CR-134009

Final Report

SPACE SHUTTLE ENVIRONMENTAL AND THERMAL CONTROL/ LIFE SUPPORT SYSTEM STUDY

73-9097

March 14, 1973

Contract NAS 9-11592

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Prepared for

NASA Manned Spacecraft Center

Houston, Texas

GARRETT

AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

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FOREWORD

This report was prepared by the AiResearch Manufacturing Company of Los Angeles, a division of The Garrett Corporation, for the NASA Manned Spacecraft Center under Contract NAS 9-11592. It contains the result of a two-year study aimed at the definition of the space shuttle orbiter environmental and thermal control/life support system (ETC/LSS).

The study technical monitor was D.W. Morris and at AiResearch the principal investigator was J. Rousseau. Other AiResearch personnel who made significant contributions to the study include K.C. Hwang, K. Ikeda, H. Louie, G.R. Noroshita, L. Sawamura, and N. Wood.

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SECTION 1

INTRODUCTION

1. INTRODUCTION

This report summarizes the results of a two-year study of the space shuttle environmental and thermal control/life support system (ETC/LSS) conducted by the AiResearch Manufacturing Company of Los Angeles for the NASA Manned Spacecraft Center under Contract NAS 9-11592. The major objectives of the program were to:

(1) Support the NASA inhouse and funded efforts through the vehicle definition phase of the program

(2) Identify potential problems

(3) Develop system requirements in terms of maintenance, certification, and ground support requirement

The entire effort was conducted in major tasks as follows:

Task I--Survey, tradeoff comparison, and preliminary concept design

Task II--Final conceptual designs and identification of pacing technological and developmental problems

Task III--ETC/LSS refinement

Task IV--ETC/LSS support requirements

Task I covered a broad range of investigations. Discrete subtasks included:

(a) Development of requirements and constraints

(b) Development of evaluation criteria

(c) Process investigations

(d) Subsystem trade studies

(e) System synthesis

(f) Reliability/safety maintainability investigations

(g) Cost analyses

(h) Development of a preliminary specificatic

Throughout these early studies, the ETC/LSS requirements were upgraded to reflect changes in mission and vehicle definition concurrent with the definition of the ETC/LSS. The Task I effort is summarized in AiResearch report 71-7859. In addition, a major portion of the Task I effort was directed toward the arrangement of the various subsystems and emphasis placed on the thermal management loop.

The Task II activities were concerned with a more detailed definition of the ETC/LSS and an update of the data generated under Task I. Major subtasks are listed below:

(a) System level performance optimization

(b) Fault detection and isolation

(c) Cost reduction investigations

(d) Specification update

The results of these investigations are summarized in AiResearch report 72-8501.

The Task III objective was to revise the system specification to incorporate the significant changes resulting from mission and vehicle studies conducted by NASA and the prime contractors. Subtasks included

(a) System analyses

(b) Equipment sizing

(c) Packaging studies

(d) Specification update

In Task IV, the ETC/LSS support requirements were defined in terms of testing, maintenance, and ground support equipment. This major effort comprised the following subtasks:

(a) Development support requirements

(b) Operation support requirements

Numerous reports were prepared in the course of the entire study to present the results of trade studies or investigations of particular aspects of the ETC/LSS design. These reports are listed in Table 1-1. Of particular significance are reports 71-7859 and 72-8501 for data generated under Tasks I and II. Detailed data generated under Task III are presented in reports 72-7382(10), 72-7382(11), 72-7382(12), and 73-8848. These data were used to develop the information contained in this final report. Reference is made to the list of Table 1-1 for these supporting studies.

This final report contains the results of these studies. The following information is presented for each ETC/LSS subsystem (see Section 4)

Functional requirements

Performance requirements

Subsystem description

Equipment summary

LRU definition

Equipment packages

Reliability considerations

Redundancy management in flight

In addition, the subsystem maintenance requirements are summarized. Tasks were defined for the following maintenance activities:

(a) Scheduled maintenance, including postflight servicing, preventative maintenance, and preflight servicing

(b) Ground checkout prior to flight

(c) Corrective maintenance

The time associated with each maintenance task was estimated; these data are presented in Section 5.

Development and qualification plans were developed to determine the extent of testing required for certification of the ETC/LSS and also to identify the requirements for new test equipment. The ETC/LSS test requirements are presented in Section 6.

Instrumentation necessary for redundancy management and for ground checkout were identified. Investigations were conducted to determine the requirements for instrumentation redundancy. As a result of these analyses, an instrumentation list was prepared and is presented in Section 7. This list includes only the instruments necessary for the ETC/LSS. It does not include vehicle- and mission-level instrumentation, nor for monitoring interfacing subsystems.

Finally, a functional description of the ground support equipment (GSE) necessary for ground maintenance was prepared. This description is presented in Section 8.

TABLE 1-1

STUDY DOCUMENTATION

Document Title	AiResearch Report No.
Design Requirements	71-7380, Rev. 1
Selection Criteria	71-7512
Booster Cabin Pressurization	71-7532
Orbiter On-Orbit Quiescent Storage	71-7544
Fire Detection and Extinguishment	71-7598
Bacteria Control in Water Management System	71-7546
CO_2 and Humidity Control Trade Study	71-7553
Reliability/Maintainability Guidelines	71-7698
Gas Storage Investigations	71-7710
Thermal Management Studies	71-7815
Preliminary Specification	71-7860
Cost and Schedule Data	71-7859
ETC/LSS Definition	72-8501
Space Shuttle Thermal Management System Design Optimization Program (50640) Performance Prediction Program (50650)	72-8602
Vapor Cycle Refrigeration Unit	72-8[illegible]73
Atmosphere Control Subsystem Design Optimization	72-8848
Redundancy Management Ground Checkout	73-8989
Monthly Progress Reports	71-7382(1) through 71-7382(12)

SECTION 2

SUMMARY

2. SUMMARY

2.1 DESIGN APPROACHES

Although the space shuttle ETC/LSS generally employs processes that are well developed, certain aspects of the mission and of the vehicle design differ considerably from previous space programs. Among the novel requirements that will significantly impact the configuration of the space shuttle ETC/LSS are (1) the reusability of the system after a very short turnaround time, and (2) the 10-year operational life of the equipment. In addition, the impact of the traditional system weight and power on vehicle, and booster sizing impose severe limitations on design.

Within the frame of reference of these technical problems, programmatic constraints concerned with minimum acquisition cost, and optimum balance between acquisition cost and the cost of ownership have far-reaching consequences on the possible approach to the development of the space shuttle ETC/LSS.

The first step in the evolution of the recommended ETC/LSS was to carefully examine the mission and vehicle constraints and to translate these upper-level technical and programmatic requirements into design and development guidelines. The rationale employed is summarized in Table 2-1.

The recommended system was evolved as a result of trade studies involving system arrangement as well as detailed examination of the hardware. Since a minimum-weight system meeting the life requirements is not necessarily optimum in terms of acquisition or operational cost, a fine balance must be established

TABLE 2-1

SUMMARY OF DESIGN APPROACHES

Space Shuttle Requirements	Approach	Implementation

Minimum Acquisition Cost	• No technical risk
	• Proven manufacturing techniques
	• Expediency in certification
		• Existing process technology
		• Early demonstration of new processes
		• Existing hardware
		• Avoid material compatibility problems
		  – Use of steel in water loops
		  – No dynamic elastomers in Freon loops
		• Existing tooling for detail parts
		• Existing manufacturing controls
		• No major capital investment
		• Minimum hardware
		• Selective development
		• LRU-level qualification

Minimum Ownership Cost	• Minimum number of components • Minimum number of component designs • Minimum maintenance • Effective maintenance • Minimum GSE • Minimum spares inventory	• Minimum new STE • Minimum redundancy • Equipment commonality • Equipment life/reliability • Maintainability in design • Modify available GSE • Equipment commonality
Minimum Weight	• Optimum system arrangement • Minimum equipment weight	• Minimum redundancy • Advanced design and manufacturing techniques
FO-FS Design	• Functional redundancy • Effective redundancy management	• Optimum LRU definition • Man-in-loop
Reusability	• Long-life equipment	• Design margins • No material compatibility problems
Short Turnaround	• Minimum maintenance • Effective maintenance	• Equipment life/reliability • Maintainability in design

between the factors affecting design. Major trade studies involved initial cost, weight, and maintainability.

2.2 PROCESS/EQUIPMENT SELECTION

Table 2-2 summarizes the recommended processes and equipment. As indicated, most of the processes and equipment are based upon years of experience in both aircraft and spacecraft systems. Examples are sorbent beds, fans, pumps, and heat exchangers. In a few instances, concepts which represent advances in technology are recommended. In all cases the feasibility of these concepts has been demonstrated and prototype equipment is being developed. These programs, funded by NASA over the past few years, include:

(a) Wickless condensate separator

(b) Flash evaporator for reentry heat rejection

(c) Composite pressure vessels

(d) Bacteria control in potable water systems

(e) Silver ion monitoring in potable water systems

(f) Instrumentation reliability

Stainless steel is recommended as the material of construction for the water coolant and the potable water subsystems. This approach is conservative insofar as it obviates potential material compatibility problems. Significant weight savings could be realized through the use of aluminum in these loops.

In terms of system arrangement, minimum weight is achieved while providing a high degree of redundancy through the use of multifluid heat exchangers in all cases.

2.3 EQUIPMENT SUMMARY

Table 2-3 is a summary of the components and component designs that comprise the ETC/LSS. Most of the equipment is new. Existing and/or modified

TABLE 2-2

PROCESS/EQUIPMENT SELECTION SUMMARY

Subsystem	Process/Equipment Selection	Rationale
Atmosphere revitalization	• Condenser with integral wickless water separation	Fully developed, recent R&D
	• Cabin fan	Vane axial design; Apollo base
	• Temperature control	DC-10 modified; reliability demonstrated
	• Radial flow LiOH beds	3 mm Hg PCO_2 design with 93 percent utilization efficiency
	• Steel heat exchangers	No material compatibility problems
	• Centrifugal pumps	Magnetic drive; Apollo base
	• Avionics fans	Vane axial; similar to cabin fans
	• Flash evaporator	Flexibility demonstrated; NASA funded R&D
Atmosphere control	• Composite tanks	Major weight saving; no catastrophic failures
	• Skylab PO_2 control	Demonstrated life and reliability
	• Carleton regulators--shutoff valves	Apollo Skylab base; proven hardware
Water management	• Bladder tanks	Apollo base; minimum cost
	• Silver chloride bacteria control	Feasibility demonstrated, NASA funded R&D
	• Hydrogen separation	Apollo base
Freon coolant loop	• Wet pump motors	Long life; existing technology
	• Multifluid heat exchangers	Minimum connectprs; minimum weight; ease of redundancy management
	• No dynamic elastomers	No material compatibility problems
Instrumentation	• Surface type temperature sensors	Apollo base
	• Strain gage type pressure sensors	Apollo base

TABLE 2-3

EQUIPMENT SELECTION SUMMARY

Functional Components

Subsystem	Components				Component Designs			
	As-Is	Modified	New	Total	As-Is	Modified	New	Total
Atmosphere revitalization	9	14	41	64	5	4	15	25
Atmosphere control	40	57	27	124	5	16	9	30
Water management	8	8	16	32	3	4	9	16
Freon-21 heat rejection	2	18	42	62	1	6	18	25
Vapor cycle unit (2 units)	12	2	4	18	6	1	2	9
Total	71	99	130	300	21	31	53	105

Monitoring Instrumentation*

Subsystem	Instruments				Instrument Designs			
	As-Is	Modified	New	Total	As-Is	Modified	New	Total
Atmosphere revitalization	21	2	-	23	6	1	-	7
Atmosphere control	34	2	-	36	8	1	-	9
Water management	2	2	1	5	2	2	1	5
Freon-21 heat rejection	15	2	-	17	4	1	-	5
Vapor cycle unit	-	-	-	-	-	-	-	-
Total	72	8	1	81	20	5	1	26

*Control instrumentation included as part of the functional components list components primarily consist of valves and instrumentation transducers. A breakdown of the equipment according to these categories is presented in the table.

In general, the major components such as fans, pumps, and heat exchangers are new and cannot be made common because of the high weight penalties involved in stressing commonality for this type of equipment. As a result, the highest degree of commonality can be found in the atmospheric control subsystem; because of the relatively low weight of the components, common designs can be specified at a minimum penalty.

2.4 WEIGHT AND POWER

The weight and power usage of the ETC/LSS subsystems are presented in Table 2-4. Component wet weight is estimated at 1422 lb excluding the weight of structures, lines, and electrical harnesses. Total expendable weight for a crew of 4 men and a 7-day mission (plus 4-day contingency) is 579.8 lb, for a launch weight of 2002 lb (excluding takeoff water).

Normal continuous power draw (excluding spikes for heaters and valve actuation) is estimated at 885 watts with only one active avionics bay. With three active avionics bays, total normal power is 1225 watts. Under maximum cabin heating conditions, as much as 2385 watts can be expended to maintain cabin temperature at the selected level.

The vapor cycle units will only be used during Ferry flight. The weight and power of these units is not included in the total shown in the summary table.

2.5 CABIN NOISE

An estimate of cabin noise attributable to the cabin and avionics fans and to the water pump is presented in Figure 2-1. The data are given for one

TABLE 2-4

WEIGHT AND POWER SUMMARY

Subsystem	Weight, lb		Power, watts	
	Fixed Wet	Expendable 4 men, 11 days	Continuous	Maximum Intermittent
Atmosphere revitalization	381.6	209 (LiOH and filters)	462.5 (one avionics bay)	1500 (heater; 340 2 additional avionics bays)
Atmosphere control	467.5	275 (O_2-N_2)	4	—
Water management	107	8.8 (filters)*	2	275 (water heater)
Freon coolant loop	465.9	130 (NH_3)	416	65 (bypass valve)
Vapor cycle units (2)	237.2	—	20,000	—
Total** (orbital configuration)	1422	579.8	884.5	—

*Assumes no takeoff water

**One third the ammonia will be used during prelaunch.
Total for orbital configuration; does not include vapor cycle units.

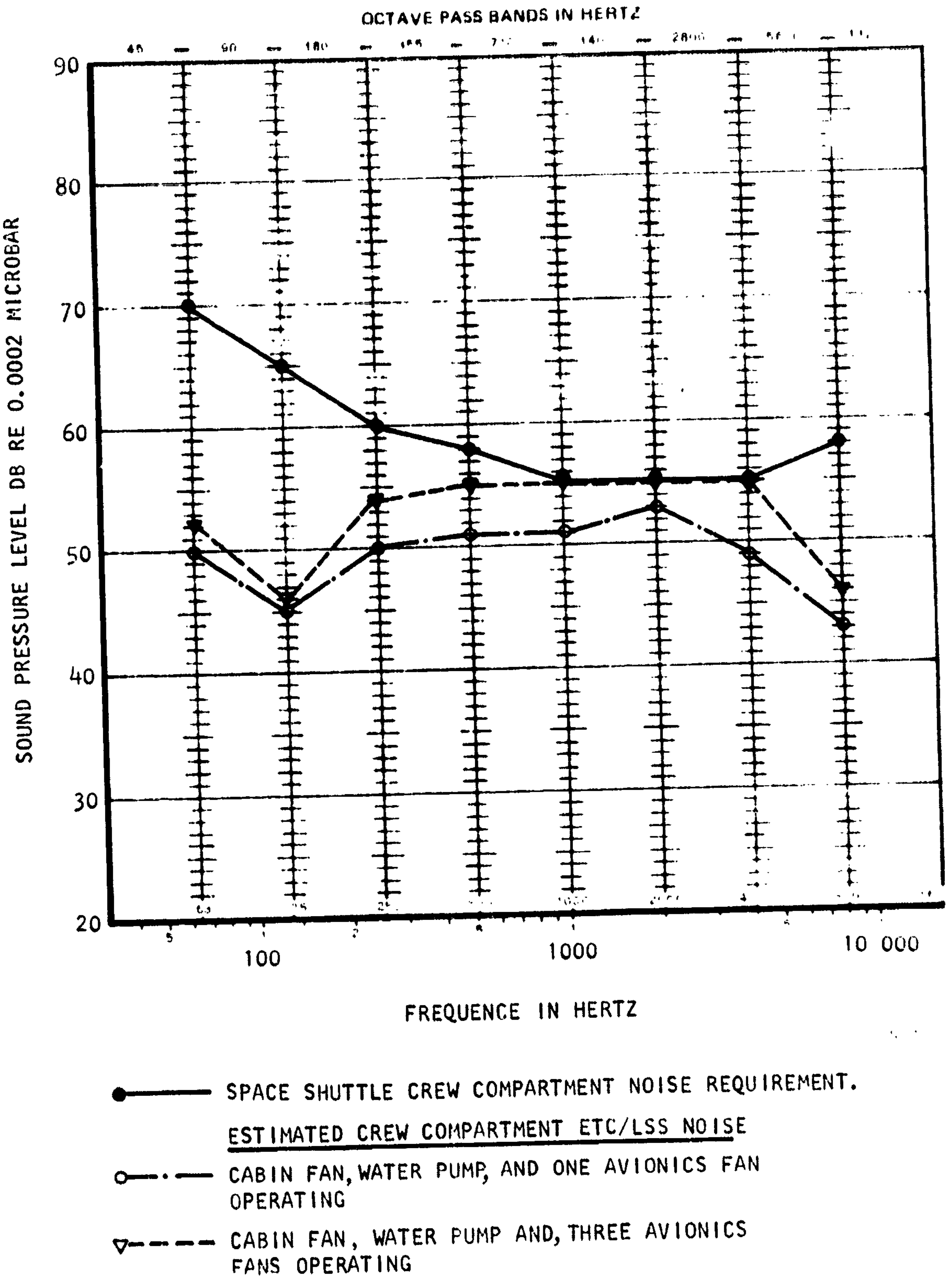


Figure 2-1. Estimated Space Shuttle Crew Compartment Noise Levels

and three active avionics fans. It was assumed that all rotating equipment is located under the floor of the lower pressurized compartment. The total noise transmitted to the cabin includes airborne and conducted noise. The specification requirements are met in all cases.

2.6 MAINTENANCE REQUIREMENTS

A summary of the onboard maintenance requirements for the four subsystems considered is presented in Table 2-5. The time to service, check out, and perform corrective maintenance is estimated at 50.7 man-hours based on a 7-day mission. With a two-man maintenance crew, total elapsed time is 25.4 hr. The largest portion of the maintenance time is expended in the atmosphere control subsystem. Checkout of this subsystem alone accounts for more than 25 percent of the total maintenance time. The instrumentation and GSE necessary to support the maintenance activities are discussed in Sections 7 and 8.

2.7 CERTIFICATION APPROACH

The certification program is designed to minimize test hardware cost and to eliminate duplication in test operations Figure 2-2 gives an overall view of the test program. Development will primarily be conducted at the component level only. The scope of this testing will depend upon the hardware category. For existing equipment (as-is or modified), breadboard testing will be aimed at suitability demonstration to verify particular features of performance or design. For new equipment the development program will be more extensive and is designed to assure against failures in qualification.

Only selected packages will be tested during development to (1) identify and resolve potential interface problems, (2) ascertain structural integrity, and (3) verify maintainability concepts.

TABLE 2-5

MAINTENANCE SUMMARY

Subsystem	Scheduled Maintenance (Servicing) Man-Hours/Flight	Flight Readiness Ground Checkout Man-Hours/Flight	Onboard Corrective Maintenance Man-Hours/10^3 Operating Hours
Atmosphere revitalization	6.1	7.3	0.64
Atmosphere control	4.6	13.8	7.05
Water management	4.3	3.5	0.40
Freon coolant loop	3.1	6.5	0.65
Total	18.1	31.1	8.74

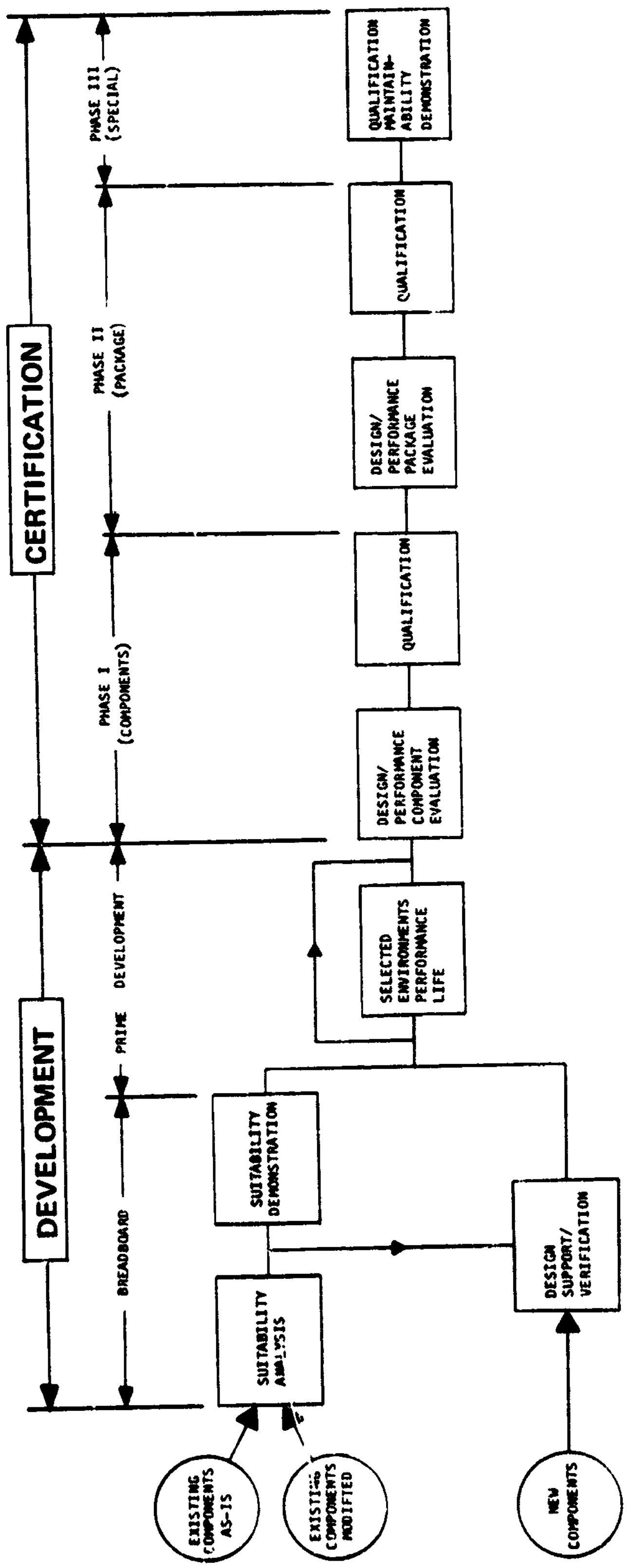


Figure 2-2. Certification Approach

The major portion of the qualification test program will be conducted at the end-item or LRV level. This constitutes a more realistic approach because the performance and structural interfaces between the various components are accounted for. It is also expedient because it eliminates much duplication. The only component level qualification tests recommended are special tests such as EMI and explosive atmosphere, which are more conveniently conducted on a component basis, and tests of a destructive nature such as burst.

The large majority of the test equipment that will be used is readily available from previous contracts. Minor modifications will be required to some equipment to accommodate the higher requirements of the space shuttle ECT/LSS in specific areas. New STE only involves new fluid processes such as test stands for the Freon-21 equipment.

2.8 INSTRUMENTATION REQUIREMENTS

Instrumentation transducers are necessary for (1) system control, (2) redundancy management in flight, and (3) ground checkout and maintenance. A total of 95 instruments are recommended including redundant sensors. Table 2-6 is a breakdown of these sensors by type and application for each subsystem. Of the 95 instruments, only 7 are redundant; in most applications, information redundancy is provided by sensors incorporated in the system for purposes other than redundancy.

2.9 GSE REQUIREMENTS

The GSE necessary to support ground maintenance activities is listed in Table 2-7.

TABLE 2-6

INSTRUMENTATION SUMMARY

INSTRUMENTATION APPLICATION

Subsystem	Control	Application: Redundancy Management	Checkout
Atmosphere control	3	25	11 + (23)
Atmosphere revitalization	6	23	1 + (13)
Water management	-	5	(2)
Freon-21 cooling loop	2	15	4 + (9)
Total	11	69	16 + (47)

( ) indicates alternate use of either a control or a redundancy management transducer for checkout

INSTRUMENTATION TYPE

	Transducer Type							
Subsystem	Pressures	Differential Pressure	Temperature	Quantity	Flow	Special	Test Ports	Position
Atmosphere control	29	3	2	-	2	3	-	-
Atmosphere revitalization	2	11	13	2	-	1	-	1
Water management	1	-	1	2	-	1	5	0
Freon cooling loop	5	2	10	2	-	-	-	2
Totals	37	16	26	6	2	5	5	3

TABLE 2-7

GSE FUNCTIONAL SUMMARY

GSE Description	Purpose	Functional/Performance Requirement
N_2 test set	Provide GN_2 under controlled conditions for test, checkout, purging, and drying during ETC/LSS maintenance; principal applications for N_2 loop ACS and interfacing ETC/LSS subsystem and for WMS and FCL	(1) Capability of operating from any N_2 storage source. (2) Provide flow characteristics up to 150 lb/hr at an inlet pressure of 130 psig at 70°F. (3) Provide regulated GN_2 gas pressures at: 0 to 5 psig, 0 to 150 psig, and 0 to 3500 ±10 percent psig. (4) Provide ±0.5 percent measurement capabilities for above ranges. (5) Provide capability of supply warm dry nitrogen to 75° ±5°F. (6) Capable of supplying 25 lb N_2 at 3100 psig at 70°F in 15 min.
O_2 test set	Provide GO_2 under controlled conditions for test and checkout of O_2 loop of ACS	(1) Capability of operating from any GO_2 source. (2) Provide flow capabilities up to 150 lb/hr at an inlet pressure of 90 psig, 70°C. (3) Provide regulated GO_2 gas pressure at: 0 to 110 psig, 0 to 900 psig 0 to 3500 psig. (4) capable of supplying 25 lb O_2 at 3100 psig at 70°F in 15 min.
Vacuum test set	Provides a means to reproduce a space quality level for test, checkout, and servicing of various major ETC/LSS subsystems. Primary application is for ACS and is also used for FCL and WMS servicing	(1) Capability of pumping down a volume of 6000 cu in. to 10^{-5} psi within 60 min and maintaining this level with a leakage rate of air at 5 lb/day. (2) Provide a capability for rough and fine vacuum measurement including pressure and leakage flow up to 0.125 lb/hr.
Cabin temperature control test set	Test provides the capability through built-in signal simulation of qualitative and quantitative checkout of the cabin temperature controller, signal sensors, and causing temperature control valves and heater to cycle.	(1) Test set will be capable of operating cabin temperature control system, self-powered. (2) Capable of integrating temperature control for faults. (3) Provide subsystem control in checkout of subsystem through cabin temperature selector.
Water coolant service and checkout cart	Provide deaerated, dyed, deionized coolant water for ARS liquid cooling loop at operating pressure for servicing or checkout of cooling loop	(1) Provide capability of operating from either spacecraft or self-powered cooling system pumps and valves. (2) Delivery of water coolant at 50-psi nominal for servicing and system checkout. (3) Provide measurement capability of 0.5 percent accuracy for temperature and pressure transducers. NOTE: For major servicing, vaccum test set (3) can be used for evacuating system prior to fill
Potable water service cart	For servicing potable water system prior to flight. Replaces expendable drinking water for drinking and thermal management	(1) Provides sterilized water for servicing potable water system for preflight. (2) Delivery pressure shall be no greater than 50 psia at 200 lb/hr flow.
Potable water decontamination cart	Used for decontamination of system using potable water or requiring cleansing flush with water and uses in ARS for condensor servicing	(1) Flush water treated to 1000 deg PPB AgCl. (2) Capability for providing live steam for decontamination flush. NOTE: Drying purge should be pre-contamination with N_2 test set
F-21 servicing and checkout cart	Used for test and checkout and servicing of F-21 loops	(1) Provide processed (dyed) F-21 at 300 psig for servicing and leakage test. (2) Provide capability to operate coolant pump from self-contained or spacecraft power. (3) Capability for deservicing F-21 loops for heavy maintenance (4) Capability for evaluating subsystem to 200 microns for reservicing system (5) Capability for processing 250 lb F-21. (6) Measurement capability for pressure and temperatures. NOTE: Requirement (4) could be incorporated with (3) vacuum test sets.
Freon-21 bypass valve controller test set	Provides for checkout of Freon-21 bypass valve circuits	(1) Capable of operating from spacecraft power or being self-powered. (2) Contain test logic to integrate controller for faults and quantitatively evaluate control sensor for fault. (2) Capability to perform simulated operating cycle and evaluate bypass valve function.
NH_3 service cart	Provide NH_3 at proper temperature and pressure for servicing	(1) Capable of providing 300 lb of NH_3 at 600 lb/hr at 128 ±5 psig minimum and at 70 ±2°F.
NH_3 recovery and vapor disposal cart	Used to safely contain dumped NH_3 or NH_3 vent vapor during servicing and after system is serviced to protect personnel and equipment	(1) 300-lb storage capacity of NH_3 saturated vapor. (2) Allow safe venting or scrubbing of NH_3 at 9 lb/min and at pressures up to 1000 psig (3) Recovery for case (2) can be all saturated vapor with concurrent venting from disposal unit
Flash evaporator closure	Provide flightworthy/pressure tight closure for maintenance and test	(1) Capable of providing gas-tight sealing; concurrently allowing pressurization to 2 psid during maintenance and checkout test. (2) Provision for adaptation of N_2 test set (1) measurement instruments for test and checkout

SECTION 3

OVERALL REQUIREMENTS

3. OVERALL REQUIREMENTS

The vehicle/mission level requirements for the design of the ETC/LSS are presented in Table 3-1 and discussed in the following paragraphs. Detailed subsystem design data are presented with the discussion of each subsystem.

TABLE 3-1

VEHICLE/MISSION LEVEL REQUIREMENTS

Parameter	Requirement
Mission duration	
Baseline	7 days
Range	2 to 30 days
Crew size	
Normal crew	4 men
Passengers	0 to 6 men
Number of missions	100 per vehicle over a 10-year period
Number of vehicles	5
Equipment design life	10 years
Turnaround time between flights	14 days
Cabin pressure	14.7 ±0.2 psia
Cabin temperature (selectable)	65° to 80° $\pm 2^\circ F$
Cabin volume	2000 cu ft
Airlock volume	250 cu ft
Avionics bay volume (3 bays)	150 cu ft (each)
Vehicle leakage	10 lb/day
Thermal loads	Obtained from NR report ECLSS-141-72-2 dated May 1972.

Expendable storage is based on the average requirements for the baseline 4-man, 7-day mission; sufficient expendables must be provided to sustain operation for four days of emergency operation.

Reliability guidelines are as follows. The first failure will not result in degraded performance; adequate provisions are made to continue operation at design point performance. The second failure can result in performance degradation or alternate operational modes that will satisfy crew safety requirements, although compromising the mission and/or crew comfort. Pressure vessels, heat exchangers, and interconnecting lines are considered to be primary structures and need not be subjected to the redundancy requirements of other equipment types. These guidelines will provide near FO-FS (fail operational-fail safe) capabilities for all critical functions.

With respect to maintainability guidelines, no maintenance will be performed in flight except in emergency situations. Sufficient instrumentation must be provided to enable the flight crew to effectively manage the redundant elements of the subsystems without ground support. The on-board computer will be used only for instrumentation readout, parameter comparison to preset min/max values, parameter display, and alarm. Fault detection/fault isolation logic will not be programmed in the computer. All equipment necessary for fault isolation at the LRU level and all instrumentation sensors necessary for ground checkout will be installed on the subsystems. The onboard computer will be available for ground checkout operations.

SECTION 4

SYSTEM DESCRIPTION

4. SYSTEM DESCRIPTION

4.1 GENERAL

The entire ETC/LSS was divided into the following major subsystems.

- Atmospheric revitalization
- Atmospheric control
- Water management
- Freon-21 heat rejection
- Ferry flight heat sink

For each subsystem, the following data are presented

(a) Functional requirements

(b) Performance requirements

(c) Subsystem description

(d) Equipment summary

(e) LRU definition

(f) Equipment packages

(g) Equipment redundancy

(h) Redundancy management

These are discussed briefly in the following paragraphs.

4.1.1 Functional and Performance Requirements

The requirements presented in Section 3 were amplified using data provided by the NASA and NR, and also the results of investigations conducted at AiResearch. These data were further developed from the subsystem to the component level to permit equipment characterization. Equipment functional and performance requirements are presented in the equipment summary.

4.1.2 Subsystem Description

Schematics of each subsystem are presented. The numbering system for the components as listed below is based on that used by NR at the end of their Phase B activities:

2.0 and 3.0	Atmosphere revitalization
1.0	Atmosphere control
4.0	Water management
7.0	Freon-21 heat rejection
10.0	Ferry flight heat sink

4.1.3 Equipment Summary

Equipment characteristics are presented in tabular form. For each component, the following data are presented:

(a) Item number

(b) Item description

(c) Number of items required

(d) Functional and performance requirements

(e) Item weight (dry and wet)

(f) Envelope

(g) Power requirement

(h) Equipment category in terms of qualification status

(i) Design features

These tables incorporate the results of detailed component selection and preliminary design studies. Extensive surveys were made of equipment availability from previous space programs to identify components which could be used on the space shuttle without modification or with only minor modifications. Most of the components in this category comprise valves, connectors and instrumentation transducers. The major equipment such as heat exchangers, fans, pumps, etc. are new.

4.1.4 LRU Definition and Equipment Packages

A preliminary definition of component groupings into line replaceable units (LRU's) was developed as the result of redundancy management investigations, packaging studies, and maintainability analysis. Since it was assumed that the equipment will be accessible, the LRU definition is near optimum from an ETC/LSS viewpoint. Additional constraints imposed by installation requirements could have a significant impact on the LRU definition; however, in most cases the packages developed could be modified easily to conform to the detailed vehicle installation constraints.

In defining the LRU packages, two categories of components were identified

(a) LRU components which will be replaced onboard and which are part of a larger equipment grouping (for example, the inlet pressure transducer on a pump package). The transducer is replaceable on-line; however, when the pump package is removed, the transducer also will be removed.

(b) Shop-replaceable units (SRU) components. Replacement of this category of component will entail removing the LRU package from the vehicle and then removing the component from the package. This last maintenance action will usually be effected at the shop level, although SRU replacement in specific cases could be done onboard.

4.1.5 Equipment Redundancy and Redundancy Management

All subsystems were developed to assure that the FO-FS criterion was satisfied in terms of subsystem functions. The guidelines defined in Section 3 were used to evaluate the recommended subsystem arrangements in this respect.

In developing equipment redundancy, considerable emphasis was placed on the following factors to assure the effectiveness of the FO-FS quality of the subsystem.

(a) Number of instruments necessary for subsystem health monitoring in flight

(b) Logic required for interpretation of the information derived from the subsystem transducers

(c) Crew tasks involved in restoring subsystem health

In the performance of the redundancy management studies, the ground rules discussed below were followed:

(a) It was assumed that the onboard computer would be used for transducer interrogation only, and would not contain the fault detection/isolation logic. The computer will identify out-of-tolerance conditions and alert the crew if such a condition exists. Also, the crew can interrogate the computer for additional transducer readouts as desired.

(b) The interpretation of the instrumentation readouts will be done by the flight crew without the assistance of ground support crew and facilities. As a consequence, the redundancy management modules were defined in terms of easily identifiable and detectable subsystem functions. In this manner, fault ambiguity is eliminated and corrective actions are simplified.

(c) One aspect of fault detection not covered in these analyses is concerned with instrumentation redundancy. In the analyses conducted, it was assumed that the information was available to the crew, and instrumentation failures were ignored. Generally, instrumentation redundancy will be necessary, and procedures to identify instrumentation failures (as opposed to functional equipment failures) will have to be identified. Instrumentation redundancy is discussed in Section 7.

(d) Another assumption made was that no ETC/LSS instrumentation is required for fault detection in interfacing subsystems. As a result, a minimum instrumentation list was defined for all subsystems.

(e) The data presented for each subsystem in tabular form is concerned only with the primary leg of redundant subsystem arrangement. Fault detection in the secondary leg is the same and requires the same instrumentation.

4.2 ATMOSPHERE REVITALIZATION SUBSYSTEM (ARS)

4.2.1 Functional Requirements

The atmosphere revitalization subsystem comprises the equipment necessary for control of the cabin atmosphere temperature and for removal of the contaminants generated within the pressurized compartment. In addition, the ARS provides the capability for thermal control of all equipment located within the pressurized compartments. Specifically, the ARS performs the following functions.

(a) Automatic cabin temperature control at a value selected by the crew

(b) Ventilation of the pressurized compartment

(c) Humidity condensation and removal

(d) Control of PCO_2 below acceptable levels

(e) Removal of trace contaminants and odors

(f) Removal of particulate matter and bacteria

(g) Cooling of the potable water supply

(h) Thermal control of the pressurized cabin walls

(i) Cooling of the air-cooled avionics located in three separate bays

(j) Cooling of the cold plates located within the avionics bays

(k) Thermal management system heat sink during ascent and entry

Thermal control is effected by means of redundent water loops. With the exception of the ascent and entry phases of the mission, the heat collected by the water loop is dumped into the Freon-21 heat rejection subsystem outside the pressurized compartment. During ascent and entry, water evaporators in the water coolant loops serve as the entire thermal management system heat sink.

4.2.2 Performance Requirements

Major performance requirements are listed in Table 4-1.

4.2.3 Subsystem Description

A schematic of the subsystem is presented in Figure 4-1. The instrumentation identified on the schematic is discussed in Section 7. Subsystem functions are accomplished as discussed in the following paragraphs.

4.2.3.1 Cabin Temperature Control

Cabin air is circulated through the ARS loop by one of three redundant fans (Item 2.5). In normal operation, when cooling is required this air is cooled in the humidity control/cabin heat exchanger (Item 2.6) and returned to the cabin via the distribution ducts. The amount of heat removed in the heat exchanger is controlled by regulating the quantity of process air through this unit. The maximum airflow through the humidity control heat exchanger is 880 lb/hr. Mechanically linked flow control valves (Item 3.2) are provided for this purpose. The use of a dual valve will assure proper flow distribution and stability of operation. The position of the valves is automatically controlled by the cabin temperature controller (Item 3.4), which uses signals from the selector (Item 3.5), the temperature sensor (Item 3.3), and anticipator (Item 3.4). The selector is set manually by the crew; the anticipator provides cooling rate information to the sensor and reduces temperature excursions to a minimum. A manual override is incorporated in the selector design to permit manual override of the controller and to position the bypass valve directly from the selector. As an added feature, the valve actuator can be overriden manually. When heating is required, the controller will switch on the electrical heater and modulate the power to the heater to effect the cabin temperature

TABLE 4-1

ARS PERFORMANCE REQUIREMENTS

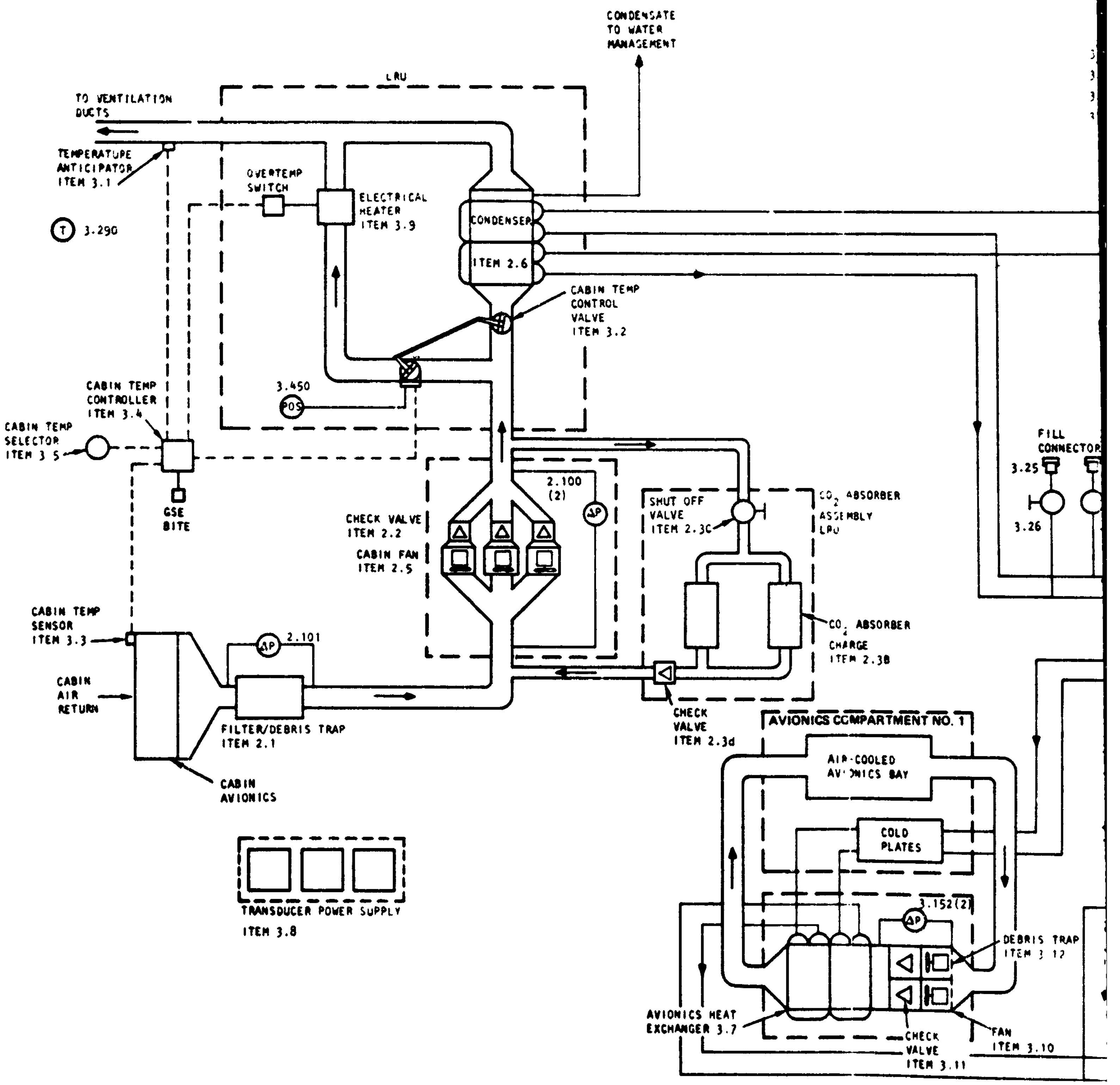
Subsystem Function	Parameter	Value
General	Cabin pressure	14.7 psia
	Cabin volume	2000 cu ft
	Crew size	4 to 10 men
	Mission duration	7 days nominal, 2 to 30 days range
Cabin temperature control	Selectable temperature range	65° to $80^\circ F$
	Control accuracy	$\pm 2^\circ F$
	Loads	
	Cabin sensible load	6400 to 2100 Btu/hr excluding cabin fan
	Cabin avionics load	3460 to 430 Btu/hr
	LiOH sensible load	800 Btu/hr (10-man design)
Ventilation	Nominal design point	25 ft/min
	Range	15 to 40 ft/min
Humidity removal	Cabin dewpoint	39° to $61^\circ F$
	Cabin latent load	2000 Btu/hr (10-man design)
	LiOH latent	400 Btu/hr (10-man design)
PCO_2 control	Cabin PCO_2	
	Nominal	3.0 mm Hg maximum with 4 men at maximum metabolic rate)
	Range	0 to 7.6 mm Hg
	Fail-safe operation	10 mm Hg
	Emergency	15 mm Hg for a maximum of 2 hr
	CO_2 production rate	
	Nominal design point	2.11 lb/man-day
	Range	1.88 to 2.5 lb/man-day
Odor removal	See Table 4-2	
Particulate matter and bacteria control	Airborne bacterial concentration	500 microbes/cu ft
Water coolant loop data	Cooling water specification	MSC-SPEC-C20A
	Water flow rate	550 lb/hr
	Water circuit ΔP	40 psi
	Maximum water temperature in cold wall	60° to $70^\circ F$
	Maximum water temperature at cold plate circuit inlet	$75^\circ F$
	Maximum air temperature at air-cooled avionics inlet	$100^\circ F$
	Maximum air temperature at air-cooled avionics outlet	$130^\circ F$
	Chilled potable water supply temperature	40° to $50^\circ F$
Expendable evaporant heat sink	Control temperature	
	Inlet water temperature initiating unit operation	$55^\circ F$
	Outlet temperature control range	35° to $45^\circ F$
	Design point loads (ascent)	
	Load	73,600 Btu/hr (maximum)
	Water inlet temperature	$174^\circ F$
	Water outlet temperature	$40^\circ F$
Air-cooled avionics circuit design data	Airflow rate	1000 lb/hr
	Air ΔP	2 in. H_2O excluding heat exchanger
	Avionics bay pressure	14.3 psia
	Water flow to each avionics bay	1/3 of total (183.3 lb/hr)
	Design load	8220 Btu/hr with a water inlet temperature of $77^\circ F$

TABLE 4-2

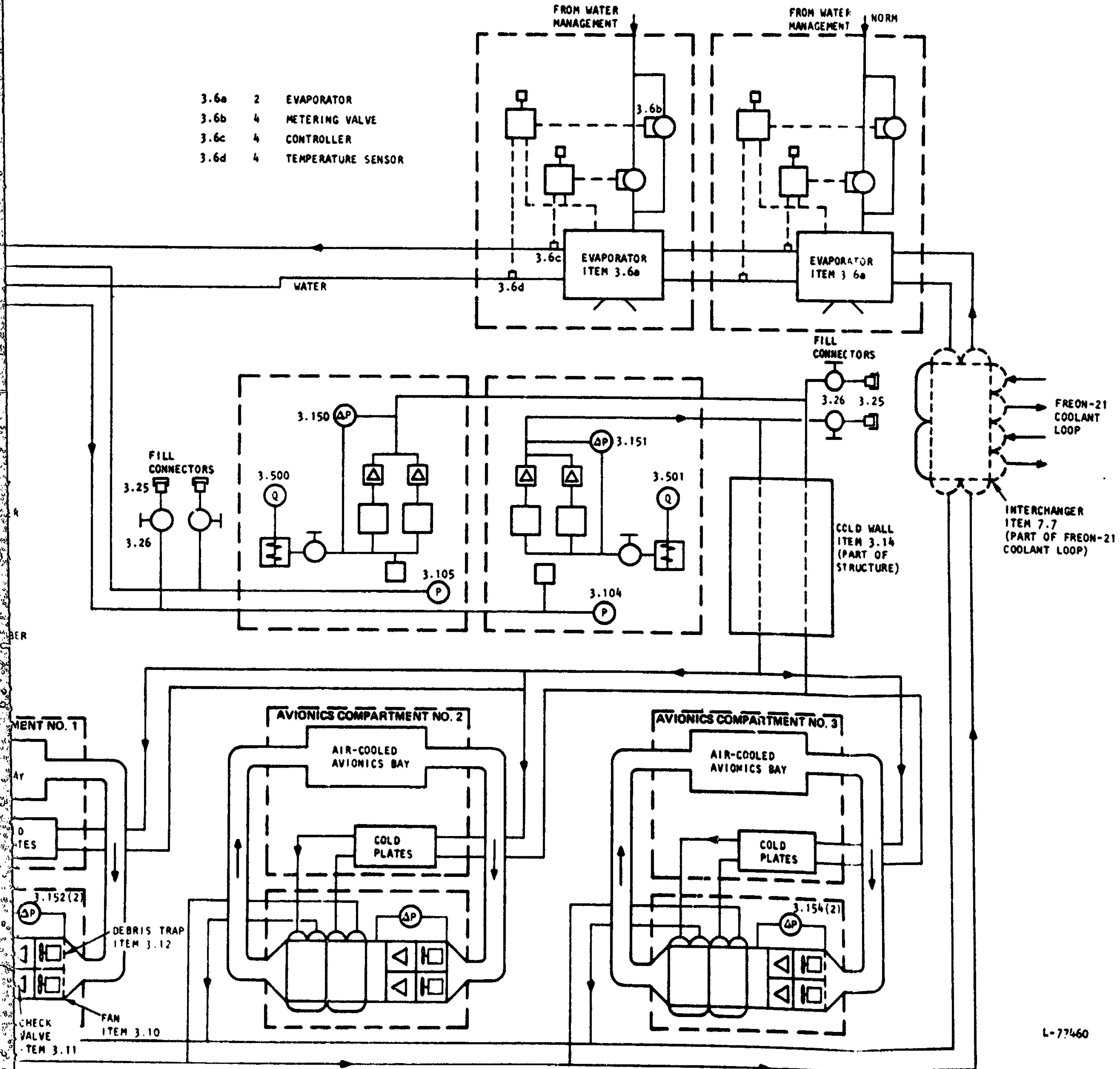
MAXIMUM CONCENTRATION AND PRODUCTION RATE OF TRACE CONTAMINANTS (10-MAN CREW)

Contaminant	Biological Production Rate, gm/day	Maximum Allowable Concentration, mg/m^3
Acetone	0.005	240.0
Acetaldehyde	0.002	36.0
Ammonia	10.0	3.5
n-Butyl alcohol	0.03	30.0
Carbon monoxide	0.162	29.0
Ethyl alcohol	0.10	190.0
Hydrogen	0.50	215.0
Hydrogen sulfide	0.000583	1.0
Indole	1.0	126.0
Methyl alcohol	0.10	26.0
Methane	6.0	1720.0
Methyl mercaptan	0.21	2.0
Phenol	3.78	1.9
Propyl mercaptan	0.21	92.0
Pyruvic acid	3.78	0.9
Skatol	0.21	141.0

FOLDOUT FRAME 1

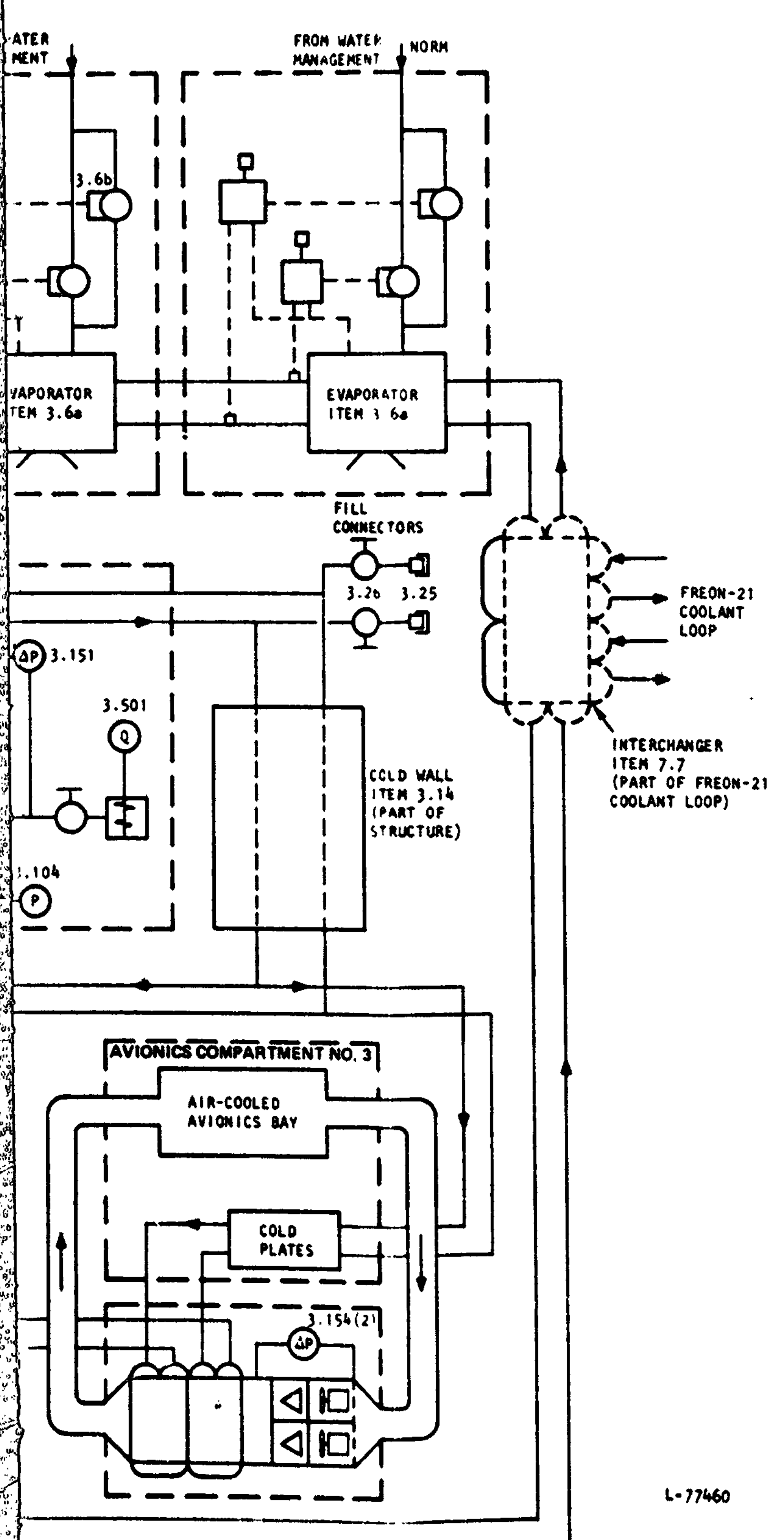


FOLDOUT FRAME 2



FOLDOUT FRAME 2 1

FOLDOUT FRAME 3



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ITEM NO.	FUNCTIONAL AND PERFORMANCE REQUIREMENTS	NUMBER REQUIRED
2.1	FILTER-DEBRIS TRAP	1
2.2	CHECK VALVE, REVITALIZATION FAN	3
2.3a	CO_2 ABSORBER CANISTER	2
2.3b	CO_2 ABSORBER ELEMENT	EXPENDABLE
2.3c	SHUTOFF VALVE	1
2.3d	CHECK VALVE	1
2.5	FAN, REVITALIZATION	3
2.6	HEAT EXCHANGER, CABIN/HUMIDITY CONTROL	1
2.100	FAN ΔP TRANSDUCER	2
2.101	DEBRIS TRAP ΔP TRANSDUCER	1
2.500	CO_2 PARTIAL PRESSURE SENSOR	1
3.1	SENSOR, CABIN TEMPERATURE ANTICIPATOR	1
3.2	VALVE, CABIN TEMPERATURE CONTROL	1
3.4	CONTROLLER CABIN TEMPERATURE	1
3.5	SELECTOR, CABIN TEMPERATURE	1
3.6	EXPENDABLE EVAPORANT HEAT SINK	2
3.7	HEAT EXCHANGER AVIONICS	3
3.8	POWER SUPPLY TEMPERATURE TRANSDUCER	1
3.9	ELECTRICAL HEATER	1
3.10	FAN, AVIONICS COOLING	6
3.11	CHECK VALVE, AVIONICS FAN	6
3.12	AVIONICS FAN DEBRIS TRAP	6
3.24	PUMP PACKAGE ASSEMBLY, WATER COOLANT	2
3.25	WATER FILL CONNECTOR	4
3.26	WATER SHUTOFF VALVE	4
3.104	SECONDARY PUMP INLET PRESSURE TRANSDUCER	1
3.105	PRIMARY PUMP INLET PRESSURE TRANSDUCER	1
3.150	PRIMARY WATER PUMP ΔP TRANSDUCER	1
3.151	SECONDARY WATER PUMP ΔP TRANSDUCER	1
3.152	AVIONICS BAY 1 FAN ΔP TRANSDUCER	2
3.153	AVIONICS BAY 2 FAN ΔP TRANSDUCER	2
3.154	AVIONICS BAY 3 FAN ΔP TRANSDUCER	2
3.155	INTERCHANGER OUTLET TEMPERATURE TRANSDUCER (PRIMARY)	1
3.256	EVAPORATOR OUTLET TEMPERATURE TRANSDUCER (PRIMARY)	1
3.257	INTERCHANGER OUTLET TEMPERATURE TRANSDUCER (SECONDARY)	1
3.258	EVAPORATOR OUTLET TEMPERATURE TRANSDUCER (SECONDARY)	1
3.259	EVAPORATOR OUTLET TEMPERATURE TRANSDUCER (SECONDARY)	1
3.260	EVAPORATOR OUTLET TEMPERATURE TRANSDUCER (PRIMARY)	1
3.290	CABIN TEMPERATURE SENSOR	1
3.450	TEMPERATURE CONTROL VALVE POSITION INDICATOR	1
3.500	PRIMARY ACCUMULATOR QUANTITY TRANSDUCER	1
3.501	SECONDARY ACCUMULATOR QUANTITY TRANSDUCER	1

Figure 4-1. Atmosphere Revitalization, Subsystem Schematic

control function. Even in the heating case, a minimum airflow is maintained through the heat exchanger to assure humidity control. This flow is estimated at 200 lb/hr to maintain the dewpoint in the cabin below 61°F with a latent load corresponding to a crew of 10 men.

4.2.3.2 Ventilation

The airflow through the ARS is returned to the cabin through a duct system featuring several diffusers; the flow through the ARS provides ventilation velocities in the crew compartment adequate for crew comfort in zero-g.

4.2.3.3 Humidity Condensation and Removal

Cabin humidity is maintained within the specified limit by condensation in the humidity control/cabin heat exchanger. The extended surfaces of this heat exchanger are at a temperature level that is lower than the dewpoint of the process air. As a result, condensation will occur on these cold surfaces. Condensate thus formed is entrained by the airstream to the exit end of the heat exchanger, where it is removed with a small fraction of the process air through passages provided for this purpose. The condensate removal passages are an integral part of the heat exchanger; they are located at the end of the coolant passages and from the air-side constitute an extension of these passages. The two-phase mixture is drawn into the rotary phase separator (part of the waste management subsystem) for liquid separation and storage; the air from the separator is returned to the cabin.

4.2.3.4 CO_2 Control

A portion of the fan flow is diverted to the CO_2 absorber (Item 2.3) and returned to the main ARS duct upstream of the fan. Thus, the full fan pressure rise is available for the design of the CO_2 absorber. Carbon dioxide is removed by absorption in two parallel, radial-flow LiOH beds. Each bed contains

4.95 lb of high-porosity-grade LiOH for high utilization efficiency (93 percent minimum) over the entire range of inlet air temperature anticipated (75° to 110°F).

The airflow rate through the LiOH is 120 lb/hr; at this flow rate, the CO_2 partial pressure in the cabin will be maintained below 3 mm Hg with 4 men at maximum metabolic rate. Each sorbent bed has a CO_2 capacity of 4.22 lb, corresponding to the average daily production of 2 men. In operation the beds will be on stream for 24 hr; they are replaced alternatively every 12 hr.

With a 10-man crew, the cabin PCO_2 will increase to 6.5 mm Hg; charge replacement interval is estimated at 5.5 hr.

4.2.3.5 Trace Contaminant Removal

Odor removal is accomplished by 0.45 lb of activated charcoal packaged with the LiOH sorbent.

4.2.3.6 Particulate Matter and Bacteria Control

A full-flow filter installed in the return air duct upstream of the fan will collect dust and bacteria from the cabin. A relief valve will permit automatic bypass of the filter element should the filter pressure drop become excessive due to clogging. The filter is replaceable in flight.

4.2.3.7 Thermal Control

As shown in the schematic of Figure 4-1, two loops are routed in parallel through all the heat transfer equipment and provide the redundancy necessary for the mission. The two loops are identical.

Starting at the pump (Item 3.24), water is circulated through the cold wall panels and then divide into three equal streams that are directed to the avionics bays. These three parallel streams serve as the heat sinks for the cold plate networks and the avionics heat exchangers (Item 3.7). The streams then rejoin, and the entire water flow is cooled either in the interchanger (Item 7.7) by the Freon-21 or in one of two evaporators (Item 3.6), depending on the mission phase.

During the major portion of the mission, the Freon-21 constitutes the heat sink for the water coolant. During ascent/burn and entry, when the radiator is not deployed, the entire thermal management system load is rejected to expendable water in the evaporators. The evaporators also serve as a backup to the radiator in orbit and supplement the radiator when its heat rejection capacity is exceeded. The cold water stream from the evaporators is circulated through the potable water chiller (Item 4.4) and the cabin/humidity control heat exchanger (Item 2.6).

All subsystem heat exchangers are multifluid units with redundant passages to accommodate the two water loops. The air-water heat exchangers (cabin/humidity control and avionics heat exchangers) feature single air passages. The interchanger is a four-fluid unit with any one of the water loops thermally linked to either of the Freon-21 loops. The single exception is the water chiller, where separate units are arranged in series to provide chilled water from either loop.

Since the subsystem has no controls (temperature or flow), the temperature levels will be essentially dependent on the loads and the Freon-21 loop performance. The water flow rate and the avionics fan flow are adequate to provide the heat sink requirements and maintain the equipment within the temperature limitations specified previously.

4.2.4 Equipment Summary

Table 4-3 lists all equipment contained in the ARS. Monitoring and checkout instrumentation is included in the listing for completeness; Section 7 of this proposal discusses the instrumentation in more detail. The table summarizes the design features and performance of the equipment. Also given are the component weight, envelope, and power consumption when applicable.

Overall subsystem characteristics are summarized below.

(a) Number of components

Functional components: 64 (excluding LiOH charge)

Monitoring instrumentation: 23

(b) Number of component designs

Functional components: 25

Monitoring instrumentation: 7

(c) Total wet weight excluding expendables: 381.6 lb

(d) Expendable weight (4-man crew): 19.0 lb/day

(e) Power requirement: 462.5 watts (continuous with one avionics bay active)

802.5 watts (three avionics bays active)

In addition, power must be provided for heater operation when necessary. The electric heater (Item 3.9) can consume as much as 1.5 kw (3 phase, 400 Hz, 115/200 v). Under these conditions the vehicle will be powered down; the fuel cells will easily accommodate this demand.

Most of the equipment listed in Table 4-3 represents new designs. Equipment such as the cabin fan will be similar to equipment developed for previous space programs. The temperature control system is essentially off-the-shelf DC-10 equipment modified to incorporate electric heater control capability.

