REPORT ON THE DEVELOPMENT OF THE MANNED ORBITAL RESEARCH LABORATORY (MORL) SYSTEM UTILIZATION POTENTIAL

Task Area IV
MORL System Improvement Study

BOOK 2

SM-48816

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The Manned Orbital Research Laboratory (MORL) is a versatile facility for experimental research which provides for:

- Simultaneous development of space flight technology and man's capability to function effectively under the combined stresses of the space environment for long periods of time.

- Intelligent selectivity in the mode of acquisition, collation, and transmission of data for subsequent detailed scientific analyses.

- Continual celestial and terrestrial observations.

Future application potential includes use of the MORL as a basic, independent module, which, in combination with the Saturn Launch Vehicles currently planned for the NASA inventory, is responsive to a broad range of advanced mission requirements.

The laboratory module includes two independently pressurized compartments connected by an airlock. The larger compartment comprises the following functional spaces:

- A Control Deck from which laboratory operations and a major portion of the experiment program will be conducted.
- An Internal Centrifuge in which members of the flight crew will perform re-entry simulation, undergo physical condition testing, and which may be useful for therapy, if required.
- The Flight Crew Quarters, which include sleeping, eating, recreation, hygiene, and liquids laboratory facilities.

The smaller compartment is a Hangar/Test Area which is used for logistics spacecraft maintenance, cargo transfer, experimentation, satellite checkout, and flight crew habitation in a deferred-emergency mode of operation.

The logistics vehicle is composed of the following elements:

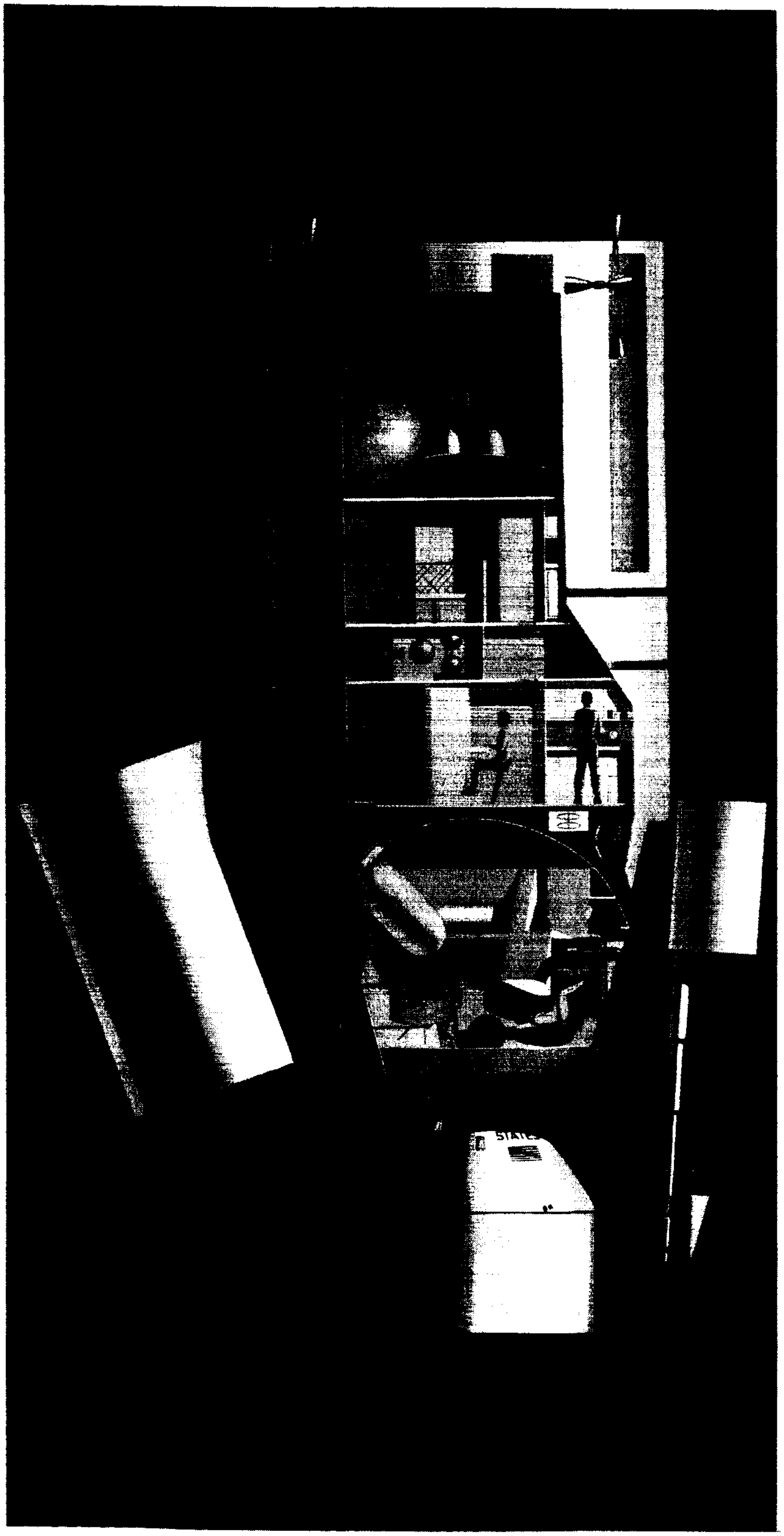
- A Logistics Spacecraft which generally corresponds to the geometric envelope of the Apollo Command and Service Modules and which includes an Apollo Spacecraft with launch escape system and a service pack for rendezvous and re-entry maneuver propulsion; and a Multi-Mission Module for either cargo, experiments, laboratory facility modifications, or a spacecraft excursion propulsion system.
- A Saturn IB Launch Vehicle.

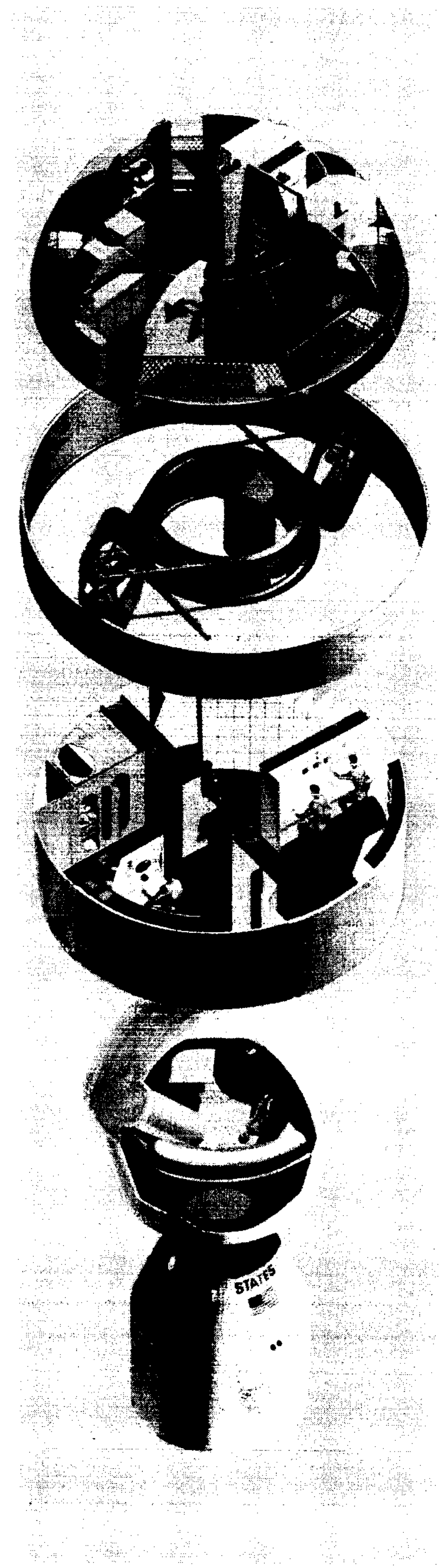
Integration of this Logistics System with MORL ensures the flexibility and growth potential required for continued utility of the laboratory during a dynamic experiment program.

