Liquid Propellant, Fuels, Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey.
2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965, Battelle Memorial Institute.

TABLE 3.5.2 COMPATIBILITY OF SPS OXIDIZER SYSTEM MATERIALS NORMALLY EXPOSED TO NITROGEN TETROXIDE - Concluded

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING*	REFERENCE/ PAGE NO.**	REMARKS
Bipropellant Valve		Cres Stainless		G	2/28	
		Aluminum		G	2/28	
		Teflon	Coated Springs	G	2/28	
		Teflon T	Bearing	G	2/28	
		Teflon	Seal	G	2/28	
		Teflon TFE	Washer	G	2/28	
		Teflon FEP	Washer	G	2/28	
Propellant Utilization Valve		Cres Stainless				
		Teflon	Gate Assembly	G	2/28	
		Dixon 95-1	Lubricant	U		Acceptable in this application since failure is required for exposure.
		Flora-Carbon Lub				

*G - Good, P - Poor, U - Unknown.

**References:

1. Compatibility of Plastics with Liquid Propellant, Fuels, Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey.
2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965, Battelle Memorial Institute.

TABLE 3.5.3 COMPATIBILITY OF SPS FUEL SYSTEM MATERIALS NORMALLY EXPOSED TO AEROZINE 50

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING *	REFERENCE** PAGE NO.	REMARKS
Tanks	Titanium FAL 4V			G	2/28	
Screen Assembly		Stainless Steel		G	2/28	
		Teflon	Seal	G	2/28	
Door Assembly		Titanium		G	2/28	
		Cress Steel		G	2/28	
		Teflon	Seal	G	2/28	
		Butyl Rubber	O-Ring	P	1/8	Acceptable for this application since it is a secondary seal.
Fuel Probe		Aluminum 3003	Conduit Tube	G	2/28	
		Aluminum 2024	Clamp, Rod	G	2/28	
		Titanium 6061	Base Flange	G	2/28	
		Cress Steel	Clamps	G	2/28	
		Glass, Pyrex	Primary Sensor	G	2/28	
		Teflon TFE	Clamp and Pin	G	2/28	
		Teflon FEP	Insulator Collar	G	2/28	
		Kovar		U		Test reqd. for reaction
Pressure Transducer		Ni Span C		U		Test reqd. for reaction
		Teflon		G	2/28	
		V-Ring	Seal			

* G - Good
P - Poor
U - Unknown data

TABLE 3.5.3 COMPATIBILITY OF SPS FUEL SYSTEM MATERIALS NORMALLY EXPOSED TO AEROZINE 50 - CONCLUDED

SPACECRAFT COMPONENT	COMPONENT MATERIAL	CONTAINED MATERIALS	NONMETALS APPLICATIONS	COMPATI-BILITY RATING *	REFERENCE** PAGE NO.	REMARKS
Probe		Stainless Steel		G	2/19	
		Titanium		G	2/19	
		Aluminum		G	2/19	
		Teflon TFE/FEP	Bladder	G	2/20	
		Teflon TFE	Gasket	G	2/20	
		Teflon TFE	Vent Probe	G	2/20	
		Teflon TFE	Pad	G	2/20	
		Teflon TFE	Vent Line Spacer	G	2/20	

**

REFERENCES

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, new Jersey

2. Compatibility of Materials with Rocket Propellants and Oxidizers, January 1965; Battelle Memorial Institute

TABLE 3.5.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO AEROZINE 50

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING*	REFERENCE/ PAGE NO.	REMARKS
Aluminum	Structure and/or Tubing	Indefinite	G	2/19	
Aluminum	Name Plates	Indefinite	P	2/20	Probably similar to Mystic 7402.
Aluminum/Silicone	Tape	L24 hours	P	2/20	Probably similar to Mystic 7402.
Aluminum/Epoxy	Honeycomb	L24 hours	P	2/19	Depends on type of epoxy.
Aluminized Mylar/H-Film	Thermal Insulation	H-Film dissolves immediately	P	2/19	Mylar dissolves in 30 days. H-Film dissolves immediately.
Anodized Aluminum	Structures (gold, blue, and brown	Indefinite	G	2/19	Probably similar to other aluminum alloys.
Epoxy/Fiberglas	Circuit Boards	Decomposes in 1 hour	P	2/19	Electrical properties will degrade.
Fiberglas	Spot Ties	Indefinite	G	3/13-1	
H-Film (polyimide)	Wire Insulation	1 hour	P	2/19	H-Film begins to dissolve immediately
Kynar (polyvinylidene chloride)	ID Sleeves and Heat-Shrink Tubing	30 days	P	2/20	Kynar will crack and blister at 160° F.
Neoprene/Fiberglas	Bandaids	Data Discrepancy	P	1/37	

*G - Good
P - Poor
U - Unknown

TABLE 3.5.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO AEROZINE 50 - Continued

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING	DOCUMENT/ PAGE NO.	REMARKS
Nomex (Aromatic Nylon)	Spot Ties	Approximately 60 days	P	1/38	Swells after extended exposure.
Nylon	Paints (red, yellow, and black)		P	2/20	Bleach/Washout
Phenolic/Fiberglas	Pipe Standoff		P	2/19	
Polyimide/Teflon TFE	Wire Insulation	1 hour	P	2/20	The polyimide begins to dissolve immediately.
Polyolefin	Heat-Shrink Tubing		P	2/19	Depends upon type.
Silicone Rubber RTV 102	Potting Compound		P	1/55	No data.
Silicone Rubber RTV 560/577	Potting Compound		P	1/55	No data.
Silicone Rubber LASR 5000	Cable Clamps		P	1/55	No data.
Silicone Rubber AMS 3245	Inserts and Connectors		P	1/55	No data.
Stainless Steel	Tubing	Indefinite	G	2/19	
Teflon TFE/Silicone	Tape	Teflon OK	P	1/55	No data.
Teflon TFE	Wire Insulation		G	1/55	
Teflon TFE	Wire Wrap		G	1/55	

TABLE 3.5.4 COMPATIBILITY OF MATERIALS NOT NORMALLY EXPOSED TO AEROZINE 50 - Concluded

MATERIAL(S)	USAGE	APPROXIMATE TIME TO FAILURE	COMPATIBILITY RATING	DOCUMENT/ PAGE NO.	REMARKS
Teflon TFE	Strain Relief Guard		G	1/55	
Teflon TFE	ID Tags		G	1/55	
Teflon TFE/FEB	Heat-Shrink Tubing		G	1/55	
TG-15000 Fiberglas	Thermal Insulation		U		
	Torque Stripe Paint		P	3	Bleaches
73-X	Marking Ink		P	3	Bleaches
Vinyl (polyvinyl chloride)	Wire Insulation		P	2/19	Similar to Tygun
Avcoat II	Heatshield Material		U	3	
Cork	Door Sealant		U		
Unidentified	Sleeves (black and yellow)		U		
Unidentified	Lanyard Cover (green)		U		
Unidentified	Potting Compounds (blue and brown)		U		

REFERENCES

1. Compatibility of Plastics with Liquid Propellants, Fuels, and Oxidizers, January 1969; Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey

2. Compatibility of Materials with Rocket Propellants, and Oxidizers - January 1965; Batelle Memorial Institute

3. Hypergolic Propellant Materials Compatibility, No. CR 64-88; Martin Company

helium leakage. The relief valves are sized to accommodate pressure increase from any thermal sources such as soak-back from engine burns.

3.5.3.3 HELIUM TANKS

There are two helium supply tanks in the SPS. These tanks have no electrical interfaces or internal sources of tank pressure increase. The fuel cells are an external source of pressure and temperature increase to the tanks. This is insignificant during normal operations. Fuel cell temperatures are closely controlled and an overheated fuel cell would be shut down before it could cause a significant pressure increase in the helium tanks. The SPS tanks are partially shielded by the radial beams and would not respond to the F/C temperature increase in flight. The probability of a helium tank failure is remote in the absence of any significant sources of temperature or pressure increases.

3.5.3.4 N_2 TANKS

Two N_2 tanks are located on the forward end of the SPS engine. They supply the N_2 for activation of the bipropellant valves. They have no electrical interfaces of sources of pressure increase. Rupture of these tanks is remote in view of the high factors of safety and the absence of any sources of pressure increase.

3.5.3.5 FUEL SUMP AND STORAGE TANKS

The SPS fuel sump and storage tanks are located in sectors 5 and 6 of the service module. The pressure control and relief capabilities are discussed in paragraphs 3.5.3.1 and 3.5.3.2. The only internal source of pressure increase is the gauging probes which are discussed in paragraph 3.5.4.1. It is concluded that the probes are not a significant source of temperature or pressure increase unless ignition occurs.

Failures were experienced with the tanks during the program development. These were associated with the use of methol alcohol in the tanks. Existing process control prohibits the use of methol alcohol in the tanks.

These tanks are considered acceptable in their present application in view of the absence of a single failure which would significantly increase the tank pressure or temperature. Corrective action has been accomplished for all defined failures.

3.5.3.6 OXIDIZER SUMP AND STORAGE TANKS

The SPS oxidizers sump and storage tanks are located in sectors 2 and 3 of the service module. The pressure control and relief capabilities are discussed in paragraphs 3.5.3.1 and 3.5.3.2. The gauging probe is an internal source of pressure increase and is discussed in paragraph 3.5.4.1. It is concluded that the gauging probes will not cause a significant temperature or pressure increase unless ignition occurs.

Tank failures experiences during program development were associated with the use of methol alcohol and uninhibited N_2O_4. Process control changes and the use of inhibited N_2O_4 have been instituted as corrective actions.

These tanks are considered conditionally acceptable in their present application. The only reservation is the possible flammability of teflon in the N_2O_4. There are no other single point failures which would significantly increase tank pressure or temperature.

3.5.4 ELECTRICAL COMPONENTS

The following electrical components interface with the propellant feed system. Table 3.5.5 is a summary of the electrical characteristics of these components.

3.5.4.1 PROPELLANT GAUGING PROBES

Each of the SPS propellant tanks contains a probe assembly for quantity sensing. Propellant quantity is measured by two separate sensing systems, primary and auxiliary. The primary sensors are cylindrical capacitance probes, mounted axially in each tank. In the oxidizer tanks, the probes consist of a pair of concentric electrodes with the oxidizer used as the dielectric. In the fuel tanks, a pyrex glass probe, coated with silver on the inside, is used as one conductor of the capacitor. Fuel on the outside of the probe is the other conductor. The pyrex glass itself forms the dielectric. The auxiliary system utilizes point sensors mounted at intervals along the primary probes to provide a step function impedance change when the liquid level passes their location centerline. Figures 3.5.2 and 3.5.3 are exploded views of the fuel and oxidizer probe assemblies. The system is powered only during SPS burns.

A hazard analysis for shorted voltages in the sensors of the probes has been performed and is included as appendix "a." A hazard for fuel probe leakage is also included as appendix "b." These analyses conclude that the power available at a shorted sensor cannot cause a significant temperature increase to the thermal mass of the probe assemblies unless ignition occurs. Kovar is used which could act as a catalysis for decomposition of A-50. Test is required to resolve this question.

3.5..4.2 TEMPERATURE MEASUREMENTS

Temperature sensors are provided on the fuel and oxidizer tanks and lines. They are bonded to the tank or line exterior and do not introduce additional materials to the fluid systems. The sensors operate at 2 milliamperes at 0 to 5 volts and are not a significant heat source to the system. The signal conditioners operate at 30 milliamperes maximum and are fused at 0.25 amperes.

TABLE 3.5.5. SPS ELECTRICAL COMPONENT CHARACTERISTICS.

