NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 5C

CORRECTIVE ACTION STUDY AND IMPLEMENTATION

FOR

GOVERNMENT FURNISHED EQUIPMENT

MAY 1970

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

PANEL 5C REPORT

MSC Apollo 13 Investigation Team
Panel 5C, Government-Furnished Equipment (GFE)
Corrective Action and Study Implementation

May 8, 1970

APPROVED BY: [signature]
PA/R. S. Johnston
Panel Chairman

CONCURRENCES: [signature]
PG15/J. W. Thompson (ASPO)

[signature]
EC/J. Correale (CSD)

INDEX

SECTION	TOPIC	PAGE
	Index to Tables and Illustrations.	2
	GFE Investigation Team Membership.	3
1.0	Introduction, Purpose and Scope	4
2.0	Scope of MSC Apollo 13 GFE Investigation Team Activities	4
3.0	Mode of Operation.	5
4.0	Study Results	5
4.1	Pressure Vessel Data	5
4.2	Criticality Review	5
4.3	Life Support Systems Detailed Investigation.	5
4.4	Contingency Equipment Use Study.	12
5.0	Findings, Conclusions, and Recommendations	12
6.0	Appendix	15
6.1	Pressure Vessel Data	15
6.2	Criticality Review	21
6.3	Life Support Systems Detailed Investigation.	34
6.3.1	EMU Single Point Failure Review.	34
6.3.2	Pre- and Post-flight Suit Leakage Summary.	60
6.4	Contingency Equipment Use Study.	62

ATTACHMENTS

1.	Memo: Scope of MSC Apollo 13 GFE Investigating Team Activities
2.	Minutes: GFE Panel 5C Meeting No. 1
3.	Minutes: GFE Panel 5C Meeting No. 2
4.	Minutes: GFE Panel 5C Meeting No. 3
5.	Memo: Transmittal of Data on Contingency Use to PD

INDEX TO TABLES AND ILLUSTRATIONS

TABLE	TITLE	PAGE
I	GFE Criticality Rating Criteria	6
II	GFE Criticality I & II Classifications.	6
III	Pre- and Post-flight Spacesuit Leakage Summary.	13
A1	Lunar Orbital Experiments Pressure Vessel Data.	16
A2	List of Pressure Vessels - Lunar Surface Experiments. . .	17
A3	Crew Equipment Pressure Vessel Data	20
A4	GFE Criticality Ratings	22
A5	EMU Single Point Failure Study.	35
A6	PLSS Primary Oxygen Supply Bottle Data.	43
A7	EMU Primary Oxygen Bottle Qualification Test Results. . .	44
A8	OPS Oxygen Bottle Data.	46
A9	Pre- and Post-flight PGA Leakage History Summary.	61

FIGURE	TITLE	PAGE
1	PLSS Flow Schematic	8
2	OPS Flow Schematic	9
3	PGA Leakage Rate History.	11
A1	Stress Rupture Life of SNAP 27 FCA.	19
A2	Oxygen Ventilating Circuit Schematic.	39
A3	PLSS O_2 Bottle Protection	42
A4	Protection of OPS O_2 Bottle	47
A5	OPS Flow Schematic	51
A6	Pressure Garment Assembly	55
A7	Suit Feed Throughs	57
A8	PGA Leakage Rate History.	58

MSC APOLLO 13 INVESTIGATION TEAM

CORRECTIVE ACTION STUDY AND IMPLEMENTATION

GOVERNMENT-FURNISHED EQUIPMENT (GFE)

Chairman - Richard S. Johnston

Members - J. Correale (CSD)

D. Grimm (FCSD)

J. Langford (Lunar Surface Experiments)

E. Jones (Lunar Orbital Experiments)

C. McCollough (R&QA)

N. Vaughn (Safety)

J. Thompson (ASPO)

1.0 Introduction, Purpose and Scope

This document provides a description of the Apollo 13 Government-Furnished Equipment (GFE) Corrective Action and Study Implementation Panel Activities, a summary of the results of the various studies undertaken, and the significant conclusions and recommendations reached. The appendix contains the notes and reports generated during the tenure of the team. Referrel documents, such as the spacecraft stowage lists, operations handbook, and test documentation can be made available upon request. Copies of Failure Mode and Effects Analysis (FMEA) documents pertinent to specific life support or survival equipment are available for review in the office of the chairman.

2.0 Scope of MSC Apollo 13 GFE Investigation Team Activities

The scope of the GFE investigation is defined by the following activity descriptions.

2.1 Pressure Vessel Data Accumulation

Compile a listing with pertinent design data for all government-furnished equipment. This information is required to assist the Investigation Team Panel No. 6 in its detailed investigation of all Apollo pressure vessels.

2.2 Criticality Review

Review all GFE to determine those items which are presently designated as Criticality I and to determine if any items should be upgraded to Criticality I (See Criticality definitions on page 6).

2.3 Detailed Investigation

Review the acceptability of the design of Criticality I equipment items and make recommendations for design studies and/or changes.

2.4 Contingency Use Study

Review the need for adding contingency type equipment in either spacecraft and determine feasibility of using existing equipment for uses other than those for which it was designed.

2.5 Exclusion of Non-metallic Materials Review and Electronic Circuit Analysis

Evaluation of GFE materials and electronic circuit elements will not be considered during this investigation based on the extensive equipment redevelopment which resulted from the Apollo 204 investigation. The use of non-metallic materials, their proximity to ignition sources and other safety aspects have been continually reviewed by all levels of program management.

3.0 Mode of Operation

The GFE investigation proceeded according to the following steps:

a. Review Failure Mode and Effects Analyses for adequacy and completeness.
b. Re-examine the rationale for acceptance of single point failures.
c. Review and submit recommendations for any proposed hardware changes.
d. Provide all tank data and contingency use study results to Panel No. 6 for further detailed investigation.

4.0 Study Results

Detailed reports prepared during the various studies are included in the appendix. This section includes a summary of the results.

4.1 Pressure Vessel Data

A total of 7 types of high pressure tanks and cartridges were identified in flight GFE. Of these, two are filled with O_2 and the rest contain CO_2, N_2 or He. Detailed tank analysis is to be conducted by the Systems Engineering Division. The raw data collected by the GFE Team is included in the appendix. It should be noted that electrical wiring is not contained in any of the GFE pressure tanks.

4.2 Criticality Review

The total complement of Apollo GFE was reviewed by item to re-evaluate presently established criticality ratings. No major rating changes were required. The criteria used in determining the criticality of equipment end items is shown in Table I, page 6. Criticality I end items were then examined with regard to the criticality ratings of the single point failure modes inherent in the equipment. The criteria used for rating single point failures of Criticality I end items is included in Table I. Table II, page 6 is a compilation of the Criticality I and II equipment items and Criticality I single point failure modes. Ratings for all GFE are included in the appendix along with an index to existing Failure Modes and Effects Analysis (FMEA) documentation (see Section 6.2, page 21)

4.3 Life Support Systems Detailed Investigation

All GFE Criticality I End Items were included in the Life Support Systems and detailed investigation was limited to this equipment.

TABLE I

GFE Criticality Rating Criteria

Hardware (End Item) Criticality Classification

I. Item necessary to sustain crewman's life
II. Item necessary to perform mission
III. Other

Single Point Failure Criticality Classification

I. Failure would cause loss of crewman's life
II. Failure would cause loss of mission or second failure would cause loss of crewman's life
III. Other

TABLE II

GFE Criticality I and II Classifications

Criticality I Equipment Items	Criticality I Single Point Failure Modes
Pressure Garment Assembly (PGA)	1. Catastrophic leakage of pressure retention layer. 2. Catastrophic leakage of PGA connectors, zipper, wrist disconnects, etc.
Portable Life Support System (PLSS)	1. Catastrophic leakage through the oxygen ventilation circuit. 2. Explosion of the Primary oxygen supply bottle.
Oxygen Purge System (OPS)	1. Explosion of the oxygen supply bottle. 2. Catastrophic leakage through the oxygen flow regulator bellows. 3. Catastrophic leakage through the umbilical hose.

Criticality II Equipment Items	
Liquid Cooling Garment	Communications Carrier
Oxygen Mask and Hose Assembly	PLSS LiOH Cartridge and Battery
PLSS Remote Control Unit	Lunar Extravehicular Visor Assy
EV Gloves and Lunar Boots	Purge Valve Assembly
Emergency Supply Umbilical	

4.3.1 Portable Life Support System (PLSS)

PLSS Criticality I single point failure modes consist of rupture (explosion) of the primary oxygen supply (POS) bottle causing damage to the crewman or the rupture of any element in the oxygen ventilation circuit resulting in premature loss of the oxygen supply (see Figure 1, page8). Note that blockage of the ventilation circuit or inadvertant disconnection of a PLSS umbilical connector are not considered Criticality I failure modes because of the backup protection of the Oxygen Purge System (OPS) and the incorporation of self-sealing connectors in the PGA.

The ventilation circuit single point failure mode was incorporated into the PLSS because elimination would require a redundant ventilation circuit, redundant PGA interfaces, and complex crossover valving which would yield unacceptable weight and volume growth and an increase in potential failure points. The failure mode has been accepted due to the reliable natureof the system components and the extensive, stringent qualification and pre-flight testing program to which the equipment is subjected. There have been no instances recorded of incipient or actual failure in this mode of the PLSS ventilation circuit.

The PLSS primary oxygen supply bottle failure mode was accepted in the basic design because no other means was feasible, within weight/volume limitations, for the application. Qualification test results indicate that the bottle design provides an actual safety factor of 2.1, based on the ratio of the lowest actual burst pressure recorded during test to the maximum operating pressure possible during mission conditions. The PLSS structure plus an internal shield protects the bottle from damage from external sources during pre-flight handling and during the mission. There are no potential external or internal electrical current inputs to the oxygen bottle. No failures of the PLSS oxygen bottle have occurred.

4.3.2 Oxygen Purge System (OPS)

The Criticality I single point failure modes of the OPS consist of explosion of the oxygen bottle causing damage to crewman or equipment, massive rupture of the flow regulator primary bellows permitting oxygen flow out of the suit through the OPS umbilical to vacuum, and rupture of the OPS umbilical again permitting oxygen loss (see Figure 2, page 9).

The single point failure mode of the OPS oxygen bottle was accepted in the equipment design using the same rationale as was used for the PLSS oxygen bottle. Qualification test results indicate an actual safety factor of 2.2. Again, the OPS structure protects the bottle during handling or use, and no potential electrical inputs to the bottle are found in the equipment after deletion