In addition to the requirements imposed by the experiment program, system design parameters must reflect operational requirements for each phase of the mission to ensure:

- Functional adequacy of the laboratory.
- Maximum utilization of available facilities.
- Identification of important parameters for consideration in future planning of operations support.

For this reason, a concept of operations was developed simultaneously with development of the MORL system.

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PREFACE

This report is submitted by the Douglas Aircraft Company, Inc., to the National Aeronautics and Space Administration's Langley Research Center. It has been prepared under Contract No. NAS1-3612 and describes the analytical and experimental results of a preliminary assessment of the MORL's utilization potential.

Documentation of study results are contained in two types of reports: A final report consisting of a Technical Summary and a 20-page Summary Report, and five Task Area reports, each relating to one of the five major task assignments. The final report will be completed at the end of the study, while the Task Area reports are generated incrementally after each major task assignment is completed.

The five Task Area reports consist of the following: Task Area I, Analysis of Space Related Objectives; Task Area II, Integrated Mission Development Plan; Task Area III, MORL Concept Responsiveness Analysis; Task Area IV, MORL System Improvement Study; and Task Area V, Program Planning and Economic Analysis.

This document contains 1 of the 5 parts of the Task Area IV report, MORL System Improvement Study. The study evaluates potential improvements to the MORL, necessitated by the limitations identified in Task Area III, and evaluates those improvements stemming from investigations aimed at increasing the effectiveness of the MORL through the addition of new system elements.

The contents and identification of the five parts of this report are as follows: Book 1, Douglas Report SM-48815, presents the summary of the Task Area effort and the results of the configuration, structure, electrical power, logistics system and performance analyses; Book 2, Douglas Report SM-48816, presents the results of the analyses performed on the Environmental Control/Life Support subsystem; Book 3, Douglas Report SM-48817, presents the results of the analyses performed on the Stabilization and Control subsystem; Book 4, Douglas Report SM-48818, presents the results of the analyses performed on the Communications and Telemetry subsystem; Book 5, Douglas Report SM-48819, presents the results of the analyses performed on the Propulsion subsystem.

Requests for further information concerning this report will be welcomed by R.J. Gunkel, Director, Advance Manned Spacecraft Systems, Advance Systems and Technology, Missile & Space Systems Division, Douglas Aircraft Company, Inc.

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Section 1
INTRODUCTION AND SUMMARY

This document contains a description of the Environmental Control/Life Support (EC/LS) system studies performed in connection with the MORL Phase IIb study, Task Area IV, titled MORL System Improvement Study. The objectives of this portion of Task Area IV were as follows:

1. Modify the EC/LS system to correct any limitations or marginal capabilities identified as a result of the study of the expanded Experimental Plan and the Mission Development Plan.
2. Identify new system elements stemming from advances in technology which will improve the EC/LS system and emphasize maximum system flexibility and growth capability.
3. Detail the research and technological development required.
4. Identify potential MORL support by the Apollo Applications Program through system development testing.

1.1 DESCRIPTION OF THE PHASE IIa SYSTEM

The principal functional objectives of the EC/LS system for MORL are as follows:

1. Maintain a habitable and safe laboratory environment so that crew members may perform active work programs.
2. Maintain suitable environmental conditions for the operational and experimental equipment contained within the laboratory.
3. Conserve on-board supplies and minimize the use of expendable items.

The EC/LS system consists of the following operational subsystems:

1. Atmosphere supply.
2. Atmospheric purification.
3. Water management.
4. Waste management.
5. Compartment conditioning.

6. Cooling system.
7. Heating system.
8. Heat transport system.
9. Pumpdown system.

The Phase IIa laboratory atmosphere consisted of 50% oxygen and 50% nitrogen at a total pressure of 7 psia. The atmosphere supply subsystem stored consumable oxygen and nitrogen as subcritical fluids and provided gases for one complete repressurization of the laboratory. On-board subcritical tanks were resupplied liquid oxygen and nitrogen by a transfer system from similar tanks in the multimission logistics spacecraft.

The Phase IIa atmospheric purification subsystem consisted of identical purification circuits located in the cabin and in the hangar. Each circuit removed particulates, controlled laboratory humidity, killed bacteria, removed odors, oxidized and filtered trace contaminants, and removed carbon dioxide. A closed loop operating mode for emergency intravehicular space suit operation was also provided. Trace contaminant detection was accomplished by a mass spectrometer-gas cromatograph. A separate purification circuit was installed for the Biological/Liquids laboratory that controlled odor, bacteria, contaminants, and temperature.

The water management subsystem required no water resupply. Perspiration, respiration, urine, and wash water were recovered and purified. The atmospheric purification circuit collected perspiration and respiration water. Two open loop air evaporation systems which are integrated with the atmospheric purification circuit accomplished urine and wash water reclamation. The system operating efficiency assured a positive water balance, and provided water used for the experiments and the portable life support system (PLSS).

The waste management subsystem consisted of two sets of processing units which dehydrated all laboratory waste. Fecal waste was collected in a separate system, and was manually transferred, along with all other types of wet waste, to the dehydrators. After processing, the wastes were manually transferred to empty food containers for storage until disposal through the empty cargo module.

A separate ventilation circuit was provided for temperature control and ventilation in the main laboratory. The purification circuits in the hangar and the Biological/Liquids laboratory were used to accomplish the above functions in their respective locations.

The heating circuit generated the heat required for certain EC/LS functions within MORL by means of a small radioisotope heat exchanger. A circulating fluid absorbed heat from a radioisotope heat exchanger and transferred it to a heat transport loop within the laboratory.

The cooling circuit utilized a circulating fluid to receive waste heat from the heat transport circuit within the laboratory and to reject this heat to space through a radiator, that is integrated with the vehicle structure.

The transport circuit consisted of a water circulation system which received heat from the heating circuit and carried it to the components inside the laboratory that required heat. It also absorbed heat from the components inside the laboratory that required cooling and transferred this heat to the cooling circuit.

A pumpdown system was provided to recover the air from equipment locks, man locks, and the hangar, during planned decompressions. For the air-locks, the atmosphere was pumped back into the cabin or hangar. The hangar atmosphere was pumped into a separate tank and stored until recompression.

A more detailed description of the EC/LS system, as it was defined in the MORL Phase IIa study, is contained in Reference 1.

1.2 SUMMARY OF SYSTEM CHANGES

Most of the changes made to the EC/LS system were a result of the Task III Responsiveness Analysis, which indicated the desirability of operating MORL with a nine-man crew for extensive periods, and a concurrent change to an isotope power source which allowed significant improvements to the EC/LS system at modest costs.

Whereas the Phase IIa system was designed for a single operating mode, the Phase IIb system is designed to operate in three modes to provide greater operating flexibility. The modes are the following:

1. Basic Mode--As in the Phase IIa system, this mode accommodates a crew of six men, has a completely "closed" water cycle, and an "open" oxygen cycle. However, the Phase IIb system provides oxygen by the electrolysis of water which is resupplied as required, rather than by the resupply of cryogenic oxygen.
2. Nine-Man Crew Mode--The Phase IIb system can accommodate a crew of nine men for indefinite periods of time with no compromise to crew safety and only a modest operating inconvenience. Some subsystems must be operated a greater number of hours per day, and expendable items must be replenished at more frequent intervals. The Phase IIa system could accommodate a nine-man crew for relatively shorter periods of time and more frequent resupply would be required.
3. Oxygen Regeneration Operating Mode--The Phase IIb system can be operated in a "closed" oxygen cycle mode after MORL is retrofitted with a hydrogenation reactor. The Phase IIa system could not operate in an O_2 regeneration mode.

The operational subsystems remain the same as in the Phase IIa system with the exceptions that the heating subsystem is eliminated and the carbon dioxide reduction subsystem is added.

1.2.1 Atmosphere Supply

The atmosphere supply subsystem provides a 147-day supply of oxygen for six men. This oxygen is stored in the forms of water and gaseous oxygen. The gaseous oxygen is sufficient for one complete repressurization of the main laboratory, and will last 8.2 days as a consumable when used to back up the main supply. Nitrogen for one complete repressurization of the main laboratory, plus 90 days of consumable use, is stored gaseously in five tanks. Oxygen is provided by electrolyzing the water in five electrolysis modules to produce breathing oxygen. The hydrogen produced is normally vented overboard.