COMPONENT	NORMAL OPERATING ELECTRICAL CHARACTERISTICS			CURRENT LIMITING	NORMAL FLUID PROPERTIES AT COMPONENT		ELECTRICAL COMPONENTS EXPOSED BY SINGLE FAILURE
	VOLT	AMPERE	WATT		PSI	TEMPERATURE °F	
PROPELLENT GAUGING PROBES			12.5 MAXIMUM FOR SINGLE SHORTED SENSOR		178	+45 TO +75	SENSORS OPERATE IN FLUIDS
PRIMARY	26 MAXIMUM			0.3 AMPERE TO 115V POWER SUPPLY			
AUXILIARY	26 MAXIMUM			0.5 AMPERE TO 115V POWER SUPPLY			
TEMPERATURE MEASURE	5 MAXIMUM	0.002		0.03 AMPERE IN SIGNAL CONDITIONER 0.25 AMPERE LINE FUSE	178	+45 TO +75	NONE
PROPELLENT UTILIZATION VALVE					178	+45 TO +75	NONE
TACH-GENERATOR	115		2.0	2 AMPERES			
MOTORS	28		3.9	1.0 AMPERE PRIMARY 1.5 AMPERE AUXILIARY			
MOTORS	57.5			0.3 AMPERE PRIMARY 0.5 AMPERE SECONDARY			
PRESSURE TRANSDUCER	5 MAXIMUM			0.015 AMPERE IN SIGNAL CONDITIONER 0.25 AMPERE LINE FUSE	178	+45 TO +75	STRAIN GAGES
LINE HEATERS	28				178	+45 TO +75	NONE
BIPROPELLENT VALVE OXYGEN			15.0	10 AMPERES FOR SYSTEM			
OXYGEN FEEDLINE	20		9.4				
OXYGEN FEEDLINE			18.8				
BIPROPELLENT VALVE FUEL			0.5	10 AMPERES FOR SYSTEM			
FUEL FEEDLINE			9.4				
FUEL FEEDLINE			18.8				
BIPROPELLENT VALVE					178	+45 TO +75	NONE
SOLENOIDS	28			10 AMPERES			
POSITION TRANSDUCER	28			0.25			

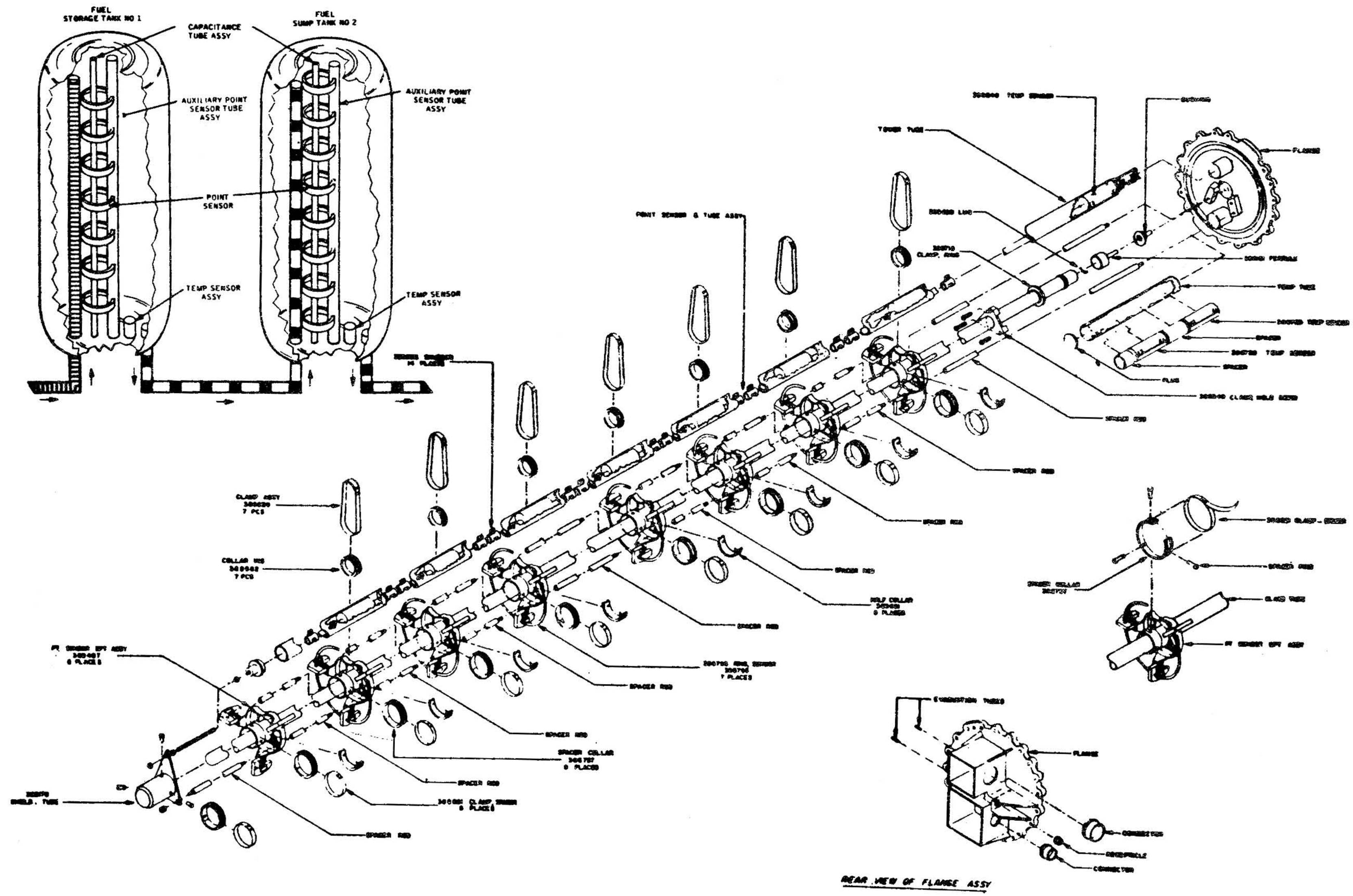


FIGURE 3.5.2. FUEL PROBE ASSEMBLY.

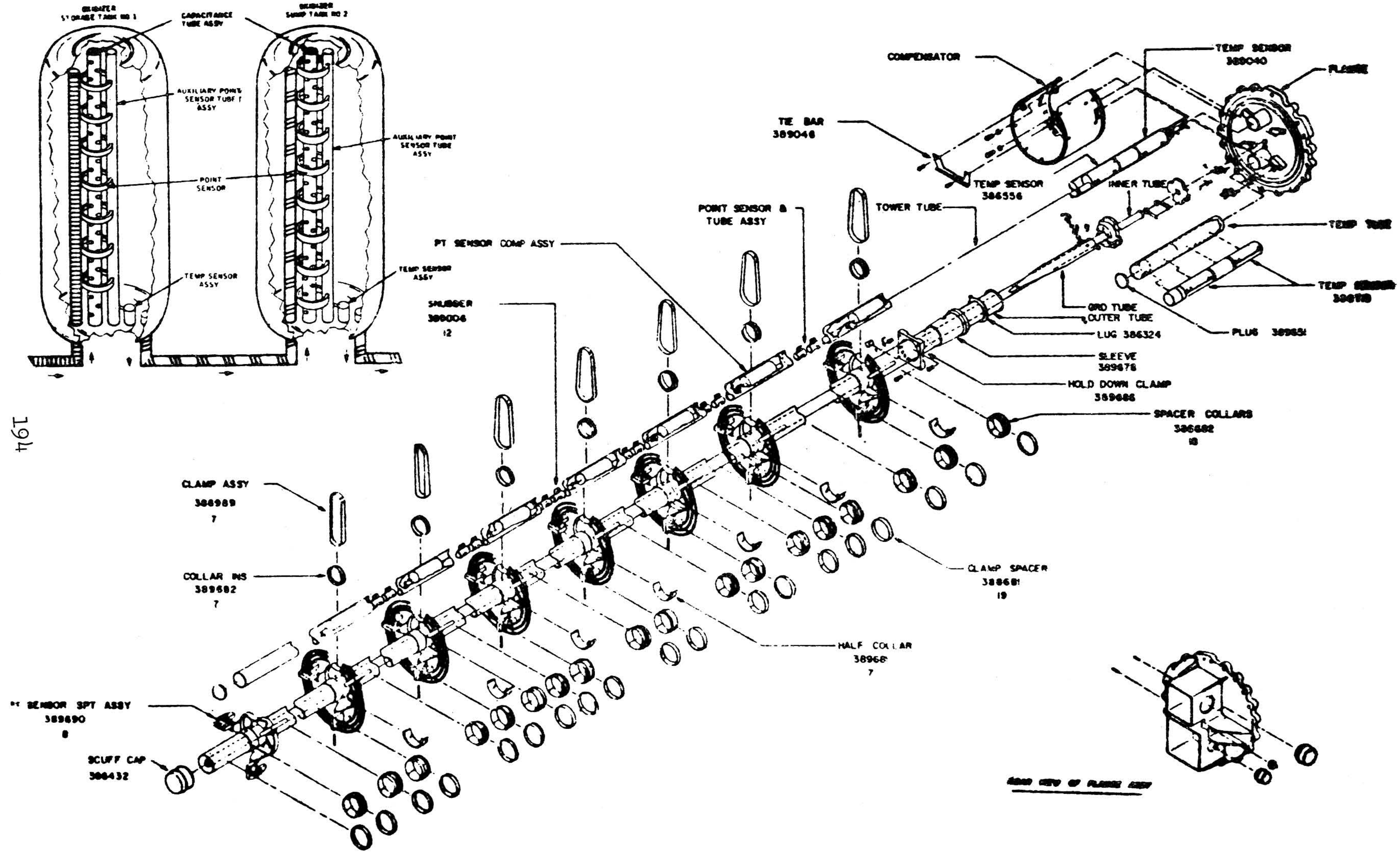


FIGURE 3.5.3. OXIDIZER PROBE ASSEMBLY.

3.5.4.3 PROPELLANT UTILIZATION VALVE

The propellant utilization valve is located in the oxidizer line and is used to control the oxidizer to fuel ratio during SPS burns. The electric motors and gear train are isolated from the N_2O_4 by redundant bellows as shown in figure 3.5.4. The bellows have a burst pressure greater than 1200 PSI. The failure of both bellows is considered remote. There have been no bellows failures in the PU valve development. The motors are designed for an normally operate with locked rotors. The two motors and the control electronics operate at approximately 12 watts and are powered only during SPS burns. This is not a significant heat input into the system.

3.5.4.4 PRESSURE TRANSDUCER

A cross-section of the pressure transducer body is shown in figure 3.5.5. The diaphram is integrally machined and has a minimum burst pressure of 1500 PSI. Failure of the diaphram would expose only the strain gauges to the propellants and is considered remote in view of the high factor of safety. Failure of the seals would expose propellant to the outside and not to the electrical components. The sensor operates at 2 milliamperes and are not a significant heat source to the system. The current is limited to 15 milliamperes by diodes in the signal conditioner. The body of the transducer is Ni-Span-c which could act as a catalysis for decomposition of A-50. Test is required to resolve this question.

3.5.4.5 LINE HEATERS

SPS line and engine heater installation is shown in figure 3.5.6. A simplified electrical schematic is shown in figure 3.5.7. The heaters are laminated between silicone impregnated fiberglass layers. The assemblies are bonded to the lines with RTV silicone. When on, they produce a temperature increase of approximately one degree per hour. They are manually controlled to supply heat to the system if required. Their use is not required during normal mission operations. If left unattended in the powered condition, they could heat the propellants and produce some increase in tank pressure. This unlikely event could be accommodated by the pressure relief valves. The failure mode is for the resistance element to fail open which does not constitute a hazard to the system.

3.5.4.6 BIPROPELLANT VALVES

Figure 3.5.8 is a cross-section of the bipropellant valve through the oxidizer and fuel parts. Valve position indicators are operated by the gear rack and are isolated from the propellants by six seals. The large thermal mass of the valve assembly prevents any significant temperature increase from a shorted transducer. Valve operation is by N_2 actuators and does not involve an electrical interface with the propellants.

3.5.5 SUMMARY OF UNRESOLVED ISSUES

The only unresolved issues on the SPS are those of material compatibility as noted in 3.5.2. Of particular concern is the lack of data on the combustibility of teflon in N_2O_4. Teflon is used extensively in the gauging probe and its applications should be reviewed after flammability tests on the teflon in N_2O_4.

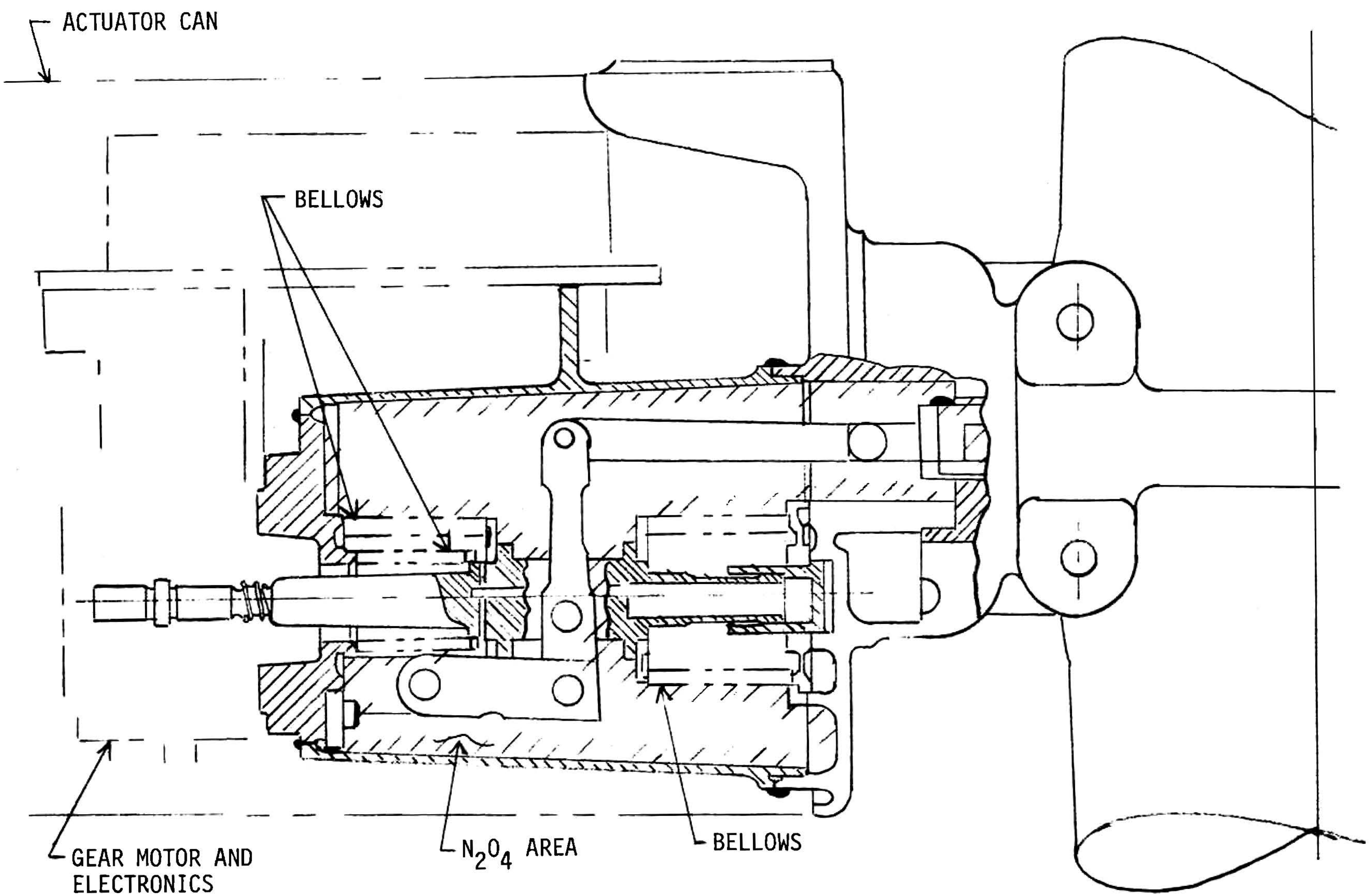


FIGURE 3.5.4. PROPELLANT UTILIZATION VALVE.