TABLE 4-3

EQUIPMENT SUMMARY, ATMOSPHERE REVITALIZATION ASSEMBLY

Item No.	Description	No. Req'd	Functional and Performance Requirements	Item Weight, lb	Envelope Size, in.	Power, watts	Equipment Category	Remarks [illegible]
2.1	Filter-Debris Trap	1	Removes particulate matter and bacteria from air stream. Full flow filter with filter element changeable daily. Air flow: 880 lb/hr. Pressure drop 0.[illegible] in. H_2O. Inlet pressure 14.7 psia. Operating temp: 65°-85°F. Filtration requirements: 0.3 micron absolute.	7.0 (Canister Only) 5.0 (Filter Element)	13 dia by 27 long	-	New	[illegible] Relief valve [illegible]
2.2	Check Valve, Revitalization Fan	3	Prevents recirculation of process air through inactive fans. Flow rate 1000 lb/hr. Inlet pressure: 14.7 ±0.2 psia. Inlet temp: 100°F (max). ΔP: 0.4 in. H_2O max at operating conditions.	0.25	4.8 dia by 5 long	-	Similar	Rubber flappers supported [illegible] screen in check direction. Valve is installed in the ducting immediately downstream of the cabin fan. Similar to Apollo suit compressor check valve.
2.3a	CO_2 Absorber Canister	2	Assembly incorporates two LiOH canisters mounted in parallel with appropriate isolation valves and provisions for periodic replacement of the LiOH absorber in flight. Process air flow: 60 lb/hr per canister at 1.0 in. H_2O ΔP.	6.0	15 by 10 by 10	-	New	Parallel radial flow canisters with manual shutoff valve in inlet duct and a check valve in outlet duct for flow interruption during recharge operation. Scroll type inlet manifold for uniform flow through the charge.
2.3b	CO_2 Absorber Element	Expendable	Removes CO_2 from the atmosphere by absorption on LiOH. Bed includes charcoal for odor control. Absorber element CO_2 capacity: 4.22 lb. Charge life: 24 hr. Cabin CO_2 level: 3 mm Hg nominal. Maximum CO_2 removal rate: 0.88 lb/hr (10 men).	7.0 Expendable	7.75 dia by 11.8 long	-	New	Radial flow sorbent bed. Contains 4.35 lb LiOH and 0.45 lb activated charcoal. Bed container is aluminum with cylindrical stainless steel screens at inlet and outlet. Armalon felt prevents dusting. Charge designed to maintain PCO_2 3 mm Hg in cabin with 4 men. Utilization efficiency 0.93 with 4 men on 12-hr staggered charge replacement. With 10 men cabin PCO_2 is 6.5 mm Hg charge replacement time is 5.5 hr.
2.3c	Shutoff Valve	1	Used to isolate CO_2 absorber canisters during charge replacement.	0.3	2.5 dia by 3 long		Existing	Manual butterfly valve.
2.3d	Check Valve	1	Used to isolate CO_2 absorber canisters during charge replacement.	0.15	2.5 dia by 3 long		Similar	Rubber flapper valve similar to Item 2.2 but for size.
2.5	Fan, Revitalization	3	Circulates cabin air through the ARS for purposes of atmospheric purification and temperature control. Flow rate: 1000 lb/hr. Inlet pressure: 14.7 psia. Pressure rise: 4.0 in. H_2O. Inlet temperature: 91°F.	4.2	4.8 dia by 6.9 long	214 1 phase 400 Hz 115/200 v	Similar	Vane-axial type with deswirl vanes. Aluminum construction. Overall efficiency: 51 percent. Speed: 11,500 rpm. Designed for low noise level. Estimated life in excess of 18,000 hr. Bearing arrangement similar to Apollo cabin fan. Incorporates thermal protectors.
2.6	Heat Exchanger, Cabin/Humidity Control	1	Provides a heat sink for cabin air cooling and humidity condensation and evaporation. Water coolant is the heat sink. <u>Cold side (coolant water)</u>--Flow: 550 lb/hr. Inlet temp: 40°F. Water ΔP: 2.0 psi. <u>Hot side (process air)</u>--Flow: 880 lb/hr. Inlet temp: 100.3°F. Inlet dew-point: 53.0°F. ΔP: 1.9 in. H_2O. Sensible Q: 11,687 Btu/hr. Latent Q: 2400 Btu/hr.	55 (Dry) 61 (Wet)	20.5 by 5.51 by 6.725	-	New	Plate fin stainless steel unit with integral condensate removal section. Incorporates redundant coolant passages. 4-pass cross counter-flow arrangement with internal mitered fins for liquid manifolding between passes. Copper fins on air side

TABLE 4-3 (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.5	[illegible]	-	[illegible]	[illegible]
[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	-	[illegible]	
[illegible]	[illegible]	1	0-30 [illegible]	1.3	[illegible]	-	[illegible]	[illegible]
[illegible]	[illegible] Temperature [illegible]	1	Senses temperature of the ARS process air in the return duct for purposes of temperature control. Operating temperature range 45° to 60°F.	0.15	1.125 dia by 5.75 long	-	[illegible]	[illegible]
3.2	Valve, Cabin Temperature Control	1	Bypasses ARS process air around the cabin humidity control heat exchanger to effect cabin temperature control. Maximum flow: 880 lb/hr, inlet temperature: 100°F (max), ΔP: 0.1 in. H_2O at 880 lb/hr flow.	6.5	[illegible] 12.8 by 4.4	-	[illegible] DC-10 Details	[illegible]
3.3	Sensor, Cabin Temperature	1	Senses cabin air temperature; signal used by the cabin temperature controller for temperature regulation. Operating temperature range: 65° to 85°F.	0.22	1.125 dia by 2.25 long	-	Existing DC-10	Similar [illegible] overall [illegible]
3.4	Controller, Cabin Temperature	1	Controls the bypass flow around the cabin/humidity control heat exchanger. Anticipator type control. Control range: 65° to 85°F (selectable). Control accuracy ±2°F.	4.4	10.6 by 6.51 by 4.0	6	Modified DC-10	Modular [illegible] with [illegible] around [illegible] control system [illegible] set. The controller [illegible] DC-10 [illegible] porate an electronic [illegible] control module.
3.5	Selector, Cabin Temperature	1	Used by the crew to manually select a cabin temperature in the range from 65° to 85°F.	0.6	2 dia by 5.25 long	-	Existing DC-10	Panel mounted [illegible] capability for [illegible] manual control. [illegible] control mode, the [illegible] (item 3.4) [illegible] bypass [illegible] cabin temperature [illegible] valve can be actuated [illegible] from the selector.
3.6	Expendable Evaporant Heat Sink	2	Water is the evaporant, serves as the vehicle primary heat sink during ascent, burn and entry. In orbit serves as a supplement to the radiator and also as a backup. Ascent-burn condition, Q = 73,580 Btu/hr (maximum). Water coolant flow: 550 lb/hr. Water coolant inlet temp: 174°F. Water coolant outlet temp: 40°F (control). Water ΔP: 4 psi. Radiator supplement in orbit, Q = 10,000 Btu/hr. Evaporator switched "on" when inlet water is 45°F. Control temperature: 40 ± 5°F.	73 (wet, total assembly)	23 dia by 24	6 (for control)	New	Spray flash evaporator [illegible] bly includes evaporator [illegible] 3.6a), water nozzle [illegible] flow control valves [illegible] 3.6b), 2 controllers [illegible] 3.6c), 2 sensors [illegible] Stainless steel evaporator with extended surface [illegible] water coolant [illegible] freezing. Copper fins are used. Surface temperature [illegible] maintained above 35 [illegible] troller. Parker [illegible] spray nozzle. [illegible] modulation control [illegible] Controller incorporates [illegible] port for checkout [illegible] control system.

TABLE 4-3 (Continued)

Item No.	Description	No. Req'd	Functional and Performance Requirements	Item Weight, lb	Envelope Size, in.	Power, watts	Equipment Category	Remarks, Design Features
3.[illegible]	Heat exchanger avionics	3	Cools the air circulated in the avionics bays for the purpose of thermal control. Water is the heat sink. Design point is post landing. Hot Side (Air)--Q 5210 Btu/hr (one bay). Flow: 1000 lb/hr. Inlet temp 133°F. Air ΔP: 1.0 in. H_2O. Air pressure 14.3 psia. Cold Side (Water Coolant)--Flow: 183.3 lb/hr (one bay). Inlet temp: 7[illegible]°F. Pressure drop 2 psi.	14 Dry 16 wet	9.7 by [illegible] by 4.5		New	3-[illegible] plate-[illegible] design, [illegible] passages, [illegible] construction, [illegible] crossflow [illegible] configuration.
3.8	Power Supply Temperature Transducer	1	Provides signal conditioning and power for all ETC/LSS temperature and pressure transducers. Triple redundancy.	8.1	6.5 by 5.[illegible] by 8.3	11.5 1 phase 115 v 400 Hz	New	Manual [illegible] redundant element. [illegible] 0-5 vdc, 1. vdc [illegible]
3.[illegible]	Electrical Heater	1	Dissipates electrical energy into the ARS process air stream to maintain cabin temperature at desired level under certain mission phases when heating is required. Air flow: 680 lb/hr Air inlet temp: 880°F Air inlet pressure: 14.7 psia Air ΔP: 0.64 in. H_2O Heating capacity: 5000 Btu/hr	4.5	10 by 6.6 by 2	1500 3 phase 400 Hz 115 200 v	Existing	Plate fin unit with strip heaters; maximum surface temperature, [illegible], [illegible] construction. [illegible] incorporates over-temperature [illegible] switches [illegible]
3.10	Fan, avionics cooling	[illegible]	Circulates cooling air through the avionics bay and the avionics heat exchangers; 2 fans per bay Flow rate: 1000 lb/hr Inlet pressure: 14.3 psia Inlet temp 130°F (max) Pressure rise: 3.0 in. H_2O	3.8	4.6 dia by 6.75 long	170 (1 phase 115 to 200 v. 400 Hz)	Similar	Similar to cabin fan [illegible] 2.[illegible]. Vaneaxial design [illegible] deswirl vanes. Aluminum construction. Bearing arrangement similar to Apollo [illegible] fan. Estimated l[illegible] hr. Noise level well within specification.
3.11	Check valve, avionics fan	[illegible]	Prevents recirculation of avionics cooling air through the inactive redundant fan. Flow rate: 1000 lb/hr air at 14.3 psia and 130°F (max.) [illegible] temp: ΔP = 0.5 in. H_2O	0.2	4.6 dia by 5 long		Similar	Similar to Item 2.2. Rubber flappers supported by stainless steel screen in check direction similar to Apollo suit compressor check valve.
3.12	Avionics fan debris trap	[illegible]	Protects fan against debris entrained by process air in avionics circuit. Removes particles larger than 0.04 in. dia. Flow rate: 1000 lb/hr [illegible] 130°F (max.) Pressure drop: 0.1 in. H_2O at operating conditions	0.1	4.6 dia by 0.2			Stainless steel screw.
[illegible].24	Pump package assembly, water coolant	2	Package includes 2 pumps (Item 3.24a), 2 check valves (Item 3.24b), 1 accumulator (Item 3.24c), 1 isolation valve (Item 3.24d), 1 filter (Item 3.24e). Circulates water through the primary and secondary cabin coolant loops; also maintains water pressure in this loop. Flow rate: 550 lb/hr at ΔP of 40 psid Inlet pressure: 20 psia Inlet temperature: 7[illegible]°F (max.) Accumulator effective capacity 35 cu in.	15 lb wet, each primary and secondary.	10 by 8 by 6 (each, primary and secondary)	61 3 phase, 115 v, 400 Hz	Similar	Primary and secondary pumps packaged as separate LRU's. Steel construction. Centrifugal pump driven through magnetic coupling by ac motor. Motor removable without breaking water loop integrity. Both primary and secondary pump packages are identical. Pump speed: 22,000 rpm. Pump bearings: graphite design similar to Apollo. Estimated life: 18,000 hr. limited by motor ball bearings.

TABLE 4-3 (Continued)

Item No.	Description	No. Req'd	Functional and Performance Requirements	Item Weight, lb	Envelope Size, in.	Power, watts	Equipment Category	Remarks, Design Features
3.[illegible]	Water fill connector	4	Used for servicing water coolant loops. Water flow: 10 lb/min at ΔP of 1 psi	0.2	1 by 2		Modified	Existing design modified to incorporate key features
3.[illegible]	Water shutoff valve	4	Isolates water coolant loops from fill connectors. Water flow: 10 lb/min at ΔP of 1 psi	0.8	3 by 3.5 by 2		Modified	Modified Apollo valve. Modification involves changing material to steel and increasing port size.
3.104	Secondary pump inlet pressure transducer	1	Used to monitor loop performance: 0 to 60 psig range	0.2	1 dia by 2.5		Existing	Strain gage type. Power and signal conditioning from Item 3.8.
3.105	Primary pump inlet pressure transducer	1	Same as 3.104.	0.2	1 dia by 2.5		Existing	Identical to 3.104
3.150	Primary water pump ΔP transducer	1	Used to monitor pump performance: 0 to 60 psid	0.2	1 dia by 2.5		Existing	Similar to 3.104
3.151	Secondary water pump ΔP transducer	1	Same as 3.150	0.2	1 dia by 2.5		Existing	Identical to 3.150
3.152	Avionics bay 1 fan ΔP transducer	2	Used to monitor avionics bay fan performance, 0 to 10 in. H_2O.	0.5	2 dia by 3		Existing	Identical to Item 3.100
3.153	Avionics bay 2 fan ΔP transducer	2	Same as 3.152	0.5	2 dia by 3		Existing	Identical to Item 3.100
3.154	Avionics bay 3 fan ΔP transducer	2	Same as 3.152	0.5	2 dia by 3		Existing	Identical to Item 3.100
3.255	Interchanger outlet temperature transducer (primary)	1	Used for redundancy management	0.03			Existing	Power and signal conditioning from Item 3.8, surface type sensor.
3.256	Evaporator outlet temperature transducer (primary)	1	Used for redundancy management	0.03			Existing	Identical to 3.255
3.257	Interchanger outlet temperature transducer (secondary)	1	Used for redundancy management	0.03			Existing	Identical to 3.255
3.258	Evaporator outlet temperature transducer (secondary)	1	Used for redundancy management	0.03			Existing	Identical to 3.255
3.259	Evaporator outlet temperature transducer (secondary)	1	Used for redundancy management	0.03			Existing	Identical to 3.255
3.260	Evaporator outlet temperature transducer (primary)	1	Used for redundancy management	0.03			Existing	Identical to 3.255
3.2[illegible]0	Cabin temperature sensor	1	Same as Item 3.3	0.22	1.125 dia by 2.55 long		Existing	DC-10 thermistor type unit - power and signal conditioning from Item 3.8.
3.450	Temperature control valve position indicator		Part of Item 3.2. Used during ground checkout.				Existing	Incorporated in the design of the temperature control valve.
3.500	Primary accumulator quantity transducer	1	Used to monitor loop leakage	0.6	1.5 by 5 by 4.3		Existing	Pressure measurement Bourdon tube with variable reluctance transducer.
3.501	Secondary accumulator quantity transducer	1	Same as 3.500	0.6	1.5 by 5 by 4.3		Existing	Same as 3.500

The water coolant pump is a scaled-up version of the Apollo Block II pump, and is repackaged to enhance maintainability.

4.2.5 LRU Definition

The arrangement of the subsystem components into line replaceable units (LRU's) will depend essentially on installation constraints; however, factors such as equipment weight, fluid interfaces, and component MTBF will weigh heavily in the final definition of LRU's and in providing accessibility to the various subsystem components. In defining the LRU's listed in Table 4-4, major consideration was given to the factors discussed below.

The CO_2 absorber LRU package (LRU 2-F) must be made accessible directly to the crew to facilitate routine charge replacement in flight, and the filter-debris trap assembly (LRU 2-D) also must be directly accessible for daily replacement of the filter element. Adequate space must be provided for handling the large filters.

The weight of the remainder of the ARS equipment (without LRU's 2-D and 2-F) is estimated at about 100 lb. It is highly desirable to break down this equipment into smaller LRU's. Furthermore, removal of the condenser because of its interfaces with the two water coolant loops and because of its weight (61 lb) should be avoided unless the condenser itself has failed. Condenser failure can only occur by leakage. To ensure that the condenser is not removed from the system by error, provisions must be incorporated to permit visual inspection of the unit for leakage. A dye in the water loop is recommended to facilitate inspection. Internal leakage (water into the process air stream) could be detected by inspection of the humidity condensate line to the phase separator; external leakage detection will have to be <u>in situ</u>. The condenser need not be accessible as a component LRU for this purpose. For these

TABLE 4-4

ARS LRU DEFINITION

LRU Ident	Item No. LRU	Item No. SRU	No. Items Per LRU	Description	LRU's Per Sub-system	Remarks
2-A				ARS cooling assembly	1	
2-A-1				Fan assembly	1	
		2.2	3	Fan check valve		Fan-check valve could be removable as LRU, depending on installation constraints
	2.5		3	Fan		
	2.100		2	ΔP transducer		
2-A-2				Cabin heat exchanger assembly	1	LRU-SRU definition essentially dependent on installation constraints
		2.6	1	Heat exchanger		
	3.2		1	Cabin temperature control valve		
	3.9		1	Heater electric		
2-B	3.4		1	Cabin temperature controller	1	Could be part of 2-A-2 depending on installation constraints
2-C	3.5		1	Cabin temperature selector	1	Same as 2-B
2-D				Debris trap assembly	1	
	2.101		1	Debris trap ΔP transducer		
	2.1		1	Filter debris trap		Replaceable in flight; must be made accessible
2-E	3.3		1	Cabin temperature sensor	1	
2-F	2.3			CO_2 removal assembly	1	
		2.3a	2	CO_2 absorber canisters		
		2.3b	2	CO_2 absorber element		Replaceable in flight; must be made accessible
		2.3c	1	Shutoff valve		
		2.3d	1	Check valve		
2-G	3.8		1	Transducer power supply	1	
2-H	3.1		1	Anticipator	1	

TABLE 4-4 (Continued)

LRU Ident	Item No.		No. Items per LRU	Description	LRU's per Sub-system	Remarks
	LRU	SRU				
3-A				Evaporator assembly	2	Nozzle removable as LRU
		3.6a	1	Evaporator		
	3.6b		2	Water flow control valve		
	3.6c		2	Evaporator controller		
	3.6d		2	Temperature sensor		
3-B	-	-		Air-cooled avionics package	3	
3-B-1	3.7		1	Avionics heat exchanger	3	
3-B-2	-	-		Avionics fan package	3	LRU/SRU definition will depend on packaging constraints and accessibility
	3.10		2	Avionics fan		
		3.11	2	Fan check valve		
		3.12	2	Debris trap		
	3.152*		2	Fan ΔP transducer		*1 for bay 1 (1)
	3.153*		2	Fan ΔP transducer		*2 for bay 2 (1)
	3.154*		2	Fan ΔP transducer		*3 for bay 3 (1)
3-1-1	Part of 3.24			Primary water pump package	1	
		3.24a	2	Water pump		
		3.24b	2	Pump check valve		
		3.24c	1	Accumulator		
		3.24d	1	Accumulator isolation valve		
		3.24e	1	Filter		
	3.105		1	Inlet press transducer		
	3.500		1	Accumulator quantity sensor		
	3.150		1	Pump ΔP transducer		

(1) Identical part different item no.

TABLE 4-4 (Continued)

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Sub-system	Remarks
3-1-2	Part of 3.24			Secondary water pump package	1	
		3.24a	1	Water pump		
		3.24b	1	Pump check valve		
		3.24c	1	Accumulator		
		3.24d	1	Accumulator isolation valve		
		3.24e	1	Filter		
	3.104		1	Inlet press transducer		
	3.501		1	Accumulator quantity sensor		
	3.151		1	Pump ΔP transducer		
3-P	3.255		1	Interchanger outlet temperature	1	Primary loop
3-Q	3.257		1	Interchanger outlet temperature	1	Secondary loop
3-R	3.259		1	Evaporator outlet	1	Secondary loop
3-S	3.260		1	Evaporator outlet	1	Primary loop
3-T	3.258		1	Evaporator outlet	1	Secondary loop
3-U	3.256		1	Evaporator outlet	1	Primary loop
3-V	-	-		Fill connector assembly	4	
		3.25	1	Fill connector		
		3.26	1	Water shutoff valve		

reasons, the condenser is considered a shop replaceable unit (SRU) packaged with the heater (Item 3.9) and the temperature control valve (Item 3.2). These two items will be checked out by means of BITE on the temperature controller (Item 3.4). They need not be accessible for ground checkout purposes; however, packaging should be such that either of these components can be removed from the vehicle without the necessity for condenser removal.

It is desirable in terms of spares provisioning that the fans be removable separately. Efforts will be made to package the fans in such a manner that each fan is an LRU. Accessibility will depend essentially on the available space for the ARS.

The remainder of the ARS equipment will be replaceable as single component LRU's.

The cabin temperature selector (Item 3.5) will be panel-mounted in the crew compartment. The temperature controller could be located either with the selector or under the floor with the remainder of the ARS. The controller incorporates the capability for checkout of the entire temperature control system, including the temperature sensors (Items 3.1 and 3.3), the control valve (Item 3.2), the selector (Item 3.5), and the cabin heater (Item 3.9). For ease of checkout it is recommended that the controller be located with the selector in an easily accessible area.

The cabin temperature sensor (Item 3.3) will be installed in the cabin. Because the process air to the ARS is used as a heat sink for cabin electronics, the temperature of the air in the ARS return duct is not representative of cabin temperature. Provisions will be made to assure adequate flow over the sensor (300 ft/min minimum). Packaging the return duct sensor (Item 3.1) for removal as a single component should not present any difficulty.

Depending on installation constraints, it is desirable to have the avionics fan packages 3-B-2 removable as a unit separate from the avionics heat exchanger. This approach will reduce maintenance time appreciably because fan replacement will not involve breaking the water coolant loops.

As mentioned previously, the primary and secondary pumps are packaged as separate assemblies and will be replaceable as such. Depending on accessibility, however, it would be desirable to break down the pump packages into smaller LRU's to minimize spares inventory and possibly reduce the turnaround time in the event of a component failure within the pump package. The pump motor could be replaced without breaking into the water loop.

Special provisions will be made so that the pressure transducers will be replaceable without having to service the entire water loop. This will be accomplished by isolating the failed transducer from the loop and either evacuating that small portion of the subsystem between the transducer and the isolation valve. A better approach would be to flush, with water from the accumulator, the air trapped in the transducer downstream of the isolation valve. Since maintenance will be effected on the ground, advantage will be taken of the gravity field in packaging the transducers.

The flash evaporator is a relatively heavy and bulky component. To enhance maintainability, all components within the evaporator package, including the spray nozzle, should be accessible for replacement as separate LRU's.

4.2.6 Equipment Packages

Using the above guidelines packages were developed for the major LRU's contained in the ARS. The packages described below are:

CO_2 absorber assembly (LRU 2-F)

Cabin heat exchanger assembly (LRU 2-A-2)

Cabin fan assembly (LRU 2-A-1)

Air-cooled avionics package (LRU 3-B)

Water pump package (LRU 3-1-1)

4.2.6.1 CO_2 Absorber Assembly (LRU 2-F)

This LRU, depicted in Figure 4-2, comprises the following components:

Two CO_2 absorber canisters (Items 2.3a)

One butterfly shutoff valve (Item 2.3c)

One check valve (Item 2.3d)

In addition, the canisters will house the CO_2 absorber elements.

This LRU should be installed in the cabin area with the canister covers and the shutoff valve accessible to the crew for charge replacement.

The two canisters are mounted (top and bottom) on an aluminum frame that will be secured to the vehicle structure at eight locations. Removal of the LRU entails undoing the right mounting bolts and disconnecting the two V-band clamps on the inlet and outlet ducts. The valves and ducting are mounted on the canisters by means of hose-band clamps.

Overall dimensions are 24 in. by 16 in. by 21.5 in. The total weight of the assembly is 17.7 lb, excluding the two LiOH sorbent beds.

4.2.6.2 Cabin Heat Exchanger Assembly (LRU 2-A-2)

This LRU is shown in Figure 4-3. The package was developed assuming compatibility with the vehicle structure. The three components comprising this assembly are mounted on a structure that attaches to the vehicle by means of bolts. A mixing chamber is provided to minimize losses while assuring good mixing between the condenser and the bypass air streams.

Hose-band clamps are used between all package components. It is desirable to have all components accessible for removal from the vehicle as separate LRU's.

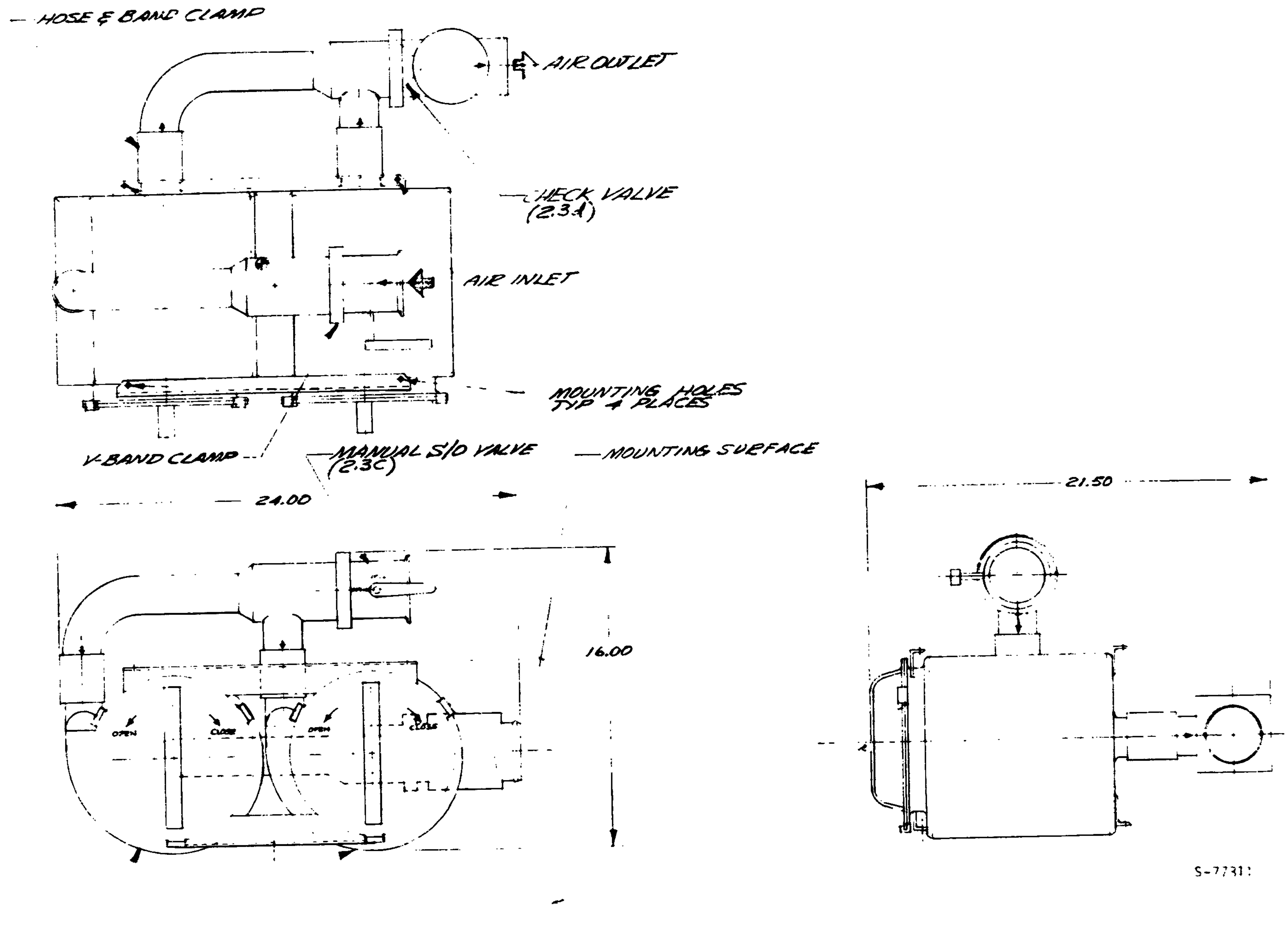

Figure 4-2. CO_2 Absorber Assembly

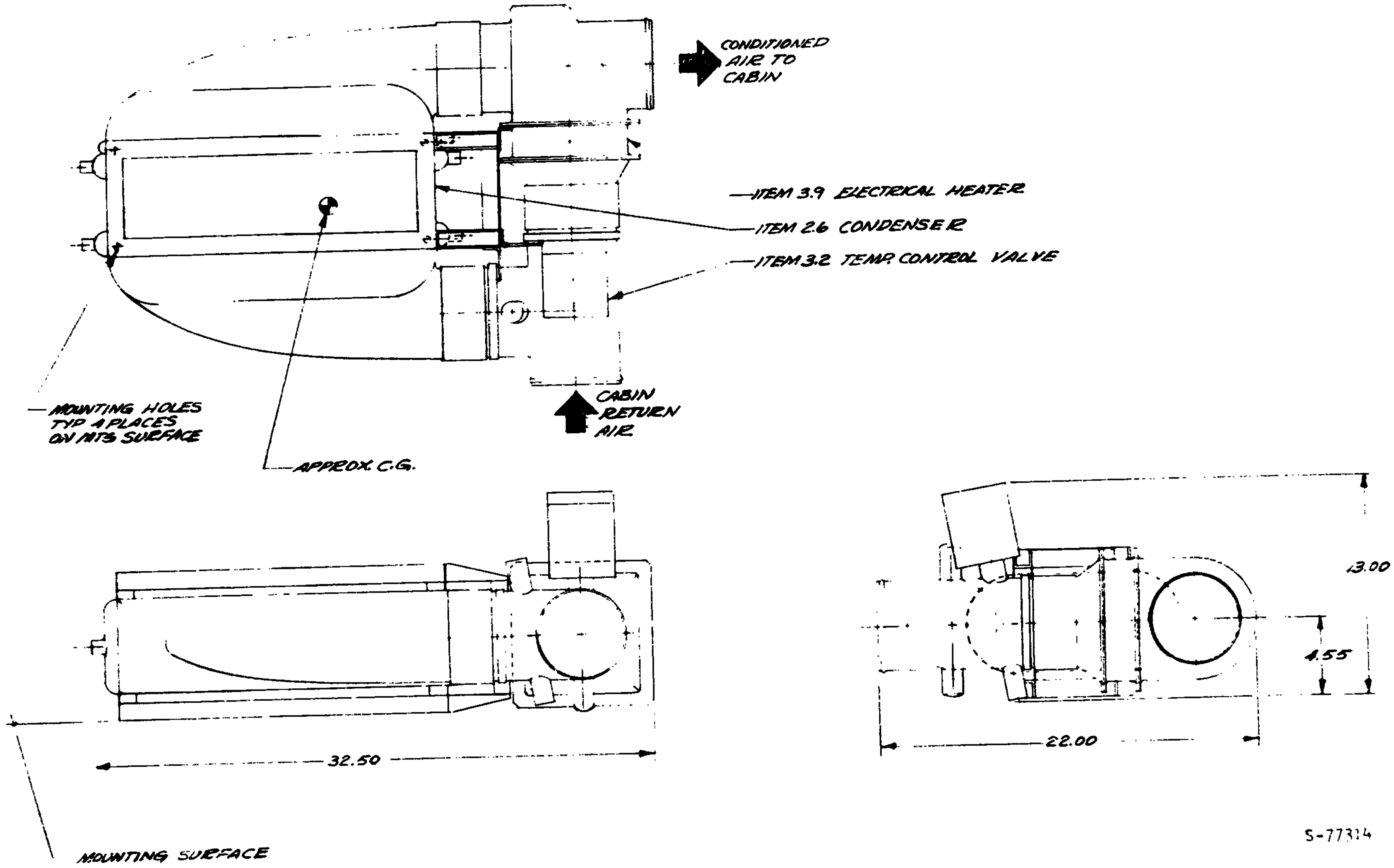

Figure 4-3. Heat Sink and Heater Outline

The weight of this LRU including structure is estimated at 81.8 lb. A hoist will be necessary to assist in replacement of the condenser. The hoist point is shown in Figure 4-3.

Replacement of the temperature control valve or the heater will require removal of the two hose clamps and the screws securing these components to the LRU frame.

When the condenser needs replacement, the entire assembly will be removed from the vehicle. This will entail disconnecting (1) two water coolant loops, (2) two V-band clamps on the inlet and outlet ducts, (3) the electrical connector to the valve actuator, (4) the screws securing the frame to the spacecraft, and (5) the condensate line to the waste management phase separators.

4.2.6.3 Cabin Fan Assembly (LRU 2-A-1)

This package (Figure 4-4) was developed to provide minimum size while maintaining acceptable flow paths within the manifolds. In this respect a longer package would be preferable. The complete package incorporates three fan-check valve subassemblies (Items 2.2 and 2.5), two pressure transducers (Items 2.100), and cylindrical inlet and outlet manifolds. The entire assembly is secured to the spacecraft structure by two bolts on each manifold. The air inlet and outlet ducts could be turned at any angle to accommodate the interface constraints of the vehicle ducting and the cabin heat exchanger assembly (LRU 2-A-2).

The transducers are mounted on the inlet manifold by four screws and should be made accessible for replacement as single components. The fan-check valve subassemblies are supported between the two manifolds by means of V-band clamps. They can be removed separately by simply disconnecting the V-band clamps at the inlet of all three fans, the V-band clamp at the package inlet, and the

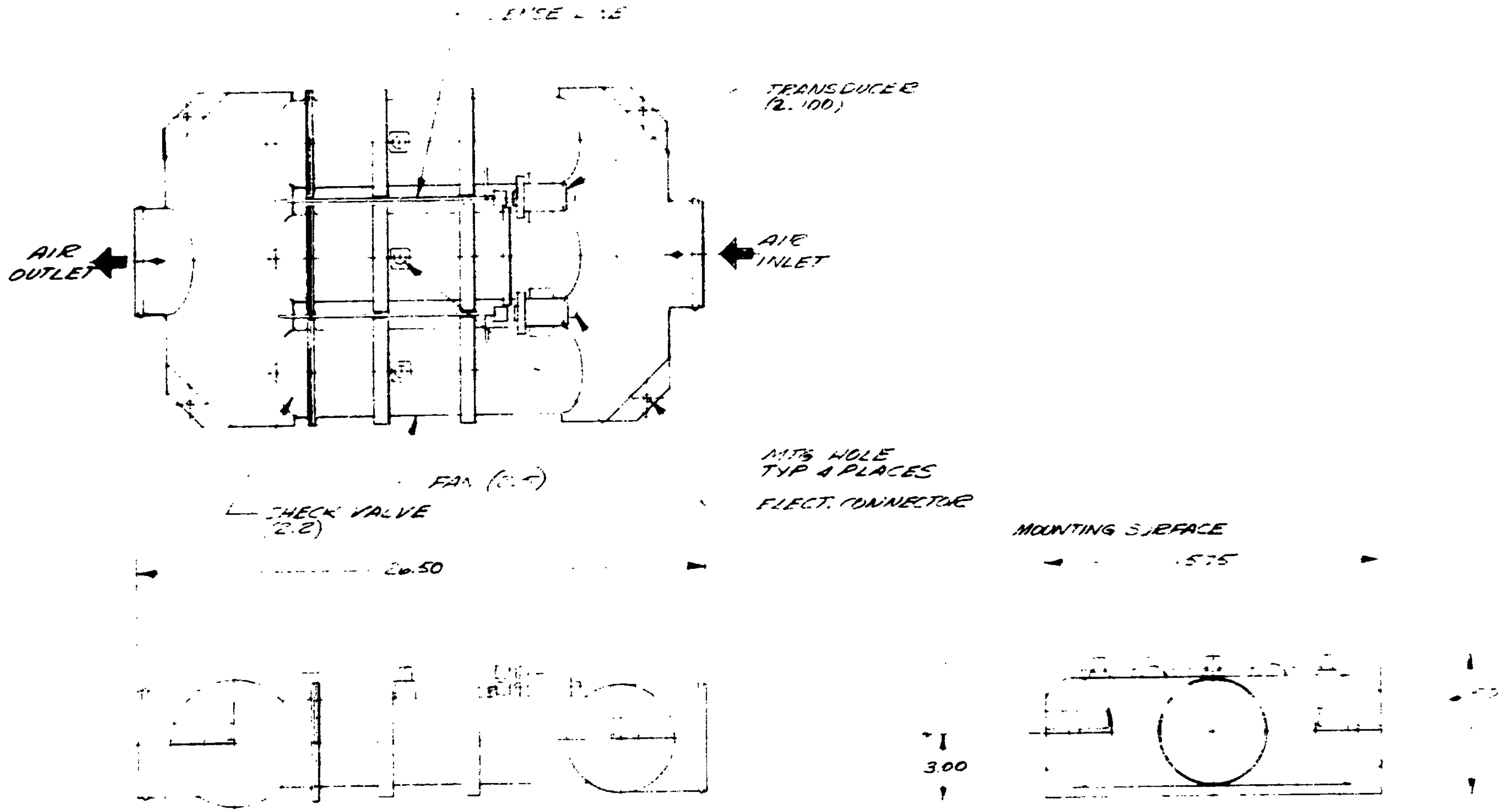

Figure 4-4. Fan Assembly

transducer sense lines. This will provide sufficient space for removal of a fan by disconnecting the fan connector and the V-band clamp at the outlet of the fan being replaced.

The estimated weight of the entire package is 20.5 lb.

4.2.6.4 Air-Cooled Avionics Package (LRU 3-B)

Figure 4-5 shows the air-cooled avionics package. Three such packages will be necessary to provide the heat sink capabilities for the three vehicle avionics bays. The package includes the following equipment

- Avionics heat exchanger (Item 3.7), a three-fluid unit with redundant water passages
- Two fans with check valve and debris trap (Items 3.10, 3.11 and 3.12)
- Two pressure transducers (Item 3.152)

The heat exchanger flanges are bolted to the inlet and outlet manifolds. The fans are mounted in the duct by means of V-band quick-release clamps. The fan inlet duct is connected to the avionics ducting by means of a beaded hose connector. The heat exchanger outlet manifold (not shown) is also connected in the same manner. Both pressure transducers are installed on the same side of the package for accessibility; three screws secure each transducer to the heat exchanger manifold.

For all packages involving the thermal loop, the air-cooled avionics package was designed to provide component accessibility and permit component removal without having to disconnect the water coolant lines. Both transducers are readily accessible. Removal of the fan assembly (including check valve and debris trap) can be effected by disconnecting (1) the inlet transition duct (beaded hose connector), (2) the V-bands at the inlet of both fans (to permit removal of the transition duct), (3) the V-band at the outlet of the fan being replaced, and (4) the electrical connector to the fan.

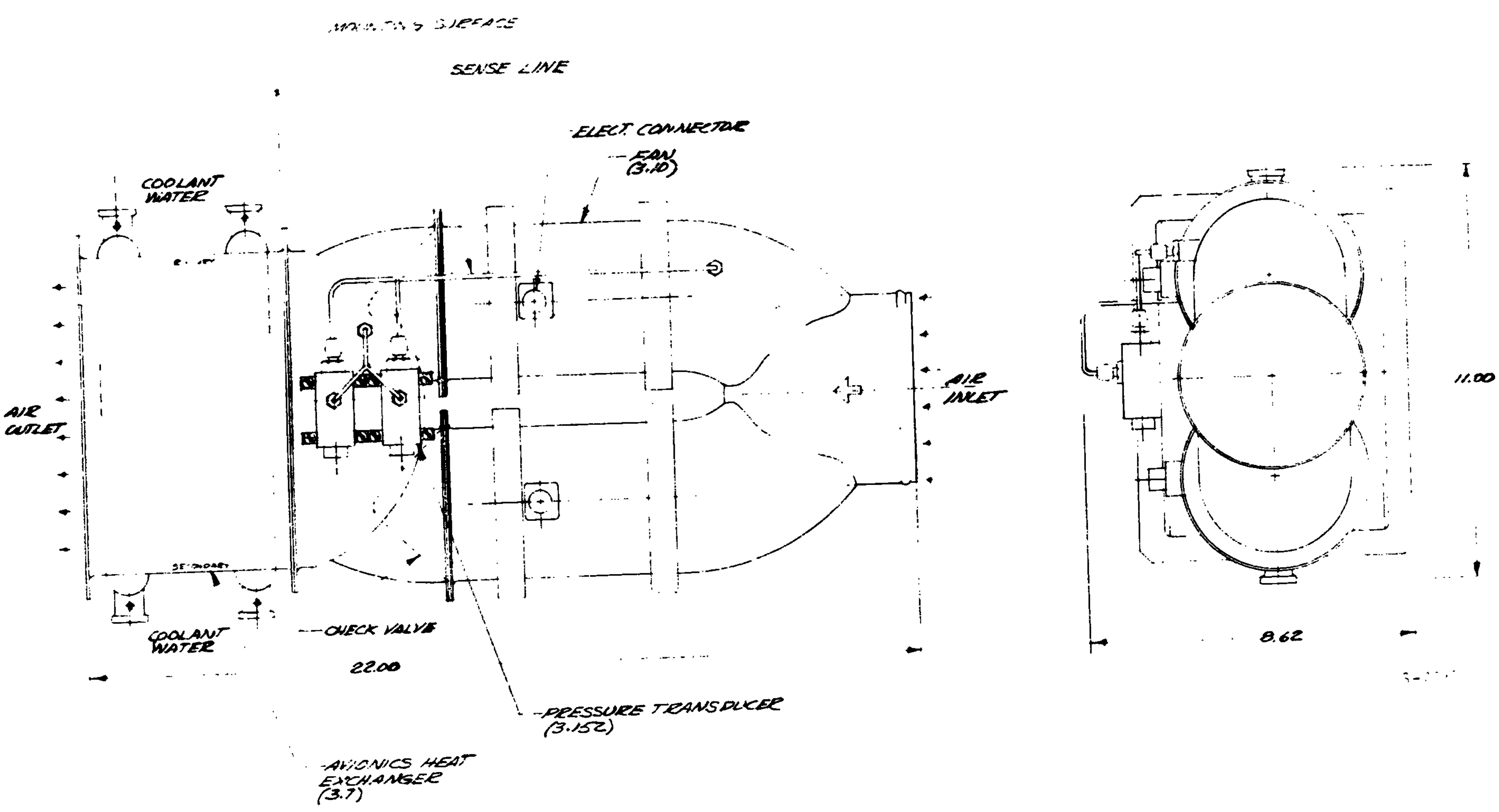

Figure 4-5. Air-Cooled Avionics Package Assembly, LRU 3-B

The overall dimensions of the package are 22 in. by 11 in. by 8.62 in., as shown in the figure. The weight of the components is calculated as 25.2 lb wet; the overall package weight, including ducting and mountings, is estimated at 30.3 lb.

4.2.6.5 <u>Evaporator Assembly (LRU 3-A)</u>

The evaporator assembly is depicted in Figure 4-6. The package includes the flash evaporator with spray nozzle, the evaporator controller and sensors, and the evaporant water control valve.

Overall dimensions are given in Figure 4-6. Total package weight including the structure is estimated at 73 lb. The frame supporting the 61-lb evaporator is designed so that the unit can be mounted to withstand vertical or horizontal acceleration loads. The frame is such that both units could be mounted side by side.

Removal of the evaporator package will involve the following:

Disconnecting the evaporant water feed line

Disconnecting the water coolant loop lines

Disconnecting the electrical leads to the power supply

Disconnecting the vacuum duct

As illustrated in Figure 4-6, all components of the package are accessible for removal as LRU's without the necessity for removing the evaporator itself. Even the spray nozzle is accessible from the side of the package.

4.2.6.6 <u>Water Pump Package (LRU 3-1-1)</u>

The pump package is depicted in Figure 4-7. The secondary pump package is identical to the primary. Removal of any of the pump package components (accumulator, filter, pump proper) will entail breaking into the water coolant loop; therefore, no attempt was made to provide component-level in-line replaceability.

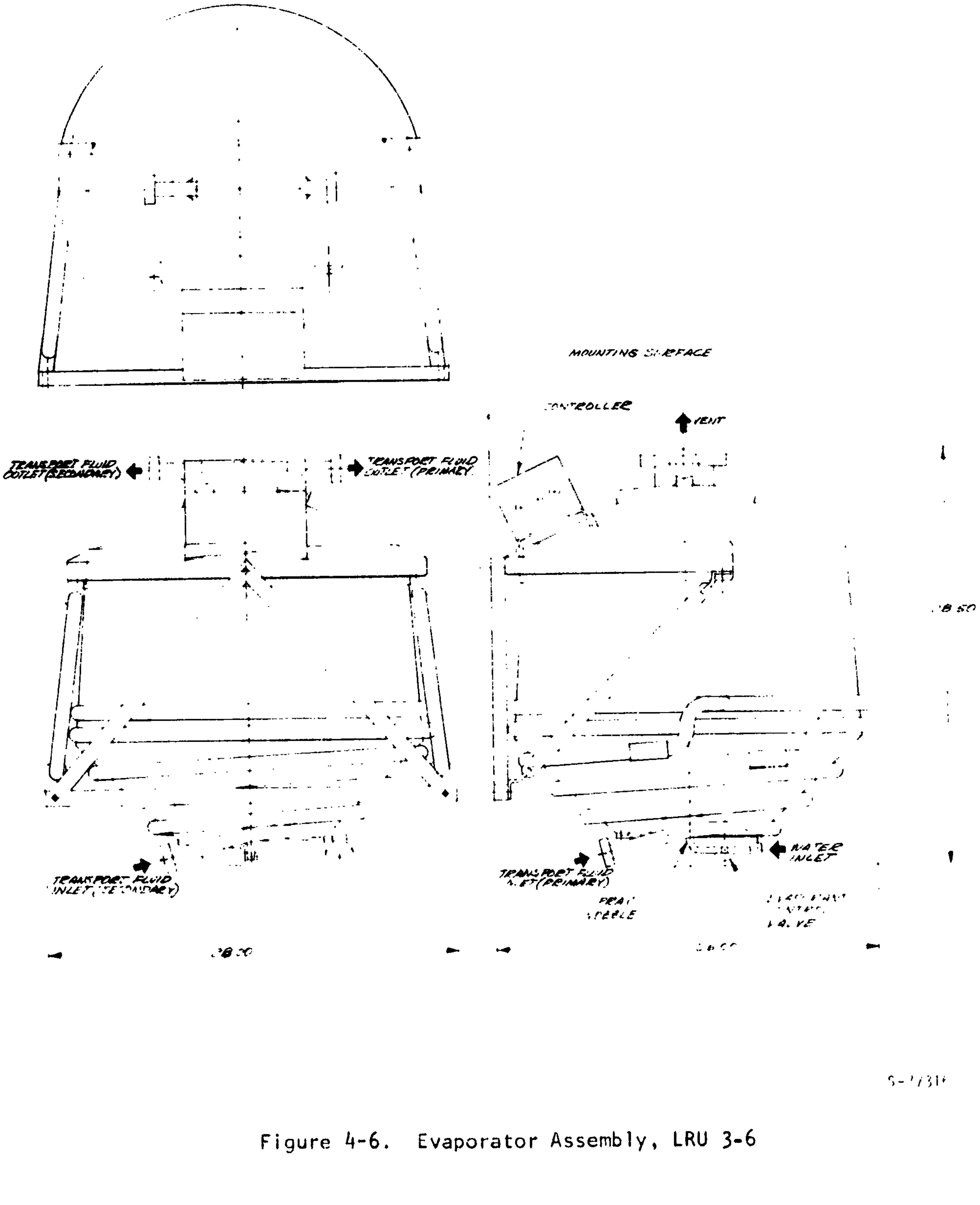

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Figure 4-6. Evaporator Assembly, LRU 3-6

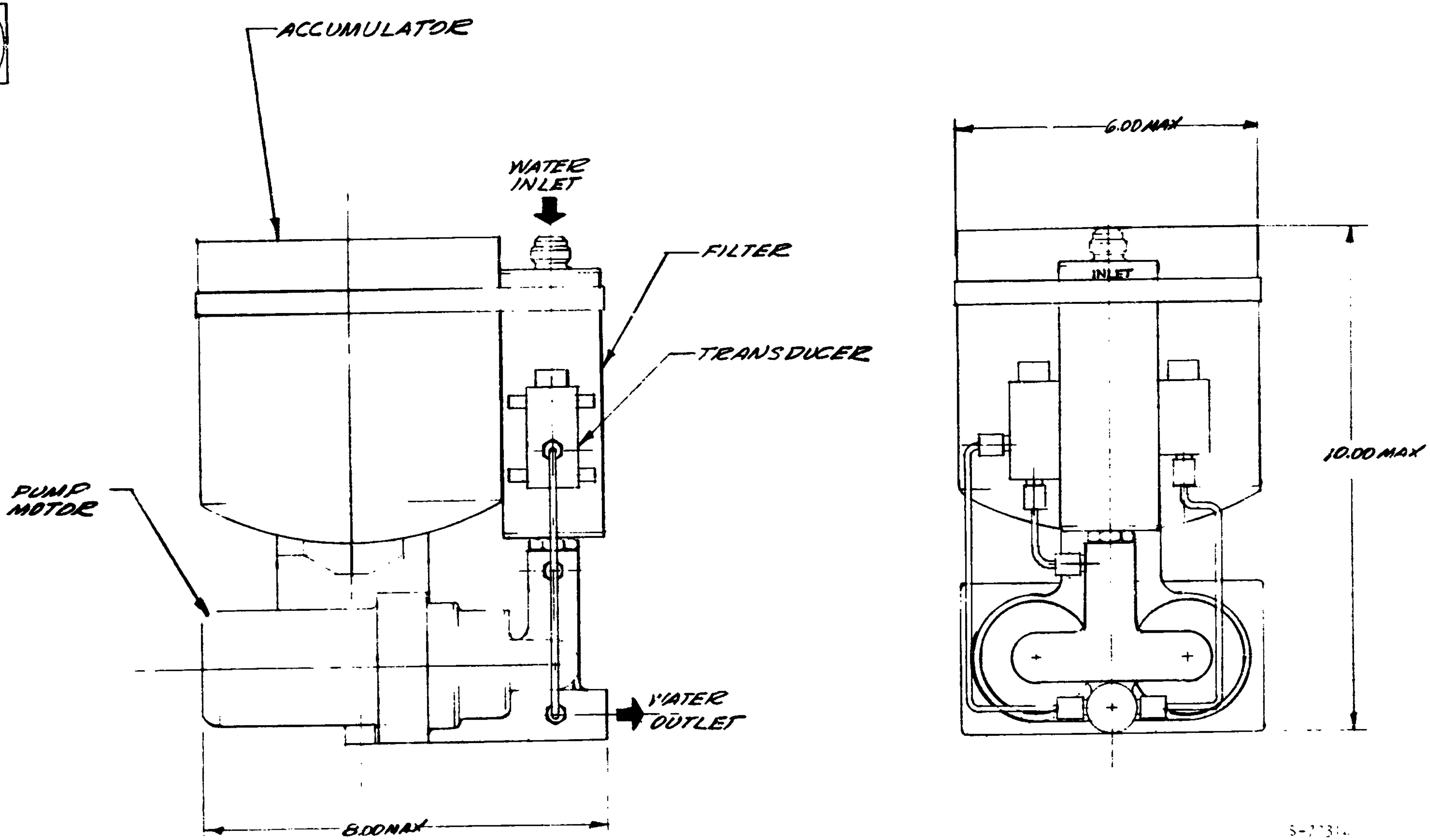

Figure 4-7. Water Pump Assembly, LRU 3-1-1

The filter is designed to match the 18,000-hr life of the pump. The pump motor, however, is accessible and can be removed without opening the loop. In locating the pump package in the vehicle, provisions should be made to take advantage of this feature. Failure of the motor ball bearings due to lack of lubrication is the normal failure of the pump package.

Envelope dimensions of the pump package are 10 in. by 8 in. by 6 in. The weight is 16 lb.

It is recommended that the ΔP and P sensors be made accessible as separate LRU's.

4.2.7 Equipment Redundancy

The equipment arrangement depicted in Figure 4-1 was developed to satisfy the space shuttle requirements as dictated by crew safety and mission reliability considerations from the prelaunch phase to landing. The following discussions highlight the capabilities of the subsystem in this respect.

4.2.7.1 Debris Trap (Item 2.1)

Blockage of the filter element will result in a failure. The blockage will occur over a period of tim., and will cause a slow deterioration in performance rather than a complete failure of the ARS functions. A ΔP sensor will alert the crew of the need for filter replacement. The indication will be given before performance degradation significantly affects overall flow through the system.

A relief valve built into the unit provides against complete failure of the filter element.

4.2.7.2 Cabin Fans and Check Valves (Items 2.5 and 2.2)

Three blowers are provided in parallel. The estimated life of each blower is approximately 18,000 hr. The three-blower arrangement provides a fail-operational/fail-safe (FO-FS) configuration. Only one check valve is used with each blower because of the very high reliability of the check valves and of because of the very low probability of a series check valve-blower failure.

A ΔP indicator will alert the crew of a blower or check valve failure. All blowers should be checked between flights. Redundant sensors are used.

4.2.7.3 Cabin Heat Exchanger (Item 2.6)

The condenser incorporates redundant passages for the two water coolant loops. The separator is a purely static device. The only mode of failure of this unit is structural and occurs through plugging of the suction holes between the airflow passages and the condensate manifold. Since complete blockage of all the holes is almost impossible, no redundancy other than providing numerous suction holes is necessary.

4.2.7.4 CO_2 Removal Assembly (Item 2.3)

The canisters are pressure vessels. Operation on one canister is adequate to maintain PCO_2 below the maximum allowable. Operation of the valves (check valve or diverter valve) in the package is not essential in a pressurized cabin.

The integrity of the LiOH charge is backed up by a 4-day contingency reserve. Failure of a charge to absorb CO_2 will result in cabin PCO_2 being higher than normal.

4.2.7.5 Temperature Control System (Items 3.1, 3.2, 3.3, 3.4, and 3.5)

None of this equipment is redundant. Adequate backup is provided to permit mission completion through manual override. Failure of the sensors (Items 3.1 and 3.3) or the controller (Item 3.4) circuitry will result in loss of the automatic function; however, the temperature selector incorporates manual override provisions so that the valve can be actuated directly, thus bypassing the controller function. In addition, a manual override is provided on the valve itself and is used to disengage the actuation mechanism and position the butterflies.

4.2.7.6 Electrical Heater (Item 3.9)

Failure of the heater does not involve crew safety. The heater is only required during low-power level conditions. By increasing power level, intolerable situations could be remedied without compromising mission success.

4.2.7.7 Transducer Power Supply (Item 3.8)

This component incorporates a triple-redundant power supply function. The signal conditioning elements to each transducer are not redundant. Failure of these elements will result in loss of function equivalent to loss of transducer. Instrumentation redundancy is discussed in Section 7; adequate redundancy and backup is provided to assure FO-FS for all critical functions.

4.2.7.8 Water Coolant Loop

Although most of the equipment of a thermal loop can generally be considered as pressure vessels (lines, heat exchangers, reservoirs, etc.), a number of essential components such as valves, pumps, and controllers tend to compromise the reliability of these loops. For space operation, the thermal loop is essential not only to provide a comfortable environment for the crew, but also to assure proper functioning of other vehicle essential subsystems: namely, the vehicle power supply and electronic equipment. Consequently, provisions must be made to ensure against loss of thermal management that could be the result of a catastrophic failure, such as coolant line breakage and heat exchanger failure through blockage or leakage. Such pressure vessel failures can be minimized by incorporation of redundant loops. This approach has been used successfully on previous manned space vehicles, and is recommended for the space shuttle.

The schematic of Figure 4-1 was developed to provide a high degree of reliability. Adequate redundancy has been provided to permit operation at design performance after failure of any one component. Degraded mode operation can result from a second failure, depending on the functions of the two failed components (or modules). Degraded mode operation could result in (1) cabin temperatures exceeding the limits specified for crew comfort, and (2) the requirement for minimum power operation.

4.2.7.9 Interchanger (Item 7.7)

The interchanger is a four-fluid heat exchanger of stainless steel construction. The exchanger itself is a pressure vessel, so that FO-FS does not literally apply to this unit; however, much redundancy is provided because any one of the Freon loops can be used to cool either of the water loops. Such a four-fluid unit provides a degree of flexibility that, with two interchangers, could only be achieved through the use of numerous switchover valves that would compromise the reliability of the entire system. Since the interchanger constitutes a single-point failure for the system, its location must be carefully selected to protect it from hazards resulting from meteoroids or catastrophic failures of other subsystems. As mentioned previously, the unit itself will not fail totally. If leakage or blockage in one set of passages occurs, the redundant loop is available as a backup.

4.7.7.10 Water Chiller (Item 4.4)

One water chiller unit is provided in each loop. The cooling water flows through a serpentine tube within the reservoir. Failure of this unit corresponds to a prime structure failure.

4.2.7.11 Water Pumps (Item 3.24)

The hermetically sealed centrifugal pumps have inherent long life capability, as demonstrated by life testing of the Apollo water-glycol pump. The estimated life of the pump is in excess of 18,000 hr.

Two pumps are provided in each module to permit flexibility of operation (both systems are identical) and to assure fail-safe conditions in the case where one water loop fails and one pump fails subsequently in the other loop. A second pump in a secondary system is then necessary to assure flow in the loop and fail-safe operation. The incorporation of two pumps in the secondary loop results in a 2-lb penalty.

The accumulators have steel bellows that maintain system pressure. Such bellows can be designed for infinite life, and the accumulators are considered highly reliable units and require no backup. Accumulator failure is similar to failure of a primary structure and will require switching to the redundant loop.

The filter serves to protect the pump against debris entrained by the water. Rather than complete plugging, filter failure will be the result of accumulation of debris on the surface of the filter element. This will slightly reduce the coolant flow through the loop and result in performance deterioration. A ΔP sensor across the filter will detect filter deterioration.

The check valves installed at the outlet of each pump are highly reliable and have been demonstrated as such in Apollo service. Failure of a check valve on an operating pump will have no effect. Failure of a check valve on a non-operating pump is very unlikely in flight; such a failure will require pump switchover and, if the redundant pump also is failed, loop switchover.

4.2.7.12 Air-Cooled Avionics Loops

The air-cooled avionics loops are essential for mission completion and crew safety. For this reason, parallel blowers are used in each loop. Avionics redundancy is provided by the three separate bays.

Single check vlaves are installed on each blower. This appears adequate in view of (1) the very high reliability of the check valve design, and (2) the very low probability of a series check valve-blower failure. All blowers and check valves will be checked between flights. A P indicator across the check valve blower assembly will monitor performance.

The heat exchanger incorporates dual coolant loops to accomodate the redundant water loops.

4.2.7.13 Evaporator Packages (Item 3.6)

Redundant evaporator assemblies are provided. Each assembly can provide cooling to either water loop through a separate control system. Considering the two loops and the two evaporators, the FO-FS criterion is satisfied. Also, the ammonia evaporators could provide cooling in emergency for a 20-min period at full power.

4.2.8 Redundancy Management

The general guidelines defined in Section 3 were used to determine the sensors necessary for control of the subsystem redundant elements in flight. The requirements for crew intervention were also identified. The ARS redundancy management requirements are summarized in Table 4-5.

Historical data have shown that the sorbent beds (static devices) inherently are very effective and will not fail in service. The humidity control/cabin heat exchanger can fail only through leakage, which is considered here as coolant loop failure. The condensate removal device consists of slots at the exit end of the condenser and is not subject to plugging; a filter in the ARS ducting will preclude dust entering the unit. Loss of the condensate removal function will be traced to the phase separator in the waste management system.

A critical review of the equipment contained in the subsystem indicates that the fans and the temperature control system are the high failure rate elements.

TABLE 4-5

REDUNDANCY MANAGEMENT SYSTEM, ATMOSPHERE REVITALIZATION SUBSYSTEM

Functional Symptom	Onboard Sensor	Possible Causes	Redundancy Management Action	Remarks
1. Cabin temp high Fan ΔP normal Water coolant loop normal	Cabin temp sensor 3.290	1.1 Temperature selector (3.5) failure 1.2 Temperature sensor (3.3) failure 1.3 Temperature anticipator (3.1) failure 1.4 Cabin temperature controller (3.4) failure 1.5 Valve actuator failure (3.2)	1.1 Verify position and use manual mode 1.2 Same as above 1.3 Same as above 1.4 Same as above 1.5 Same as above (see remarks)	1.1 If correction action ineffective, actuate valve manually 1.2 Same as above 1.3 Same as above 1.4 Same as above 1.5 Manual valve actuation to override actuator required
2. Cabin temp low Fan ΔP normal Water coolant loop normal	Cabin temp sensor 3.290	2.1 Through 2.5 as in symptom 1	2. Same as in symptom 1	2. Same as in symptom 1
3. Fan ΔP high Debris trap ΔP normal	Fan ΔP 2.100	3.1 Blockage 3.1.a Check valve 3.1.b Structural failure of control valve 3.2	3.1. Switch to redundant fan 3.1.b Inspect and position manually	3.1.a This is the first action item 3.1.b Improbable failure
4. Debris trap ΔP high Fan ΔP high	Debris trap ΔP 2.101	4.1 Debris trap plugged	4.1 Change debris trap	
5. Fan ΔP low	Fan ΔP 2.100	5.1 Fan failure (or impending)	5.1 Switch to redundant fan	
6. PCO_2 high	Cabin PCO_2 2.500	6.1 Low flow due to fan failure 6.2 Expended LiOH cartridge 6.3 Check valve failure (close) 6.4 Shutoff valve failure	6.1 See 5 above 6.2 Change LiOH cartridge 6.3 None 6.4 None	6.3 Valve design precludes failure of this type; no such failure on record 6.4 Improbable failure
7. High dewpoint Water coolant loop normal Fan ΔP normal	Cabin instrumentation or crew	7.1 Phase separator failure	7.1 See waste management subsystem	7.1 Not covered here
8. Heater-on warning	Part of controller circuitry	8.1 Electrical malfunction within controller	8.1 Deactivate power circuit to heater	

TABLE 4-5 (Continued)

Functional Symptom	Onboard Sensor	Possible Causes	Redundancy Management Action	Remark
1. Pump ΔP high	Pump ΔP 3.150	1.1 Filter plugged	1.1 Switch to redundant pump, condition will persist, switch to redundant loop	
		1.2 Loop blockage	1.2 Same as 1.1 above	
2. Pump ΔP low Pump inlet pressure normal	Pump ΔP	2.1 Pump failure	2.1 Switch over to redundant pump	
		2.2 On-line check valve closed	2.2 Switch to redundant pump	
		2.3 Standby pump check valve failed open	2.3 Switch to redundant pump	
3. Accumulator quantity low	Accumulator Q3.500	3.1 System leakage	3.1.a Switch to redundant loop	
			3.1.b Isolate failed loop accumulator	Recommend isolation valve be solenoid operated if not readily accessible.
4. Pump inlet pressure low	Pump inlet P3.105	4.1 Filter plugging	4.1 Same as 1.2 (switch to redundant loop)	
		4.2 Accumulator failure	4.2 Switch to redundant loop	
5. Pump inlet pressure high	Pump inlet P3.105	5.1 Accumulator failure	5.1 Switch to redundant loop	Recommend burst disc in water line near intercooler in unpressurized area, to prevent damage to water loop component, due to overpressure, and to assure crew safety.
		5.2 Leakage of Freon-21 into water loop at interchanger	5.2.a Switch to redundant loop	
			5.2.b Isolate failed loop accumulator	
			5.2.c Switch over Freon-21 loop	
6. Primary evaporator outlet temp high; pump sensors normal	Temp sensor 3.256	6.1 Evaporator package malfunction	6.1 Switch to secondary evaporator	
7. Primary evaporator outlet temp low Pump sensors normal	Temp sensor 3.256	7.1 Evaporator control malfunction	7.1 Switch to secondary evaporator	Possibility of freezing in water coolant. If on secondary evaporator, switch off evaporator.
8. Avionics ΔP high	Fan ΔP 3.152	8.1 Blockage		
		8.1.a Check valve	8.1.a Switch to redundant fan	
		8.1.b Debris trap	8.1.b Switch to redundant fan	
		8.1.c Air loop, ducting	8.1.c Switch to redundant fan, condition will persist, power down avionic bay	
9. Avionics fan ΔP low	Fan ΔP 3.152	Fan failure	9.1 Switch to redundant fan	

Fan failure will be detected immediately by the fan ΔP transducer(s); interpretation of the data is extremely simple, as is the corrective action.