The electrolysis modules are designed so that they can be shut down during time periods when the electrical power used to operate them is needed for the experimental program. The capacity of the electrolysis modules is such that, for a crew of six, three modules satisfy the demand. For a nine-man crew, all five modules are required to operate. When a nine-man crew is on board the MORL, the water required to satisfy the oxygen needs for the extra three men is stored in the cargo module until the on-board tanks have been depleted enough to receive it. When operated in the oxygen regeneration mode, the hydrogen normally vented overboard is directed to an accumulator in the carbon dioxide reduction subsystem. If the oxygen regeneration mode is selected while a nine-man crew is on board, the system will operate in a "closed" oxygen mode for six men and an "open" oxygen mode for three men.

The water used to provide consumable oxygen is resupplied from the logistics cargo module. The water is automatically transferred from tanks in the cargo module to the on-board tanks by a positive explusion gas pressurization system. A manual transfer system is provided as a backup.

The electrolysis of water to provide consumable oxygen is advantageous for MORL because:

1. It is simpler, more reliable, and cheaper than cryogenic storage and transfer systems.
2. The excess metabolic water is electrolyzed to reduce water resupply requirements by 20%.
3. It allows the use of more palatable wet foods for the crew.
4. It establishes a technology (electrolysis portion of an oxygen regeneration system) that will be required for future deep space missions.
5. It is readily adaptable to a nine-man crew operation.

1.2.2 Atmosphere Purification

The Phase IIa subsystem provided two six-man atmospheric purification circuits, one for the main laboratory and one for the hangar. This subsystem can readily accommodate a crew of nine because most of the time three men will be occupying the hangar. Even if the main laboratory is occupied by more than six men simultaneously, the effect on the atmospheric purification circuit is negligible.

To accommodate the requirement to operate in an oxygen regeneration mode, the carbon dioxide removal system was designed to collect carbon dioxide. This required the following provisions:

1. Heating coils in the molecular sieves to desorb the beds to a carbon dioxide accumulator rather than to space.
2. A vacuum pump to transfer the carbon dioxide to an accumulator.
3. Full flow silica gel bed desorbtion rather than bleed flow desorbtion to minimize waste heat requirements.
4. Increased minimum molecular sieve bed cycle time to improve CO_2 purity and reduce waste heat requirements.
5. Control of molecular sieve bed cycle time by the partial pressure of carbon dioxide during periods of low bed loading (crew split between hangar and laboratory) to improve the CO_2 purity.

These changes are designed and installed in the launch system even though the oxygen regeneration operating mode will not be utilized in the early phases of the mission. This approach minimizes retrofit problems when activation of the oxygen regeneration subsystem is desired.

1.2.3 Water Management

The Phase IIa water management subsystem is normally operated 18 hours to process a 1-day supply of water for a crew of six. The capacity of the Phase IIb system was increased to handle the same volume in 16 hours. This allows the accommodation of a nine-man crew if the system is operated 24 hours per day. The tanks were resized to hold one day's water production for nine men rather than six men. The excess metabolic water recovered is directed to the water supply tanks where it is either electrolyzed, to reduce the amount of water resupplied in the basic operating mode, or used to help close the oxygen cycle in the oxygen regeneration operating mode.

1.2.4 Waste Management

A combined waste collection, processing, and storage concept is used instead of the Phase IIa system that required separate hardware for each function. The new system was chosen as it eliminates manual handling of wastes and saves approximately 15 man-minutes of crew time per day. The combined system utilizes an expendable collection sphere into which the wastes are deposited. Every 30 days a new sphere replaces the filled sphere which is then stored until disposed of with the empty cargo module. A fan and filter system ensures proper collection of the wastes and the return of uncontaminated air to the laboratory during waste collection. During on-line storage, the sphere is vented to vacuum so that the wastes freeze. The water eventually sublimes leaving a dormant residue. A vacuum pump is provided to recover most of the atmosphere in the sphere prior to evacuation. During nine-man crew occupancy it is necessary to provide additional spheres, and to replace the sphere every 20 days rather than every 30 days.

1.2.5 Compartment Conditioning

The main laboratory cooling and ventilation circuit was increased in capacity because the larger power system increased the air heat load.

A separate ventilation circuit was designed for the hangar which is similar to the one used in the main laboratory. In Phase IIa, the hangar atmospheric purification subsystem was used as a combined purification/ventilation circuit. However, Task III analysis showed that the hangar would probably be occupied continuously and that the air heat load would be beyond the capability of the atmospheric purification circuit.

1.2.6 Cooling Circuit

Redesign of the cooling circuit was required because of the change to an 11 kWe Isotope Brayton Cycle power system and to accommodate the requirement for an oxygen regeneration operating mode. The isotope power system parasitic-load control, which absorbs the electrical output of the power system that is not demanded by the laboratory, is installed in the EC/LS system cooling circuit. This is advantageous to the power system because the power system radiator does not have to designed to dissipate this heat, and to the EC/LS system because it ensures a constant load on the EC/LS radiator. A constant EC/LS radiator load eliminates fluid freezing problems and the need for a regenerative heat exchanger in the cooling circuit.

The EC/LS radiator is increased in size to reject the added heat generated by the additional electrical energy dissipated within MORL, and to reject the increased waste heat required for the oxygen regeneration operating mode. The circumferential EC/LS radiator occupies the conical section of MORL plus a 13.2 ft cylindrical section. The power system radiator occupies the rest of the available cylindrical surface.

1.2.7 Heat Transport Circuit

The isotope heating circuit required in Phase IIa is eliminated because waste heat from the isotope power system supplies this need. The heat transport circuit has two water loops; one for heating and one for cooling. The heating loop transfers 4 kW of waste heat at 300 psi and $360^{\circ}F$, to the laboratory where it is utilized by those EC/LS components that require heat. The cooling circuit collects the laboratory waste heat at a maximum of $120^{\circ}F$ and transfers it to the cooling circuit that rejects the heat to space.

1.2.8 Atmospheric Pumpdown

Atmospheric pumpdown subsystem requirements are the same as in Phase IIa except that the size of the storage tank was increased to accommodate the enlarged hangar volume resulting from the structural change to a flat forward bulkhead.

1.2.9 Carbon Dioxide Reduction Subsystem

The carbon dioxide reduction subsystem chosen for the oxygen regeneration operating mode is the Bosch hydrogenation process. The Bosch process converts carbon dioxide gas into water. This water is transferred to the atmosphere supply subsystem where it is converted into gaseous oxygen. A hydrogen accumulator is also provided as the hydrogenation unit must be able to operate when the electrolysis modules are shut down. The entire carbon dioxide reduction subsystem is not launched with MORL but is supplied when it is deemed desirable to switch to the oxygen regeneration mode. Retrofit problems are minimized as all other EC/LS system requirements other than the reduction subsystem, are installed with the launch vehicle. These provisions are made for the following reasons:

1. Regeneration is not required for the first year of orbital operations as excess cargo capacity exists. This excess capacity is made possible by known crew rotation requirements.
2. In subsequent MORL operations, crew rotation schedules may be lengthened to the point where it is desirable to reduce resupply weight.

3. If it develops that the reduction to resupply will not be required; then oxygen regeneration operation can be utilized on MORL as a full-scale experiment to establish this technology, which is essential for deep-space missions.

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Section 2
ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEM IMPROVEMENT ANALYSIS

2.1 INTRODUCTION

Changes to the Phase IIa EC/LS system have resulted from the following sources:

1. Recommendations made in the Task III Responsiveness Analysis.
2. Changes imposed by conversion to a new electrical power system.
3. Recommendations made in the improvement analysis on the EC/LS system itself.

The results of the Responsiveness Analysis of Task Area III indicated that while MORL should be initially designed for a six-man crew, it would be desirable to be able to increase the crew to nine sometime after launch. The crew increase could be permanent or could be for temporary periods. An increase on a temporary basis would be for relatively long periods of time in order to allow significant portions of the experimental program to be accomplished.