PLSS FLOW SCHEMATIC

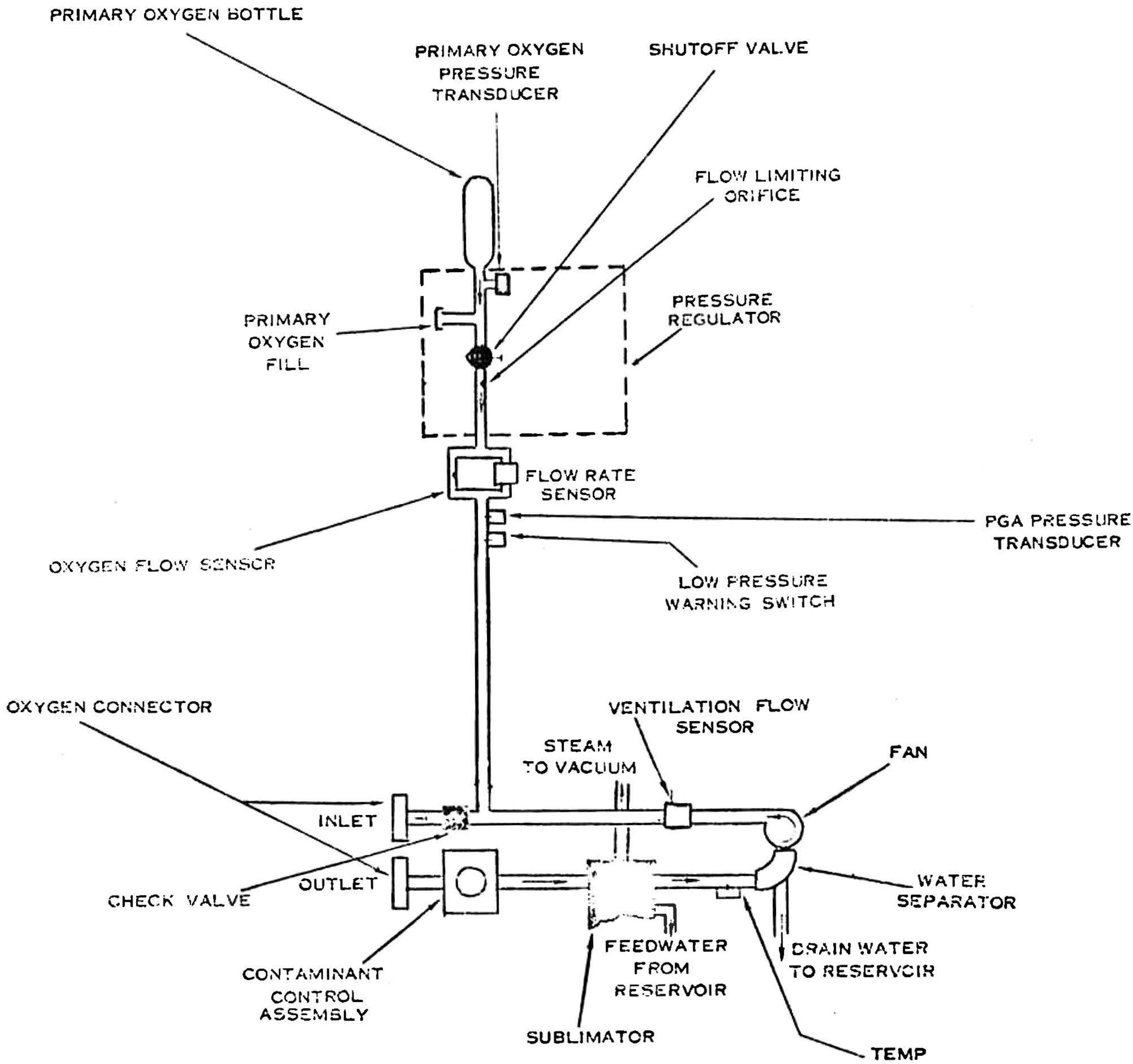


FIGURE 1

OPS FLOW SCHEMATIC

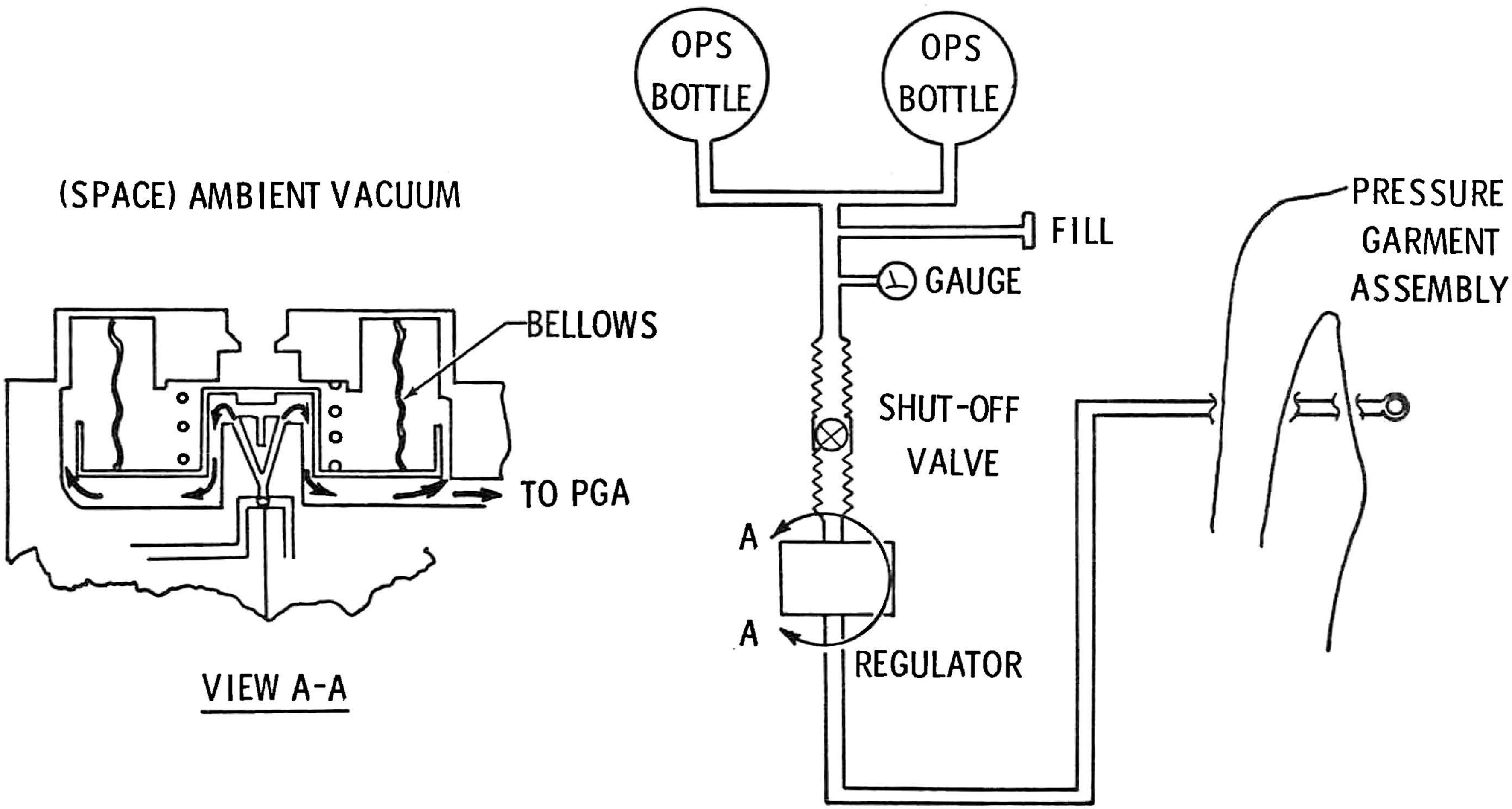


FIGURE 2

of the regulator heater circuitry which was incorporated in OPS units used on previous Apollo missions. There have been no instances of failure of any OPS oxygen bottles to this point of the Apollo Program.

The OPS regulator primary bellows rupture failure mode was accepted during OPS design due to the complexity of the equipment required for elimination. The added complexity would add several single point failures of a lower criticality and lead to lower overall equipment reliability. Component testing of the bellows indicates an actual safety factor of more than 10.0. This has been borne out by an extensive qualification test program. Each flight unit is also thoroughly tested at the component, subsystem and system level prior to committment to flight. There have been no instances of failures recorded against the bellows.

The OPS oxygen umbilical design has been accepted for the same reasons as the PLSS umbilicals. No failures have been detected during any test to this point in the program.

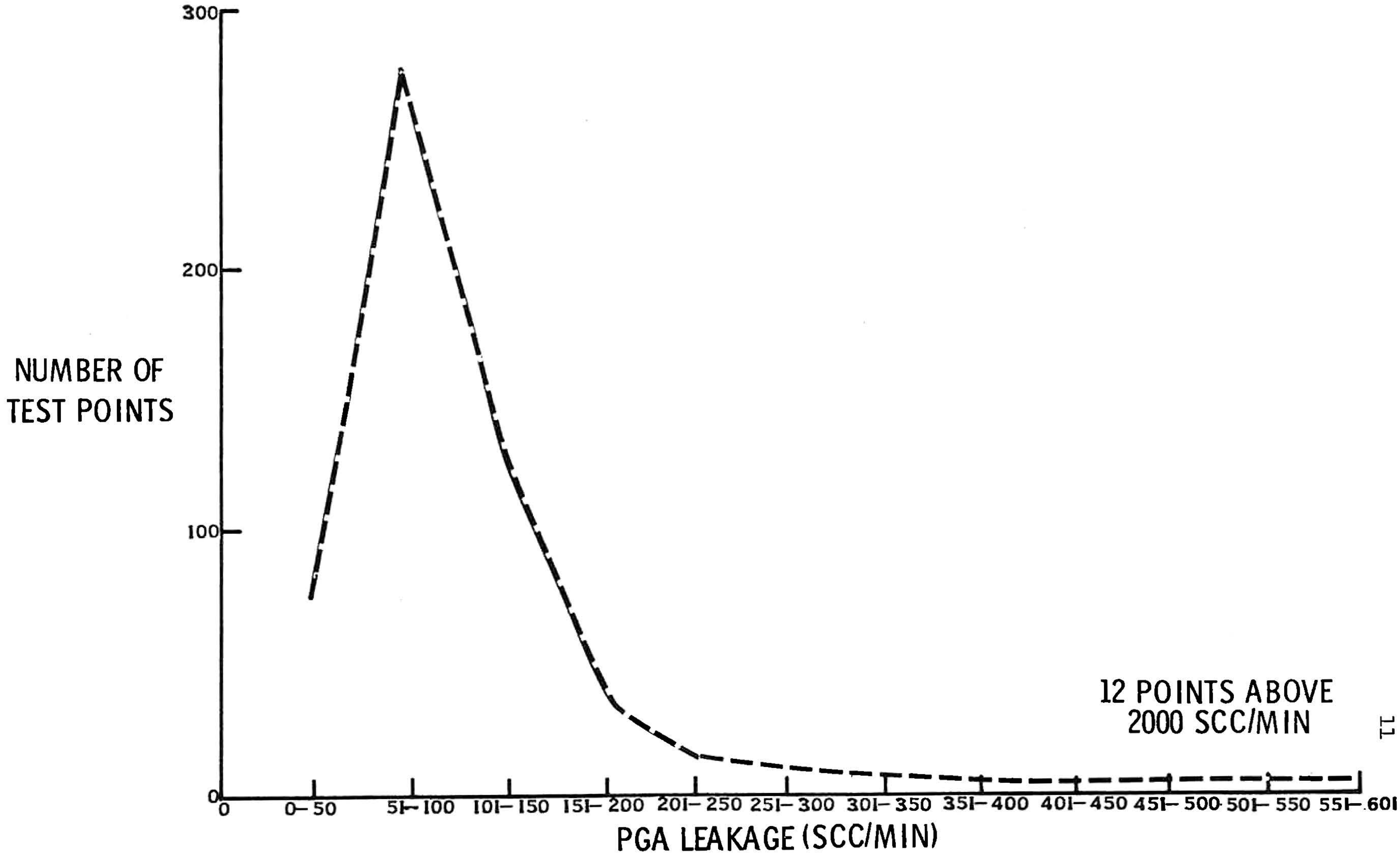
4.3.3 Spacesuit - Pressure Garment Assembly (PGA)

The PGA Criticality I single point failure modes consist of rupture of the single layer pressure bladder, convolutes, or helmet; or high leakage rates (greater than the PLSS/OPS make-up capability of 8#/hour or 44,400 scc/min) through the PGA closure mechanism, the neck or glove connect rings, or the self sealing gas/liquid suit connectors.

The noted failure modes were identified during PGA design and development and were accepted due to the reliability characteristics of the materials and mechanisms involved and because use of redundancies in the PGA would effect mobility, bulk, and comfort; equipment donning, doffing and hookup operations; and overall system reliability.

Justification for confidence in the PGA design, manufacture and test approach is available in the test data accumulated during the Apollo Program. Figure 3, page 11, provides a plot of the leakage rate history for 28 PGA's representing the worst cases of 115 controlled type flight suits that have been processed in Apollo to this point. Each point on the curve indicates the number of times that a leak rate of that magnitude was noted during a total of 579 individual leak rate tests. Of the 579 points, approximately 10% (59) of the points were in the range above the PGA leak specification limit of 180 scc/min and only 12 points were greater than 2000 scc/min (2000 scc/min is the flow rate from the PLSS primary oxygen bottle which would trigger an alarm indicator to denote an excessive flow rate). One of those 12 points was greater than the PLSS/OPS oxygen makeup capability. This failure is attributed to human error in that serious abrasion of the protective patch over the shoulder convolute was noted during unmanned testing but was permitted to continue until a hole was worn through the pressure layer.

FIGURE 3
PGA LEAKAGE RATE HISTORY
579 TEST POINTS FROM PDA, REC. INSPECTION, PIA, AND POST TEST INSPECTIONS ON 28 PGA's (WORST CASES OF 115 CONTROLLED TYPE FLIGHT SUITS)



Leakage rates approaching the higher level rates indicated in Figure 3 would never be permitted in PGA's to be used for an Apollo mission, and would be detected during the extensive pre-installation acceptance (PIA) testing conducted at KSC in the period just preceding the mission. Table III, page 13, provides a compilation of the actual leakage characteristics of PGA's that have been used to this point in the Apollo earth orbital, lunar orbital or lunar surface mission operations. Of the 39 test points shown, all are well within the 180 scc/min specification except for data from two PGA's. A waiver for use of the Command Module Pilot's PGA was granted for Apollo 9 because previous test history of the unit indicated the absence of a structural problem, the fact that the point of leakage was traced to an area of the unit that was well protected, and that the measured rate was well below the mission critical level.

The excess leakage measured on the Apollo 12 Commander's PGA was traced to the right boot bladder, which was subjected to abrasion from the right instep of the crewman during the mission. The boot bladder assembly has subsequently been redesigned to improve service and reliability and the new design has been incorporated into all Apollo flight PGA's.

4.4 Contingency Equipment Use Study

A brief study was made of the potential contingency application of stowed equipment aboard the CM or the LM. The results, which have been transmitted to the Systems Engineering Division for inclusion in an in depth review of contingency use modes, are included in the appendix.

5.0 Findings, Conclusions, and Recommendations

The following findings, conclusions, and recommendations are based on the results of the data review accomplished during the GFE investigation panel activities.

5.1 Findings

a. There are no electrical circuits in any GFE pressure vessels.

b. Pressure vessel design parameters are sufficient to provide a safety factor against explosive rupture of at least 2.0 as determined by actual burst test results.

c. The Failure Mode and Effects Analyses for Criticality I GFE end items have adequately considered all potential failure modes and the effects thereof.

TABLE III

PRE- AND POST-FLIGHT LEAKAGE SUMMARY ASSOCIATED WITH APOLLO FLIGHT PRESSURE GARMENT ASSEMBLIES

FLIGHT NUMBER	CREWMAN	PGA SERIAL NO.	PRE-FLIGHT PGA LEAKAGE (PIA) CC/MIN.	POST-FLIGHT PGA LEAKAGE CC/MIN.
Apollo 7	CDR	A7L-004	60	90
	CMP	A7L-005	90	100
	LMP	A7L-006	125	265
Apollo 8	CDR	A7L-030	60	50
	CMP	A7L-037	87	35
	LMP	A7L-031	55	65
Apollo 9	CDR	A7L-020	90	54
	CMP	A7L-019	200*	225
	LMP	A7L-015	55	53
Apollo 10	CDR	A7L-047	60	75
	CMP	A7L-043	108	75
	LMP	A7L-044	60	75
Apollo 11	CDR	A7L-056	33	117
	CMP	A7L-033	60	85
	LMP	A7L-077	95	115
Apollo 12	CDR	A7L-065	105	400**
	CMP	A7L-066	55	18
	LMP	A7L-067	51	45
Apollo 13	CDR	A7L-078	80	***
	CMP	A7L-088	130	***
	LMP	A7L-061	58	***

* Flown on Waiver Number FLC 8812-4W-0240

** Post-flight test failure - MR 03952

*** Data not available - PGA's yet to go post test.

NOTE: All data taken at sea level ambient conditions using O_2 with PGA pressurized to 5.75 psig.

d. The Criticality Ratings for GFE provide a conservative guideline for the identification of equipment necessary for crew life support and mission completion.

e. The identification of Criticality I single point failure modes in Criticality I end items is accurate and comprehensive.

f. The rationale for acceptance of all Criticality I single point failure modes in GFE life support equipment is adequate and has been proven by sufficient test programs.

g. Test and mission use results have confirmed the reliability of GFE life support equipment.

5.2 Conclusions

a. The present design of all Criticality I flight GFE is satisfactory to support continuation of the Apollo Program.

b. Existing manufacture, test and review procedures adequately assure the provisioning of flight worthy equipment.

c. The existing life support equipment Criticality I single point failures are acceptable due to the reliability and safety margins available in the equipment.

5.3 Recommendations

Based upon these conclusions it is recommended that no changes to design, manufacture, test or review requirements be made and that existing equipment continue to be used to support the Apollo Program.

6.0 Appendix

6.1 Pressure Vessel Data

(For PLSS/OPS pressure vessel data see Sec. 6.3, pages 42 and 46).

TABLE A1

LUNAR ORBITAL EXPERIMENTS PRESSURE VESSEL DATA

EXPERIMENT	CRITICALITY I	FMEA	PRESSURE VESSEL
Gamma Ray Spectrometer	No	Completed	None
X-Ray/Alpha Spectrometer	No	Completed	None
Mass Spectrometer	No	In MSC Review	None
Panoramic Camera	No	Being Revised	None*
Mapping Camera	No	Being Revised	None***
Laser Altimeter	No	Being Revised	None**
IR Scanning Radiometer	No	Required by RFP	None
Far UV Spectrometer	No	Required by RFP	None
Subsatellite	No	Required by RFP	Batteries

*Contains N_2 plumbing. Maximum pressure is 28 PSIG in camera. N_2 supply provided by NR as CFE.

**Laser head contains one atmosphere of N_2. Volume is approximately 15 cubic inches.

***May require N_2 supply. If so, will utilize same supply as panoramic camera.

TABLE A2

LIST OF PRESSURE VESSELS-LUNAR SURFACE EXPERIMENTS

Exp. - Subsystem Component	Contractor	Approx. Dim	Gas	Design/Proof Pressure	Working Pressure	Relief Valve Press	FMEA	Apollo Flt Assignment
PSE - Caging System .04-O.D. SS thin wall tubing	BxA	1.6 in.^{3}	10% helium +nitrogen	666/1000 PSIA	333 PSI	No	Yes	All
Outer Case - Soft Spun aluminum	BxA	10.75 Dia x 16.5" long	Air	No	Ambient	No	Yes	All
Sample Return Containers	MSC	22 x 18 x 10	Vacuum	/14.7 PSI	15.0 PSI	No	NO	All
LGEC - Pressure Bottle	Goerz	1 in^3	Dry Air	760 PSI	500 PSI		YES	14 & Subq.
- Case	Goerz	14 x 6 x 5	Dry Air	1.5 PSI/	1.5 PSI	1.5 PSI	YES	14 & Subq.
RTG	AEC	20 x 6.0-O.D. 4.5-I.D.	Argon	14.7 @ Ambient	25 @ 1100°F	No Static	Yes	All
- Fuel Element	AEC	18 x 2 Dia	Helium	Ambient-1000	PSI After	6 yrs.	Yes	All
Drill - Battery Cell	Martin	5 x 5 x 8	Nitrogen	-/20 PSI	8 $\pm$ 3 PSI	8 $\pm$ PSI	Yes	16
- Battery Case	Martin	10 x 5 x 8	Nitrogen	-/20 PSI	5 $\pm$1/2 PSI	5 $\pm$1/2 PSI	Yes	16
- Power Head	Martin	14 x 8 Dia	Nitrogen	-/60 PSI	15 $\pm$ 2 PSI	15 $\pm$ 2 PSI	Yes	16
CS* Components								
Reed Relays	BxA		Air	No	14.7 PSI	No	No	All
T05 Relays	BxA		Air	No	14.7 PSI	No	No	All
Capacitors	BxA		Air	No	14.7 PSI	No	No	All

*Central Station

1. Fuel Capsule Assembly - FCA pressure is a time-dependent function of the Pu-238 half-life and results from the creation of helium atoms after alpha decay. The curve on page 19 shows pressure build-up as a function of years after FCA fueling. The curve is conservative since it assumes the formation of a pressure contributing helium atom for each Pu-238 alpha disintegration and assumes 100% retention of the helium. Considering the capsule clad strength, the curve shows 3 to 4 year design lifetime margin for capsules thus far fabricated (thru Apollo 16).