Failure of the temperature control system will be detected through high and low temperature in the cabin. This identification parameter could be somewhat sluggish, depending on the failure and on the loads at the time of the failure. Ample time is available for corrective action. Here, failure of the automatic control systen will involve manual control through the end of the mission. The cabin temperature selector design incorporates provisions for positioning the flow diverter valve directly, even in the event of a controller failure. Furthermore, the diverter valve actuator can be overridden manually through direct action on the valve itself.

Because of the relatively slow response of cabin temperature to a failure, corrective action will require a stepwise procedure and monitoring of the cabin temperature for a short time period to determine whether manual operation can be effected through the selector or through manipulation of the diverter valve.

High cabin PCO_2 can be corrected only by changing the LiOH charges. This constitutes a very unlikely failure, as noted in the table.

Heater failure (on or off) may not be readily detected through subsystem performance parameters, depending on the cabin loads and the cabin temperature setting. Provisions are incorporated in the system to prevent overheating of the equipment in the event of heater-on failure. The necessity of the heater for mission success will depend on the cabin loads, which are essentially determined by vehicle orientation and electrical load profile. Undoubtedly, heater failure could degrade particular missions. Consequently, a warning signal through the controller BITE circuit is incorporated to give indication of failure.

Before defining the instrumentation necessary for monitoring the performance (or the health) of the coolant loop equipment, it is appropriate to identify the possible failure modes of this equipment. Heat exchangers can fail only through leakage. Thermodynamically, a heat exchanger can perform normally even if it leaks. Therefore, temperature measurements will not provide the information necessary to identify heat exchanger failure. Leakage, however, can be determined by the quantity of fluid stored in the loop accumulator.

The water coolant pump assures flow through the system, and as long as the flow is maintained, the heat exchangers will perform within specification. The pump performance, as measured by pump pressure rise, is an essential parameter in terms of redundancy management.

Another parameter of importance is the pump inlet pressure. This parameter determines accumulator performance and provides an indication of excessive leakage that should have been detected normally by low accumulator quantity.

The only redundancy management actions involve switching pumps in the primary loop or switching from the primary to the secondary loop. The first action will be taken upon pump failure, and the second in the event of two pump failures, leakage, or accumulator failure.

It is recommended that the Freon-21 and water loops incorporate blow-out plugs to prevent overpressurization of these circuits. The water loop plug should be located in the unpressurized area of the vehicle near the interchanger.

The avionics cooling air loops consist of a heat exchanger and redundant fans with associated check valves and debris traps. The only equipment to monitor in flight is the fan, check valve, and debris trap assemblies. This is done by ΔP monitoring. Heat exchanger leakage is monitored as discussed above.

4.3 ATMOSPHERIC CONTROL SUBSYSTEM (ACS)

4.3.1 Functional Requirements

The functions of the atmospheric control subsystem are (1) oxygen storage and supply; (2) nitrogen storage and supply; (3) cabin oxygen partial pressure (PO_2) and total pressure (PT) control; and (4) miscellaneous services, including water tank pressurization, airlock and tunnel pressurization and depressurization, EVA support, and emergency supply. Redundancy of components in this subsystem provides total system operation after a failure of any component and total system operation to the extent of crew safety after a second failure of any component.

Oxygen from this subsystem is used for the following:

(a) Cabin metabolic consumption

(b) Cabin and avionics bays leakage makeup

(c) Airlock and tunnel pressurization

(d) Cabin repressurization

(e) Prebreathing prior to EVA

(f) PLSS recharge

(g) Emergency breathing

Nitrogen from this subsystem is used for the following:

(a) Cabin and avionics bay leakage makeup

(b) Water tank pressurization

(c) Airlock and tunnel pressurization

(d) Cabin repressurization

4.3.2 Performance Requirements

The space shuttle specifications that influence the design of this subsystem are listed in Table 4-6.

TABLE 4-6

DESIGN REQUIREMENTS

Design Parameter	Requirement
Cabin total pressure	14.7 ±0.2 psia
Cabin PO_2	3.1 ±0.1 psia
Design crew size	4 men (10 men maximum)
Vehicle leakage rate	10 lb/day
Crew O_2 consumption	1.76 lb/man/day
Mission duration	7 days
Contingency emergency duration	4 days
Maximum duration of atmospheric supply and control	11 days
Cabin volume	2000 cu ft
Airlock volume	250 cu ft
Avionics bay volume	127 cu ft (total number per vehicle: 3)
Airlock repressurization time	5 min
Cabin repressurization time (from 0 to 14.7 psi)	1 hr
Avionics bay pressure with respect to cabin	-0.4 psid
Maximum avionics bay pressure with respect to cabin	±0.6 psid
Water tank pressure	18 (+3, -0) psig
Portable emergency supply	12 l/min at a regulated pressure of 70 to 100 psig and a temperature of 35° to 70°F for 10 min minimum

4.3.3 Subsystem Description

A schematic of this subsystem is presented in Figure 4-8. The oxygen storage and supply, nitrogen storage and supply, and cabin PO_2 and PT control are triple redundant; each of these functions are accomplished by a primary, secondary, and auxiliary (emergency) module.

4.3.3.1 Oxygen Storage and Supply

Primary oxygen supply is provided from the primary cyrogenic oxygen supply for the power reactant system distribution (PRSD). Similarly, the secondary oxygen supply is provided from the secondary PRDS cryogenic oxygen tankage. Oxygen from both of these sources is delivered to the ECS at a nominal pressure of 900 psia and a temperature from -200° to +160°F. The secondary and primary oxygen supply modules are identical. The delivered oxygen flows through a capillary flow restrictor-heater (Item 1.14), which limits the flow to 7.5 lb/hr and the temperature to a minimum of -40°F. The restrictor-heater is a capillary tube wrapped around two parallel lengths of the Freon-21 thermal coolant loop. Both legs of the primary and secondary oxygen supply connect into a common manifold, and each leg contains a check valve (Item 1.15) to prevent counterflow in either of the legs, thus isolating the supply lines in event of failure in the cryogenic delivery system.

The auxiliary (emergency) supply consists of two PRD-49 filament-wound, aluminum-lined spherical tank modules. Each spherical tank contains 37.5 lb of usable oxygen. The storage pressure at 70°F is 3000 psig. When high oxygen flow rates are required to maintain cabin pressure, exceeding the cryogenic supply delivery capability, the high-pressure oxygen tanks will furnish the necessary capacity. During cabin repressurization and/or airlock repressurization, the maximum flow rate from each tank module can be as high as

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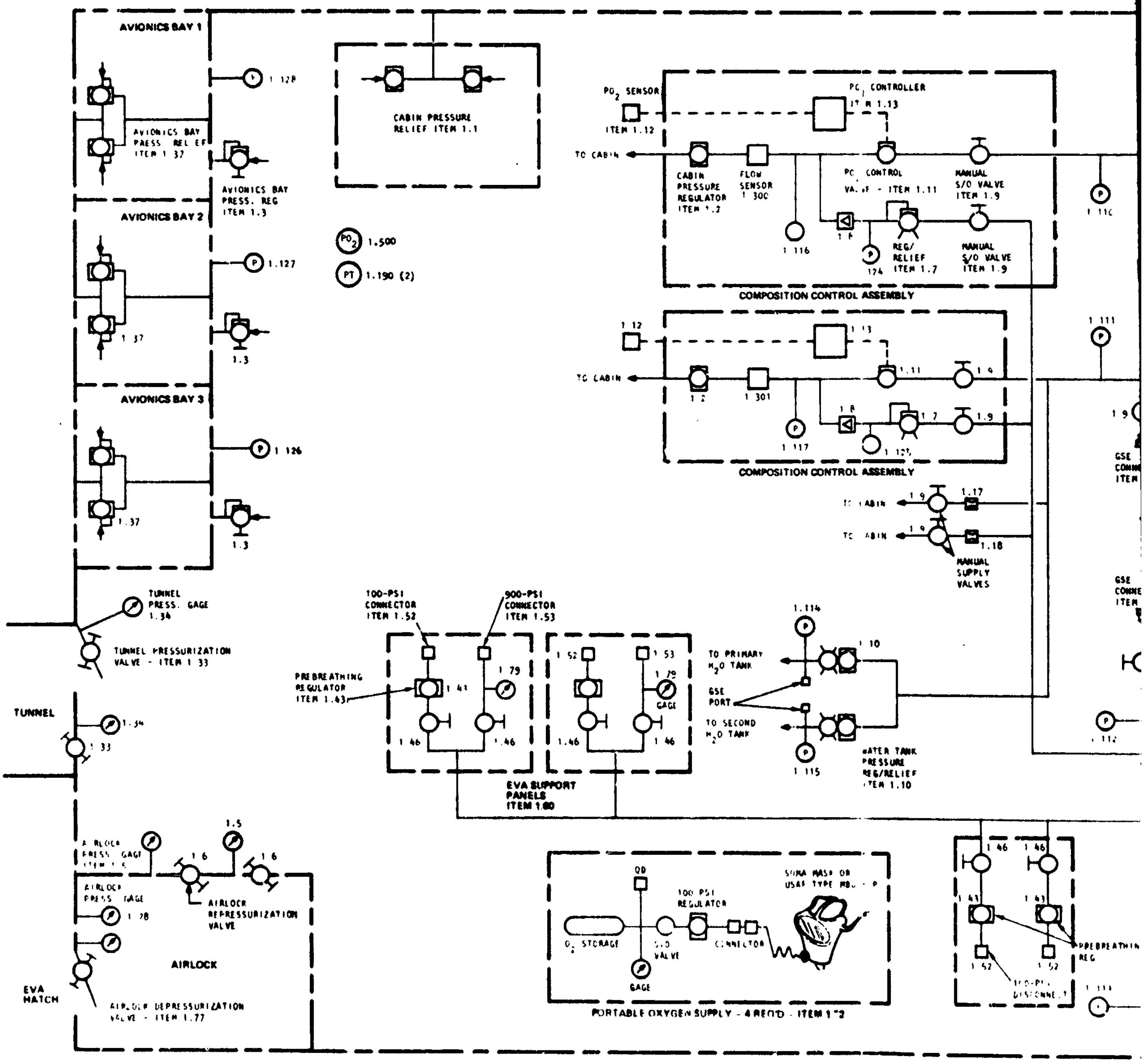

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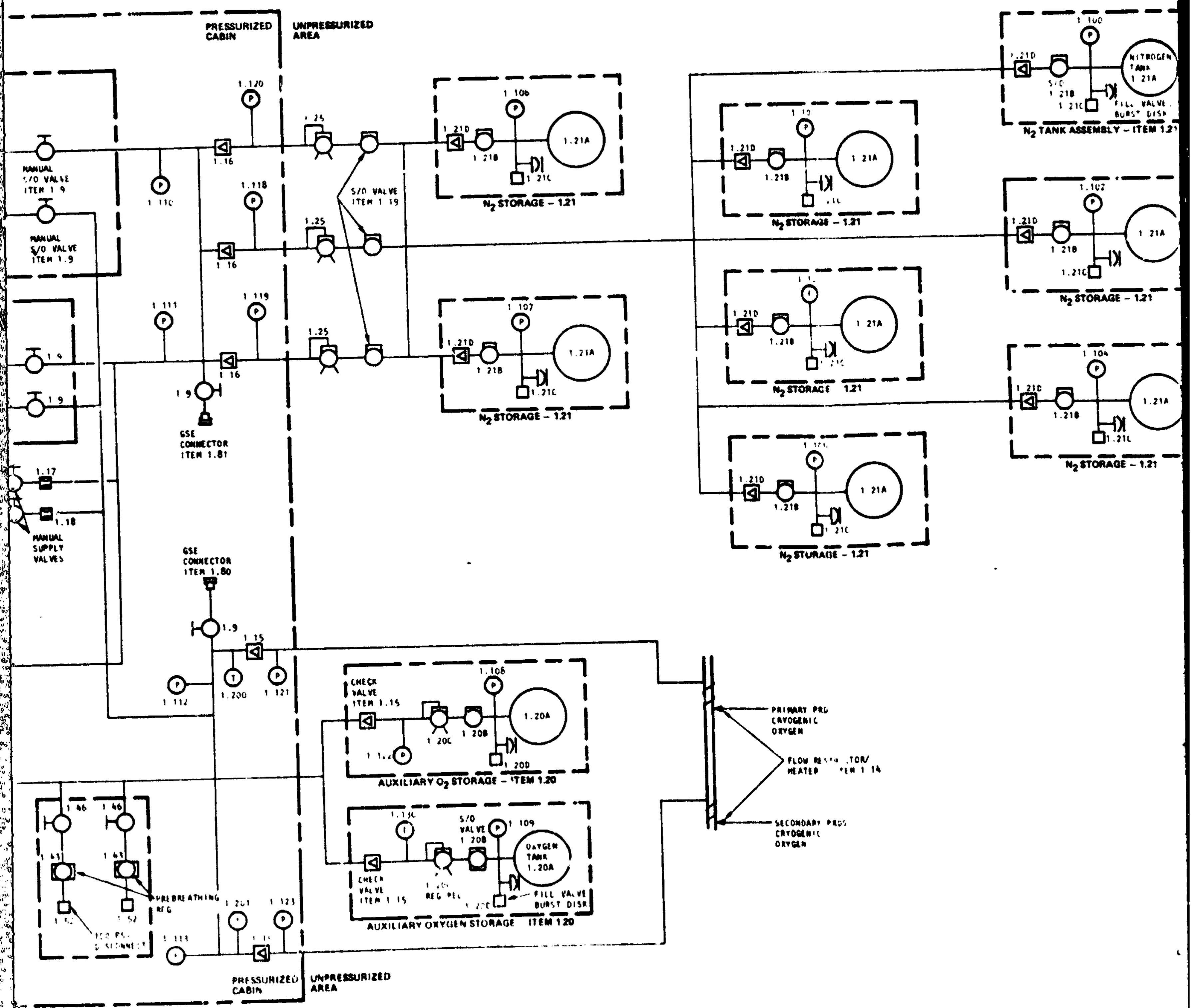

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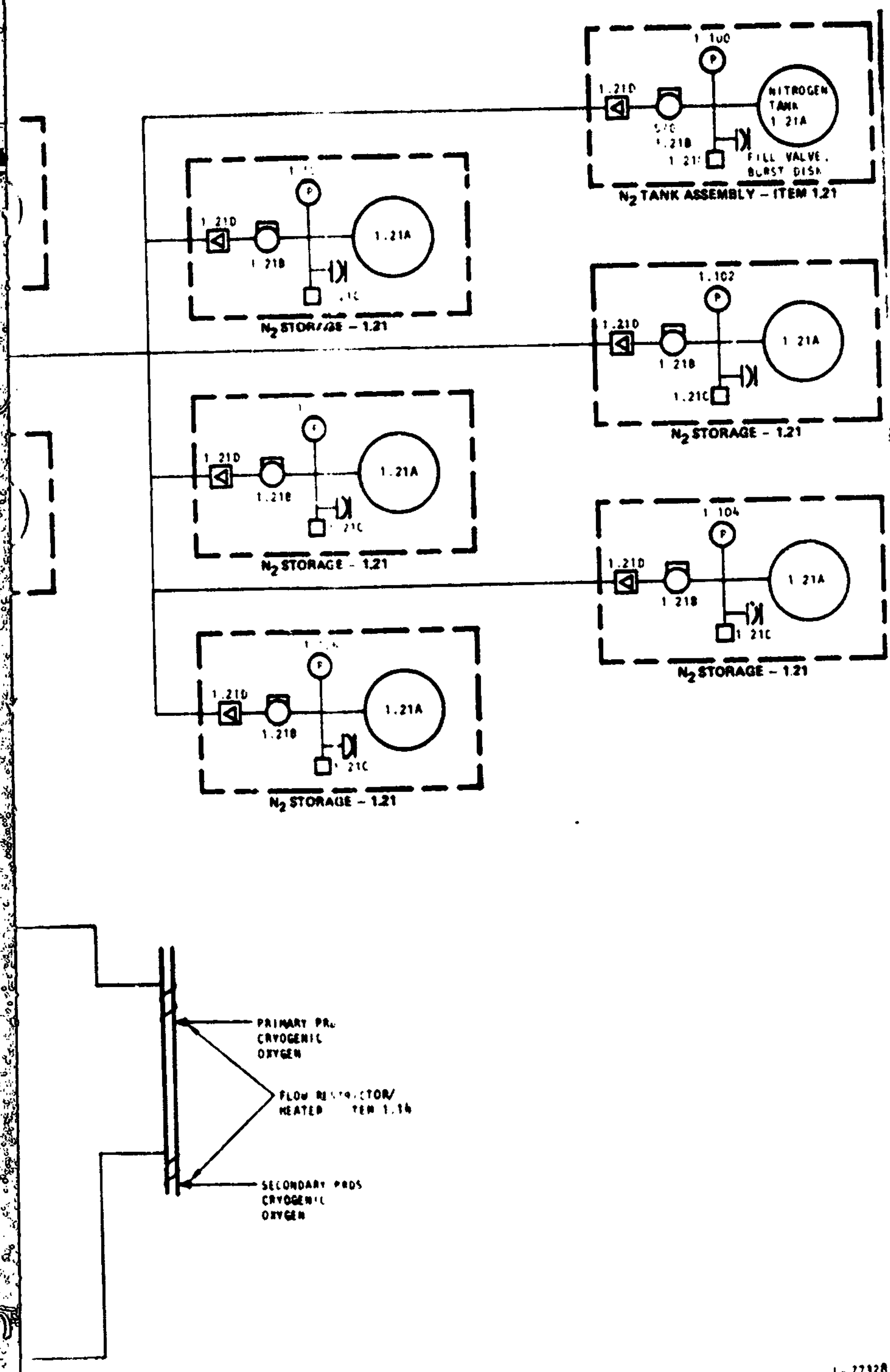


ITEM NO.	DESCRIPTION	NUMBER REQUIRED
1.1	CABIN PRESSURE RELIEF VALVE	1
1.2	CABIN PRESSURE REGULATOR VALVE	2
1.3	AVIONICS BAY PRESSURIZATION VALVE	3
1.5	AIRLOCK PRESSURE GAGE	2
1.6	AIRLOCK PRESSURIZATION VALVE	?
1.7	O_2 PRESSURE REGULATOR/RELIEF VALVE	2
1.8	GAS CHECK VALVE	2
1.9	GAS SHUTOFF VALVE, MANUAL	8
1.10	WATER TANK REGULATOR/RELIEF VALVE	2
1.11	PO_2 CONTROL VALVE	2
1.12	PO_2 SENSOR	2
1.13	PO_2 CONTROLLER	2
1.14	OXYGEN FLOW RESTRICTOR AND HEATER	2
1.15	OXYGEN CHECK VALVE	4
1.16	N_2 CHECK VALVE	3
1.17	NITROGEN FLOW LIMITING ORIFICE	1
1.18	O_2 ORIFICE	1
1.19	NITROGEN SOLENOID SHUTOFF VALVE	3
1.20	OXYGEN STORAGE TANK ASSEMBLY	2
1.20a	OXYGEN STORAGE TANK	2
1.20b	OXYGEN TANK SHUTOFF VALVE	2
1.20c	OXYGEN AUXILIARY SOURCE REGULATOR/RELIEF VALVE	2
1.20d	OXYGEN TANK FILL VALVE/BURST DISC	2
1.21	NITROGEN STORAGE TANK ASSEMBLY	8
1.21a	NITROGEN STORAGE TANK	8
1.21b	NITROGEN STORAGE TANK SHUTOFF VALVE	8
1.21c	NITROGEN TANK FILL VALVE/BURST DISC	8
1.21d	NITROGEN CHECK VALVE	8
1.25	NITROGEN REGULATOR/RELIEF VALVE	3
1.33	PAYLOAD TUNNEL PRESSURIZATION VALVE	2
1.34	PAYLOAD TUNNEL PRESSURE GAUGE	2
1.37	AVIONICS BAY PRESSURE RELIEF VALVE	3
1.43	PREBREATHING OXYGEN REGULATOR	4
1.46	EVA SUPPORT STATION O_2 SHUTOFF VALVE	6
1.52	EVA SUPPORT STATION CONNECTOR (100 PSI)	4
1.53	EVA SUPPORT STATION CONNECTOR (900 PSI)	2
1.72	PORTABLE OXYGEN SYSTEM	4
1.77	AIRLOCK DEPRESSURIZATION VALVE	2
1.78	EVA HATCH PRESSURE GAGE	2
1.79	PLSS SERVICE PRESSURE GAGE	2
1.80	OXYGEN GROUND GROUND SERVICE DISCONNECT	1
1.80a	OXYGEN DISCONNECT PRESSURE CAP	1
1.81	NITROGEN GROUND SERVICE DISCONNECT	1
1.81a	NITROGEN GROUND DISCONNECT PRESSURE CAP	1
1.100	N_2 SOURCE TANK PRESSURE	1
1.101	N_2 SOURCE TANK PRESSURE	1
1.102	N_2 SOURCE TANK PRESSURE	1
1.103	N_2 SOURCE TANK PRESSURE	1
1.104	N_2 SOURCE TANK PRESSURE	1
1.105	N_2 SOURCE TANK PRESSURE	1
1.106	N_2 SOURCE TANK PRESSURE	1
1.107	N_2 SOURCE TANK PRESSURE	1
1.108	O_2 SOURCE TANK PRESSURE	1
1.109	O_2 SOURCE TANK PRESSURE	1
1.110	N_2 MANIFOLD PRESSURE	1
1.111	N_2 MANIFOLD PRESSURE	1
1.112	O_2 MANIFOLD PRESSURE	1
1.113	O_2 MANIFOLD PRESSURE	1
1.114	N_2 WATER TANK PRESSURE	1
1.115	N_2 WATER TANK PRESSURE	1
1.116	PRIMARY GAS SUPPLY PRESSURE	1
1.117	SECONDARY GAS SUPPLY PRESSURE	1
1.118	N_2 SUPPLY PRESSURE (LEG 2)	1
1.119	N_2 SUPPLY PRESSURE (LEG 3)	1
1.120	N_2 SUPPLY PRESSURE (LEG 1)	1
1.121	PRIMARY O_2 SUPPLY PRESSURE	1
1.122	AUXILIARY O_2 SUPPLY PRESSURE	1
1.123	SECONDARY O_2 SUPPLY PRESSURE	1
1.124	REGULATED O_2 PRESSURE PRIMARY	1
1.125	REGULATED O_2 PRESSURE SECONDARY	1
1.126	AVIONIC BAY DELTA P	1
1.127	AVIONIC BAY DELTA P	1
1.128	AVIONIC BAY DELTA P	1
1.130	AUXILIARY O_2 SUPPLY PRESSURE	2
1.190	CABIN TOTAL PRESSURE	1
1.200	O_2 MANIFOLD TEMPERATURE	1
1.201	O_2 MANIFOLD TEMPERATURE	1
1.300	N_2/O_2 FLOW	1
1.301	N_2/O_2 FLOW	1
1.500	PARTIAL O_2 SENSOR	1

Figure 4-8. Atmosphere Control

150 lb/hr. The expulsion of the oxygen during repressurization may cause the temperature to drop to -20°F. The oxygen auxiliary supply contains sufficient oxygen for one cabin repressurization, for seven airlock repressurizations, and for 4-day emergency contingency. In adddition to the tanks, each module includes the following equipment:

(a) One solenoid isolation valve (Item 1.20b)

(b) One pressure regulator/relief valve (Item 1.20c) that controls the pressure to 800 psig

(c) One fill and safety valve (Item 1.20d) that incorporates a burst disc for protection in the event of tank overpressurization

(d) One pressure transducer (Item 1.108 or 1.109)

The auxiliary oxygen supply is routed to the common manifold between the secondary and primary supply. The regulated pressure of 800 psig and the check valve in the auxiliary legs prevent use of auxiliary oxygen during normal operation. The auxiliary supply is regulated to a pressure slightly lower than the primary and secondary supply to prevent usage in normal operation, yet the tanks can be maintained on stream.

4.3.3.2 Nitrogen Storage and Supply

Nitrogen is stored in eight PRD-49 filament-wound, 5096-0 aluminum-lined spherical tank modules. Initially, each tank contains 25 lb of usable nitrogen at 3000 psig. Each tank module contains a solenoid isolation valve (Item 1.21b), a fill/safety valve that incorporates an overpressurization burst disc (Item 1.21c), a check valve (Item 1.21d), and a pressure transducer (Item 1.100 through 1.107). Normally, only one tank will be on stream at any one time, and all tanks are manifolded together. Three separate lines are fed from this manifold. Each line includes a solenoid isolation valve (Item 1.19), a pressure regulator valve (Item 1.25) that controls downstream pressure to 140 psig, and a check valve. This arrangement provides regulator/relief isolation capability. Downstream of the check valves the three 140-psi lines join into a second manifold from which nitrogen is distributed to the composition control module and the water tank pressure regulators.

4.3.3.3 Cabin PO_2 and PT Control

Cabin partial oxygen pressure and total pressure is normally maintained by one of two redundant modules; only one module is on stream at any one time. Depending on the cabin oxygen partial pressure, the module will selectively feed oxygen or nitrogen to the cabin. Manual shutoff valves (Item 1.9) located on the two-gas control panel isolate the oxygen and nitrogen supply to the module in normal operation. Oxygen is routed to a regulator/relief valve (Item 1.7) which reduces the pressure to 100 psig. The nitrogen and oxygen lines in each control composition module are mated into a common manifold that leads to the cabin pressure regulator (Item 1.2). When the cabin pressure decreases, the cabin pressure regulator will open, allowing either nitrogen or oxygen to discharge to the cabin. When the cabin oxygen partial pressure reaches 3.2 psia, the PO_2 sensor (Item 1.12) in conjunction with the PO_2 controller (Item 1.13) opens the PO_2 control solenoid valve (Item 1.11) in the nitrogen supply line; nitrogen at a higher pressure than the oxygen supply will then flow through the cabin pressure regulator to maintain total cabin pressure. A check valve (Item 1.8) downstream of the oxygen regulator (Item 1.7) prevents the flow of oxygen when the PO_2 control solenoid valve (Item 1.11) is open. When the cabin PO_2 drops to 3.0 psia, the PO_2 control solenoid valve is closed by the PO_2 controller. This enables oxygen to flow to the cabin upon demand.

Upon failure of both composition control modules, the cabin total pressure and cabin oxygen partial pressure are maintained by two manually operated valves (Item 1.9) tied-in with the nitrogen and oxygen manifolds. Certain PO_2 and PT information (Items 1.500 and 1.190) will be used by the crew for this purpose. Restricting orifices (Items 1.17 and 1.18) in the emergency lines limit the flow to specified values. The emergency valves will be manually manipulated as required to maintain the cabin pressure limits. Figure 4-9 graphically illustrates the cabin total and oxygen partial pressure cycling during a typical emergency situation.

A relief valve (Item 1.1) with redundant elements prevents overpressurization of the cabin. The valve is sized to maintain cabin pressure below 15.7 psig.

4.3.3.4 <u>Water Tank Pressurization</u>

Nitrogen from the 140-psig manifold is reduced to 18 (-0, +3) psig by two dual regulator/relief valve modules (Item 1.10) to pressurize the two 100-lb water tanks. The redundant elements in each valve can be isolated manually.

4.3.3.5 <u>Avionics Bay Compartment Pressurization</u>

The avionics bays are pressurized by flow from the cabin through a pressure regulator (Item 1.3) which maintains the avionics bays at a pressure 0.4 psig lower than cabin. In the event of cabin depressurization,or avionics bay overpressurization (as in the event of a fire in the bay), redundant overboard pressure relief valves (Item 1.37) will limit the pressure in the bays to 0.6 psid above the cabin pressure. Blowout panels between the avionics bays and the cabin are provided to prevent structural damage in emergencies.

NOTES: 1. 10-MAN CREW
2. LEAKAGE RATE: 10 LB/DAY
3. CABIN VOLUME: 2000 FT^3

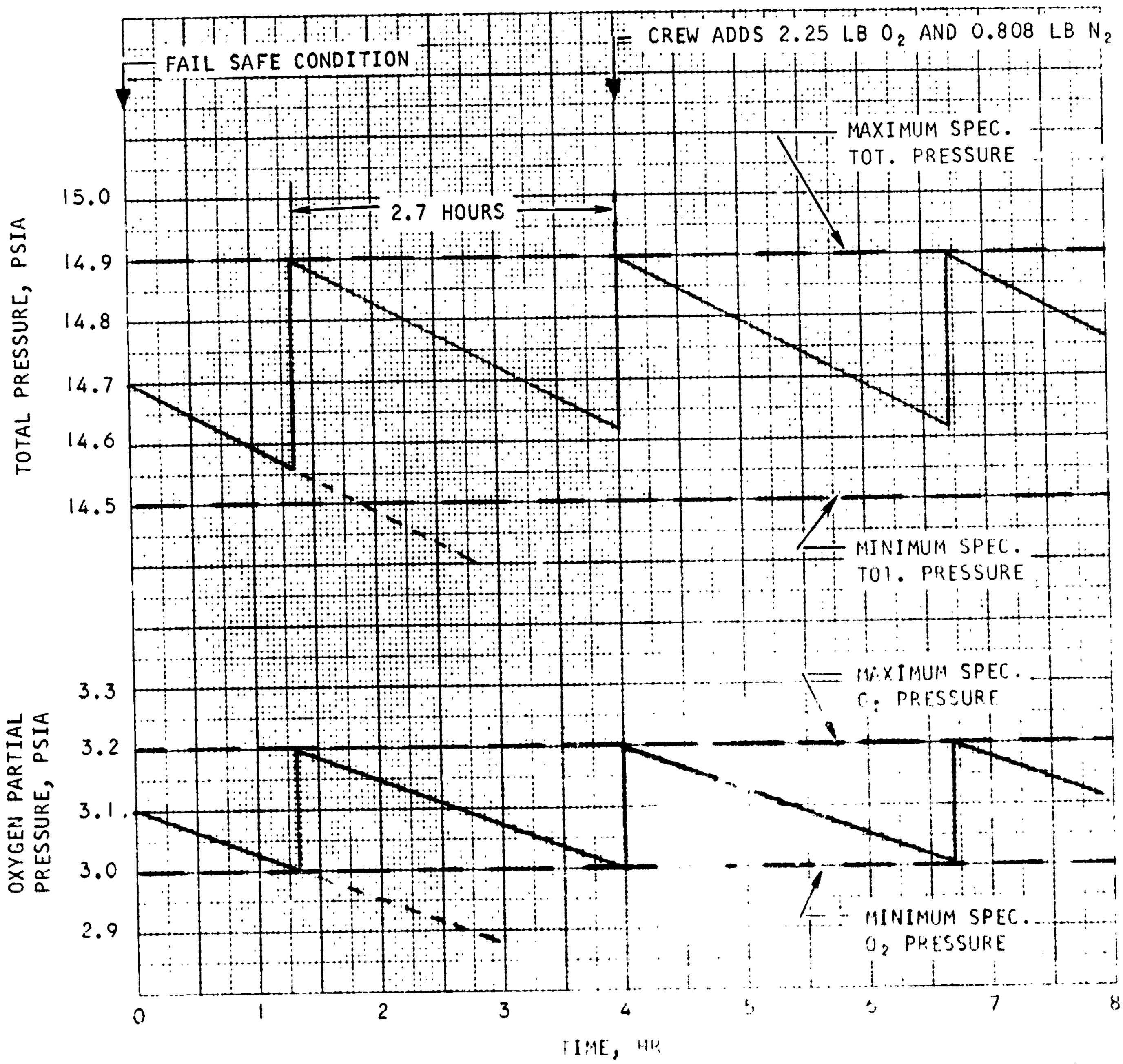


Figure 4-9. Total and Oxygen Pressure Cycling During Emergency Condition

4.3.3.6 Airlock and Tunnel Operation

A manually operated valve (Item 1.77) is used to depressurize the airlock by venting to ambient. The airlock depressurization valve (Item 1.77) will be operable from inside and outside the vehicle. Manually operated valves (Items 1.6 and 1.38) are provided to repressurize the airlock and tunnel from the cabin. These valves can be operated from within the cabin and also from within these compartments. Redundancy provides fail-operational capability.

4.3.3.7 EVA Support

Oxygen from the 900-psig manifold is routed to connectors for PLSS recharge and prebreathing. Two EVA support panels are provided. Each panel incorporates provisions for PLSS resupply through a connector (Item 1.53). In addition, the oxygen from the manifold is reduced to 100 psia and routed to connectors for oxygen prebreathing prior to EVA. Shutoff valves (Item 1.46) isolate the connectors when not in use. A pressure gage (Item 1.79) is used for monitoring PLSS recnarge operation. These gages also can be used as backups for the manifold instrumentation.

4.3.3.8 Emergency Oxygen Supply

Emergency oxygen is provided to the crew for use in cases of atmospheric contamination or cabin depressurization. The EVA support mask disconnects can be used for this purpose. Oxygen at 100 psia is delivered to two connectors on the crew support panels to provide extended emergency oxygen breathing capabilities. Four portable oxygen units (Item 1.72) are stored onboard the vehicle; each unit has the capacity to support one crew man for 10 min in an emergency. The portable oxygen units can be recharged by using the high pressure connectors located on the EVA support panels.

4.3.4 Equipment Summary

Table 4-7 summarizes the characteristics of the equipment shown in the schematic of Figure 4-8. The instrumentation is included in the table. Reference is made to Section 7 for a discussion of instruments. The atmosphere control subsystem is characterized by a large number of components. This is the result of the numerous functional requirements and the high degree of redundancy necessary to provide FO-FS.

A summary of the data of Table 4-7 is presented below

Number of Components	
Functional components	124
Monitoring instrumentation	36
Number of Component Designs	
Functional components	30
Monitoring instrumentation	9
Equipment Weight	
Fixed dry weight	467.5 lb (including 4 portable emergency O_2 supply)
Expendable weight (O_2-N_2)	275 lb
Launch weight	742.5 lb
Power Requirements	4 w for the PO_2 controller (all instrumentation transducer power is supplied by Item 3.8)

In selecting components for this subsystem, emphasis was placed on commonality to reduce initial cost and spares provisioning. Examples include:

(a) Gas Shutoff Valve--A standard Carleton toggle valve is used to provide the functions of Items 1.9 and 1.46. A total of 14 toggle shutoff valves are used.

TABLE 4-7

EQUIPMENT SUMMARY,
ATMOSPHERE CONTROL SUBSYSTEM

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Prevent overpressurization of crew compartment; crack pressure 15.1; [illegible] temperature [illegible] to [illegible]; full flow capacity [illegible] lb/hr at 15.[illegible] psia [illegible]	[illegible]	[illegible]	-	New	Redundant element [illegible] override [illegible] relief [illegible]
[illegible]	[illegible]	[illegible]	Maintain crew compartment total pressure at 14.[illegible] psia. Inlet pressure [illegible] to 150 psi normal, 215 psig max.; normal flow rate: 1 lb/hr for a cabin pressure of 14.7 psia; repressurization flow rate: 150 lb/hr.	1.[illegible]	3.5 × [illegible] × 4.5	-	Modified	Include two [illegible] 1.[illegible] lb [illegible] qualified for [illegible] The second [illegible] designed for high flow capability [illegible] and will open in pressure [illegible] 0.[illegible] psid. [illegible] Apollo [illegible] mod.
1.3	Avionics [illegible] pressurization valve	[illegible]	Maintain avionics bay at 0.4 psid below cabin pressure thus allowing air to flow from the cabin. Avionic leakage: 1 lb/day; inlet pressure: normal 14.7 psia, maximum 15.7 psia; max. flow rate; 10 lb/hr to maintain 0.6 psid; temperature: 70°F.	0.[illegible]	1.5 [illegible] × 1.[illegible]	[illegible]	Similar	Normally closed element [illegible] open [illegible] between [illegible]
1.5	Airlock pressure [illegible]	[illegible]	Measure airlock pressure relative to cabin for operating pressure: -1 to +15 psid; accuracy: ±0.1 psi from -1 to 1.0 psid, ±0.3 psi from -1 to 15 psid; leakage: 6 × 10[illegible] lb/hr at 15 psid, 70°F.	0.30	2.37 × 2.37 × 1.30	-	Modified	Bourdon tube pressure [illegible] Apollo [illegible]
1.6	[illegible]	[illegible]	Pressurize manually the airlock from the cabin atmosphere. Airlock volume: 250 ft cu; operating pressure: 0 to 15 psid cabin to airlock, airlock pressurization time: [illegible] minutes.	[illegible]	[illegible]	[illegible]	New	[illegible] wall mounted valve [illegible] operable from [illegible]
1.7	[illegible] pressure [illegible] relief [illegible]	[illegible]	Regulate oxygen pressure to 1[illegible] psi; inlet pressure: [illegible] to 1000 psia. Inlet temperature [illegible] to 160°F; nominal flow rate to [illegible] cabin oxygen partial pressure: 1 lb/hr; max. flow during repressurization: 1[illegible] [illegible] temperature [illegible] drop to [illegible] flow conditions; relief pressure [illegible]	0.50	[illegible]	-	Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 4-7 (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] water [illegible] inlet pressure [illegible] inlet pressure [illegible] regulated pressure [illegible] relieve at [illegible] relief [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Allows flow of oxygen to the [illegible] the nitrogen [illegible] Inlet temperature [illegible] 160°F; inlet pressure [illegible] inlet pressure [illegible] 135 [illegible] maximum flow [illegible] temperature [illegible] drop [illegible] pressure drop 5 [illegible] flow; internal leakage [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Measures [illegible] controller (Item [illegible]); nonoperating temperature [illegible] to 160°F; operating temperature [illegible]; operation [illegible] partial pressure.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] control valve (Item 1.11 [illegible]) [illegible] 1.11 [illegible] 3.2 [illegible] partial pressure [illegible] below [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4-7 (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	Weight, lb	Envelope, in.	Power, W	Equipment Category	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	New	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] internal leakage [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Regulator [illegible]	[illegible]	[illegible] pressure [illegible] flow rate [illegible] relief pressure [illegible]	[illegible]	[illegible]	[illegible]	Modified	Modified [illegible]
[illegible]	[illegible]	[illegible]	Operating pressure [illegible] flow [illegible] valve flow [illegible] external leakage [illegible]	[illegible]	[illegible]	[illegible]	Modified	Valve qualified [illegible]
[illegible]	[illegible]	[illegible]	[illegible] pressure [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] leakage [illegible]	[illegible]	[illegible]	[illegible]	New	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] valve flow [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

C2

TABLE 4-7 (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Power, W	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] relief pressure [illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] volume [illegible] internal leakage [illegible]	[illegible]	[illegible]	-	New	[illegible]
[illegible]	[illegible]	[illegible]	Measure [illegible]	[illegible]	[illegible]		Similar	[illegible]
[illegible]	[illegible]	[illegible]	Two relief valves [illegible] external leakage [illegible]	[illegible]	[illegible]	-	New	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] relief pressure [illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] operating pressure [illegible] external leakage [illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] flow [illegible] pressure drop [illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] inlet pressure [illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] airlock [illegible] external leakage [illegible]	[illegible]	[illegible]	-	New	[illegible]
[illegible]	[illegible]	[illegible]	[illegible] between [illegible]	[illegible]	[illegible]	-	Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Modified	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Modified	[illegible]

TABLE 4-7 (Continued)

[illegible]	[illegible]	[illegible]	[illegible] Requirement	[illegible] Weight, lb	Envelope [illegible]	Power, W	Equipment Category	Remarks [illegible]
[illegible]	[illegible]	[illegible]	Protect [illegible]	[illegible]	[illegible]	-	Modified	
[illegible]	N_2 [illegible] Ground [illegible]	1	For N_2 [illegible] 150 p[illegible] [illegible] 250 p[illegible] flow [illegible] pre[illegible]ure drop [illegible]	[illegible]	1.75 dia [illegible]	-	Modified	[illegible] fixture.
1.8[illegible]	Nitrogen Ground [illegible] Connect [illegible]	1	Protect [illegible] connect and [illegible]	0.05	-	-	Modified	
[illegible]	N_2 [illegible] Tank Pressure	1	Range 0 to 3500 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	N_2 Source [illegible] Pressure	1	Range 0 to 3500 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
1.1.10	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	0.2	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
1.1.104	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	0.2	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	0.2	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	0.2	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	N_2 Source Tank Pressure	1	Range 0 to 3500 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
[illegible]	[illegible] Source Tank Pressure	1	Range 0 to 3500 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.[illegible]
[illegible]	[illegible] Tank Pressure	1	Range [illegible] 3500 p[illegible]	[illegible]	1 dia × 2.5	-	Existing	Strain gage type; power and signal conditioning from [illegible]
[illegible]	[illegible] Pressure	[illegible]	[illegible]	[illegible]	1 dia × 2.5	-	Existing	[illegible] conditioning [illegible]
1.1.11	N_2 Manifold Pressure	1	Range 0 to 200 psig	0.2	1 dia × 2.5	-	Existing	Strain gage type, power and signal conditioning from Item 3.8.
1.1.11[illegible]	[illegible] Manifold Pressure	1	Range [illegible] to 1000 psi[illegible]	0.2	1 dia × 2.5	-	Existing	Strain gage type, power and signal conditioning from Item 3.[illegible]
1.1.113	[illegible] Manifold Pressure	1	Range 0 to 100 psi	[illegible]	1 dia × 2.5	-	Existing	Strain gage type, power and signal conditioning from Item 3.[illegible]
[illegible]	N_2 Water Tank [illegible]	1	Range 0 to 50 psi[illegible]	0.2	1 dia × 2.5	-	Existing	Strain gage type, power and signal conditioning from Item 3.[illegible]
1.1.11[illegible]	N_2 Water Tank Pressure	1	Range 0 to 50 [illegible]	[illegible]	1 dia × 2.5	-	Existing	Strain gage type, power and signal conditioning from Item 3.[illegible]

TABLE 4-7 (Continued)

Item No.	Description	No. Req'd	Functional and Performance Requirements	Item Weight, lb	Envelope in.	Power, W	Equipment Category	Remarks/Design Features
1.11[illegible]	Primary Gas Supply Pressure	[illegible]	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.117	Secondary Gas Supply Pressure	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.118	N_2 Supply Pressure (Leg 2)	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.119	N_2 Supply Pressure (Leg 3)	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.120	N_2 Supply Pressure (Leg 1)	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.121	Primary O_2 Supply Pressure	1	Range: 0 to 1000 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.122	Auxiliary O_2 Supply Pressure	1	Range: 0 to 1000 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.123	Secondary O_2 Supply Pressure	1	Range: 0 to 1000 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.124	Regulated O_2 Pressure Primary	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8.
1.125	Regulated O_2 Pressure Secondary	1	Range: 0 to 200 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight; power and signal conditioning from Item 3.8
1.126	Avionic Bay Delta P	1	Range: -2 to 2 psid	0.5	2 dia x 3	-	Existing	Linear variable transformer type. Power and signal conditioning from Item 3.8.
1.127	Avionic Bay Delta P	1	Range: -2 to 2 psid	0.5	2 dia x 3	-	Existing	Linear variable transformer type. Power and signal conditioning from Item 3.8.
1.128	Avionic Bay Delta P	1	Range: -2 to 2 psid	0.5	2 dia x 3	-	Existing	Linear variable transformer type. Power and signal conditioning from Item 3.8.
1.130	Auxiliary O_2 Supply Pressure	1	Range: 0-1000 psig; used for checkout only	0.2	1 dia x 2.5	-	Existing	Strain gage type; no read in flight, power and signal conditioning from Item 3.8
[illegible]	[illegible] Pressure	2	Dedicated cabin instrumentation pressure	0.2	1 dia x 2.5	-	Existing	Strain gage type; power and signal conditioning from Item 3.8.
1.200	O_2 Manifold Temperature	1	Temperature range: -75 to 175°F	0.03	-	-	Existing	Surface type sensor. Power and signal conditioning from Item 3.8.
1.201	[illegible] Temperature	1	Temperature range: -75 to 175°F	0.03	-	-	New	Same as Item 1.200
[illegible]	[illegible] Flow	1	Monitor cabin leakage flow [illegible]	1.5	3.8 x 5.25 x 1.5	-	New	
[illegible]	[illegible] Flow	[illegible]	Monitor [illegible] leakage flow [illegible]	1.5	3.8 x 5.25 x 1.5	-		Same as Item [illegible]
[illegible]	[illegible]	[illegible]	Monitor partial O_2 pressure dedicated [illegible] Instrument pressure range 0 to 5 psia	[illegible]	1 x 1 [illegible]	-	[illegible]	Same as Item [illegible]

(b) Check Valve--An existing rubber umbrella type valve qualified for Apollo is proposed for Items 1.8, 1.15, 1.16, and 1.21d for a total of 17 valves.

(c) Regulator/Relief--As shown in the table, Carleton regulators are proposed throughout. Although they are not the same unit, the designs are similar and use many of the same detailed parts.

(d) Solenoid Shutoff Valve--The same valve is used throughout (Items 1.10, 1.19, 1.20b, and 1.21b), for a total of 16 applications.

(e) Connectors--Many of the quick-disconnects are standard disconnect, which are similar except for a key feature incorporated to prevent misuse.

(f) Instrumentation--Of the 31 pressure transducers required, two basic designs are used. Four dash number versions of the same design are used.

The total dry weight (467.5 lb) of the subsystem is listed below by requirement categories:

(a)	Tanks (O_2 and N_2)	297 lb
(b)	Valves and controls	124.8 lb
(c)	Portable O_2 supply	33.6 lb
(d)	Instrumentation	11.2 lb

Since minimizing tank weight will result in the greatest saving, filament-wound vessels with aluminum liners were used.

4.3.5 LRU Definition

The atmospheric control subsystem is packaged into major line replaceable units (LRU's) based on redundancy management and ground checkout investigations, installation constraints, and hardware maintenance. Table 4-8 lists the major LRU packages for this subsystem.

TABLE 4-8

ACS LRU DEFINITION

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Subsystem	Remarks
1-A	1.1		1	Cabin relief valve	1	
1-B	-	-	-	N_2 manifold assembly	1	Remove and replace ... are replaceable after ... is removed
	NPN		1	N_2 manifold assembly		
		1.16	3	Check valve		
		1.120	1	Press transducer		
		1.118	1	Press transducer		
		1.119	1	Press transducer		
		1.110	1	Press transducer		
		1.111	1	Press transducer		
1-C		-	-	O_2 manifold assembly	1	Similar to 1-B
		-	1	O_2 manifold		
		1.15	2	Check valve		
		1.112	1	Press transducer		
		1.113	1	Press transducer		
		1.200	1	Temperature sensor		
		1.201	1	Temperature sensor		
		1.121	1	Press transducer		
		1.122	1	Press transducer		
1-D	-	-		2 gas control panel assembly	2	
		1.9	2	Toggle shutoff valve		
		1.11	1	PO_2 control valve		
		1.13	1	PO_2 controller		
		1.300 or	1	Flow sensor		Primary
		(1.301)	1	Flow sensor		Secondary
		1.116	1	Pressure transducer		Primary
		1.117	1	Pressure transducer		Secondary
		1.2	1	Cabin pressure regulator		
		1.8	1	Check valve		
		1.124	1	Press transducer		Primary
		1.125	1	Press transducer		Secondary
		1.7	1	O_2 press regulator/relief valve		
1-E	-	-		N_2 manual pressurization valve	1	
		1.9	1	Toggle shutoff valve		
		1.17	1	Orifice (N_2)		
1-F	-	-		O_2 manual pressurization valve	1	
		1.9	1	Toggle shutoff valve		
		1.18	1	Orifice (O_2)		
1-G	1.10	-	2	Water tank regulator/relief valve	1	
		1.114 or	1	Press transducer (water tank)	2	Primary
		1.115	1	Press transducer (water tank)		Secondary
1-I	1.3		1	Avionics bay pressure regulator	3	
1-J	1.5		1	Airlock pressure gage	2	
1-K	1.6		1	Airlock pressurization valve	2	
1-L	1.14		1	O_2 flow restrictor	2	
1-M	1.20			Oxygen storage tank assembly	2	
		1.20A	1	Tank		
	1.20B		1	O_2 isolation shutoff valve		
	1.20C		1	O_2 source regulator/relief valve		

TABLE 4-8 (Continued)

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Subsystem	Remarks
1-M cont	1.20D		1	O_2 fill valve/burst disc		
	1.15		1	Check valve		
	1.108		1	Press transducer		Primary
	1.108		1	Press transducer		Secondary
1-N	1.21	-		N_2 storage tank assembly	8	
		1.21A	1	Tank		
	1.21B		1	N_2 isolation shutoff valve		
	1.21C		1	N_2 fill valve/burst disc		
	1.21D		1	N_2 check valve		
	1.100 thru 1.107		1	Press transducer		One transducer per LRU
1-O	1.25		1	N_2 press regulator/relief valve	3	
	1.19		1	N_2 shutoff valve	3	
1-P	1.33		1	Payload tunnel pressurization valve	2	
1-Q	1.34		1	Payload tunnel pressure gage	2	
1-R	1.37		1	Avionics bay relief valve	3	
1-S	1.60	-	-	EVA support panel	2	
		1.43	1	Prebreathing O_2 regulator		
		1.46	2	O_2 shutoff valve		
		1.52	1	Connector 100 psi		
		1.53	1	Connector 900 psi		
		1.79	1	PLSS service pressure gage		
1-T	-	-		Flight station service panel	2	
		1.43	1	Prebreathing O_2 regulator		
		1.46	1	O_2 shutoff valve		
		1.52	1	Connector 100 psi		
1-U	1.72		1	Portable O_2 system	4	
1-V	1.77		1	Airlock depressurization valve	2	
1-W	1.78		1	EVA hatch pressure gage	2	
1-X	1.126		1	Press transducer, avionics bay 3		
1-Y	1.127		1	Press transducer, avionics bay 2	1	
1-Z	1.128		1	Press transducer, avionics bay 1	1	
1-AA	1.12 and 1.500		1	PO_2 sensor	3 1	Fault detection and isolation with LRU 1-D
1-BB	1.190		1	Cabin pressure transducer	2	

Generally, the components of this subsystem consist of small lightweight equipment (except for the gas storage tanks). In defining the LRU's, considerable attention was given to minimize the redundancy management actions required from the crew. Also, the equipment groupings were developed to minimize maintenance time in the event of failures.

As shown in the table, most of the LRU's consist of shop replaceable units (SRU's). Replacement of the SRU's will not be effected onboard the vehicle. Rather, the entire LRU will be removed and replaced as a unit.

Package arrangement of the components within the major LRU's is presented in para. 4.3.6.

4.3.6 Equipment Packages

A large number of these components will be installed as single components (for example, the cabin and avionics relief valves, and the airlock and tunnel pressure gages and pressurization valves). These components will be delivered as end items. The following discussions are only concerned with the equipment groups involving gas storage, composition control, water tank pressurization, and EVA support.

4.3.6.1 O_2/N_2 Control Panel

The gas control panel incorporates subsystem LRU's defined in Table 4-7 as follows:

1-B	N_2 manifold assembly
1-C	O_2 manifold assembly
1-D	2-gas control assembly (2 required)
1-E	N_2 manual repressurization
1-F	O_2 manual repressurization
1-G	Water tank pressurization

In addition, the O_2/N_2 control panel will incorporate all switches necessary for actuation of the O_2/N_2 tank and manifold solenoid isolation valves.

Figure 4-10 depicts the entire panel and the location of the LRU's, as described subsequently. Each LRU is removable from the panel as a separate package. The panel face is engraved for ease of component identification; a schematic also is engraved to enhance redundancy management. There are eight fluid connections to the panel: three oxygen inlet lines, three nitrogen inlet lines, and two water tank pressurization lines. Interconnecting lines between the LRU's are all internal to the overall panel assembly.

The entire panel is 6.0 in. by 20.0 in. by 28.25 in. as shown. Mounting of the various LRU's on the spacecraft structure is discussed below.

4.3.6.2 N_2 Manifold Assembly (LRU 1-B)

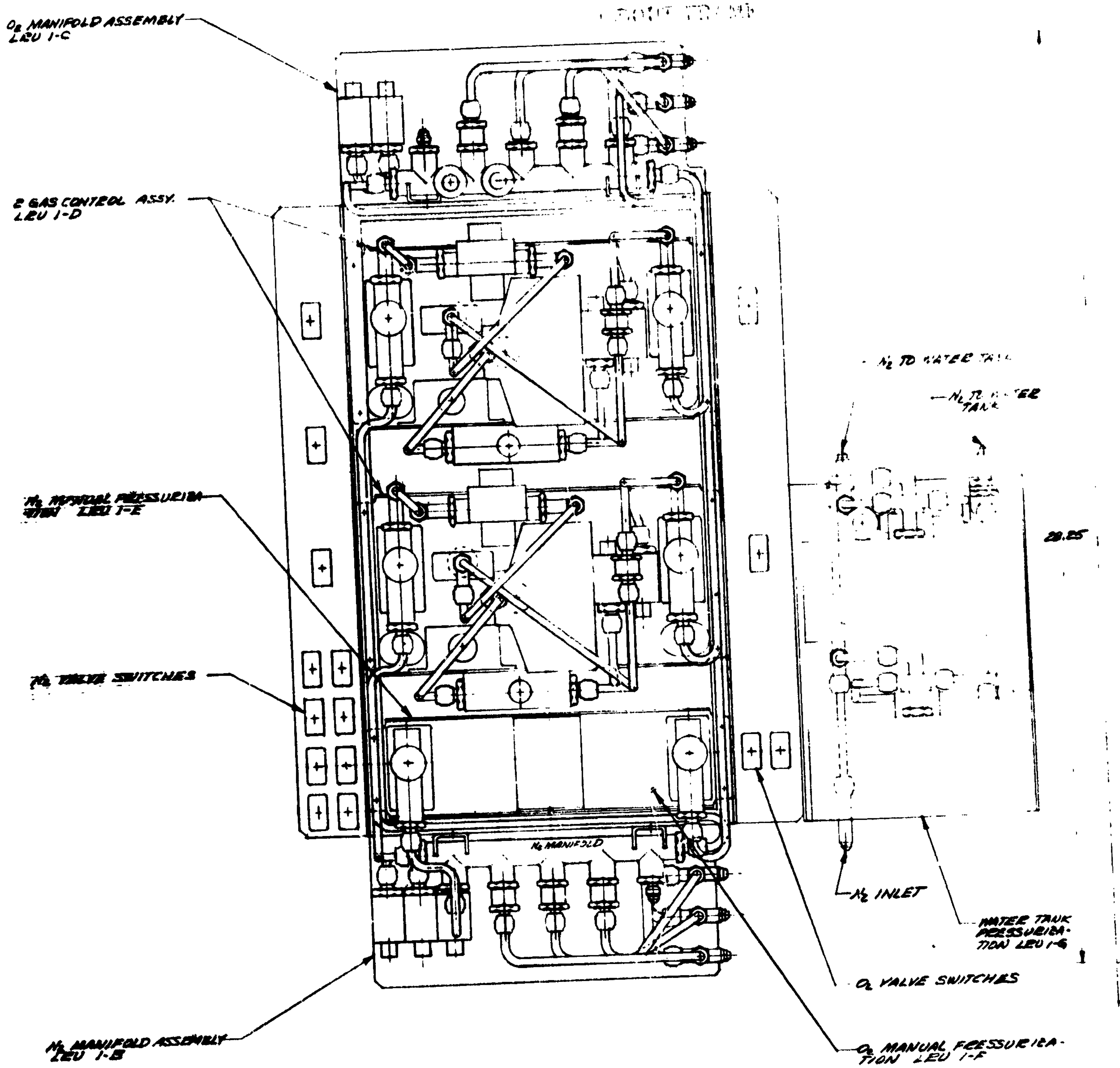
This LRU is located at the bottom of the valve control panel and incorporates the following equipment.

(a) The manifold proper

(b) Three check valves (Item 1.16)

(c) Five pressure transducers (Items 1.110, 1.111, 1.118, 1.119, and 1.120)

Figure 4-11 shows the arrangement of the components. The manifold is mounted on an aluminum frame located behind the hinged face of the panel. Two screws secure the manifold to the frame. The frame is attached to the vehicle structure. All components are line mounted on the manifold. Nitrogen at 140 psig enters the manifold assembly through three lines at the left of the LRU. Three pressure transducers are connected to these lines upstream of the three check valves. Nitrogen from the check valves enters the manifold and exits through four ports. Two of these supply nitrogen to the 2-gas control assemblies, one



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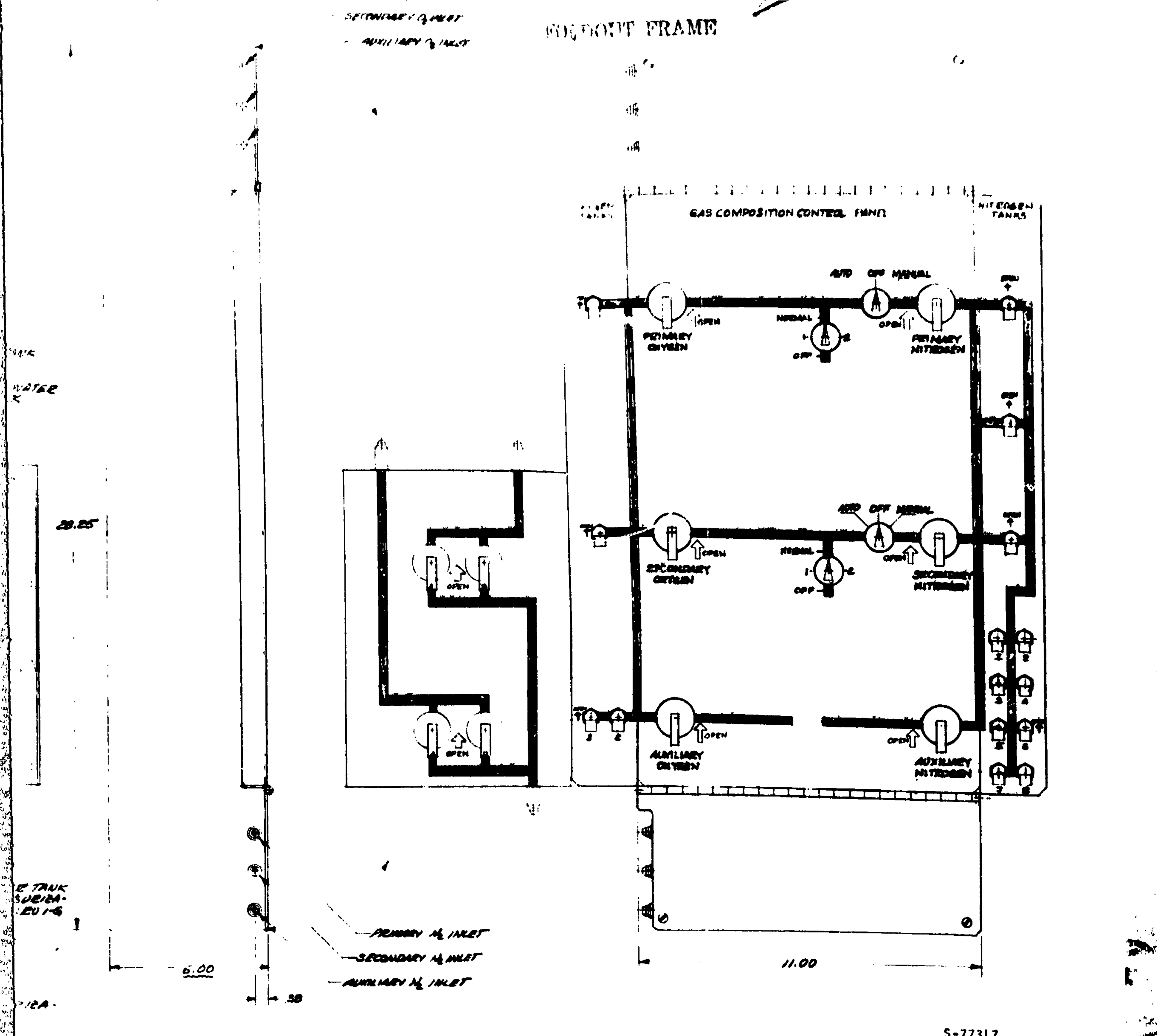

Figure 4-10. Control Panel Installation

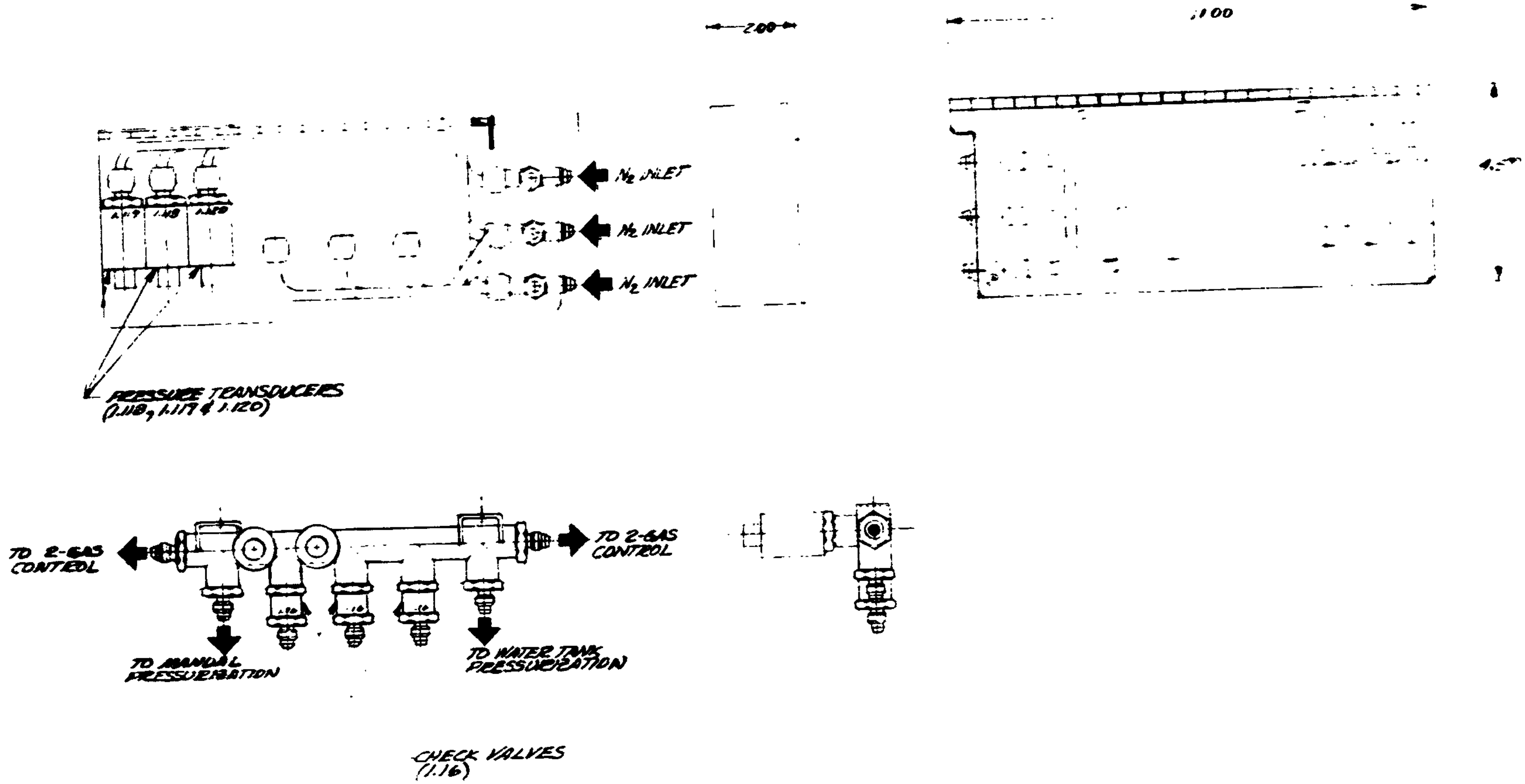

Figure 4-11. N_2 Manifold Assembly, LRU 1-5

to the manual repressurization valve, and the fourth to the GSE connector and water tank pressurization assembly (LRU 1-G) on the right of the wall panel.