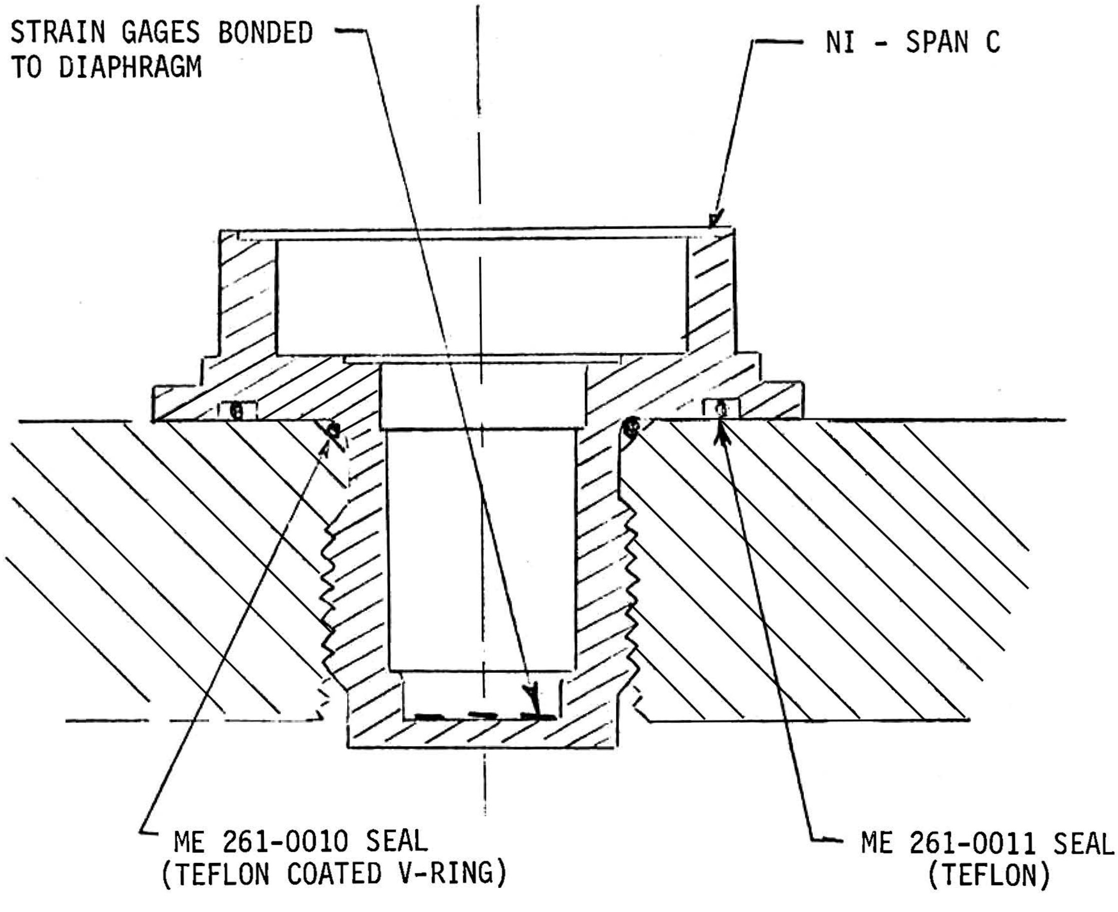


FIGURE 3.5.5. PRESSURE TRANSDUCER BODY

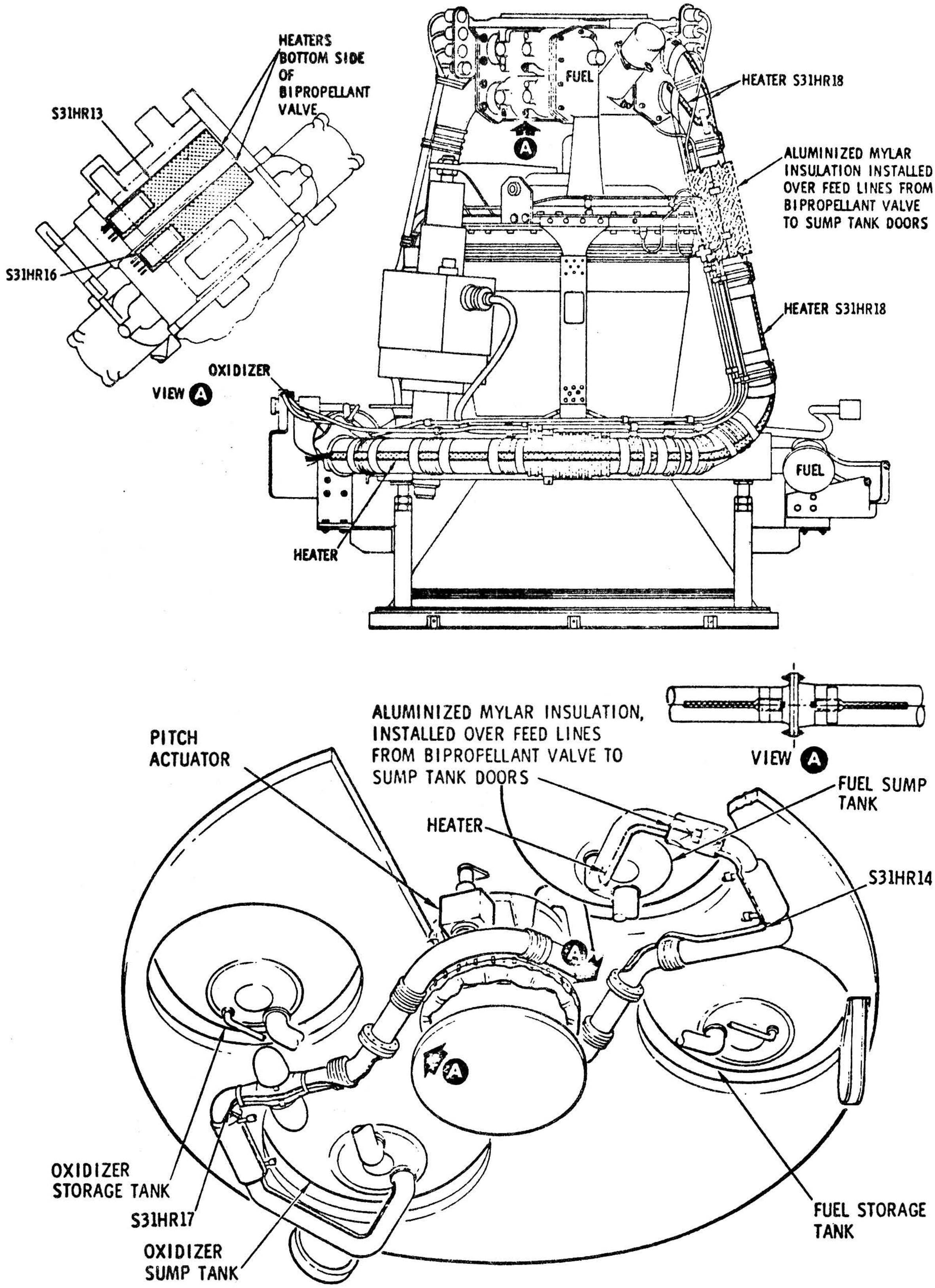


FIGURE 3.5.6. SPS HEATER INSTALLATION.

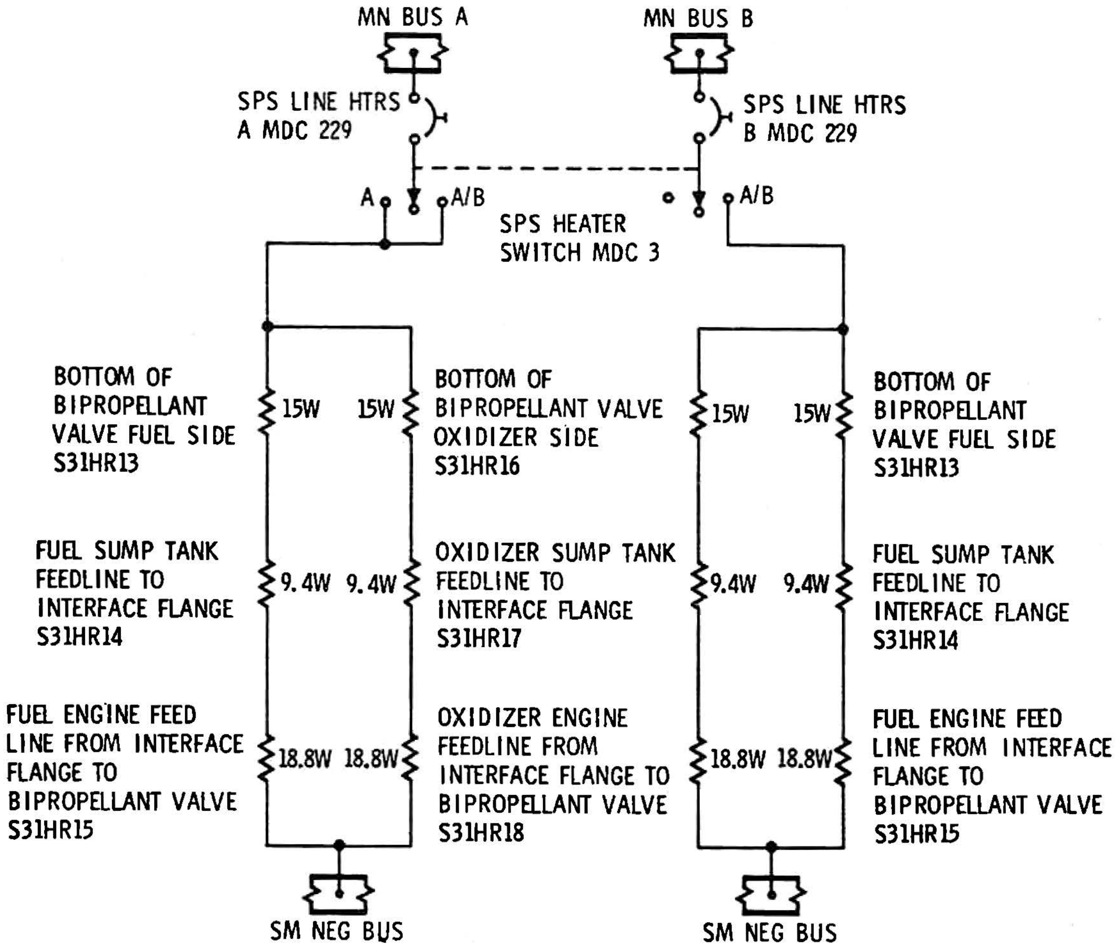


FIGURE 3.5.7. SPS HEATER SCHEMATIC.