A further result of Task III was the identification of the fact that the Hangar/Test area would be used as an experimental area to a much greater extent than was apparent in Phase IIa. This imposes new design requirements on the EC/LS system in the hangar.

The change to an Isotope Brayton Cycle electrical power system had a significant effect on the EC/LS system, resulting in some compatibility changes. Other changes in the EC/LS system were made because of the availability of free waste heat.

The remaining work in the improvement analysis stems from recommended changes intended to provide more flexibility and growth potential in the system and to take advantage of technological improvements that have occurred.

2.2 SYSTEM REQUIREMENTS

2.2.1 Atmospheric Requirements

The system will control atmospheric conditions as shown in Table 2-1.

Table 2-1
ATMOSPHERIC REQUIREMENTS

Parameter	Design Value
Laboratory temperature	$75 \pm 5^{\circ}F$ (adjustable range)
Laboratory humidity	50% (35° to $65^{\circ}F$ dew point)
Laboratory pressure	7.0 ± 0.2 psia
Atmospheric mixture	50% O_2, 50% N_2
CO_2 partial pressure	4 mm Hg nom 8 mm Hg max.

2.2.2 Metabolic Requirements

The system is designed for human metabolic rates as shown in Table 2-2.

2.2.3 Vehicle Requirements

The vehicle configuration consists of two independently pressurized compartments, the main laboratory and the Hangar/Test area. Normally, the atmospheres of these two compartments are isolated, and an airlock is used for transfers between them. The main laboratory is used to control flight operations, to perform experiments, and to provide crew living quarters. The hangar is used for experimentation, logistics spacecraft maintenance, crew and cargo transfer, and crew habitation in a deferred-emergency mode of operation. An airlock is provided to effect transfers from the laboratory to the aft interstage, which is an unpressurized area used for installation of functional systems. An equipment airlock is provided in the hangar to accommodate experiments which require exposure to space. The EC/LS system is designed to accommodate the following vehicle requirements:

1. Crew Size--Six nominal or nine with some minor limitations to operating capability.

2. Electrial Load--Power source output of 11 kWe.

3. Compartment Volumes--Laboratory, 6,700 cu ft; Hangar/Test area, 3,300 cu ft; and airlock, 150 cu ft. Free air volumes 80% of gross volumes.

4. Vehicle Atmospheric Leakage--1 lb/day per compartment; 2 lb/day total.

5. Vehicle Heat Leakage--No heat is transferred through the vehicle walls.

6. Consumable Storage--147-day on-board storage capability.

Table 2-2
METABOLIC REQUIREMENTS

Parameter	Design Value
Oxygen consumption	1.92 lb/man-day
Carbon dioxide production	2.32 lb/man-day
Water consumption	6.17 lb/man-day
Urine production	
Including solids	4.07 lb/man-day
Without solids	3.92 lb/man-day
Respiration and perspiration	2.78 lb/man-day
Feces output	
Including solids	0.34 lb/man-day
Without solids	0.26 lb/man-day
Metabolic water production	0.79 lb/man-day
Wash water	3.00 lb/man-day
Heat output	
Nominal	10,850 Btu/man-day
Design (shirt sleeve)	500 Btu/man-hour
Design (space suit)	1,000 Btu/man-hour

2.2.4 Functional Requirements

For purposes of definition, the hardware which accomplishes the environmental control and life support functions for MORL is referred to as the EC/LS system. Various hardware logic groups have been formed on a functional basis into subgroupings called subsystems. Table 2-3 shows the grouping of these subsystems and their functions.

2.3 SYSTEM DESIGN

The system is designed to operate in three distinctly different operational modes to satisfy the requirement for maximum system flexibility and to provide for growth capability. The operational modes are the following:

1. Basic--This is the operating mode that will probably be used for most of the mission duration. It features an open oxygen system, a closed water system, and is designed to accommodate a crew of six with maximum safety and reliability. The system requires minimum attention by the crew. Oxygen is provided by electrolysis of water which may be resupplied as required.
2. Nine-Man Crew--The system is also designed to accommodate a crew of nine for relative long periods (months) of time, with no compromise to crew safety and only a slight decrease in reliability. The chief detrimental effect will be degradation to performance capability and operational convenience. In order to minimize this degradation, some subsystems are specifically designed for nine-man crew capability.
3. Oxygen Regeneration--The basic system is also designed so that it will be possible to close the oxygen cycle and eliminate the need for oxygen resupply. While this alternative is basically designed for a crew of six men, it is also possible to operate in a partial oxygen regeneration mode with a crew of nine. Since oxygen regeneration will not be utilized until later in the mission, all equipment associated with it that can be retrofitted will be resupplied to minimize launch weight.

The schematic diagram of the recommended EC/LS system is shown in Figure 2-1. The items identified by an asterisk on the schematic and on the item list are those associated with the oxygen regeneration operating mode which are not supplied with the initial launch.

Table 2-3

FUNCTIONAL REQUIREMENTS

Subsystem	Function
Atmospheric supply	Supply of breathing oxygen and nitrogen diluent.
	Provide pressure control within the compartments.
	Monitor atmospheric leakage to space.
Atmospheric purification	Remove and control carbon dioxide.
	Control relative humidity.
	Remove and control trace contaminants.
	Control atmospheric bacteria.
	Provide for intravehicular space suit operation.
Water management	Reclaim potable water from urine, perspi ration, respiration, and wash water.
	Store both contaminated and potable water
	Test potability of reclaimed water.
Waste management	Collect, transfer, process, and store or dispose of all laboratory wastes.
Compartment conditioning	Control air temperature
	Circulate and mix atmosphere.
Cooling circuit	Transfer and reject heat from the laboratory.
Heat transport circuit	Transport laboratory waste heat to the cooling circuit.
	Transport waste heat from the power system to certain EC/LS equipment in the laboratory.
Atmospheric pumpdown	Minimize atmospheric losses caused by planned decompression of compartments.

NO. REQ'D	COMPONENT NAME	ITEM NO.	NO. REQ'D	COMPONENT NAME	ITEM NO.
6	VALVE – S.O., SOLENOID	233	1	CANISTER – CHARCOAL	421
8	COUPLING	234	2	VALVE – S.O., MANUAL	422
13	VALVE – S.O., SOLENOID	235	4	VALVE – DIVERTER, MANUAL	423
1	VALVE – CHECK	236	1	VALVE – DIVERTER, TEMP. CONTROL	424
1	TANK – PLSS O_2	237	2	HEAT EXCHANGER	430
2	TANK – O_2 GAS	301	5	VALVE – WATER DISPENSER	431
5	TANK – N_2 GAS	302	1	VALVE – DIVERTER	501
4	PRESSURE REDUCER	303	33	VALVE – S.O., MANUAL	502
2	SENSOR – TOTAL PRESSURE	304	10	VALVE – CHECK	504
2	VALVE – CABIN DUMP	305	2	TANK – URINE PROCESSING	505
4	VALVE – CABIN REFILL	306	2	EVAPORATOR	506
2	DISCONNECT – PLSS REFILL	307	10	VALVE – S.O., MANUAL	503
4	PRESSURE REGULATOR	308	5	VALVE – TEMP. CONTROL	510
2	FLOW METER	309	4	SENSOR – TEMPERATURE	511
1	LEAK DETECTOR	310	2	DISCONNECT – URINE	512
4	CANISTER – SILICA GEL	311	2	PUMP – URINAL	513
4	CANISTER – ZEOLITE	312	5	HEATER – WATER TANK	515
4	VALVE – DIVERTER	313	2	VALVE – CHECK, MANUAL OVERRIDE	516
4	PUMP – WATER	314	2	FLEXIBLE HOSE – QUICK DISCONNECT	601
2	SENSOR – RELATIVE HUMIDITY	315	1	CHILLER	602
4	VALVE – DIVERTER (DUAL)	316	4	TANK – POTABLE WATER	603
2	TIMER	317	2	TANK – ACCUMULATOR	604
4	VALVE – DIVERTER (DUAL)	318	1	HEAT EXCHANGER – AIR HEATER	605
2	VALVE – DIVERTER (SINGLE)	319	1	VALVE – TEMP. CONTROL	606
4	PUMP – VACUUM	320	1	SENSOR – TEMPERATURE	607
2	VALVE – DIVERTER (DUAL)	321	2	PUMP	608
2	VALVE – S.O. SOLENOID	323	–	SENSOR – CONDUCTIVITY	609
6	VALVE – CHECK	326	1	REFRIGERATOR	610
6	FAN – SUIT CIRCUIT	327	1	FREEZER	611
3	FILTER – CHEM – SORB	402	2	PUMP	612
3	CATALYTIC BURNER	403	2	PUMP – FC-75	613
2	SENSOR – TEMPERATURE	404	1	HEAT EXCHANGER	614
2	VALVE – FLOW CONTROL	405	1	VALVE – TEMPERATURE CONTROL	617
2	ELBOW WATER SEPARATOR	406	1	SENSOR – TEMPERATURE	618
2	FLOW METER	408	1	RESERVOIR	619
3	HEAT EXCHANGER – REGENERATIVE	409	1	SENSOR – TEMPERATURE	620
2	VALVE – CHECK	410	7	VALVE – CHECK	701
3	DEBRIS TRAP & FILTER	412	4	VALVE – DIVERTER	702
5	FAN – CONTAMINANT CONTROL CIRCUIT	413	2	RADIATOR	703*
2	FLOW METER	414	1	VALVE – DIVERTER	704
2	CANISTER – CHARCOAL	415	2	ACCUMULATOR	705
2	HEAT EXCHANGER – HUMIDITY CONTROL	416	1	VALVE – S.O. MANUAL	802*
5	SWITCH – PRESSURE	417	2	ACCUMULATOR	803*
2	VALVE – DIVERTER, MANUAL	418	1	HEAT EXCHANGER – WATER TO FC-75	804*
1	TANK – HANGAR ATMOSPHERE	419	2	PUMP – WATER	805*