Access is gained to the assembly by removing two screws which secure the face of the panel to the picture frame. The panel is swung upward on a hinge and kept in that position by a spring. Removal of the LRU will entail breaking seven fluid connections and disengaging the transducer electrical connectors.

The overall dimensions of the LRU are 4.5 in. by 11.0 in. by 6 in. as shown. Overall weight including mounting structure is estimated at 2.7 lb.

4.3.6.3 O_2 Manifold Assembly (LRU 1-D)

This assembly is mounted on top of the O_2/N_2 control panel (see Figure 4-10) and is shown in Figure 4-12. It is identical to the N_2 manifold assembly described previously except that only two check valves and two inlet [illegible] ucers are used. The empty transducer port is capped. Compon[illegible] cluded in the assembly are:

(a) Manifold proper

(b) Two chec valves (Item 1.15)

(c) Four pressure transducers (Items 1.112, 1.113, 1.121, and 1.122)

(d) Two surface-type temperature transducers (Items 1.200 and 1.201)

The temperature transducers are mounted on the oxygen inlet lines from the cryogenic supply tanks. Oxygen is supplied to the package from the left and distributed in the same manner as the nitrogen. Mounting of this LRU is identical to the nitrogen manifold assembly. Overall dimensions are also the same (4.5 in. by 11.0 in. by 6 in.); the 2.35-lb weight is slightly lower.

As an alternate design approach, the use of different thread sizes for the oxygen and nitrogen equipment will be considered to prevent errors in maintenance. The major disadvantage of this approach is the higher cost incurred due to loss of commonality.

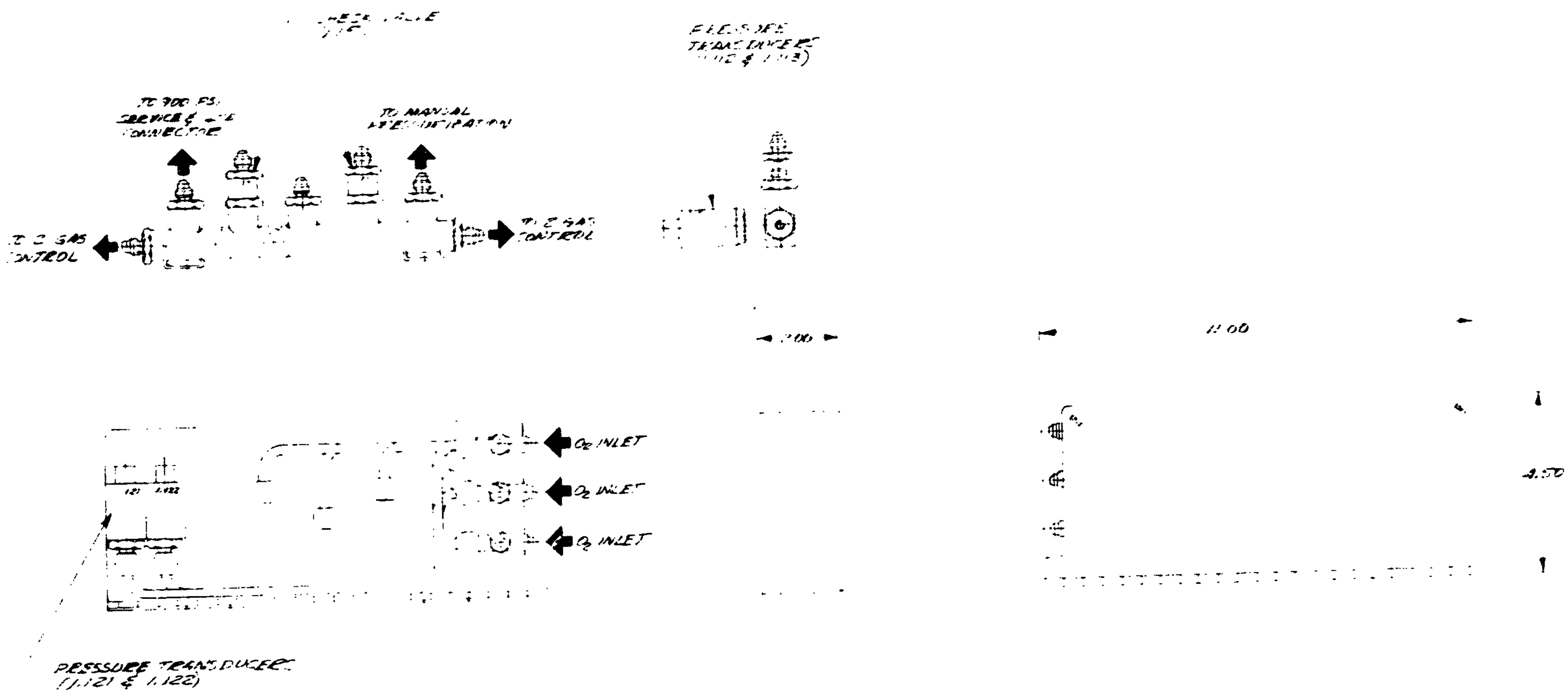

Figure 4-12. O_2 Manifold Assembly, LRU 1-C

4.3.6.4 Two-gas Control Assembly (LRU 1-D)

This assembly is depicted in Figure 4-13. Two assemblies are mounted in the O_2/N_2 control panel (see Figure 4-10). Each assembly incorporates the following equipment

(a) Two toggle shutoff valves (Item 1.9)

(b) PO_2 control valve (solenoid) (Item 1.11)

(c) PO_2 controller (Item 1.13)

(d) Oxygen regulator (Item 1.7)

(e) Cabin pressure regulator (Item 1.2)

(f) Check valve (Item 1.8)

(g) Flow sensor (Item 1.300)

(h) Two pressure transducers (Item 1.116 and 1.117)

All components are mounted on an aluminum channel secured to the O_2/N_2 control panel frame by four screws. Access is gained to the LRU by removing the face of the panel. Oxygen and nitrogen are fed to the LRU from either side. Access holes are provided for disconnecting these two fluid lines from the front. Adequate electrical harness length is provided so that the electrical connector to the transducers, solenoid valve, and controller can be disconnected after removal of the assembly from the panel.

Overall dimensions are 5.0 in. by 11.0 in. by 7.62 in. Overall weight of the assembly, including mountings, lines, and connectors, is estimated at 12.3 lb.

4.3.6.5 O_2 and N_2 Manual Pressurization (LRU's 1-E and 1-F)

These two LRU's consist of a manual shutoff valve (Item 1.9) and an orifice (Item 1.17 or 1.18) each. They are removable separately as shown in Figure 4-10. Each valve is secured to an aluminum channel mounted on the frame.

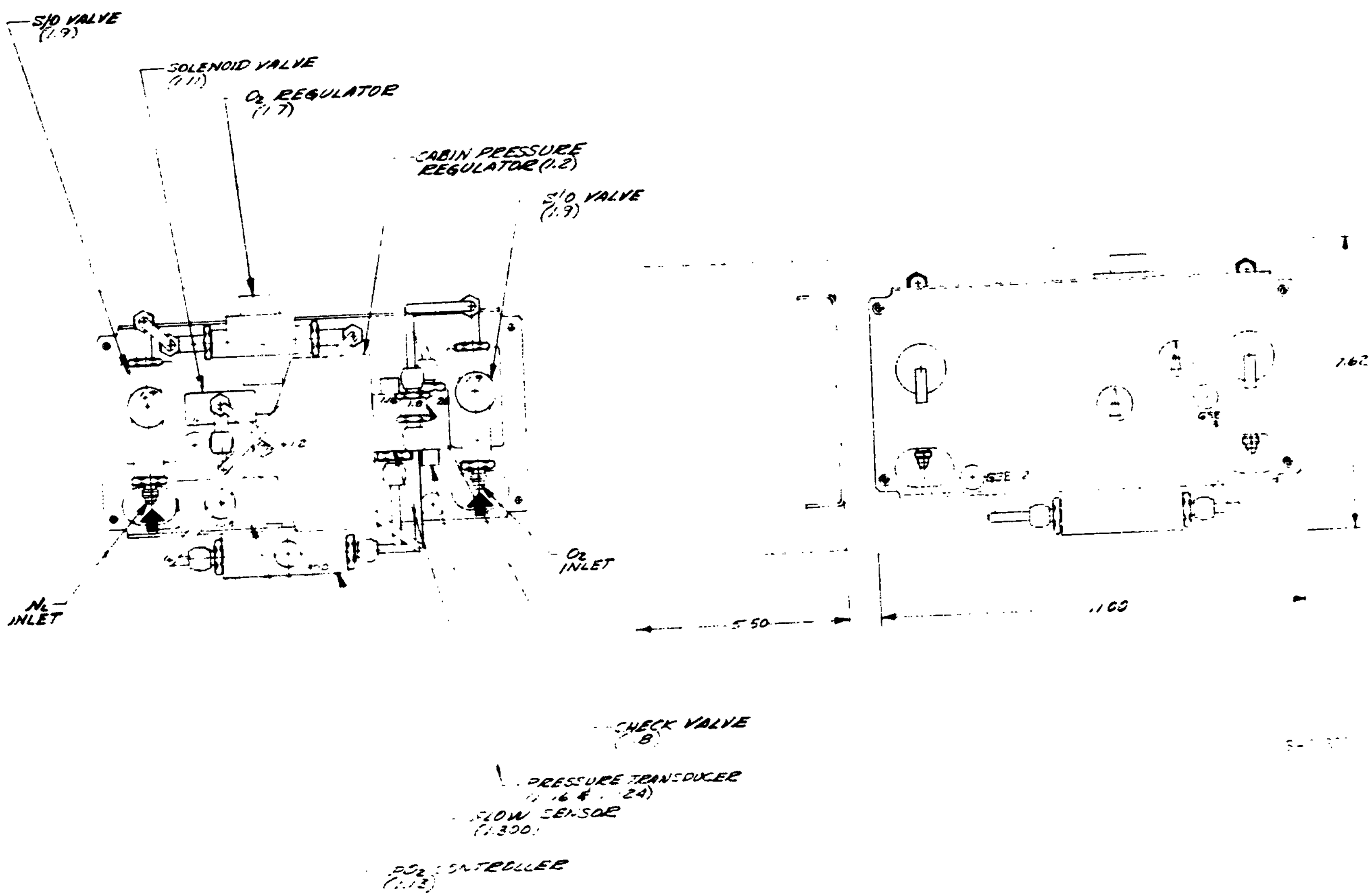

Figure 4-13. Two-Gas Control Assembly

The channel can be removed by unfastening four standard screws and one fluid connection to gain access to the valve.

Overall dimensions for one LRU are 3.0 in. by 3.5 in. by 4.5 in. Estimated weight is 1.46 lb.

4.3.6.6 Water Tank Pressurization (LRU 1-G)

This LRU is mounted on the left side of the O_2/N_2 control panel and consists of two water tank pressure regulators/relief valves (Item 1.10). Each valve assembly incorporates dual regulators/relief elements and manual selector valves for isolation of either regulator/relief element. Pressure transducers (Items 1.114 and 1.115) for tank pressure monitoring also are included in the package. A test port is included on the face of the panel (see Figure 4-14).

The regulator/relief valves and transducers are mounted on an aluminum channel secured by four screws to the vehicle structure Removal of the LRU will entail removing these four screws after disconnecting the three nitrogen lines (one from the N_2 manifold and two to the water tanks). The fluid connectors are accessible from the front of the panel. Electrical connections can be broken after removal of the LRU from the mounting structure.

4.3.6.7 EVA Support Panel (LRU 1-S)

Two EVA support panel LRU's are located near the airlock and are used for PLSS recharge and for connecting the oxygen mask assembly for prebreathing prior to EVA or in emergency situations. Figure 4-15 shows the arrangement of the components, which include

(a) Prebreathing O_2 regulator (Item 1.43)

(b) Two oxygen shutoff valves (Item 1.46)

(c) 100-psi connector (Item 1.52)

(d) 900-psi connector (Item 1.53)

(e) PLSS service pressure gage (Item 1.79).

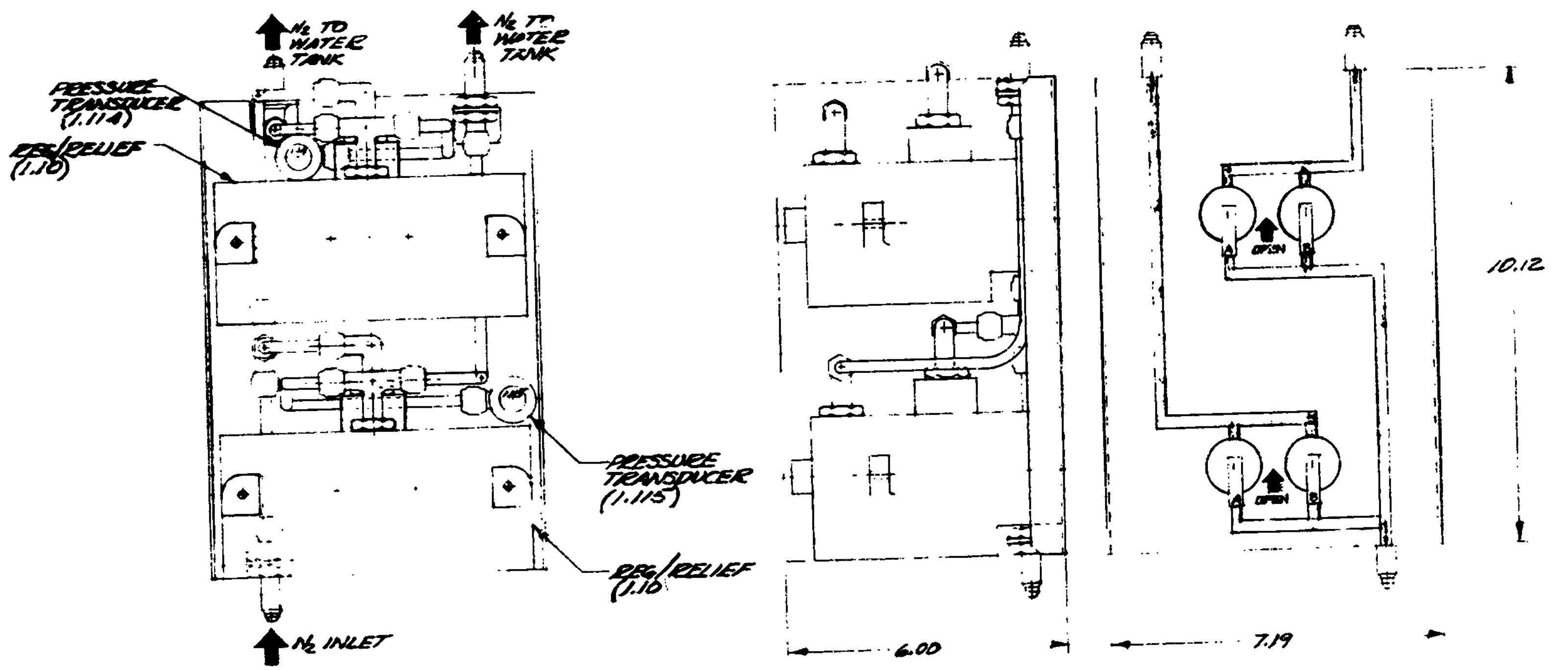

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Figure 4-14. H_2O Tank Pressure Regulator/Relief Panel, LRU 1-G

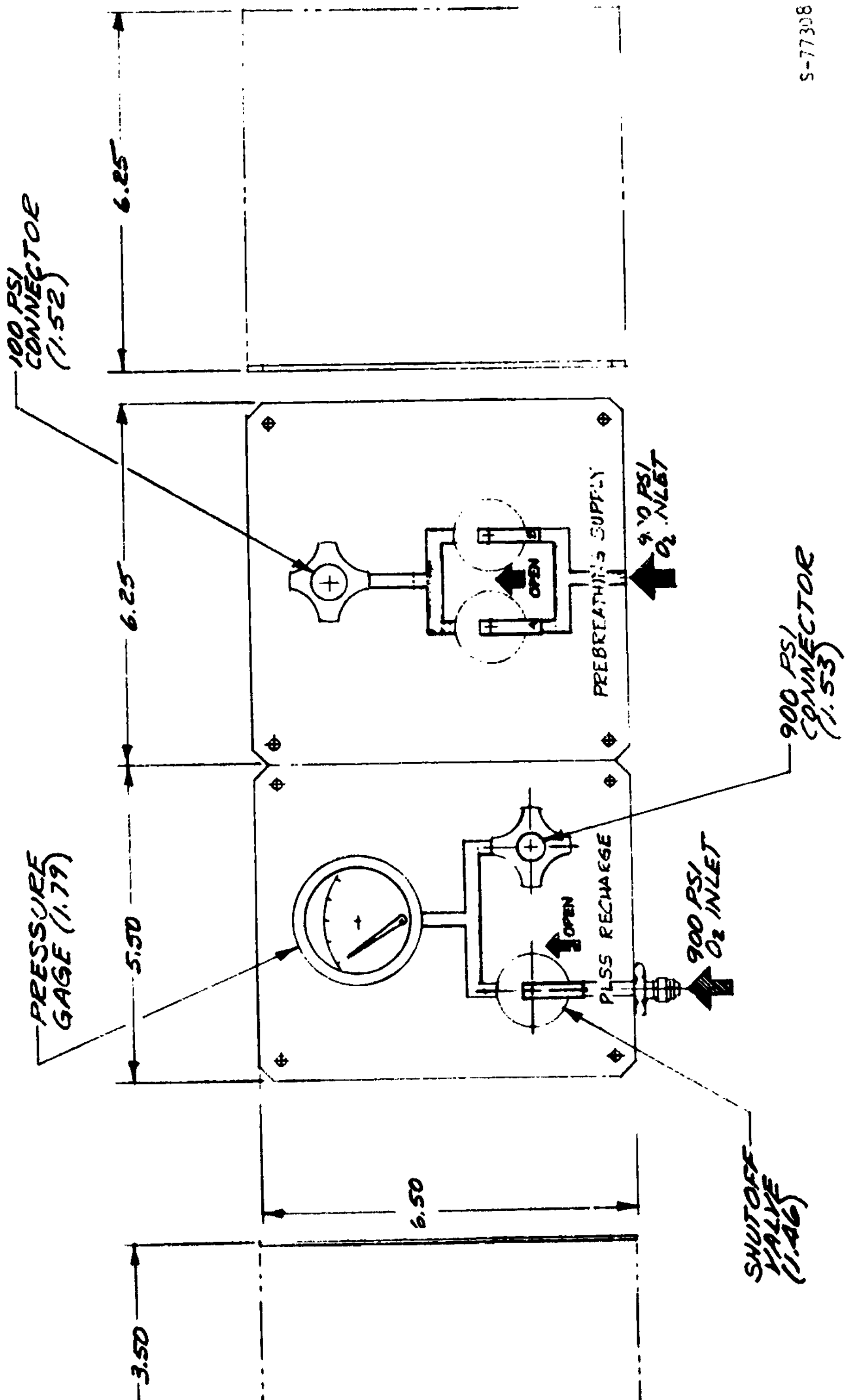


Figure 4-15. EVA Support Panels LRU.1-S

As shown, the PLSS recharge equipment and the prebreathing equipment can be removed separately. All components are mounted on two aluminum panels that are secured to the vehicle structure by four screws. One fluid connection (900-psi O_2) must be uncoupled before the panel can be removed; it is accessible from the front of the panel.

Overall dimensions are given in Figure 4-15. The overall weight is estimated at 2.68 lb for the PLSS recharge panel and 4.61 lb for the prebreathing panel.

4.3.6.8 N_2 Storage Tank Assembly (LRU 1-N)

The LRU for the N_2 storage tank assembly consists of the following equipment:

(a) Nitrogen tank

(b) Solenoid isolation valve

(c) Fill valve and burst disc

(d) Tank pressure transducer

Figure 4-16 shows the assembly. The tank is mounted on a frame designed for wall or floor installation. The frame is such that the tanks can be nested together in groups of three or six. The entire assembly is mounted to the vehicle structure by means of four bolts. All small components are accessible and can be removed as separate LRU's without the requirements for tank replacement. Should the tank fail, the entire assembly will be removed from the spacecraft.

Overall dimensions of the package are noted in Figure 4-16. The weight of the assembly is estimated at 36.2 lb.

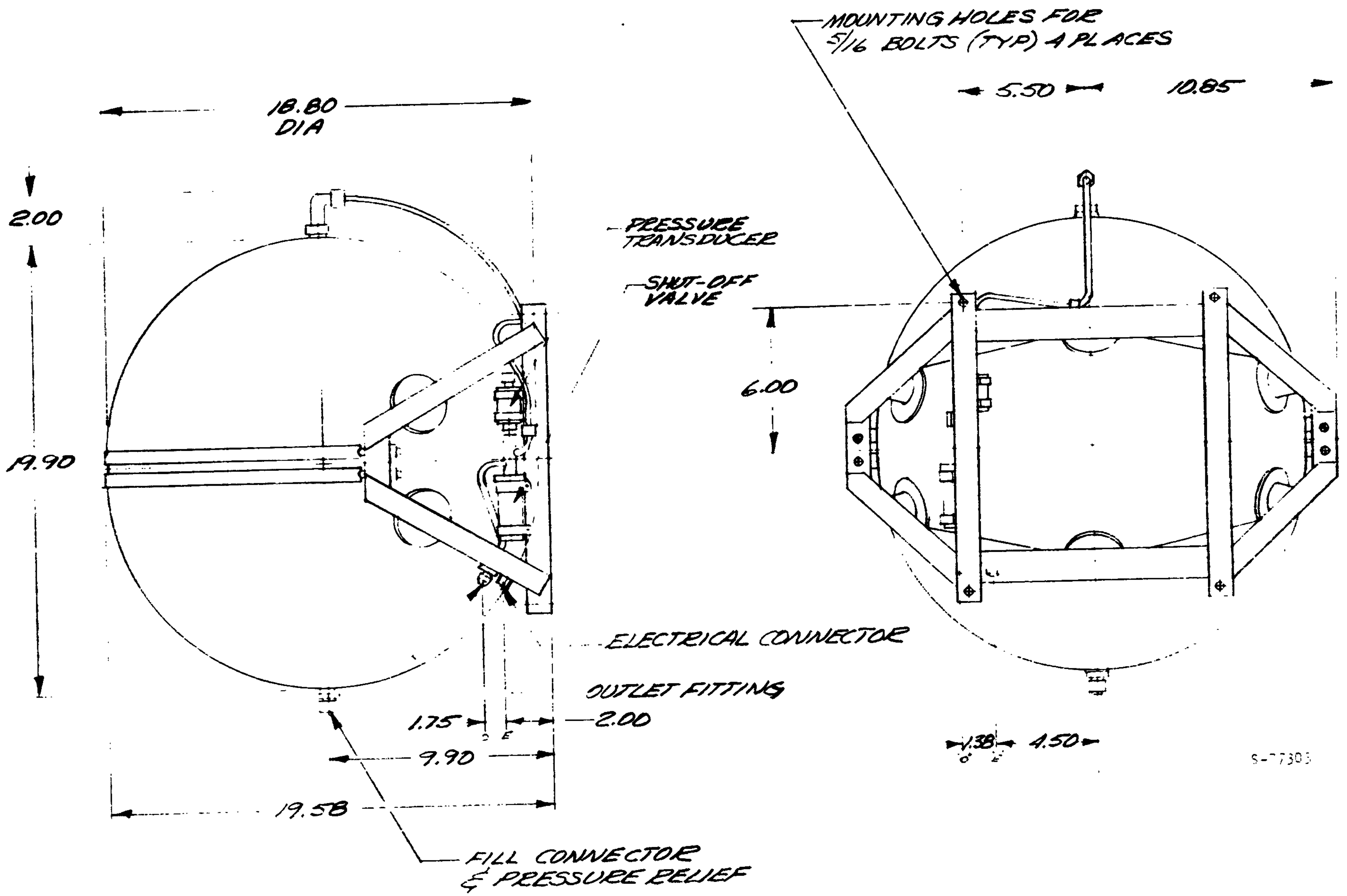


Figure 4-16. Oxygen-Nitrogen Storage Tank Assembly, IRU 1-M

4.3.6.9 Oxygen Storage Tank Assembly (LRU 1-M)

The oxygen storage tank assembly (LRU 1-M) is similar to the nitrogen except that the tank is larger and heavier. Also, the oxygen assembly includes a pressure regulator/relief valve. The frame to support the oxygen tank will be similar to the nitrogen frame. The weight is estimated at 54.8 lb.

4.3.7 Equipment Redundancy

The equipment arrangement depicted in Figure 4-8 is adequate to meet the reliability requirements of the space shuttle orbiter. Ample redundancy is provided and backup operating modes are available to assure crew safety after two failures. A review of the subsystem in terms of equipment malfunction follows.

4.3.7.1 Nitrogen Storage Module

A total of eight nitrogen storage modules are provided. The loss of any one module will not result in a situation involving crew safety. However, it could result in a degradation of the mission objectives. About 30 lb of N_2 are necessary for the 4-day contingency and 100 lb for cabin repressurization. Should one or two tanks be lost, ample capability remains unless a situation develops necessitating cabin repressurization. Such a case would probably result in mission abort, although operation at lower cabin pressure is possible. Figure 4-17 shows the rate of cabin total pressure decay if nitrogen flow to the cabin were completely stopped and the oxygen partial pressure were maintained at 3.1 psia. The data show that the cabin pressure will drop by 2 psi (from 14.7 psia) in about 60 hr. The low rate of cabin pressure decay is acceptable for orbital operation. However, since the cabin relief valve has no inflow capability, repressurization using either oxygen or nitrogen will

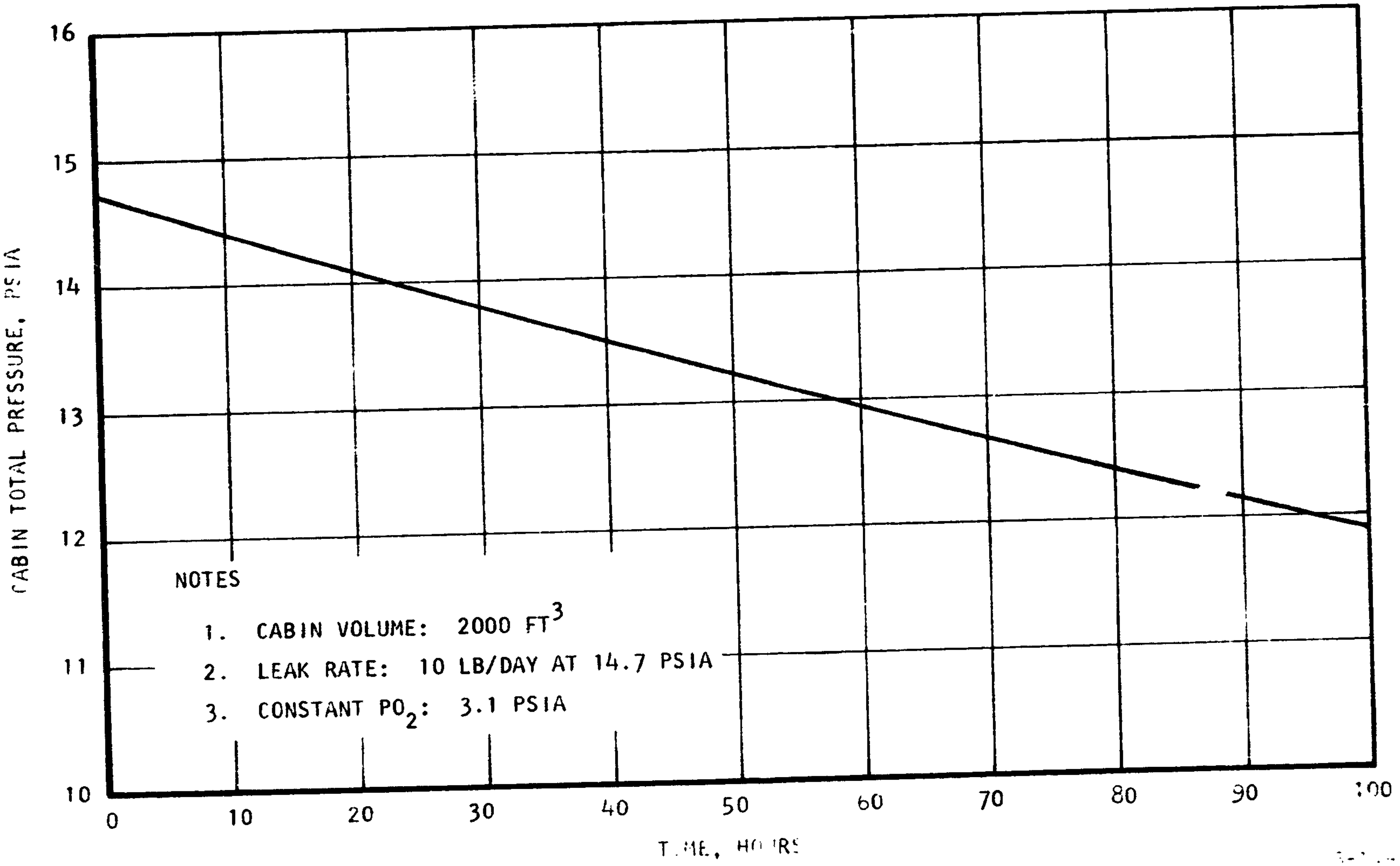


Figure 4-17. Cabin Total Pressure History without N_2 Feed

be necessary before entry. Another mode of operation would be to maintain cabin total pressure by addition of oxygen. In this case the cabin PO_2 will increase slowly. The levels of oxygen pressures obtained as a function of time are shown in Figure 4-18. This also is an acceptable mode of operation for durations as long as four days.

Generally, a nitrogen storage module will fail as a result of the failure of a valve. The storage tank itself is a pressure vessel, and the FO-FS criterion does not apply. The most likely failure mode of the composite tank is leakage due to cycle life fatigue of the metal liner. This type of failure is consistent with the intent of fracture mechanics and fracture control. Check valves are used on each module to back up the tank isolation valves.

4.3.7.2 Oxygen Supply Module

Primary and secondary oxygen supply lines from the cryogenic tanks are provided for normal operation. The flow capability of these cryogenic tanks is limited by the tank pressurization scheme so that the high flow required for cabin pressurization in one hour and airlock repressurization in five minutes can only be obtained from the high-pressure oxygen storage tanks. Two such tanks are provided. Both are necessary if one cabin repressurization is to occur during the mission. The loss of a tank would degrade mission success because repressurization would be slower (2 hours) if all oxygen were derived from the cryogenic tanks. Also, the loss of a tank would diminish the overall oxygen supply and the mission would have to be shortened. Failure of a high-pressure tank, however, does not involve crew safety because four sources of oxygen actually are available. It is recommended that only one tank be on stream at any time and that alternate tank usage be scheduled through the mission. In this manner the loss of expendable oxygen will be minimized in the event of a failure.

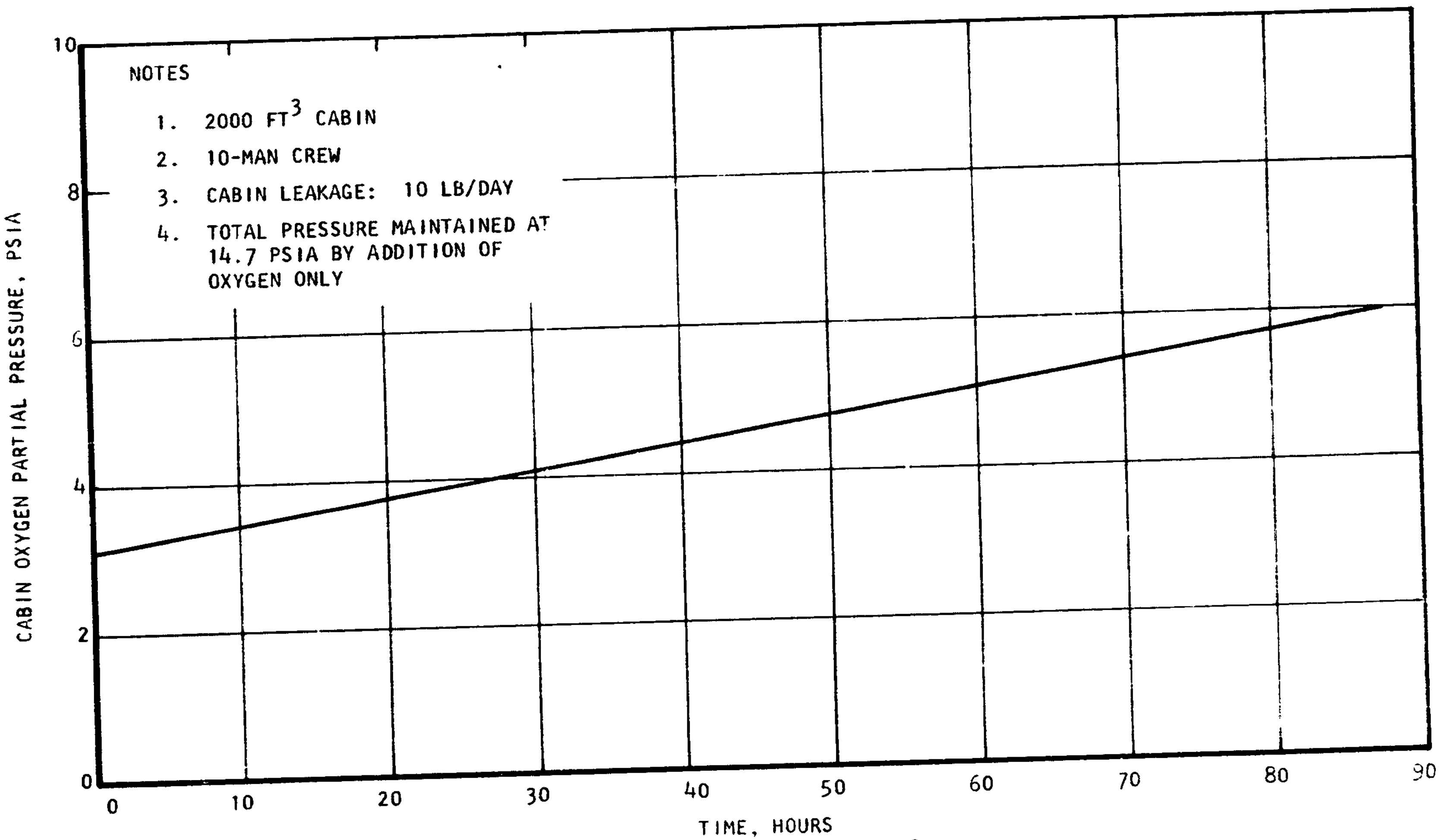


Figure 4-18. Cabin Oxygen Partial History with No Nitrogen Feed

The oxygen module is similar to the nitrogen; however, a regulator is incorporated in the package.

4.3.7.3 140-psi N_2 Supply

Three parallel regulators (Item 1.25) are used to reduce the nitrogen pressure to 140 psi (nominal). These regulators are located in the unpressurized area and can be isolated by means of solenoid shutoff (Item 1.19) and check valves (Item 1.16). Double failures could disable the entire nitrogen supply. However, as mentioned above operations could be continued for as long as four days using only oxygen for cabin pressurization. No airlock operation or cabin repressurization would be possible. Only one regulator will be on stream at any one time. The other two will be isolated by means of the solenoid isolation valve. The arrangement shown in the schematic of Figure 4-8 meets the FO-FS criterion.

4.3.7.4 900-psi Oxygen Supply

Check valves are provided in all four oxygen supply lines from the cryogenic and high-pressure gas tanks to isolate a failed supply.

4.3.7.5 Two-Gas Control Module

FO-FS capability is provided by three control modules: two are automatic and one is manual. The arrangement of these modules is such that inflight failure detection is simple and requires a minimum of instrumentation and crew interpretation (see later discussion). The manual mode is recommended for reasons of weight and cost. Furthermore, as mentioned previously crew intervention in the manual mode (FS conditions) is minimal, and the mission would not have to be aborted because of the very high reliability of the manual repressurization valves.

4.3.7.6 Water Tank Pressurization

Two water tanks that are essentially pressure vessels are provided. No tank failure is anticipated over the entire life of the vehicle. Each tank is pressurized by means of a regulator/relief valve incorporating redundant regulator/relief elements. Check and isolation valves are provided in the design to permit selection of either or both regulator/relief elements. With this arrangement failure of one element of a regulator/relief will not involve loss of capability. Mission degradation, however, will occur after failure of the second element of the same regulator. Fail-safe operation will be assured by the second tank.

With close inventory of the water in the second tank, it may be possible to continue the mission.

4.3.7.7 Miscellaneous Gas Supply Functions

The cabin pressure relief valve (Item 1.1) incorporates redundant elements with solenoid override for opening or shutting any one element. Fail-safe operation is through the solenoid override feature.

The avionics bays are pressurized from the cabin by means of a relief-type valve (Item 1.3) consisting of a molded rubber poppet which cracks open when the differential pressure between the cabin and the avionics bay is 0.4 psid. No backup is necessary because this type of valve has an extremely high reliability. Fail-safe operation is provided by a blowout panel, which will prevent structural damage in case of valve failure. The avionics bay relief valve (Item 1.37) incorporates the same redundancy and override features as the cabin relief valve.

Redundant PLSS recharge facilities are provided. Failure of both will not compromise crew safety. Similarly redundant airlock pressurization valves (Item 1.6) and pressure gages (Item 1.5) are included to permit normal operation after the first failure. The same rationale apply to the tunnel pressurization and airlock repressurization equipment (Items 1.77, 1.78, 1.33, and 1.34). Four prebreathing oxygen supplies are available, which is more than adequate for EVA support. The requirements for four stations is established by consideration of long-term emergency oxygen supply for the 4-man crew.

4.3.8 Redundancy Management

The redundancy management requirements for the atmospheric control subsystem are summarized in Table 4-9. The subsystem is divided into four functional groups:

(a) Gas storage and supply (O_2 and N_2)

(b) Cabin total and oxygen pressure control

(c) Avionics bay pressure control

(d) Water tank pressurization

Miscellaneous functions of the atmospheric control subsystem, such as prebreathing O_2 equipment, airlock pressurization, etc., will be fault detected directly by the crew without instrumentation. This type of equipment, consisting generally of manual valves or disconnects, is not considered in Table 4-9

One aspect of the gas storage subsystem that merits attention is the requirement for N_2 and O_2 inventory control throughout the mission. A periodic check of the remaining supplies should be made at preset intervals and compared to the quantities predicted at the start of the mission. In this manner, vehicle and system leakage will be assessed accurately and situations involving crew safety avoided.

TABLE 4-9

REDUNDANCY MANAGEMENT SUMMARY, ATMOSPHERE CONTROL SUBSYSTEM

Functional Symptom	Onboard Sensor	Possible Causes	Redundancy Management Action	Remarks
1. Low N_2 tank pressure (on-line tank)	P 1.106	1.1 Tank depletion [illegible] 400 p[illegible] 1.2 Tank assembly leakage	1.1.a Switch on standby tank as per schedule 1.1.b Check usage schedule to identify if tank depletion rate is normal or not 1.2 Same as 1.1.a and 1.1.b	1.1.a Only one tank [illegible] normal operation 1.1.b N_2 inventory must be monitored throughout the mission to identify abnormal leaks either from the cabin or the equipment
2. Low N_2 tank pressure (standby tank)	P 1.100	2.1 Tank assembly leakage internal 2.2 Tank assembly leakage external	2.1 Shutoff on line tank and switch on faulty N_2 tank 2.2 Same as 2.1	2.1 See 1.1.b, action will minimize losses 2.2 See 1.1.b
3. Low O_2 tank pressure (on-line)	P 1.108	3.1 Regulator/relief (1.20c) leakage 3.2 Leakage of other tank assembly component (tank, fill valve, or transducer)	3.1 Isolate tank with solenoid shutoff valve (1.208) 3.2 Isolate tank with solenoid shutoff valve (1.208), condition will worsen	3.2 Degraded mode operation, reduced amount of O_2 for rapid airlock pressurization and or emergency
4. 140-psi N_2 manifold pressure low On-line tank pressure normal	P 1.110	4.1 Regulator (1.25) failure (closed)	4.1 Isolate faulty regulator and switch on redundant unit	4.1 Only one regulator on in normal operation
5. 140-psi N_2 manifold pressure high	P 1.110	5.1 Regulator (1.25) failure (open)	5.1 Same as 4.1	
6. 900-psi O_2 manifold pressure low Flow sensor normal (1.300)	P 1.112	6.1 Cryogenic supply malfunction 6.2 900-100 O_2 pressure regulator (1.7) failure (open)	6.1 None 6.2 Override valve 7.24; if condition persists, switch loop	6.1.a This condition must be detected from cryogenic storage and supply subsystem sensors 6.1.b If condition persists, mission must be aborted 6.2.a Delivery capability of cryogenic supply system exceeded 6.2.b High O_2 flow from relief valve may be [illegible]
7. 900-psi O_2 manifold pressure low High flow to cabin (1.300)	P 1.112	7.1 Excessive cabin leakage	7.1 Try to isolate leak, if unsuccessful monitor gas inventory and plan abort	
8. Cabin PO_2 high Cabin PT ok N_2 manifold pressure ok	Cabin PO_2 1.500	8.1 PO_2 controller/sensor failure (1.12, 1.13) 8.2 PO_2 control valve (1.11) failed closed 8.3 Small O_2 leak into cabin	8.1 Switch over to redundant PT/PO_2 control LRU 8.2 Same as 8.1	
9. Cabin PO_2 low Cabin PT ok O_2 manifold pressure ok	Cabin PO_2 1.500	9.1 PO_2 controller sensor failure (1.12, 1.13) 9.2 PO_2 control valve (1.11) failed open 9.3 Small N_2 leak into cabin	9.1 Same as 8.1 9.2 Same as 8.1 9.3 Same as 8.1	
10. Cabin PT high Cabin PO_2 high O_2 and N_2 manifold ok	PT 1.190 PO_2 1.500	10.1 O_2 leakage into cabin	10.1 Same as 8.1	
11. Cabin PT high Cabin PO_2 low O_2 and N_2 manifold ok	PT 1.190 P[illegible] 1.500	11.1 N_2 leakage into cabin	11.1 Same as 8.1	
12. Cabin PT high PO_2 ok [illegible]	[illegible] 1.192	12.1 Cabin pressure regulator [illegible] failure 12.2 [illegible]	12.1 [illegible] 12.2 [illegible]	

TABLE 4-9 (Continued)

Functional Symptom	Onboard Sensor	Possible Causes	Redundancy Management Action	Remarks
13. Cabin PT low PO_2 ok	PT 1.190	13.1 Cabin pressure regulator (1.2) failure	13.1 Same as 8.1	
14. Water tank pressure high	P 1.114	14.1 Open regulator failure (1.10) 14.2 Closed relief valve failure (1.10)	14.1 Switch to redundant unit 14.2 Same as 14.1	
15. Water tank pressure low N_2 manifold pressure ok	P 1.114	15.1 Regulator or relief valve (1.10) failure	15.1 Same as 14.1	
16. Erratic tank pressure N_2 manifold ok	P 1.114	16.1 Tank bladder failure	16.1.a Shut off both regulator sections 16.1.b Shut off water tank	
17. Avionics bay pressure high	P 1.126	17.1 Pressure regulator (1.3) failure	17.1.a Shut off avionics bay regulator (1.3) 17.1.b Manual control of avionics bay pressure	Degraded mode operation
		17.2 Excessive leakage from cabin into avionics bay	17.2.a Shut off avionics bay regulator (1.3); condition will persist 17.2.b Attempt to isolate leakage and repair if avionics bay pressure can be controlled by manual override of avoinics bay relief valve (1.37) (not recommended)	May involve periodic crew action [illegible] mission; if so, recommend redundant regulator.
		17.3 Fire in avionics	17.3 Extinguish fire	
18. Avionics bay pressure low Cabin pressure ok	P .1126	18.1 Avionics bay pressure relief valve (1.37) leakage	18.1 Override relief valve (1.37) close	
		18.2 Pressure regulator (1.3) failed closed	18.2 Same as 17.1.b	See 17. above

Flow sensors in the nitrogen or oxygen streams of the cabin pressure regulators will not provide a continuous measurement of cabin leakage because either oxygen or nitrogen is introduced into the cabin at any time. Locating the flow sensor immediately upstream of the cabin pressure regulator is preferable. Cabin leakage is not a subsystem parameter.

The redundancy management tasks are relatively simple for the atmospheric control subsystem once a procedure is established for gas inventory control. It consists mainly of (1) monitoring the storage pressure of the storage tanks and supply manifolds with corresponding isolation tanks necessary for isolation of the faulty components, and (2) monitoring PO_2 and P_T; the only fault rectification task involves switchover to the redundant gas composition control LRU.

The rationale for fault isolation is fairly simple, as shown in Table 4-9. Minimum crew training will be necessary because the redundancy management modules were defined as simple functional modules.

In general, storage tank and manifold pressure will respond relatively fast to a failure unless the leakage is small. Corrective action accordingly should be executed as soon as possible after detection of the fault to preserve expendables. It is recommended that a minimum number of storage tanks be kept on-line commensurate with the mission requirements.

The cabin PO_2 and P_T parameters will be somewhat sluggish by comparison except in the event of rapid increase in cabin leakage. Due to the damping effect of the large cabin, ample time will be available for correction of an ETC/LSS subsystem faulty module.

4.4 WATER MANAGEMENT SUBSYSTEM

4.4.1 Functional Requirements

The water management subsystem purifies and stores the fuel cell water for use in crew food and waste management, and for use as an expendable in the water coolant loop flash evaporators.

4.4.2 Design Requirements

The design requirements for this subsystem are given below by functional usage. The component design requirements are summarized in para. 4.4.4.

Water Source

Fuel cell: Type A or Type B (TBD)

Supply rate: 0.8 lb water per kw·hr

Maximum water production rate: 11.0 lb/hr

Hydrogen removal: Palladium permeable tubes

Bacteria control: Silver ion generation

Supply pressure: 15-25 psig

Supply temperature: 150° - 200°F

Water Storage

Number of tanks: 2

Tank capacity: 100 lb water at 70°F

Minimum tank pressure: 15 psig

Nominal tank pressure: 18 psig

Tank bladder relief: 24 psig (maximum)

Water Distribution

Hot water supply temperature: $150^{\circ} \pm 5^{\circ}$F

Cold water supply temperature: 50°F maximum

Maximum cold water flow rate: 60 lb/hr

Maximum sublimator flow rate: 75 lb/hr

Urine flush: 0.33 lb/cycle at delivery rate of 300 lb/hr

4.4.3 Subsystem Description

The water management subsystem consists of four major equipment groups that perform the functions of conditioning, distribution, storage, and control for the potable water. These four equipment groups are:

Conditioning--Silver ion generator and deionizer, and hydrogen separator

Potable Water Delivery--Water heater, water chiller, and distribution

Storage--Tankage

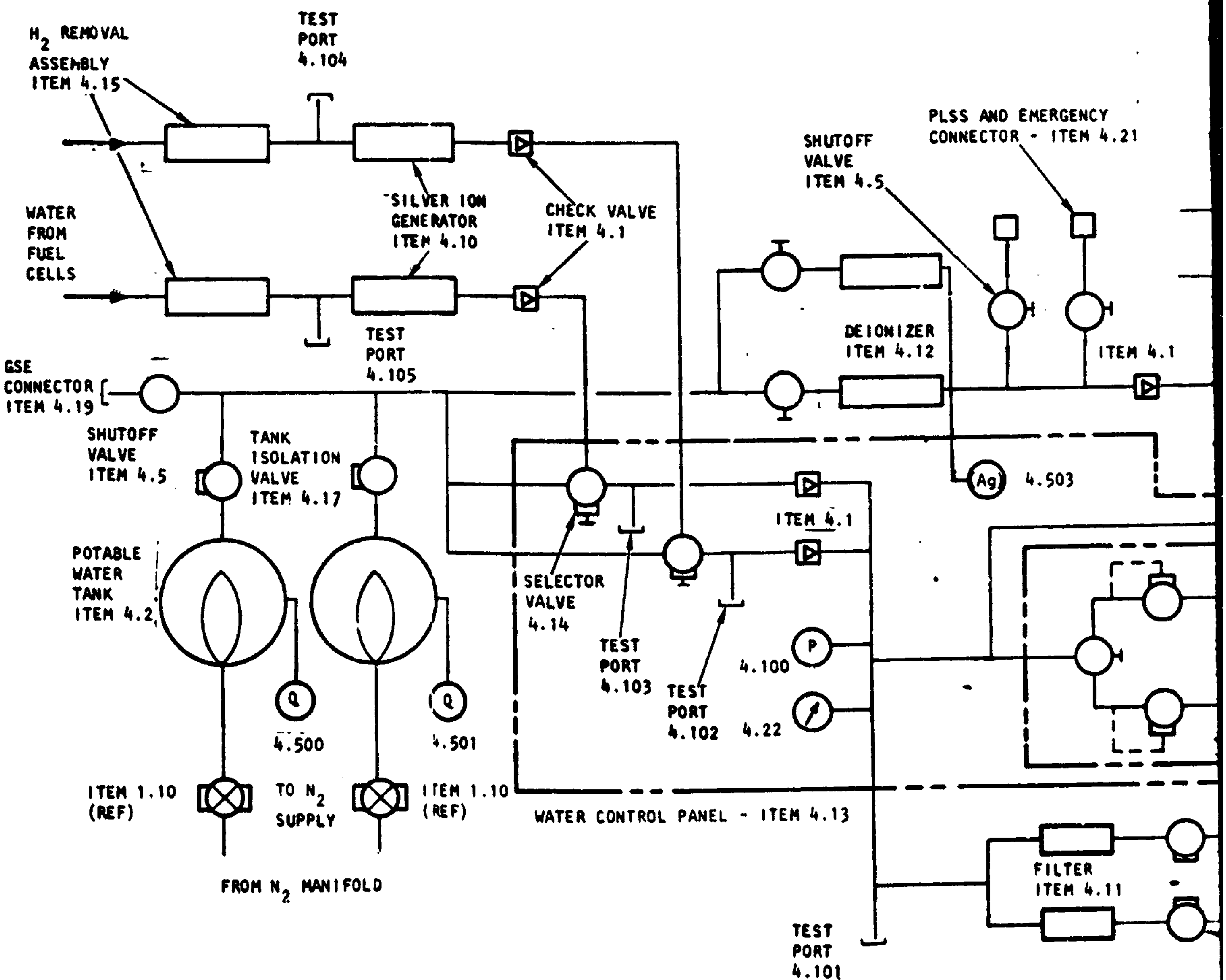
Control--Valves, regulators, and selectors required for operation

Figure 4-19 shows the component arrangement for the water management subsystem; the components are arranged to provide redundancy of the functions.

Potable water is produced by the reaction of hydrogen and oxygen in the fuel cell power supply. This water is processed in a hydrogen separator to remove gaseous and dissolved hydrogen from the water delivered to the potable water assembly. All fuel cell water is treated by addition of silver ions as a biocide to assure a biologically safe supply of potable water, and to limit growth of organisms within the system.

Water stored in the pressurized water tanks may be withdrawn upon demand by the crew through either a water heater or a water chiller for food reconstitution and drinking at the food management system and water supply area. The water supplied to the crew for drinking or food preparation is circulated through the deionizer bed for removal of the excess silver.

FOLDOUT FRAME 1



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FOLDOUT FRAME

ITEM NO.	DESCRIPTION	NUMBER REQUIRED
4.1	WATER CHECK VALVE	5
4.2	POTABLE WATER TANK	2
4.4	WATER CHILLER	2
4.5	WATER SHUTOFF VALVE	4
4.7	WATER HEATER	1
4.8	WATER PRESSURE RELIEF VALVE	1
4.10	SILVER ION GENERATOR	2
4.11	WATER FILTER	2
4.12	POTABLE WATER DEIONIZER	2
4.13	WATER CONTROL PANEL	1
4.14	SELECTOR VALVE	2
4.15	HYDROGEN REMOVAL ASSEMBLY	2
4.16	WATER DUMP NOZZLE	1
4.17	WATER SOLENOID SHUTOFF VALVE	4
4.19	GSE CONNECTOR	1
4.21	PLSS AND EMERGENCY CONNECTOR	2
4.22	PRESSURE GAGE	1
4.100	WATER PRESSURE SENSOR	1
4.200	WATER NOZZLE TEMPERATURE SENSOR	1
4.500	WATER TANK QUANTITY	1
4.501	WATER TANK QUANTITY	1
4.503	SILVER ION DETECTOR	1

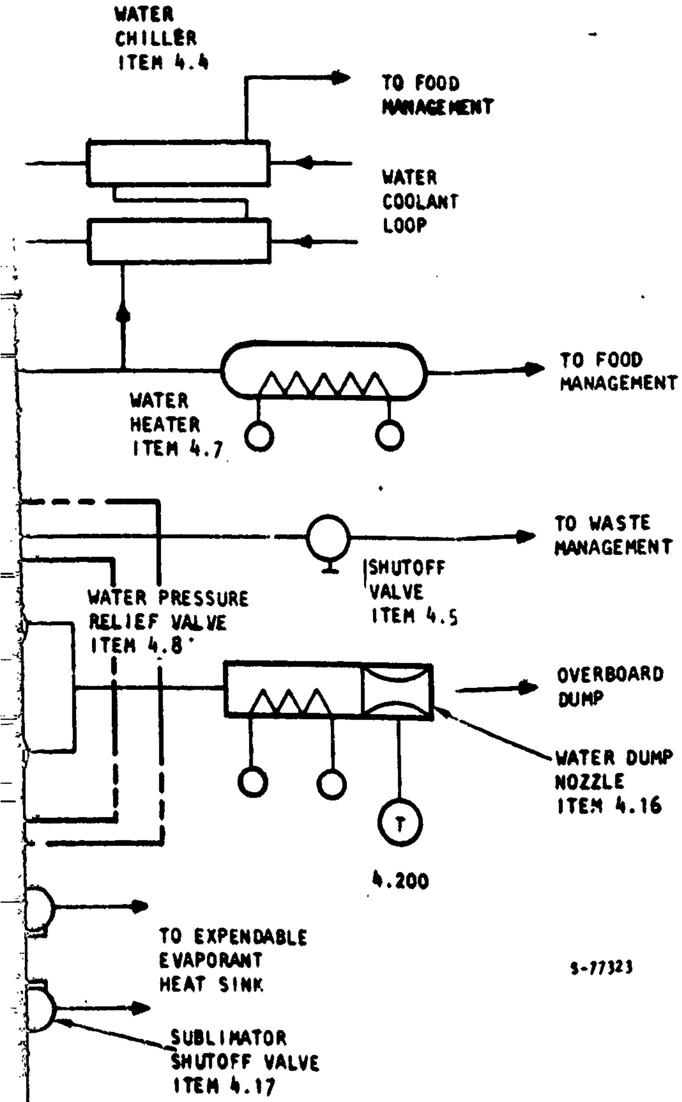

Figure 4-19. Water Management

The operational modes for the potable water management subsystem are controlled by the position of the selector valves (Item 4.14) on the water control panel (Item 4.13). The selector valve is a four-position, three-port valve that permits isolation or interconnection of the ports as shown in Figure 4-20.

The fuel cell water delivery pressure is a nominal 18 psig with a maximum delivery pressure of 25 psig. The water tank pressure regulator (Item 1.10) will control the tank bladder pressure to a nominal value of 18 psig. Thus, with the selector valves in the NORMAL position, as the fuel cell delivers water to the water management system, the water pressure level within the system will rise with no water consumption. When the water pressure reaches a nominal value of 21 psig, the relief portion of the water tank pressurization valve (Item 1.10) will crack open, thereby allowing the bladder to collapse and the water tank to be filled by the fuel cell water. If both water tanks are full, the system water pressure level will rise to the maximum fuel cell delivery pressure of 25 psig, at which time the water pressure relief valve (Item 4.8) will crack to allow the water to be dumped overboard through the water dump nozzle (Item 4.16).

This method of dumping will not be used normally since the space shuttle overall requirements prohibit dumping of liquids to space. The water relief valve and nozzle are incorporated as a safety device. Normally water dumping will be effected through the flash evaporators. A periodic inventory of the water tanks will be made, and tank dumping will be scheduled as part of mission planning. This will require crew override of the flash evaporator normal control.

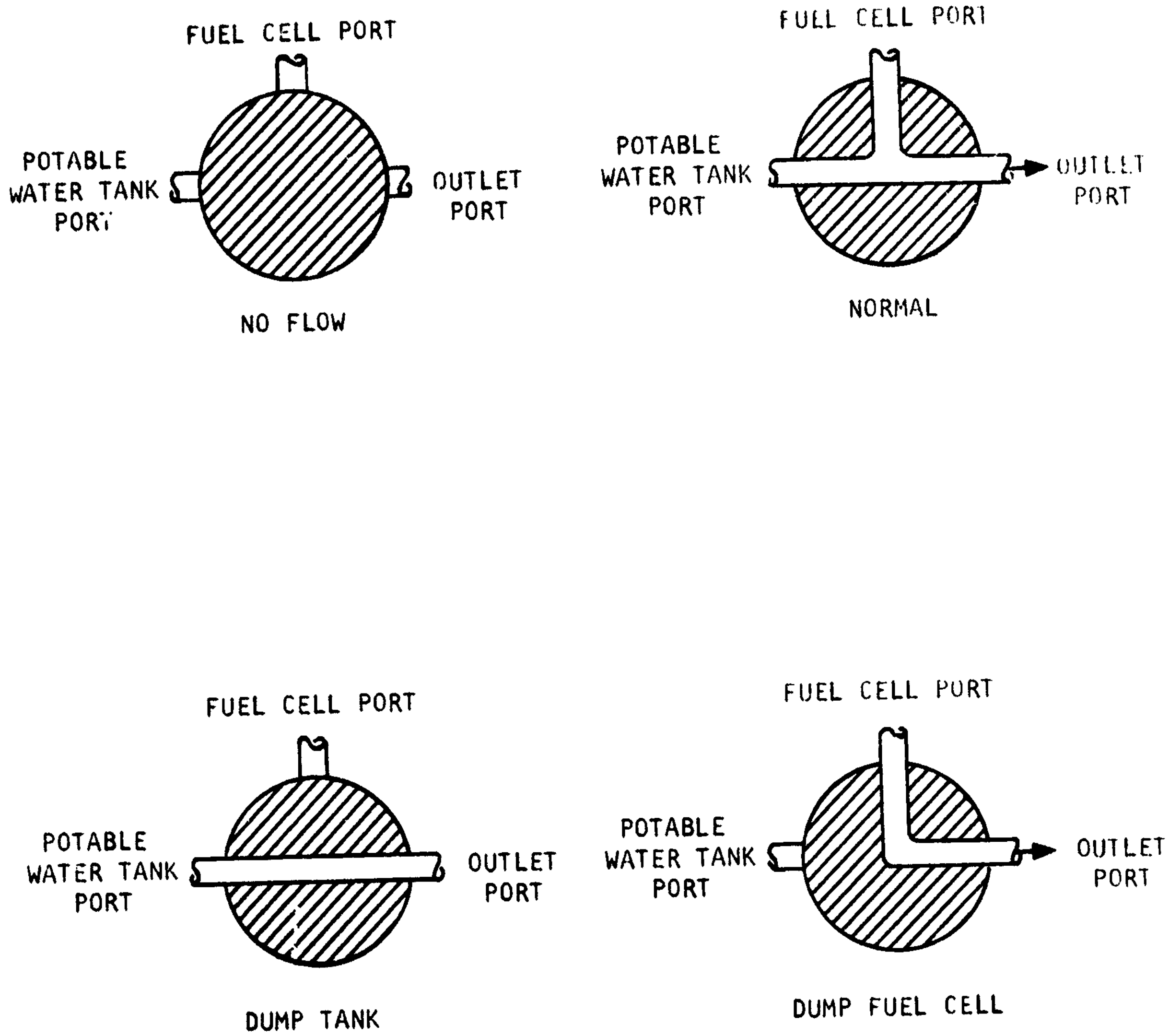

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Figure 4-20. Potable Water Selector Valve Position

The flash evaporator shutoff valves (Item 4.17) are solenoid operated valves that normally are open. These valves may be closed to override the evaporator controls or to isolate the water management subsystem from the evaporators for system checkout. The particulate filter (Item 4.11) is required to protect the evaporator spray nozzle from plugging.

The water supply from the fuel cell is treated against bacteriological contamination by the addition of silver ions (Item 4.10). These ions are removed by the deionizer (Item 4.12) prior to the astronauts' use of the water for drinking or food preparation purposes. Because the water chiller (Item 4.4) has a favorable mass-flow ratio at its design point, no chilled water reservoir is required since the unit is capable of supplying water continuously at its maximum design flow of 60 lb/hr and design temperature of 50°F (max).

4.4.4 Equipment Summary

A summary of the equipment shown in the schematic of Figure 4-19 is presented in Table 4-10. Most of the equipment is new. Components from previous programs that meet the performance requirements of the space shuttle will be modified because most of this Apollo equipment is aluminum, and the proposed material of construction is stainless steel. The data presented in Table 4-10 are summarized below.