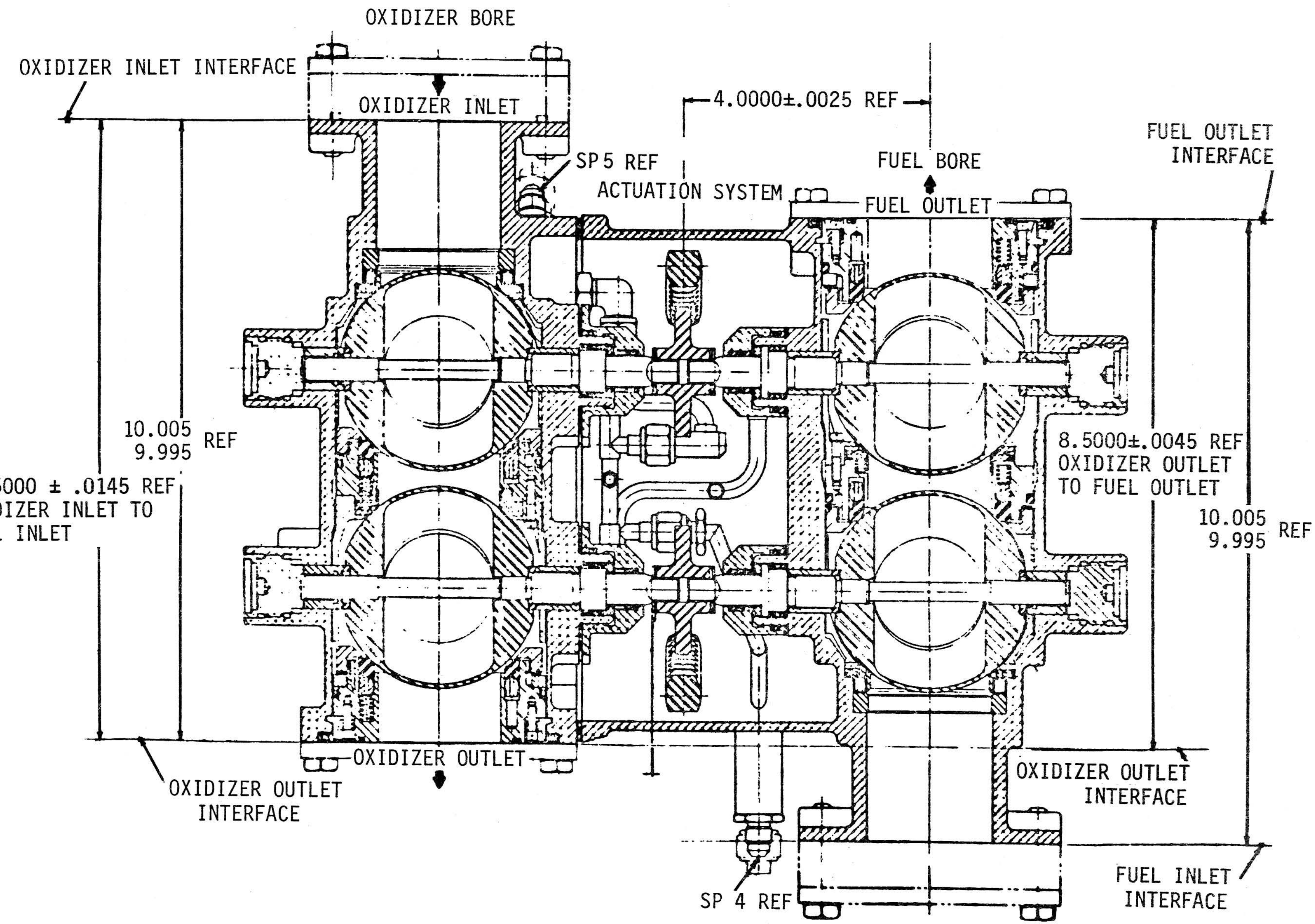


FIGURE 3.5.8. BIPROPELLANT VALVE

3.6 MECHANICAL SYSTEM

3.6.1 FUNCTIONAL DESCRIPTION

The CSM mechanical system includes nitrogen supply tanks for several functions and a fire extinguisher. The pressure vessel characteristics are summarized in table 2.0. Tank materials are listed in table 3.6.1.

3.6.2 PRESSURE VESSELS

3.6.2.1 SIM GN_2 Tank

The SIM GN_2 tank is located on the X_s = 264 SIM shelf behind the panoramic camera as shown in Figure 3.6.1. The tank supplies GN_2 for the SIM cameras. There are no internal components or electrical interfaces to the tank. There are no external sources of temperature or pressure increase for the tank. The tank is acceptable for its application as it has an adequate factor of safety and there are no significant sources of pressure or temperature increase.

3.6.2.2 Docking Probe GN_2 Tanks

There are four GN_2 tanks in the docking probe. Each tank can provide GN_2 for a probe retraction. Figure 3.6.2 illustrates their installation. The design mission requires only two retractions. There are no internal components and no electrical interfaces to the tanks. There are no significant external sources of temperature or pressure increase for the tanks. The tanks are acceptable for their application as they have a factor of safety greater than 3 and there are no significant sources of tank pressure increase. The only failures associated with the tanks were leakage of components down stream of the tank. The tanks are sealed by a welded diaphram which is pierced for a probe retraction and do not have a failure history as components.

3.6.2.3 Side Hatch GN_2 Tanks

There are two GN_2 tanks in the side hatch counterbalance to assist side hatch opening. Figure 3.6.3 illustrates their installation. These tanks are identical to the docking probe tanks except for an end support fitting. They are acceptable for their application as there are no significant sources for temperature or pressure increase. The tanks have a factor of safety greater than 3 and have been subjected to handling tests which demonstrated impact resistance. Charged tanks were dropped 10 feet onto concrete with no damage.

3.6.2.4 Fire Extinguisher

A fire extinguisher is located in the CM cabin. The tank is charged with a water jel and "freon 12". A polyethelene bladder separates the charge from the expulsion charge of "freon 12 and 115." There are no electrical interfaces or spark mechanisms for the tank.

Normally, there are no external sources of temperature or pressure increase. Any fire for which the extinguisher is required would be a source of heat. The extinguisher is provided with a rupture disk which assures against overpressurization of the tank. The maximum rupture disk pressure is 375 psi and the tank has a burst pressure of 1860 psi. Rupture of the disk dumps the water jel into the cabin and does not harm the CM materials. The tank is considered acceptable for its present application.

Table 3.6.1, Materials, Mechanical System

Part Name	Part Number	Material
Pressure Vessel SIM GN_2 Tank	ME 282-0051	
K Seal	12100 PA4	17-4 PH Gold-Plated
Fitting	V37-460106-3	3041
Nut	MC 174-C10W	CRES 316
P/T Sensor	ME 449-0124-0002	NI-SPAN-C
Shell	6499-7	6AL-4V Titanium
Pressure Vessel GN_2 Docking Probe	ME 901-0697-0005	718 Inconel
Diaphram	ME 901-0697-0005	CRES 304L
Pressure Vessel GN_2 Side Hatch	ME 282-0052-0001	718 Inconel
Diaphram		CRES 304L
Fire Extinguisher	ME 282-0010-0003	
Pressure Vessel		Inconel
Bladder		Polyethylene
Charge		Water Jel/Freon 12 and 115

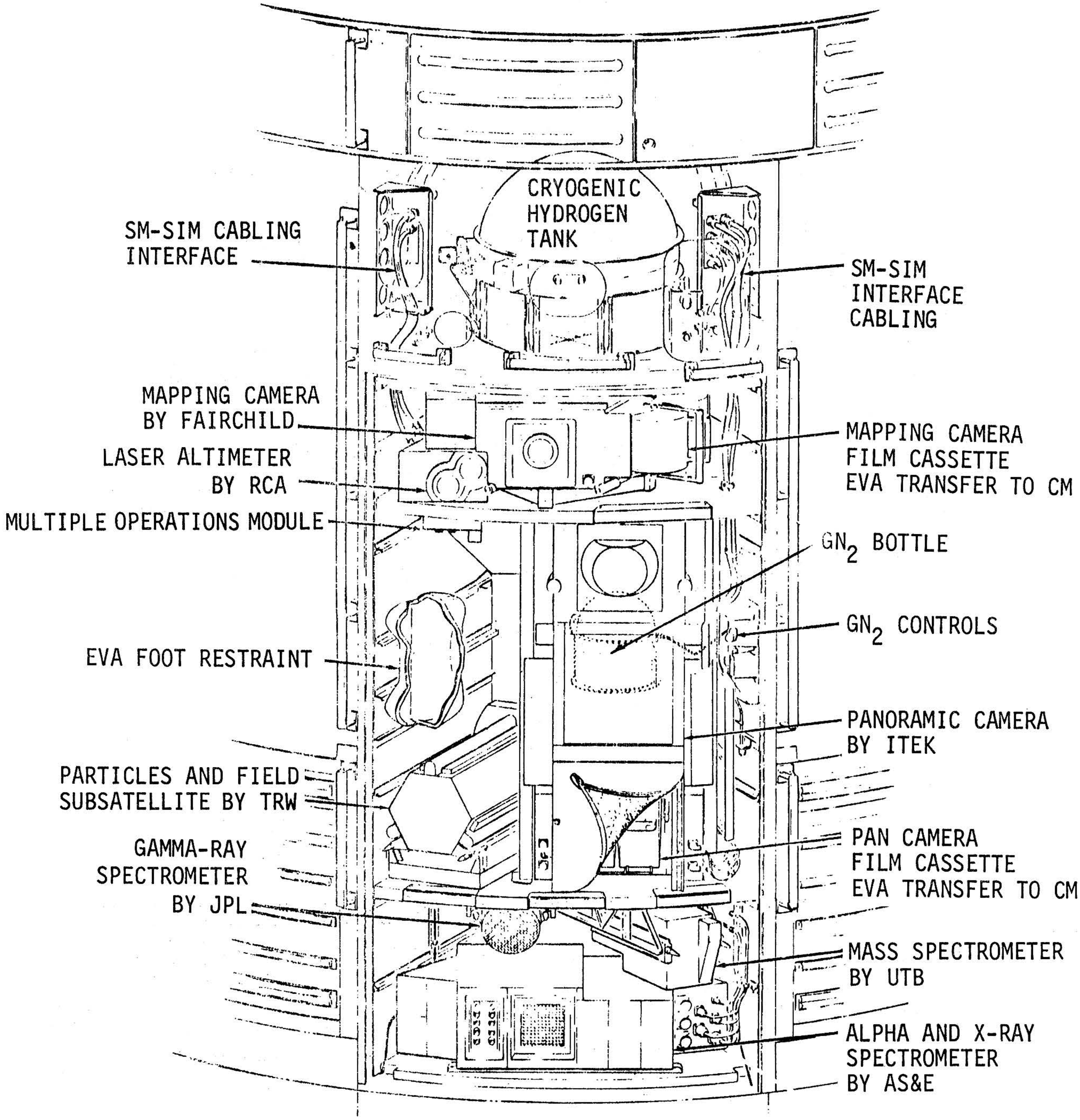


FIGURE 3.6.1. GENERAL ARRANGEMENT, SIM BAY

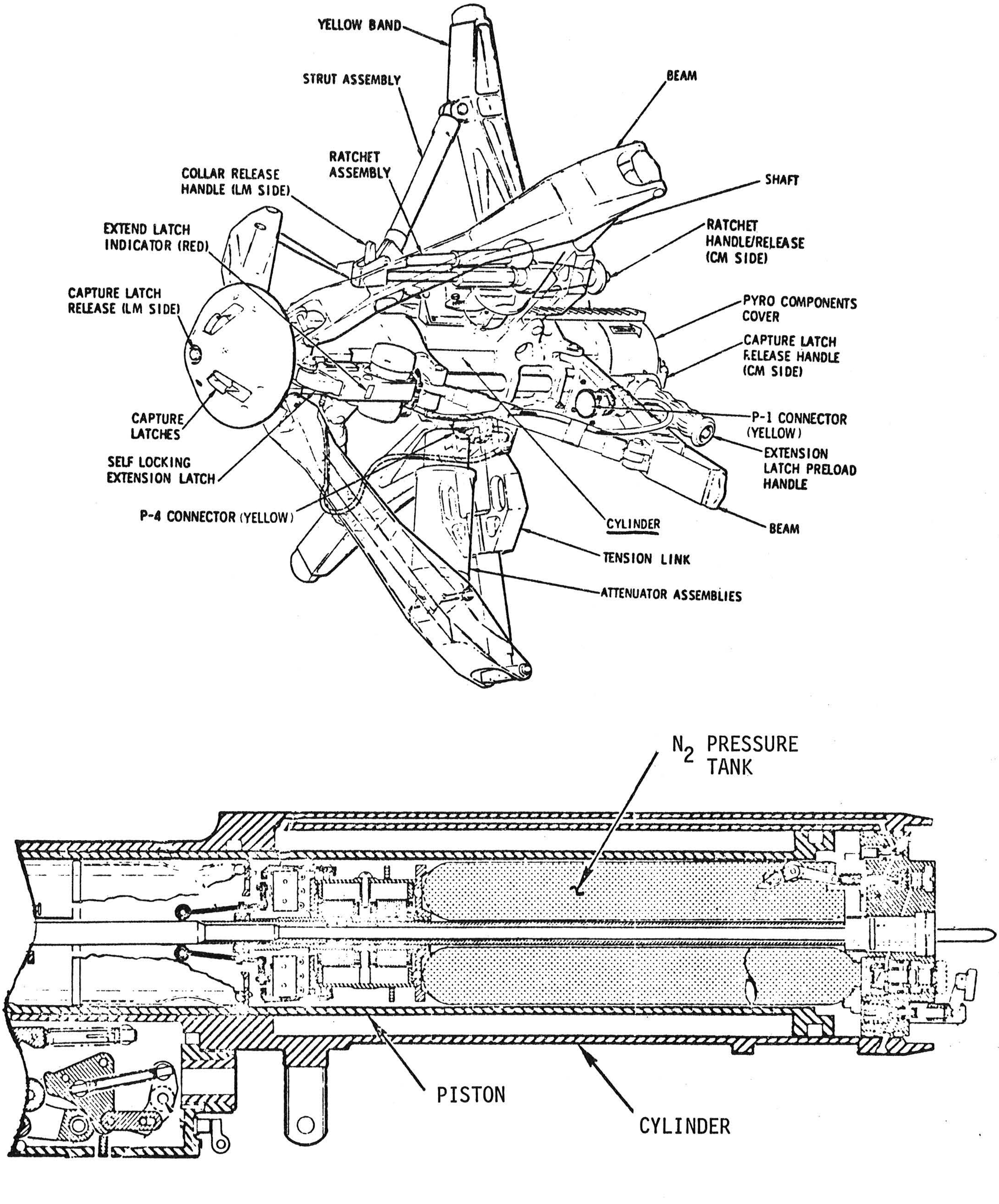


FIGURE 3.6.2. DOCKING PROBE ASSEMBLY.