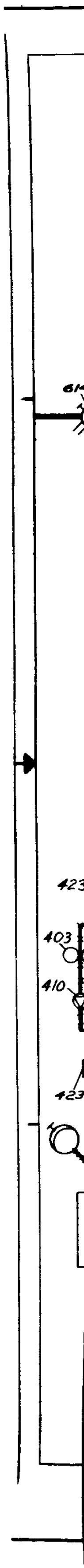
Figure 2-1. MORL Phase IIb EC/LS System

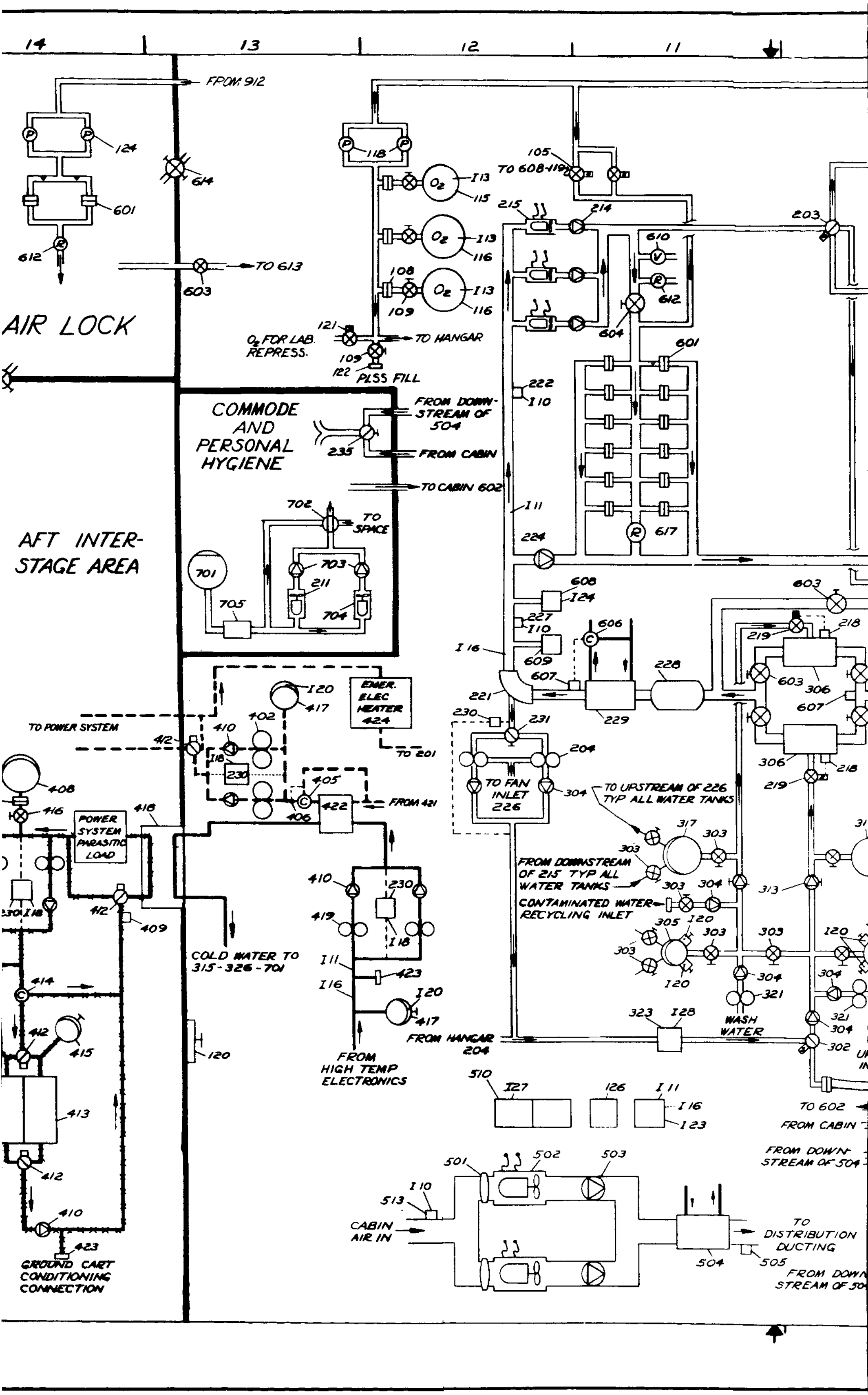
NO. REQ'D	COMPONENT NAME
1	HEAT EXCHANGER – REGENERATION
1	HEAT DUMP HEAT EXCHANGER
9	DISCONNECT – GSE
1	HEATER
2	VALVE THROTTLE
2	SENSOR, TEMP
6	DEBRIS TRAP
2	FAN – CABIN VENTILATION
1	HEAT EXCHANGER – CABIN COOLING
2	SENSOR – TEMPERATURE
1	VALVE – TEMPERATURE CONTROL
2	VALVE, CHECK
1	MASS SPECTROMETER
2	LAMP – ULTRA VIOLET
1	LAMP – ULTRA VIOLET
2	SENSOR, TEMP
1	FAN, HANGAR
1	HEAT EXCHANGER
24	CONNECTOR – SUIT
4	VALVE – DIVERTER
8	VALVE – S.O., MANUAL
6	VALVE – S.O., MANUAL
4	PRESSURE REGULATOR
3	VALVE – TEMPERATURE CONTROL
3	SENSOR - TEMPERATURE
2	SENSOR – O_2 PARTIAL PRESSURE
2	SENSOR – CO_2 PARTIAL PRESSURE
2	VALVE – VENT (SIGNAL FROM #609)
4	O_2 FACE MASK
4	VALVE – RELIEF, ABSOLUTE
1	PUMP – VACUUM
4	VALVE – AIR LOCK DUMP
2	VALVE – SUIT BYPASS
2	HEAT EXCHANGER – AIR COOLER
3	VALVE – S.O., SOLENOID
1	VALVE – CHECK
2	COLLECTOR
2	VALVE, VACUUM
6	VALVE, CHECK
2	FAN
2	FILTER, DEBRIS & CHARCOAL
1	CONDENSER, WATER
1	CONTROL, FLOW
1	REACTOR
1	HEAT EXCH., REGENERATIVE