Number of components

Functional components	32 (including silver ion generator and deionizer)
Monitoring instrumentation	5

Number of component designs

Functional components	16 (including silver ion generator and deionizer)
Monitoring instrumentation	4

TABLE 4-10

EQUIPMENT SUMMARY, WATER MANAGEMENT SUBSYSTEM

[illegible]	[illegible]	[illegible]	[illegible] and Performance Requirement	Unit weight, [illegible]	Envelope, [illegible]	Power, [illegible]	Equipment [illegible]	Remarks [illegible]
[illegible]	Water [illegible]		Prevent water flow reversal. Max. pressure drop [illegible] at [illegible] lb/hr water flow rate. Max. crack pressure [illegible] psig. Min. operation pressure [illegible] psig nominal, 18 [illegible] max. [illegible]	[illegible]	[illegible]	-	[illegible]	[illegible] umbrella type valve [illegible] Apollo [illegible] Good [illegible]
[illegible]	[illegible] water tank	[illegible]	Store potable water for C[illegible] usage. Capacity, 100 lb water at 70°F. Max. water expulsion rate [illegible] lb/hr at [illegible] psig. [illegible] pressure [illegible] psig nominal, 18 psig maximum, [illegible] psig [illegible] 10 yr service life.	[illegible] 115 [illegible]	[illegible]	-	Similar	Similar [illegible] tank [illegible] alloy, [illegible]
[illegible]	Water [illegible]		Provide [illegible] water at [illegible] max. temperature. Water [illegible] inlet temperature [illegible] F. Max. water flow rate [illegible] Max. pressure drop [illegible] at [illegible] coolant [illegible] inlet temperature [illegible] F, [illegible] flow rate [illegible] Max. pressure drop 1.0 psi, redundant coolant loops.	[illegible] dry, [illegible] wet	[illegible]	-	New	Unit [illegible] with [illegible] tions. All [illegible] to prevent [illegible] installed [illegible] one in each coolant water [illegible] and materials similar [illegible]
[illegible]	Water [illegible] valve	[illegible]	Manual [illegible] valve. Max. pressure [illegible] psi at 3.0 lb/hr, water flow rate at [illegible] inlet pressure. Max. [illegible] pressure [illegible] psia. Max. external leakage.	[illegible]	[illegible] × 3 × 3.5	-	Modified	Similar design to Apollo [illegible] stainless steel, [illegible] Poppet type valve [illegible] dynamic seal [illegible] tion from full [illegible]
[illegible]	[illegible] heater	[illegible]	Heat [illegible] tank water [illegible] Tank will [illegible] water [illegible] capable of heating water at [illegible] rate [illegible] Max. operating pressure [illegible] flow rate [illegible]	[illegible]	[illegible]	[illegible]	New	All welded construction [illegible] stainless [illegible] penetration [illegible] attach[illegible]
[illegible]	Water [illegible]		[illegible] water [illegible] prevent [illegible] tank. [illegible] Max. water flow [illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
[illegible]	[illegible]		[illegible] water supply. [illegible] water. Max. [illegible] Max. pressure [illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
[illegible]	Water [illegible]		[illegible] water [illegible] Max. [illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
[illegible]	[illegible]		[illegible] Max. [illegible]	[illegible]	[illegible]		[illegible]	[illegible]

TABLE 4-10 (Continued)

Item No.	[illegible]	Qty	Function and Performance Requirements	Unit Weight, lb	Envelope, in.	Power, W	Equipment Status	Rationale/Justification
[illegible]	Water [illegible] control [illegible]	[illegible]	Panel contains [illegible] selector valves [illegible], pressure relief valve [illegible], [illegible] tank isolation valve [illegible] water [illegible] valve [illegible]	-	7 x [illegible] x 4		New	Groups manual selector valves and [illegible] switches for potable management system [illegible] malfunctions must be detected [illegible] instrumentation scan [illegible]
[illegible]	[illegible] selector valve	[illegible]	Three-port, [illegible] manual valve. Connects tank, fuel cell water supply and water distribution ports. Valve positions [illegible], NORMAL, SUMP TANK, SUMP FUEL [illegible].	[illegible]	3 x 3.[illegible] x [illegible].3	-	Modified	Similar [illegible] used [illegible] made of CRES and [illegible] teflon.
[illegible]	[illegible]	[illegible]	Reduces [illegible] partial pressure to [illegible] percent [illegible] total pressure [illegible] at [illegible] F. Maximum water flow rate [illegible] 11. [illegible] at [illegible]	1[illegible].0	11 [illegible] dia x 12	-	Similar	[illegible]
[illegible]	Water [illegible]	1	Electrically heated [illegible] vernatherm [illegible] nozzle. Maximum water flow rate [illegible] at [illegible]	[illegible]	[illegible] dia x [illegible]	11.4	Similar	Similar [illegible]
[illegible]	Water [illegible] valve	[illegible]	Mechanically, latching [illegible] rate [illegible] valve. Water inlet temperature [illegible] inlet pressure [illegible] max. [illegible] max. at [illegible] at inlet [illegible]. External leakage [illegible] cc/hr at [illegible] and [illegible] internal leakage [illegible]	[illegible]	4 [illegible] dia x [illegible]	2 amp at 28 vdc	Similar	Similar to [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]

Weight	
Fixed weight	107 lb (including water stor[illegible])
Expendable weight	8.8 lb (silver ion generator and deionizer)
Power, continuous	2 w

In addition, intermittent power will be necessary for operation of the water heater (275 w) and of the overboard dump nozzle (9.4 w).

4.4.5 LRU Definition

Table 4-11 gives the definitions for the potable water management subsystem line replaceable units (LRU). These LRU's were based on considerations of redundancy management, ground checkout, and servicing requirements.

4.4.6 Equipment Packages

This subsystem consists mainly of single (or duai) component LRU's: the only LRU assembly incorporating more than two components is the water control panel. Figure 4-21 shows this panel and the arrangement of the components. The following equipment is mounted on the panel:

- Two manual selector valves (Item 4.14)
- Two check valves (Item 4.1)
- A dual water relief valve with selector (Item 4.8)
- A manual water shutoff valve (Item 4.5)
- A water pressure gage (Item 4.22)
- A water pressure transducer (Item 4.100)
- Two switches for remote actuation of the water tank isolation valves (Item 4.17)

TABLE 4-11

POTABLE WATER LRU DEFINITION

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Sub-system	Remarks
4-A	4.13			Water panel assembly	1	
		4.1	2	Check valve		
		4.5	1	Water shutoff valve		
		4.8	1	Water relief valve		
		4.14	2	Selector valve		
		4.100	1	Pressure transducer		
		4.22	1	Pressure gage		
4-B	-	-		Potable water tank assembly	2	
		4.2	1	Water tank		
	4.17		1	Solenoid shutoff valve		
		4.500*	1	Water tank quantity		* Primary tank
		4.501*	1	Water tank quantity		* Secondary tank
4-C	4.4		1	Water chiller	2	
4-D	4.7		1	Water heater	1	
4-E	4.10		1	Silver ion generator	2	
4-F	4.11		1	Water filter	2	
4-G	4.12		1	Deionizer	2	
4-H	4.15		1	H_2 separator assembly	2	
4-I	-	-		Dump nozzle assembly	1	
		4.16	1	Water dump nozzle		
		4.200	1	Temperature sensor		
4-J	4.17		1	Solenoid shutoff valve	2	
4-K	-	-		GSE service connector assembly	1	
		4.5	1	Shutoff valve		
		4.19	1	GSE connector		
4-L	4.1		1	Check valve	2	
4-M	-	-		PLSS water service	2	
		4.1	1	Check valve		
		4.5	1	Water shutoff		
		4.21	1	PLSS/emergency connector		
4-N	4.503		1	Silver ion detector	1	

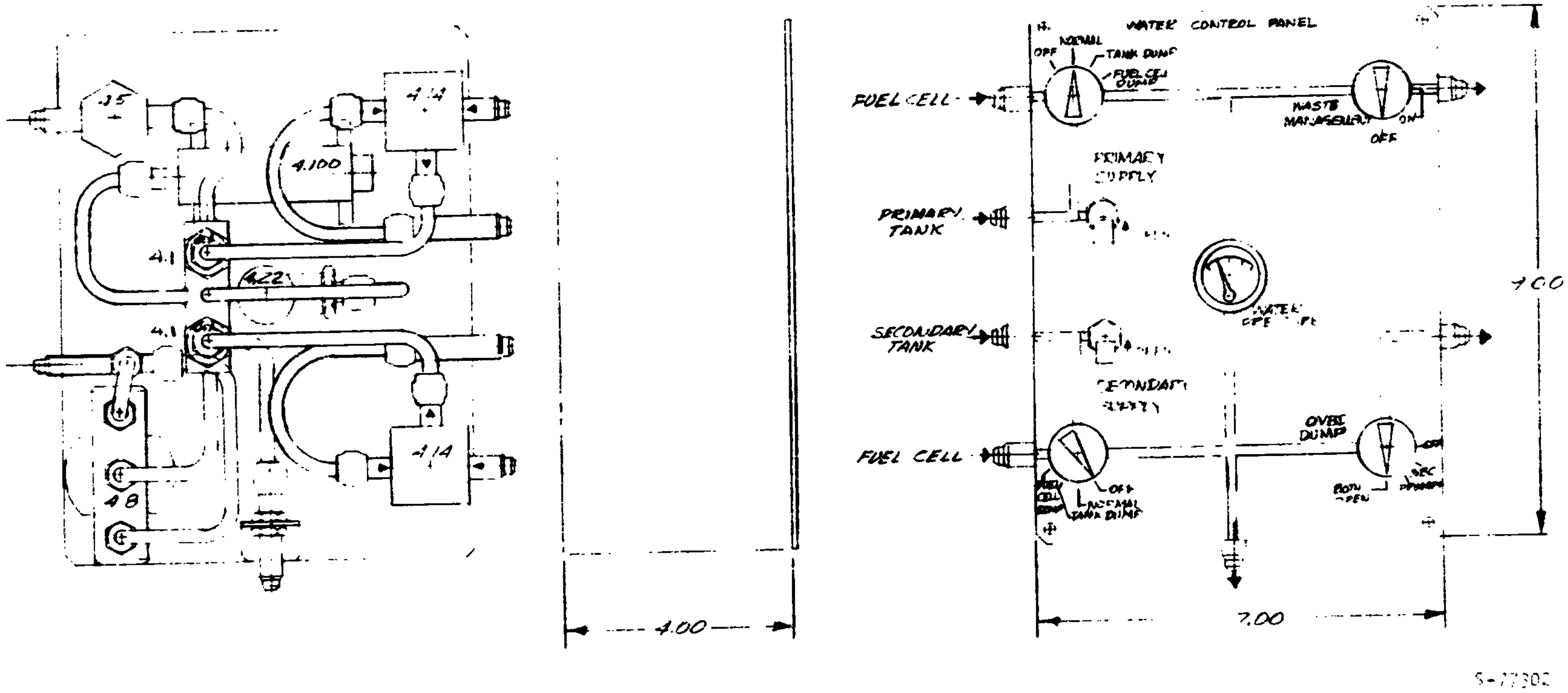


Figure 4-21. Water Control Panel

As shown, all components are mounted on a flat panel that is fastened to the vehicle structure by means of four screws. The water flow through this portion of the subsystem is engraved on the face of the panel; also shown is the information necessary for operation of the valves and switches.

The panel is removable as a single assembly. Seven water lines accessible from the front of the panel need to be disconnected and the four screw fasteners undone to remove the panel. Electrical connectors will then be disengaged. Adequate wiring length is provided for this operation.

The weight of the components included in this assembly is 3.5 lb. Overall LRU weight including the panel and interconnecting lines and connectors is estimated at 5.0 lb. Overall dimensions are shown in Figure 4-21.

4.4.7 Equipment Redundancy

The arrangement shown in Figure 4-19 generally provides for mission completion after failure of any one component and for crew safety after failure of the second component. Some exceptions are apparent in the subsystem schematic; however, deviation from the FO-FS criterion was deemed acceptable after careful examination of the hardware, its reliability, and its failure modes and effects as determined from historical data gathered from previous experience with particular equipment designs and concepts.

The entire subsystem and its components are reviewed below in terms of reliability and backup operational modes. Each subsystem function is examined separately.

4.4.7.1 Potable Water from the Fuel Cells

Each line from the fuel cells to the potable storage tanks incorporates a hydrogen separator, a check valve, and a silver ion generator.

The hydrogen separator is a static unit incorporating palladium tubes through which the fuel cell water is circulated. Hydrogen diffuses through the palladium wall and is dumped overboard. Such a device has been qualified under the Apollo program.

The check valve is an umbrella-shaped polymer check successfully used in the Gemini and Apollo systems. The only failure ever experienced with this valve is excessive leakage. In the shuttle application, back-flow of water from the storage tanks to the fuel cell would require failure of one of the fuel cells, whereby the fuel cell water supply would be depressurized. Dual check valves are used to prevent this occurrence; it is assumed that the second check valve (or an isolation valve) is in the fuel cell subsystem water delivery line. Either supply can be isolated by means of selector valve 4.14.

In terms of potability, it is assumed that the fuel cell water will satisfy the space shuttle water specification. The silver ion generator (item 4.10) in the fuel cell water supply line will add silver ions to the water stream at the desired concentration. This location was selected to obviate bacteria growth within any portion of the subsystem.

4.4.7.2 Water Tank Module

Two fresh water modules are installed in parallel. Each tank is sized for one-half the capacity requirement. Water dumping will be necessary after failure of a tank module, although crew safety will be assured.

The two-tank approach is recommended because of the very high reliability of the tank itself and the relatively high weight penalty (21.5 lb) associated with providing a redundant tank. Failure of one tank will not affect crew safety. However, it will compromise mission success to a certain degree, depending on the constraints imposed on water dumping through the coolant loop evaporators.

4.4.7.3 Crew Water Consumption

Hot water provisioning to the crew does not involve crew safety nor mission reliability. Redundant electrical heaters are provided in the water heater. Upon failure of both heaters (a very remote possibility), only cold water will be available. The effect is crew discomfort.

The cold water supply is essential for crew safety and mission completion. An emergency water supply is provided through Item 4.21 as a backup to the potable water module. Two water chillers are in series in the potable water subsystem so that either water coolant loop can be used as the heat sink.

In terms of potability, it is assumed that water from the fuel cell will satisfy the potability requirements for space shuttle water. The silver ion generators included in the line from the fuel cell will maintain an adequate silver concentration in the system to prevent bacteria migration from the points of use including the waste management subsystem.

Two deionizer beds are provided with shutoff valves to permit bed isolation. Only one bed is on-stream at any time, so that bed failure can be detected by means of the silver ion detector. These beds are static devices that are over-designed for the intended service life, which makes failure very unlikely; rather, bed failure will correspond to an increase in the silver ion content of the potable water stream above the specification value of 50 ppb. As much as ten times this concentration could be consumed by the crew without ill effects.

4.4.7.4 Backpack Refill

Two valves (Item 4.5) with quick-disconnects (Item 4.21) provide adequate redundancy for this function, which does not involve crew safety.

4.4.7.5 Relief Valve

Normally a close inventory of the water contained in the tanks will be kept, and dumping of excess water will be effected through the evaporators by crew intervention. The relief valves only will be used to prevent overpressurization when normal dumping cannot (or has not) be accomplished. This method of dumping violates the ECS design requirements, which specify no liquid dumping. The relief feature is included only as a safety device.

4.4.8 Redundancy Management

In-flight monitoring of the water management subsystem is relatively simple. Redundancy management involves the redundant tanks, selector valves, and pressure relief valves; the redundancy management actions are summarized in Table 4-12.

TABLE 4-12

REDUNDANCY MANAGEMENT SUMMARY, WATER MANAGEMENT SUBSYSTEM

Functional Symptom	On Board Sensor	Possible Causes	Redundancy Management Action	Remarks
1. Water manifold pressure high and water tank quantity normal (or full)	P 4.100 T 4.200 Q 4.500 P 1.114	1.a) Relief valve failed close	1.a) Switch over to redundant relief valve	
		1.b) Dump nozzle clogged or frozen closed	1.b) Use alternate dump system (water boiler) and use redundant dump nozzle heater to melt possible blockage	
		1.c) Water boiler clogged or frozen	1.c) Use dump nozzle	1.c) Verify heater is on
		1.d) N_2 gas regulator failed wide open	1.d) Use redundant gas regulator	
2. Water manifold pressure low and water tank quantity normal (full)	P 4.100 T 4.200 Q 4.500 P 1.114	2.a) Relief valve failed open	2.a) Same as 1.a	
		2.b) Water check valve failed closed	2.b) Select redundant water supply leg	2.b) Improbable failure
		2.c) Water selector valve failed	2.c) Same as 2.b	2.c) This would be detected at the time of valve operation
		2.d) Upstream blockage	2.d) Same as 2.b	
		2.e) N_2 gas regulator failed closed or low	2.e) Same as 1.d	
3. Fresh water does not feed, water manifold pressure normal	P 4.100	3.a) Check valve failed closed	3.a) Potable water is available from PLSS source	
		3.b) Fresh water valve failed closed	3.b) Same as 3.a	
4. Cold fresh water is too hot		4.a) Water chiller failed	4.a) No action in this subsystem	
		4.b) Water coolant loop failed	4.b) No action in this subsystem	
5. Hot fresh water is cold		5. Heater failed	5. None	Not critical in terms of crew safety
6. Silver ion count out of spec		6.a) Failure of AgCl column (low Ag)	6.a) Use redundant water supply leg, same as 2.b	
		6.b) Failure of deionizer (high Ag)	6.b) Use redundant bed	6.b) Improbable failure

4.5 FREON-21 HEAT REJECTION SUBSYSTEM

4.5.1 Functional Requirements

The Freon-21 heat rejection subsystem provides thermal control capability for the equipment located in the unpressurized area of the vehicle. The subsystem incorporates a number of heat sinks for ultimate heat rejection during all phases of the mission except for ascent/burn and entry when the evaporators are used. Specifically, the Freon-21 heat rejection subsystem serves as a heat sink for the following:

(a) Water coolant loop during all mission phases except ascent/burn and entry

(b) Payload support coolant loop

(c) Fuel cell units

In addition, the Freon-21 provides the heat necessary for (1) conditioning the cryogenic oxygen supplied to the ECS from the primary and secondary tanks, and maintaining the temperature of the hydraulic fluid above a minimum value in the four vehicle hydraulic circuits

The three heat sinks installed in the loop are (1) a GSE heat exchanger for vehicle heat rejection to a GSE coolant during ground operations, (2) a radiator for heat rejection to space during orbital operations, and (3) redundant ammonia boilers for cooling on the ground during prelaunch and post landing.

In addition, provisions are incorporated for circulating Freon-21 to two vapor cycle units mounted in the engine pods during ferry flight. During ascent/burn and entry, all thermal energy collected by the Freon-21 subsystem in the unpressurized area of the vehicle is dumped into the water loop for ultimate rejection to evaporating water.

4.5.2 Performance Requirements

The following subsystem data were used for equipment design. These data, together with component design information presented later, were derived from loads provided in NR report ECLSS-191-72-2.

Freon-21 flow rate	2200 lb/hr
Freon-21 circuit ΔP	60 psi
Maximum operating pressure	250 psi
Freon-21 temperature range	35° to 200°F max.
Total Freon-21 loop volume	3.5 cu ft (including accumulator)

The design point performance requirements for the various components of the Freon-21 heat rejection subsystem correspond to different mission phases. For this reason, component design data (loads, flows, and temperature levels) are presented with the characteristics of the components. These requirements were established from thermodynamic data in the NR report referenced above for a number of mission phases. The ammonia heat sink subsystem component problem statements, however, were obtained as a result of optimization studies.

Ammonia is used as an expendable evaporant for short-term prelaunch and postlanding cooling of the Freon-21 loop. Reliability guidelines require that redundant ammonia boilers (and controls) be used as well as redundant storage tanks and delivery systems. The ammonia inventory is stored in two parallel tanks. Each tank contributes to the total quantity of ammonia required during prelaunch; however, the ammonia remaining in any one tank is adequate to handle the entire postlanding load.

A schematic of the subsystem given in Figure 4-22 shows all equipment necessary for control and redundancy management of the cooling system.

The desigr of the equipment (tank and boiler) for minimum weight will depend on the amount of superheat attainable in the boiler or the utilization effectiveness of the expendable ammonia. Parametric data were generated to determine the optimum operating point in terms of overall weight and boiler design limitations. The data listed below were used in these investigations.

Prelaunch load	75,000 Btu/hr for 15 min
Postlanding load	75,000 Btu/hr for 15 min
Freon-21 temperature at boiler outlet	$40^{\circ}F$
Ammonia storage temperature	$160^{\circ}F$ (max)
Ammonia tank fill temperature	$70^{\circ}F$ (saturated)
Freon-21 temperature at boiler inlet	$176^{\circ}F$

Figure 4-23 is a plot of the weight of the system equipment and expencable weight as a function of the degree of superheat of the ammonia stream at boiler outlet. The data show that the total weight of the system is dictated by the quantity of ammonia to be stored on board. The highest degree of superheat commensurate with boiler design will result in the lightest overall weight.

On the basis of these data, the following values were used for the design of the ammonia system equipment.

Tank capacity	127 lb (total for two tanks including 10 percent reserve)
Ammonia temperature at boiler outlet	$150^{\circ}F$

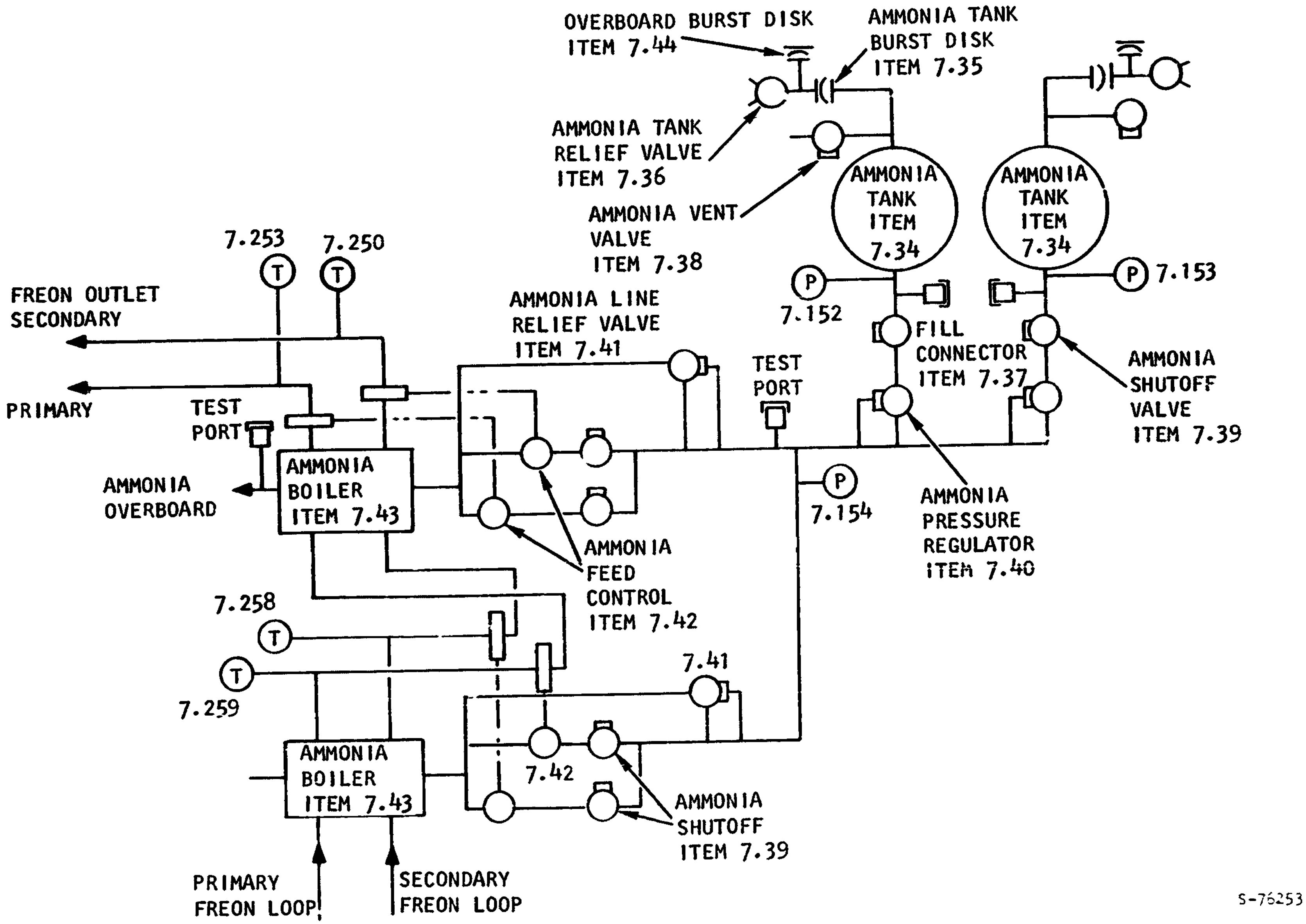


Figure 4-22. Ammonia Heat Sink Subsystem Configuration

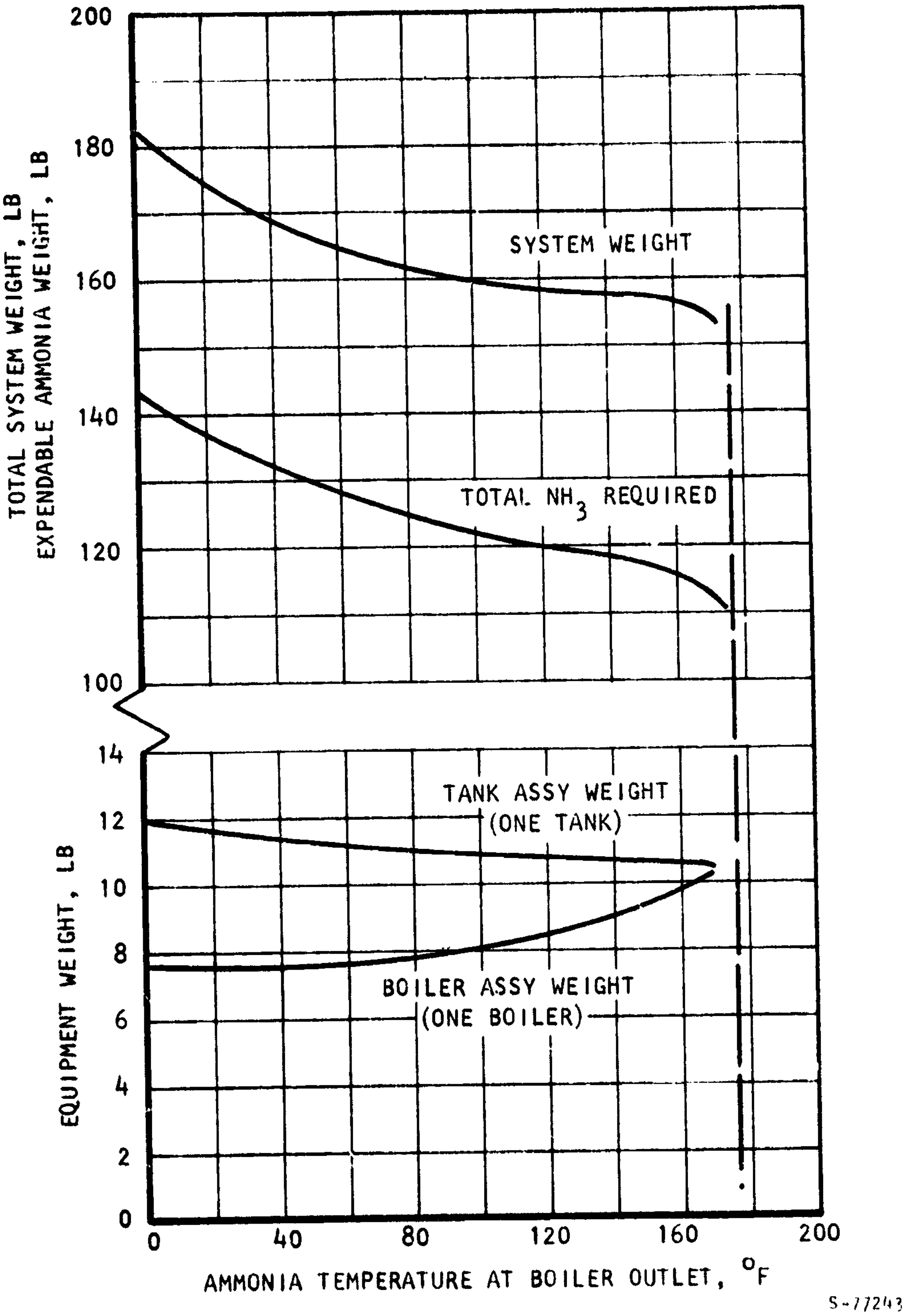


Figure 4-23. Ammonia Subsystem Optimization

4.5.3 Subsystem Description

A schematic of the subsystem is presented in Figure 4-24. The subsystem features two redundant Freon-21 loops that are identical. Either loop can provide complete thermal control in the unpressurized area of the vehicle.

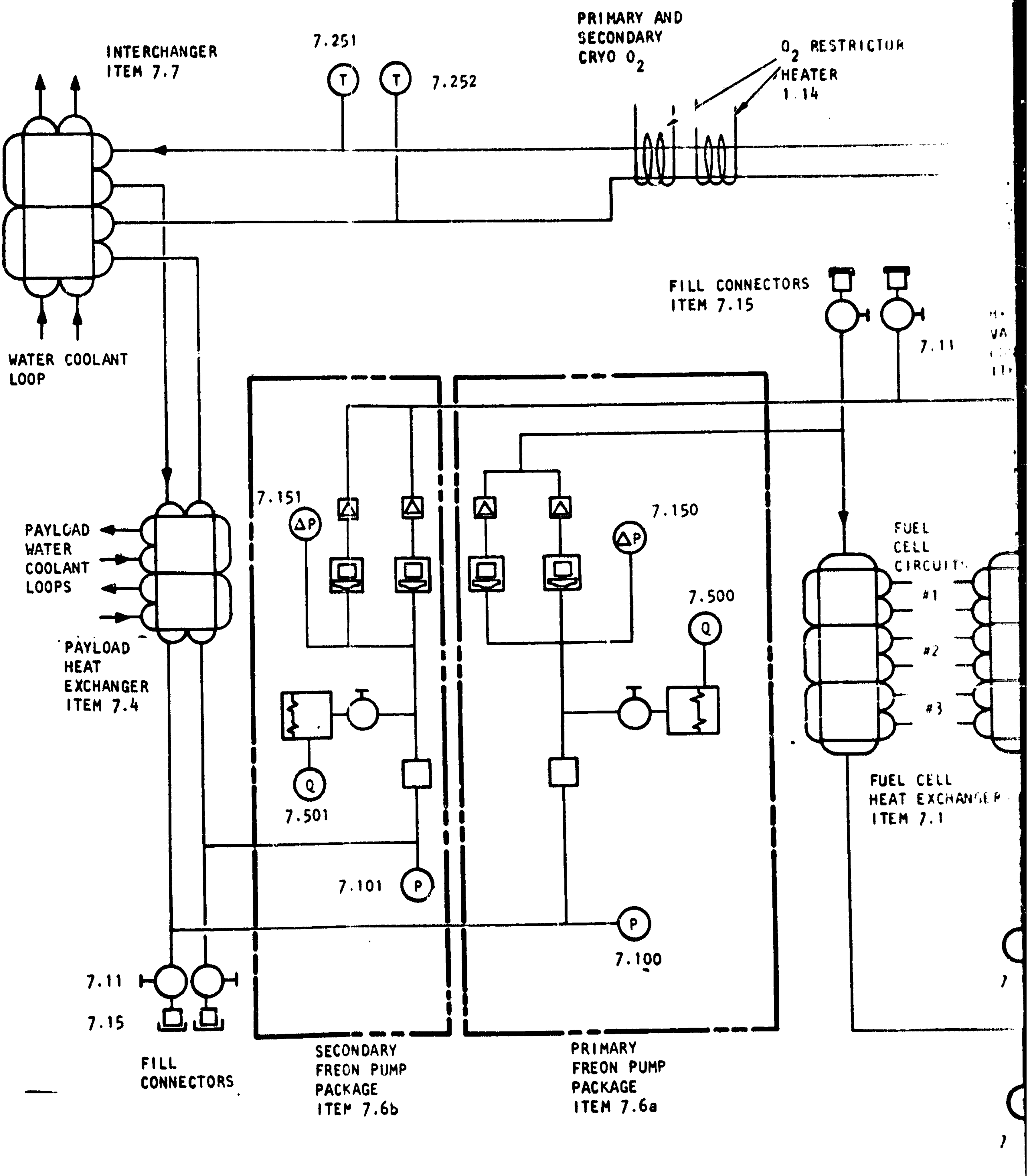
Freon from the heat sink section of the loop is circulated through the cryogenic heater (Item 1.14). This heat exchanger consists of a tube brazed to both Freon-21 lines and thermally conditions the cryogenic oxygen supplied to the ECS from the PRDS supply. One heat exchanger per cryogen supply line is used. The two Freon-21 lines are brazed together at this point to prevent freezing of the Freon in the inactive loop. This cryogenic heat exchanger (Item 1.14) is part of the atmospheric control subsystem.

The cold Freon then enters the interchanger (Item 7.7) where it serves as a heat sink for the water coolant loops during all mission phases except when the flash evaporator is used as the sole vehicle heat sink during ascent and entry. The interchanger is a four-fluid unit where either Freon loop can cool either of the redundant cabin water loops.

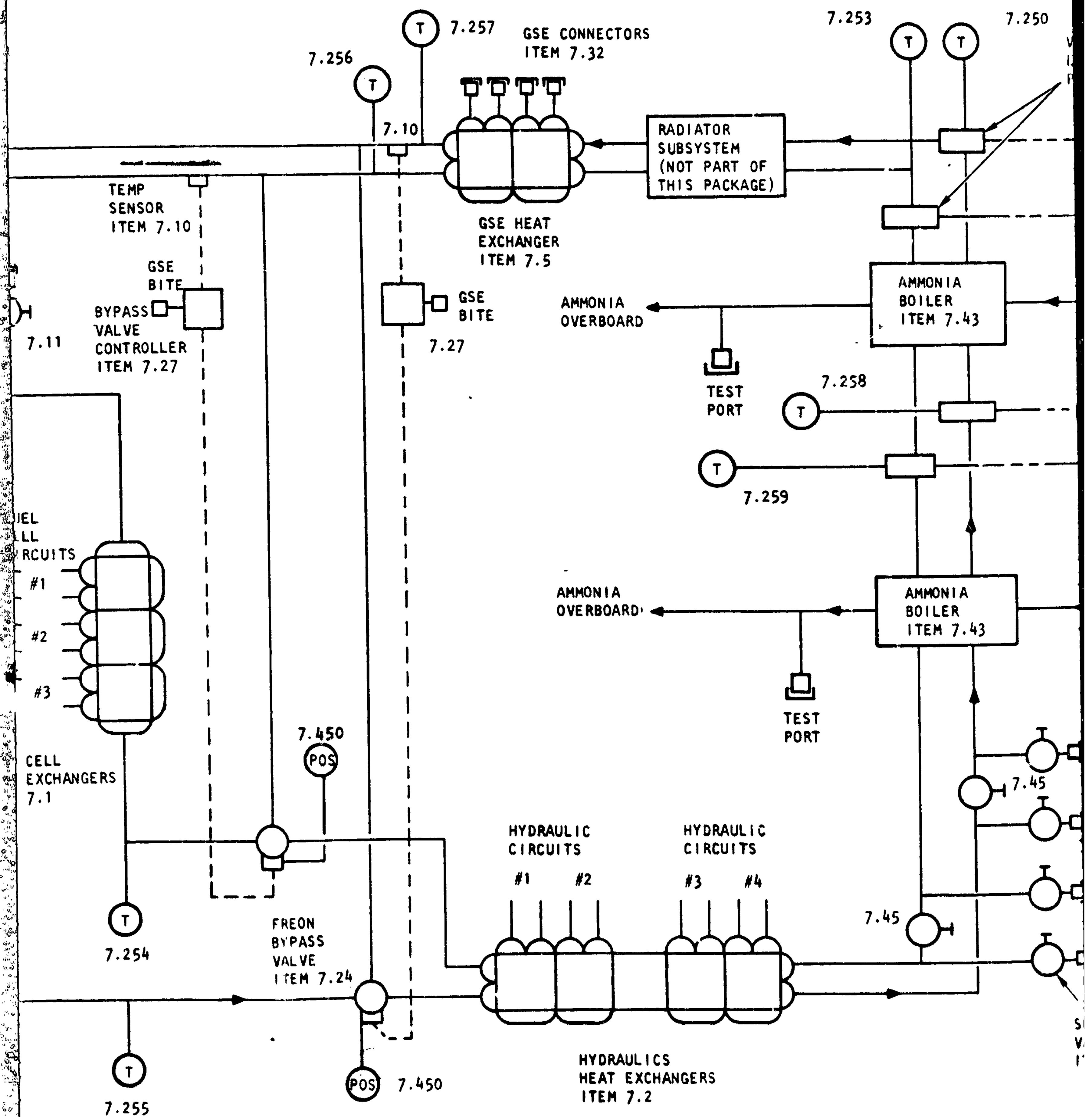
From the interchanger, both Freon loops enter the payload support heat exchanger (Item 7.4). Here again a four-fluid unit is proposed that thermally links the redundant Freon and payload support coolant loops (water).

The Freon pumps that assure flow through either loop are located downstream of the payload heat exchanger. This location appears optimum in terms of Freon temperature for high pump efficiency and low Freon loop pressure. Two pumps with appropriate check valves are used in each loop. Relative to the rest of the Freon loop equipment, the pump is the high-failure-rate functional component, so that the use of four pumps provides FO-FS capabilities.

FOLDOUT FRAME



FOLDOUT FRAME 2



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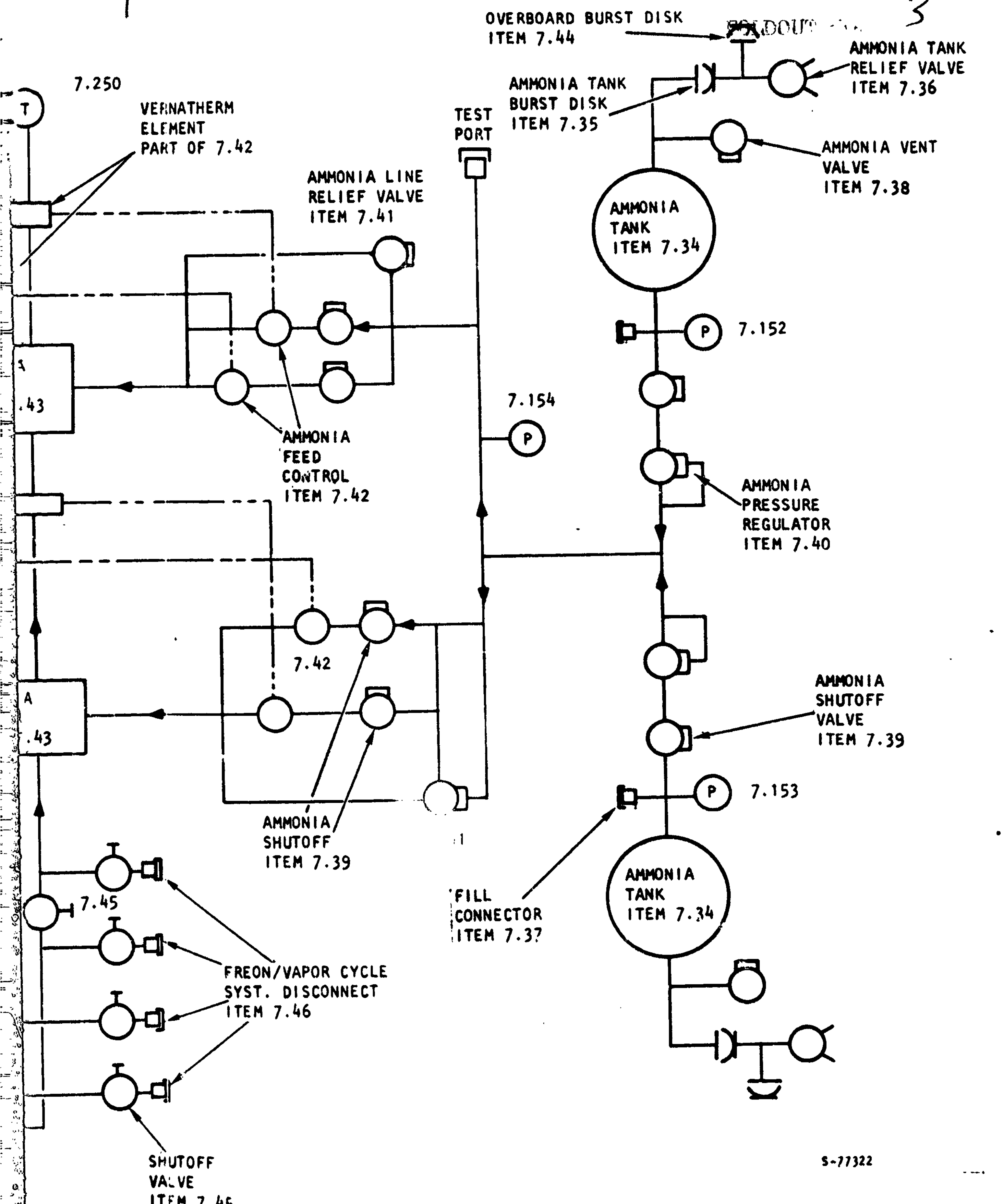
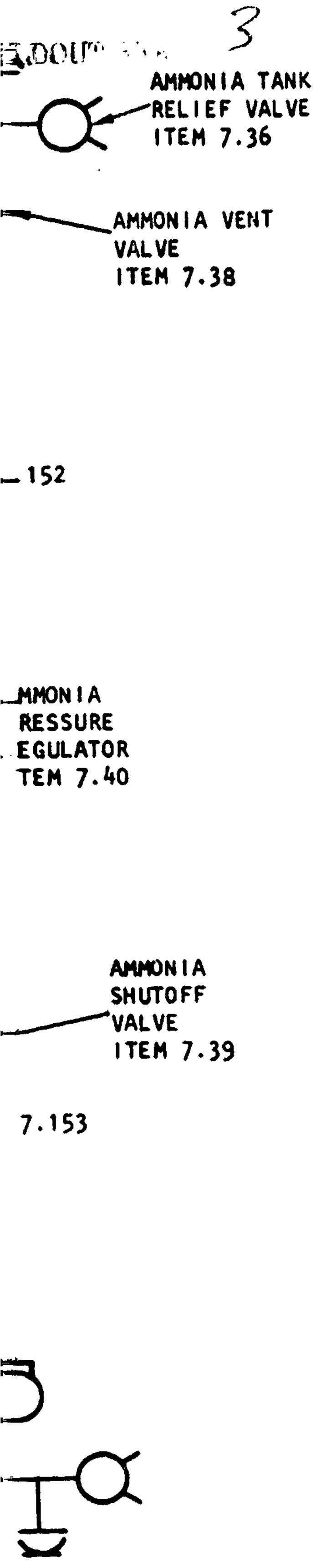


ITEM NO.	
7.1	FUEL
7.2	HYDRA
7.4	PAYLO
7.5	GSE H
7.6a	PRIMA
7.6b	SECON
7.7	FREON
7.10	FREON
7.11	SHUTO
7.15	FILL
7.24	GSE H
7.27	GSE H
7.32	GSE
7.34	AMMON
7.35	AMMON
7.36	AMMO
7.37	AMMON
7.38	AMMO
7.39	AMMO
7.40	AMMO
7.41	AMMO
7.42	AMMON
7.43	AMMO
7.44	OVER
7.45	FREO
7.46	VAPO
7.100	PRIM
7.101	SECO
7.150	PRIM
7.151	SECO
7.152	AMMO
7.153	AMMO
7.154	AMMO
7.250	RADI
7.251	INTE
7.252	INTE
7.253	RADI
7.256	GSE
7.257	GSE
7.258	PRIM
7.259	PRIM
7.450	FREO
7.500	PRIM
7.501	SECO

FOLDOUT FRAME 3

FOLDOUT FRAME 4



ITEM NO.	DESCRIPTION	NUMBER REQUIRED
7.1	FUEL CELL HEAT EXCHANGER	2
7.2	HYDRAULIC HEAT EXCHANGER	1
7.4	PAYLOAD HEAT EXCHANGER	1
7.5	GSE HEAT EXCHANGER	1
7.6a	PRIMARY FREON PUMP PACKAGE	1
7.6b	SECONDARY FREON PUMP PACKAGE	1
7.7	FREON-21/WATER INTERCHANGER	1
7.10	FREON-21 TEMPERATURE SENSOR	2
7.11	SHUTOFF VALVE	4
7.15	FILL CONNECTORS	4
7.24	GSE HEAT EXCHANGER BYPASS VALVE	2
7.27	GSE HEAT EXCHANGER BYPASS CONTROLLER	2
7.32	GSE CONNECTOR	4
7.34	AMMONIA TANK	2
7.35	AMMONIA TANK BURST DISC	2
7.36	AMMONIA TANK RELIEF VALVE	2
7.37	AMMONIA FILL CONNECTOR	2
7.38	AMMONIA TANK VENT VALVE	2
7.39	AMMONIA SHUTOFF VALVE	6
7.40	AMMONIA PRESSURE REGULATOR	2
7.41	AMMONIA LINE RELIEF VALVE	2
7.42	AMMONIA FEED VERNATHERM	4
7.43	AMMONIA BOILER	2
7.44	OVERBOARD BURST DISC	2
7.45	FREON MANUAL SHUTOFF VALVE	6
7.46	VAPOR CYCLE CONNECTOR	4
7.100	PRIMARY PUMP PACKAGE INLET PRESSURE TRANSDUCER	1
7.101	SECONDARY PUMP INLET PRESSURE TRANSDUCER	1
7.150	PRIMARY PUMP PACKAGE ΔP TRANSDUCER	1
7.151	SECONDARY PUMP ΔP TRANSDUCER	1
7.152	AMMONIA TANK PRESSURE TRANSDUCER (PRIMARY)	1
7.153	AMMONIA TANK PRESSURE TRANSDUCER (SECONDARY)	1
7.154	AMMONIA MANIFOLD PRESSURE TRANSDUCER	1
7.250	RADIATOR INLET TEMPERATURE TRANSDUCER (PRIMARY)	1
7.251	INTERCHANGER INLET TEMPERATURE TRANSDUCER (PRIMARY)	1
7.252	INTERCHANGER INLET TEMPERATURE TRANSDUCER (SECONDARY)	1
7.253	RADIATOR INLET TEMPERATURE TRANSDUCER (SECONDARY)	1
7.256	GSE HEAT EXCHANGER OUTLET TEMPERATURE TRANSDUCER (SECONDARY)	1
7.257	GSE HEAT EXCHANGER OUTLET TEMPERATURE TRANSDUCER (PRIMARY)	1
7.258	PRIMARY AMMONIA BOILER OUTLET TEMPERATURE TRANSDUCER	1
7.259	PRIMARY AMMONIA BOILER OUTLET TEMPERATURE TRANSDUCER	-
7.450	FREON BYPASS VALVE POSITION INDICATOR	1
7.500	PRIMARY ACCUMULATOR QUANTITY TRANSDUCER	1
7.501	SECONDARY ACCUMULATOR QUANTITY TRANSDUCER	1

S-77322

Figure 4-24. Freon-21 Heat Rejection Loop

Accumulators at pump inlets will maintain Freon pressure and make up for small leaks in the loops.

Freon discharge from the pump is further used as the coolant for the fuel cell subsystems. Three fuel cells are installed on the vehicle; two are normally on stream, while the third is a redundant unit. Fuel cell redundancy management requires that all or any fuel cell be cooled by either Freon loop. Two fuel cell heat exchangers (Item 7.1) are used, one in each Freon loop. Each fuel cell heat exchanger is a four-fluid unit as illustrated in the schematic. Detailed design studies have shown this approach to be near optimum in terms of overall weight; it was selected to obviate the inefficiencies and the potential development problems that could arise with a five-fluid unit.

The temperature of the Freon at fuel cell outlet is the highest in the circuit. When necessary, this Freon is used to heat the vehicle four hydraulic circuits and maintain hydraulic fluid temperature above $-20^{\circ}F$. The hydraulic heater consists of two shell-and-tube heat exchangers manifolded together to form a single unit. In this manner any or all hydraulic circuits can be heated by either of the Freon-21 loops.

At this point the Freon is circulated through the vehicle heat sinks installed in series: the ammonia boiler, the radiator, and the GSE heat exchanger. In addition this section of the circuit incorporates provisions for routing the Freon to two vapor cycle refrigeration units that constitute the vehicle heat sink during ferry flight.

Two ammonia boilers are installed in series. The boilers are redundant; one unit has the capacity to handle the entire load in either loop. Vernatherm valves in each loop sensing the Freon temperature at boiler outlet control the flow of ammonia to the boiler from the storage tanks. The control temperature is $40^{\circ} \pm 5^{\circ}F$.

The ammonia storage tanks (Item 7.34) and associated valves are also redundant. Each tank has sufficient capability to handle half the prelaunch load and the entire postlanding load for 15 minutes. The tanks are protected from overpressurization through two burst discs and a relief valve. The first burst disc (Item 7.35) will protect the tank from overpressurization; the relief valve (Item 7.36) downstream of the first burst disc will open to relieve the tank as soon as the first disc bursts. Should the tank pressure continue to rise, the second burst disc (Item 7.44) will open and all tank contents will be dumped overboard. This second burst disc constitutes a safety feature and provides the flow capacity to prevent dangerous pressure buildup in the tank while limiting the relief valve flow capacity to reasonable values.

Isolation valves (Item 7.39) are provided on the tanks and on the ammonia feed lines for the purpose of redundancy management. These valves permit the use of any boiler with any Freon loop and any one of the two tanks.

Relief valves (Item 7.41) will prevent pressure buildup in the lines between the ammonia isolation valves after system shutdown.

The GSE heat exchanger (Item 7.5) is used on the ground as a heat sink for either of the Freon-21 loops. Water-glycol from a ground support cooling cart serves as the heat sink. Provisions are made for interfacing with redundant water-glycol loops. Bypass capabilities are included in the loops to maintain the temperature of the Freon at the GSE heat exchanger outlet at 35°F during ground operations. A bypass valve (Item 7.24) in each Freon loop is provided for this purpose. The valve is actuated by a controller (Item 7.27) that receives a signal from a temperature sensor (Item 7.10) on the Freon line downstream of the GSE heat exchanger.

During ferry flight the Freon (primary and secondary) is routed through two vapor cycle refrigeration unit evaporators. These redundant cooling systems could be mounted in the engine pods or in the payload bay. Each unit can handle the entire load in either Freon loop. Manual shutoff valves (Item 7.45) and quick-disconnects (Item 7.46) are used for rerouting the Freon during ferry flight.

Fill connectors (Item 7.15), with caps keyed to prevent misuse, are provided for servicing the Freon-21 loop. Shutoff valves (Item 7.11) back up the connectors and eliminate possibility of external leakage through the connectors.

4.5.4 Equipment Summary

A summary of all equipment shown on the schematic of Figure 4-24 is presented in Table 4-13. Data tabulated include functional and performance requirements, equipment design features, and characteristics.

Most of the equipment included in this subsystem is new and will be designed to meet the particular performance requirements of the space shuttle. A large portion of this equipment is heat exchangers, and no particular problems are anticipated in their design or development. The circulating pump uses a wet motor and Freon-lubricated journal bearings. The design is based on a wealth of experience on this type of pump. The GSE heat exchanger controller is a modified design used for cabin temperature control on the DC-10.

TABLE 4-13

EQUIPMENT SUMMARY
FREON-21 HEAT REJECTION LOOP

Item No.	Description	No. Reqd/ Shipset	Functional and Performance requirements	Item Weight, lb	Envelope, in.	Power, w	Equipment Category	Remarks, Design Feature
7.1	Fuel cell heat exchanger	2	Used to reject fuel cell waste heat to the Freon-21. Three fuel cell coolant loops are thermally coupled to the two Freon-21 loops in two 4-fluid heat exchangers. Any two of the three cells are normally in operation and require cooling. Type A Fuel Cell Design Fuel cell coolant: FC-40, 1100 lb/hr (2 circuits) Inlet temperature: 215.6°F Heat rejection: 27,000 Btu/hr (2 circuits) ΔP: 0.62 psi Freon flow: 2200 lb/hr Freon inlet temperature: 123.6°F Freon ΔP: 0.61 psi	4.9 (dry) 8.3 (wet)	1.6 x 4.25 x 20	-	New	Four-fluid plate fin unit. Counterflow configuration. Aluminum construction. Design point is with two fuel cells at 14 kw. Two units required, one in each Freon loop.
			Type B Fuel Cell Design Fuel cell coolant: water, 4000 lb/hr (2 circuits) Inlet temperature: 188.5°F Heat rejection: 34,200 Btu/hr (2 circuits) ΔP: 0.72 psi Freon flow: 2200 lb/hr Freon inlet temperature: 123.6°F Freon ΔP: 0.60	5.8 (dry) 7.7 (wet)	1.7 x 4.25 x 10.7	-	New	Similar to heat exchanger designed for Type A fuel cell except stainless steel construction.
7.2	Hydraulic heat exchanger	1	Serves to transfer heat from either Freon-21 loop to any one or all of the four vehicle hydraulic loops. One six-fluid heat exchanger is recommended. Cold Side (MIL-H-83282) Flow rate: 1687 lb/hr Inlet temperature: -20°F Outlet temperature: 0°F Pressure drop: 2 psi (maximum) MIL-H-83282 pressure: 500 psi Hot Side (Freon-21) Q: 15,000 Btu/hr (total for four circuits) Flow: 2200 lb/hr Inlet temperature: 90°F (sleep) Pressure drop: 2 psi (maximum) Freon-21 pressure: 250 psia	9.3 (dry) 12.8 (wet)	3.25 dia x 12.5	-	New	Two 5-fluid tubular heat exchanger assembled as one unit. MIL-H-83282 fluid inside the tubes (one pass). Freon in shell (four pass across tube bundle), stainless steel unit, [illegible] tubes, 45 tubes per hydraulic circuit. Split header to accommodate four hydraulic circuits.
7.4	Payload heat exchanger	1	Provides a heat sink for the redundant payload water coolant circuits. Either Freon-21 loop can be used to cool either of the payload water circuits. Design point is coast/adjust. Hot Side (Water) Q 21,500 Btu/hr Water flow: 550 lb/hr Inlet temperature: 125 Water pressure: 30 psia Water ΔP: 2 psi Cold Side (Freon-21) Flow rate: 2200 lb/hr Inlet temperature: 74°F Freon-21 pressure: 260 psi Freon-21 ΔP: 3 psi	18 (dry) 23.4 (wet)	1.5 x 23 x 6.4	-	New	Four-fluid plate fin unit. Counterflow configuration. Stainless steel construction. Nickel fin on the Freon side.

TABLE 4-13 (CONTINUED)

Item No.	Description	No. Reqd/ Shipset	Functional and Performance Requirements	Item Weight, lb	Envelope, in.	Power, w	Equipment Category	Remarks/Design Features
7.5	GSE heat exchanger	1	Provides a heat sink for the vehicle during ground operations. Hot Side (Freon-21) Q 81,229 Btu/hr Freon-21 flow: 2200 lb/hr Freon-21 outlet temperature: 35°F Freon-21 pressure: 260 psi ΔP: 4 psi Cold Side (RS-89 Water-Glycol) Flow: 5000 lb/hr Inlet temperature: 10°F Pressure: 50 psi Pressure drop: 10 psi	10.7 (dry) 14.2 (wet)	14.5 x 4.5 x 2.1	-	New	Four-fluid plate fin unit. Counterflow configuration. Stainless steel construction. Heat exchanger size could be reduced appreciably by reducing the GSE fluid temperature level.
7.6A	Primary Freon pump package	1	Circulates Freon-21 through the unpressurized areas of the vehicle for purposes of thermal control. Pump package includes two pumps (Item 7.6a), two check valves (Item 7.6b), one accumulator (Item 7.6c), one isolation valve (Item 7.6d) and one filter (Item 7.6e). Freon-21 flow: 2200 lb/hr at ΔP of 60 psid Inlet pressure: 260 psig Ambient pressure: 0 to 14.7 psia Inlet temperature: 125°F (maximum) Accumulator effective capacity: 1020 in.3	44.2 (dry) 104 (wet)	15 x 13 x 28.2	410	New	Centrifugal pumps driven by 3-phase ac motors. Wet motor construction with Freon lubricated graphite bearings. Rotational speed: 11,000 rpm. Anticipated life: 18000 hr. Aluminum construction. Accumulator has steel bellows pressurized externally with nitrogen. Accumulator constitutes 65 percent of the dry weight of the package.
7.6B	Secondary Freon pump package	1	Same package as 7.6A.	44.2 (dry) 104 (wet)	14 x 13 x 28.2	410	New	Identical to 7.6A.
7.7	Freon-21/water interchanger	1	Constitutes the heat sink for the water loop during all mission phases except ascent/burn and entry when evaporator constitutes the heat sink. Freon-21 is the coolant. During ascent/burn and entry the water cools the Freon-21. Four-fluid heat exchanger with redundant water and Freon-21 passages. Any one water loop is thermally coupled to any one Freon-21 loop. Water Side (Hot) Flow: 550 lb/hr Inlet temperature: 119°F Pressure: 30 psia ΔP: 2 psi Heat rejection: 40,700 Btu/hr Freon-21 Side (Cold) Flow: 2200 lb/hr Inlet temperature: 40°F Pressure: 250 psi ΔP: 5 psi	87.6 (dry) 111.2 (wet)	32 x 6.1 x 5.8	-	New	Four-fluid counterflow unit. The heat exchanger package incorporates two identical sections (folded arrangement) for ease of installation. Stainless steel construction. Considerable weight reduction (33 lb) could be realized by relaxing water temperature level by 2.3°F at design point. Design point is post landing.
7.10	Freon-21 temperature sensor	2	Senses Freon temperature at GSE heat exchanger outlet. Signal is used by controller (Item 7.27) for Freon flow bypass control. Temperature	0.19	0.91 dia by 2.6	-	Existing	Each sensor consists of two thermistor beads connected in series and encapsulated in a stainless steel sheath. The sheath is housed in a sensor body that fits into a well immersed in the fluid. Sensor is removable without breaking into the liquid loop. Qualified for [illegible].
7.11	Shutoff valve	4	Shutoff valve used to back-up servicing connectors.	0.35	3.3 x 2 x 3	-	Similar	Bellows type valve to prevent leakage [illegible]

TABLE 4-13 (CONTINUED)

Item No.	Description	No. Reqd/ Shipset	Functional and Performance Requirements	Item Weight, lb	Envelope, in.	Power, w	Equipment Category	Remarks Design Feature
7.1[illegible]	Fill connector	4	Used for interfacing with GSE during ground servicing operations. Unit includes a cap for protection and also to preclude leakage. A key is incorporated in design to prevent misuse or error in maintenance.	0.6	1.6 dia x 1.6	-	Modified	Standard qualified design modified to include key feature and cap seal
7.24	GSE heat exchanger bypass valve	2	Diverts Freon-21 around the heat sink position of the loop upon signal from controller (Item 7.27). Maximum flow in through or bypass mode 2200 lb/hr. Maximum ΔP: 0.3 psi at design flow.	1.5	2.5 x 2.4 x 5.0	-	New	Power from controller (Item 7.27) - 8 va at 115 v. Aluminum housing with stainless steel moving parts. Teflon bushing used for long life. Actuator qualified under Apollo program. Design incorporates position indicator (7.450).
7.27	GSE heat exchanger bypass controller	2	Receives signal from temperature sensor (Item 7.10) to bypass Freon around the heat sink portion of the loop so that temperature at GSE heat exchanger outlet is maintained at 35°F min. This control scheme serves as a backup to the radiator bypass.	3.8	8.25 x 4.1 x 5.0	6	Modified	Solid-state controller. DC-10 temperature controller modified to eliminate feedback logic. Incorporates test connector to permit interrogation of the entire control system by means of GSE test set.
7.32	GSE connector	4	Provides interface for circulation of GSE coolant (water-glycol) through the GSE heat exchanger. Water glycol flow: 5000 lb/hr at 10°F. Maximum ΔP: 20 psi at design flow. Design incorporates cap for protection, and key to prevent misuse.	0.6	1.6 dia x 1.6	-	Modified	Standard design modified to include key feature.
7.34	Ammonia tank	2	Stores liquid ammonia for use as expendable evaporant during ground operations (prelaunch and postlanding). Storage capacity: 65 lb; maximum temperature: 160°F saturated. Fill pressure at 70°F saturated: 128.8 psia.	9 lb (dry)	18.9 dia sphere	-	New	Cryoformed 301 stainless steel vessel. Shell thickness: 0.020 in. Three-point mounting. Service life: 10 years. Maximum delivery rate: 3.5 lb/min.
7.35	Ammonia tank burst disc	2	Provides ammonia tank overpressurization protection while precluding leakage. Burst pressure: 510 to 530 psia. Maximum flow, 500 lb NH_3/hr saturated at 1000 psia.	1.0	1 1/2 dia x 1	-	Similar	Inconel diaphragm. Similar to existing designs.
7.36	Ammonia tank relief valve	2	This valve provides venting and reseal capability in event of ammonia tank overpressurization. The valve will only open after burst disk (Item 7.35) has ruptured. Crack pressure: 470 psia; full flow at 490 psia. Flow capacity: 10 lb/hr at 160°F saturated ammonia.	0.3	1 dia x 3.5	-	Similar	Spring loaded closed in-line relief valve. Low spring rate and full porting assure minimum pressure build up with increasing flow. A similar design has been used in many space applications.
7.37	Ammonia fill connector	2	Used to service ammonia tank (fill and dump) Fill pressure is 128.8 psia at 70°F. Maximum pressure is 530 psia. Design includes cap and key feature. Maximum flow rate: 15 lb/min with 2.0 psi ΔP.	0.37	1.25 dia x 1.25	-	Existing	Standard design modified to include key feature.
7.38	Ammonia tank vent valve	2	Vents ammonia vapor during fill operation. Also can be used for dumping in emergency on the ground.	0.35	3.3 x 2 x 3	-	Similar	Aluminum manual shutoff valve.
7.39	Ammonia shutoff valve	6	Isolates ammonia tanks and boilers when not in use. Solenoid valve normally closed. Maximum flow 4 lb/min with 30 percent vapor at 60 psia.	2.9	2.4 x 2.5 x 5.5	-	New	Latching solenoid valve. Similar to design developed for MOL project.
7.40	Ammonia pressure regulator	2	Regulates ammonia delivery pressure from the tanks. Regulated pressure: 65 ± 4 psia at 4.0 lb/min with 30 percent vapor. Inlet pressure: 128.8 to 570 psia.	2.5	2.7 x 2.7 x 4	-	New	Similar to existing designs. Uses metal [illegible]
7.41	Ammonia line relief valve	2	Prevents line overpressurization due to normal heating of fluid trapped in the ammonia delivery line after use of the boiler.	0.3	1 dia x 3.5	-	Similar	This unit is identical to the [illegible] except for the [illegible].