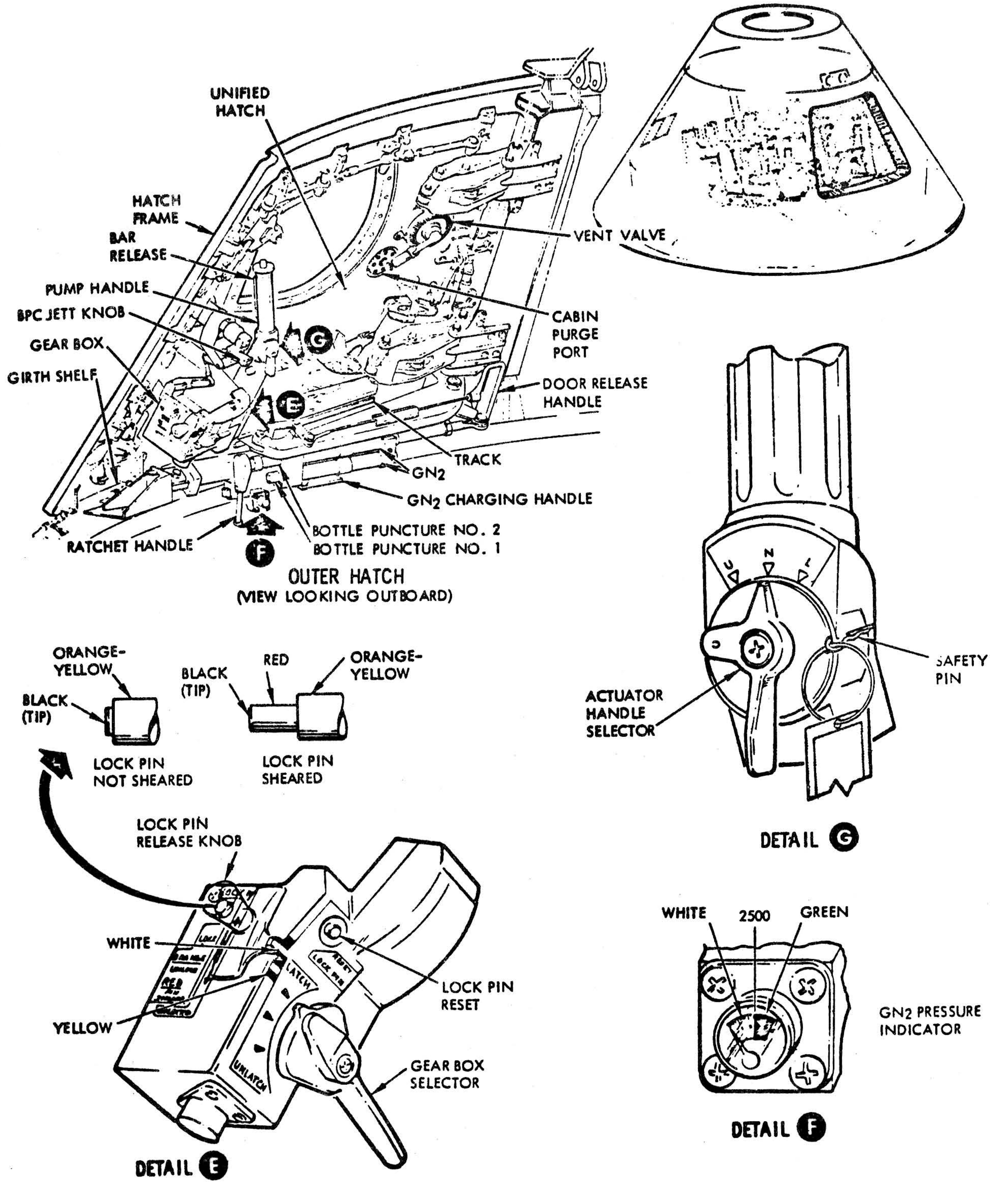


FIGURE 3.6.3. SIDE ACCESS HATCH.

4.0 DAMAGE POTENTIAL

4.1 INTRODUCTION

An investigation was initiated to estimate the damage which would be produced by the structural failure of a pressurized vessel in the Command and Service Modules. The CSM cryogenic oxygen tank is being investigated by Team # 1 and was omitted from this investigation. Because a thorough investigation would require substantial amounts of time and money, the investigation is limited to gross assessments of expected damage. Assuming a tank failure, damage assessments are based on the expected failure modes, the stored energy of the tank and their proximity to essential equipment, crew, or other pressurized vessels. Failure mode data from actual planned or inadvertent tests are included for comparison.

Each tank was assumed to contain limit pressures and be at a high ullage condition. Failure modes were obtained by fracture mechanics which uses a critical flaw size to predict whether failure would be by tank fragmentation or tank leakage with no fragmentation. The fragmentation mode was subdivided into predicted fragment sizes; a tank that would split into a small number of relatively large pieces is referred to as a rupture failure. A failure that results in many small sections is termed a fragment failure. The distinction between these two rapid failure cases is based upon the tank material properties. Tank failures that result in leakage only are not considered to cause mechanical damage and are included in this investigation for identification purposes only. Tanks that rupture are assumed to produce limited shrapnel with the primary damage resulting from pressure forces. Fragmentation failures produce damage by pressure forces and shrapnel. It is noted that most tanks will fail in a fragmentary manner if any of the three following conditions exists: (1) pressurized to burst pressures, (2) penetrated by a sufficiently large particle, or (3) the tank material is weakened by thermal or other environmental processes.

Very little data were found which could be used for estimating space vehicle damage caused by a pressure vessel failure. It is apparent that tanks with stored energy equivalents of several pounds of T. N. T. would produce catastrophic failures of a space vehicle.

For stored energy equivalents of a fraction of a pound of T.N.T. (which is the case for several tanks in the CSM and LM), estimation of damage becomes more difficult. Tanks with low energy levels could conceivably rupture or fragment with little resulting damage if ideal conditions prevailed. For the estimated damage presented in this report, the assumption was made that the tank exhibiting a fragmentary mode of failure will produce shrapnel that penetrates surrounding equipment and structure.

Two previous tank failures were used as a basis for estimating damage produced by tanks having fractional T.N.T. equivalents. One failure was a "hydrostatic" test of the SPS fuel and oxidizer tanks of S/M-017. A summary of the test condition and damage follows.

A fuel tank ruptured under a pressure of approximately 240 psi with an ullage of 4.3%. This pressure and ullage would represent approximately 0.134 pounds of T.N.T. The failure initiated at a point well below the liquid level rupturing the lower region into several large pieces. When the failure reached the ullage area, the dome of the tank fragmented. Shrapnel and blast forces from this tank failure initiated a failure of an adjacent oxidizer tank. The oxidizer tank also had a potential of .134 pounds of T.N.T., thus the combined potential was .264 pounds of T.N.T. Damage to the service module was extensive and under mission conditions would have resulted in total destruction of the SM and possibly the CM.

One additional tank failure which had a fractional T.N.T. energy equivalent was used in damage estimation. This was a tank failure which occurred in the Structures and Mechanics Laboratory in 1965 (reference 7). A thin-walled 301 stainless steel tank failed under a pressure of 1337 psi and an ullage condition of 1.7% representing a T.N.T. energy equivalent of approximately .019 pounds of T.N.T. The tank that failed was submerged in a water bath in a second tank for the purpose of obtaining volumetric changes. The tank containing the bath had a flanged cover from which a graduated glass standpipe extended upward. When the inner tank ruptured, the bath tank ruptured, sending the flanged top approximately 25 feet upward to the building roof structure, bending a steel "I" beam (6" WF 15.1 wgt) and column buckling two steel T sections. The T sections were formed by bolting together two angle sections, 2" X 2", 3/16" thick. Also, a sand bag protection barrier around the tank was toppled.

The structural damage caused by these two tank failures with energy equivalents of a fraction of a pound of T.N.T., together with analysis performed in the references 1 through 4, were used to estimate the damage capability of rupturing tanks.

Estimated damage is discussed in each of the following sections on the Service Module and the Command Module. Included in the discussion of each section are tables listing the tanks in a descending order of potential damage capability.

In addition to the above failures, data from reference 3 conclude the following. Reference 3 documents the results of a study by Southwest Research Institute on the damage potential associated with an SPS helium tank explosion in the NASA MSC Vibration and Acoustic Test Facility. The conclusions of this report state that there is a high probability of extensive damage and likeliness that the exterior walls of the building would be blown off and that the CM would separate from the SM.

In order to calibrate the reader on potential damage associated with explosions, data are presented in Table 4-1 to show representative explosive devices T.N.T. equivalents.

TABLE 4-1 TYPICAL EXPLOSIVE EQUIVALENTS

EXPLOSIVE DEVICE	LB. TNT EQUIV.
Rifle Primer (or Firecracker)	0.000092
.22 Long Rifle Cartridge	0.000232
.45 Pistol Cartiridge	0.000563
No. 8 Electric Blasting Cap	0.00127
.30 M2 Ball Rifle Cartridge	0.00480
.50 M2 Ball MG Cartridge	0.0226
20 MM HE Projectile	0.025
MKII Fragmentation Hand Grenade	0.125
One Stick (one lb) 100% Gel. Dynamite	1
Antitank Mine	5

T.N.T. equivalent values are calculated by the following equation:

$$\text{Tank stored energy} = \frac{\Delta PV}{\gamma - 1}$$

$$\text{For } P_2 = 0$$

$$E = \frac{PV}{\gamma - 1}$$

Use 1.4×10^6 Ft-Lb/Lb T.N.T as heat explosion of T.N.T.

Then T.N.T. equivalent of pressurized tank is

$$T = \frac{E}{1.4 \times 10^6} = \frac{PV}{(\gamma - 1)(1.4 \times 10^6)} \quad \text{Lb T.N.T. equivalent}$$

γ = ratio of specific heats (gas only)

4.2 DISCUSSION

4.2.1 SERVICE MODULE TANKAGE

The Service Module tanks included in this examination are tabulated in descending order of potential damage capability in Table 4-2. Included in this table are tank identification, quantity of tanks, failure mode (based on limit pressure and fracture mechanics) limit pressure, and T.N.T. energy equivalent. The T.N.T. values for the tanks were computed using limit pressure data and a 100% ullage condition.

4.2.1.1 SPS Helium Tanks

Of all the SM tankage, the centrally located helium pressure tanks for the SPS have the maximum potential damage capability. Failure of either of the SPS helium tanks will result in an initial explosion, equivalent to approximately 11 pounds of T.N.T., which is expected to propagate failures in the adjacent helium tank and four SPS propellant tanks. The resulting total explosive force, approximately equal to 43 pounds of T.N.T.; * would destroy the service module and could be catastrophic in that the CM could be destroyed by the explosion or by shrapnel penetration of the pressure cabin. Examination of data taken from the test failure of S/C-017 SM indicates that a low T.N.T. energy level can cause extensive structural damage. The calculated combined energy equivalence for the two low ullage (4.3% ullage) tanks was .264 pound of T.N.T. In the event that the CM survives the explosion, damage to the aft heatshield and separation controller could be catastrophic to CM reentry.

4.2.1.2 SPS Propellant Tanks

The four SPS propellant tanks have approximately equal potential damage capability. Failure of any one of the SPS propellant tanks could propagate

*Empirical data on effects of internal explosions in aircraft show that 1 lb of T.N.T. detonated within the fuselage of any known aircraft will completely demolish the fuselage. (reference 3).