ITEM NO.	NO. REQ'D	COMPONENT NAME
807*	1	SEPARATOR, WATER
808*	1	BLOWER
809*	1	CARBON COLLECTOR
810	1	VALVE DIVERTER
811*	1	ACCUMULATOR, WATER
812	1	PUMP
814	5	VALVE, PRESSURE CONTROL
815	1	VALVE, TEMP. CONTROL
819*	1	ACCUMULATOR, CO_2
820*	1	ACCUMULATOR, H_2
901	5	CELL, ELECTROLYSIS
902	1	FILTER, OXYGEN
903*	1	FILTER H_2
904	5	REGULATOR, PRESSURE
905	5	VALVE, TEMP CONTROL
906	1	ACCUMULATOR, WATER
907	1	FILTER, WATER
908	5	VALVE, CHECK
909	10	VALVE RELIEF
910	1	CONTROL
911	5	TANK, WATER
912	1	TANK, O_2 ACCUMULATOR
913	1	CONNECTOR
914	3	CONNECTOR
915	2	VALUE, PRESSURE CONTROL
916	10	VALVE, CHECK
I10**	6	FLOW METER
I11	16	SENSOR – PRESSURE
I12	4	SENSOR – PRESSURE
I13	5	SENSOR – PRESSURE
I15	2	FLOW METER – INTEGRATING, N_2
I16	24	SENSOR – TEMPERATURE
I17	3	SENSOR – TEMPERATURE
I18	5	SENSOR – DIFFERENTIAL PRESSURE
I20	11	SENSOR – TANK QUANTITY
I21	1	SENSOR – TANK QUANTITY
I22	1	SENSOR – TANK QUANTITY
I23	4	SENSOR – HUMIDITY
I24	2	SENSOR O_2 PARTIAL PRESSURE
I25	1	SENSOR – CO, NH_3, H_2, H_2O, CH_4, N_2
I26	2	SENSOR – CO_2 PARTIAL PRESSURE
I27	1	SENSOR – TRACE CONTAMINANTS
I28	1	SENSOR – CONDUCTIVITY

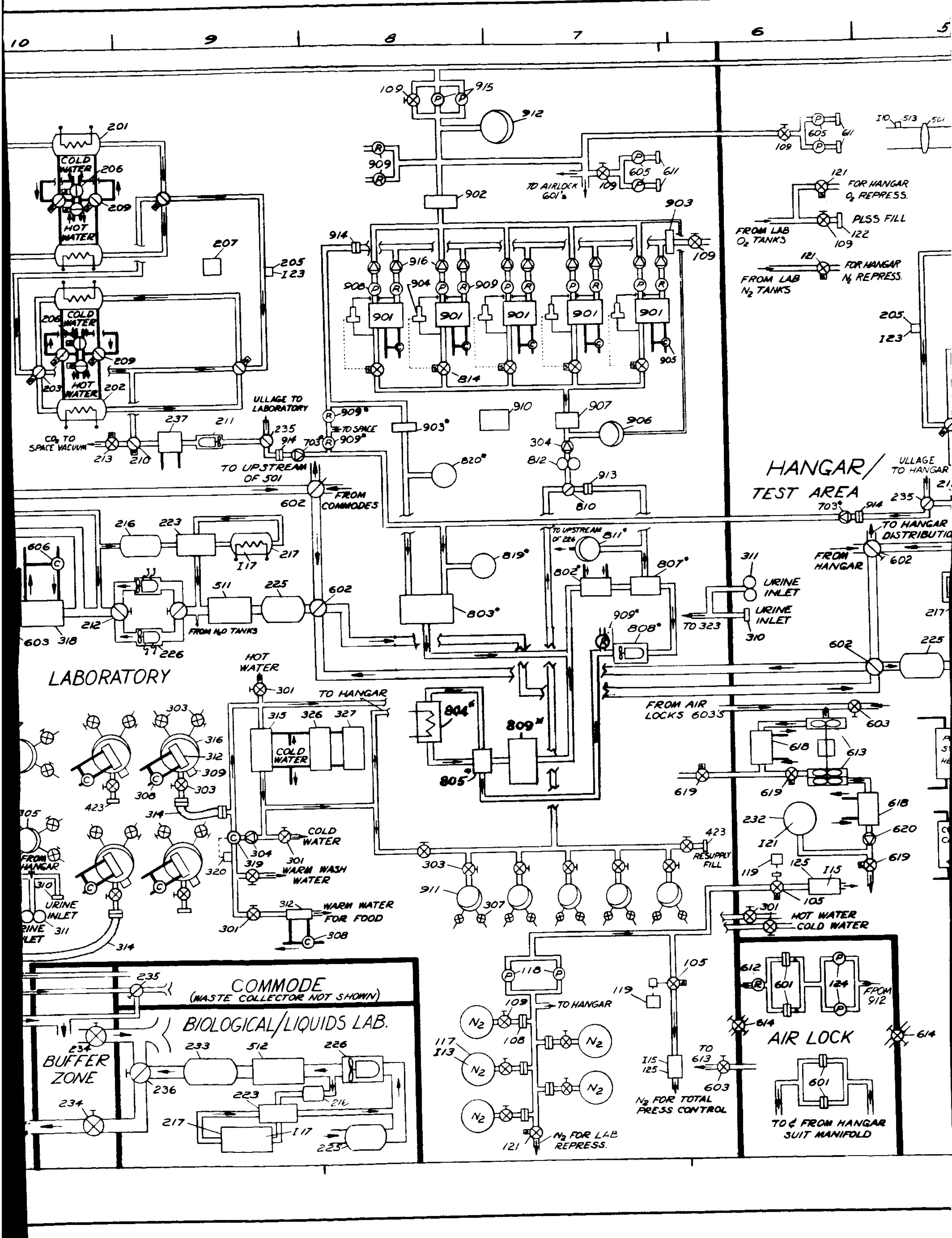
*INDICATES ITEMS REQUIRED FOR O_2 REGENERATION WHICH ARE RESUPPLIED WHEN REQUIRED.

**THE "I" INDICATES AN INSTRUMENT COMPONENT. ONLY THE INSTRUMENTATION PICKUP POINT IS SHOWN ON THE SCHEMATIC UNLESS THE INSTRUMENT HAS A CONTROL FUNCTION.