TABLE 4-13 (CONTINUED)

Item No.	Description	No. Reqd' Shipset	Functional and Performance Requirements	Item Weight, lb	Envelope, in.	Power, w	Equipment Category	Remarks: Design Feature
7.42	Ammonia feed [illegible]	4	Control the flow of ammonia to the boiler to maintain a Freon temperature at boiler outlet of 40 ± 5°F.	1.0	2 x 3.75 x 3.75	-	Similar	Aluminum housing with steel working parts. Wax sensing element located in an sealed housing located in Freon-21 stream. Valve poppet is fully closed at 35°F and fully opened at 45°F. Design incorporates relief feature to prevent overpressurization of line upstream of the boiler. Thermal sensing element contained within sealed bellows to isolate it from ammonia and Freon. Similar valves are commonly used for temperature control. Accuracy specified does not present any problem.
7.43	Ammonia boiler	2	Serves as a heat sink for the Freon during ground operations (prelaunch and postlanding). Boiler incorporates redundant Freon passages and can cool either fluid stream as required. Q = 75000 Btu/hr with Freon temperature of 176°F and flow rate of 2200 lb/hr. Ammonia inlet enthalpy corresponding to saturated liquid at 160°F. Freon ΔP: 2 psi (maximum) at flow conditions.	3.2	5.8 x 7.7 x 0.9	-	New	Three-fluid unit with redundant Freon [illegible] Four-pass cross counterflow configuration. Aluminum plate fin construction. [illegible] outlet temperature: 120°F.
7.44	Overboard burst disc	2	Provides protection for the ammonia tank in event of rapid pressurization. High flow capability. Flow rate: 500 lb/hr at 1000 psia. Disc ruptures at 550 to 570 psia.	1.0	1.5 dia x 1	-	Similar	Inconel diaphragm; similar to existing design.
7.45	Freon manual shutoff valve	6	Used to divert Freon flow to the vapor cycle system evaporator during ferry flight. Flow capacity: 2200 lb/hr.	0.35	3.3 x 2 x 3	-	Similar	Identical to item 7.11.
7.46	Vapor cycle connector	4	Provides the interface between the vehicle Freon loops and the major cycle system during ferry flight. Design incorporates key feature and a cap to assure against leakage.	0.6	1.6 dia x 1.6	-	Modified	Standard connector modified to include key.
7.100	Primary pump package inlet pressure transducer	1	Pump performance monitoring; used for redundancy management and ground checkout; 0 to 300 psig.	0.2	1 in. dia x 3	-	Existing	Power and signal conditioning from item 3.P.
7.101	Secondary pump inlet pressure transducer	1	Same as 7.100	0.2	1 dia x 3	-	Existing	Same as 7.100.
7.150	Primary pump package ΔP transducer	1	Pump performance monitoring; used for redundancy management and ground checkout; 0 to 80 psid.	0.2	1 dia x 3	-	Existing	Same as 7.100.
7.151	Secondary pump ΔP transducer	1	Same as 7.150	0.2	1 dia x 3	-	Existing	Same as 7.150.
7.152	Ammonia tank pressure transducer (primary)	1	Used for redundancy management, ground checkout and servicing; 0 to 1000 psig.	0.2	1 dia x 3	-	Existing	Same type as 7.100.
7.153	Ammonia tank pressure transducer (secondary)	1	Same as 7.152.	0.2	1 dia x 3	-	Existing	Same as 7.150.
7.154	Ammonia manifold pressure transducer	1	Used for redundancy management and ground checkout; 0 to 200 psig.	0.2	1 dia x 3	-	Existing	Same type as 7.100.
7.250	Radiator inlet temperature transducer (primary)	1	Used for redundancy management.	0.03	-	-	Existing	Surface temperature sensor; power and signal conditioning from item 3.P.

TABLE 4-13 (CONTINUED)

Item No.	Description	No. Reqd/ Shipset	Functional and Performance Requirements	Item Weight, lb	Envelope, in.	Power, w	Equipment Category	Remark Design Feature
7.251	Interchanger inlet temperature transducer (primary)	1	Same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.252	Interchanger inlet temperature transducer (secondary)	1	Same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.253	Radiator inlet temperature transducer (secondary)	1	Same as 7.250	0.03	-	-	Existing	Same as 7.250.
7.256	GSE heat exchanger outlet temperature transducer (secondary	1	Used for ground checkout; same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.257	GSE heat exchanger outlet temperature transducer (primary)	1	Used for ground checkout; same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.258	Primary ammonia boiler outlet temperature transducer	1	Used for redundancy management; same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.259	Primary ammonia boiler outlet temperature transducer	1	Used for redundancy management; same as 7.250.	0.03	-	-	Existing	Same as 7.250.
7.450	Freon bypass valve position indicator	-	Used in checkout of bypass control system; part of 7.24.	-	-	-	-	-
7.500	Primary accumulator quantity transducer	1	Used for loop performance monitoring; 0 to 100 percent.	-	-	-	Similar	Potentiometer type; similar to Apollo water tank quantity transducer. No problem anticipated in [illegible] environment. Part of accumulator 7.[illegible].
7.501	Secondary accumulator quantity transducer	1	Same as 7.500	-	-	-	-	Same as 7.500.

The ammonia storage, feed, and boiler do not present any particular problem in terms of material compatibility or component design.

The transducers are existing equipment. All temperature transducers are surface type transducers except for the sensor (Item 7.10) used for control of the GSE bypass valve, and their replacement will not involve breaking into the Freon loop. The thermistor (Item 7.10) used to match the requirements of the modified DC-10 controller (Item 7.27) is a well-type unit, and also can be replaced without opening the Freon loop.

Data presented in Table 4-13 are summarized below:

Number of components	
Functional components	62
Instrumentation transducers	17
Number of component designs	
Functional components	25
Instrumentation transducers	5
Component weights	
Dry weight	302.9 lb
Wet weight	465.9 lb
Expendable ammonia	130 lb (total)
Launch weight	550.9 lb
Power	416 w

Much of the Freon-21 heat rejection subsystem equipment is in the ammonia storage, delivery, and boiling subsystem, which is fully redundant. Some of the hardware is also the same because of the loop redundancy (for example, the GSE bypass control equipment). In general, however, loop redundancy does not correspond to a large increase in the number of subsystem components, since the approach is to use multifluid heat exchangers.

The wet weight shown accounts for fluid holdup in the various subsystem heat exchangers, both the Freon and the other fluids (water coolant, hydraulic fluid, GSE water glycol, and FC-40 in the fuel cell heat exchanger.)

The expendable weight is the total ammonia charge. Since half will be used during prelaunch operations, the launch weight includes only 85 lb of expendable ammonia.

The power requirement for the subsystem is that necessary for the pump (410 w) and the GSE bypass controller (6 w). Power to the controller is quiescent power when the control valve (Item 7.24) is inactive. This is representative of orbital operation when the bypass subsystem is on standby.

The sensors are powered through Item 3.8, which is not part of the subsystem.

4.5.5 LRU Definition

In defining the LRU's for this subsystem (see Table 4-14), primary consideration was given to the lengthy maintenance tasks involved in draining and charging the Freon-21 loop. Equipment designs and groupings were based on minimum requirements for breaking into one or both of the Freon-21 loops. For example, two separate pump packages are proposed for the primary and secondary loops. Surface temperature sensors are used throughout. A large coolant accumulator, 1020 cu in. effective capacity, is proposed; this accumulator will provide for small Freon leaks and obviate the requirements for frequent maintenance actions to eliminate these small leaks.

TABLE 4-14

FREON-21 LOOP LRU DEFINITION

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Sub-system	Remarks
7-A	7.1		1	Fuel cell heat exchanger assembly	2	
7-B	7.2		1	Hydraulic heat exchanger assembly	2	
7-C	7.4		1	Payload heat exchanger assembly	1	
7-D	7.5		1	GSE heat exchanger assembly	1	
7-E		-	1	Primary Freon pump package	2	
		7.6a	2	Freon-21 pump		
		7.6b	2	Freon-21 check valve		
		7.6c	1	Freon-21 accumulator		
		7.6d	1	Freon-21 isolation valve		
		7.6e	1	Freon-21 filter		
	7.100		1	Pump inlet pressure		
	7.150		1	ΔP transducer	1	
	7.500		1	Accumulator quantity transducer		
7-F	7.10		1	Temperature sensor	2	
7-G	7.24		1	GSE heat exchanger bypass valve	2	
7-H	7.27		1	GSE heat exchanger bypass valve controller	2	
7-I	7.7		1	Freon/water interchanger	1	
7-J	7.32		1	GSE connector	4	
7-K	-			Fill connector assembly	4	
		7.11	1	Shutoff valve		
		7.15	1	Freon fill connector		
7-L		-		NH_3 Tank assembly	2	
		7.34	1	Tank		
	7.35		1	Burst disc		
	7.36		1	Relief valve		
	7.37		1	Fill connector		
	7.39		1	Shutoff valve, solenoid		

TABLE 4-14 (Continued)

LRU Ident	Item No. LRU	Item No. SRU	No. Items per LRU	Description	LRU's per Sub-system	Remarks
7-L cont	7.38		1	Vent valve		
	7.44		1	Overboard burst disc		
	7.152*		1	NH_3 tank pressure transducer (PRI)		*Primary tank
	7.153**			NH_3 tank pressure transducer (SEC)		**Secondary tank
7-M		7.40	1	NH_3 pressure regulator	2	
7-N	-	-		NH_3 boiler package	2	
		7.43	1	NH_3 boiler		
	7.41		1	NH_3 relief valve		
	7.39		2	NH_3 solenoid shutoff valve		
		7.42	2	NH_3 feed valve (vernatherm)		
7-O	7.250		1	Temperature sensor radiator inlet (primary)	1	
7-P	7.251		1	Temperature sensor interchanger inlet (primary)	1	
7-Q	7.252		1	Temperature sensor interchanger inlet (secondary)	1	
7-R	7.253		1	Temperature sensor radiator inlet (secondary)	1	
7-U	7.256		1	Primary loop GSE HX outlet temperature sensor	1	Prelaunch monitoring only
7-V	7.257		1	Secondary loop GSE HX outlet temperature sensor	1	Prelaunch monitoring only
7-W	7.154		1	Pressure transducer NH_3 delivery	1	
7-X	7.258		1	NH_3 boiler outlet temperature (primary loop)	1	
7-Y	7.259		1	NH_3 boiler outlet temperature (secondary loop)	1	
7-Z	7.45		1	Freon manual shutoff valve	6	
7-AA	7.46		1	Vapor cycle connector	4	

It is recommended that a dye be used in the Freon to facilitate leakage isolation. A Freon sniffer will also be used for this purpose. Table 4-14 is a listing of the LRU's. Examination of the table reveals only six major packages involving several components:

The Freon pump package incorporating two LRU's (primary and secondary pump LRU's).

The ammonia tank assemblies (two required).

The ammonia boiler assembly (two required).

The remainder of the components are separate LRU's. Installation constraints might dictate at a later date that some of these components be grouped together; however, efforts should be made to reduce spares and facilitate maintenance to make these components accessible for ease of replacement.

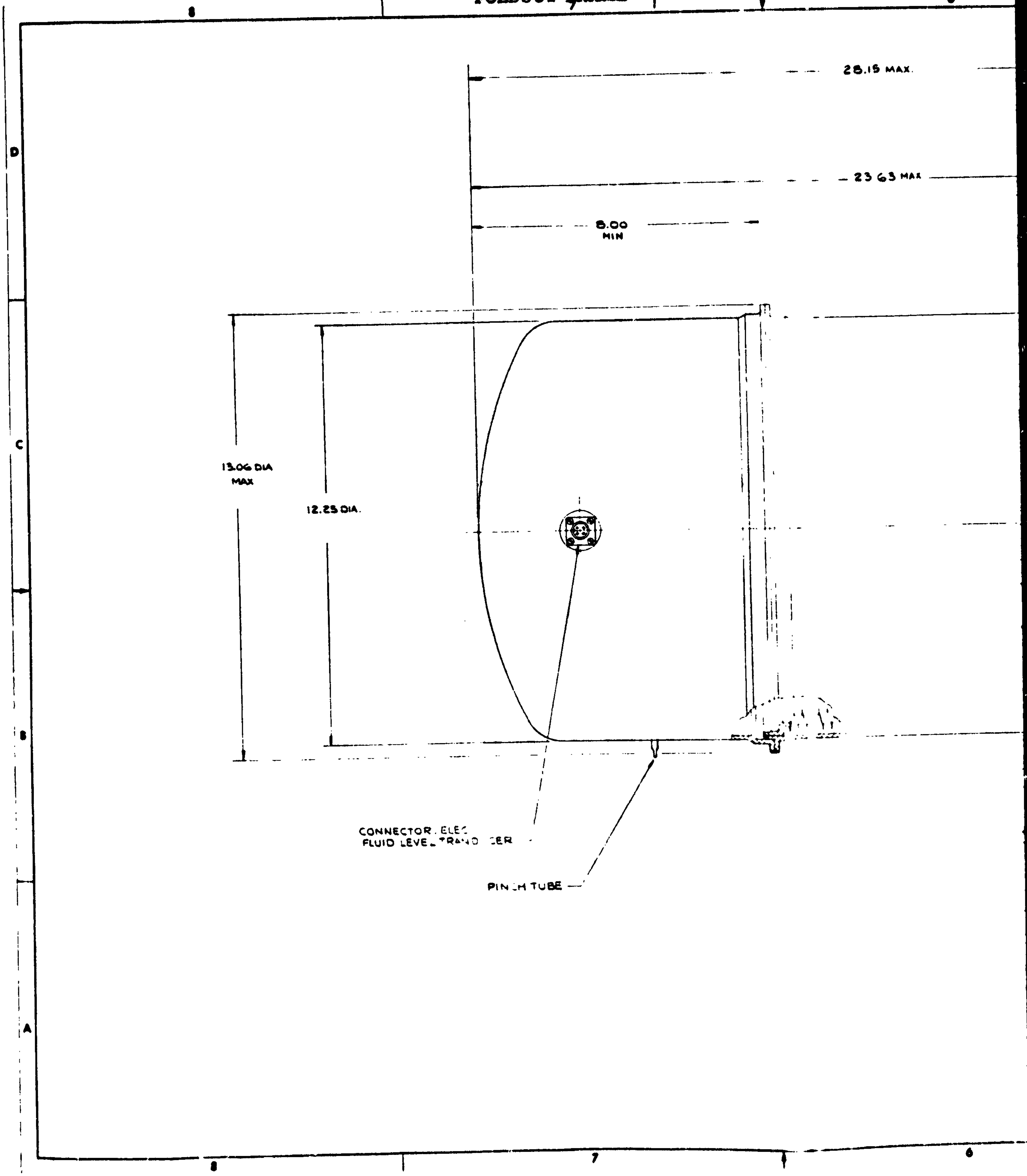
4.5.6 Equipment Packages

The maintainability features of the Freon loop packages are discussed in the following paragraphs. Generally, replacement of the various loop heat exchangers will not entail any particular problems other than those associated with the integrity of the Freon and interfacing subsystem fluid loops. In the case of the interchanger (111 lb, wet), a hoist will be necessary to assist in the replacement task.

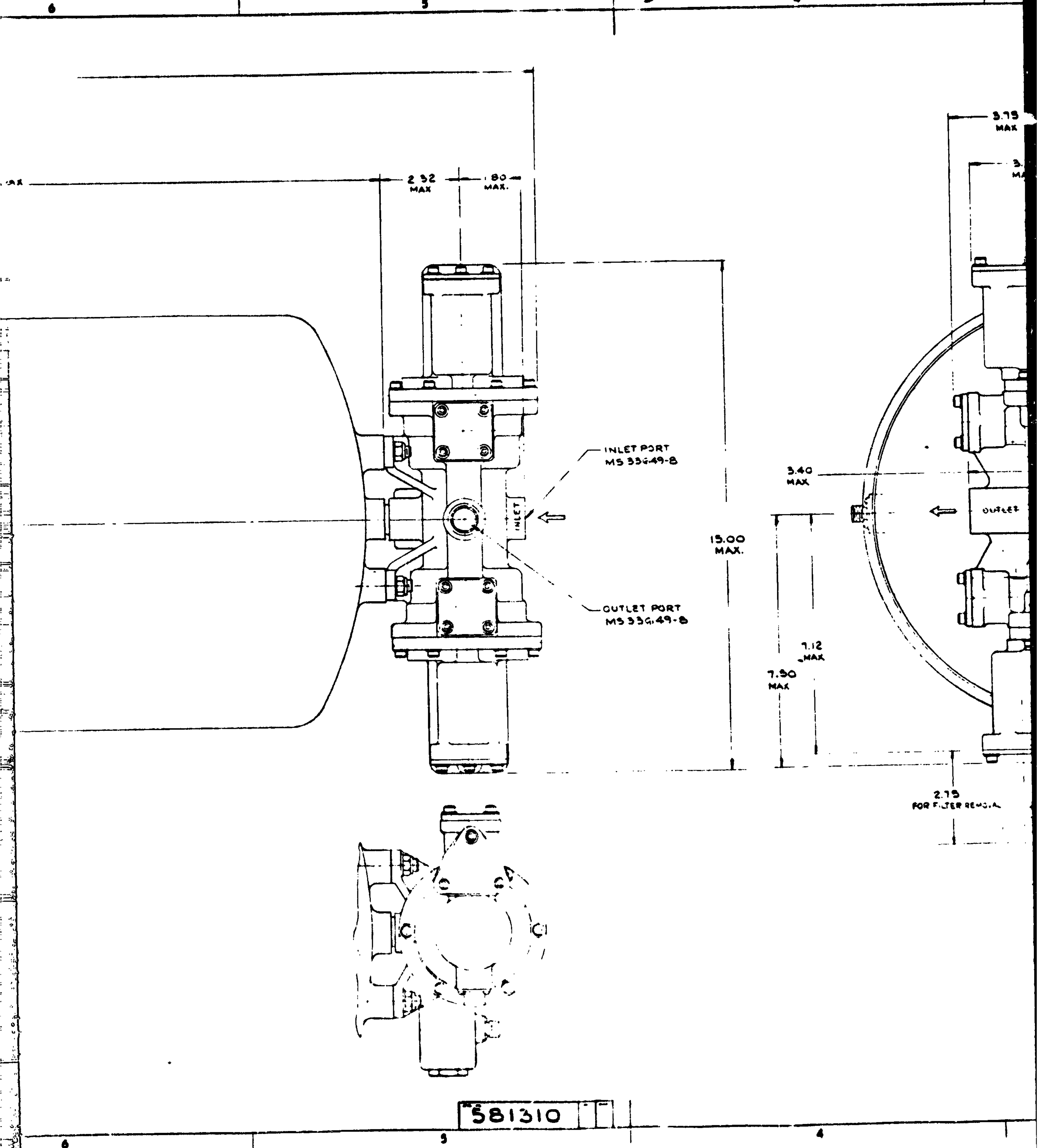
4.5.6.1 Freon Pump Package (LRU's, 7-E)

Drawing 581310 shows the pump package. Overall dimensions are 28.15 in. by 15 in. by 13 in. The package weight is estimated at 44.2 lb (dry). The dry weight of the accumulator accounts for 29.4 lb of the total; the pump-motor assemblies are 4.8 lb each. The wet weight of the unit is 104 lb including the accumulator Freon content.

FOLDOUT FRAME

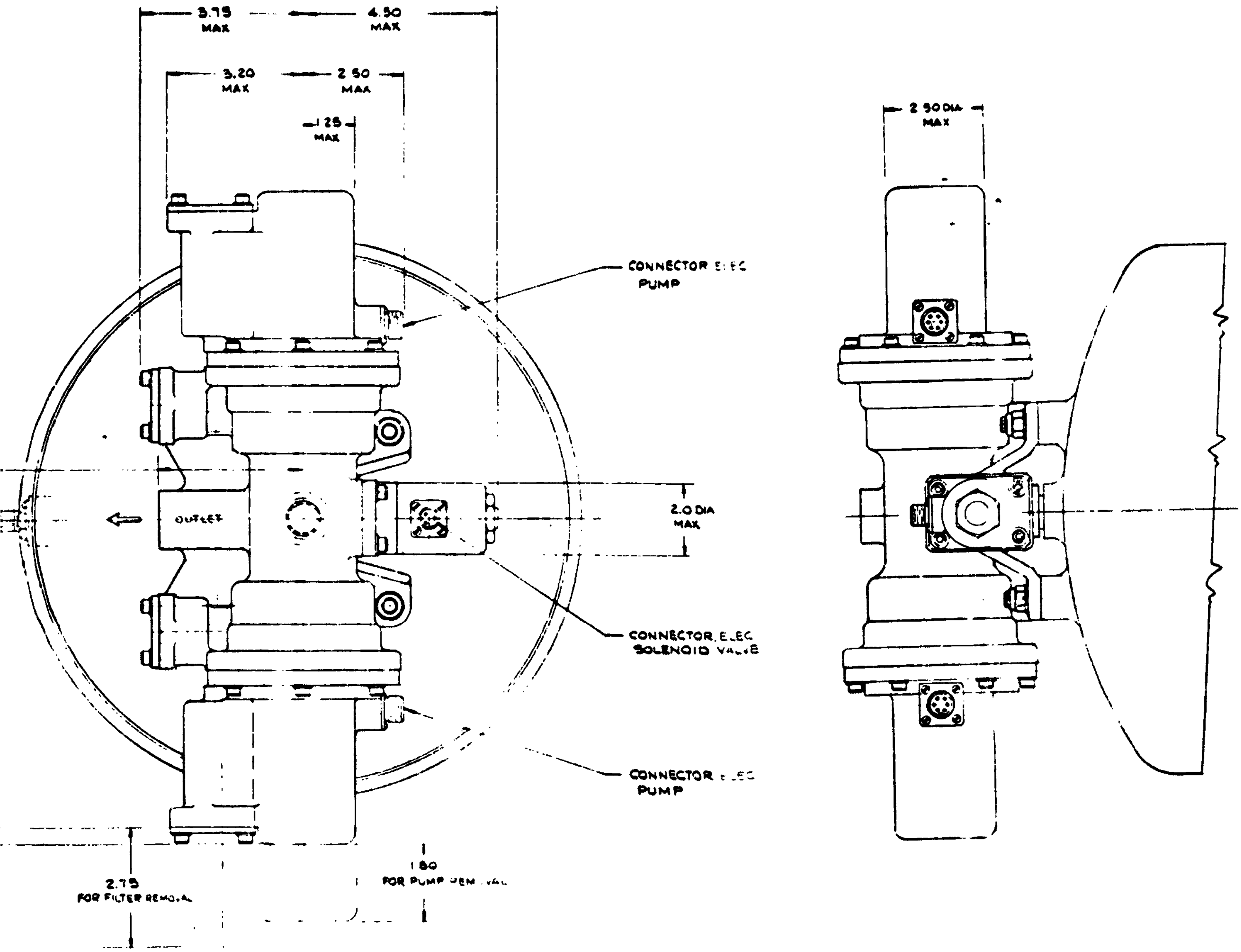


FOLDOUT FRAME 2



FOLDOUT

3 2



2. ACCUMULATOR CAPACITY - .020 IN^3 MIN AT FULL BELLOWS STROKE

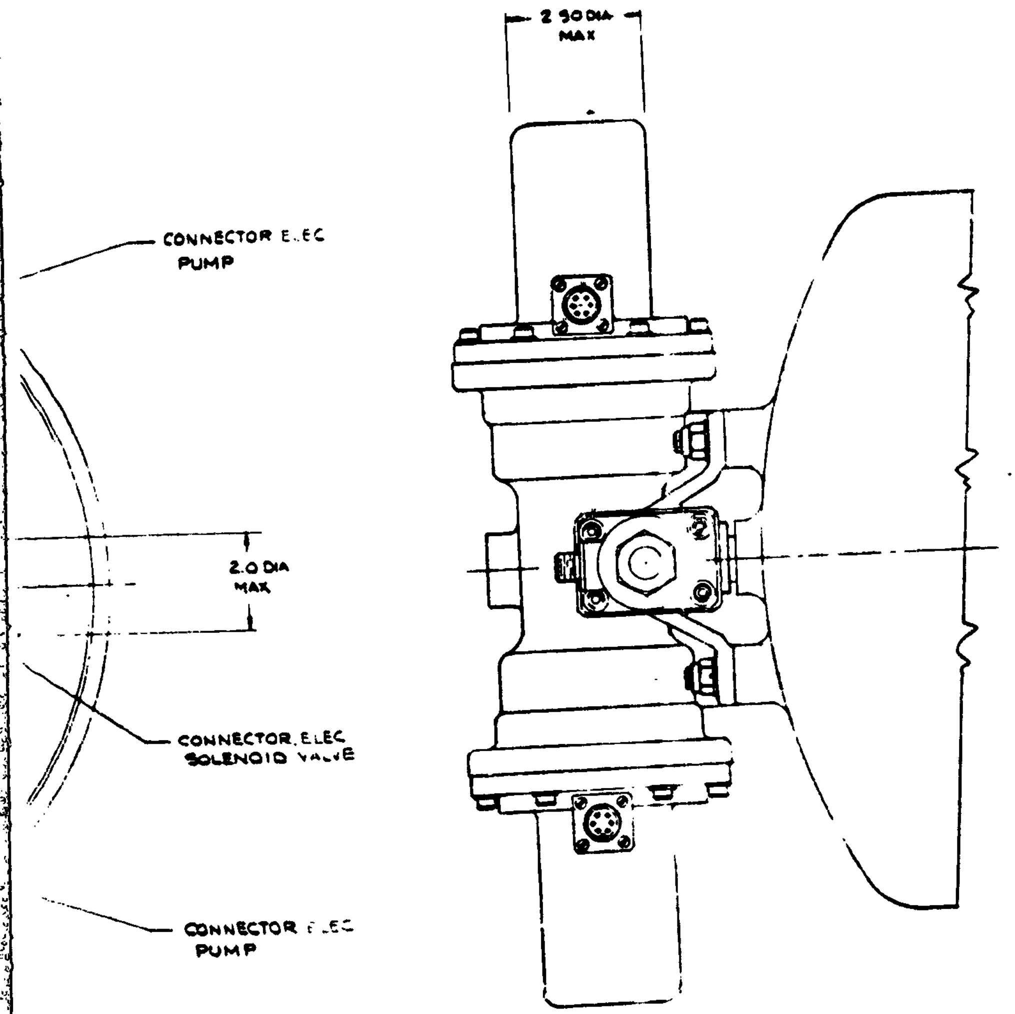
1. MOUNTING PROVISIONS FOR THIS UNIT ARE NOT SHOWN, BUT SHALL BE PROVIDED TO COMPLY WITH CUSTOMERS REQUIREMENTS.

NOTES UNLESS OTHERWISE SPECIFIED

3 2

FOLDOUT FRAME 3

FOLDOUT FRAME 4



2. ACCUMULATOR CAPACITY - .020 IN^3 MIN AT FULL BELLOWS STROKE
1. MOUNTING PROVISIONS FOR THIS UNIT ARE NOT SHOWN, BUT SHALL BE PROVIDED TO COMPLY WITH CUSTOMERS REQUIREMENTS.

NOTES UNLESS OTHERWISE SPECIFIED

AIRESEARCH MANUFACTURING COMPANY

PUMP PACKAGE ASSY OUTLINE, FREON

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The pump/motor and filter assembly can be removed without the necessity for removing the accumulator. Spring-loaded flapper valves are installed in the pump inlet manifold on which the accumulator is mounted. These valves are normally held open mechanically by a probe that is part of the pump inlet. When the pump is removed, the flapper valve will close and the pressure of the Freon will press it on its seal. In this manner the pump/motor can be replaced as a separate LRU. In terms of package maintainability, this is a very desirable feature.

The pump motor assembly can be removed by removing six bolts and the electrical connector to the pump. Removal of the entire package for corrective maintenance requires (1) disconnecting the Freon inlet and outlet fittings, (2) disconnecting the power supply to the pumps and the electrical connectors to the pressure and ΔP transducers, and (3) removing the mechanical supports securing the package through the base of the accumulator.

4.5.6.2 Ammonia Boiler Package (LRU 7-N)

This assembly incorporates the following components.

(a) Ammonia boiler (Item 7.43)

(b) Two vernatherm NH_3 flow control valves (Items 7.42)

(c) Two solenoid isolation valves (Item 7.39)

(d) Ammonia line relief valve (Item 7.41)

(e) Temperature transducers (Items 7.258 and 7.259)

Figure 4-25 depicts the arrangement. All components are mounted on a triangular frame that can be attached to the vehicle structure at three points. All components are identified on the package by their item numbers.

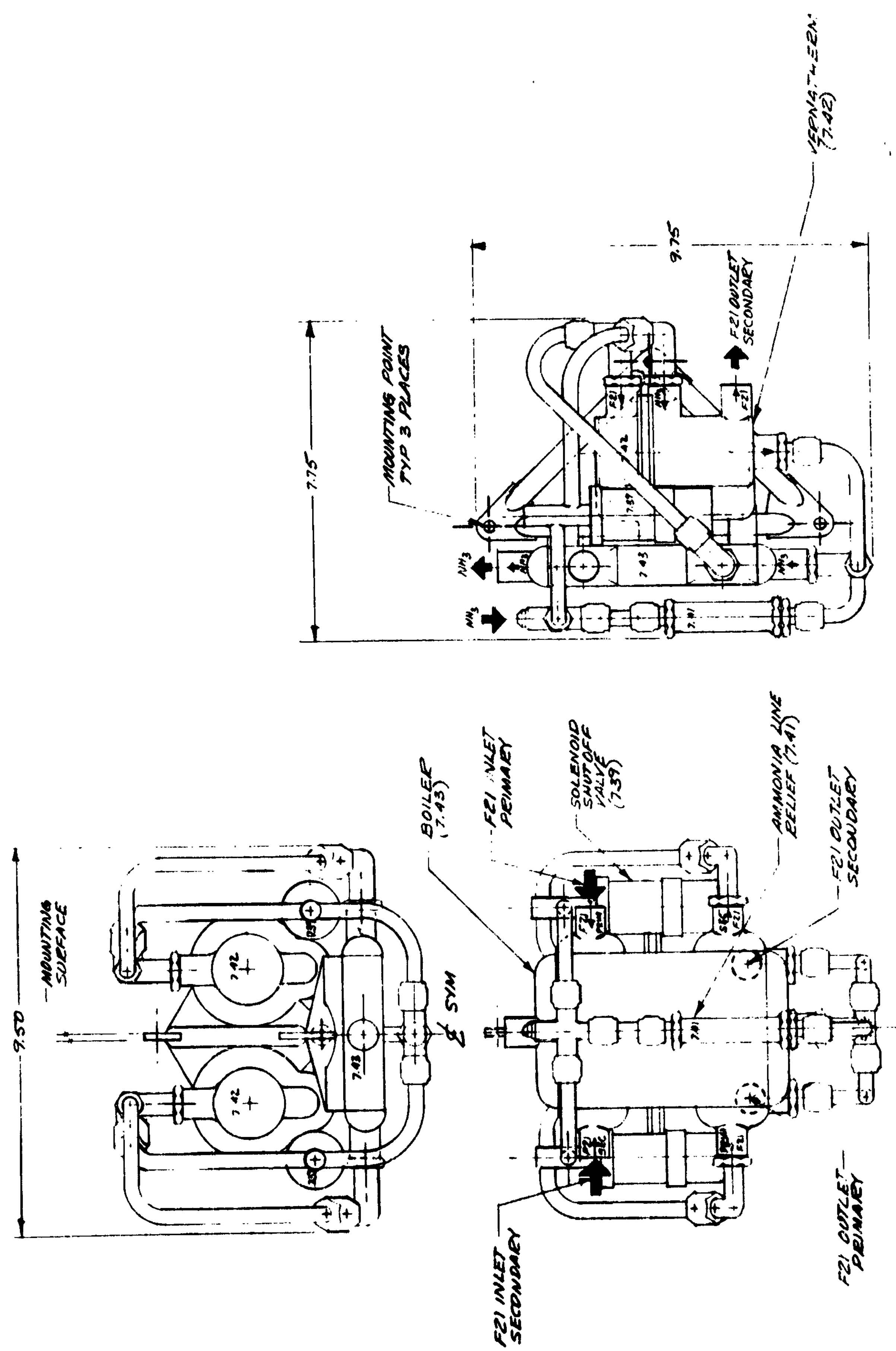

Figure 4-25. Boiler Assembly, LRU 7-N

As illustrated, all components in the ammonia feed line (Items 7.39 and 7.41) to the vernatherm can be removed as separate LRU's. Accessibility is provided while maintaining a very compact arrangement. Replacement of the vernatherm valves (Item 7.42) will entail breaking the Freon-21 connections and removal of other components. For these reasons, the vernatherm valves and the boiler itself will be removed, together with the entire package.

The overall dimensions of the package are shown in Figure 4-25. The weight of the components included in the package is calculated at 11.3 lb. The weight of the lines, structures, and connectors for the solenoid valves is estimated at 2.6 lb, for a total of 13.9 lb.

4.5.6.3 <u>Ammonia Tank Assembly (LRU 7-L)</u>

This assembly consists of

(a) Ammonia tank (Item 7.34)

(b) Ammonia fill connector (Item 7.37)

(c) Ammonia tank vent valve (Item 7.38)

(d) Ammonia tank burst disks and relief valves (Items 7.35, 7.36 and 7.44)

(e) Ammonia shutoff valve (Item 7.39)

(f) Ammonia tank pressure transducer (Item 7.152)

The package is shown in Figure 4-26. The spherical tank is supported by three bipod struts attached to the vehicle structure. The valves and transducers are line-mounted and are accessible for removal as single elements. The manual vent valve (Item 7.38) is easily accessible for ease of tank servicing. The vent valve outflow will have to be processed to preclude danger to the maintenance crew. GSE will be necessary for processing tank vent flow during the fill operations.

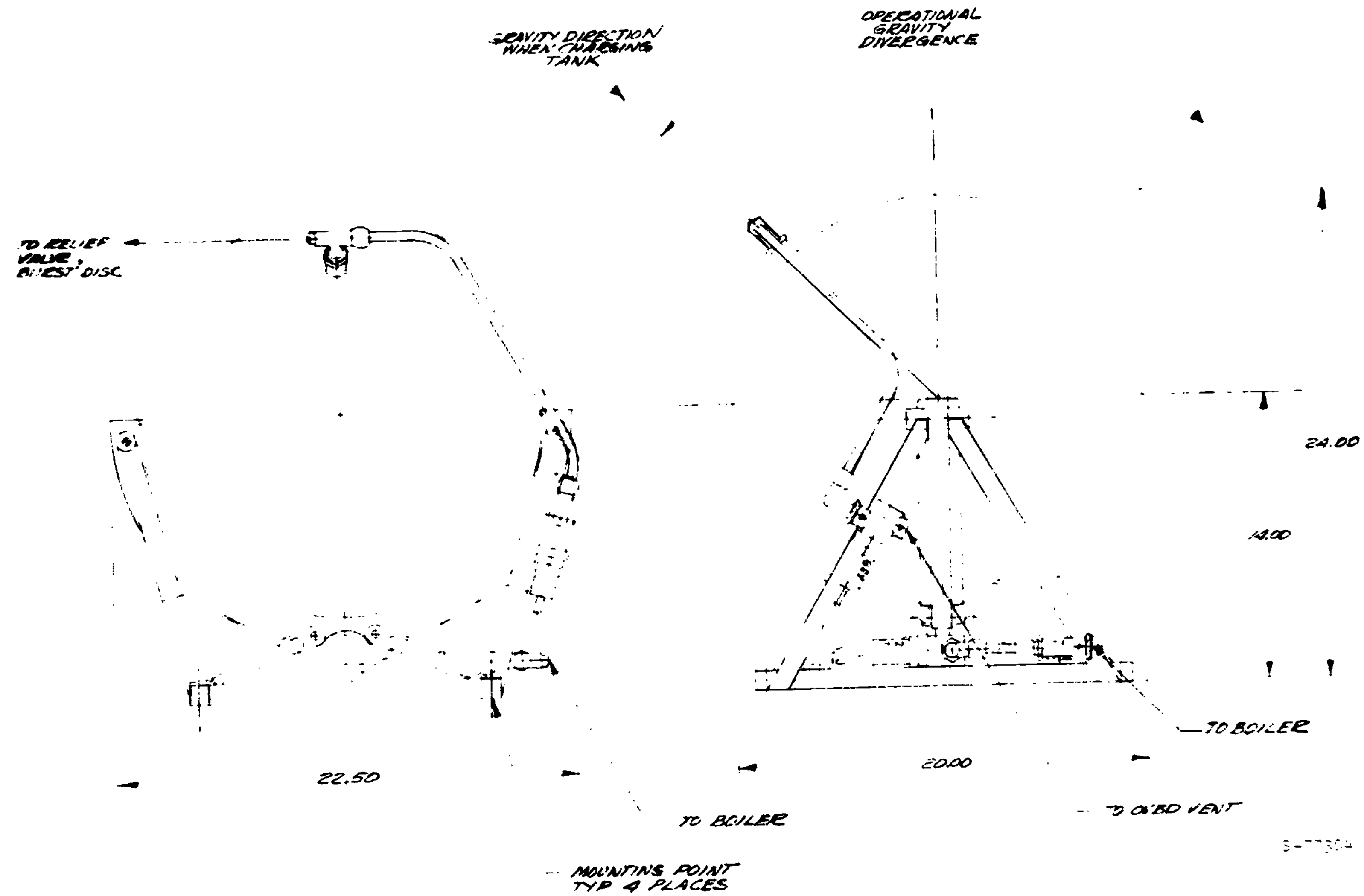

Figure 4-26. NH_3 Tank Assembly

Package dimensions are shown in Figure 4-26. Overall weight including lines, structure, and connectors is estimated at 19.0 lb (dry).

4.5.7 Equipment Redundancy

The Freon-21 coolant loop is similar to the water loop in terms of redundancy. Two pumps per loop are recommended, with a single accumulator in each loop.

The design of the radiator panels and controls is beyond the scope of this contract. The only failure considered here is a complete failure of both redundant radiator circuits. Under these conditions, the radiators will be immediately isolated and all Freon flow will bypass the unit. The cooling function will be performed by the sublimator, which will be activated automatically upon sensing the high temperature at inlet. This will constitute a mission abort situation. Two evaporators are available in the water coolant loop, enhancing the fail-safe feature of the heat sinks.

All heat exchangers have redundant passages to accommodate the two Freon loops. Provisions are made for cooling either Freon loop with either of two vapor cycle units during ferry flight.

The GSE bypass valve and control need not be redundant because this circuit is not normally required during flight except when the radiator bypass has failed.

Two ammonia boilers are included in the design. Each boiler can be used with either Freon loop. Triple redundancy is not required because boiler operation does not involve crew safety. However, the arrangement shown would require a minimum of three failures before complete loss of the cooling function.

The ammonia storage and delivery system is redundant. Either of the two boilers can be fed from either ammonia tank. The capacity of each tank is sufficient to provide for one-half the prelaunch and all the postlanding evaporant. Thus, complete redundancy is provided, and triple redundancy is not incorporated in the system because the function does not involve crew safety. It is recommended that both tanks be opened to the boilers for all ground cooling functions.

4.5.8 Redundancy Management

The redundancy management features of the Freon-21 heat rejection subsystem are peculiar to the nature of the equipment comprised in the redundant loops. A summary of the Freon-21 heat rejection subsystem redundancy management analysis is presented in Table 4-15.

With the exception of the pumps, the GSE bypass valve and controls, the ammonia boilers, and the radiator, all other components are passive heat exchangers.

Heat exchangers can only fail through leakage. Thermodynamically, a heat exchanger will perform normally even if it leaks. Therefore, temperature measurements will not provide the information necessary to identify heat exchanger failure. Leakage, however, can be determined by the quantity of fluid stored in the loop accumulator.

The Freon-21 coolant pump assures flow through the system, and as long as the flow is maintained, the heat exchangers will perform within specification. Thus, pump performance, as measured by pump pressure rise, is an essential parameter in terms of redundancy management.

TABLE 4-15

REDUNDANCY MANAGEMENT SUMMARY,
ATMOSPHERE CONTROL SUBSYSTEM

Functional Symptom	Onboard Sensor	Possible Causes	Redundancy Management Action	[illegible]
1. Pump ΔP high	Pump ΔP 7.150	1.1 Filter plugged 1.2 Loop blockage	1.1 Switch to [illegible] pump [illegible] 1.2 Same as 1.1 [illegible]	
2. Pump ΔP low Pump inlet pressure normal	Pump ΔP 7.153	2.1 Pump failure	2.1 Switch to redundant pump	
3. Accumulator quantity low	Accumulator Q7.50[illegible]	3.1 System leakage	3.1.1 Switch to redundant loop	
4. Pump inlet pressure low	Pump inlet P7.1[illegible]	4.1 Filter plugging 4.2 Accumulator failure	4.1 Same as 1.2 switch to redundant loop 4.2 Switch to redundant loop	
5. Pump inlet pressure high	Pump inlet P7.100	5.1 Accumulator failure	5.1 Switch to redundant loop	
6. Interchanger inlet temperature high Pump sensor normal	Temp sensor 7.251	6.1 Radiator failure 6.2 GSE bypass valve failure (or control) 6.3 Overload on the system	6.1 Switch to redundant loop, if condition persist activate water evaporator 6.2 Switch to redundant loop 6.3 Reduce load	[illegible]
7. Interchanger inlet temperature low	Temp sensor 7.2[illegible]1	7.1 Radiator control failure	7.1 Switch to redundant loop to [illegible] freezing at water loop [illegible] interchanger 7.7	
8. NH3 tank pressure high	Tank pressure 7.152	8.1 Overheating	8.1 Vent through [illegible]	[illegible]
9. NH3 tank pressure low	Tank pressure 7.152	9.1 Leakage	9.1 [illegible] redundant [illegible]	
10. NH3 boiler outlet temperature [illegible] (ground operation only) Pump sensor normal	Temp sensor 7.25[illegible]	10.1 Primary boiler [illegible] failure	10.1 Switch to redundant unit	
11. NH3 boiler outlet temperature low (ground operation only)	Temp sensor	11.1 Primary boiler control failure	11.1 Switch to redundant [illegible]	

Another parameter of importance is the pump inlet pressure. This parameter determines accumulator performance and provides an indication of excessive leakage that should have been detected normally by low accumulator quantity.

The only redundancy management actions involve switching pumps in the primary loop or switching from the primary to the secondary loop. The first action will be taken upon pump failure, and the second in the event of two pump failures, leakage, or accumulator failure.

With respect to the three loop functional packages mentioned above, the GSE bypass valve will not be operated normally during space flight so that no failure of the bypass valve or control system is anticipated. In the event of failure, the valve can be overridden through the controller. The radiator subsystem is considered as a separate subsystem with its own failure detection instrumentation and redundancy management scheme. Outlet temperature measurement should be sufficient to monitor the overall performance of the radiator and its controls to identify a failure. If such a failure were to occur, the redundant secondary Freon loop would have to be activated. If the failure is such that it extends to the secondary loop, the evaporator would have to be activated and the mission aborted.

The approach used for redundancy management of the ammonia boiler package is similar. Freon temperature at primary boiler inlet is monitored. Should this temperature exceed the safe limit, the primary boiler will be deactivated and the secondary boiler will be switched on. Boiler operation does not involve crew safety. Also, both tanks should be opened to the active boiler in normal operation.

4.6 FERRY MODE HEAT SINK

4.6.1 Functional Requirements

For the basic space flight mission, the thermal energy collected by the thermal management subsystem will be rejected to space either through a radiator or to an expendable evaporant. During ferry flight, however, the ambient atmosphere will be used as the ultimate heat sink; this represents a special condition for the operation of the liquid Freon-21 coolant loop.

Since the ferry mission is distinct from the basic orbiter mission, the scheme under consideration is to utilize an "add-on" refrigeration package. This refrigeration package will be installed in the engine pod and tied into the Freon-21 coolant loop by means of quick-disconnect couplings and the necessary valving so that Freon-21 flow will be diverted through the refrigeration package. The package will be removed from the vehicle before the space flight mission.

Because the ferry flight mode is similar to that of a low-performance aircraft, air cycle and vapor cycle refrigeration equipment commonly used in aircraft air conditioning systems are considered suitable for this application. Both types of refrigeration equipment have demonstrated a high degree of reliability and service life in airline operation, and off-the-shelf hardware that will meet the requirements of the ferry mission is available.

The results of penalty studies conducted to determine the relative weight penalties associated with air cycle and vapor cycle refrigeration show a definite advantage in favor of the vapor cycle approach. In addition, the vapor cycle unit offers a significant operational advantage because only electrical power is necessary for ground operations. In terms of reliability or maintenance requirements, both approaches are comparable. Furthermore, since the equipment involved in both concepts represents only slight modifications of proven hardware, the cost associated with the development and qualification of air cycle and vapor cycle refrigeration systems are not a determining factor. Thus, the vapor cycle system is recommended.

4.6.2 Performance Requirements

The system is designed for an evaporator heat load of 40,500 Btu/hr (675 Btu/min) on a 103°F day at sea level. It will cool 2200 lb/hr of liquid Freon-21 from 113° to 40°F. Operating conditions are defined in Table 4-16.

TABLE 4-16

VAPOR CYCLE UNIT DESIGN CONDITIONS

Mode	Idle	Cruise	Loiter
Day	Hot	Hot	Hot
Altitude, ft	0	20,000	2,000
Mach No.	0	0.5	0.3
Ambient pressure, psia	14.69	6.75	13.67
Ambient temperature, °F	103.0	25.5	95.4
Bleed pressure, psia	44	450	70
Bleed temperature, °F	460	1,000	700
Ram pressure, psia (80 percent recovery)	14.69	7.76	13.98
Ram temperature, °F	103	50	99
Ambient humidity	154	52	154
Freon-21 flow, lb/hr	2,200	2,200	2,200
Freon-21 return temperature, °F	118	113	113
Freon-21 supply temperature, °F	45	40	40

4.6.3 Subsystem Description

The vapor cycle unit is shown schematically in Figure 4-27. The basic objectives in the development of the unit are to (1) develop a simple, compact, lightweight vapor cycle unit; and (2) utilize components that are available within a reasonably short development time. The estimated total wet weight of the unit is 122.4 lb (including 3.8 lb of Freon-21 in the evaporator).

The vapor cycle system includes an evaporator, a two-stage centrifugal compressor, a condenser, a condenser fan, and Freon controls. The controls include an expansion/surge dual control valve and a condenser pressure control. The system operates with Freon-114, chosen for its compatibility with a centrifugal compressor now in production.

The basic thermodynamic cycle for the refrigeration system at the design condition is shown in Figure 4-28. The refrigerant enters the evaporator as a low-temperature (30°F) mixture of liquid and vapor at approximately 13 psia (point 1 in the diagram). In this low-pressure side of the cycle, the pressure remains essentially constant as the refrigerant passes through the evaporator. In the evaporator, the liquid portion of the refrigerant evaporates as it absorbs heat from the heat transport fluid (liquid Freon-21). The Freon-114 refrigerant leaves the evaporator as a saturated vapor at 30°F and mixes with a small amount of motor-cooling Freon at the compressor inlet (point 2). The mix temperature remains essentially at 30°F.

Next, the vapor enters the two-stage centrifugal compressor, where it is compressed to 86 psia at 160°F (point 3). (On this high side of the cycle the pressure remains essentially constant between the compressor discharge and the dual control valve.) The vapor then enters the condenser, where it is condensed at a temperature of 140°F by transfer of heat to the outside air drawn through

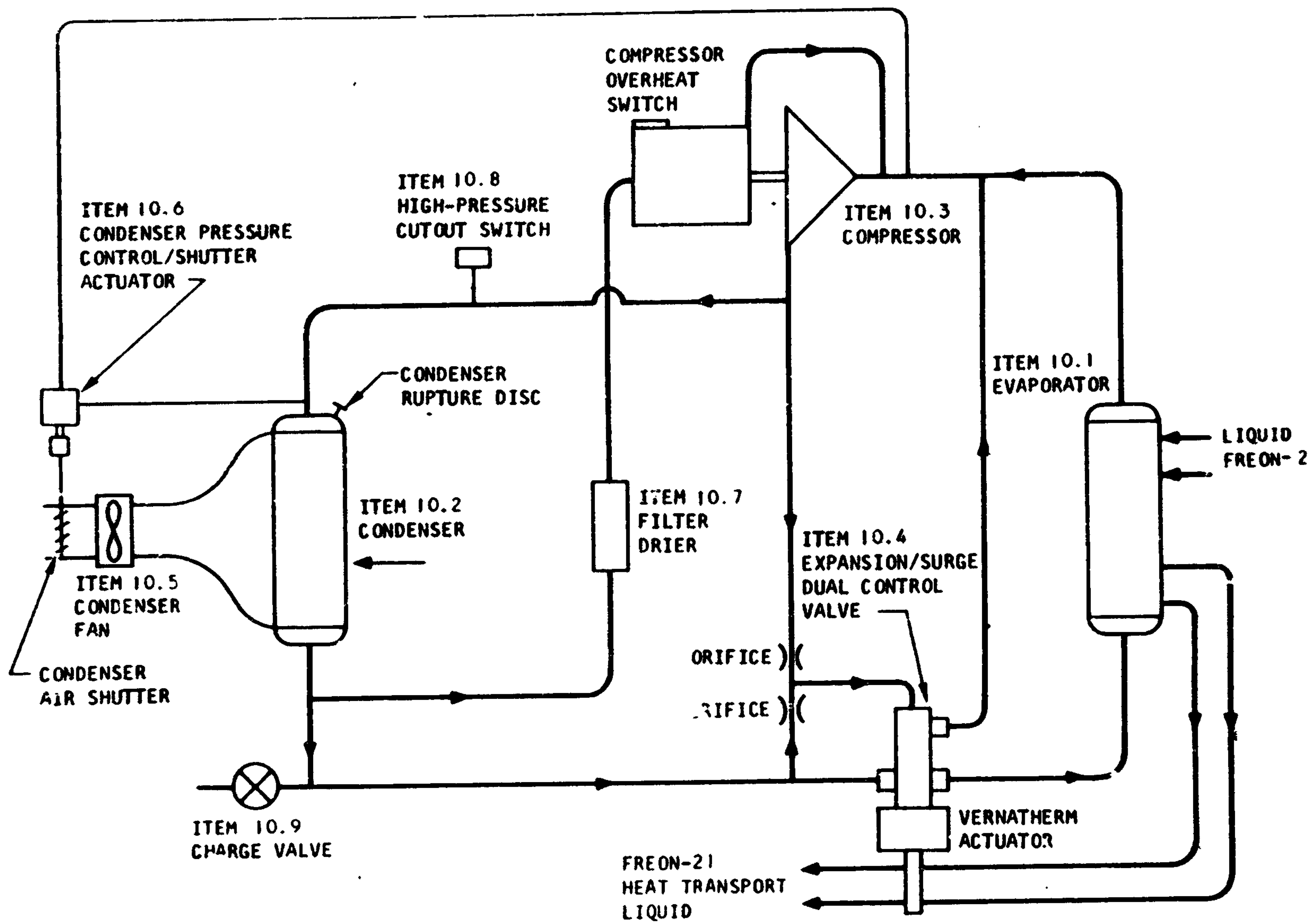

Figure 4-27. Schematic Diagram, Vapor Cycle System

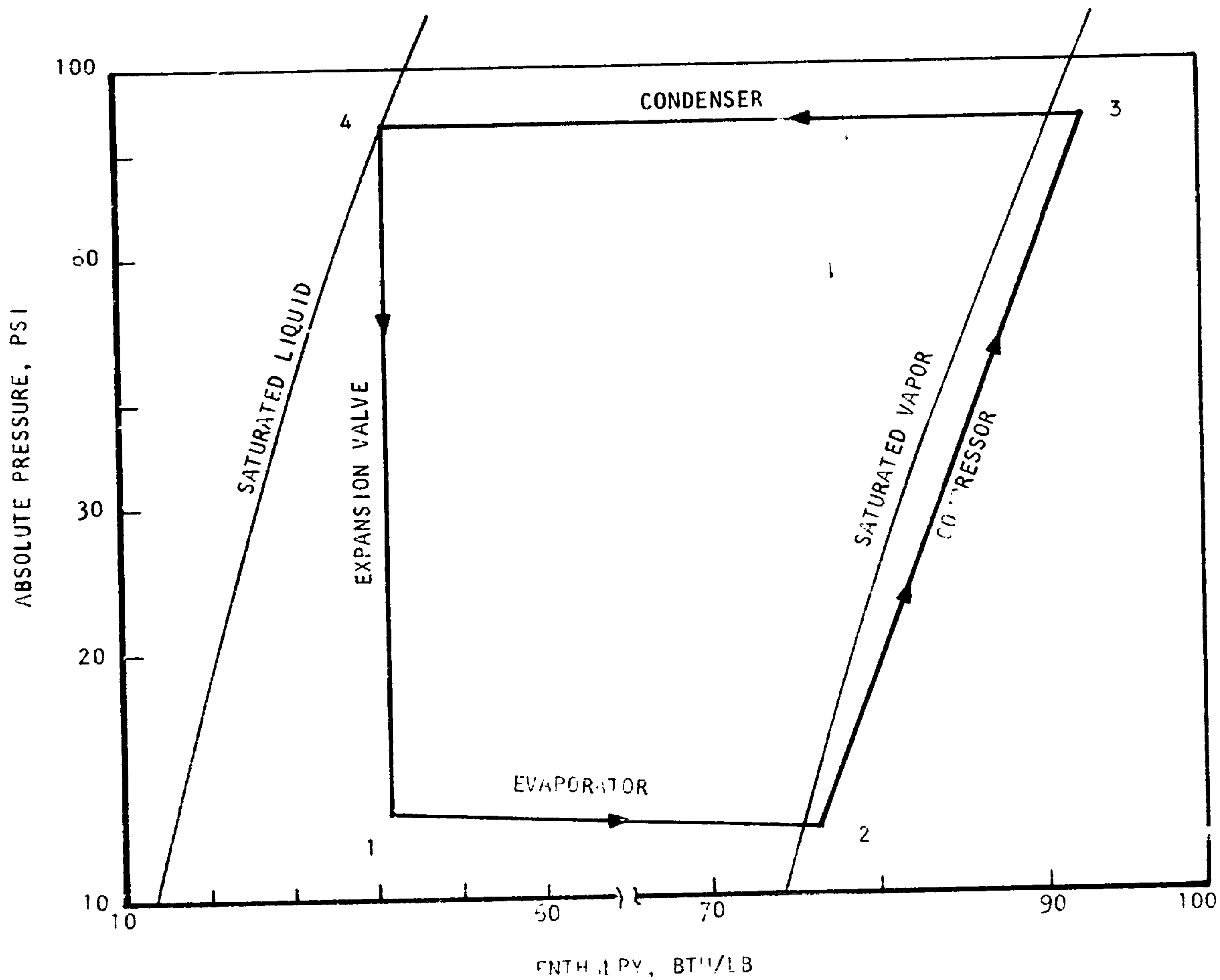

Figure 4-28. Diagram of Freon-114 Refrigeration Cycle at Design Conditions

the condenser by the cooling air (points 3 and 4). The liquid Freon then flows to the expansion valve section of the dual control valve, where it expands into a two-phase mixture of liquid and vapor (point 1), and the cycle is repeated.

Freon-114 is selected as the working fluid because it is a lower pressure refrigerant than either Freon-12 or -22 and results in lighter condenser and evaporator designs; however, in this respect Freon-11 and -113 are lower pressure refrigerants than -114. The major reason for selecting Freon-114 is that it provides a very good match between evaporator design and compressor efficiency. For the use of a centrifugal compressor, a low-density fluid is desirable; on the other hand, the compressor performance requirements are intimately related to the evaporator pressure drop (which results in a reduction in evaporator temperature). Careful design studies conducted for this application have shown Freon-114 to be the best overall refrigerant.

Although toxicity is not a critical requirement in the present application because the unit will be installed in the engine pods, Freon-114 is also much less toxic than either -11 or -113 according to the Underwriter's Laboratories "Classification of Comparative Hazard to Life of Gases and Vapors."

4.6.4 Equipment Summary

Table 4-17 presents a list of the equipment required, functional and performance descriptions, estimated weights, and estimated power requirements for the vapor cycle unit.

The vapor cycle unit requires a total of nine individual components, a wiring harness, a structural frame and the necessary brackets for mounting the components, and a number of ducts and tubes for component interconnection. The number of required components has been reduced to a minimum, primarily by the simplification of the various controls necessary for proper system

TABLE 4-17

EQUIPMENT SUMMARY, VAPOR CYCLE SYSTEM

Name	Number Required	Functional and Performance Requirements	Weight lb (dry)	Power kw	Remarks
Evaporator	1	Heat sink for Freon-21 heat transfer liquid, cools liquid Freon-21 flow of 22 [illegible] lb/hr from 113°F to 40°F (40,500 Btu/hr heat load) by boiling Freon 114	4.5	0	Two independent liquid Freon [illegible] in 2-pass [illegible] construction; aluminum plate-fin construction; 7.6 x 4.55 x 4.65 inches overall.
Condenser	1	1125 Btu/min heat rejection to 156 lb/min of air entering at 103°F, 140°F condensing temperature	28.4	0	Freon-114-to-air heat exchanger [illegible] plate-fin construction [illegible] 12.5 x 4.6 inches overall [illegible] with 165 psig rupture diaphragm to unload the compressor in the event of malfunction in other protective [illegible]
Compressor	1	Compresses 21.6 lb/min of Freon-114 from 11.75 psia at 30°F to 86 psia at 160°F (enthalpy rise of 17.7 Btu/lb)	53.0	7.3	2-stage centrifugal compressor driven by 23,500 rpm, [illegible] 115/200-volt 3-phase, 400-Hz induction motor
Expansion/Surge Dual Control Valve	1	Controls liquid Freon-21 temperature leaving the evaporator to 40 ±5°F by regulating Freon-114 flow, also prevents compressor from surging during low load operation	3.0	0	Vernatherm temperature sensor actuated
Condenser Fan	1	Provides cooling air for the condenser during ground operation, rated to deliver 2350 cfm at 3.66-in H_2O static pressure rise with inlet air at 14.6 psia and 133°F.	19.5	2.2	Driven by 7,600 rpm, 3-hp, 115/200-volt 3-phase, 400-Hz induction motor, includes integral shutters
Condenser Pressure Control Shutter Actuator	1	Controls condenser pressure by opening shutters wide open at 82.5 psia and closing shutters at 73.0 psia; maintains adequate condenser pressure under all operating conditions, limits compressor suction pressure to a minimum of 10 psia	2.4	0	Utilizes Freon-114 pressure differential existing across the compressor for actuator power
Filter Drier	1	Traps foreign matter and moisture from the recirculating Freon-114 charge	0.7	0	Contains desiccant material between fine mesh screens at inlet and outlet of cylindrical shell
High Pressure Cutout Switch	1	Operates to shut down the compressor whenever the compressor discharge pressure reaches 145 psig	0.3	0	Connected electrically in series with the motor overheat switch
Charge Valve	1	Back-seating type to prevent leakage when the valve is opened during the evacuation or charging process	0.3	0	A cap is provided to act as a double seal on the valve stem
Miscellaneous Ducting and Tubing	TBD	Interconnects system components	3.0	0	Includes orifices
Mounting Frame and Miscellaneous Brackets	1	Frame for mounting system components	15.0	0	
Wiring Harness	1	Provides electrical interface of package with vehicle power	1.5	0	
Freon-114 Charge			7.[illegible]	0	
		Total weight	113.6		

operation. The exact number of ducts and tubes will be determined when the packaging is finalized. The estimated total package weight, including Freon-114 charge, is 118.6 lb. The total power requirement is 10.0 kw (7.9 kw for the compressor and 2.1 kw for the condenser fan).

4.6.5 Maintainability

Maintainability of the vapor cycle system was a major consideration in component selection as well as system packaging. The components were selected from proven equipment on the basis of simplicity and reliability. The number of components has been reduced to a minimum through the use of controls that provide multiple functions. Where possible, simple orifices have been substituted for control valves and sensors, thus improving reliability and maintainability. There are no electronic controls in the system. Freon compressors in airline service have accumulated over 30 million operating hours and have demonstrated an MTBF of 45,000 hr.

The system will be packaged as a single hermetic unit to maintain the integrity of the Freon-114 loop. No dynamic seals will be used and the plumbing will be welded to minimize the number of static seal joints. These design concepts are used to reduce refrigerant leakage and thereby increase the service life of the equipment. At the low temperatures to which the system will be exposed, the pressure in the Freon-114 loop could become negative and air could leak into the system. For this reason the system must be air-tight, and the use of quick-disconnect connections is not recommended. The vapor cycle unit interfaces with the vehicle Freon-21 loop, however, and recharging of this loop will be necessary if a vapor cycle needs replacement. Since the Freon-114 loop must be evacuated to 200 microns before recharging, a lengthy pump-down period could be required.

The dual control valve is designed to attach directly to the Freon-21 outlet ports on the evaporator. Removal of the package is accomplished by disconnecting four Freon-21 lines from the evaporator, two air ducts from the condenser circuit, the electrical connectors, and the frame mounting bolts. It is estimated that the package could be replaced in one hour or less, depending on the type of disconnect fittings used.

The overall vapor cycle maintenance task on the vehicle would consist of determining whether the package is performing properly by monitoring the liquid Freon-21 temperatures and the compressor power. If a package problem is indicated, the entire unit will be replaced and the suspect unit returned to shop for evaluation and repair.

SECTION 5

MAINTENANCE

5. MAINTENANCE

5.1 GENERAL CONSIDERATIONS

Among the most important of the space shuttle ETC/LSS requirements are the guidelines covering the operational phase of the vehicle. Factors such as minimum operational cost, reusability, and short turnaround translate into subsystem arrangements, equipment packages, and components that must incorporate a high degree of reliability and yet that can be maintained effectively on the ground.

High system reliability is achieved through equipment quality and the rational application of the FO-FS criterion. This aspect of the space shuttle ETC/LSS design is discussed in a previous section of this report.

In support of the subsystem schematic development, extensive analyses were conducted to assure that the arrangements recommended were optimum from the standpoint of redundancy management in flight and also in terms of ground maintenance. The results of the redundancy analyses have been discussed previously. This report section considers the ground maintenance aspect of the space shuttle ETC/LSS.

An assessment was made of the maintenance requirements of the four subsystems described in Section 4. The objectives of these investigations were to:

(a) Validate the maintainability features incorporated in the design, LRU package definition, FD-FI approaches

(b) Identify additional instrumentation required for ground checkout, but not necessary for control or redundancy management in flight.

(c) Identify the GSE required to support the ground maintenance activities

(d) Determine the time involved in performing the routine and unscheduled maintenance tasks

(e) Provide basic data for spares definition

(f) Provide data basic to the development of the space shuttle operational cost

Only onboard maintenance was considered. Depots or shop-level maintenance was not investigated. The overall onboard maintenance has been divided in three major areas of activities:

(a) Scheduled Maintenance--Including postflight servicing, preventative maintenance and preflight servicing.

(b) Ground Checkout--Functional check of all components and LRU's (including redundant legs) to establish flight worthiness

(c) Corrective Maintenance--This involves LRU level remove and replace actions following fault detection during flight or as a result of scheduled maintenance activities.

Although ground checkout is essentially part of scheduled maintenance, it is considered separately mainly because of the specificity of this particular phase of the maintenance activities.

5.2 GUIDELINES AND ASSUMPTIONS

5.2.1 General Guidelines

The general guidelines used in the performance of the maintainability analyses are listed below:

(a) Power is available for activation of all system electrical components

(b) The onboard computer or equivalent is available for readout of the system instrumentation transducers

(c) GSE is available in the vicinity of or onboard the vehicle. The time involved in GSE hook-up was included in the analyses, but the time expended in making the GSE available is not included.

(d) GSE is available without interference.

(e) Maintenance tasks can be performed without interference from other maintenance crews.

(f) Generally, two men of skill levels 3 and 5 are necessary. This is specially true of maintenance tasks involving personnel safety.

(g) Spare LRU's will be available without delays

Various aspects of the maintenance activities particular to a subsystem are discussed with the data specific to that subsystem.

5.2.2 Specific Guidelines

The data presented for each subsystem were developed using the following guidelines for each phase of maintenance

5.2.2.1 Post Flight Servicing

This task includes the following activities:

(a) Deactivation of the subsystem

(b) Disposal of solid expendables

(c) Flushing of the gaseous and liquid expendables

(d) Securing the subsystem to prevent damage or contamination between flights

Flight data analysis and scheduling of corrective maintenance will not be performed onboard and are not considered here. Corrective maintenance tasks identified as a result of flight data analysis will normally be performed before ground checkout.

5.2.2.2 Preventative Maintenance

This will include (1) postflight operations which can be defined [illegible] as expendable disposal and/or flushing, and (2) replacement of life limited items.

5.2.2.3 Preflight Servicing

This involves (1) expendable replenishment, and (2) removal of the protective closures installed after the flight.

5.2.2.4 Flight Readiness Ground Checkout

The portion of the ground maintenance activities considered here will take place after postflight servicing and flight data analysis. It does not involve unscheduled maintenance or repair actions resulting from failures in flight or failures identified as a consequence of the ground checkout FD/FI activities themselves.