TABLE 4.2.— SM TANKS LISTED IN DESCENDING ORDER OF POTENTIAL DAMAGE CAPABILITY

Pressure vessel	QUANTITY REQUIRED	Failure* Mode	Limit Pressure PSI	TNT Equivalent LBS
Pressure tank Helium SM/SPS	2	Frag.	3685	10.960
Propellant Tank Oxidizer Storage SM/SPS	1	Frag.	225	4.414
Propellant Tank Fuel Storage SM/SPS	1	Frag.	225	4.414
Propellant Tank Oxidizer Sump SM/SPS	1	Frag.	225	4.414
Propellant Tank Fuel Sump SM/SPS	1	Frag.	225	4.414
Pressure Tank Helium SM/RCS	4	Frag.	4500	0.362
Pressure Tank GN_2 SM/SPS	2	Frag.	2900	0.051
Pressure Tank Pan** Camera GN_2/SM	1	Frag.	4500	0.593
Propellant Tank Primary Oxidizer SM/RCS	4	Rupture	248	0.062
Propellant Tank Primary Fuel SM/RCS	4	Rupture	248	0.049
Cryogenic Tank LOX SM/EPS	2	Leak	1020	1.215
Cryogenic Tank LH_2 SM/EPS	2	Leak	285	0.489
Pressure Tank F/C GN^2	3	Leak	1500	0.259
Propellant Tank Secondary Oxidizer SM/RCS	4	Leak	248	0.039
Propellant Tank Secondary Fuel SM/RCS	4	Leak	248	0.032

* Failure mode estimates are based on limit pressure conditions and fracture mechanics as prescribed in "Apollo Command and Service Module Pressure Vessel Operating Criteria Specifications," SEV-0028, G. M. Ecord and S. V. Glorioso.

** Experimental camera for J mission.

failures in the remaining SPS propellant tanks and possibly the SPS helium tanks, causing an explosion approximately equal to 43 pounds of T.N.T. The damage to the CSM will be equivalent to the damage description contained in the discussion of the SPS helium tanks.

4.2.1.3 RCS Helium Pressure Tanks

Failure of any one of the four RCS helium pressure tanks could propagate a failure in the adjacent SPS propellant tank.

4.2.1.4 Pressure Tank GN_2 SPS

Failure of either of the two GN_2 pressure tanks could propagate a failure in the SPS propellant tanks.

4.2.1.5 Pressure Tank Pan Camera GN_2

Failure of the GN_2 pressure tank for the Pan Camera carried in the scientific bay during mission J (Apollo 16) could propagate a failure in the SPS propellant tanks.

4.2.1.6 RCS Primary Propellant Tank

Failure of one of the four RCS primary oxidizer propellant tanks or of one of the four RCS primary fuel propellant tanks can in the worst case fail the adjacent SPS propellant tank. A rupturing tank, as we have in this instance, will possibly fragment into several large pieces. The probability of impacting the SPS tanks, although not defined, would certainly be smaller than in the case of a fragmentary failure. A minimum damage estimate, assuming the SPS tanks are not failed, would involve possible loss of adjacent tubing, electrical wiring, RCS quad and any equipment in the path of the fragment trajectories.

4.2.1.7 Remaining Tanks

The remaining tanks, LOX cryogenic tank, LH_2 cryogenic tank, F/C pressure tank, RCS secondary oxidizer, and RCS secondary fuel propellant tanks, fail in a leak mode at limit pressures, which is not considered as a blast or shrapnel damage hazard, but as a possible material compatibility problem.

4.2.2 COMMAND MODULE TANKAGE

There are approximately 20 pressure vessels contained within the Apollo Command Module. The fire extinguisher, hatch pressure assist, and the docking probe pressure bottles were excluded from this discussion due to small T.N.T. equivalent values and large design margins.

The remaining tanks are listed in Table 4-3 in a descending order of potential damage capability. The table presents the probable failure mode, limit pressure and T.N.T. energy equivalent. This order was established on the location of the tank within the CM and the factors presented in the table.

The guide used to compare the severity of damaged caused by a tank failure were as follows:

1) The most severe damage would be direct body injury to the crew caused by shrapnel or by rapid decompression.

2) A second order of severity would be penetration of the crew compartment causing a less rapid loss of pressure.

3) The least severe damage to the CM would be a failure causing the loss of a system or systems.

4.2.2.1 Helium Pressure Tanks - RCS

The two helium tanks are installed in the aft equipment bay within inches of the pressure cabin sidewall. This sidewall is of aluminum sandwich construction about one inch thick and would provide little protection against shrapnel penetration.

The helium tanks are fragmentary type vessels and have a stored energy equivalent to approximately 0.14 pound of T.N.T. Should either of these tanks fail, relatively large holes would be made in the pressure cabin resulting in rapid decompression. However, because of shielding of the crew members by equipment bays, the shrapnel hazard is estimated to be slight (references 4 and 5).

In addition, it is expected that a failure of helium tank 2 would rupture the two adjacent RCS fuel tanks with damage to the RCS fuel and oxidizer tubing and wiring routed through the frames behind this tank. The fire caused by RCS fuel and oxidizer mixing could be catastrophic.

4.2.2.2 Oxygen Surge Tank - ECS

The ECS oxygen surge tank would be hazardous to the crew should it fail. This vessel is located within the pressurized crew compartment and is installed in the left-hand equipment bay approximately 18 inches from the nearest astronaut. Analysis shows that this tank will fail in a rupture mode, separating into large fragments. The close out panel would afford little protection for the crew against shrapnel. The panel itself could become a missile due to blast pressure.

In addition to the hazard of possible direct injury to the crew, it is probable that the crew compartment will be rapidly vented due to shrapnel being blown through the cabin sidewall or by rupture due to blast loading.

TABLE 4.3.— CM TANKS LISTED IN DESCENDING ORDER OF POTENTIAL DAMAGE CAPABILITY

Pressure vessel	Quantity	Failure* Mode	Limit Pressure PSI	TNT Equivalent LBS
Pressure Tank Helium CM/RCS	2	Fragment	5000	0.157
Oxygen Surge Tank CM/ECS	1	Rupture	1020	0.192
Oxidizer Tank CM/RCS	2	Rupture	360	0.056
Propellant Tank CM/RCS	2	Rupture	360	0.047
Cabin Repress, Oxygen CM/ECS	3	Leak	1210	0.062
Glycol Reservoir CM/ECS	1	Leak	60	0.002
Potable Water CM/ECS	1	Leak	50	0.008
Waste Water CM/ECS	2	Leak	60	0.015
Life Raft Pressure	2	Leak	4500	0.027
Cyclic Accum.	1	Leak	140	0.0002

* Failure mode estimates are based on limit pressure conditions and fracture mechanics as prescribed in "Apollo Command and Service Module Pressure Vessel Operating Criteria Specification," SEV-0028, G. M. Ecord and S. V. Glorioso.

4.2.2.3 Propellant and Oxidizer Tanks - CM/RCS

All of the propellant and oxidizer tanks of the CM/RCS are located in the aft equipment bay and have approximately the same stored energy (.05 pound of T.N.T.). The damage caused by the failure of any one of these tanks will be characteristic of each tank.

All of these tanks are assumed to fail in a rupture mode under the conditions specified in the introduction of this section.

Like the RCS helium tanks, all of this tankage is installed within inches of the crew compartment sidewall, with a damage potential of fragments penetrating the crew compartment sidewall resulting in rapid decompression. However, if catastrophic failure of the crew compartment does not occur there will be considerable damage to the tubing and wiring bundles installed in the aft equipment bay. Failure of these tanks could result in damage to both RCS fuel and oxidizer tubing for systems A and B. A minimum damage estimate would be the loss of one CM RCS and a maximum damage estimate would be a catastrophic fire caused by mixing the fuel and oxidizer. Shrapnel hazards to the crew are estimated to be minimal.

Failure of system 2 oxidizer tanks could result in damage to the tubing and wiring which connect the SM to the CM. This could result in complete loss of the SM's systems resulting in the inability to separate prior to entry.

The proximity of the propellant tanks to each other and to one of the helium pressure tanks provides the same type of hazard as discussed in the failure of the helium tank. These tanks are within 12 inches of each other and the failure of either tank would probably result in the failure of all three.

4.2.3 REMAINING TANKS

It is predicted that the three cabin repressurization bottles, the water glycol reservoir, the potable and waste water tanks, and the two life raft pressurization bottles will only leak when subjected to limited pressure; therefore, they do not present a significant hazard of damage to other structures or systems other than by contamination.

4.3 SUMMARY

Estimates of structural damage to the SM and CM produced by pressure vessel failures were made by comparing the energy levels of these tanks with selected low-energy tank failure data. The majority of the SM and LM tanks have the energy capacity to cause massive structural damage. The oxygen surge tank, considered to be the most hazardous CM tank, presents a significant shrapnel hazard to the crew. The cover panel of the surge tank compartment will likely add to the tank shrapnel hazard. This panel could be dislodged by the tank's rupture and could become a missile within the crew compartment. The failure of any of the high energy CM tanks could result in rapid decompression of the crew compartment and damage to tubing and wiring. Both fuel and oxidizer tubing and wiring are installed in the aft equipment bay with these tanks.

Because of the large damage capability of the CSM tankage, it is recommended that all tank acceptance criteria, test and checkout procedures and operational procedures be reviewed and improved to insure all tankage is satisfactory at acceptance and is not degraded during usage prior to flight. Of particular interest is the O_2 surge tank which has been accepted (by MR action) with porosity as large as .014", if in the weld. This criteria should be reviewed to insure its acceptability.

5.0 CONCLUSIONS

The following conclusions are based on the results of the data review accomplished during the Panel 6 activities and discussed previously in this report. All subsystem and components reviewed are considered acceptable as is, with the exceptions noted below:

a. ENVIRONMENTAL CONTROL SYSTEM (ECS)

The quantity gaging system (including the electronics) in the potable water and waste water tanks is exposed to oxygen at pressures of 25 psia during flight and 35 psia during countdown. The electronics is supplied by 28 Vdc through two 5 amp circuit breakers. The acceptability of this design will require additional ignition tests which have already been initiated.

The following tasks were not completed during the ECS review due to lack of detailed component information:

(1) Review of cyclic accumulator O_2 control valve

(2) Review of O_2 flow transducer

(3) Review of O_2 pressure transducer, 100 psi system

(4) MSC review of nonmetallics, which are used on ECS O_2 line components, that NR has accepted by similarity.

(5) Verify that no electrical source could come in contact with the 100 or 900 psi aluminum lines in the O_2 control panel and the ECU.

The required information is being assembled by the contractor and the review will be completed.

b. ELECTRICAL POWER SYSTEM (EPS)

It was not possible to establish the acceptability or unacceptability of the cryogenic hydrogen tank design. Sufficient information could not be found in the literature to conclusively state that shorting of the internal electrical components of the tank would not initiate a sustained reaction of some kind which could eventually either fail the tank or destroy all internal functional capability. The necessary tests to resolve these issues have been initiated.

Even if such sustained reactions are shown not to exist, it is not possible to determine whether shorting of a single internal component will or will not damage through propagation to enough of the other internal functions of the H_2 tank to cause a mission abort. The necessary tests to determine the extent of propagation have been initiated.

Compatibility tests are required to establish the acceptability of solder and brass in H_2 and have been initiated.

The direct contact between high pressure gaseous oxygen (935 psi) and Teflon covered wiring such as in the fuel cell oxygen shut off solenoid is considered an unacceptable design.

The O_2 purge valves and reactant pressure regulator have nonmetallic materials in high mechanical stress applications whose acceptability could not be unconditionally established. The necessary impact tests have been initiated. The pressure switch and the pressure transducer in the O_2 system valve module and the pressure transducer in the fuel cell are conditionally acceptable pending receipt of further detailed information.

Pyro and entry battery test data are not sufficient to establish pressure capability and acceptance procedures and not adequate to insure satisfactory quality control during manufacturing. The necessary test will be performed to provide this assurance. The batteries are believed to have the required pressure capability.

c. SERVICE PROPULSION SYSTEM (SPS)

It was not possible to establish the acceptability or unacceptability of the direct contact of electrical components and Teflon with oxidizer and fuel which exists in the SPS quantity gaging sensors. Analysis indicates there should be no problem. Test have been initiated to confirm this analysis.

Compatibility (reactive decomposition of A-50 with Kovar or Ni-Span-C) tests are required and have been initiated to establish the acceptability of:

(1) Kovar in Aerozine 50

(2) Ni-Span-C in Aerozine 50

(3) Solder in N_2O_4 (flammability)

6.0 RECOMMENDATIONS

a. Perform analyses of the ECS water quantity gaging system to determine the integrity of the transducer cover and the non-propagation of flame to the bladder for a worst case short in the transducer. If the results indicate a marginal factor of safety, perform a test using actual hardware for both flight and ground conditions. At the same time, the requirement for a water quantity gaging system should be re-examined to determine if it is mandatory for flight.

b. Complete the ECS review for the following:

(1) Cyclic accumulator O_2 control valve

(2) O_2 flow transducer

(3) O_2 pressure transducer, 100 psi system

c. Complete the review of all nonmetallics on ECS O_2 line components that NR has accepted by similarity. If any nonmetallics are found not acceptable for O_2, then review the components which contain these nonmetallics, with the guidelines for this study.

d. Test plans already initiated should be completed to determine whether:

(1) Sustained reactions can be initiated by means of electrical shorts in the CSM cryogenic hydrogen tank wiring. If reactions can be initiated, are they sufficiently energetic to rupture the hydrogen tank or lines?