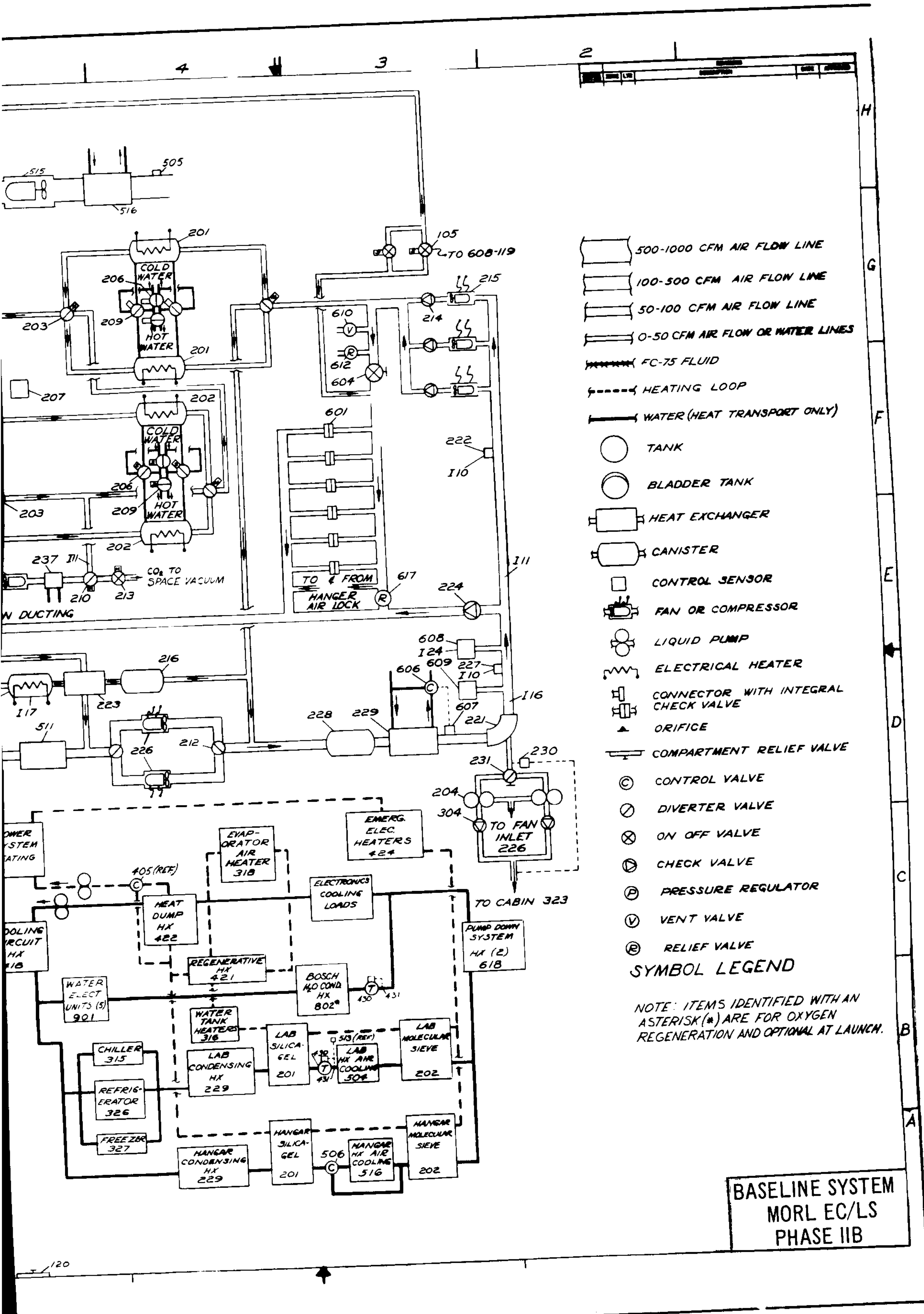




14
13
12
11
FROM 912
AIR LOCK
TO 613
O2 FOR LAB. REPRESS.
TO HANGAR
PLSS FILL
TO 608-119
COMMODE AND PERSONAL HYGIENE
FROM DOWN-STREAM OF 504
FROM CABIN
TO CABIN 602
TO SPACE
AFT INTER-STAGE AREA
TO POWER SYSTEM
EMER. ELEC HEATER 424
TO 201
FROM 421
POWER SYSTEM PARASITIC LOAD
COLD WATER TO 315-326-701
FROM HIGH TEMP ELECTRONICS
FROM HANGAR 204
TO FAN INLET 226
TO UPSTREAM OF 226 TYP ALL WATER TANKS
FROM DOWNSTREAM OF 215 TYP ALL WATER TANKS
CONTAMINATED WATER RECYCLING INLET
WASH WATER
TO 602
FROM CABIN
FROM DOWN-STREAM OF 504
CABIN AIR IN
TO DISTRIBUTION DUCTING
FROM DOWN-STREAM OF 504
GROUND CART CONDITIONING CONNECTION



10
9
8
7
6
5
LABORATORY
HANGAR/ TEST AREA
COLD WATER
HOT WATER
CO2 TO SPACE VACUUM
ULLAGE TO LABORATORY
TO UPSTREAM OF 501
TO SPACE
FROM COMMODES
TO AIRLOCK 601's
FROM LAB O2 TANKS
FOR HANGAR O2 REPRESS.
PLSS FILL
FROM LAB N2 TANKS
FOR HANGAR N2 REPRESS.
ULLAGE TO HANGAR
TO HANGAR DISTRIBUTION
FROM HANGAR
FROM H2O TANKS
TO UPSTREAM OF 226
URINE INLET
TO 323
FROM AIR LOCKS 603'S
HOT WATER
TO HANGAR
WARM WASH WATER
WARM WATER FOR FOOD
FROM HANGAR
RESUPPLY FILL
HOT WATER
COLD WATER
COMMODE
(WASTE COLLECTOR NOT SHOWN)
BIOLOGICAL/LIQUIDS LAB.
BUFFER ZONE
N2 FOR LAB REPRESS.
N2 FOR TOTAL PRESS CONTROL
TO 613
AIR LOCK
FROM 912
TO & FROM HANGAR SUIT MANIFOLD


500-1000 CFM AIR FLOW LINE
100-500 CFM AIR FLOW LINE
50-100 CFM AIR FLOW LINE
0-50 CFM AIR FLOW OR WATER LINES
FC-75 FLUID
HEATING LOOP
WATER (HEAT TRANSPORT ONLY)
TANK
BLADDER TANK
HEAT EXCHANGER
CANISTER
CONTROL SENSOR
FAN OR COMPRESSOR
LIQUID PUMP
ELECTRICAL HEATER
CONNECTOR WITH INTEGRAL CHECK VALVE
ORIFICE
COMPARTMENT RELIEF VALVE
CONTROL VALVE
DIVERTER VALVE
ON OFF VALVE
CHECK VALVE
PRESSURE REGULATOR
VENT VALVE
RELIEF VALVE
SYMBOL LEGEND
NOTE: ITEMS IDENTIFIED WITH AN ASTERISK(*) ARE FOR OXYGEN REGENERATION AND OPTIONAL AT LAUNCH.
COLD WATER
HOT WATER
TO 608-119
CO_2 TO SPACE VACUUM
TO ⊄ FROM HANGER AIR LOCK
TO FAN INLET 226
TO CABIN 323
EMERG. ELEC. HEATERS 424
EVAPORATOR AIR HEATER 318
HEAT DUMP HX 422
ELECTRONICS COOLING LOADS
PUMP DOWN SYSTEM HX (2) 618
REGENERATIVE HX 421
BOSCH H_2O COND. HX 802*
WATER ELECT UNITS (5) 901
WATER TANK HEATERS 316
LAB SILICA-GEL 201
LAB HX AIR COOLING 504
LAB MOLECULAR SIEVE 202
CHILLER 315
REFRIGERATOR 326
FREEZER 327
LAB CONDENSING HX 229
HANGAR CONDENSING HX 229
HANGAR SILICA-GEL 201
HANGAR HX AIR COOLING 516
HANGAR MOLECULAR SIEVE 202
BASELINE SYSTEM
MORL EC/LS
PHASE IIB

The following paragraphs describe, by subsystem, the changes required to accommodate the three operating modes. At the beginning of each subsystem discussion, a brief description of the Phase IIa subsystem is given for the sake of completeness. Substantiation and tradeoff data supporting these changes are contained in Appendix A.

2.3.1 Atmosphere Supply Subsystem

The following paragraphs present a discussion of the atmosphere supply subsystem.

2.3.1.1 Phase IIa Subsystem

The Phase IIa subsystem provided a 7-psia total pressure atmosphere which is a mixture of 50% oxygen and 50% nitrogen by volume. Oxygen and nitrogen to make up for expected losses were stored on-board MORL in tanks as subcritical liquids. Gaseous oxygen and nitrogen, sufficient for one complete main laboratory repressurization, could be used as backup sources. A simple on-off control system was used to control the partial pressure of oxygen and the total pressure in each compartment. The amount of nitrogen inflow was measured and monitored in order to assess the atmospheric leakage status of the compartments. Oxygen and nitrogen were resupplied by positive pressure expulsion of cryogenics from bladdered storage tanks within the cargo module.

2.3.1.2 Changes Required for the Basic Operating Mode

The subsystem required for the basic operating mode is the same as for the Phase IIa, except that water, instead of subcritical oxygen, is resupplied and stored on board. Subcritical nitrogen storage is eliminated in favor of gaseous storage, and breathing oxygen is obtained by electrolyzing the resupplied water. The excess metabolic water produced by the crew is also electrolyzed to reduce water resupply requirements.