2. Generator Assembly - GA is hermetically sealed to retain an inert (Argon) atmosphere for the thermoelements. The internal pressure of GA is approximately 11 psia at 70°F (the conditions of pre-launch storage and translunar mission prior to fueling). After generator fueling on the lunar surface, the pressure stabilizes at ~25 psia (at operating temperature).

FIGURE A 1

STRESS RUPTURE LIFE OF THE SNAP 27 FCA

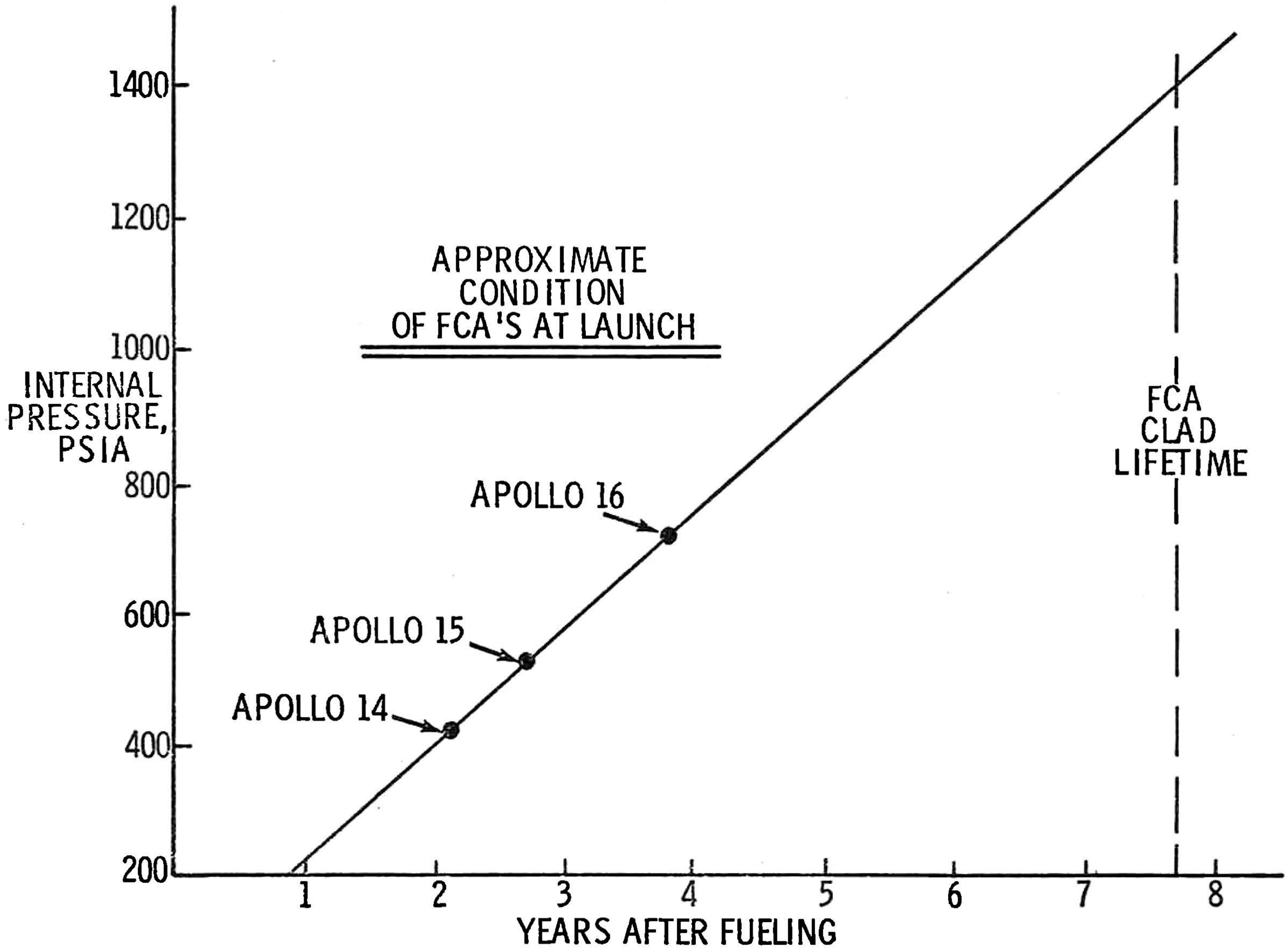


TABLE A3 - CREW EQUIPMENT PRESSURE VESSEL DATA

PRESSURE VESSEL	P/N	QTY REQ'D	VESSEL DIMENSIONS	VESSEL MATERIAL	DESIGN PRESSURE		NORMAL OPERATING PRESSURE	FACTOR SAFETY		QUAL BURST PRESS.	MANUFACTURER
					PROOF	BURST		ACTUAL	THEO.		
Three-Man Life Raft Cylinders	SEB401 00064-203	2	11" long x 2" dia.	301 stainless steel	4600	5600	1000	5.0	3.7	7500-7800	Arde'
Dual Life Vest Assembly Cyclinders*	SDB401 00179-001	2	3" long x 0.75" dia.	Nickel plated steel	*	7000	800-1000	7.0 min.	7.0	*	Knapp-Monarch
Pad Emergency Air Pack Cylinders (mission - essential GSE)	Arde' D 3703	5	11" long X 2" dia.	301 stainless steel	6000	9000	3600	2.9	2.5	10,600-11,600	Arde'

*OFF-the-Shelf DOD item - not all information available.

Theoretical Safety Factor = Design Burst Pressure/Maximum Operating Pressure

Actual Safety Factor = Lowest Actual Burst Pressure/Maximum Operating Pressure

6.2 Criticality Review

TABLE A4 - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
A0100	SEB33100100-209	Camera, 16mm Data Acquisition	III	No
A0101	SEB33100125-203 or -204 or -205	Magazine, 16mm Data Acquisition	III	No
A0102	SEB33100018-301	Lens, 18mm	III	No
A0103	SEB33100019-302	Lens, 75mm	III	No
A0104	SEB33100038-301	Cable, Power (DAC)	III	No
A0106	SEB33100051-204	Mirror, Right Angle	III	No
A0107	SEB33100102-210	Camera, 70mm Electric Hasselblad	III	No
A0108	SEB33100082-215	Magazine, Lunar Surface Hasselblad	III	No
A0112	SEB12100018-202	Kit, Pilots Preference	III	No
A0113	SEB12100050-201	Tape	III	No
A0114	SKB32100083	File, Flight Data	III	No
A0115	SEB33100186-205	Exerciser, In-flight	III	No
A0117	SEB33100063-301	Cover, Meter	III	No
A0118	SEB33100063-302	Cover, Meter	III	No
A0122	SEB33100104-201	Spotmeter, 1 Deg. Auto.	III	No
A0124	SEB33100092-301	Timer, Interval 2 Speed	III	No
A0125	SEB32100095-305	Glare Shield, Floodlite	III	No
A0126	SEB33100010-301	10mm Lens	III	No
A0127	SEB33100262-302	Voice Recorder (with Cassette and Batteries)	III	No
A0128	SEB33100263-302	Tape, Cassette	III	No
A0129	SEB33100264-301	Battery, Voice Recorder	III	No
A0130	SEB12100078-302 or -303	Monocular 10x40	III	No

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA	
A0131	SEB33100043-301	Intervalometer, Hassel Electric Camera	III	No	
A0132	SEB33100032-201	Lens, 250mm	III	No	
A0134	SEB33100266-301	Fuse, 16mm Camera (Spare)	III	No	
A0137	SEB32100094-301	Clip, Flight Data File	III	No	
A0138	SEB32100025-301	Data Card Kit	III	No	
A0146	SEB33100020-303	Cable, Remote Control	III	No	
A0149	SEB33100306-301	Camera, Lunar Topographic	III	No	
A0150	SEB33100310-301	Cable, Lunar Topographic	III	No	
A0151	SEB33100308-301	Control Box, Lunar Topographic	III	No	
A0152	SEB33100307-301	Magazine, Lunar Topographic	III	No	
A0153	SEB33100040-304	Camera, Hasselblad Electric Data	III	No	
A0154	SEB33100261-301	Lens, 80mm	III	No	
A0155	SEB33100295-302	Camera/Power Pack Assy 16mm L.S.	III	No	
B0100	SEB42100082-215	Kit, Medical Accessories	III	No	
B0101	SEB40100151-203	Kit, Survival Rucksack No. 1	III	Yes	CSD-A-797
B0102	SEB40100152-202	Kit, Survival Rucksack No. 2	III	Yes	CSD-A-797
B0103	SEB42100086-203	Dispenser, Tissue	III	No	
B0104.1	SEB42100079	Assy, C/M Utility Towel	III	No	
B0105	SEB13100077-206	Bag, Helmet Stowage In-flight	III	Yes	CSD-A-788
B0106	SEB13100061-208	Garment, Constant Wear	III	Yes	CSD-A-788

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA	
B0107	A6L-400000-13	Garment, Liquid Cooled	II	Yes	ILC-8-812-4L-0002
B0109	A6L-503000-10	Kit, EMU Maintenance	III	Yes	ILC-8-812-4L-0002
B0110	14-0131-01	Water Dispenser/Fire Extinguisher Assy	III	Yes	Whirlpool 14-00836
B0111	651-400-07 & -08	Mask and Hose, Oxygen	II	Yes	CSD-A-658
B0112.1	BW-1060-001 or -002	Jacket Assy, ICG	III	Yes	CSD-A788
B0112.2	BW-1061-001	Trouser Assy, ICG	III	Yes	CSD-A-788
B0112.3	BW-1062-002	Boot, Right, ICG	III	Yes	CSD-A-788
B0112.4	BW-1062-001	Boot, Left, ICG	III	Yes	CSD-A-788
B0113	A6L-501000-05	Subsystem, Fecal Containment	III	Yes	ILC-8-812-4L-0002
B0115	ACR-FA-5	Penlights	III	No	
B0116	14-149-01	Clamp, UCTA	III	No	
B0117	14-0133-01	System, Urine Transfer	III	Yes	Whirlpool 14-00843
B0118	14-02051	Receiver Assy, UTS, (Spare)	III	Yes	Whirlpool 14-00843
B0120.1	SEB42100112-201 and -202 and -203	Stowage Bag Assy, Roll-on-Cuff	III	No	
B0121	A7L-502003-03	Shield, Helmet Protective	III	Yes	ILC-8-812-4L-0002
B0130	BW-1052-001	Pad, Headrest	III	No	
B0132	BW-1053-001 and -002	Heel Restraint (Pr)	III	No	
B0134	SEB12100083-301	Adapter, UCTA Transfer	III	No	
B0135	A6L-507000-03	Adapter, CWG Electrical	III	Yes	ILC-8-812-4L-0002
B0137	SEB12100084-301	Eyepatch	III	No	
B0138	A7L-101118-01	Protective Cover, PGA Electrical Connector	III	Yes	ILC-8-812-4L-0002

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA	
B0139	BW-1079-002	Brush, Vacuum	III	No	
B0144	SEB14000010-303	Receptacle Assy, Urine	III	No	
B0145	SEB39104914-303	Gas Separator Cartridge H_2O Disp. Adapter Assy.	III	No	
B0147	SEB13100134-301	Bag, Jettison Stowage	III	No	
C0100	14-0122	Items, Food and Hygiene	III	Yes	14-00829
C0101	14-0123	Package, Food	III	Yes	14-00829
D0100	RFB-OP-4-2-001	Meter, Radiation Survey	III	No	
D0101	SEB12100045-303	Dosimeter, Passive Radiation	III	No	
E0104	SLB16100920	Headset, Lightweight	III	No	
E0105	75101-126-04	Eartube, Universal	III	No	
E0110	SEB16101081-301	Apollo Color TV System	III	No	
A0200	SEB12100033-201	Sunglasses	III	No	
A0201	SEB12100034-203	Pouch, Sunglasses	III	No	
A0202	SEB12100039-001 or -002	Chronograph	III	No	
A0203	SEB12100030-202	Watchband	III	No	
A0204	SEB12100051-204	Pens, Data Recording	III	No	
A0205	SEB12100082-301	Pen, Marker	III	No	
A0206	SEB12100081-301	Pencil	III	No	
A0207	SEB33100047-302	Sliderule	III	No	
A0208	SEB12100085-301	Bag, Motion Sickness	III	No	
B0200	A7L-100000-TBD	Pressure Garment Assembly - EV	I	Yes	ILC-8-812-4L-0002
B0200.1	A7L-100002	Torso Limb Suit Assy - EV	I	Yes	ILC-8-812-4L-0002
B0200.2	A7L-102043-03	Helmet Assy, Pressure	I	Yes	ILC-8-812-4L-0002

TABLE A4 - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA	
B0200.3	A7L-103000-18/19	Gloves, IV-Pair	I	Yes	ILC-8-812-4L-0002
B0200.4	16536G-04	Communication Carrier	II	Yes	D. Clark
B0200.5	A7L-201123-01	Pocket, Checklist and Scissors	III	Yes	ILC-8-812-4L-0002
B0200.6	A7L-201121-01	Pocket, Checklist	III	Yes	ILC-8-812-4L-0002
B0201	A7L-100000-TBD	Pressure Garment Assy - IV	I	Yes	ILC-8-812-4L-0002
B0201.1	A7L-100004-TBD	Torso Limb Suit Assy - IV	I	Yes	ILC-8-812-4L-0002
B0201.3	A7L-103000-18/-19	Gloves, IV-Pair	I	Yes	ILC-8-812-4L-0002
B0201.4	16536G-04	Carrier, Communication	II	Yes	DCM-A3C-05
B0201.5	A7L-201049-03	Pocket, Checklist and Scissors	III	Yes	ILC-8-812-4L-0002
B0201.6	A7L-201047-03	Pocket, Checklist	III	Yes	ILC-8-812-4L-0002
B0202	SEB40100165-203	Vest, Dual Life	III	Yes	CSD-A-798
B0203	SEB42100083-306	Assy, Bioinstrumentation	III	Yes	Space labs 501-005
B0204	SDB42100059-202	Scissors	III	No	
B0205	14-0108-02	UCTA	III	Yes	Whirlpool 14-00810
B0206	ACR-FA-5	Penlights	III	No	
B0207	SEB13100084-202	Assy, Bio Belt	III	Yes	CSD-A-788
B0208	SEB13100061-208	Garment, Constant Wear	III	Yes	CSD-A-788
B0210	SEB42100104-004/-005	Earplugs	III	No	
D0200	SEB16100703-201	Dosimeter, Personal	III	No	
D0201	SEB12100045-201	Dosimeter, Passive	III	No	
E0200.1	SEB42100104-002/-003	Earpiece, Molded (Comm Carrier)	III	No	

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
E0200.2	75101-TBD	Eartube, (Comm Carrier)	III	No
I0400	SEB39104304-301	Experiment Assy, S-158	III	No