(2) If no sustained reactions can be identified, can a single electrical short within the tank or conduit result in failure of enough tank functions (heaters, fans, quantity, temperature) to result in a mission abort.

e. Reevaluate the desirability of adding AVT tests on tanks with internal electrical components.

f. Complete the redesign of the fuel cell oxygen shutoff valve (or system) already initiated.

g. Complete the testing already initiated to determine whether sustained reactions can be initiated in the SPS quantity gaging sensors within the energy limits of each application.

h. Complete the testing already initiated to resolve the compatibility issues of the conclusions.

i. Proceed with the MSC tests of impact of non-metallic materials in high pressure oxygen to resolve the issues associated with the oxygen purge valve and reactant pressure regulators.

j. Review expected information on oxygen system valve module pressure switch and pressure transducer and fuel cell pressure transducer to determine validity of conclusions reached to date and take necessary action if proven invalid.

k. Complete the testing already initiated to determine the burst capability of the entry and pyro battery cases and modify the acceptance test procedure to include a proof pressure test consistent with the results of the burst test.

l. Review all pressure vessel acceptance criteria, test and checkout procedures and operational procedures.

APPENDIX A

NO OF PAGES 8

REPORT NO. E-851

REFERENCE:

APPENDIX "A"

ATTACHMENTS:

HAZARD ANALYSIS
ASSUMING SHORTED VOLTAGES AT
THE FUEL AND OXIDIZER
PRIMARY AND AUXILIARY SENSORS

SIMMONDS PRECISION PRODUCTS, INC.

APR 22 1970

NORTH AMERICAN #M7J3XAA-575001A
CONTRACT #NAS9-150
SSO #V-26083-DX-A2 RATING

	PREPARED		APPROVED	APPROVED
BY	D. St.Pierre		J.FitzPatrick	W. Dunn
SIGNED	D. St.Pierre		[illegible]	[illegible]
DATE	4-22-70		[illegible]	

REV LETTER	DATE	REV BY	PAGES AFFECTED	NO PAGES IN REPORT

INTRODUCTION

This hazard analysis was conducted to determine the effects of various sensor failure modes with emphasis on additional power dissipation resulting from sensor malfunctions.

ANALYSIS

Following are the voltages present at the fuel and oxidizer sensors. These voltages are generated in the control unit and are derived from 115 V, 400 Hz primary and auxiliary line from NR.

TABLE I

	OXIDIZER		FUEL	
	PRIMARY	AUXILIARY	PRIMARY	AUXILIARY
LINE	COLUMN A	B	C	D
1-	+26 VAC_P	-26 VAC_A	-20 VAC_P	+26 VAC_A
2-		27 V, 6KC		8 V, 6KC
3-		2.7 V, 6KC		+10 VDC
4-		+10 VDC		- 6 VDC
5-		- 6 VDC		

Voltages which are of interest in this task are the ones listed on Line 1 of Table I. Voltages on Lines 2 through 5 of Column D were analyzed and discussed as part of Engineering Report E-803 of June, 1969. Summary of that report related to +10 VDC, -6 VDC, and 6 KC voltages of the auxiliary system follows:

All three power supplies shorted at the sensor, which is worst case, would cause an increase in current through the 0.5 amp auxiliary system fuse on the 115 VAC line of less than 0.06 amp. This would require only an additional 7 watts from the 115 VAC, 400 Hz power line. 60% of the additional power would be dissipated in the control unit regulating circuit and the remainder dissipated at the points shorting in the fuel probes.

OXIDIZER SENSOR AUXILIARY VOLTAGES

Voltages listed on Lines 2 through 5 of Column B have basically the same characteristics as the ones of Column D discussed in E-803. Analysis of +10 VDC, -6 VDC, and 6 KC auxiliary oxidizer voltages will not be performed due to similarity to auxiliary fuel voltages analysis; conclusions drawn from auxiliary fuel could readily be applied to auxiliary oxidizer.

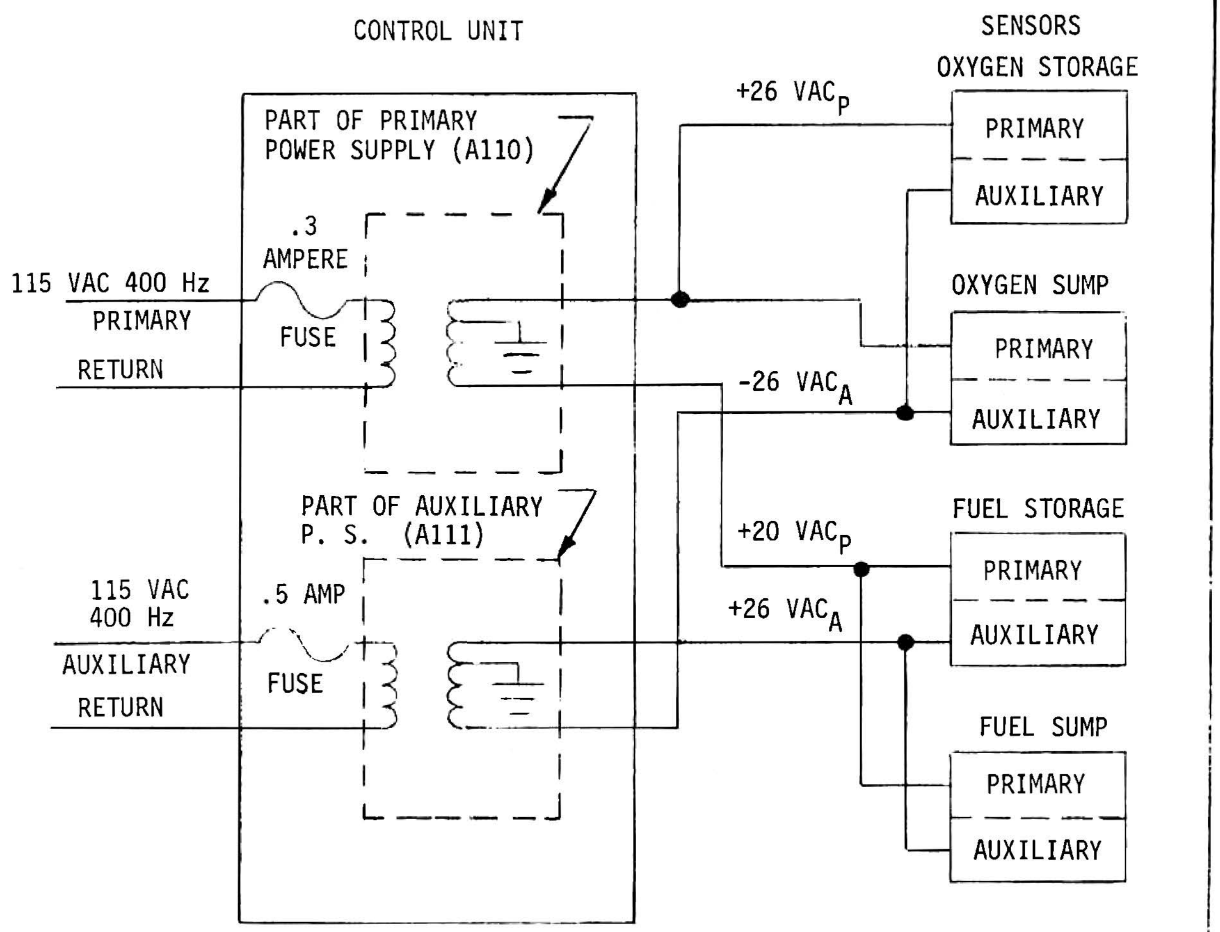


FIGURE 1

Figure 1 shows the routing of the voltages listed in Table I, Line 1. The voltages are generated in the primary and auxiliary power supply and delivered to the sensors temperature sensitive resistors.

Fuses used in the power supplies have the following characteristics:

	PRIMARY (A110)	AUXILIARY (A111)
Fuses Type:	GFA-"A"-TRON 300 Ma	GFA-"B"-TRON 500 Ma
Character-istics:	Will carry 100% load and open in 10 seconds at 200%. Opening time increases as T^2	Will carry 100% load and open in 10 seconds at 150%. Opening time increases as T^2

Tests were conducted on a Block II control unit to actually measure the amount of power that could be distributed by the control unit under sensors shorted or maximum power transfer condition.

Maximum power transfer is achieved when load (R_o) is equal to the impedance of the source (Z_{Eg}). Maximum power transfer is the point where an increase in current will not result in increased power. Maximum load power is delivered when the slope of P_L and Z_L is zero as shown by diagram.

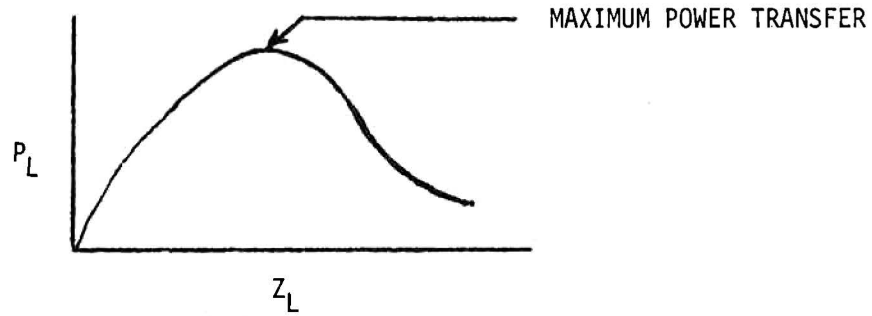


Figure 2 and Figure 3 illustrate the test setup used to determine effective resistance of sensor power source. This is accomplished by loading voltage source to 1/2 its unloaded value. At that point, effective resistance of the power source is the same as the load resistance.

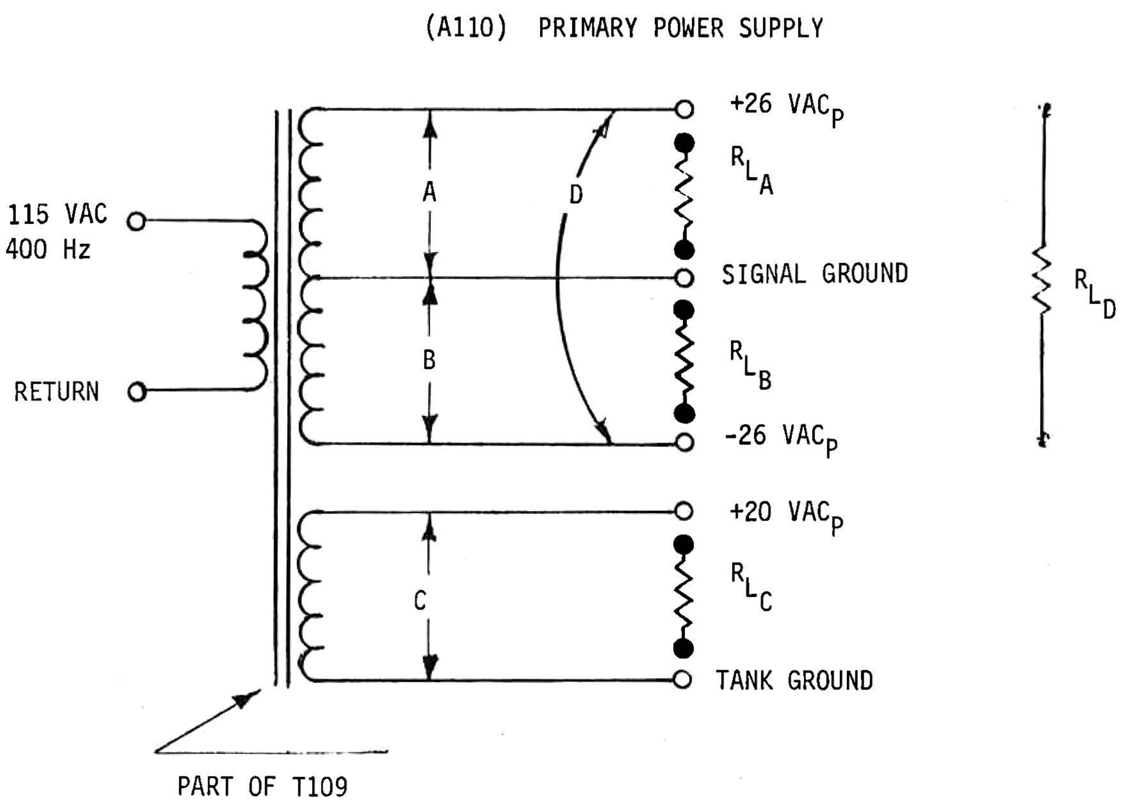


FIGURE 2

Power dissipation and load for each circuit at maximum power transfer is as follows:

	Power	R_L
A	= 8.5 watts	17
B	= 8.5 watts	17
C	= 2.3 watts	35
D	= 10.7 watts	58

(A111) AUXILIARY POWER SUPPLY

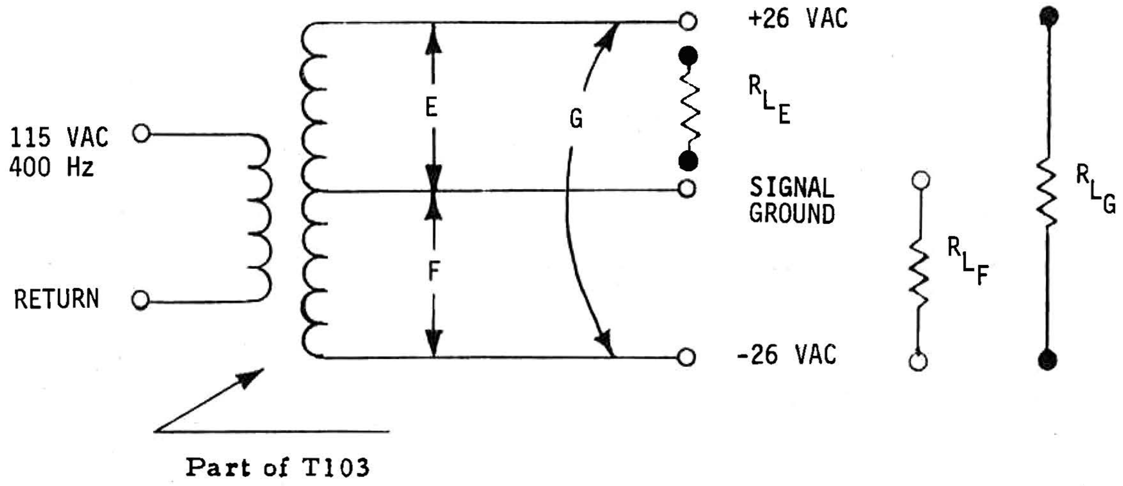


FIGURE 3

Maximum power transfer and load for each circuit is as follows:

	R_L
E = 7.8 watts	20
F = 8.2 watts	20
G = 9.6 watts	65

Table 2 is a tabulation of power dissipation as a result of the failure of one or more sensors.