The ground checkout procedures recommended are designed to assure LRU integrity. In most cases, this involves testing of the components comprising a particular LRU. These tests are conducted concurrently or sequentially. The kinds of tests necessary include, in general, the following:

(a) Leakage

(b) Functional check

(c) Performance in some cases, as for pumps, fans, regulator and relief valves

(d) All transducers are verified. Pressure transducers are compared to GSE gages; temperature transducers are checked by comparison to ambient and through analysis of flight data. Special test equipment is necessary for checkout of special transducers such as the PO_2 sensor

(e) BITE is incorporated on most controllers; a GSE test set is necessary to perform controller checkout

5.2.2.5 Corrective Maintenance

In developing the requirements for corrective maintenance, the following assumptions were made, in addition to the general groundrules listed above:

(a) The time estimates developed include the time for GSE hookup, fault check, remove and replace action, checkout of the new LRU in the system, and GSE disconnect.

(b) The maintenance action rates were derived from the LRU failure rates using derating factors based on extensive experience with the type of equipment incorporated in the subsystem. This derating factor is established by considerations of secondary failures, erroneous fault detection and isolation, and defective parts due to manufacturing deficiencies.

(c) Maintenance times were estimated using the packaging data presented in Section 4.

(d) LRU installation will be such that all LRU's as defined previously are accessible for replacement without the necessity for removal of other equipment to gain access.

[illegible] de, of this section summarizes the results of the maintenance [illegible] or each subsystem. The vapor cycle refrigeration unit is not considered here. The only onboard maintenance task associated with this subsystem will consist of removing the entire unit.

5.3 ATMOSPHERE REVITALIZATION SUBSYSTEM (ARS)

5.3.1 Scheduled Maintenance

Table 5-1 presents a summary of the scheduled maintenance requirements for the ARS. Scheduled maintenance items are relatively simple and consist of the following:

(a) Servicing the CO_2 processing subsystems, which involves removal of expended LiOH charges and replacement of the shuttle inventory.

(b) Servicing the debris trap subsystem expendable filters in the same manner as above.

(c) Purging and/or draining the condensate separation device with a solution containing bactericide. This will involve activating the phase separators in the waste management subsystem.

(d) Servicing the water coolant loop will involve drying and securing the flash evaporators.

The task times shown in Table 5-1 assume that the operations will be performed by two mechanics with skill level 3 or 5. Postflight servicing will require 38 min. and will require GSE for water boiler servicing. Turnaround maintenance operations will require 70 min. Allowing 30 min for GSE installation and preparation for operation 2.2, the total task time is estimated at 100 min. The potable water cart and the N_2 service cart, also used for servicing the nitrogen supply subsystem, will be necessary for this phase of the scheduled maintenance operations.

Expendable servicing elapsed time is estimated at 45 min. This includes 10 min for task buyoff by the flight inspector and entry into flight data records. No GSE is required.

TABLE 5-1

SCHEDULED MAINTENANCE SUMMARY
ATMOSPHERE REVITALIZATION SUBSYSTEM

LRU	Number Required	Description	Postflight Servicing Operation (Time)	Turnaround Maintenance Operation (Time)	Expendable Servicing Operation (Time)	Maintenance Operations
		Atmosphere revitalization				
2-A-1	1	Cabin fan and valve package	2.1 (2 min)		-	2.1 Verify fan power if off and all fan controls are off
2-A-2	1	Cabin heat exchanger assembly (condenser heater package)	-	2.2(30 min)	-	2.2 Flush with potable water decontamination cart and flow hot N_2 to dry out heat exchanger and H_2O separator. Assure that filter is in place.
2-B	1	Cabin temperature controller	2.3 (4 min)	-	-	2.3 Verify cabin temperature controller power is off and temperature selector is in OFF position.
2-C	1	Cabin temperature selector	2.4 (0 time)	-	-	2.4 Operation concurrent with 2.3
2-D	1	Debris trap assembly		2.5 (15 min)	2.6 (15 min) 2.7 (5 min)	2.5 Remove and replace filter in trap and remove all expended filters 2.6 Replace expended filter inventory for next flight 2.7 Inspect and sign off operation 2.6
2-E	1	Cabin temperature sensor	-	-	-	
2-F	1	CO_2 removal assembly	-	2.8 (20 min)	2.9 (20 min) 2.10 (5 min)	2.8 Remove flight LiOH cartridges and all expended cartridges 2.9 Replace all expended LiOH cartridges for next flight 2.10 Inspect and sign off operation 2.9
2-G	1	Transducer power supply	2.11 (2 min)	-	-	2.11 Verify transducer power supply power is off on all three channels
2-H	1	Cabin temperature anticipator	-	-	-	
3-A	2	Flash water boiler	3.1 (20 min)	-	-	3.1 Drain boiler line and purge with N_2 to dry injector and install protective closure on boiler vents; to be done in conjunction with servicing of water management subsystem
3-B	3	Avionics air cooling package	3.2 (6 min)	-	-	3.2 Verify fan power is off and all fan control switches are off
3-B-1	3	Avionics Hx package	-	-	-	
3-B-2	3	Avionics air cooling fan package	-	-	-	
3-1-1	1	Primary water pump package	3.3 (2 min)	3.4 (5 min)	3.5	3.3 Verify that pump power is off and pump controls are off 3.4 Inspect filter visually for bypass 3.5 Service will be accomplished as part of ground checkout
3.1-2	1	Secondary water pump package	3.6 (2 min)	3.7	3.8	3.6 Repeat operation 3.3 3.7 Repeat operation 3.4. Task time is 0 done concurrently with 3.4. 3.8 Repeat operations 3.5.
3-P	1	Interchanger outlet temperature (primary loop)	-	-	-	
3-Q	1	Interchanger outlet temperature (secondary loop)	-	-	-	
3-V	4	Fill connector assembly	-	-	-	

5.3.2 Flight Readiness Ground Checkout

Checkout of the ARS is summarized in Table 5-2. The requirements are relatively simple and are concerned mainly with the fan, the pump, and functional check of the temperature control equipment. The remainder of the subsystem equipment will be verified concurrently. The debris trap/filter will be replaced between flights, and requires only a ΔP check. No test of the LiOH cartridges is recommended onboard the vehicle. Special test equipment will be necessary to interface with the BITE incorporated in the design of the controller.

Since the controller interfacing components are derived from the DC-10 program, the test set necessary for semiautomatic checkout of the control system will be basically that developed for the DC-10. This set will require modification to include heater control circuitry check capabilities. A certain amount of BITE is designed into the controller; however, most of the BITE circuitry is in the test set.

No thermal performance test is planned for the water coolant loops, as shown in Table 5-2. Checkout is limited to visual inspection for leak detection and exercising the dynamic components (pumps and fans) to verify function and performance. Subsystem instrumentation will be checked out concurrently; sensor continuity check will be performed sequentially using BITE incorporated in the design of Item 3.8. In addition to the BITE necessary for checkout of the cabin temperature control equipment, the only GSE required is the N_2 test set for evaporator checkout. It is recommended that a dye be added to the water for ease of leak detection as noted in the table

TABLE 5-2

GROUND CHECKOUT SUMMARY
ATMOSPHERE REVITALIZATION SUBSYSTEM

LRU	Definition/Function	Test Requirements: Leakage	Test Requirements: Static	Test Requirements: Dynamic	Test Requirements: Visual/Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation*: T	P	ΔP	Special	GSE	C/O Operation	Remarks
2-A	Temperature and humidity control unit/cabin ventilation: humidity condensation and separation; cabin temp control											No c/o operation; remove and replace LRUs; c/o performed at the level of 2-A-1 and 2-A-2	
2-A-1	Cabin fan package/cabin ventilation; process air circulation through ARS			X	X		-	-	A		None	1. Sequentially c/o fans (2.5) and check valves (2.2) operation by powering fans	1. Vehicle power required 2. Fan and check valve removable as a unit 3. LRU 2-D is verified concurrently
2-A-2	Condenser/heater/package/process air cooling; process air heating; condensate separation	X	X	X	X				A	R Position	Controller GSE test set	1. Condenser c/o; (a) visual inspection; (b) flow through condensate separation passages; verified by ΔP 2. Heater c/o; verify continuity, c/o through controller (3.4, LRU 2-C) BITE 3. Temperature control valve c/o; manually operate valve through open to closed cycle	1. Assumption made that condenser (2.6), heater (3.9), and valve (3.2) are removable as an assembly due to packaging constraints 2. Use GSE test set from ACS and WMS 3. Condensate separation function requires powering of the dynamic phase separator 4. Temperature controller incorporates sufficient BITE to check out valve function 5. Position indicator (3.450) required on temperature control valve (3.2)
2-B	Temperature controller/controls cabin temperature by flow diversion			X			-	-	-	BITE	Controller GSE test set	1. Verify operation with GSE test set	1. This check also verifies LRUs 2-C (temperature selector), 2-E (temperature sensor), 2-H (temperature anticipator), and Item 3.9 above
2-C	Temperature selector/permits manual selection of cabin temperature					X	-	-	-	BITE	Controller GSE test set	1. Checked out with LRU 2-B	1. Analysis flight data recorder.
2-D	Debris trap/particulate and bacteria removal			X			-	A	-	-	None	1. Pressure drop check	1. C/o performed concurrently with LRU 2-A-1 (cabin fan package)
2-E	Cabin temperature sensor/signal to controller					X				BITE	Controller GSE test set	1. Checked out with LRU 2-B	1. Qualitative check with controller GSE and flight data analysis
2-F	CO_2 absorber assembly/CO_2 and odor removal				X		-	A	-		None	1. Flow check	1. Quantitative check performed concurrently with 2-A-1 (fan)
2-G	Power supply transducer/power supply to all ECLSS transducers					X	-	-	-	BITE	None	1. Built-in test determines status of LRU 2-G and all ECLSS transducers	1. Analysis of flight data recorder
2-H	Cabin temperature anticipator/signal to controller					X	-	-	-	BITE	BITE incorporated in LRU 2-B	1. Checked out with LRU 2-B	1. Qualitative check with controller GSE and flight data analysis
3-A	Flash water boiler assembly	X	X		X			A		BITE	1. 140 psi test set N_2 2. Pressure closure for boiler outlet for leak-leakage test with pressure gage 3. Controller test set	1. Sequential leakage test of (a) isolation valve; (b) injector metering valve 2. Checkout of controller operation with GSE test unit	1. Checkout to be accomplished concurrently with checkout of water management subsystem 2. Isolation valve leakage test accomplished with metering valve open. To be done via GSE on controller GSE BITE plug 3. Checkout to be accomplished with N_2 only

*A [illegible] red for c/o.

TABLE 5-2 (Continued)

LRU	Definition/Function	Test Requirements: Leakage	Static	Dynamic	Visual/ Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation*: T	P	ΔP	Special	GSE	C/O Operation	Remarks
3-B (3 per shipset)	Air-cooled avionics package/avionics temperature control											No c/o operation; remove and replace LRU; c/o performed at the level of 3-B-1 and 3-B-2	-
3-B-1	Avionics heat exchanger/heat sink for air cooled avionics; air water heat exchanger	X			X	X			A		None	1. Inspection for external and internal leakage - 3 avionics bays	1. Recommend dye in water coolant
3-B-2	Avionics fan package/ ventilation of avionics bays			X	X		-	-	A		None	1. Sequentially c/o fans (3.10), check valves (3.11), and debris trap (3.12) in all 3 avionics bays	1. Check valve and debris trap through sequential operation of the fans
3-1-1	Primary water pump pump package/circulates cooling water through pressurized compartment thermal loop	X		X	X		A	A	A (Q)		None	1. Visual inspection for external leakage 2. Verify accumulator quantity	1. Vehicle power required 2. Recommend dye in water 3. Sequential pump check verifies check valve performance
3-1-2	Secondary water pump package/same as 3-1-1			X			A	A	A (Q)		None	1. See LRU 3-1-1;	See LRU 3-1-1
3-P through 3-Q	Water temperature sensors/monitoring of water coolant loop					X	-	-	-	-	None	1. Readout should be ambient 2°F	1. Flight data record 2. C/o through item 3.8
3-V	Fill connector assembly				X		-	-	-	-	None	1. Leakage check by visual inspection	

*A: available; R: Required for c/o

The sequence of the checkout operations are shown in Table 5-3. The sequence is based on system requirements and also on the efficient use of a 2-man maintenance crew. The task time for each checkout operation and the cumulative total of all task times are given. The tasks involving the second man are identified by parentheses. Some of the factors that were considered in the development of the data are discussed below.

The development of the table is predicated on the availability of skill level 3 and skill level 5 mechanics. Use of a skill level 5 mechanic to operate spacecraft systems, controls, and test consoles and to determine GSE disposition is recommended; the mechanic must be an ARS specialist. With this background he can direct a skill level 3 mechanic to perform all the tasks required to complete checkout as shown.

The table shows completion of checkout without failure, and the final maintenance time frame allows an indeterminate time for corrective maintenance to restore the system to operating conditions. Clear access is assumed for all procedures requiring inspection or visual observation. Furthermore, it is assumed that the GSE is available on or in the vicinity of the vehicle.

The times shown include installation of GSE and securing the subsystem following checkout. The total time required is estimated at 7.3 man-hours for a total elapsed time of 220 min with two men performing the maintenance operations. A larger crew would result in a reduction of elapse time at the cost of increased man-hour requirements.

TABLE 5-3

CHECKOUT TIMELINE
ATMOSPHERE REVITALIZATION SUBSYSTEM

Operation	Checkout Time, min	Cumulative Time, min
ATMOSPHERE LOOP		
Hook up ARS cabin temperature test set	15	15
Check out ARS test set	10	25
Cabin fan ΔP check out	15	40
Check out item 3.8 and ETC/LSS transducers	(45)	(45)
Perform cabin temperature control checkout	35	75
Checkout humidity control heat exchanger and H_2O separator	(15)	(60)
Inspect debris trap	(10)	(70)
Inspect LiOH canister and check manual operation	(15)	(85)
Buy off control checkout	10	85
Buy off ARS circuit checkout	(15)	(100)
Complete ARS sign-off	15	100
or		
Prepare corrective maintenance work sheet	As required to buy off atmosphere loop	
WATER AND AVIONICS LOOPS		
Hook up GSE service cart/checkout cart	20	20
Checkout GSE cart	10	30
Prepare for leakage check	10	40
Perform leakage test, visual inspection	(30)	(50)
Transducer comparison	5	45
Check out primary pumps	15	60
Check out secondary pumps	15	75
Check out transducers	10	85
Inspect heat exchanger air cooled avionics 3 bays visually	(30)	(80)
Top off and service primary and secondary loops and accumulators if necessary	20	105
Sequential check of avionics bays fans	(30)	(110)
Buy off checkout and avionics bays heat exchanger check out	10 (10)	115 (120)
or		
Prepare corrective maintenance work sheets	As required to buy off ARS	
( ) Parentheses indicate second man activity.		

5.3.3 Unscheduled Maintenance

An estimate was made of the onboard corrective maintenance required for the ARS. Table 5-4 presents a summary of the data. The maintenance times shown for each LRU include:

(a) GSE hookup, assuming that the GSE is readily available onboard or in the vicinity of the vehicle

(b) Fault isolation to ascertain that the defective LRU is indeed faulty and to prevent unnecessary LRU replacement

(c) Remove and replace action

(d) Checkout of the new LRU in the system

(e) GSE disconnect

Skill level 3 or 5 is required for corrective maintenance onboard the vehicle. As shown in the table, all maintenance tasks can be performed by one man except for removal of the cabin heat exchanger assembly; the weight of this assembly is estimated at 81.8 lb.

The cabin fans are assumed to be accessible for removal as single units. If the entire package (three fans and check valves) has to be removed from the vehicle as a LRU, the maintenance man-hours per operating hours (MMH/OH) for this package would increase from 46 to 210 hr/10^6 hr.

The time shown does not include the time necessary for servicing the water coolant loop. This will require 2 men for 5 hr. It is assumed here that components can be replaced without flushing, evacuating and refilling. This will require that special connectors be used and that the components be charged with wate- before installation. Provisions will be made for flushing the loop of air trapped at the interfaces.

TABLE 5-4

ONBOARD CORRECTIVE MAINTENANCE, ATMOSPHERE REVITALIZATION SUBSYSTEM

Item No.	Item Description	Maint. Crew Size	Elapsed Time, hr	Maint. Man-Hour Task	No. LRU's in System	Maint. Action Rate, Item/10^6 hr	Maint. Man-Hours Operating per 10^6 hr	Remarks
2-A-1	Fan and valve assembly	1	0.5	0.5	3	-	-	Removal of entire fan package not necessary
	ΔP transducer	1	0.2	0.2	2	[illegible]	[illegible]	Removable as LRU
	Fan and valve	1	0.3	0.4	3	30.0	36.[illegible]	Single fan/valve removable
2-A-2	Cabin heat exchanger	2	2.6	5.2	1	31.0	[illegible]	Include electrical [illegible] valve; servicing of water [illegible] not included in [illegible] necessary, this would require [illegible] elapsed time
2-B	Cabin temperature controller	1	0.3	0.3	1	30.0	9.0	
2-C	Cabin temperature selector	[illegible]	0.3	0.3	1	15.0	4.5	
2-D	Debris trap assembly	1	0.5	0.5	1	3.0	1.5	
	Debris trap ΔP transducer	1	0.2	0.2	1	25.0	-	Removable as LRU
2-E	Cabin temperature sensor	1	0.2	0.2	1	10.0	2.0	
2-F	CO_2 removal assembly	1	0.6	0.6	1	10.0	6.0	
	CO_2 canister	1	0.5	0.5	1	5.0	-	Removable as separate LRU
2-G	Transducer power supply	1	0.4	0.4	3	30.0	36.0	
2-H	Cabin temperature anticipator sensor	1	0.2	0.2	1	10.0	2.0	
3-A	Flash evaporator assembly	2	1.5	3.0	2	*5.0	30.0	*Entire assembly removed only in event of flash evaporator failure; servicing of water coolant loop not included in task time; this would require an additional 10 maintenance hours per occurrence.
	Spray nozzle	1	0.5	0.5	2	20.0	20.0	Removable as LRU's
	Evaporant solenoid S O valve	1	0.4	0.4	2	15.0	12.0	Removable as LRU's
	Controller	1	0.3	0.3	2	20.0	12.0	Removable as LRU's
	Temperature sensor	1	0.3	0.3	2	10.0	6.0	Removable as LRU's
3-B-1	Avionics heat exchanger	1	1.4	1.4	3	8.0	33.6	Servicing of water coolant loop not included in task time, this would require an additional 10 maintenance hours per occurence.
3-B-2	Avionics fan package	1	0.8	0.8	3	90.0	-	Not removed as a package; assumes fans are accessible for single fan/valve replacement
	Fan check valve	1	0.4	0.4	6	18.0	43.2	Removable as LRU's
	ΔP transducers	1	0.2	0.2	6	25.0	30.0	Removable as LRU's
3-I-1	Primary water pump package	1	1.2	1.2	1	*25.0	30.0	*Removed only when accumulator, pump, or valves are defective
	Pump motor	1	0.8	0.8	2	25.0	40.0	Removable as LRU's
	Pressure transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's
	ΔP transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's
3-I-2	Secondary water pump package	1	1.2	1.2	1	*25.0	30.0	*Removed only when accumulator, pump or valves are defective
	Pump motor	1	0.8	0.8	2	25.0	40.0	Removable as LRU's
	Pressure transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's
	ΔP transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's

TABLE 5-4 (Continued)

LRU Ident.	LRU Description	Maint. Crew Size	Elapsed Time hr	Maint. Man-Hour Task	No. LRU Subjected	Maint. Action Rate (Fixes, $\times 10^6$ hr)	Maint. Man-Hour Operating hr $\times 10^6$	Remarks
3-[illegible]	Interchanger outlet temperature ([illegible] loop)	1	0.3	0.3	1	10.0	3.[illegible]	
[illegible]	Interchanger outlet temperature (Secondary loop)	1	0.3	0.3	1	10.0	3.[illegible]	
3-[illegible]	Evaporator outlet temperature (Secondary loop)	1	0.3	0.3	1	10.0	3.0	
3-S	Evaporator outlet temperature (Primary loop)	1	0.3	0.3	1	10.0	3.0	
3-T	Evaporator outlet temperature (Secondary loop)	1	0.3	0.3	1	10.0	3.0	
3-U	Evaporator outlet temperature (Primary loop)	1	0.3	0.3	1	10.0	3 0	
3-V	Fill connector assembly	1	0.4	0.4	1	0.7	0.28	
						TOTAL	635.3	

All components of the flash evaporator assembly will be accessible for replacement as LRU's. The entire flash evaporator package will be replaced only in the event of a failure of the evaporator itself, so that the maintenance action rate listed for the assembly is that of the evaporator.

As for the cabin fans, it was assumed that the avionics fans will be accessible for replacement as single components. If not, the maintenance man-hours per operating hours (MMH/OH) would increase from 73.2 to 216 hr per 10^6 operating hours.

For the pump packages it was assumed that the transducers were removable as separate LRU's. Any other failure would require removal of the entire package. This includes the pump itself, the check valve, the accumulator, the accumulator isolation valve, and the filter. This approach is recommended to minimize the risks of air inclusion in the water coolant loops. Here special fittings and air flushing provisions need be incorporated only at pump package inlet and outlet. As mentioned previously, the pump motor is the most probable cause of pump failure and the motor is replaceable without breaking the coolant loop. In specifying installation constraints this feature should be considered. In Table 5-4 it was assumed that the pump motors are replaceable separately. All coolant loop temperature transducers are surface type; their replacement does not involve loop integrity.

The total (MMH/OH) is estimated at 0.64 man-hours per 1000 operating hour for the ARS. As indicated in the table, this assumes that the water coolant loop will not require servicing when the heat exchanger assemblies or the pumps are replaced. If it does, the task time for these LRU's would increase by 10 man-hours as indicated in the table, and the MMH/OH for the subsystem would be 1.51 hr per 1000 operating hours; this serves to illustrate the desirability of designing these components for replacement [illegible] to service the coolant loops.

5.4 ATMOSPHERE CONTROL SUBSYSTEM

The various functions of the atmosphere control subsystem and the [illegible] ous components involved suggest that maintainability [illegible] in the design of this subsystem. These studies were concerned with equipment packaging into LRU's to permit (1) thorough checkout [illegible] flight readiness, (2) ease of subsystem data interpretation in flight to permit accurate and rapid corrective action in the event of malfunction, and (3) equipment accessibility for expedient repair action when necessary.

5.4.1 Scheduled Maintenance

The most important aspect of scheduled maintenance for the subsystem is postflight maintenance. The scheduled maintenance activities and estimates of the time involved in the performance of each task are summarized [illegible] 5-5

5.4.1.1 Postflight Servicing

Securing the subsystem will consist of powering down the subsystem, returning all control to the off (or deactive) position, and dumping the residual expendables (O_2/N_2).

Final servicing operation will consist of installing external protective closures on all external skin vents and protective closures on all breathing O_2 disconnects and open ports in the ACS. This will prevent inadvertent damage and contamination of the subsystem.

Excluding the closures, only the following GSE is needed to accomplish postflight maintenance.

O_2 test set

N_2 test set

Maintenance skill levels 3 or 5 will be required for postflight deservicing. Deactivation will be accomplished by a minimum of two men working through the O_2/N_2 control panel. It is recommended that a skill level 5 be used for operating the subsystem, while a skill level 3 performs the various other operations.

The total task time for postflight is 92 min (1.54 hr). An additional 30 min will be necessary for GSE hookup, resulting in a total predicted elapsed time of 122 min, or 2.03 hr. This estimate is based on sequential operations by an average of two men.

Deservicing the pressure N_2 and O_2 vessels can be accomplished through the N_2 and O_2 manifolds, or by reversing the suggested filling operations. For ground and personnel safety, special handling of gaseous O_2 discharge should be observed.

5.4.1.2 Turnaround Maintenance

The only maintenance operation scheduled for this subsystem is the removal and replacement of Item 1.72, portable O_2 system. The most efficient means of handling this item is a shop inspection. The pressure gage indicating quantity should be verified by weighing the assembly to actually determine the O_2 available. If the assembly was expended during the last mission, it must be refilled, inspected, and placed back into inventory.

5.4.1.3 Expendable Servicing

After flight commitment, the expendable O_2 and N_2 must be serviced. It is estimated that, including GSE hookup, the total operation will take 60 min, assuming that the gas storage tanks are filled concurrently. For ground safety, a minimum of two men are recommended for this operation. As part of the preflight servicing operations, all protective closures will be removed.

TABLE 5-5

SCHEDULED MAINTENANCE SUMMARY
ATMOSPHERE CONTROL SUBSYSTEM

LRU	No. Reqd	Description	Postflight Servicing	Turnaround Maintenance	Preflight Servicing	Maintenance Operations
						System time line checkout [illegible] in Table 5-7.
1-A	1	Cabin Pressure Relief Valve	---	---	---	Component verified for flight by data analysis and ground checkout.
1-B	1	N_2 Manifold Assembly	---	---	---	
1-C	1	O_2 Manifold Assembly	---	---	---	
1-D	2	2-Gas Control Panel	1.1 (5 min)	---	---	1.1 Switch off all control power and return all valves to off position.
1-E	1	N_2 Manual Pressurization Valve	1.2 (2 min)	---	---	1.2 Verify manual valve is closed.
1-F	1	O_2 Manual Pressurization Valve	1.3 (2 min)	---	---	1.3 Repeat operation of 1.2.
1-G	1	Water Tank Pressure Regulator and Relief Valve	1.4 (5 min)	---	---	1.4 Place regulator selector to OFF for [illegible] both primary and secondary loops
1-I	3	Avionics Bay Pressurization Valve	---	---	---	
1-J	2	Airlock Pressure Gage	1.5 (5 min)	---	1.21	1.5 Install protective closure on gage inlet.
1-K	2	Airlock Pressurization Valve	1.6 (5 min)	---	1.22	1.6 Verify that valve is closed and install protective closures (dust covers).
1-L	2	O_2 Flow Restrictor and Heater	---	---	---	
1-M	2	Auxiliary O_2 Storage Tank Assembly	1.7 (2 min)	---	1.9 (20 min)	1.7 Verify power is OFF on all valves; concurrent with 1.1.
			1.8 (20 min)	---	---	1.8 Dump all residual gases through GSE connector 1.80; use O_2 test set for [illegible]
						1.9 Fill O_2 tanks for next flight. Use O_2 test cart.
1-N	8	N_2 Storage Tank Assembly	1.10 (2 min)	---	1.12 (20 min)	1.10 Repeat operation 1.7.
			1.11 (20 min)	---	---	1.11 Repeat operation 1.8; use O_2 test set.
						1.12 Fill N_2 tanks for next flight. Use N_2 test cart.
1-O	3	N_2 Pressure Regulator and Relief Valve	---	---	---	
1-P	2	Payload Tunnel Pressurization Valve	1.13 (5 min)	---	---	1.13 Repeat operation 1.6.
1-Q	2	Payload Tunnel Pressure Gage	1.15 (2 min)	---	---	1.15 Repeat operation 1.5.
1-R	3	Avionics Pressure Relief Valve	---	---	---	
1-S	2	EVA Support Panel	1.16 (5 min)	---	1.23	1.16 Verify all shutoff valves are closed and install protective closures on all QD's.
1-T	2	Flight Station Service Panel	1.17 (5 min)	---	1.24	1.17 Repeat operation 1.16.
1-U	4	Portable O_2 System	---	1.18 (5 min)	1.18 (5 min)	1.18 Remove for SRU inspection and refill as needed. Certify inspection and ready for flight use.
1-V	2	Airlock Depressurization Valve	1.19 (5 min)	---	1.25	1.19 Repeat operation 1.6.
1-W	2	EVA Hatch Pressure Gage	1.20 (2 min)	---	1.26	1.20 Repeat operation 1.5
1-X	1	Avionics Bay ΔP Gage (Bay 3)	---	---	---	
1-Y	1	Avionics Bay ΔP Gage (Bay 2)	---	---	---	
1-Z	1	Avionics Bay ΔP Gage (Bay 1)	---	---	---	
1-AA		PO_2 Sensor	---	---	---	
1-BB	2	Cabin Pressure Transducer	---	---	---	1.21 through 1.26 Remove protective closures.

N_2 and O_2 ground servicing carts will be required. Facility or GSE capacity should allow for simultaneous filling of three N_2 and two O_2 tanks. During filling of O_2 tanks, normal safety precautions for handling high-purity high-pressure O_2 should be observed.

5.4.1.4 Flight Readiness Ground Checkout

This portion of the maintenance operation is concerned with assuring that the subsystem, including all redundant elements, is functionally sound, thus assuring the high reliability necessary for spaceflight. The ground checkout requirements developed were based on the assumption that all equipment requires verification. As experience is gained with operation of the vehicle and its subsystems, the lengthy ground checkout activities could be abbreviated considerably. On-condition monitoring techniques could be developed; however, this would involve activation of all redundant subsystem elements during the flight and might result in unacceptable crew involvement.

The checkout requirements of this subsystem are summarized in Table 5-6. The checkout procedure will require handling of high pressure N_2 and O_2 equipment. The major GSE necessary to implement checkout includes: (1) a high-pressure N_2 test set, (2) a high-pressure O_2 test set, and (3) a vacuum test set. In addition, small gages and adapters will be required.

Large quantities of oxygen and nitrogen will be used in the performance of the leakage and flow check. Special safety precautions should be used while checking the high-pressure oxygen. It is suggested that this portion of the subsystem which interfaces with the cryogenic oxygen supply, be checked out together with the cryogenic storage subsystem.

As shown in Table 5-6, a large portion of the test activities is concerned with leakage check of the LRU's and dynamic checks of the numerous regulator/relief valves. Also, the PO_2 control equipment operation will be verified.

TABLE 5-6

GROUND CHECKOUT SUMMARY, ATMOSPHERE CONTROL SUBSYSTEM

Item	Definition/Function	Test Requirements: Leakage	Static	Dynamic	Visual/Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation*: F	P	ΔP	Special	GSE	C/O Operation	Remarks
1-A	Cabin pressure relief valve prevents overpressurization of cabin	X		X							1. Vacuum test set 2. Cabin pressure simulator	1. Measure leakage 2. Valve operation: crack reseat and manual override	1. All instrumentation on GSE 2. Test ports built-in relief valve to interface with cabin pressure simulator
1-B	N_2 manifold assembly, 140-psi N_2 supply from regulated storage	X						P			1. 140-psi N_2 test set	1. Verify manifold and component leakage 2. Verify transducers by comparison with GSE equipment	1. 3 pressure transducers required for check valve C/O (items 1.118, 1.119, 1.120) 2. Component replacement could be effected on board after panel removal to gain access
1-C	O_2 manifold assembly/900-psi O_2 supply from regulated storage	X						P			1. 900-psi O_2 test set	1. Verify manifold and component leakage 2. Verify transducers by comparison with GSE equipment 3. Temperature transducer check by comparison with ambient	1. 3 pressure transducers required for check valve C/O (items 1.121, 1.122, 1.123) 2. Component replacement could be effected on board after panel removal to gain access
1-D	2-gas control panel (2 required)/maintains PO_2 and PT	X	X	X				A R		A(Q) A(PO_2)	1. PO_2 adapter for use in conjunction with N_2 and O_2 test set	1. Sequential leakage check of all N_2 components 2. Functional check of sensor (1.12), controller (1.13) and solenoid valve (1.11) with O_2 rich and O_2 poor simulated atmospheres 3. Sequential leakage check of all O_2 components 4. Flow check of 900-100 O_2 pressure regulator (1.7) 5. Flow sensor check (1.300, 1.301) 6. Static check of cabin pressure regulator (1.2) 7. Pressure transducers check verified by comparison with GSE sensors	1. 2 pressure transducers required for O_2 component leakage check (items 1.124, 1.125) 2. Additional PO_2 sensor (1.12) check by comparison to ambient 3. Solenoid valve operation verified by pressure readout (1.116, 1.117) 4. Components optionally replaceable on board after removal of LRU
1-E	N_2 manual pressurization valve emergency N_2 supply	X									1. 140-psi N_2 test set 2. Pressure gage	1. Leakage check	
1-F	O_2 manual pressurization valve emergency O_2 supply										1. 900-psi O_2 test set 2. Pressure gage	1. Leakage check	

*[illegible], R: recor[illegible]

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TABLE 5-6 (Continued)

LPU	Definition/Function	Test Requirements: Leakage	Static	Dynamic	Visual/Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation: T	P	ΔP	Special	GSE	C/O Operation	Remarks
1-G	Water tank pressurization (2 required)/pressurize water tank to 20 psig with N_2	X		X							1. 140-psi N_2 test set 2. Adapter for test port	1. Internal leakage 2. Regulator flow check 3. Relief valve leakage 4. Relief valve crack and reseat	1. Test port required downstream of valve 2. Transducers checkout by comparison with GSE gage
1-I	Avionics bay pressure regulator (3 required)/maintains avionics bay at 0.4 psid below cabin	X		X							1. Vacuum test set	1. Leakage check 2. Crack and reseat 3. Normal flow check	1. Emergency flow check qualitative 2. Vacuum test set same as above 3. Pressure transducer (1.126, 1.127, 1.128), checked concurrently
1-J	Airlock pressure gage (2 required)/monitors airlock pressure	X		X							1. Vacuum test set	1. Leakage check 2. Gage calibration by comparison to GSE gage	
1-K	Airlock pressurization valve (2 required)/used to pressurize airlock from cabin atmosphere	X									1. Vacuum test set	1. Leakage check 2. Functional check	
1-L	O_2 restrictor and heater/conditions cryogenic O_2 supply												Flight data analysis
1-M	Auxiliary O_2 storage tank assembly (2 required)/emergency and [illegible] ion O_2 supply	X		X							900-psi O_2 test set	1. Sequential leakage 2. Regulator pressure/flow check 3. Relief valve crack and reseat 4. Pressure transducer checked by comparison with GSE gage	1. Same instrumentation (1.122) required as for O_2 manifold C/O
1-N	N_2 storage tank assembly (8 required)/storage and supply of N_2 to ECS	X									N_2 test set	1. Leakage check 2. Pressure transducer checked by comparison with GSE gage	1. Test set pressure at 3000 psi 2. Solenoid [illegible] valve operation checked with N_2 pressure regulator (1.25[illegible])
1-O	N_2 pressure regulator (3 required)/maintains 140-psi pressure level in N_2 manifold	X		X							N_2 test set	1. External leakage 2. Regulator pressure flow check	
1-P	Payload tunnel pressurization valve/used to pressurize tunnel from cabin atmosphere	X									1. Vacuum test set	1. Leakage check 2. Functional check	
1-Q	Payload tunnel pressure gage monitors tunnel pressure	X									1. Vacuum test set	1. Leakage check 2. Calibration [illegible] parison to [illegible]	

TABLE 5-6 (Continued)

LRU	Definition/Function	Test Requirements: Leakage	Static	Dynamic	Visual/ Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation: T	P	ΔP	Special	GSE	C/O Operation	Remarks
1-R	Avionics bay relief valve (3 required)/ prevents overpressurization of avionics bay	X		X							1. Vacuum test set 2. Cabin pressure simulator	1. Leakage check 2. Valve operation: crack, reseat, and manual override	1. Relief valve incorporates test ports for interface with cabin pressure simulator
1-S	EVA support panel (2 required)/1. prebreathing O_2 supply (100 psi) 2. 900-psi O_2 supply	X	X								1. 900-psi O_2 test set 2. Pressure gage 3. Pressure gage 4. Disconnect adapter for poppet leakage	1. Sequential leakage of all components 2. Prebreathing regulator lock-up 3. Final leakage check of disconnect	
1-T	Flight station service/ Same as 1-S	X	X								Same as 1-S	Same as 1-S	
1-U	Emergency O_2 supply (4 required)/provides 10 minutes of O_2 in emergency				X						None	1. Read pressure gage installed on LRU	
1-V	Airlock depressurization valve/used to dump airlock atmosphere overboard	X									1. Vacuum test set	1. Leakage check 2. Functional check	1. C/O performed concurrently with LRU 1-W
1-W	EVA hatch pressure gage/ monitors airlock pressure	X									1. Vacuum test set	1. Leakage check 2. Calibration by comparison with GSE gage	
1-X 1-Y 1-Z	Avionics bay pressure gage (3 required)/ monitors avionics pressure gage	X									1. Vacuum test set	1. Leakage check 2. Calibration by comparison with GSE gage	1. Performed concurrently with LRU 1-I
1-AA	PO_2 sensor/cabin oxygen partial pressure monitoring			X							1. N_2 and O_2 test sets	1. Verify calibration	
1-BB	Cabin pressure transducer	X									None	1. Verify by comparison to ambient	

Because of the large number of components involved and the many redundant paths, ground checkout will consume an appreciable amount of time. A preliminary analysis was made of the time necessary for a 2-man crew to complete the maintenance task. Table 5-7 summarizes the checkout operations performed by these two men and also defines the checkout sequence.

Generally, a sequential leak check of the oxygen and nitrogen supply system is performed. The pressure transducers are checked concurrently. As illustrated in the table, the oxygen and nitrogen legs are checked out at the same time. This will be followed by regulator/relief valves testing and checkout of the storage tank assemblies. The two men constituting the maintenance crew are identified; the second man's time is in parentheses.

The total time for checkout of the atmosphere control subsystem is estimated at 385 min with 2 men. This could be shortened considerably by using a larger maintenance crew. However, the number of men which can be used is limited because much of the testing must be conducted sequentially. Also, space available for the maintenance crew will be a limiting factor. It is estimated that a four-man crew would represent the maximum, with a 3-man crew being optimum in terms of elapsed time.

5.4.2 Unscheduled Maintenance

Table 5-8 presents a summary of the requirements. The same basis was used in the preparation of these data as for the subsystems discussed previously. Much of the equipment is single components; others, such as the LRU's of the O_2/N_2 valve panel, incorporate many components (Ref. 1-B, 1-C, and 1-D) that will be removed and replaced as a unit. Component replacement within these LRU's will be done at the shop level.

TABLE 5-7

CHECKOUT TIMELINES
ATMOSPHERE CONTROL SUBSYSTEM

Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min
Power up ECS	10	10	Hook up PO_2 control GSE	20	75	Simultaneously pressurize N_2 and O_2 manifold and perform N_2 manifold and O_2 manifold leakage acceptance	20	95	Flow check panel N_2 components	35	130
Perform N_2 and O_2 GSE hookup (2 men) and adapt facilities, equipment, and portable test gages	45 (60)	55 (60)	Check out GSE hookup	(15)	(75)	Perform O_2 900-psi services; check out leakage Note: Concurrent with simultaneous pressurization, read pressure gages and transducers	(40)	(115)	Vacuum test set build-up GSE check out cabin relief valve	(10)	(125)
									Check out vacuum test set	(10)	(135)
									Check out cabin relief valve	(10)	(145)
Flow check panel O_2 components	35	165	Buy off transducer checkout, O_2/N_2 panel excluding sources	20	205	Pressurize all gas sources N_2 and O_2 to 3000 $^{+100}_{-0}$ psig	30	235	Perform leakage check of all high pressure components	20	280
Install checkout GSE N_2 pressurization (water tank)	(15)	(160)	Depressurize both manifolds N_2 and O_2 for high pressure checkout of source	(15)	(205)	Install vacuum test component GSE for checkout of			Buy off 900-psi O_2 service	(10)	(265)
Check out primary water tank pressurization	(15)	(175)				Payload hatch	(10)	(215)	Set GSE test sets for N_2 flow check 3000/140 psi reg. (primary)	(15)	(280)
Repeat for secondary tank	(15)	(190)				Check out GSE hookup	(5)	(220)			
Check out cabin regulator both paths	20	185				Check out payload hatch	(10)	(230)			
						Repeat above for EVA hatch	(25)	(255)			
						Check out press. of N_2 and O_2 source for stabilization	10	245			
						Read out pressure gages for sources o[illegible]ckout	15	260			
Set up GSE for O_2 flow test 3000/850 psi reg.	10	290	O_2 primary auxiliary regulator	(15)	(340)	Secure high pressure system	30	(370)	Buy off ACS checkout (2 men)	15	385
Sequentially flow check both O_2 and N_2			O_2 secondary auxiliary regulator	15	370	and/or perform corrective maintenance	As required to buy-off ACS repair				
N_2 primary reg.	(15)	(295)									
N_2 secondary reg.	(15)	(310)									
N_2 fail-safe reg.	(15)	(325)									
Verify transducer source readouts during reg. test and concurrently close out 900-psi O_2 service or perform corrective maintenance	75	355									
	As required to buy-off ACS repair										

Note: ( ) denotes second man

TABLE 5-8

UNSCHEDULED MAINTENANCE SUMMARY
ATMOSPHERE CONTROL SUBSYSTEM

LRU Ident.	LRU Definition	Maint. Crew Size	Elapsed Time, hr	Maint. Man-hours/ Task	No. LRU/ Subsystem	Maint. Action Rate/Item $1/10^{-6}$ hr	Maint. Man-hours/ Operating hr, $hr/10^{-6}$ hr	Remarks
1-A	Cabin pressure relief valve	1	1.7	1.7	1	59.7	101.5	Single item.
1-B	N_2 manifold assembly	1	1.7	1.7	1	57.4	97.6	See text for description of LRU.
1-C	O_2 manifold assembly	1	1.7	1.7	1	77.4	131.6	See text for description of LRU.
1-D	2-gas control panel assembly	2	4.6	9.2	2	291.3	5360.0	See text for description of LRU.
1-E	N_2 manual pressurization valve	1	0.9	0.9	1	0.55	0.5	Single component on O_2/N_2 control panel; see text.
1-F	O_2 manual pressurization valve	1	0.9	0.9	1	0.55	0.5	Single component on O_2/N_2 control panel; see text.
1-G	Tank pressure regulator and relief valve	1	1.0	1.0	1	165	165	See text for description of LRU.
1-I	Avoinics bay pressurization valve	1	1.0	1.0	3	18.0	54.0	Single component
1-J	Airlock pressure gage	1	0.5	0.5	2	5.5	5.5	Single component
1-K	Airlock pressurization valve	1	1.2	2.4	2	3.1	14.9	Single component, flange mounted.
1-L	O_2 flow restrictor and heater	1	1.0	2.0	2	1.0	4.0	Involves interface with both Freon loops; no servicing of Freon loop assumed; if servicing necessary, add 5 hr.
1-M	Gaseous O_2 storage tank assembly	2	3.7	7.4	2	5.0*	74.0	*Tank assembly removed only when tank is defective; tank MMH/OH = 5.0.
	Isolation valve/fill valve/ pressure transducer	1	0.7	0.7	2	33.6	47.1	Removable as LRU after separate leak check of tank if failure is by leakage.
	Check valve	1	0.5	0.5	2	1.1	1.1	Removable as LRU's.
	Regulator/relief	1	0.5	0.5	2	57.8	57.8	Removable as LRU's.

TABLE 5-8 (Continued)

LRU Ident.	LRU Definition	Maint. Crew Size	Elapsed Time, hr	Maint. Man-hours/ Task	No. LRU/ Subsystem	Maint. Action Rate/Item $1/10^{-6}$ hr	Maint. Man-hours/ Operating hr, $hr/10^{-6}$ hr	Remarks
1-N	Gaseous N_2 storage tank assembly	2	3.7	7.4	8	5.0*	296.0	*Tank assembly removed only when tank is defective; tank MMH/OH = 5.0.
	Isolation valve/fill valve/ pressure transducer	1	0.7	0.7	2	33.6	47.1	Removable as LRU after separate leak check of tank if failure is by leakage.
1-O	N_2 pressure regulator/relief valve assembly	1	0.7	0.7	3	59.8	125.6	
	N_2 solenoid shutoff valve (1.19)	1	0.5	0.5	3	8.4	-	P ovable as LRU's.
1-P	Payload tunnel pressurization valve	1	1.0	1.0	1	3.10	3.1	
1-Q	Payload tunnel pressure gage	1	0.5	0.5	1	5.5	2.8	Wall mounted.
1-R	Avionics bay pressure relief valve	1	1.7	1.7	3	59.8	305.0	
1-S	EVA support panel	1	1.0	1.0	2	40.0	80.0	
1-T	Flight station service panel	1	1.0	1.0	1	28.45	28.5	
1-U	Portable O_2 system	1			4	AR	-	Stowage.
1-V	Airlock depressurization valve	1	1.0	1.0	1	3.11	3.1	
1-W	EVA hatch pressure gage	1	0.5	0.5	1	5.5	2.8	Wall mounted.
1-X	Avionics bay ΔP (bay 3)	1	0.3	0.3	1	25.0	7.5	
1-Y	Avionics bay ΔP (bay 2)	1	0.3	0.3	1	25.0	7.5	
1-Z	Avionics bay ΔP (bay 1)	1	0.3	0.3	1	25.0	7.5	
1-AA	PO_2 sensor	1	0.5	0.5	3	10.0	15.0	
1-BB	Cabin pressure transducer	1	0.3	0.3	2	25.0	7.5	
						TOTAL	7054.1	

The O_2 and N_2 gas storage tank assemblies will not be removed from the vehicle unless the tank is defective. In this case leakage identification to determine whether the tank, the pressure transducer, the isolation valve or the fill valve is leaking might be difficult. The procedure recommended is as follows. If the tank assembly is leaking, the tank will be disconnected and checked for leaks separately. If the tank is leaking, it will be replaced. If not, the isolation valve, pressure transducer, and fill valve will be replaced. Leakage isolation to any one of these components will be effected at the shop level. The time involved in performing this separate leak check is accounted for in the table.

The total time estimated for onboard corrective maintenance of the subsystem is 7 hr per 1000 operating hr. About 75 percent of all corrective maintenance will involve the two-gas control panel. Adequate spares should be provided for this particular LRU.

5.5 WATER MANAGEMENT SUBSYSTEM

5.5.1 Scheduled Maintenance

The recommended scheduled maintenance operations for the water management subsystem are discussed below. Table 5-9 summarizes the operations for each LRU.

Scheduled maintenance is predicated on performance of the checkout with N_2 gas. Also, decontamination of the subsystem will be required only as a result of accidental contamination or after heavy maintenance. Cartridge-type replacement is used for the deionizing column on the silver chloride columns. The expendable evaporant side of the flash evaporator should be preflight-serviced at the same time. If required, postflight servicing could be deferred until preventative maintenance.

TABLE 5-9

SCHEDULED MAINTENANCE SUMMARY WATER MANAGEMENT SUBSYSTEM

[illegible]RU	[illegible]	Description	Postflight Servicing	Turnaround Maintenance	Preflight Servicing	[illegible]
		Water [illegible]	4.1 ([illegible] [illegible]) Optional	4.1 ([illegible] [illegible]) Required	4.2 (30 [illegible])	4.1 The [illegible] water [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] water [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] for bacterial [illegible]
4-A	1	Water control panel assembly				
4-B	2	Potable water tank assembly	In conjunction with 4.1			4.2 System will be [illegible] [illegible] [illegible] water [illegible] sample will be analyzed for bacter[illegible] [illegible]. [illegible] analysis time could take [illegible] [illegible] [illegible] elapsed time. If decontaminat[illegible] [illegible] [illegible] servicing time is estimated at [illegible] [illegible] tamination is found; three [illegible] [illegible] ing with steam and filling. [illegible] [illegible] [illegible] period could be necessary [illegible] [illegible] [illegible] off.
4-C	[illegible]	Water chiller	In conjunction with 4.1			
4-D	1	Water heater	4.3 (3 min)			4.3 Verify that heater power is off.
4-E	2	Silver ion generator		4.4 (20 min)		4.4 Replace both beds prior to operation (4.2).
4-F	2	Water filter		4.6 (20 min)		4.5 Leakage check [illegible] [illegible]
4-G	1	Deionizer		4.7 (15 min)		4.6 Inspect and/or replace prior to operation (4.2) [illegible] repeat (4.5).
						4.7 Replace deionizer and repeat leakage check [illegible]
4-H	2	H_2 removal asse bly	4.9 (5 [illegible])	4.8 (10 min)		4.8 Visual inspection of vacuum vent and install protective closure on vacuum vent per 4.1
4-I	1	Water dump nozzle assembly	In conjunction with 4.1			4.9 Install protective [illegible] [illegible] vacuum vent per (4.1).
4-J	1	Water solenoid shutoff valve	In conjunction with 4.1			
4-[illegible]	1	GSE service connector assembly	In conjunction with 4.1			
4-M	1	PLSS water service	4.10 (5 min)			4.10 Install protective [illegible] [illegible] per (4.1).
4-N	1	Silver ion detector	TBD	TBD		

NOTE: Decimal number identifies a maintenance operation.

Number in parenthesis is the time necessary to perform the task.

The silver ion detector scheduled maintenance is not defined. This equipment is currently under development, and data for a maintainability estimate is not currently available.

5.5.1.1 Postflight Servicing

The major maintenance operation is to deactivate the potable water system. Following the drain of potable water, a GN_2 purge with the GSE test set will be performed. Drying is completed after about 10 min, and the exhaust air is between 85° and $90^{\circ}F$ as a minimum. The system will be closed out with 2 to 5 psig within the system. This will leave the potable water tank expulsion devices extended, assuring good service life. The system should be closed out at this point, and all outlets should be capped with protective closures.

5.5.1.2 Preventative Maintenance

Prior to ground checkout, all filters, the deionizing column, and silver ion columns should be replaced and the subsystem decontaminated if needed. No GSE is required or special equipment needed to accomplish these maintenance tasks.

5.5.1.3 Expendable Servicing

The subsystem will be serviced with potable water after ground check when the vehicle is committed to flight. The potable water service cart will be used to fill the subsystem with potable water at the required quality level.

5.5.1.4 Maintenance Skill Level

Postflight servicing will require two men, one of skill level 3 and one of skill level 5, to perform all operations. Preventative maintenance and expendable servicing can be performed by either one or two men; times shown for preventative maintenance and servicing are for a skill-level-5, single-man operation.

Total postflight task time is 68 min [illegible] 30 min of the 68 min is for GSE hookup. Total [illegible] maintenance is 65 min (with one man); no GSE is [illegible]

It is estimated that the average task time [illegible] potable water is 30 min (one man). The 4-hr [illegible] elapsed time of 12 to 18 hr if bacterial count is [illegible] quality. A servicing time of 1.5 hr including [illegible] developed by using a short flush with steam and by eliminating the require- ments for bacterial culture analysis of the system.

5.5.2 Flight Readiness Ground Checkout

Following servicing operations, the subsystem will be [illegible] and the filters, silver ion generator, and deionizer will have been replaced. A check on water purity and sterility will be made as part of the [illegible] servicing operations.

Ground checkout will be performed with nitrogen. [illegible] will be used for this purpose. A summary of the requirements are presented in Table 5-10. As shown in the table, checkout operations involve leakage checks and verification of the various valve functions.

A preliminary analysis of the time involved in conducting the checkout operations is presented in the form of timelines in Table 5-11. Assuming a two-men crew (skill levels 3 and 5), it is estimated that the entire main- tenance activity will require 105 min. This time estimate includes GSE hookup (37 min). The total time elapsed could be reduced by [illegible]

The arrangement of checkout operations and subsystem [illegible] fig- ure. Checkout sequencing as a requirement of subsystem [illegible] allow any appreciable shortening of the ground checkout time.

TABLE 5-10

GROUND CHECKOUT SUMMARY
WATER MANAGEMENT SUBSYSTEM

Para	Item	Test Requirements*: Leakage	[illegible]	[illegible]	[illegible]	Other (See Remarks)	Equipment Requirements: [illegible]	Instrumentation: [illegible]	P	Use	GSE Required	Checkout Operation	Remarks
4-A	Water [illegible]										1. [illegible] N_2 test [illegible] 2. Adaptor for water panel checkout use with [illegible] N_2 test [illegible]	1. Sequential leakage test of water panel components 2. [illegible] of relief valve crack and reseat 3. Qualitative C/O of selector valve operation 4. Instrumentation P4.100 and P4.101 C/O by comparison with GSE gages	1. Test ports (TP-1, TP-2, TP-3, TP-4 and TP-5) accessible from front of panel
4-B	Potable Water Tank Assembly							A		Quan	1. Test set gage for leakage	1. Sequential leakage check of tank 2. C/O of tank quantity transducer from empty to full	
4-C	Water Chiller										1. None	1. Visual inspection for dyed coolant as evidence for leakage	
4-D	Water Heater										1. None	1. Continuity and qualitative functional check	1. Overtemp cutoff will turn heater off
4-E	[illegible] Generator										1. None	1. Unit replaced during scheduled maintenance every flight	1. C/C for external leakage
4-F	Water Filter										1. None	1. Unit C/O or replaced during scheduled maintenance 2. Verify that ΔP flag has not tripped	
4-[illegible]	De[illegible]										1. None	1. Visual inspection for leakage while system is pressurized. Unit replaced during scheduled maintenance	
4-H	H_2 Separator Assembly										1. Adaptor to H_2 vacuum test port to evaluate gross leakage	1. [illegible]	1. [illegible]
4-[illegible]	Dump Nozzle Assembly										1. None	1. Energize heater and verify by reading T4.200 2. C/O T4.[illegible] sensor by comparing ambient and operating readout	1. No checkout of nozzle required. C/O is to heater and temp sensor
4-[illegible]	Solenoid [illegible] Valve						See Remarks						1. Checkout as part of water [illegible] system evaluate operation and leakage
4-[illegible]	[illegible]										1. [illegible] N_2 test [illegible] 2. [illegible] leakage [illegible]	1. Qualitative operation and visual external leakage C/O	
4-[illegible]	[illegible] Water [illegible]										1. [illegible]	1. Sequential leakage test of panel components and qualitative operation of manual valve	
4-[illegible]	[illegible]										Re[illegible] BITE	1. BITE [illegible]	[illegible]

*A: available; R: required for C/O

TABLE 5-11

CHECKOUT TIMELINE SUMMARY
WATER MANAGEMENT SUBSYSTEM

Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min	Operation	Checkout Time, min	Cumulative Time, min
Verify subsystem has been deserviced	10	10	Perform panel leakage check	20	55	Verify valve panel transducer	5	80	Check out water heater	15	35
Hook up N_2 test set and adapters	(25)	(25)	Check leakage of H_2O primary storage tank	10	65	Verify selector valve operation for smoothness	with above		Buy off WMS checkout	(10)	(55)
Hook up test ports on panel	25	35	Check leakage of H_2O secondary storage tank	10	75	Check out relief valve operation	(10)	(75)	or		
Check out GSE installation	(12)	(37)	Check out PLSS service	(5)	(42)	Check out dump nozzle	(10)	(85)	Prepare corrective maintenance work sheets	As required to buy off WMS	
			Check waste valve interface leakage	(23)	(65)				Reference work off flash water boiler leakage	As required for flash boilers	

( ) Parenthesis indicates second man activity.

Concurrently, the buyoff of the water cooling loop flash evaporator occurs during checkout of this subsystem. Potable water is the expendable evaporant for boiler operation. At the completion of checkout operations the subsystem will be left slightly pressurized to minimize entry of atmosphere.

5.5.3 Unscheduled Maintenance

The total onboard corrective maintenance time for this subsystem is estimated at 0.4 man-hours per 10^3 operating hr. Table 5-12 gives a breakdown of the unscheduled maintenance requirements. It is assumed that decontamination of the water management subsystem will not be necessary after replacement of single components. Special precautions will have to be taken to prevent bacterial contamination. In the case of the water control assembly described earlier, the large number of interface connections will probably result in system contamination. The data of Table 5-12 include the requirement for a 4-hr decontamination task when the panel is replaced. If bacterial cultures are necessary, an additional 18 hr will be necessary to ascertain the effectiveness of the decontamination procedure and system buyoff.

5.6 FREON-21 HEAT REJECTION SUBSYSTEM

5.6.1 Scheduled Maintenance

The scheduled maintenance recommendations for the Freon-21 cooling loop are discussed below. The Freon-21 loop, like the water cooling loop, is a closed circuit and is passive except for the Freon circulation pumps; it requires a very minimum amount of scheduled maintenance activity. The NH_3 cooling subsystem will require purging of all the NH_3 prior to securing the loop for the next scheduled operation. This establishes the requirements for personnel and vehicle safety equipment.

TABLE 5-12

ONBOARD CORRECTIVE MAINTENANCE SUMMARY
WATER MANAGEMENT SUBSYSTEM

LRU Ident.	LRU Definition	Maint. Crew Size	Elapsed Time, hr	Maint. Man-hour / Task	No. LRU/ Subsystem	Maint. Action Rate/Item $1/10^{-6}$ hr	Maint. Man-hour / Operating hr, hr/10^{-6} hr	Remark
4-A	Water control panel assembly	1	5.2	5.2	1	64.7	33[illegible].4	See water control panel description; include decontamination of potable water subsystem; could be as long as 18 hr if bacteria culture necessary.
4-B	Potable water tank assembly	1	0.9	0.9	2	16	25.8	Includes water tank, quantity sensor, and solenoid shutoff valve.
	Solenoid S/O valve	1	0.4	0.4	2	10.0	-	Removable as LRU.
4-C	Water chiller	1	0.55	0.55	2	1.0	1.1	Includes coolant [illegible] interface, [illegible] loop servicing.
4-D	Water heater	1	0.85	0.5	1	[illegible].0	2.0	Electrical heater; water subsystem.
4-E	Silver ion generator	-	-	-	-	-	-	Expendable item; part of scheduled maintenance.
4-F	Water filter	1	0.55	0.55	2	2.0	2.2	Will require periodic replacement as part of scheduled maintenance.
4-G	Deionizer	-	-	-	-	-	-	Expendable item; part of scheduled maintenance.
4-H	H_2 removal assembly	1	0.8	0.8	2	10	16	Installed in unpressurized compartment.
4-I	Water dump nozzle assembly	1	0.7	0.7	1	2.5	1.75	Installed on vehicle outer shell.
4-J	Water solenoid S/O valve	1	0.4	0.4	2	10	8	Single item.
4-K	GSE service connector assembly	1	0.5	0.5	1	3.0	1.5	Installed in unpressurized area.
4-M	PLSS water service	1	0.7	0.7	1	2.7	1.89	Inside cabin.
4-N	Silver ion detector	-	-	-	-	-		Item under development; no estimate made at this time.
						TOTAL	399.7	

The Freon-21 loops will not be opened unless corrective maintenance is necessary. Leakage check will be done as part of the flight readiness checkout operations.

Table 5-13 presents the recommended scheduled maintenance operations for each LRU; times to complete the operations also are shown.

5.6.1.1 Postflight Servicing

Postflight servicing of the Freon loop is quite simple. The only maintenance task consists of power shutoff and verification that the pump controls and the GSE bypass valve controls are off.

The NH_3 boiler subsystem requires dumping of residual NH_3 followed by a GN_2 purge of the system to clear the subsystem of NH_3 vapor. The dump and purging operation utilizes existing ground checkout GSE. During this operation, maintenance personnel will be required to wear protective clothing and breathing masks.

5.6.1.2 Preventative Maintenance

No scheduled maintenance is planned for either the Freon cooling loop or NH_3 boiler loops.

5.6.1.3 Expendable Servicing

The only requirement for expendable servicing is loading, NH_3. Because of the toxicity and safety problem with NH_3, it is recommended that it be loaded at the same time as propellant loading. The system is basically closed cycle after servicing except for either relief valve or burst disc venting, which is a secondary failure. Unsafe discharge of NH_3 can be handled by the GSE NH_3 disposal cart. Conditioning of the NH_3 for loading is handled by another GSE cart. This cart assures that NH_3 is loaded at the proper pressure and temperature so that in normal operation relief venting should not occur.

TABLE 5-13

SCHEDULED MAINTENANCE SUMMARY
FREON-21 HEAT REJECTION SUBSYSTEM

LRU	Req'd	Description	Post-Flight Servicing	Turn-Around Maintenance Preventative	Pre-flight Servicing	Maintenance Operations
7-A	2	Fuel cell Hx assembly	-	-	-	
7-B	2	Hydraulic Hx assembly	-	-	-	
7-C	1	Payload Hx assembly	-	-	-	
7-D	1	GSE Hx assembly	-	-	-	
7-E-1	1	Primary Freon pump package	7.1 (2 min)	-	7.2	7.1 Verify that pump power is off and pump controls are off. 7.2 Servicing will be accomplished as part of ground checkout (if required)
7-E-2	1	Secondary Freon pump package	7.3 (0)	-	7.4	7.3 Repeat 7.1. 7.4 Repeat 7.2.
7-F	2	Temp sensor	-	-	-	
7-G	2	GSE Hx bypass valve	-	-	-	
7-H	2	GSE Hx bypass valve controller	7.5 (2 min)	-	-	7.5 Verify power is off controller and control switch is off.
7-I	1	Freon-water interchanger	-	-	-	
7-J	4	GSE connector	-	-	-	
7-K	4	Fill connector	-	-	-	
7-L	2	NH_3 tank assembly	7.6 (30 min)	-	7.7 (30 min)	7.6 Attach NH_3 disposal cart and drain residual NH_3 out of tanks and purge NH_3 tanks both with N_2 and install GSE outflow vent adapter on vent tube. 7.7 Use GSE service cart and NH_3 disposal unit to fill NH_3 tanks at 128 psig at 70°F.
7-M	2	NH_3 pressure regulator	-	-	-	
7-N	2	NH_3 boiler package	7.8	-	-	7.8 N_2 purge. Performed with 7.6.
7-O	1	Radiator in temp sensor (primary)	-	-	-	
7-P	1	Interchanger in temp sensor (primary)	-	-	-	
7-Q	1	Interchanger in temp sensor (secondary)	-	-	-	
7-R	1	Radiator in temp sensor (secondary)	-	-	-	
7-U	1	GSE Hx out temp sensor (primary loop)	-	-	-	
7-V	1	GSE Hx out temp sensor (secondary loop)	-	-	-	
7-W	1	NH_3 delivery press transducer	-	-	-	
7-X	1	NH_3 boiler out temp (primary)	-	-	-	
7-Y	1	NH_3 boiler out temp (secondary)	-	-	-	
7-Z	6	Freon manual shutoff valve	-	-	-	
7-AA	6	Vapor cycle connector	-	-	-	

Handling of NH_3 will use similar equipment or the same equipment that is used for hydrazine so that this equipment should be readily available to service the ETC/LSS.

To perform postflight servicing will require 64 min (0.9 hr). Thirty minutes of this time is required to hook up the GSE. Since the major maintenance operation is deservicing NH_3, safety and handling problems will require a minimum of two men. Servicing of the NH_3 will require 60 min total which includes 30 min for GSE hookup.

5.6.2 Flight Readiness Ground Checkout

Thermal performance verification will not be performed as part of the ground checkout operations. Checkout of the Freon loops proper will be limited to (1) visual inspection for leak detection and (2) exercising the dynamic components (pumps and control valves) to verify function and performance. The ammonia storage and delivery equipment will be checked out using nitrogen. The same test set as for the atmospheric control subsystem can be used here. Table 5-14 summarizes the checkout procedure.

It is recommended that a dye be incorporated in the Freon-21 for ease of leakage detection. In addition, the use of a Freon sniffer is recommended.

Checkout of the GSE heat exchanger bypass system will require a test set for interfacing with the controller BITE. The valve should be checked for leakage and function integrity when the GSE heat exchanger is in use. All instrumentation will be verified during the functional check of the loop.