TABLE A4 - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
A1000	SEB33100100-209	Camera, 16mm Data Acquisition	III	No
A1005	SEB33100113-303	Filter, Polarizing	III	No
A1007	SEB12100018-202	Kit, Pilots Preference (PPK)	III	No
A1008	SKB32100077	File Assembly, Flight Data	III	No
A1011	SEB33100010-302	Lens, 10mm	III	No
A1013	SEB33100015-302	Strap, Interim Stowage	III	No
A1015	SEB33100040-304	Camera, Lunar Surface Electric Hasselblad	III	No
A1016	SEB33100048-303	Lens, 60mm	III	No
A1020	SEB33100266-301	Fuse, 16mm Camera (Spare)	III	No
A1021	SEB33100277-303	Adapter, Brkt, RT Angle, 16mm Camera	III	No
A1022	SEB33100020-303	Cable, Remote Control, 16mm Camera	III	No
A1023	SEB33100046-301	Protective Cover, Reseau	III	No
A1024	SEB32100025-301	Kit, Data Card	III	No
A1025	SEB32100099-301	Clamp, Book	III	No
A1026	SEB32100094-301	Clip, Data File	III	No
A1027	SEB33100294-302	Trigger, Electric Hasselblad Camera	III	No
A1028	SEB33100293-302A	Handle, Electric Hasselblad Camera	III	No
A1029	SEB33100291-301	Tether, EVA Retractable	III	No
A1031	SEB12100050-202	Tape, Roll	III	No
A1032	V36-601170-41	Bungee Cord	III	No
A1036	SEB32100094-302	Clip, Data File	III	No
A1039	SEB33100397-301	Pliers, Needle Nose	III	No

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
A1040	SEB33100302-302	Checklist, EVA Cuff	III	No
A1041	SEB33100564-301	Bracket, Wedge, 16mm Camera	III	No
B1001	SV721783-9	Remote Control Unit -	II	HSD-SVHSER 5441
B1001.1	SV742170-2	Bracket, Camera Mount	III	HSD-SVHSER 5541
B1002	SV710854-9	Cartridge, PLSS LiOH	II	HSD-SVHSER 5441
B1003	SV718783-9	Cartridge/Canister, PLSS LiOH	II	
B1004	SV701900-19 or -20*	Battery, PLSS * or -21 or -22	II	SVSHER 5541
B1007	SEB40100185-303	Medical Package, LM	III	No
B1008	SEB42100080-202	Utility Towel Assy, LM	III	No
B1009	14-0111-01	Defecation Collection Device	III	Whirlpool - 14-00838
B1010	14-0131-01	Water Dispenser/Fire Extinguishing Assembly	III	Whirlpool - 14-00836
B1012	SV730101-2-16	Oxygen Purge System (OPS)	I	HSD-SVSHER 5441
B1013	A6L-502000-09	Bag, Helmet Stowage	III	ILC-8-812-4L-0002
B1014	A7L-205000-05	Lunar Extravehicular Visor Assembly-LEVA	II	ILC-8-812-4L-0002
B1015	A7L-203025-09/-10	Gloves, EV	II	ILC-8-812-4L-0002
B1016	A6L-503000-10	Kit, EMU Maintenance	III	ILC-8-812-4L-0002
B1017	A6L-505000-03	Purge Valve Assembly	II	ILC-8-812-4L-0002
B1018	A7L-106043-05/06	Boots, Lunar-PR	II	ILC-8-812-4L-0002
B1020	SJB33100199-314	Kit, LEC-Waist Tether	III	CSD-A-598 & -600 (see items below)
B1020.1	SEB33100198-301OR*	Bag Assembly, LEC + Wt *-303	III	No
B1020.2	SEB33100191-313	Conveyer Assembly, Lunar Equipment	III	CSD-A-598 & -600
B1020.3	SDB33100214-304	Bag, Deploy. Lunar Equipment Conveyer	III	No

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
B1020.4	SEB33100191-312	Life Line, (Light Weight)	III	CSD-A-598 & -600
B1020.5	SDB33100214-301 OR*	Bag, Deploy. Life Line * -305	III	No
B1020.6	SEB33100192-301	Tether, Waist EVA	III	CSD-A-598 & -600
B1020.7	SEB33100192-302	Tether, Waist EVA	III	CSD-A-598 & -600
B1021	SV723426-1	Straps, Attach. OPS/PGA	III	SVHSER 5441
B1022	SV723409-1	Straps, Attach. OPS/PGA	III	SVHSER 5441
B1023	SEB12100084-301	Eyepatch	III	No
B1024	SEB11100066-349	PLSS/EVCS Assembly	I	(see below)
B1024.1	SV706100-6-33	PLSS	I	SVHSER 5441
B1024.2	8358750-503	EVCS-1	II	Informal (no Doc. No.)
B1025	SEB11100066-350	PLSS/EVCS Assembly	I	(see below)
B1025.1	SV706100-6-33	PLSS	I	SVSHER 5441
B1025.2	8358751-503	EVCS-2	II	Informal (no Doc. No.)
B1027	SEB13100134-301	Bag, Jettison Stowage	III	No
B1041	SEB33100290-302	Safety Line, Lunar Surface (100 Ft)	III	CSD-A-600
B1043	14-0112-01	Towels, LM Utility (Red)	III	No
B1044	14-0112-03	Towels, LM Utility (Blue)	III	No
B1045	SEB39105185-301	Brush, Lunar Dust	III	No
B1047	SDB33100214-306	Bag, Lunar Surface Safety Line	III	No
B1048	14-0145-01	Device, In-Suit, Drinking	III	No
B1052	SV729602	Umbilical, Emergency Supply (Buddy System)	II	SVHSER 5441
B1053	SV729603	Bag, Stowage, Umbilical (Buddy System)	III	SVHSER 5441
C1000	14-0121	LM Food Assembly (2-2/3 Man Days)	III	14-00829

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
E1001	TBD	TV System, LM Color	III	No
N1001	SEB39105177-301	Flag Kit, Lunar Surface	III	No
N1002	TBD	Flag Kit, Symbolic	III	No
G4000.1	2338660 Rev. R	Mounting Assembly RTG Fuel Cask	III	ATM-855
G4000.2	47E301134-G2 Rev. N	Fuel Cask	III	ATM-852
G4000.3	47D300400 Rev. N OR*	Fuel Capsule Assembly * Rev. R	III	ATM-852
G4001	2334845-Rev. U	Pallet Assembly No. 1	III	ATM-501
G4001.1	2330750-6	Active Seismic Experiment	III	ATM-501
G4001.2	2338460-2	Passive Seismic Experiment	III	ATM-501
G4001.4	2330662	Charged Particle Lunar Environment Experiment	III	ATM-501
G4002	2334849-3 Rev. AC	Pallet Assembly No. 2	III	ATM-501
G4002.1	47E300779	Radioisotope Thermo-Electric, General Assembly	III	ATM-852
G4002.2	2330660	Super-Thermal ION Detect /Cold Cathode Gage Exp	III	ATM-501
G4002.3	2335945	PSE Leveling Stool	III	ATM-501
G4002.4	SGB39101165-205	Lunar Geological Exp Tool Carrier with Tools	III	ATM-501
G4002.5		ALSEP Deployment Tools	III	ATM-501
G4003	EM64416/2-02	Sample Return Container No. 1	III	No
G4004	EM64416/2-02	Sample Return Container No. 2	III	No
G4006	SEB39100319-204	Hammer	III	No
G4007	SEB39103122-303	Scoop, Lunar Sample (Large)	III	No
G4008	TBD	Extension Handle	III	No

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA	
G4009	SEB39100340-203	Tongs	III	No	
G4011	SEB39103769-302A	Solar Wind Composition Experiment	III	No	
G4012	SEB39100317-202	Gnomon	III	No	
G4016	ML1329-EK-004-D-05	Container, Contingency Lunar Sample Return Soft	III	No	
G4018	ML0543RM001-04	Weigh Bag	III	No	
G4021	442-0003-20	Camera Assembly, LGEC	III	Yes	Document No. not assigned
G4022	442-0004-20	Container Assembly, Return Cassette-Empty	III	No	
G4024	442-0002-20	Magazine Assembly, LGEC	III	Yes	Document No. not assigned
G4025	442-0011-20	Cassette, Take-up, Lunar Geol. Exp. Camera	III	Yes	Document No. not assigned
G4029	TBD	Tool, Trenching	III	No	
G4030	442-0006-20	Cover Assembly, Spare Magazine, LGEC	III	No	
G4031	SEB39105200-301	Scale, Sample	III	No	
G4033	TBD	Magnetometer, Lunar Portable	III	Doc. No. TBD	
G4034	TBD	Reflector, Laser Ranging Retro	III	EJAM-25	
G4036	TBD	Bracket, RCU/LGEC EVA	III	No	
J4000	2501-122-M	Camera, Closeup Stereo	III	No	
J4001	2501-120	Cassette, CSC	III	No	
Instl. GFE	RFB-OP-4-2-002	RSM Bracket	III	No	
Instl. GFE	SEB16100661-201	Van Allen Belt Bosimeter	III	No	
Instl. GFE	SV713883	Gas Conn. Mount Plate	III	SVHSER 5441	
Instl. GFE	SV714121-4	Oxygen Recharge Conn.	II	SVHSER 5441	
Instl. GFE	SV710911-4	Water Recharge Conn. (LM)	II	SVHSER 5441	

TABLE A4 (cont) - GFE CRITICALITY RATINGS

ITEM NO.	PART NUMBER	NOMENCLATURE	CAT	FMEA
Instl. GFE	SV710908-5	Vehicle Water Conn. (LM)	II	SVHSER 5441
Instl. GFE	SV710911-4	Water Recharge Conn. (CM)	II	SVHSER 5441
Instl. GFE	SV710908-5	Vehicle Water Conn. (CM)	II	SVHSER 5441
Instl. GFE	14-0119	Urine Flow Indicator	III	14-00825

6.3 Life Support Systems Detailed Investigation

6.3.1 EMU Single Point Failure Review

6.3.2 Pre- and Post-flight Suit Leakage Summary

TABLE A5

EMU SINGLE POINT FAILURE STUDY

PLSS and OPS

- Oxygen Ventilation Circuit
- Primary Oxygen Bottle
- OPS Bottle
- OPS Regulator Bellows
- OPS Hose

PGA

- Pressure Bladder
- Closures

EMU SYSTEMS FAILURE MODE AND EFFECT ANALYSIS (FMEA'S)

EMU CONTRACTOR'S FMEA'S MAINTAINED CONTINUOUSLY

PLSS/OPS - Hamilton Standard Document No. SVHSER 5441

PGA/LCG - ILC Industries Document No. 88124L0003

LM/PLSS/OPS/PGA - GAC Document No. NB/SY-2-69-30

HARDWARE CRITICALITY CLASSIFICATION

I. Necessary to sustain crewman's life.

II. Necessary to perform the mission.

III. Other.

SINGLE POINT FAILURE CRITICALITY CLASSIFICATION

I. Failure would cause loss of crewman.

II. Failure would cause loss of mission or second failure would cause loss of crewman.

III. Other.

EMU CRITICALITY I SINGLE POINT FAILURES

PGA SINGLE POINT FAILURES

1. Burst or ruptured bladder.
2. Excessive pressure sealing closure leakage.

PLSS SINGLE POINT FAILURES

1. PLSS O_2 umbilical rupturing (or any rupture in the low pressure loop) - failure effect - rapid loss of suit pressure.
2. LiOH cartridge fails to sufficiently absorb CO_2 - failure effect - increase in CO_2 partial pressure. (NOTE: Criticality changed to II because a CO_2 sensor is available for Apollo 14 and subsequent).
3. PLSS high pressure O_2 system bursts - failure effect - shrapnel, resulting in penetration of PGA.

OPS SINGLE POINT FAILURES

1. OPS high pressure system bursts - failure effect - shrapnel resulting in penetration of the PGA.

2. OPS O_2 umbilical rupturing (or any rupture in the low pressure gas loop) - failure effect - rapid loss of suit pressure.

If the OPS is ever used as the primary life support system, the following single point failure must also be considered:

OPS pressure regulator fails open - failure effect - bursts PGA.

ITEM: PLSS O_2 Ventilation Circuit (see page 39)

FAILURE: Gross Leakage (8#/hour:equivalent to $\frac{1}{4}$ inch hole in suit bladder)

HISTORY: None

EFFECT: Early Depletion of Prime and Backup O_2 Supply

POSSIBLE CAUSES: Physical Damage from External Source or Structural Defect

WHY SPF PRESENT: Elimination would require redundant ventilation circuit and PGA interfaces plus complex crossover valving yielding excess weight and volume with increase in potential failure points.

ACCEPTANCE RATIONALE:

Design: Umbilicals have inner pressure wall plus fabric wrap and wire reinforcing. All component connections are bonded and clamped. Seal usage reviewed for requirements. Only components exposed to external damage are PGA umbilicals which are covered with beta cloth enclosed thermal sheath which provides abrasion protection. Internal plumbing is metallic. Umbilical axial load requirements set at 60 pounds minimum.

Qualification Test: Umbilical and bond strength and system pressure cycle endurance verified to exceed use requirements.

Flight Hardware Inspections: Component proof and leakage testing; system PDA umbilical pull test; system PDA proof and leakage; ground use and leakage testing; pre-flight PIA leakage testing.

RECOMMENDATION: No Change Required.

OXYGEN VENTILATING CIRCUIT SCHEMATIC

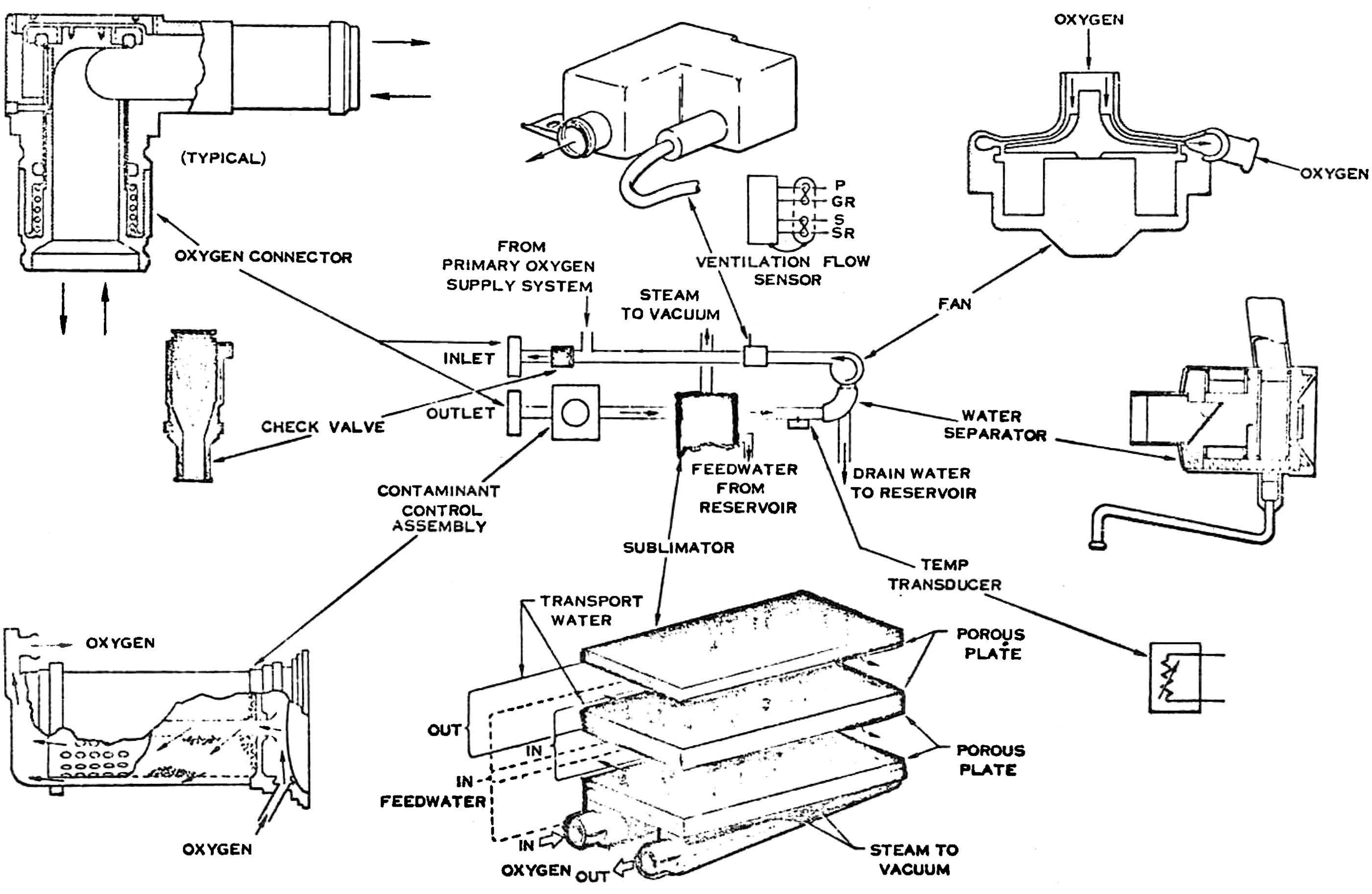


FIGURE A2

ITEM: PLSS Oxygen Bottle (See description, pages 42 - 46).