Table 2

SENSORS FAILURE MODE	POWER DISSIPATION	
	At Control Unit	At Sensors
1. Pri Ox. 26 VAC_P Shorted	8.7 watts	6.7 watts
2. Aux. Ox. 26 VAC_A Shorted	8.4 watts	6.4 watts
3. Pri. Fuel 20 VAC_P Shorted	6.1 watts	4.1 watts
4. Aux. Fuel 26 VAC_P Shorted	8.4 watts	6.4 watts
5. Pri Ox. & Aux. Ox. 26 VAC Shorted	12.6 watts	10.6 watts
6. Pri. Fuel & Aux. Fuel 20 and 26 VAC Shorted	10.0 watts	8.0 watts
7. Pri. Ox. & Pri. Fuel 20 and 26 VAC Shorted	9.9 watts	7.9 watts
8. Aux. Ox. & Aux. Fuel 26 VAC Shorted	9.3 watts	7.3 watts
9. Pri. & Aux. Fuel & Ox. 26 VAC (20 VAC Pri. Fuel) Shorted	14.5 watts	12.5 watts

CONCLUSIONS

As a result of lab testing, it was found that the maximum amount of power that could possibly be generated at the sensors due to any possible failure mode is in the neighborhood of 12.5 watts. Power dissipation occurring due to the shorting condition of one or all sensors would not result in a significant temperature change due to the large bulk of heat dissipator surrounding any shorting points within the sensors themselves.

APPENDIX B

NO OF PAGES 4

REPORT NO. E-803

REFERENCE:

APPENDIX "B"

ATTACHMENTS:

HAZARD ANALYSIS

ASSUMING AUXILIARY SYSTEM PROPELLANT LEAKAGE

SIMMONDS PRECISION PRODUCTS, INC.

	PREPARED		APPROVED	APPROVED
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DATE	6/18/69		6/18/69	6/18/69

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AE-137 9/66/100

1.0 INTRODUCTION

The following Hazard Analysis was conducted to determine the ramifications of Fuel (A-50) Leakage into the Auxiliary System cavity on; A) The Auxiliary System B) The Primary System and C) The Spacecraft.

2.0 ANALYSIS

2.1 AUXILIARY SYSTEM

The fuel (A-50) being of conductive and corrosive nature attacks the insulating material in the electronic modules (point sensor modules) located in the Auxiliary cavity. Improper point sensor indication may occur along with the loading down of the three auxiliary power supply voltages (-6 VDC, +10 VDC, +8 VAC @ 6 KHz). The power supplies are located in the control unit and are common to the entire point sensor system. Failure of these voltages reduces the Auxiliary System to a nominal flow integrator.

The above three power supplies are contained in two modules in the control unit.

These three power supplies are all transistor regulated signal type supplies with current limited outputs. All three supplies are derived from the 115 VAC 400 Hz power line. A total short on all three supplies will not draw enough extra current to blow the 0.5 amp auxiliary system fuse on the 115 VAC line.

The regulating nature of both d.c. supplies is as follows:

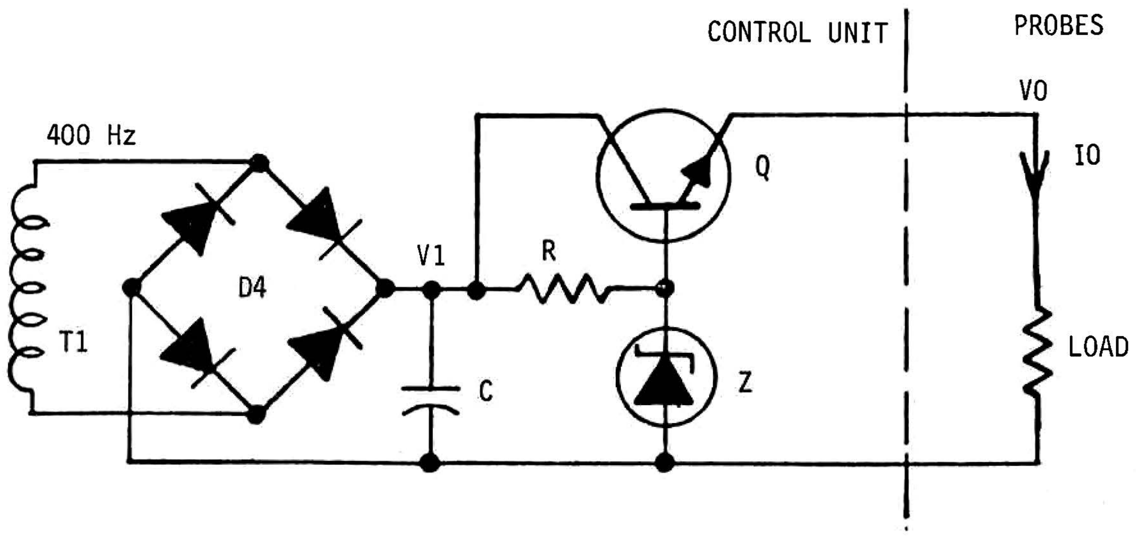

FIGURE 1

2.1 continued

An unregulated d.c. voltage appears as V_1 after being rectified from the 400 Hz transformer T_1 by the diode bridge D4. Capacitor C filters out a.c. noise caused by the 400 Hz line. The d.c. voltage V_O is limited to a maximum voltage by Q and zener diode Z. I_O is limited to a maximum value by Q and R. The current through R is used to drive Q. Thus, the maximum output current I_O is the current through R times the current gain of Q. Both the -6V and the +10V power supplies are capable of supplying approximately 100 ma without reducing the output voltage and both supplies are limited by transistor gain as described above to approximately 300 ma into a short circuit load.

The 6 KHz oscillator uses basically the same principle for regulation on an a.c. basis as follows:

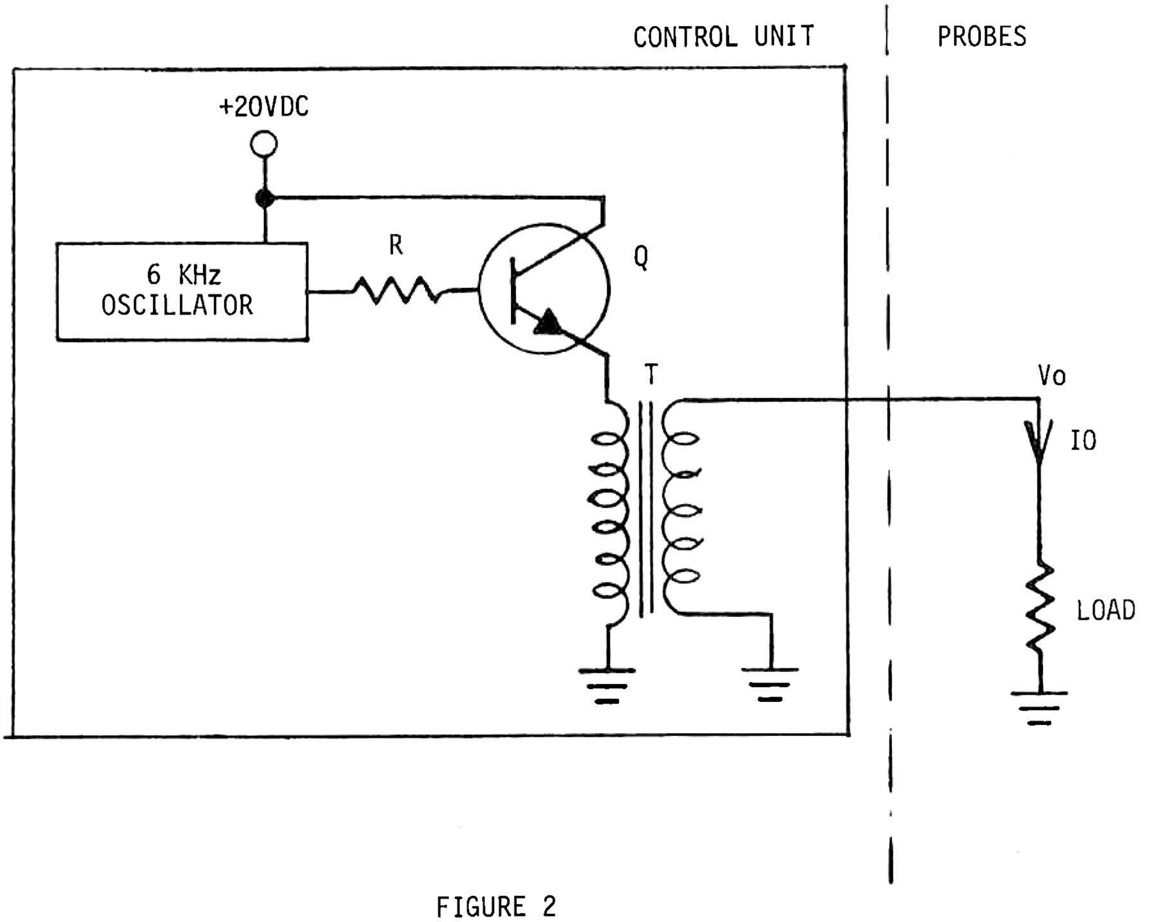

FIGURE 2

2.1 continued

Again the drive to the output transistor Q is limited by the resistor R. Output transistor Q drives the primary of transformer T. The secondary of transformer T supplies the 6 KHz signals to all four probes.

I_O is a maximum into a short circuit load and is limited to a maximum value of approximately 100 ma by the current through R and the current gain of transistor Q.

With all three power supplies shorted, the increase in current through the 0.5 amp auxiliary system fuse on the 115 VAC line will be less than 0.06 amps.

2.2 PRIMARY SYSTEM

The primary system will be completely unaffected by this or any other auxiliary system failure. All power supplies are physically separated as well as separately fused. Auxiliary and Primary probe cavities are separately hermetically sealed and separated by 0.1" aluminum wall thickness. Incoming power lines to both systems are separated as well as probe cables and connectors.

2.3 EFFECT ON SPACECRAFT

As stated in (A), an additional 0.06 amp max. may be required (7 watts) from the 115 VAC 400 Hz power line. Approximately 4.5 watts will be dissipated in the control unit regulating circuitry, and approximately 2.5 watts will be dissipated total at the points of shorting in the fuel probe. Neither of these power dissipations is seen as a significant temperature rise due to the low wattage and large bulk of heat sinking around the units.

3.0 CONCLUSIONS

In the event that a fuel leak occurs in the PUGS Fuel Probe Auxiliary cavity, the resulting effects would at no time endanger the integrity of the Spacecraft, nor the ability to successfully carry out the mission objective.

3.0 continued

Considering the Auxiliary System point sensor operation (Reference A), the two conditions which could theoretically occur are: incorrect Auxiliary Power supply voltages and a short circuit.

Concerning the incorrect voltages, if these voltages are reduced or totally eliminated due to loading, then the point sensor operation would be disrupted causing an inaccurate Auxiliary System. However, the Auxiliary System would still function, but, limited in operation to a nominal flow integrator.

In a worst case shorted condition, it has been calculated that at no time would sufficient additional current be drawn from the 115 VAC,Hz power source to cause the 0.5 amp fuse to blow. This is a result of the system design incorporating current limiting capabilities into the power supply outputs.

Power dissipation occurring due to the shorting condition is not seen as a significant temperature rise considering the low wattage value and extensive heat sink absorbers surrounding the affected components. Reference C for specifics relating to Spacecraft effect.

The relationship of the Primary System during an Auxiliary System anomaly is one of complete isolation from both a physical and electrical standpoint. Thus, its operation is completely unaffected.

APOLLO 13 INVESTIGATION TEAM

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