Table 5-15 shows the relationship of checkout operations described in Table 5-14 relative to maintenance sequence and time logic. The data include the setup time for GSE hookup through completion of the checkout operations.

TABLE 5-14

GROUND CHECKOUT SUMMARY
FREON-21 HEAT REJECTION SUBSYSTEM

LRU	Definition/Function	Test Requirements					Equipment Requirements					C/O Operation	Remarks
		Leakage	Static	Dynamic	Visual/ Inspect	Other (See Remarks)	Instrumentation*				GSE		
							T	P	ΔP	Special			
7-A	Fuel cell heat exchanger (7.1) 2 required/ fuel cell subsystem heat sink	x	x		x						Freon sniffer	1. Visual examination 2. Inspection with sniffer 3. Repeat operation for all LRUs	1. Flight data analysis 2. Recommended dye 3. Internal leakage detected by pressure rise in fuel cell circuits
7-B	Hydraulic heat exchanger (7.2), 2 required/ heat source for the 4 vehicle hydraulic loops	x	x		x						Freon sniffer (as above)	Same as LRU 7-A	1. Same as LRU 7-A
7-C	Payload heat exchanger/ thermal control of payload coolant loop	x	x		x						Same as LRU 7-A	Same as LRU 7-A	1. Same as LRU 7-A 2. Internal leakage detected by abnormal pressure level in payload coolant circuit
7-D	GSF heat exchanger/ thermal sink during ground operations	x	x		x						Same as LRU 7-A	Same as LRU 7-A	1. Same as LRU 7-A 2. Internal leakage detected by monitoring GSE loop pressure
7-E-1	Primary pump package/ circulates cooling water through Freon-21 thermal loop			x	x			A	A	A(Q)	None	1. Visual inspection for leakage 2. Inspection with sniffer 3. Verify accumulator quantity 4. Sequentially check pump ΔP and pump inlet pressure	1. Vehicle power required 2. Sequential pump check verifies check valve performance
7-E-2	Secondary pump package/same as 7-E-1			x	x			A	A	A(Q)	None	See LRU 7-E-1	See LRU 7-E-1
7-F	Temperature sensor (2 required)/signal controller (7.27)		x							BITE	Controller GSE test set	1. Checked with LRU-7H	
7-G	Freon bypass valve (2 required)/diverts Freon around heat sink section of loop	x		x		R				R (POS)	Controller GSE test set	1. Checked with LRU 7-H 2. Internal leakage C/O during GSE heat exchanger by comparison of Freon temperature in the through leg upstream and downstream of the bypass junction	1. Position indicator (7.450) 2. GSE test set provides read out of temp sensor 7.10 downstream of bypass junction 3. Temperature sensor required for checkout upstream of bypass junction (items 7.254 and 7.255 for prim and sec loop)
7-H	Freon bypass controller (2 required)/maintains minimum temp at GSE heat exchanger outlet and serves as a backup to radiator bypass			x						BITE	Controller GSE test set	1. Verify controller, sensor and bypass valve operation with GSE test set	
7-I	Interchanger/thermal link between water coolant and Freon thermal loop	x	x		x						Freon sniffer	1. Same as LRU 7-A	1. Same as LRU 7-A 2. Internal leakage detected by [illegible] pressure in water [illegible] loop
7-J	GSE connectors (4 required)/interface with GSE coolant loop	x			x						None	1. Visual inspection	
7-K	Fill connectors (4 required)/servicing of the Freon loop	x			x						Freon [illegible]	[illegible]	
7-O thru 7-[illegible]	Temperature transducer [illegible] required/monitor[illegible] [illegible] operation and ground [illegible]			x							[illegible]	[illegible]	

TABLE 5-14 (Continued)

LRU	Definition/Function	Test Requirements: Leakage	Static	Dynamic	Visual/Inspect	Other (See Remarks)	Equipment Requirements: Instrumentation*: T	P	ΔP	Special	GSE	C/O Operation	Check Out Time	Remarks
7-L	Ammonia tank assembly (2 required)/storage of ammonia for ground cooling	X						A			140-psi N_2 test set	1. Leakage check through fill connector and also through vent line 2. Pressure sensors (7.152, 7.153) C/O by comparison with GSE gage		
7-M	Ammonia pressure regulator (2 required)/controls ammonia pressure to boiler		X	X				A			140-psi N_2 test set	1. Regulator leakage 2. Flow check		1. Test performed with GSE attached to tank fill connector 2. Test port required downstream of regulator
7-N	Ammonia boiler package (2 required)/provides a heat sink for the Freon-21 loops during ground operations (prelaunch, postlanding)	X		X							140-psi N_2 test set Adapter for boiler capping	1. Valve leakage 2. Relief valve crack and reseat 3. Solenoid valve operation 4. Boiler leakage		1. Test port required for valve and heat exchanger leakage

*A: available; R: required for C/O

TABLE 5-15

TIMELINE CHECKOUT SUMMARY FREON HEAT REJECTION SUBSYSTEM

Operation	Checkout Time, min	Cumulative Time, min
Front section visual leakage check	40	40
Mid section visual leakage check	15	55
Rear section visual leakage check	15	70
Install bypass valve test set		(15)
Check out GSE	(15)	(30)
Perform FCL static checkout leakage		
Check out primary pump package	15	85
Checkout secondary pump package	15	105
Check out loop transducers	(20)	(50)
Check out bypass valves	(25)	(75)
Hook up N_2 test cart to NH_3 system	(20)	(95)
Install boiler exhaust closures	(10)	(105)
Hook up test port	(10)	(115)
Checkout GSE	(10)	(125)

Operation	Checkout Time, min	Cumulative Time, min
Top off accumulators as required	(no time)*	
Buy off loops	20	125
Leakage check NH_3 tank (primary)	(5) 5	(130) 130
Leakage check NH_3 tank (secondary)	(5) 5	(135) 135
Regulator checkout	(5) 5	(140) 140
Regulator lock-up	(5) 5	(145) 145
Install boiler controller test set	(5) 5	(150) 150
Checkout out controller GSE	(5) 5	(155) 155
Check NH_3 boiler control and valve (primary)	(10) 10	(165) 165
Check NH_3 boiler control and valve (secondary)	(10) 10	(175) 175
Check out transducer temperature and pressure	(10)	(185)
System buy off	20 (20)	195 (195)

( ) Parenthesis indicates second man activity.

* Would require 20 minutes per loop, including GSE hook-up.

The following considerations were required to perform this analysis. Entry into the subsystem is not required and the system is serviced and topped off after the last checkout operation only if required as a result of pump package check.

If the system were to become contaminated or heavy corrective maintenance is required, the component connector designs will permit isolation of the failed part for replacement. Replacement parts will be precharged so that contamination will be minimal. Reservicing will require pump down of the subsystem to a 200 Hg vacuum (for drying) prior to charging. It is estimated that this task will take approximately 5 hr for vacuum purges and 30 min for reservice. Total time is 330 min. Contamination of the Freon loop is not considered in the timeline analysis.

The total task time presented is for checkout of the Freon 21 loops, and the NH_3 evaporant subsystem requires 195 min. Initial tasks are devoted to Freon loop checkout; after 75-min elapsed time, the second man completes the Freon loop works and initiates checkout of the NH_3 loops with GN_2. After 125 minutes elapsed time, the first man also is involved with NH_3 subsystem checkout.

Two skill level 2 mechanics will be required to perform the checkout. Both men should be completely versed in refrigeration and handling of such refrigerants as Freons and ammonia NH_3.

To check out the Freon 21, the service and ground checkout cart is needed. In addition, a vacuum service unit with Freon sniffers are needed if leakage and reservicing is required.

5.6.3 Unscheduled Maintenance

A summary of the Freon 21 coolant loop onboard corrective maintenance requirements is presented in Table 5-16. Only remove and replace actions are considered. The time shown includes GSE installation and disconnect. However, it is assumed that the GSE will be available in or near the vehicle.

None of the corrective actions shown include servicing of the Freon loop. As mentioned previously, it is assumed that the components will be installed in a charged condition and that provisions will be incorporated in the design of the interfaces for rapid purging of any air entrapped while making the corrections.

If servicing of the Freon 21 and interfacing liquid loop is necessary after replacement of the heat exchangers, a total of 2000 maintenance hours will be added to the 646 shown in Table 5-16.

The transducers on the Freon pump packages are replaceable as single items. To minimize the hardware requirements, it is recommended that the entire pump package be removed (including accumulator) should any of the other package components fail.

Removal of the ammonia tank assembly will only be done if the tank is defective. It is recommended that after a leak has been detected for the tank assembly, a sequential leak check of the tanks and valve packages be conducted to isolate the leak. This will reduce overall maintenance time.

The total MMH/OH estimated for the Freon 21 subsystem is estimated at 0.65 man-hour/10^3 operating hr.

TABLE 5-16

ONBOARD CORRECTIVE MAINTENANCE SUMMARY FREON-21 HEAT REJECTION SUBSYSTEM

LRU Ident.	LRU Definition	Maint. Crew Size	Elapsed Time, hr	Maint. Man-hours/ Task	No. LRU/ Subsystem	Maint. Action Rate/Item, $1/10^{-6}$ hr	Maint. Man-hours/ Operating hr $hr/10^{-6}$ hr	Remarks
7-A	Fuel cell heat exchanger	1	1.5	1.5	2	8.0	24.0	Does not include servicing of either the Freon-21 or the fuel cells liquid loops.
7-B	Hydraulic heat exchanger	1	2.5	2.5	1	12.0	30.0	Does not include servicing of either the Freon-21 or the hydraulic loops.
7-C	Payload heat exchanger	1	1.7	1.7	1	8.0	13.6	Does not include servicing of the loops.
7-D	GSE heat exchanger	1	1.7	1.7	1	8.0	13.6	
7-E-1	Primary Freon pump package	2	1.2	2.4	1	70.0	168.0	Package weight is 104 lb; does not involve loop servicing.
	Pressure transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's.
	ΔP transducer	1	0.2	0.2	1	25.0	5.0	Removable as LRU's.
7-E-2	Secondary Freon pump package	2	1.2	2.4	1	70	168.0	Only one pump-motor in package; see above for pump-motor removal.
	Pressure transducer	1	0.2	0.2	1	25.0	5.0	
	ΔP transducer	1	0.2	0.2	1	25.0	5.0	
7-F	Temperature sensor (Item 7.10)	1	0.2	0.2	2	5.0	2.0	Well-type sensor.
7-G	GSE heat exchanger bypass valve	1	0.7	0.7	2	12.0	16.8	
7-H	GSE HX bypass valve controller	1	0.3	0.3	2	30.0	18.0	
7-I	Freon-water interchanger	2	2.5	5.0	1	8.0	40.0	111-lb unit.
7-J	GSE connector	1	0.4	0.4	4	3.0	4.8	
7-K	Fill connector assembly	1	0.5	0.5	4	2.0	4.0	
7-L	NH_3 tank assembly	1	2.2	2.2	2	5.0*	22.0	*Entire assembly removed only if tank failed; sequential leakage necessary; leak check time included.
	Overboard burst disc (7.49)	1	0.7	0.7	2	8.4	11.8	Removable as LRU's.
	Burst disc (7.35)	1	0.7	0.7	2	8.4	11.8	Removable as LRU's.

TABLE 5-16 (Continued)

LRU Ident.	LRU Definition	Maint. Crew Size	Elapsed Time, hr	Maint. Man-hours/ Task	No. LRU/ Subsystem	Maint. Action Rate/Item, $1/10^{-6}$ hr	Maint. Man-hours/ Operating hr $hr/10^{-6}$ hr	Remarks
	Relief valve (7.36)	1	0.7	0.7	2	8.4	11.8	Removable as LRU's.
	Vent valve (7.38)	1	0.7	0.7	2	8.4	11.8	Removable as LRU's.
	Solenoid shutoff valve (7.39)	1	0.7	0.7	2	14.2	19.9	Removable as LRU's.
	Fill connector (7.37)	1	0.7	0.7	2	14.2	19.9	Removable as LRU's.
	NH_3 tank pressure transducer	1	0.7	0.7	2	14.2	19.9	Removable as LRU's.
	NH_3 tank pressure transducer	1	0.2	0.2	2	20.0	8.0	Removable as LRU (electrical failure).
	Solenoid shutoff valve	1	0.4	0.4	2	8.0	6.4	Removable as LRU (actuator failure).
7-M	NH_3 pressure regulator	1	0.5	0.5	2	30.0	30.0	
7-N	NH_3 boiler package	1	1.1	1.1	2	15.0	33.0	Entire package removed only if boiler or vernatherm has failed.
	NH_3 solenoid shutoff valve (7.39)	1	0.5	0.5	4	10.0	20.0	Removable as LRU's.
	NH_3 relief valve (7.41)	1	0.5	0.5	2	6.0	6.0	Removable as LRU's.
7-O thru 7-Y	8 temperature sensors	1	0.3	0.3	8	10.0	24.0	Surface-type sensors.
7-W	NH_3 delivery pressure transducer	1	0.2	0.2	1	25.0	5.0	
7-Z	Freon manual shutoff valve	1	0.5	0.5	6	1.0	3.0	
7-AA	Vapor cycle connector	1	0.5	0.5	4	3.0	6.0	
						TOTAL	645.9	

5.7 SUMMARY OF MAINTENANCE REQUIREMENTS

A summary of the onboard maintenance requirements for the four subsystems considered is presented in Table 5-17. The time to service, check out, and perform corrective maintenance is estimated at 50.7 man-hours based on a 7-day mission. With a two-man maintenance crew, total elapsed time is 25.4 hr. The largest portion of the maintenance time is expended in the atmosphere control subsystem. Checkout of this subsystem alone accounts for more than 25 percent of the total maintenance time. The instrumentation and GSE necessary to support the maintenance activities are discussed in Sections 7 and 8.

TABLE 5-17

MAINTENANCE SUMMARY

Subsystem	Scheduled Maintenance (Servicing) Man-Hours/Flight	Flight Readiness Ground Checkout Man-Hours/Flight	Onboard Corrective Maintenance Man-Hours/10^3 Operating Hours
Atmosphere revitalization	6.1	7.3	0.64
Atmosphere control	4.6	13.8	7.05
Water management	4.3	3.5	0.40
Freon coolant loop	3.1	6.5	0.65
Total	18.1	31.1	8.74

SECTION 6

TEST REQUIREMENTS

6. TEST REQUIREMENTS

6.1 TEST PHILOSOPHY

The overall test program is divided into two major tasks: (1) development and (2) certification. The initial task is characterized by the use of primarily R&E hardware. Certification, which includes qualification, is conducted with production hardware subject to all program traceability and quality assurance requirements.

Figure 6-1 graphically describes the overall test approach. The initial phase involves analyses to establish the suitability of existing designs. These analyses cover material compatibility, functional and performance adequacy, and structural/environmental capabilities in view of the specification requirements. The results of component selection studies were used to establish the certification requirements reflected for the as-is and modified components.

Most components will be subjected to breadboard development testing. The scope of this testing will depend upon the hardware category (existing, modified, new), the complexity of the component, and the system function. Therefore, the tests will vary from a simple demonstration of functional/performance suitability to more extensive evaluations, such as EMI suppression approaches and limited structural/life tests.

The remainder of the development program will be more formal and will be conducted using prototype configuration hardware fabricated from controlled development drawings. This more rigorous phase deals with designs using new

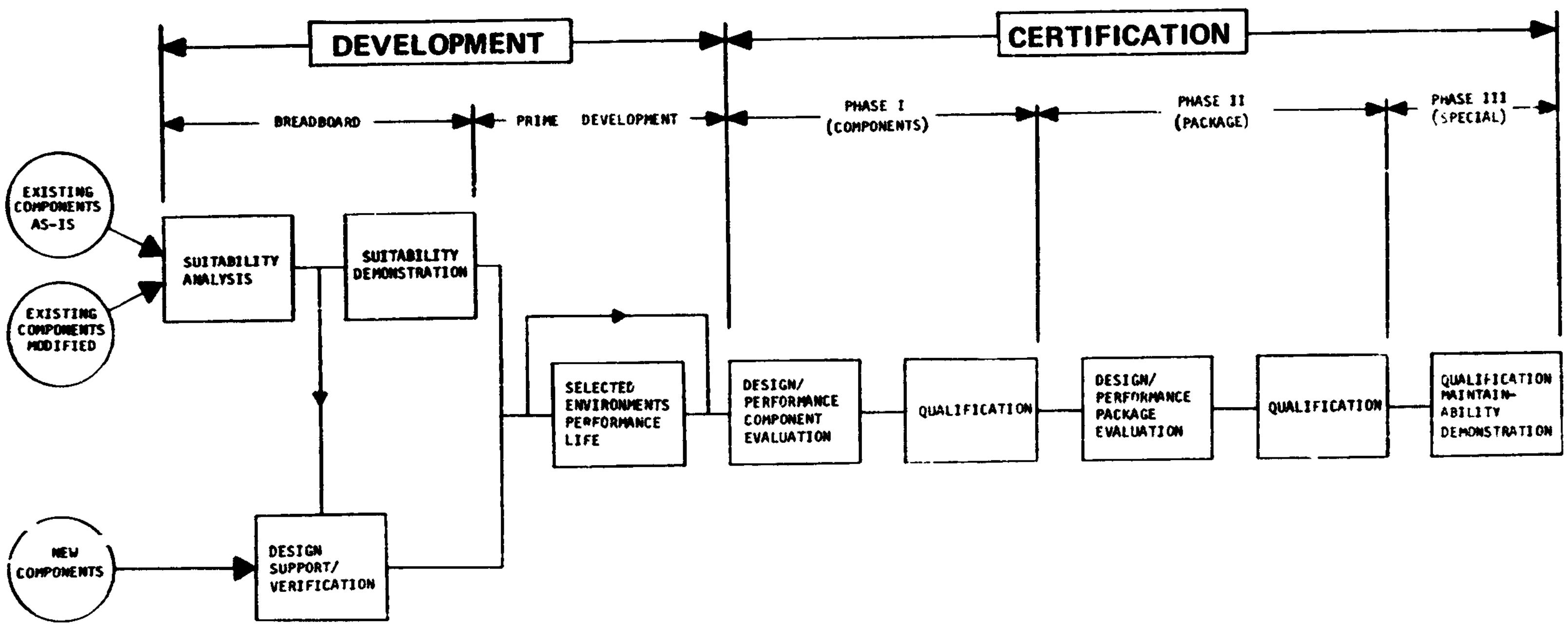

Figure 6-1. Overall Test Approach

concepts and designs for which life, extended performance, or structural integrity must be demonstrated. This phase is identified as prime development.

Certification is subdivided into three sequential phases: Phase I, component-oriented tests; Phase II, package-oriented tests; and Phase III, special tests. Two types of testing will be performed: (1) design/performance evaluation and (2) qualification. The design/performance evaluations (component and package) are basically performance tests that provide the means of evaluating acceptance and qualification test procedures and criteria.

The qualification test program is concerned with demonstrating the capability of the equipment to withstand the structural, environmental, and reliability requirements of the reusable ETC/LSS. Qualification of the ETC/LSS equipment will be accomplished by testing or assessment (analysis or similarity), or by a combination of the two. The method used to qualify a particular package or component will be determined based upon its hardware category (as-is, modified, or new), complexity, and function.

Qualification testing will be accomplished almost entirely on the final LRU (shipping configuration) level, which is justified because package testing is more representative of the conditions to which the hardware will be subjected during the mission. Where component level environmental or dynamic tests are considered necessary for particular components, they will be accomplished during the prototype development phase.

Certain qualification tests such as burst, bonding, and explosive atmosphere are strictly component tests and will be conducted on that level. Others that are component oriented (such as EMI and fatigue cycling) may be conducted on the component level.

Maintainability demonstration will be performed during final certification (Phase III). Servicing, preventative maintenance, and LRU/SRU replacement to demonstrate accessibility will be included.

6.2 DEVELOPMENT REQUIREMENTS

6.2.1 Breadboard Testing

In general, these tests will be conducted to provide design data, verify particular aspects of a design, and gain confidence that the hardware will successfully meet the requirements of the more stringent prototype development and qualification test programs.

Breadboard testing of as-is components will be limited to checkout tests to verify the suitability of a particular component qualified under a previous program but designed for a different function or to different performance requirements. Existing components that will be subjected to selected breadboard tests are (1) check valves, (2) relief valves, (3) manual valves, (4) O_2 tank, and (5) O_2 mask. These as-is components will be subjected to design suitability tests as applicable, including the following:

(a) Proof
(b) Leakage
(c) Flow vs ΔP
(d) Functional
(e) Performance

In general, breadboard testing of the modified components will be similar to those of as-is items. However, this program will be somewhat more extensive and will include tests such as life testing and more involved performance checkout. Table 6-1 identifies the scope of the breadboard test program for this category of equipment.

TABLE 6-1

COMPONENT BREADBOARD TESTS FOR
EXISTING MODIFIED COMPONENTS

Component Type	Test (As Applicable)
Electrical valves and quick disconnects	(a) Proof and leakage (b) Flow vs ΔP (c) Operating torque/force (d) EMI, power consumption, IR (e) Operating time (f) Operational stability (g) Mechanical compatibility (h) Cycle life
Orifices, regulators, and relief valves	(a) Proof and leakage (b) Calibration (c) Flow stability (d) Cyclic life
Sensors (control), controller, and temperature selector	(a) EMI, IR, dielectric, power consumption (b) Performance (c) Calibration
Temperature and pressure sensors	(a) Proof and leakage (b) Calibration (c) EMI (d) Fluid compatibility

New components will be subjected to a more comprehensive breadboard test program, as defined in general terms in Table 6-2 where the type of tests proposed are defined for each type of component. These tests are concerned with demonstration of performance, EMI suppression, and structural soundness in selected cases.

Performance maps will be generated for fans, pumps, and heat exchangers. These data will be generated in support of the system analysis effort.

All EMI suppression approaches will be developed as part of the breadboard test program. All controls will be checked out with interfacing hardware such as sensors and controlled unit.

6.2.2 Prime Development Testing

The prototype test phase covers those components and packages that use new design concepts and/or for which operational/cycle life, extended mission performance, or structural integrity must be demonstrated to confidently enter qualification. The parts will be of production configuration, and subject to all program traceability and quality control requirements.

The primary objective of this phase will be to evaluate the effects of selected critical environments, critical parametric overstress, and operational endurance. Table 6-3 lists those items considered in this category.

Package or functional group testing is recommended for selected assemblies to verify performance and identify any interaction problems (especially those associated with control functions). Four packages have been identified that will be subjected to this level of testing:

Ammonia evaporation control system
Expendable evaporant heat sink
Atmosphere revitalization
Gas control assembly

TABLE 6-2

COMPONENT BREADBOARD TESTS NEW COMPONENTS

Equipment Type	Test Description
Fans and pumps	(a) Preliminary performance maps (speed, power consumption, pressure rise, flow) (b) Magnetic coupling strength, breakdown torque (pumps) (c) Applicable EMI (d) Accumulator calibration as applicable (pumps) (e) Proof and leakage (f) Bearing life (conducted in prototype dev phase)
Manual, solenoid, relief valves, and quick disconnects	Following as applicable: (a) Proof and leakage (b) Flow vs ΔP characteristics with operating fluid (also with homologous fluid for ammonia components) (c) Operating torque/force (d) Electrical - EMI and power consumption (e) Flow/operational stability (f) Material compatibility (g) Operational cycle
Regulators	(a) Proof and leakage (b) Calibration (c) Flow/operational stability (d) Material compatibility (Item 7.40) (e) Operational cycle
Storage tanks	(a) Proof and leakage (b) Vibration-sine slows resonant dwells (c) Pressure cycle (d) Design burst
Heat exchangers, condenser, and evaporators	Following as applicable: (a) Proof and leakage (b) Preliminary performance maps - heat rejection, pressure drops (c) Pressure/thermal cycle (d) Selected environmental, including vibration-sine scans and resonant dwell worst axis; shock, worst axis; and temperature humidity (e) Attitude variation (Item 2.6 condenser only) (f) Design burst (g) Heatup, recovery, and temperature control (Item 4.7)
CO_2 absorber	(a) Proof and leakage (b) Flow vs ΔP characteristics (c) CO_2 removal effectiveness vs flow rate, relative humidity, CO_2 concentration, and temperature (d) Dusting tests - storage and system installation (e) Selected environmental, including vibration-sine scans, dwells; and worst-axis shock
H_2 separator	(a) Proof and leakage H_2 removal performance vs H_2 concentration, temperature (c) Selected environmental, including vibration-sine scans, dewlls; and worst-axis shock (d) Design burst
Filters	(a) Check filtering effectiveness with controlled contamination of process fluid flow (b) Life test with nominal contamination level (c) Adequacy of pressure relief function where applicable (d) Selected environmental, including vibration-sine scans, dwells; and worst-axis shock
Dump nozzle assembly	(a) Power consumption (b) Vacuum/freezing (c) Operational cycle (flow/no flow)
Controllers	(a) Definition of individual module characteristics (b) Applicable EMI tests (c) Performance at nominal, maximum, and minimum temperature (d) Subsystem tests with associated input command unit and output drive unit
Sensors, temperature	(a) Calibration (b) Applicable EMI (c) Input command for subsystem check with controller and valve
Transducer power supply	(a) Individual circuit evaluations (b) *Integrated circuit performance at nominal, minimum, and maximum temperature (c) *Thermal cycle (d) *Applicable EMI (e) Subsystem interface callout
Flow sensor	(a) Performance at nominal minimum and maximum temperature (b) Thermal cycle (c) EMI (d) Vibration (e) Worst-axis shock
Gages	(a) Proof and leakage (b) Calibration (c) Operational cycle (d) Design burst
Burst discs	(a) Proof and leakage (b) Actual burst
NH_3 feed vernatherm	(a) Leakage (b) Response/stability (c) Calibration (d) Vibration-sine scans, resonant dwells (e) Operational cycle (f) Thermal cycle
Silver ion generator, silver ion detector, and potable water deionizer	(a) Material selection/compatibility (b) Performance map covering total range of operation (c) Degradation vs time at nominal conditions (d) Subsystem test combining generator, detector, and deionizer

*Before and after packaging

TABLE 6-3

PRIME DEVELOPMENT PACKAGES

LRU No.	Description
1-D	Two-gas control assembly
1-M	O_2 storage tank assembly
1-AA	PO_2 sensor
2-A (Ref)	Fan
	Condenser
2-G	Transducer power supply
3-A	Expendable evaporant heat sink
3-1-2 (Ref)	Water pump
4-E	Silver ion generator
4-G	Potable water deionizer
4-H	Hydrogen separator
4-N	Silver ion detector
7-E-2 (Ref)	Freon pump
7-L	Ammonia tank assembly
7-N	Ammonia boiler package

Where possible, tests will be conducted in the development phase of the program to demonstrate the validity of the maintenance approaches incorporated in the design of the equipment packages and to verify compliance to the requirements of the NR specification. These tests will be designed to:

(a) Verify the mechanical design of the equipment
(b) Verify accessibility
(c) Determine adequacy of tools
(d) Determine the skill levels required for LRU removal
(e) Verify the time estimated for specific maintenance tasks
(f) Verify servicing procedures for equipment requiring periodic replacement, recharging, flushing, or decontamination

6.3 CERTIFICATION REQUIREMENTS

The certification program is divided into three sequential phases based primarily upon the assembly level of the hardware. Briefly, these are:

Phase I: Component or Component-Oriented Tests--These include component acceptance and qualification tests, such as EMI and explosive atmosphere, which are more conveniently conducted on a component basis before package assembly.

Phase II: Package Tests--These include package acceptance and all qualification environmental, dynamic, cycle fatigue, and operational tests.

Phase III: Package/Component Disassembly and Inspection, and Component Burst--Maintainability demonstrations also will be included in this phase.

The certification program comprises the following test categories:

(a) Design/performance evaluation
(b) Qualification
(c) Maintainability demonstration

6.3.1 Phase I Certification

The design/performance evaluations involve both component and package testing. The Phase I certification scope comprises:

(a) All components will be subjected to acceptance testing. These tests are identical to those which will be used for the production hardware.

(b) Performance maps will be generated on selected components and only on one unit of that design. These tests may be conducted at the package or component level, whichever is the more practical. Performance maps will be generated for all fans, pumps, and heat exchangers.

(c) EMI testing of all electrical components will be conducted, including fans, pumps, electrical valves, transducers, controllers, and heaters.

(d) All electrical components also will be subjected to explosive atmosphere testing.

The last two tests will be an integral part of the qualification program.

6.3.2 Phase II Certification

Phase II certification will be conducted at the package level as mentioned previously. All LRU's will be subjected to the following series of tests as applicable. The scope of the Phase II testing comprises:

(a) Acceptance Testing--All LRU's including more than one component.

(b) Operational Modes--These tests cover the entire range of steady-state conditions anticipated for the LRU. LRU's subjected to this type of testing include (1) the cabin atmosphere revitalization LRU's, (2) all fans and pumps packages, (3) all tank packages,

(c) ...

In this manner ...

overall ...

(d) ...--all LRU's ...

compartment.

(e) Vibration, Acceleration, and Shock Tests--LRU'...

(f) Temperature Cycling Tests--LRU' ...

component ... storage tanks.

(g) Pressure Cycling Tests--all LRU's ... during the operational life of the vehicle ... storage tanks and high-pressure gas ... heat exchangers ...

(h) Actuation Cycling Tests--Conducted ... regulators, relief valves, solenoid ... transducers, and all components ...

(i) Mission Simulation Tests--Selected LRU' ... atmosphere circuit, the pump package ... ammonia boiler, and the two-gas control ...

6.3.3 Phase III Certification

During Phase III, a maintainability demonstration ... The conditions of the maintainability demonstration ... will represent that which can be expected to occur ...

environment. If required, fault simulation for corrective maintenance tasks will be performed by introduction of faulty parts, deliberate misalignment, etc. into the system.

6.4 SPECIAL TEST EQUIPMENT

The special test equipment (government-owned STE) necessary to accomplish the test program is generally available from previous programs. Although most STE can be used in its present condition, a few items will require minor modifications to handle the higher performance requirements of the shuttle. Also, some existing STE will have to be relocated into cleanroom facilities.

Additional STE will have to be designed, procured, fabricated, and assembled to meet particular test requirements of the shuttle ETC/LSS equipment. These new STE items are listed below.

- Freon-21 test stands (heat exchangers)
- CO_2 absorber test loop
- Water separator test loop
- Evaporator test stand
- Silver ion generator and detector test stand
- Various vibration, acceleration, and shock test fixtures
- Miscellaneous torque adaptors and other minor equipment
- Narrow band random vibration controller

SECTION 7

INSTRUMENTATION REQUIREMENTS

7. ETC/LSS INSTRUMENTATION

7.1 INSTRUMENTATION REQUIREMENTS

The ETC/LSS requirements for instrumentation are established by the following functional and operational subsystem requirements:

(a) Control of the various subsystem elements

(b) Redundancy management to provide system health parameters for the management of redundant loops or equipment in flight

(c) Checkout of the subsystem with expedient FD/FI to the LRU level for ground checkout and preventative maintenance

These requirements establish the basic criteria upon which the minimum instrumentation list was developed. An implied requirement is that sufficient information redundancy must exist in the basic design to preclude problems that would compromise crew or vehicle safety in the event of instrumentation failure.

7.2 INSTRUMENTATION SELECTION CRITERIA

In addition to the above, the following selection criteria were used to identify instrumentation for the ETC/LSS

(a) Selection of instrumentation for ETC/LSS functions only

(b) Simplicity of redundancy management action

(c) Instrumentation or information redundancy

Instrumentation selection is based on man-in-the-loop philosophy in that the crew can perform redundancy management of the ETC/LSS using information provided by the system instrumentation. These topics are discussed in the following paragraphs.

7.2.1 Instrumentation for ETC/LSS Functions Only

A major selection criterion for the instrumentation was to provide an instrument which would be sufficient and could completely provide for the safe operation of the ETC/LSS in normal and degraded operation. In selecting ETC/LSS instrumentation, the requirements for monitoring interfacing space shuttle subsystems or mission and vehicle level parameters were not considered. The resulting instrumentation list (discussed in para. 7.3) represents the minimum required for the ETC/LSS only.

7.2.2 Redundancy Management

Information interpretation simplicity was the dominant factor in selecting instrumentation redundancy management (i.e.. to provide sufficient instrumentation onboard so that corrective action for equipment failure could always be simple, such as a switching function to activate a redundant element and isolate a failed element). Too little instrumentation results in more complexity, time consuming deductive logic, and ambiguous indication in determining corrective action.

Another factor of major importance is the level of instrumentation or information redundancy available. Prime consideration was given to the quality (resolution) and quantity (redundancy) of the available instrumentation backup.

7.2.3 Instrumentation Redundancy

Instrumentation redundancy permits continued safe operation of the ETC/LSS and allows simple redundancy management logic to be maintained after first fault indication resulting from instrumentation failure.

The level of redundancy is established considering the criticality of a single loss. In some cases redundancy is in the form of a second instrument; in other cases backup instrumentation is used to provide similar information to the crew. Generally, backup instrumentation will require interpretation and is recommended only if parameter interpretation is simple.

Certain assumptions used in the analysis of instrumentation redundancy are summarized as follows. First, it was assumed that instrumentation failure generally will result in a warning of equipment malfunction from the computer automatic readout. Such a warning will initiate a redundancy management action by the crew. Completion of the redundancy management action will identify either (1) a functional component failure if the parameter indicating the failure returns to normal, or (2) an instrument failure; if it is in the sensor, the parameter remains unchanged after switchover to a redundant functional LRU.

Second, it was postulated that the instrument has not failed and that an out-of-range transducer signal corresponds to failure of the functional component. As a result, redundancy management action will have to be taken in such situations. In actuality (except for control instruments) failure of an instrument does not degrade the capability of the component or LRU monitored by this instrument. Generally, failure of an instrument will be identified as such, and normal operation could be continued.

Finally, control instrumentation failure results in loss of that particular subsystem function so that the preceeding R/M action would restore the function by use of a redundant element, but the subsystem function is lost. In some cases a manual bypass mode of operation is provided to restore the control function by using man-in-the-loop to provide the function.

7.3 MINIMUM INSTRUMENTATION LIST

Minimum instrumentation required for the ETC/LSS is listed in Table 7-1, which is presented at the end of this section. The instruments are classified in terms of function; these are subsystem control, management of redundancy, and ground checkout and maintenance.

To be completely inclusive, Table 7-1 also defines test port provisions for instrumentation, special instrumentation, and position switches that provide information for operation and control of the subsystem.

A brief description of the data presented under each column heading of Table 7-1 follows:

(a) Item Number Identification--For each ETC/LSS instrument.

(b) Quantity--For each subsystem.

(c) Parameter Range--Measurement range for a particular instrument.

(d) Functional Application--Primary and other uses such as control, etc. of a particular instrument. The symbol X indicates the principal application and the symbol (X) indicates an alternate or secondary use of the instrument.

(e) Information Redundancy--Level of information redundancy provided, or available, for a particular instrumentation function.

(f) Remarks Column--Information pertinent to a particular transducer relative to its primary function, redundancy level, and operation in the ETC/LSS.

An analysis was conducted to determine the effect of instrumentation failure, and the capability of the crew to interpret backup instruments (primarily included for other purposes) was evaluated. The results of these studies are summarized in Table 7-1.

Examination of the data presented in the remarks column reveals that only in a few cases is instrumentation redundancy necessary. In general, adequate information is available to the crew from the backup instruments to permit redundancy management even after instrumentation failure.

TABLE 7-1

ETC/LSS MINIMUM INSTRUMENTATION LIST

Item No.	No. Req'd	Instrument Description	Parameter Range	Control	Function		Information Redundancy			Remarks
					Redund. Mgmt	Check Out	None	Redundant Instrum	Back Up	
1.100	1	N_2 source tank pressure	0-3500 psig		X	(X)			Y (1.100) and (1.111)	Primary application if for R/M and is used for c/o (Tank 1) These comments are applicable for all items. 1.100 through 1.109 for redundancy management (R/M). The principal R/M indicator of source tank quantity is gas pressure. If a sensor indicates low or zero, R/M action is to try to use that particular vessel. Backup is premised on the fact that if the vessel is empty, the manifold pressure will drop below regulated, indicating loss of that vessel. If the tank is partially full, it will then be expended most efficiently since if not used it would be lost to space. The backup instrumentation is two manifold pressures for either the N_2 or O_2 systems. In this case, backup is FS-FS.
1.101	1	Same as 1.100	0-3500 psig		X	(X)				Primary application is for R/M and is used for c/o (Tank 2)
1.102	1	Same as 1.100	0-3500 psig		X	(X)				Primary application is for R/M and is used for c/o (Tank 3)
1.103	1	Same as 1.100	0-3500 psig		X	(X)				Primary application is for R/M and is used for c/o (Tank 4)
1.104	1	Same as 1.100	0-3500 psig		X	(X)				Primary application is for R/M and is used for c/o (Tank 5)
1.105	1	Same as 1.100	0-3500 psig		X	(X)			Y (1.110) and (1.111)	Primary application is for R/M and is used for c/o (Tank 6)
1.106	1	Same as 1.100	0-3500 psig		X	(X)				Primary application is for R/M and is used for c/o (Tank 7)
1.107	1	Same as 1.100	0-3500 psig		X	(X)			Y (1.112) and (1.113)	Primary application is for R/M and is used for c/o (Tank 8)
1.108	1	O_2 source tank	0-3500 psig		X	(X)				Same as 1.100 except service is O_2 (Tank 1)

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function			Information Redundancy			Remarks
				Control	Redund. Mgmt	Check Out	None	Redundant Instrum	Back Up	
1.109	1	Same as 1.108	0-3500 psig		X	(X)			Y	Same as 1.108 (Tank 2)
1.110	1	N_2 manifold pressure	0-200 psig		X	(X)		Y		Primary application is for R/M and is used for c/o Redundant unit is 1.111 Redundant instrumentation FS configuration for N_2 systems.* *For either N_2 or O_2, R/M action is the same. The redundant loop is initiated and if transducer remains unchanged, the transducer failed. Continue with redundant loop operation and primary loop is still available. For second failure, R/M action is still the same.
1.111	1	Same as 1.110	0-200 psig		X	(X)		Y		Redundant unit for 1.110 Redundant instrumentation configuration is FS
1.112	1	O_2 manifold	0-1000 psig		X	(X)		Y		Primary application is for R/M and is used for c/o Redundant unit is 1.113, instrumentation is FS
1.113	1	Same as 1.112			X	(X)				Same as 1.112 Redundant unit for 1.112, instrumentation is FS
1.114	1	N_2 water tank pressure (gas)	0-50 psig		X	(X)			Y (4.100) and (4.22)	Primary application is for R/M and is used for c/o Water manifold pressure is available as a backup via 4.100 and 4.22 (gage). This is FO-FS backup.
1.115	1	Same as 1.114	0-50 psig		X	(X)			Y (4.100) and (4.22)	Same as 1.114 except for secondary water system.
1.116	1	N_2/O_2 pressure	0-200 psig			X				PO_2 control system.
1.117	1	Same as 1.116	0-200 psig			X				Same as 1.116 except for secondary system.

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
1.118	1	N_2 supply (Leg 2)	0-200 psig			X				N_2 check valve c/o
1.119	1	N_2 supply (Leg 3)	0-200 psig			X				N_2 check valve c/o
1.120	1	N_2 supply (Leg 1)	0-200 psig			X				N_2 check valve c/o
1.121	1	Primary O_2 supply	0-1000 psig			X				O_2 check valve c/o
1.122	1	Aux. O_2 supply	0-1000 psig			X				O_2 check valve c/o
1.123	1	Second. O_2 supply	0-1000 psig			X				O_2 check valve c/o
1.124	1	Regulated O_2 prim				X				O_2 regulator c/o (primary)
1.125	1	Regulated O_2 second.				X				O_2 regulator c/o (secondary)
1.:2	2	PO_2 sensor	0-5 psia	X	(X)			Y*	Y*	Sensor provides signal to PO_2 controller; one each is used for primary and secondary control of the system. A third unit, not part of subsystem, is provided for atmosphere monitoring and available for fail-safe manual control. *These are control sensors and are backed up in operation by a completely redundant system. Philosophically the PO_2 control function and hence the sensors are FO-FS. The FS instrument is 1.500, which is used for manual PO_2 and P_T control.
1.126	1	Avionics bay 3 ΔP	(-2) to (+2) psid		X	(X)			Y	Primary application is for R/M and is used for c/o Cabin total is a backup indication for parameter loss. Philosophically the system is FS for any of the avionics bay ΔP parameters. This is typical for 1.128 also
1.127	1	Same as 1.126 except for bay 2	(-2) to (+2) psid		X	(X)				Same as 1.126
1.128	1	Same as 1.126 except for bay 1	(-2) to (+2) psid		X	(X)				Same as 1.126
1.130	1	Aux. O_2 supply	0-1000 psig			X				O_2 check valve c/o

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
1.190	2	Cabin total pressure	0-30 psia		X	(X)		Y**		Two transducers are supplied for FS operation **A safety parameter to complement ACS instrumentation backup to this parameter is N_2 and O_2 manifold pressure. This indicator allows early detection of a runaway regulator or leaky cabin.
1.200	1	O_2 manifold temp	-75 to +175°F		X					Primary cryogenic supply ERLSS O_2 temp Cryo system temp could provide a backup for this signal. This is a R/M control signal to provide information concerning operation of heaters. This typical for 1.200 or 1.201
1.201	1	Same as 1.200	-75 to +175°F		X					Secondary cryogenic supply ERLSS O_2 temp and see 1.200
1.300	1	N_2/O_2 flow	0-2 lb/hr		X	(X)			Y	Primarily used to indicate cabin leakage. Cabin total is a backup means of indicating cabin leakage. This parameter is principally used for cabin leakage assessment or indication of cabin regulator failed open. Typical for 1.301 also.
1.301	1	Same as 1.300	0-2 lb/hr		X	(X)				Used for redundant system see 1.300 above.
1.500	1	PO_2 sensor	0-5 psia	X						Provide F.S. for dedicated instrument. This is a FS backup for PO_2 control. Permits manual PO_2 control of ACS. (See 1.12 for failure comments)
2.100	2	Fan ΔP	0-10 In. H_2O		X	(X)		Y	Y (2.101)	Primary application is for R/M and can be used for c/o. Redundant instrument is available and 2.101 is an indirect backup. This parameter is backed up by a redundant item; debris trap ΔP is also an inferred backup parameter, so that instrumentation is FO-FS. R/M action (fan switching) will identify transducer failure.

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
2.101	1	Debris trap ΔP	0-2 in. H_2O		X		X		Y (2.100)	Alert crew to service debris trap. R/M action is to change the filters if condition permits, fan ΔP is a backup parameter. Instrumentation redundancy is FS-FS.
2.500	1	PCO_2 sensor	0-30 mm Hg		X		Y			Alert crew to service CO_2 removal system. LiOH charges will be replaced periodically. Circulation failures will be indicated by fan ΔP or debris trap ΔP. Normal time replacement of LiOH canister will provide a safe CO_2 level. Failure of the LiOH bed is improbable.
3.1	1	Temperature anticipator	0-120°F	X			Y			Temp sensor provides feedback information to cabin temperature controller
3.3	1	Cabin temperature	0-120°F	X					Y (3.290)	This is a control instrument. Manual control using signal from 3.290 via temp selector will provide manual backup. The crew can manually control temperature through feel if the signal from 3.290 is lost. The preceding comments are applicable for both 3.3 and 3.290.
3.6d	4	Flush evaporator outlet temp	0-200°F	X						Control instrument.
3.290	1	Cabin temperature	0-120°F		(X)		Y			Instrument provides indication for manual mode operation. Crew will sense comfortable temperature whatever the indication.
3.450	1	Temperature control valve position indicator	Valve position			X				Principal assignment is for C.O. Position switch allows for determination of valve position for ground check.
3.104	1	Secondary water pump inlet pressure (secondary)	0-50 psig		X	(X)			Y (3.501)	Primary application is for R/M and is used for ground checkout. Indicates pump inlet pressure and accumulator pressure. Primary backup is the accumulator low pressure switch. Pump ΔP is also an indirect backup parameter. This is also true for 3.105.

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
3.105	1	Same as 3.104 except for primary loop	0-50 psig		X	(X)			Y (3.500)	Same as 3.104 except for primary system
3.150	1	Primary water pump package ΔP	0-60 psid		X	(X)			Y (3.105)	Primary application is R/M and can be used for c/o R/M action would be to initiate operation of redundant component. This would indicate instrumentation or functional component failure. The previous operational hardware is still available if transducer has failed. 3.105 is an indirect backup for R/M.
3.151	1	Secondary water pump package ΔP	0-60 psid		X	(X)			Y (3.104)	Primary application is R/M and can be used for c/o and is also an indirect backup for 3.104. This is a fail-safe loop. Water temperatures provide indirect backup.
3.152	2	Avionics bay 1 fan ΔP	0-10 in. H_2O		X	(X)		Y		Primary application is for R/M and is also used for c/o. Redundant unit is provided for FS. R/M of fans and R/M action would be to initiate operation of redundant fan. This would indicate wheather the instrument or the fan failed. If the instrument, the previous fan is still available. This comment is typical for 3.153 and 3.154 also.
3.153	2	Same as 3.152 except for bay 2	0-10 in. H_2O		X	(X)		Y		Same as 3.152
3.154	2	Same as 3.152 except for bay 3	0-10 in. H_2O		X	(X)		Y		Same as 3.152
3.255	1	Interchanger outlet temp (primary loop)	0-200°F		X				Y	Primary assignment is R/M and for overall system performance monitoring
3.256	1	Primary evaporator outlet temp (primary loop)	0-200°F		X				Y (3.260)	Primary application is R/M and also serves an indirect backup parameter for pump ΔP (primary loop). 3.260 is a direct backup for this parameter
3.257	1	Interchanger outlet temp (secondary loop)	0-200°F		X				Y 3.258 3.259	Same as 3.255. Temperatures 3.258 and 3.259 are [illegible] for this parameter.

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
3.258	1	Primary evaporator outlet temp (secondary loop)	0-200°F		X				Y (3.259)	Same as 3.256. 3.259 is a [illegible] backup parameter.
3.259	1	Secondary evaporator outlet temp (secondary loop)	0-200°F		X				Y (3.258)	Same as 3.256. 3.257 and 3.258 are indirect backups for this parameter when boiler is not in use. 3.259 [illegible] secondary boiler.
3.260	1	Secondary evaporator outlet temp (primary loop)	0-200°F		X				Y (3.255)	Same as 3.256. 3.255 and 3.256 are indirect backup parameters when [illegible] boiler is not active. 3.260 [illegible] secondary boiler.
3.500	1	Primary water accum. quantity	0-110 full		X				Y (3.105)	Primary assignment is for R.M. backup is provided by 3.105. R.M action is to wait for low system pressure warning to occur and then initiate secd. [illegible] system.
3.501	1	Same as 3.500 for secondary water accumulator	0-110 full		X				Y (3.104)	Same as 3.500, except that backup is provided by 3.104
4.100	1	Water manifold pressure	0-50 ps[illegible]		X	X			Y (4.22) and (1.114) or (1.115)	Primary application is for R/M and may be used for C/O. A visual backup is provided by 4.22 manifold gage and for most cases P1 114 (primary) or P1.115 (secondary) can also provide a backup signal. Instrumentation redundancy [illegible] FS-FS, R/M action [illegible] that both FS-FS gage and [illegible] are reading normal [illegible] corrective action [illegible]
4.101	1	Test port water manifold loop				X				[illegible]
4.102	1	Test port secondary water [illegible] valve [illegible]				X				[illegible]
4.103	1	Same as 4.102 [illegible] water [illegible]				X				[illegible]
4.104	1	[illegible] water [illegible]				X				[illegible]

TABLE 7-1 (Co[illegible]inued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function			Information Redundancy			Remarks
				Control	Redund. Mon't	Check Out	None	Redundant Instrum	Back Up	
4.1[illegible]	1	Same as above except for primary water selector [illegible]				X				Same as above except for primary water selector [illegible].
4.[illegible]	1	Water nozzle temp	0-100°F		X	(X)	Y			Primary application [illegible] be used for [illegible] backup for water [illegible] this signal [illegible] redundant [illegible] would require [illegible] signal [illegible].
4.50[illegible]	1	Water tank quantity (primary)	0-1[illegible]0		X				Y	Used for [illegible] critical information [illegible] system. [illegible] second water tank [illegible] available [illegible] backup for this failure.
4.501	1	Water tank quantity (secondary)	0-100[illegible]		X				Y	Same as above
4.503	1	Silver ion detector	[illegible]-500 ppb		X		Y			Single unit provided with BITE [illegible] vide water quality information [illegible] is sized conservatively [illegible] day mission, therefore failure [illegible] to remove excess silver [illegible] small.
7.10	2	Temp sensor (primary and secondary)	0-250°F	X		(X)	Y			Provide signal [illegible] valve [illegible] for primary and [illegible] loops. Not used [illegible] a backup [illegible]
7.10[illegible]	1	Primary Freon pump package inlet pressure sensor	[illegible]-300 psig		X	(X)			Y (7.150)	Can be used [illegible] pressure. Primary pump [illegible]
7.101	1	Same as 7.100 for secondary pump package	0-300 psig		X	(X)			Y (7.151)	Same [illegible] Secondary [illegible]
[illegible]	[illegible]	[illegible] Freon pump package [illegible]	0-8[illegible]		X	(X)			Y	[illegible]

TABLE 7-1 (Continued)

Item No.	No. Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
7.151	1	Same as 7.150 except for secondary pump	0-80 psid		X	(X)			Y	Same as 7.150 except for secondary system. Fail-safe loop. As for primary circuit, Freon temperatures will provide indirect backup.
7.152	1	NH_3 tank pressure primary tank	0-1000 psig		X	(X)			Y	Primary application is for R/M and used for c/o. NH_3 manifold pressure serves as backup. R/M action is to switch to redundant tankage assembly.
7.153	1	Same as 7.152 except secondary system	0-1000 psig		X	(X)			Y	Same as 7.152 except for secondary system. R/M action is same.
7.154	1	NH_3 manifold pressure	0-200 psig		X	(X)			Y	Primary application is for R/M of NH_3 regulators and also used for checkout. Indirect backup through Freon temperature R/M action is to use redundant storage system.
7.250	1	Radiator inlet temp (primary loop)	0-250°F		X				Y 7.251	Can provide backup signal for pump system health. Indicates health of secondary NH_3 boiler. 7.251 is backup for this instrument.
7.251	1	Interchanger inlet temp (primary)	0-250°F		X				Y 7.250	Indicates health of all upstream sinks. 7.250 is backup for this instrument.
7.252	1	Interchanger inlet temp (secondary loop)	0-250°F		X				Y 7.253	Indicates health of all upstream sinks. 7.253 is backup for this instrument.
7.253	1	Radiator inlet temp (secondary loop)	0-250°F		X				Y 7.252	Can provide backup for pump operation. Indicates health of secondary NH_3 boiler. 7.252 is backup for this instrument.
7.256	1	GSE HX outlet temp (secondary loop)	0-250°F		(X)	X	See remarks			Primarily, for ground c/o only compare with LRU-74. Additionally GSE bypass loop can be used as an emergency for radiator failure.

TABLE 7-1 (Continued)

Item No.	No Req'd	Instrument Description	Parameter Range	Function: Control	Function: Redund. Mgmt	Function: Check Out	Information Redundancy: None	Information Redundancy: Redundant Instrum	Information Redundancy: Back Up	Remarks
7.257	1	Same as 7.256 except for primary loop	0-250°F		(X)	X	See Remarks			Functionally identical to 7.256 except for primary loop.
7.258	1	Primary NH_3 boiler outlet temperature (primary loop)	0-200°F		X				Y	Primary application is health parameter for F/M of NH_3 boilers. 7.250 and 7.251 are backup parameters for this temperature. 7.250 is FO and 7.251 is FS and if two out of three are confirmed, switch to redundant NH_3 boiler.
7.259	1	Primary NH_3 boiler outlet temperature (secondary loop)	0-200°F		X				X	Same as 7.258 except for secondary loop. 7.253 and 7.252 are backup parameters for this temperature. 7.253 is FO and 7.252 is FS. Redundancy management action is to try to use primary system.
7.450	2 total (1 per valve)	Freon bypass valve position switch (primary and secondary	Position			X	Y			This is primarily a ground checkout parameter only; allows determination that valve has actually cycled.
7.500	1	Primary accumulator quantity	0-110% full		X				Y	Primarily R/M parameter and used for c/o. Primary pump inlet pressure is a backup for this parameter. R/M action is to initiate operation of redundant pump (primary loop) and if instrumentation still reads incorrectly, instrument has failed so that original pump is still available.
7.501	1	Same as 7.500 except secondary accumulator	0-110% full		X				Y (7.101)	Primarily R/M parameter and used for c/o Secondary pump inlet pressure is a backup parameter.

In some cases, instrumentation failure will require some action by the crew to determine if the instrument or the component/assembly monitored is defective. In all cases, however, diagnosis is fairly direct and simple. The symbol Y indicates the level of information redundancy for each specific instrument function.

Each ETC/LSS subsystem presents some peculiar or unique requirements in terms of instrumentation. The unique requirements or characteristics basic to the development of the minimum instrumentation list are summarized below.

7.3.1 Atmosphere Control Subsystem

Because of the numerous functions of the atmosphere control subsystem and the large amount of redundancy incorporated, many transducers are necessary for subsystem redundancy management and ground checkout. Due to the nature of the subsystem, most of the transducers are used for pressure monitoring.

Only two instruments in the ACS have been identified where redundancy is required: two sensors are recommended for cabin total pressure and two for O_2 and N_2 manifold pressure. These will provide easier fault detection by the crew than would otherwise be possible by information derived from other sensors providing indirect and complex fault detection capabilities.

7.3.2 Atmosphere Revitalization Subsystem

The minimum instrumentation list shows that the instruments required for redundancy management also will fulfill the ground checkout requirements; no additional sensors are required specifically for ground checkout. The water coolant accumulator quantity will be monitored by use of ΔP switches that correspond in a limited extent to redundant pump inlet pressure transducers. For ease of maintenance, all temperature transducers will be surface type units.

The only instruments added to the subsystem as a result of redundancy analyses are ΔP transducers to monitor fan performance. The rationale for the addition of these redundant transducers is as follows. If a fan ΔP transducer fails, the information could be interpreted as either fan or transducer failure. Switching over to the redundant fan will identify whether the transducer or the fan has failed. Assuming that the transducer is the faulty component, then no means of detecting fan failure remains. Such a situation is highly undesirable. Monitoring of avionics cooling air temperature as a backup means will not provide flow information; upon flow interruption, the air temperature sensor will remain at the same temperature. Temperature variations at the sensor will only be by radiation and conduction; thus, this parameter is inadequate. Similarly, monitoring cooling water temperature is undesirable because two (inlet and outlet) temperatures are necessary in each loop.

Differential pressure transducers are used to monitor coolant pumps in both loops. The coolant pump inlet pressure sensor will provide an indirect indication of pump operation for backup. This information, together with water temperature at the interchanger outlet, can be used to monitor loop overall performance.

The temperature transducers at the outlet of the loop heat sink (interchanger and two evaporators) are used for redundancy management. Furthermore, they constitute backup sensors. In normal operation, the upstream evaporator should be the primary unit, with the redundant evaporator downstream.

7.3.3 Water Management Subsystem

Five instruments are identified in Table 7-1 for redundancy management; these instruments also are required for ground checkout. In addition, five test ports are provided for use during ground checkout operations. Sufficient instrumentation backup is available from the N_2 pressurant subsystem pressure transducers to provide the necessary FO-FS information for control and safe operation of the subsystem.

7.3.4 Freon-21 Heat Rejection Subsystem

A review of Table 7-1 shows a total of 21 parameters are used in the Freon-21 subsystem. Two are used for control, four solely for ground checkout, and the remainder for redundancy management in flight; a number of these also are used for ground checkout.

7.4 SUMMARY

The minimum instrumentation listed in Table 7-1 is summarized below by type and application.

7.4.1 Transducer Type Summary

Table 7-2 presents a quantitative summary of the various types of transducers used in the ETC/LSS. Ninety-five transducers are used. The predominant transducers are for pressure and temperature information. In addition, five test ports are used for ground checkout. The atmosphere control subsystem uses most of the pressure measuring instrumentation, and the Freon and water cooling loops use most of the temperature measuring equipment.

Differential pressure for transducers are used to monitor fans and pumps. Quantity transducers are used for accumulators and water tank content measurement. Special transducers are principally the cabin PO_2 and PCO_2 and the WMS silver ion detector.

7.4.2 Instrumentation Application Summary

Table 7-3 presents a summary of the application of the ninety-five ETC/LSS transducers. The predominant application for ETC/LSS instrumentation is for redundancy management. Sixty-nine instruments are needed to provide FO-FS or

TABLE 7-2

ETC/LSS INSTRUMENTATION TRANSDUCER SUMMARY

Subsystem	Transducer Type							
	Pressures	Differential Pressure	Temperature	Quantity	Flow	Special	Test Ports	Position
Atmosphere control	29	3	2	-	2	3	-	-
Atmosphere revitalization	2	11	13	2	-	1	-	1
Water management	1	-	1	2	-	1	5	0
Freon cooling loop	5	2	10	2	-	-	-	2
Totals	37	16	26	6	2	5	5	3

equivalent FO-FS indication for redundancy management. Sixty-three instruments are needed for ground checkout; however, 47 of these are included primarily for redundancy management or control, and as such only 16 are needed for checkout only.

TABLE 7-3

ETC/LSS INSTRUMENTATION
APPLICATION SUMMARY

		Application	
Subsystem	Control	Redundancy Management	Checkout
Atmosphere control	3	25	11 + (23)
Atmosphere revitalization	6	23	1 + (13)
Water management	-	5	(2)
Freon-21 cooling loop	2	15	4 + (9)
Total	11	69	16 + (47)

( ) indicates alternate use of either a control or a redundancy management transducer for checkout

Complete subsystem control is achieved with 10 instruments. All are used to provide information or feedback information to electronic control units for automatic control functions within the ETC/LSS.

In summary, the tasks of redundancy management and maintainability (checkout) poses the highest requirements for subsystem instrumentation.

Since a man-in-the-loop philosophy was utilized, the instrumentation selection represents the minimum to perform the functions of control, redundancy management, and checkout. A more automated approach would require more instrumentation.

7.5 SENSOR SELECTION

A common power supply and signal conditioning is recommended for all ETC/LSS sensors with the exception of special instruments such as the flow sensors and the PCO_2 transducers. This approach offers many advantages, including;

(a) Lower average power per transducer (40 mw vs 400 mw)

(b) Lower weight

(c) Simpler sensors

(d) System compatibility with vehicle common power supply

(e) Ease of providing power supply redundancy

The sensors were selected after detailed examination of the problems encountered in Apollo. The major factors considered in the selection were reliability, maintainability, weight, and cost.

Surface-type temperature sensors are recommended for all ETC/LSS monitoring functions primarily because of the significant advantages offered in terms of replacement. This type of sensor can be removed without affecting the integrity of the liquid loops. In a few cases where the sensors are used for control, thermistors are selected on the basis of availability and development status: interfacing problems with existing controllers have been resolved. These thermistors are well-type units to preserve the integrity of the liquid loops.

All pressure sensors in the range of 0 to 2 psi and above are strain-gage type units. These transducers were selected because of the following features.

(a) Capable of high overpressure

(b) High accuracy

(c) Low-temperature sensitivity

(d) Low sensitivity to shock and vibration

(e) Continuous resolution.

For lower pressure ranges (0 to 10 in. H_2O), a linear variable differential transformer (LVDT) type unit is recommended.

The flow sensor recommended is an improved version of the type used in Apollo. This unit has been developed for industrial applications, and a flight version is currently being designed and developed under NASA contract.

Special instrumentation such as the PO_2 and PCO_2 sensors have been qualified under previous space programs. Although this equipment is life limited, its reliability has been demonstrated, and performance is adequate for space shuttle applications.

The silver ion detector used to monitor potable water silver content is currently under development under NASA sponsorship. Feasibility has been demonstrated and a prototype is currently in the design stage.

SECTION 8

GSE REQUIREMENTS

8. GSE REQUIREMENTS

8.1 GENERAL CONSIDERATIONS

Previous discussions of ETC/LSS maintainability have identified the requirements for ground support equipment. This report section summarizes these requirements and also presents a functional description of all items of GSE recommended to support operation of the space shuttle ETC/LSS.

Most of the GSE requirements are dictated by ETC/LSS routine-maintenance operations such as ground checkout and postflight and preflight servicing.

In addition, GSE will be necessary to support corrective maintenance activities such as (1) handling and transportion fixtures for large and small LRU's and components, and (2) special tools necessary for checkout and corrective maintenance. This type of GSE was not considered as part of the present study, although hoisting requirements are identified in Section 5. The packaging studies conducted and reported in Section 4 indicate that very few special tools will be required to perform corrective maintenance.

Specific items of support equipment related to maintenance personnel safety (such as breathing apparatus, masks, and protective clothing for handling of NH_3, and to a lesser extent Freon-21) is recognized. This type of equipment is not included in this discussion. Specific equipment and procedures exist within the Government inventory of equipment and handbooks procured under previous programs.

8.2 GSE REQUIREMENTS

Table 8-1 summarizes the major items of GSE identified in Section 5. A review of Table 8-1 shows that 14 pieces of equipment are required to perform ETC/LSS maintenance described in Section 5. Those items of GSE identified by an asterisk indicate a second use for equipment already used by another sub subsystem.

TABLE 8-1

GSE REQUIREMENTS

Major ETC/LSS Subsystem	Functional Maintenance Requirement	GSE Recommended and Comments
Atmosphere control	(1) Maintenance and test N_2 loops (2) Maintenance and test O_2 loops (3) Maintenance and test of component in hard vacuum	(1) N_2 test set (2) O_2 test set (3) Vacuum test set
Atmosphere revitalization	(1) Maintenance and test cabin temperature subsystem (2) Postflight condenser servicing flushing and drying (3) Water coolant servicing and test (4) Flash evaporator control, valves maintenance and checkout	(4) Cabin temperature controller test set (-) Use water decontamination cart (9); and N_2 test set (1) for drying (5) Coolant service and checkout cart (6) Controller test set for F-21 bypass valves (7) Evaporator leakage test closure; use N_2 test set (1)
Water management (potable water)	(1) Maintenance and test (2) Potable water servicing (3) Subsystem decontamination (4) Subsystem drying and purge for storage	(-) Use N_2 test set (1); GN_2 used for ground checkout and ground maintenance (8) Potable H_2O service cart (9) Decontamination and flushing cart (-) Use N_2 test set (1)
Freon cooling loop	(1) F-21 service, maintenance, and test (2) F-21 bypass valve maintenance and test (3) NH_3 servicing (4) NH_3 maintenance and checkout	(10) F-21 service and checkout cart, also use vacuum test set (3) (11) F-21 portable leakage detector (12) F-21 bypass controller test set (13) NH_3 service cart (14) NH_3 recovery and vapor disposal unit (-) N_2 test set (1) for c/o, maintenance, leakage, purge, and drying (-) Water decontamination cart (9) for flush

8.3 FUNCTIONAL DESCRIPTION

A functional description of each item of generic GSE recommended is presented in Table 8-2. The following information is summarized in the table.

(a) Generic GSE description

(b) Purpose of the GSE

(c) Qualitative summary of functional and performance required

TABLE 8-2

GSE FUNCTIONAL SUMMARY

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]