FAILURE: Rupture (Explodes)

HISTORY: None

EFFECT: Possible injury to crew and/or damage to equipment.

POSSIBLE CAUSES: Physical damage from external source or structural defect

WHY SPF PRESENT: 1. No other means presently feasible for required application.

2. Incorporation of scatter shield would require excessive weight and volume.

ACCEPTANCE RATIONALE:

Design: Reference Page 42 for physical data on POS bottle. Reference Page 44 for protection of PLSS O_2 bottle from external damage.

Qualification Tests:

Component level - Table A7 summarizes the results of cyclic and environmental testing conducted on a total of 14 bottles.

Systems level - PLSS qualification has demonstrated the capability of the O_2 bottle to satisfy the total spectrum of mission qualification requirements.

Flight Hardware Inspections:

Component Acceptance Test - Proof pressure and leakage tests plus radiographic and penetrant inspections.

System PDA - Proof pressure and external leakage tests plus visual examinations.

Ground Test Cycles - MSC PIA (including leakage tests at maximum operating pressure plus visual inspections), unmanned and manned performance evaluation.

Preflight PIA - External leakage at maximum operating pressure and final visual inspection.

RECOMMENDATION: No change in bottle design or plumbing.

NOTE: -7 PLSS Bottle changed to approximately 1400 psi operating pressure. Requalification test program will assure reliability retention.

PLSS O_2 BOTTLE PROTECTION

(TOP VIEW)

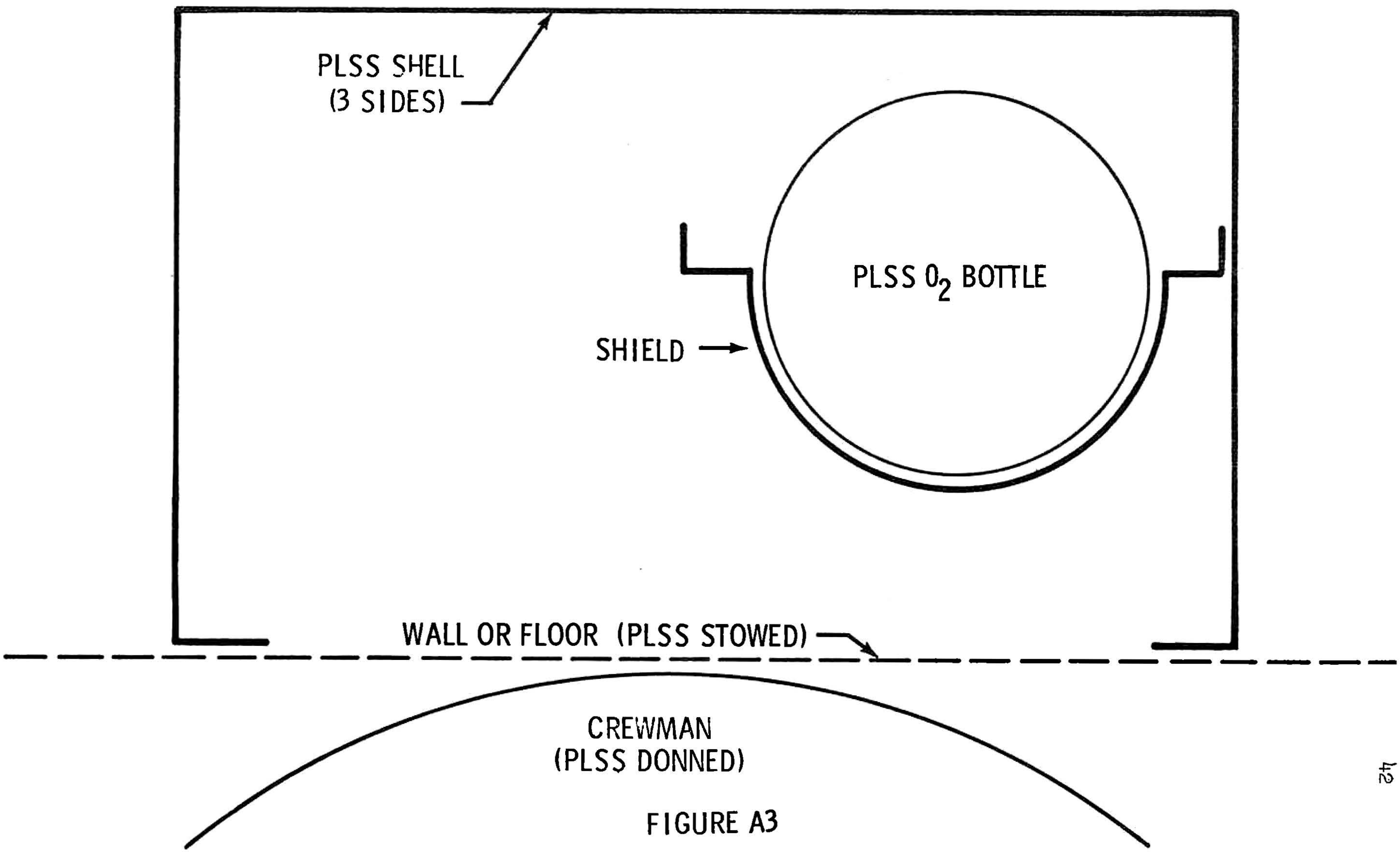


FIGURE A3

TABLE A6

PLSS PRIMARY OXYGEN SUPPLY BOTTLE DATA

ITEM	P/N	QTY/ S/C	DIMENSIONS	MATERIAL	(psia) DES. PRESSURES Limit	Proof	Burst	(psia) NORMAL OPER. PRESS.	SAFETY FACTOR Act.	Theor.	(psia) QUAL. BURST PRESS.	MFR.
POS Bottle	SV713010	2	Cycle dia. 6.082" OD Height 16.03"max. Wall Thickness 0.028" min. Volume 378 cu. in.	AISI 301 unaged	1110	1665	2220	1020 ± 10	2.1	2.0	2345 to 2450 (10 bottles burst)	ARDE, Inc.

Theoretical Safety Factor - Design burst pressure/maximum pressure; Actual Safety Factor - Lowest actual burst/ maximum oper. pressure.

TABLE A7 - EMU PRIMARY OXYGEN BOTTLE QUALIFICATION TEST RESULTS

Test Plan No. SS-4023A

Test	Vessel S/N	Environmental and/or Mission Simulation Tests	Total Operating Cycles @ 1130±20 psig 1000 Cycles Minimum Required Prior to Rupture	Total Proof Cycles @ 1685±20 psig 10 Cycles Minimum Required Prior to Rupture	Static Burst Pressure 2220 psig Min. Req.	Burst Hoop Stress psi
Proof & Operating Pressure Cycles	31		1002	12	2370	255,012
	42		1002	12	2350	254,505
	43		1002	12	2370	255,012
Operating Pressure Cycles to Failure	18		8726*	12	---	---
	23		8281*	12	---	---
Proof Pressure Cycles to Failure	26		1	2811*	---	---
	27		2	1219*	---	---
Acc. Vibr. & Impact	35	20g's for 100 sec. Two 78g saw tooth pulses 10-15ms rise time & 0-1ms delay time - all 3 along 3 orth axes.	1	1	2350	255,500
	44		1	1	2390	258,750
Humidity	29	100% rel. humidity for 10 temp. cycles 84° to 160°F 24 hrs/cycle 1 hr. @ 0°F.	2	3	2345	259,826
Salt Spray	30	1% NaCl by weight 95°F 48 hrs.	3	2	2350	257,325
Burst	13		1	3	2400	253,300
	4		1	1	2450	257,280
	41		1	1	2380	258,000

*Cycles to failure

ITEM: OPS Bottle (see description pages 46 & 47).

FAILURE MODE: Rupture (Explodes)

HISTORY: None

EFFECT: Possible injury to crew and/or damage to equipment.

POSSIBLE CAUSES: Physical damage from external source or structural defect.

WHY SPF PRESENT: (1) No other means presently feasible for required application.

(2) Incorporation of scatter shield would require excessive weight and volume.

ACCEPTANCE RATIONALE:

Design: Reference Page 46 for physical data on OPS bottle. Reference Page 47 for protection of OPS O_2 bottles from external damage.

Qualification Tests:

Component Level - The OPS bottle qual. test report is SVHSER 5249. The results of this testing, including actual bottle burst valves, are shown on pages 48 & 49.

System Qualification - The OPS underwent systems level qualification including:

- Vibration and shock
- Pressure cycling
- Thermal soak
- System operational life cycles

The OPS successfully completed this program.

Flight Hardware Inspections:

Component Level - Proof pressure and leakage tests plus radiographic and penetrant inspections.

System PDA - Proof pressure and leakage testing

Ground Test Cycle - MSC PIA (includes leakage tests at maximum operating pressure), unmanned, and manned performance evaluations.

Pre-flight PIA - leakage at maximum operating pressure and visual examination.

Recommendation: No change required.

TABLE A8

OPS OXYGEN BOTTLE DATA

ITEM	P/N	QTY/ S/C	DIMENSIONS	MATERIAL	DES. PRESSURES (psia) Limit	Proof	Burst	(psia) NORMAL OPER. PRESS.	SAFETY FACTOR Act.	Theor.	(psia) QUAL. BURST PRESS.	MFR.
OPS Bottle	SV730103	4	Spherical 7.04 ± .030D Wall Thickness =0.130 min.	AMS 5664 (Inconel 718)	6750	10130	13500	5880 ± 80	2.2	2.0	14,700 to 15,200 (5 bott burst)	Fan Steel Metallurgical Corp.

Theoretical Safety Factor - Design Burst Pressure/Maximum Operating Pressure

Actual Safety Factor - Lowest Actual Burst/Maximum Operating Pressure

PROTECTION OF OPS O_2 BOTTLES

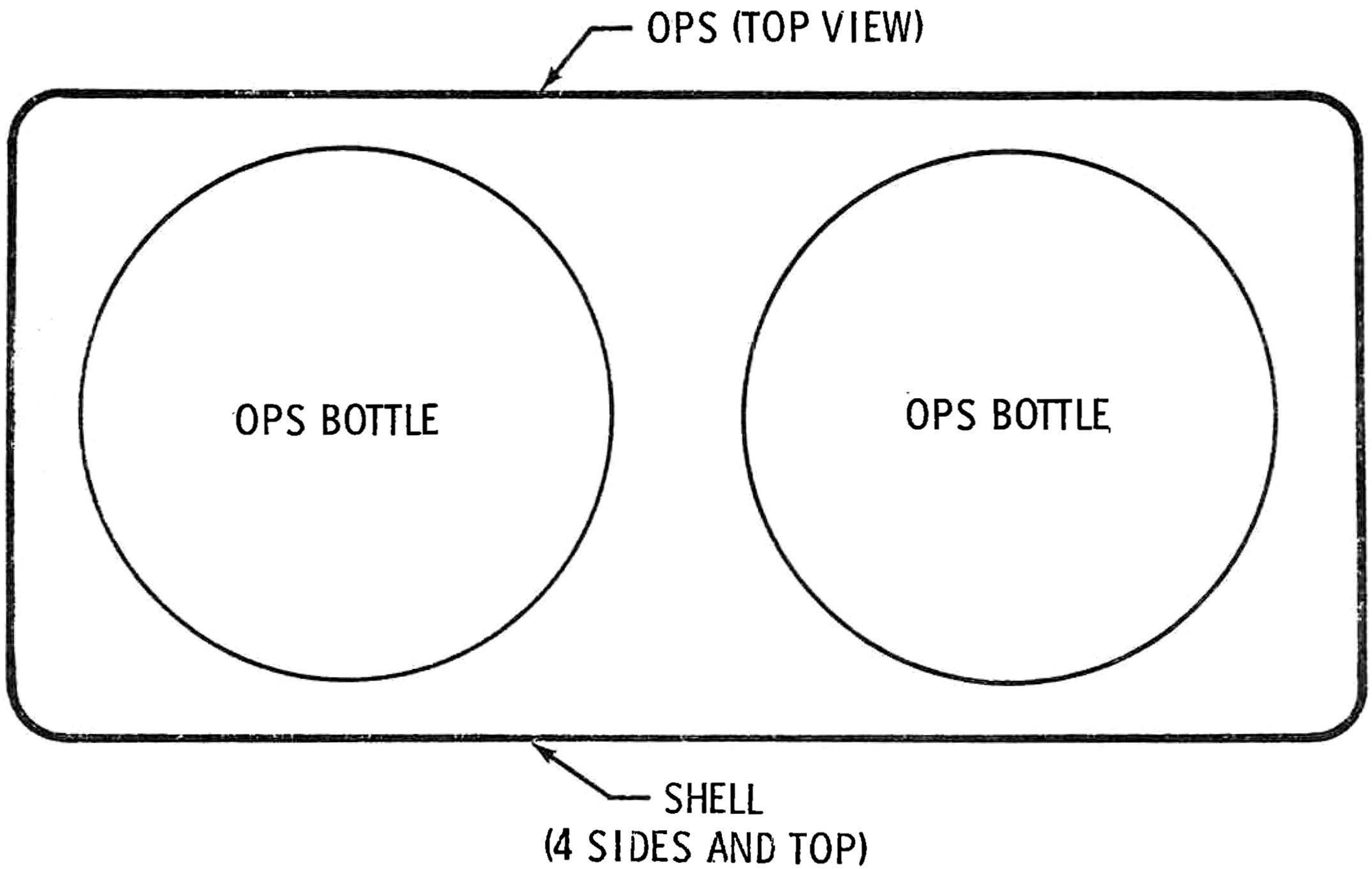


FIGURE A4

SUMMARY

S/N 16

The Oxygen Purge System (OPS) Oxygen Bottle S/N 16 was tested in accordance with paragraph 4.1 of Qualification Test Procedure SSP 3052. The test sequence was Production Acceptance Test (PAT), Burst Pressure Test, and Metallurgical Examination. All of the bottle qual production acceptance tests consisted of an examination of product, proof and dye penetrant test, and external leakage test. The burst pressure for S/N 16 vessel was 15,200 psig. The fracture origin occurred at the bottle weld bead.

S/N 11

The Oxygen Purge System (OPS) Oxygen Bottle S/N 11 was tested in accordance with paragraph 4.2 of SSP3052. The test sequence was PAT, Operating Pressure Cycling to Failure and Metallurgical Examination. The resulting cycle life of this vessel was 59,364 cycles. The fracture origin occurred at the boss end of the vessel tube joint.

S/N 17

The Oxygen Purge System (OPS) Oxygen Bottle S/N 17 was tested in accordance with paragraph 4.5 of SSP 3052. The test sequence was PAT, Proof Pressure Cycling to Failure, and Metallurgical Examination. The resulting cycle life of this vessel was 7,736 cycles. The fracture origin occurred at the boss end of the vessel tube joint.

S/N 21

The Oxygen Purge System (OPS) Oxygen Bottle S/N 21 was tested in accordance wtih paragraph 4.5 of SSP3052. The test sequence was PAT, Proof Pressure Cycling to Failure, and Metallurgical Examination. The resulting cycle life for this vessel was 4,485 cycles. The fracture origin occurred at the weld edge of the bottle.

S/N 24

The Oxygen Purge System (OPS) Oxygen Bottle S/N 24 was tested in accordane with paragraph 4.3 of SSP3052. This vessel underwent environmental tests. The test sequence was PAT, Salt Fog, Humidity, PAT, Burst Pressure Test, and Metallurgical Examination. The Burst pressure for this vessel was 15,200 psig. The fracture origin occurred at the centerline of the weld zone.

S/N 13

The Oxygen Purge System (OPS) Oxygen Bottle S/N 13 was tested in accordance with paragraph 4.4 of SSP 3052. This vessel underwent structural tests. The test sequence was PAT, Cleanliness Check, Vibration, Acceleration, Shock, Cleanliness Check, PAT, Burst Pressure Test, and Metallurgical Examination. The resulting burst pressure for this vessel was 14,800 psig. The fracture initiated at or near the outer surface of the weld.

S/N 15

The Oxygen Purge System (OPS) Oxygen Bottle S/N 15 was tested in accordance with paragraph 4.4 of SSP3052. This vessel underwent structural tests. The test sequence was PAT, Cleanliness Check, Vibration, Acceleration, Shock, Cleanliness Check, PAT, Burst Pressure Test, and Metallurgical Examination. The resulting burst pressure for this vessel was 14,700 psig. The fracture origin occurred 0.25 inches above the weld.

ITEM: OPS Regulator (Primary Bellows)

FAILURE: Massive Bellows Rupture

HISTORY: None

EFFECT: Early depletion of PLSS O_2 supply - subsequent OPS actuation would result in PGA overpressurization and/or loss of OPS oxygen supply.

POSSIBLE CAUSES: Weak or Defective Bellows

WHY SPF PRESENT:

(1) Failure potential so remote that added complexity required for elimination is not warranted. Numerous Criticality II SPF's would result from added complexity. This is failure of nonstressed non-operating component. (Reference page 51).

(2) Regulator located downstream of OPS shutoff valve to preclude regulator being under 6000 psi during normal operations.

ACCEPTANCE RATIONALE:

Design: Material - electrically deposited nickel
Proof Pressure - 30 psid
Burst Pressure - 45 psid
Actual Operating Pressure - 3.4-4.0 psid

Qualification Tests: System qualification of the OPS verified the endurance capability and structural integrity of the regulator bellows for the required environments and application.

Flight Hardware Inspection: The bellows are subjected to the following tests which would detect weak or defective units:

Component - leakage and spring rate
Subassembly (Regulator) - steady rate regulation at high and low temperatures plus internal and external regulator leakage

OPS PDA - vibration plus same as subassembly
Ground Use Cycle - MSC PIA, manned testing and performance checks (regulation and leakage)
Preflight PIA - regulator set-point check plus internal and external leakage
Pre-egress Checkout - regulator performance check

RECOMMENDATION: No change required.

OPS FLOW SCHEMATIC

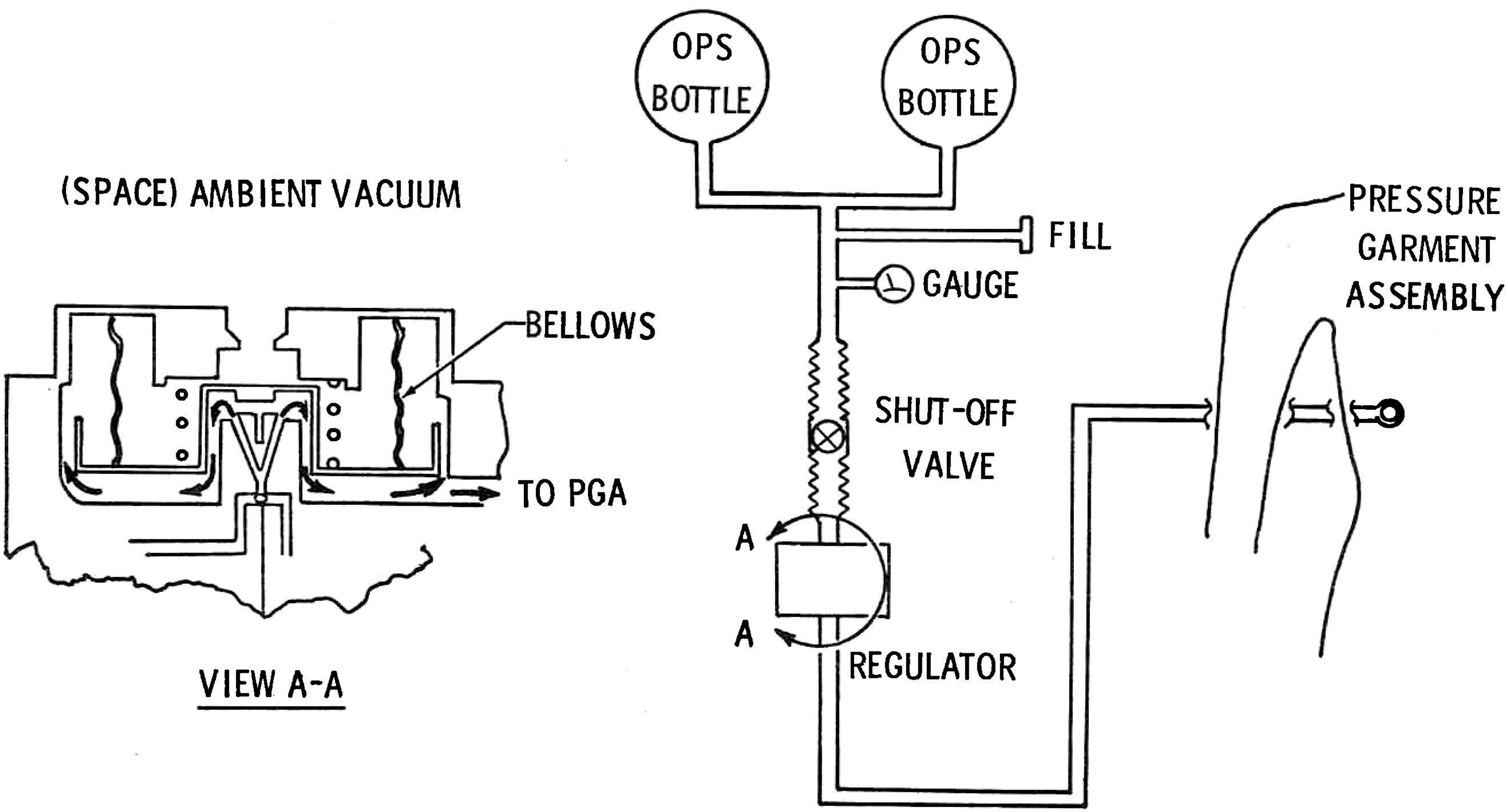


FIGURE A5

ITEM: OPS Umbilical

FAILURE: Hose Rupture - Leakage > 8#/hour

HISTORY: None

EFFECT: Loss of PGA Pressure Control

POSSIBLE CAUSES: Physical Damage from External Source or Structural Defect

WHY SPF PRESENT: Elimination would require redundant umbilical and PGA interface plus crossover valving yielding excess weight and volume with increased number of potential failure points.

ACCEPTANCE RATIONALE:

Design: Umbilical designed with inner pressure sealing liner protected by fabric wrap and wire reinforcing in outer layers. Umbilical also covered by beta fabric enclosed thermal sheath which provides added abrasion protection. Umbilical axial load requirement set at 60 pounds minimum.

Qualification Test: Umbilical and bond strenth and system pressure cycle endurance verified to exceed use requirements.

Flight Hardware Inspections: Component proof and leakage testing; system PDA umbilical pull test; system PDA proof and leakage tests; ground use and leakage tests; preflight PIA leakage testing.

RECOMMENDATION: No Change Required.

ITEM: PGA

FAILURE: a. Catastrophic leakage of pressure retention layer (see description on pages 54 & 55).
b. Catastrophic failure of PGA pressure retention layer penetration (i.e., zipper, wrist disconnects, connectors, etc.) (see description on pages 56 & 57).

HISTORY: Pressurized Apollo PGA testing has been conducted since 1965. In that time approximately 2800 hours of pressurized PGA time in controlled suits. During this period, 59 leakage rates above specification limits (180scc per minute) have been recorded. None of the failures would have been catastrophic. Twelve failures had leakage which would be considered significant (> 2000 scc/min.). One of these failures produced leakage in excess of make up capability. This failure is attributed to human error (see Failure Analysis Report, NL-01149-01 on page 59). A plot of the results of 579 test points is shown on the chart on page 58.

EFFECT: Loss of crewman protection.

POSSIBLE CAUSES: Physical damage or structural defect.

WHY SPF PRESENT: a. Connectors and other penetrations except for zipper appear to have extremely high reliability with safety lock/locks with no additional modifications required.
b. Redundant pressure layer could be developed to improve reliability. This concept was investigated early in the Apollo suit development program and was found undesirable. Prototype evaluation indicated that the double wall adversely affected mobility, bulk, and crewman comfort.

ACCEPTANCE RATIONALE:

Design: See descriptions for failure modes A and B (pages 54 & 56).

Qualification Test: PGA bladder assembly, connector seal integrity, system pressure cycle endurance and total system pressure capability verified to exceed use requirements.

Flight Hardware Inspections: Component proof and leakage testing; system PDA proof and leakage tests; ground use and leakage tests; pre-flight PIA leakage testing.

RECOMMENDATION: No change required.

PGA Single Point Failures

A. Catastrophic leakage of the pressure retention layer (see next page)

1. TLSA; (a) Single layer pressure bladder of neoprene coated nylon

   (b) Single layer convolutes of nylon reinforced neoprene

   (c) Single layer pressure retention boot of neoprene

2. Helmet; Single layer of .050 inches minimum of polycarbonate

3. Gloves; Single layer of nylon reinforced neoprene

There are no redundant pressure retention layers in the PGA.

The original design reflected the awareness of the single point failure. In addition the following CCBD's have been processed to reduce probability of failure.

6E132
6E142 Add reinforcement patches

7E114
6E160 Add protective layer to PGA

7E133 Add abrasion cover to IV gloves

7E134 Redesign PGA helmet neck ring compression band

7E135 Redesign helmet vent pad edges

7E175 Add scuff patches to torso limb suit assembly

7E335 Modify neck band

8E172 Change adhesive on shoulder ring

8E300 Add fluorel coating to IV gloves

05C52 Add redesigned scuff patches and knee patches

8E036 Add reinforcement scuff material

8E048 Relocate compression band channel slit.

8E111 Redesign cable ending

8E333 Heat treat compression band bracket

9E215 Add scuff layer protection

9E386 Incorporate redesigned boot bladder

SPACE SUIT (PGA)

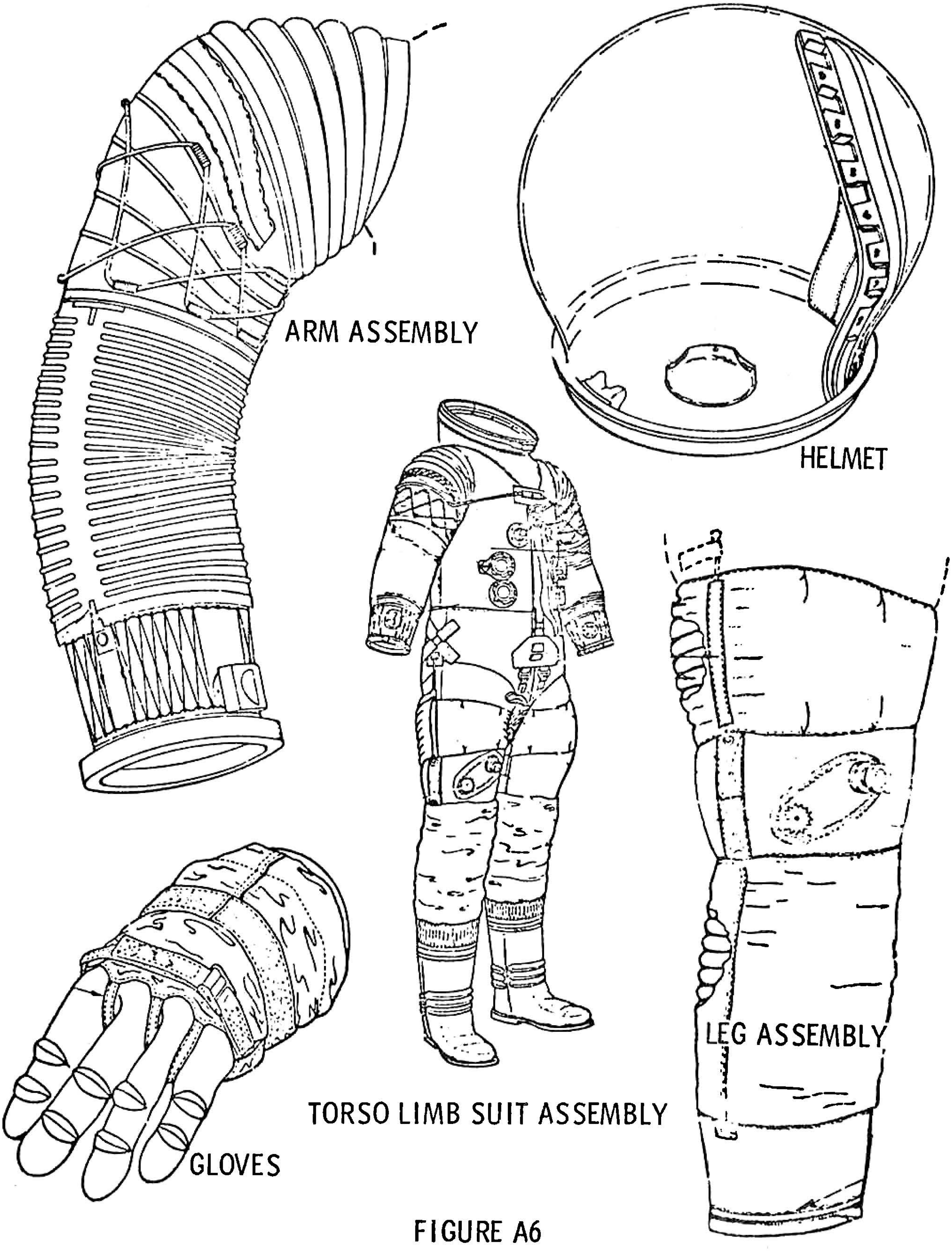


FIGURE A6

B. Catastrophic failure of a PGA pressure retention layer penetration (i.e. zipper, wrist disconnects, connectors etc.)

1. Pressure sealing closure; metal teeth intermeshed and seal of neoprene.

2. Gas connectors;(a) metal sandwiched bladder layer with penetrations through bladder for screws. (b) Metal to "O" ring seal through connector. (c) Connections are self-sealing.

3. Neck and wrist disconnects; metal to "O" ring seal through disconnects. Connectors are bonded and/or clamped to bladder for TLSA attachment.

4. Misc. penetrations same as 2 above.

There are no redundant "o" rings or pressure retention layers in the PGA.

Additional changes processed to reduce the probability of failures.

6E003	Mod. gas connector to stop leak
6E097	Change "O" ring from single to double bar
6E118	Add lock lock to glove and helmet closure
6E179 6E142	Modify slide fastener
7E076	Add safety locks to gas connectors
7E137	Change feedport material to aluminum
7E138	Redesign helmet neck ring
7E216 7E208	Add molded lip seal in wrist disconnect
8E035 8E034	Redesign wrist disconnect
8E108 8E109	Change pressure sealing zipper lock lock
8E332	Add thick contoured feed port gaskets
8E346 8E335	Improve operations of slide fastener
0E025	Change to zipper lock lock
8E029	Add lock assembly to neck ring
8E268	Redesign helmet slide and suit side neck rings
8E362	Change lock tab
8E439	Redesign feedport door
9E137	Feed port configuration change

SPACE SUIT (PGA) FEED THROUGHS

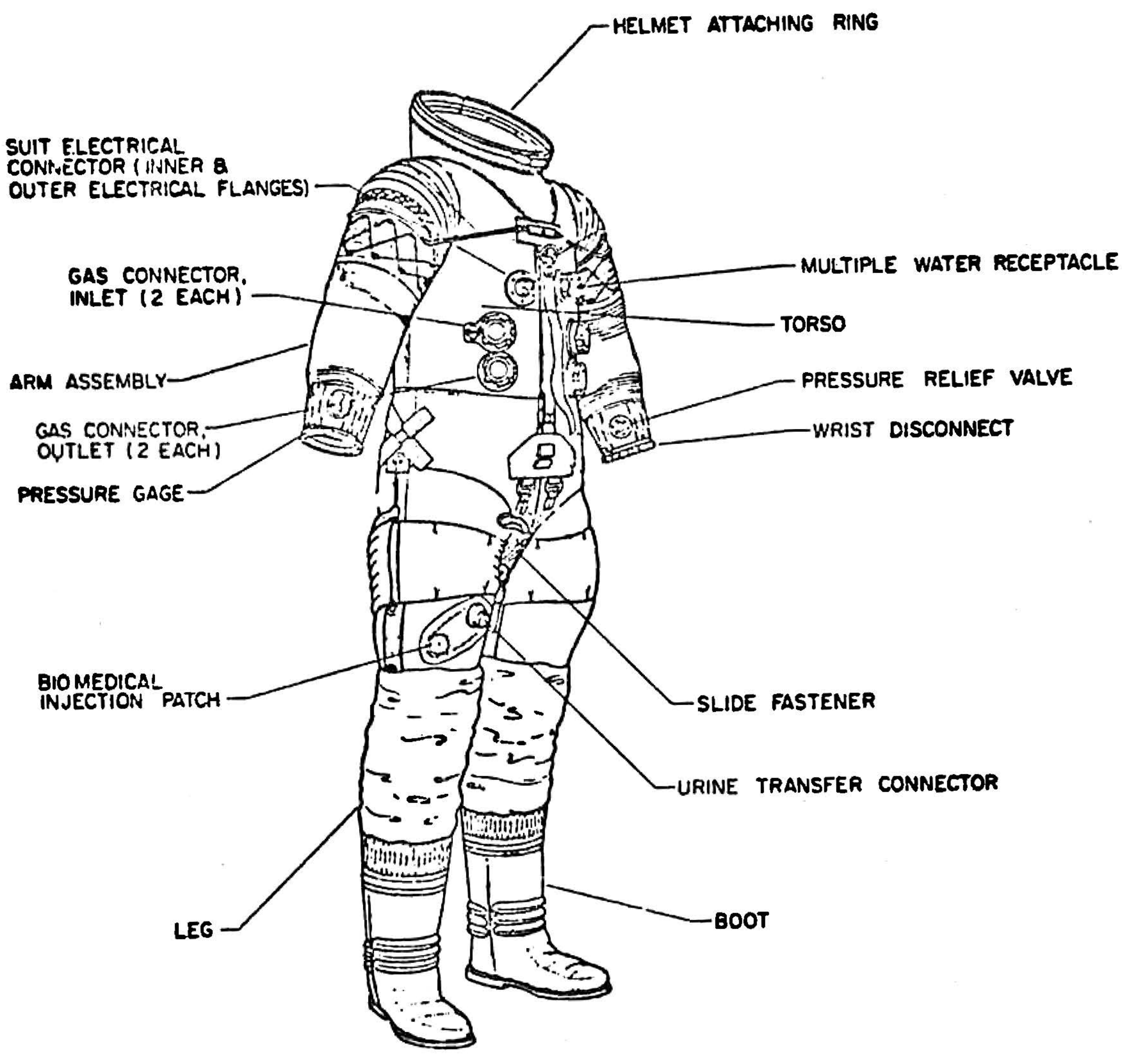
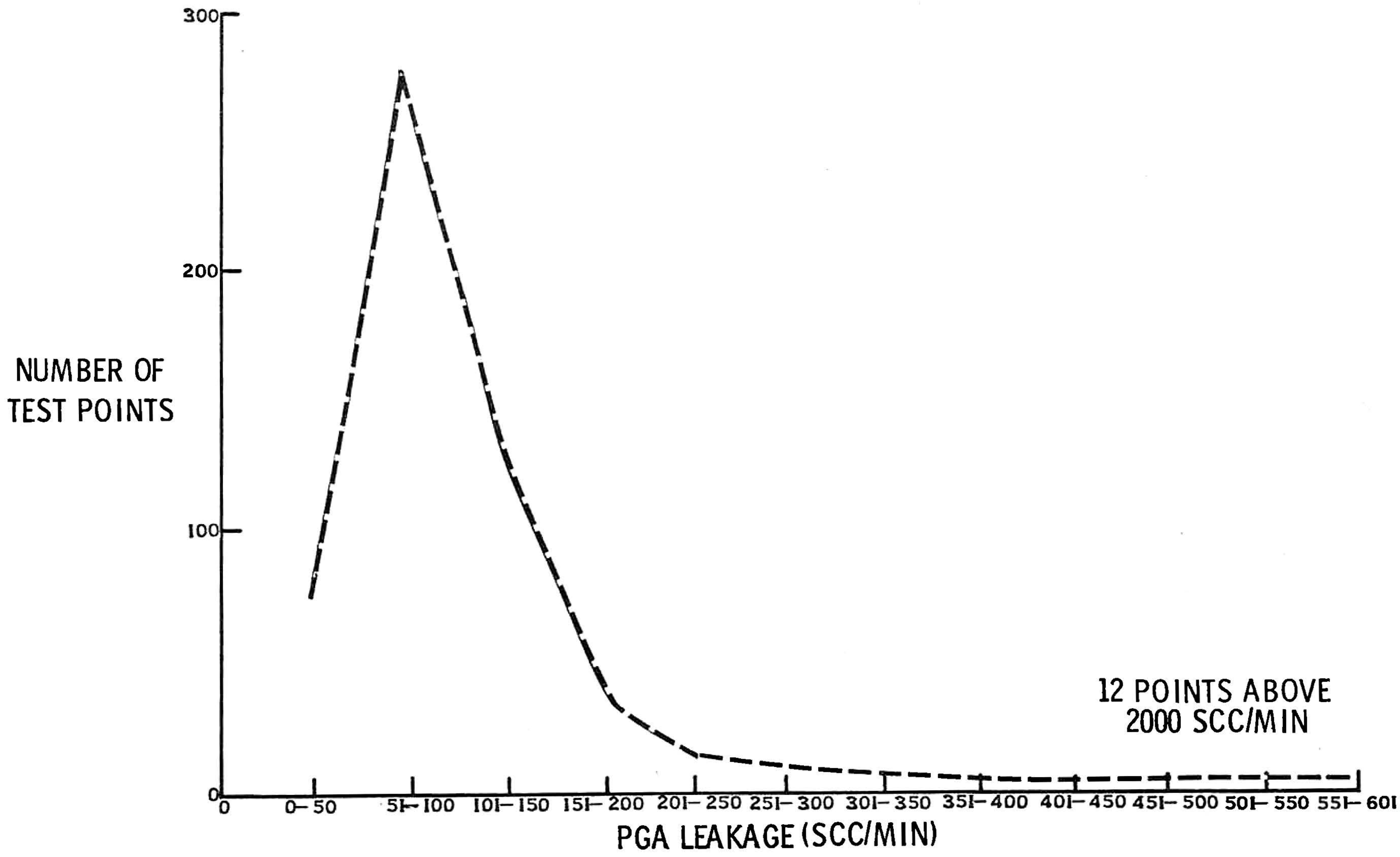


FIGURE A7

FIGURE A 8
PGA LEAKAGE RATE HISTORY
579 TEST POINTS FROM PDA, REC. INSPECTION, PIA, AND POST TEST INSPECTIONS ON 28 PGA's (WORST CASES OF 115 CONTROLLED TYPE FLIGHT SUITS)



Results

1. A conversation with Mr. Larry Young (ILC Field Representative) revealed that on 12-13-67 the shoulder cable coating split and slid back on itself exposing approximately 3½ inches of cable. Mr. Young stated that there was not any broken strands of cable visible at this time. He notified both ILC and NASA and made them aware of the problem and asked if it was advisable to cut the "hanging" piece of cable coating. Permission to cut the "hanging" piece of cable coating was obtained through Mr. Robert Davidson for ILC and from Mr. Robert Steele for NASA. The hanging piece of cable coating was then cut off by Mr. Larry Young with a pair of scissors. This left a ridge around the remaining cable coating.

   Testing was resumed and it was noted immediately that the ridge created by the end of the remaining cable coating was abraiding the Helinka Patch on the rear of the left shoulder convolute. This abrasion continued until a hole was worn through the Helinka Patch and finally through the left shoulder convolute resulting in a 2.0 CFM leakage on 1-28-67.

2. Review of the Operational Log did not reveal any unusual or extenuating circumstances which could have contributed to this failure.

Conclusions

1. It is concluded from review of the above that the hole in the left shoulder convolute was caused by continuous abraiding of the Helinka Patch and convolute by the ridge of thé shoulder restraint cable coating which resulted from cutting the "hanging" piece of cable coating off.

2. It is also concluded that this failure was human induced as testing was allowed to continue after the shoulder restraint cable coating was noted to be abraiding the Helinka Patch of the shoulder convolute.

6.3.2 Pre- and Post-Flight PGA Leakage History Summary

TABLE A9

PRE AND POSTFLIGHT LEAKAGE SUMMARY ASSOCIATED WITH APOLLO FLIGHT PRESSURE GARMENT ASSEMBLIES

FLIGHT NUMBER	CREWMEN	PGA SERIAL NO.	PREFLIGHT PGA LEAKAGE (PIA) CC/MIN.	POSTFLIGHT PGA LEAKAGE CC/MIN.
APOLLO 7	CDR	A7L-004	60	90
	CMP	A7L-005	90	100
	LMP	A7L-006	125	265
APOLLO 8	CDR	A7L-030	60	50
	CMP	A7L-037	87	35
	LMP	A7L-031	55	65
APOLLO 9	CDR	A7L-020	90	54
	CMP	A7L-019	200*	225
	LMP	A7L-015	55	53
APOLLO 10	CDR	A7L-047	60	75
	CMP	A7L-043	108	75
	LMP	A7L-044	60	75
APOLLO 11	CDR	A7L-056	33	117
	CMP	A7L-033	60	85
	LMP	A7L-077	95	115
APOLLO 12	CDR	A7L-065	105	400**
	CMP	A7L-066	55	18
	LMP	A7L-067	51	45
APOLLO 13	CDR	A7L-078	80	***
	CMP	A7L-088	130	***
	LMP	A7L-061	58	***

* Flown on Waiver Number FLC 8812-4W-0240

** Post test failure - MR 03952

*** Data not available - PGA's yet to go post test.

NOTE: All data taken at sea level ambient conditions using O_2 with PGA pressurized to 3.75 psig.

6.4 Contingency Equipment Use Study

SM DISABLED IN TOTAL DURING TLI

April 23, 1970

Survival Possibilities - CM/LM Connected

1. Oxygen System

   (a) Design lightweight adapter bag to permit use of CM LiOH canister with LM O_2 umbilicals.

   (b) Redesign B5 and B6 attach points to accept stowage of OPS's.

   (c) Provide hardware to tee in two OPS's to three crewmen in case of loss of pressure and oxygen in the CM.

   (d) Install hand regulator valves to adjust O_2 flow from OPS's and PLSS's.

2. Power System

   (a) Spare battery capacity and size required to fire SPS: The solenoids are activated approximately five minutes prior to engine ignition. This is a small power drain and it builds up to approximately 40 amps at ignition and maintains that drain on the battery until shutdown.

   The breakdown is as follows:

   6 solenoid valves at 1 amp each = 6 amps

   2 helium solenoid valves at $1\frac{1}{2}$ each = 3 amps

   2 gimbal motors at 5 amps each =10 amps

   2 gimbal motors at 10 amps each =20 amps

   1 pump gaging system at 2 amps = 2 amps

   Total amps required = 41 amps

   Voltage required is 28V DC

   The approximate size of the battery required to handle the load would not exceed 14" X 8" X 5" and would weigh on the order of 15 pounds.

The PLSS and OPS batteries would not be able to provide the power required to fire the SPS.

The spare battery could be mounted in the SM and connected to a switch on the display console in the CM. The switch would have a 40-50 amp circuit breaker and plug connection that could be used to plug in an extension cable between the CM and LM. This battery could also be used in the LM in case an emergency arose which would require power to fire the LM descent engine or related LM electrical equipment.

(b) Provide electrical extension cable to reach from CM to LM and special outlets in LM and CM to handle heavy current drain (20 amp wire and breaker).

(c) Provide the capability to use ascent and/or descent batteries for CM.

(d) Utilize tape recorder batteries to power the penlights. FCSD personnel removed the recorder batteries from the power pack and installed in the penlights. The penlights were operated for two hours without any noticeable drain on the batteries.

(e) Design holder and circuit connections for OPS and/or PLSS batteries to use in the CM under extreme contingency conditions.

3. <u>Crew Comfort</u>

(a) Wear PGA's and fecal containment subsystem for body warmth.

(b) Stow thermal underwear for each astronaut.

(c) Redesign sleeping bags for warmth as well as restraining capabilities. Also, insure adaptability to the LM.

(d) Thermal (super insulation) blanket with capability to be folded into small size.

(e) Provide sox and gloves for each astronaut.

4. <u>Water System</u>

(a) Cooling - (waste water)

(1) Maintain water level at 50% capacity and only dump total capacity prior to SIM bay experiments.

(2) Power is not required for urine dump. The delta pressure between the cabin (4.5 psia) and outside vacuum is sufficient for dump purposes.

(b) Drinking

(1) Insert emergency hookup instructions and stow water line required to connect water system from CM to LM.

Equipment required:

- CM water gun
- Tee adapter
- Spare water line with proper connectors (male/female)
- Hand primer pump

(2) Three portable plastic water bags with approximately the same capacity - (2 lbs.)/man. The bags could be designed with two spouts - one for potable water and the other for urine. The bags could be stowed for contingency and used for either purpose at the discretion of the crew. Temporary in-flight stowage of the bags with drinking water could be on the bulkhead using beta straps. Mr. McAllister suggests that the urine bags be strapped to the wire trays or on top of the metal containers under the couches, but dumped at the first opportunity.

During the Apollo 13 debriefing on April 21, 1970, the crew stated they saved all the urine and did not dump it overboard. The reason the crew did not vent the urine overboard was that they felt it would cause a change in delta V or attitude to the S/C. After the mission, a preliminary investigation showed it would not change the S/C attitude or delta V to dump urine overboard from the CM.

(3) Remove water from PLSS for contingency drinking water.

5. Tools

- Wire cutters
- Insulation tape
- Adjustable or crescent wrenches
- Twine

6. Provide contingency information on the above applicable techniques/procedures in the Flight Data File.

Prepared by: E. Rangel, D. Sedlak, P. Maceli
R. Daly, F. Parker

MSC Apollo 13 Investigation Team
Prepared April 22, 1970
Distributed April 22, 1970 66

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

REPLY TO
ATTN OF:

MEMORANDUM TO: PA/Leader, MSC Apollo 13 Investigation Team

FROM : PA/Chairman, Panel 5C, GFE

SUBJECT : Scope of MSC Apollo 13 GFE Investigation Team Activities

This team has had two meetings thus far. The primary objective of these two meetings has been to establish team members, the scope which this team should cover, define the mode of operation to be used for getting the investigation completed, and milestones established which lead to overall completion of the investigation.

The current status of accomplishments of these objectives is as follows:

a. Team Member Designation - Completed. Transmitted to Leader, Apollo 13 Investigation at 3:00 p.m., on April 20, 1970.

b. Scope of Investigation - Completed. This team will assemble the following information and investigate the following areas:

(1) Compile a listing, with pertinent design data related thereto, of all pressure vessels utilized in GFE (excluding GFE, ACE, and GSE) and furnish this information to C. H. Perrine for use in his detailed investigation of pressure vessels. This task is approximately 90% complete. The remaining data will be available on April 23, 1970.

(2) Review all flight GFE to determine all those items which are presently designated as criticality Category I and to see if lower category items should be upgraded to Category I. This review has been made with the only Category I items being in the life support areas (PLSS/OPS/PGA).

(3) Restrict the detailed investigation to the life support areas.

(4) Review the need for adding contingency type equipment to the crew station and the feasibility of utilizing existing equipment for uses other than those for which it was designed.

c. Mode of Operation - Completed. Failure mode and effects analyses are to be examined again for criticality. Rationale for acceptance of single point failures is to be reexamined. Any proposed changes in hardware design are to be reviewed and submitted to the CCP/CCB as applicable. Feasibility for adding contingency type equipment and for utilizing existing equipment for uses other than present design purposes will be presented to the team, reviewed in detail, and passed on as applicable for CCP/CCB action.

d. Milestones - The next meeting of this team will be at 11:00 a.m. on April 23, 1970. At that time, the first look at the open items previously specified will be reviewed and action assigned which will hopefully lead to final investigation completion and report submittal on or before May 1, 1970.

Richard S. Johnston

MSC Apollo Investigation Team

Government Furnished Equipment
Panel 5c
April 20, 1970

A meeting was held on April 20, 1970, to designate an Apollo 13 GFE investigation team and to establish the ground rules under which this investigation would operate. The following persons were in attendance:

Chairman - R. S. Johnston

Members - J. W. Thompson
R. E. Smylie
J. V. Correale
D. F. Grimm
D. G. Wiseman
J. H. Langford
E. M. Jones

The GFE investigation team which was established at this meeting is as specified in the enclosure. The mode of operation which this team should utilize was discussed with the following areas being designated as those which need particular emphasis.

1. EMU
    a. PLSS
    b. OPS
    c. Suit
2. Life rafts and life vests
3. Experiments (Those which could affect crew safety)
4. Contingency equipment and the utilization of existing equipment for uses other than those for which it was primarily designed.

It was agreed that the complete list of GFE (excluding G&N, ACE and GSE) would be reviewed and evaluated from the following aspects:

1. Criticality categorization (Category I, II or III)
    a. Determine whether present categorization is correct
    b. Rationale for acceptance of present categorization

2. Failure mode and effects analysis

   a. Single point failures

3. Corrective action

   a. Impact

4. Recommended new design criteria

5. Inflight maintenance (Tools)

   a. OPS oxygen for CM/LM use

   b. PLSS water for drinking purposes

   c. Use of batteries for multiple purposes

The following action items were assigned in the subject meeting:

1. Compile complete list of GFE showing present criticality categories assigned. Action. - J. W. Thompson.

2. Furnish Mr. J. W. Thompson a list of all GFE for which FMEA's are available so that they can be incorporated into preceding item 1. Action. - R&QA.

3. Identify all GFE which utilizes self-contained pressure vessels. Action. - CSD, FCSD, LSPO and LOEPO.

4. Transmit copies of all GFE FMEA's to Mr. J. Thompson. Action. - R&QA.

The next meeting of this team is scheduled for 11:00 a.m. on April 21, 1970. At this meeting, a more detailed plan of action for the investigation will be formulated. A daily meeting of this team will be held with the time being established at the April 21 meeting.

Richard S. Johnston
Chairman, GFE Panel

4-20-70
3:00 p.m.

MSC APOLLO 13 INVESTIGATION TEAM

CORRECTIVE ACTION STUDY AND IMPLEMENTATION

GOVERNMENT FURNISHED EQUIPMENT (GFE)

Chairman - Richard S. Johnston

Members - J. Correale (CSD)

D. Grimm (FCSD)

J. Langford (Lunar Surface Experiments)

E. Jones (Lunar Orbital Experiments)

C. McCollough (R&QA)

N. Vaughn (Safety)

J. Thompson (ASPO)

MSC Apollo 13 Investigation Team

Panel 5c, Government Furnished Equipment

April 21, 1970

Meeting No. 2

The second meeting of the Apollo 13 GFE investigation team was held at 11:00 a.m. on April 21, 1970. Attendees are listed on the attached page. The current status of the investigation was discussed and a review of action items from the April 20, 1970, meeting was made. All action items from the April 20 meeting are completed, except for item 4 which should be complete by April 22, 1970.

It was determined that the only criticability Category I items presently identified in the GFE area are the space suits, PLSS and OPS. Category II and III items are being further examined to determine if any of these should be upgraded to Category I.

The following action items were assigned:

1. Review FMEA's for all Category I items and present a detailed listing of the single point failures and the rationale for accepting these in the present configuration flight hardware. Action. - CSD to complete by 11:00 a.m., April 23, 1970.

2. Compile a listing of all GFE with self-contained pressure vessels and submit to ASPO Systems Engineering Division on April 21, 1970. Listings of these items are attached. Action. - J. W. Thompson.

3. Review contingency usage of existing GFE for purposes other than those for which it was designed and tool requirements for implementing such usage. Status of this review to be made at the next team meeting. Action. - J. Thompson.

The next meeting of this team will be held at 11:00 a.m., April 23, 1970, in building 2, room 763.

Richard S. Johnston
Chairman, GFE Panel 5c

Experiment	Criticality I	FMEA	Pressure Vessel
Gamma Ray Spectrometer	No	Completed	None
X-Ray/Alpha Spectrometer	No	Completed	None
Mass Spectrometer	No	In MSC Review	None
Panoramic Camera	No	Being Revised	None*
Mapping Camera	No	Being Revised	None***
Laser Altimeter	No	Being Revised	None**
IR Scanning Radiometer	No	Required by RFP	None
Far UV Spectrometer	No	Required by RFP	None
Subsatellite	No	Required by RFP	Batteries

*Contains N_2 plumbing. Maximum pressure is 28 PSIG in camera. N_2 supply provided by NR as CFE.

**Laser head contains one atmosphere of N_2. Volume is approximately 15 cubic inches.

***May require N_2 supply. If so, will utilize same supply as panoramic camera.

LIST OF PRESSURE VESSELS

EXP - SUBSYSTEM - COMPONENT	CONTRACTOR	APPROX DIM	GAS	DESIGN-PROOF PRESSURE	WORKING PRESSURE	RELIEF VALVE PRESSURE	FMEA AVAIL	FLT ASSIGN
PSE Caging Syst	BxA	1.6 in^3	10% Helium & Nitrogen	1000 PSI	333 PSI	None		All
PSE Outer Case	BxA	Dia 10.75 16.5" long	Air		Ambient	None		All
SRC's	Y12	22x18x10	Vacuum		15 PSI			
LGEC (case)	Goerz	14x6x5	Nitrogen		Ambient			
Rtg Fuel Element	AEC	2 dia x 18"	Helium		Ambient	1000 PSI after 6 years	Yes	All
Rtg	GE	$20x^{6.0D}_{4.5D}$	Trace & helium Argon	14.7 PSI @ ambient	2.5 PSI @ 1100^oF	(None Static)	Yes	All
Drill (Bat Cell)	Martin	5x5x8	Nitrogen			8 ± 3 PSI		
Drill Power Head	Martin	14x8 Dia	Nitrogen			15 ± 2 PSI		

LIST OF PRESSURE VESSELS

CREW SUPPORT EQUIP. COMPONENT	CONTRACTOR	APPROX. DIMENS.	GAS	DESIGN PROOF PRESSURE	WORKING PRESSURE	RELIEF VALVE PRESSURE	MATERIAL
PLSS O_2 Tank							
PLSS H_2O Tank							
OPS O_2 Tank							
Life Vest CO_2 Cart.							
Life Raft CO_2 Cart.							

MSC Apollo 13 Investigation Team
Prepared: April 23, 1970
Distributed: April 24, 1970

75

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

REPLY TO
ATTN OF:

MSC Apollo 13 Investigation Team

Panel 5c, Government Furnished Equipment

April 23, 1970

Meeting No. 3

The third meeting of the Apollo 13 GFE Investigation Panel was held at 11:00 a.m., on April 23, 1970. Attendees are listed on the attachment. Action items from all previous meetings were reviewed and all have been completed. A detailed report from Crew Systems Division was made by Mr. J. V. Correale, in which all criticabity Category I items were discussed. All these items are within the life support systems (PGA/PLSS/OPS). The Failure Mode and Effect Analyses for these systems were reviewed and the rationale for acceptance of all single point failures therein was presented. No recommendations for hardware design changes were made. All memebers of the Panel were in agreement with this. A copy of this report will be included in the interim report.

All GFE pressure vessel data have been given to MSC Apollo 13 Investigation Panel 6 for their use in the overall investigation of related system pressure vessels.

A listing of possible flight contingency equipment to be added to Apollo missions and utilization of existing equipment for uses other than those for which it was primarily designed was presented to the Panel for consideration. It was decided that this information would be transmitted to Panel 6 for its investigation and implementation as applicable.

The investigation assigned to Panel 5c is now considered to be complete pending further requirements imposed by the Investigation Board and/or other Investigation Panels. An interim report is now being complied and will be ready for distribution by May 1, 1970. If no further action is required by either the Investigation Board or other Panels, the interim report will be redesignated as the final report.

Richard S. Johnston

37-4/24

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: PG/M111-70

APR 24 1970

MEMORANDUM TO: PD/Chief, Systems Engineering Division

FROM : PA/Manager for Experiments and GFE
Apollo Spacecraft Program

SUBJECT : Data transmittal from GFE Investigation Team

The enclosed notes provide the results of a preliminary investigation into contingency GFE usage.

Similarly, data relative to GFE pressure vessel types and basic characteristics have been transmitted to PD4/R. Ward. No further effort will be expended in this area by this office unless you require specific data. Requests for further information may be made through PG15/J. W. Thompson, extension 4350.

Richard S. Johnston

Enclosure

cc:
PD4/J. Sevier
PD4/R. Ward

PG15:JWThompson(JJFerrell, Boeing):gjw 4-24-70

SM DISABLED IN TOTAL DURING TLI

April 23, 1970

Survival Possibilities - CM/LM Connected

1. Oxygen System

   (a) Design lightweight adapter bag to permit use of CM LiOH canister with LM O_2 umbilicals.

   (b) Redesign B5 and B6 attach points to accept stowage of OPS's.

   (c) Provide hardware to tee in two OPS's to three crewmen in case of loss of pressure and oxygen in the CM.

   (d) Install hand regulator valves to adjust O_2 flow from OPS's and PLSS's.

2. Power System

   (a) Spare battery capacity and size required to fire SPS: The solenoids are activated approximately five minutes prior to engine ignition. This is a small power drain and it builds up to approximately 40 amps at ignition and maintains that drain on the battery until shutdown.

   The breakdown is as follows:

   6 solenoid valves at 1 amp each = 6 amps

   2 helium solenoid valves at $1\frac{1}{2}$ each = 3 amps

   2 gimbal motors at 5 amps each =10 amps

   2 gimbal motors at 10 amps each =20 amps

   1 pump gaging system at 2 amps = 2 amps

   Total amps required = 41 amps

   Voltage required is 28V DC

   The approximate size of the battery required to handle the load would not exceed 14" X 8" X 5" and would weigh on the order of 15 pounds.

The PLSS and OPS batteries would not be able to provide the power required to fire the SPS.

The spare battery could be mounted in the SM and connected to a switch on the display console in the CM. The switch would have a 40-50 amp circuit breaker and plug connection that could be used to plug in an extension cable between the CM and LM. This battery could also be used in the LM in case an emergency arose which would require power to fire the LM descent engine or related LM electrical equipment.

(b) Provide electrical extension cable to reach from CM to LM and special outlets in LM and CM to handle heavy current drain (20 amp wire and breaker).

(c) Provide the capability to use ascent and/or descent batteries for CM.

(d) Utilize tape recorder batteries to power the penlights. FCSD personnel removed the recorder batteries from the power pack and installed in the penlights. The penlights were operated for two hours without any noticeable drain on the batteries.

(e) Design holder and circuit connections for OPS and/or PLSS batteries to use in the CM under extreme contingency conditions.

3. <u>Crew Comfort</u>

(a) Wear PGA's and fecal containment subsystem for body warmth.

(b) Stow thermal underwear for each astronaut.

(c) Redesign sleeping bags for warmth as well as restraining capabilities. Also, insure adaptability to the LM.

(d) Thermal (super insulation) blanket with capability to be folded into small size.

(e) Provide sox and gloves for each astronaut.

4. <u>Water System</u>

(a) Cooling - (waste water)

(1) Maintain water level at 50% capacity and only dump total capacity prior to SIM bay experiments.

(2) Power is not required for urine dump. The delta pressure between the cabin (4.5 psia) and outside vacuum is sufficient for dump purposes.

(b) Drinking

(1) Insert emergency hookup instructions and stow water line required to connect water system from CM to LM.

Equipment required:

- CM water gun
- Tee adapter
- Spare water line with proper connectors (male/female)
- Hand primer pump

(2) Three portable plastic water bags with approximately the same capacity - (2 lbs.)/man. The bags could be designed with two spouts - one for potable water and the other for urine. The bags could be stowed for contingency and used for either purpose at the discretion of the crew. Temporary in-flight stowage of the bags with drinking water could be on the bulkhead using beta straps. Mr. McAllister suggests that the urine bags be strapped to the wire trays or on top of the metal containers under the couches, but dumped at the first opportunity.

During the Apollo 13 debriefing on April 21, 1970, the crew stated they saved all the urine and did not dump it overboard. The reason the crew did not vent the urine overboard was that they felt it would cause a change in delta V or attitude to the S/C. After the mission, a preliminary investigation showed it would not change the S/C attitude or delta V to dump urine overboard from the CM.

(3) Remove water from PLSS for contingency drinking water.

5. <u>Tools</u>

- Wire cutters
- Insulation tape
- Adjustable or crescent wrenches
- Twine

6. Provide contingency information on the above applicable techniques/ procedures in the Flight Data File.

Prepared by: E. Rangel, D. Sedlak, P. Maceli
R. Daly, F. Parker

APOLLO 13 INVESTIGATION TEAM

SPECIAL FINAL REPORT DISTRIBUTION LIST

AA/R. R. Gilruth
PA/J. A. McDivitt
PA/O. G. Morris (Chairman, Panel 5b)
PA/R. S. Johnston (Chairman, Panel 5c, 8)
PA/S. H. Simpkinson
PA/R. W. Kubicki
PA/E. B. Hamblett
PT/D. D. Arabian (11) (Chairman, Panel 1)
CB/J. A. Lovell (Chairman, Panel 2)
FA/S. A. Sjoberg (Chairman, Panel 3)
BL/J. R. Brinkmann (Chairman, Panel 4)
PF/A. Cohen (Chairman, Panel 5a)
PD/C. H. Perrine, Jr. (Chairman, Panel 6)
ES/Dr. W. R. Downs (Chairman, Panel 7)
AP/Brian Duff (Chairman, Panel 10)
PP/J. G. McClintock (Chairman, Panel 11)
NA/M. L. Raines (Chairman, Panel 9)
E. P. Swieda, Apollo 13 Review Board (2)
PP/C. King
E. M. Cortright
Dr. J. F. Clark
Dr. H. M. Mark
V. L. Johnson
R. F. Allnutt
N. Armstrong
Brig. Gen. W. R. Hedrick
M. Klein
C. W. Mathews
G. Malley
R. G. Romatowski
E. Kilgore
F. Smith
H. Schurmeier
S. Himmel

DISTRIBUTION SHOULD BE MADE BY NUMBERED COPIES.
LIST SHOULD BE KEPT DESIGNATING WHAT COPY EACH RECEIVED.