Advantages

This new mode of operation of the atmosphere supply subsystem has many advantages for MORL. These are as follows:

1. The reliability of the atmosphere supply subsystem with water electrolysis is approximately twice that of the same subsystem with cryogenic storage (Appendix A. 7). Even though the reliability of the electrolysis cells (with today's level of technology) is relatively low, the installed redundancy makes the subsystem reliability better. With cryogenic storage, it is not possible to provide the equivalent redundancy because cryogenics must be used at least as fast as the minimum boiloff rate. In addition, the resupply transfer operation for water is safer and less critical than for cryogenic oxygen.
2. The excess water recovered in the water management subsystem can be electrolyzed to reduce water resupply requirements. This amounts to more than 20% of the oxygen resupply requirements.
3. As long as oxygen is resupplied in the form of water, it does not make any difference whether the water is supplied as a separate fluid or if it is contained in the food. This means that certain wet foods can be resupplied instead of dehydrated food. Some discretion must be used, because the refrigeration capabilities on-board MORL are limited, and packaging weight and volume must be considered. However, there are many wet foods that do not require refrigeration which could make an order of magnitude difference in the quality of meals. The resulting psychological and morale improvements should not be underestimated. In similar environmental circumstances, such as in submarines, the efficiency of the crew is related to the quality of the meals.
4. The cost of development of a flight qualified electrolysis system is substantially less than that of developing subcritical oxygen and nitrogen storage and positive expulsion resupply transfer systems.
5. Since water electrolysis is a necessary development for missions which are not near-Earth orbit, the use of this method would establish this technology for future missions.
6. A water electrolysis mode provides both flexibility and growth to the EC/LS system, because it is adaptable to a six- or nine-man crew and to operation with or without oxygen regeneration (Sections 2.3.1.3 and 2. 3. 1. 4).
7. Water electrolysis need not limit the ability of MORL to perform an experiment, because the system can be shut down when extra power is required by the experiments.

Capacity Sizing

For the basic operating mode (six-man crew), the use rate for consumable oxygen and nitrogen is as follows:

O_2 -- 12.94 lb/day

N_2 -- 1.24 lb/day

This includes breathing oxygen and losses of oxygen and nitrogen caused by leakage and planned decompressions of airlocks and the equipment lock. Decompression losses caused by operational and experimental requirements are also considered.

The design requirements for the storage of consumables on MORL specify that capability of 147 days stay time be provided without resupply. Since the gaseous recompression oxygen also serves as a backup to the consumable supply, the recompression tanks are sized first. The recompression oxygen is sized to provide a complete repressurization of the main laboratory and is provided in two tanks, so that a convenient handling size is obtained.

Gaseous oxygen is also required to refill the tanks in the PLSS back packs to support extravehicular operations. Since this gas is expected to be used up, it is provided in a separate tank, because it will be resupplied at every resupply period.

To eliminate the need for cryogenics altogether, the nitrogen formerly provided in subcritical tanks is included in the gaseous supply. Therefore, the nitrogen tanks combine the storage required for consumable losses and for recompression requirements. The total volume required, that is, one main laboratory recompression plus 90 days consumable use, is provided in five identical tanks. Since the total nitrogen would last 164 days if used solely as a consumable, only two to four tanks will be resupplied depending upon the actual rate of use and the actual resupply period length. Table 2-4 summarizes the pertinent data on the gaseous oxygen and nitrogen storage tanks.

Table 2-4

GASEOUS STORAGE TANKS

Tank Type	Number Required	Diameter (in.)	Sizing Criteria	Capacity as Consumable	Quantity (lb)	Pressure (psi)
GO_2	2	20.5	1 repress.	8.2 days	105	3,500
GO_2	1	16.8	PLSS	--	14	3,500
GN_2	5	23.6	1 repress. + 90 days	164 days	203	3,500

Since the excess metabolic water (3.15 lb/day) is also electrolyzed, it effectively reduces the oxygen consumption rate. The conversion of this water amounts to 2.8 lb of oxygen per day, reducing the consumable oxygen use rate to 10.14 lb/day. Therefore, the water tanks are sized to hold 147 - 8.2 = 138.8 days of storage capacity of water at a use rate of 11.42 lb/day (9/8 times 10.14 lb of oxygen/day). At launch these tanks are only filled with a 20-day supply of oxygen, or 229 lb of water. The water is contained in simple, low-pressure, uninsulated tanks installed in the main laboratory. At the first resupply, the tanks are filled by an automatic transfer system which pumps the water from tanks in the cargo module into the tanks on board MORL. At this time, 1,585 lb of water are stored in five bladdered tanks, each 20 in. in diam.

Pressure Control

The laboratory and hangar compartments are individually maintained at a total pressure between 6.8 and 7.1 psia. A signal from the compartment oxygen partial pressure sensor opens the oxygen supply valve to that compartment when the partial pressure of O_2 drops below 3.4 psia. The valve closes when the partial pressure reaches 3.5 psia. The nitrogen supply is controlled by a total pressure sensor. In normal operation, this valve will open when the compartment total pressure falls to 6.8 psia and will close at

7.0 psia. This ensures that the partial pressure of N_2 is maintained between 3.3 and 3.6 psia. The total pressure can reach 7.1 psia if immediately after the total pressure is corrected to 7.0 psia, the PO_2 sensor calls for O_2, and PO_2 is increased from 3.4 to 3.5 psia. If the partial pressure of O_2 in the compartment falls to 3.3 psia, some malfunction is assumed to have occurred. In this event, a warning alarm rings and the nitrogen supply valve closes to prevent excess nitrogen from entering the compartment.

Water Electrolysis

Stored water is converted by electrolysis units into gaseous hydrogen and oxygen. The system consists of a pump, a water accumulator, four electrolysis stacks connected in parallel, controls for the electrolysis units, and an oxygen accumulator.

A water accumulator supplies water to the cell which operates with 37.5 psig water pressure. This references the entire system to the oxygen accumulator pressure and eliminates the need for an oxygen pump upstream of the oxygen accumulator. A water pump fills the water accumulator when the quantity remaining falls to a low level and shuts off when the accumulator is filled. Cell oxygen, produced at a pressure that is 2.5 psia higher than the pressure of the water supply, is used as a source of pressure for the water accumulator bladder. Water from the accumulator is bled into the cells as required to maintain a 1.5 psi hydrogen to water pressure differential across the cell membranes. A stepped-piston regulator references hydrogen gas pressure, and when necessary to increase water pressure to the cell, activates a water feed valve. A pressure regulator bleeds oxygen from the cell as required to maintain oxygen pressure 2.5 psi above water pressure. Thus, at operating conditions, feed water will be 37.5 psig, hydrogen pressure 39 psig, and oxygen pressure 40 psig. Hydrogen bled from the cell is vented overboard.

Four electrolysis modules are connected in parallel, each of which is capable of producing 4.4 lb of oxygen per day. For a six-man crew, only three of the four are operated for a total of 13.2 lb of oxygen production per day at an average power demand of 1,480 W. The extra module is used as an installed spare in case one of the three operating modules should fail. In this case, it is necessary to activate the spare module. The failed module can be repaired at a convenient time. The most likely mode of failure is deterioration of one of the membranes in the stack contained within the module. In MORL it is necessary to replace the entire stack in this event. The modules will be designed so that the acid electrolyte can be separated and stored in a separate compartment within the module prior to this repair. This particular feature has not been built into the electrolysis modules fabricated to date, but it is considered a feasible concept.

The operation of the water electrolysis modules in conjunction with the pressure controls takes advantage of the accumulator effect of the large mass of oxygen contained in each compartment. If the partial pressure of O_2 is greater than 3.4 psi in both compartments, only two electrolysis modules will operate, producing 8.8 lb of oxygen per day. Since the expected use rate is 12.9 lb per day, the partial pressure of O_2 will gradually fall. When it reaches 3.4 psia, a third electrolysis module will automatically start, which increases the production rate to 13.2 lb/day. Since this exceeds the use rate, the PO_2 will increase. At PO_2 = 3.5 psi (in both compartments), the third module shuts off, and the cycle repeats itself. Obviously the cycle rate will vary, depending upon crew split between compartments, their metabolic rates, and the leakage. However, for the normal case (six men in the main laboratory and oxygen consumption at the expected use rate), the third unit would be on for 11.5 days and would be off for 17 hours. The control unit will be designed so that each of the installed modules takes its turn being cycled to minimize excessive start-stop operations on a single unit and to even out the operating hours over all the modules. A pressure relief valve maintains the differential pressure required between the electrolysis units and the oxygen supply manifold.

An accumulator, which stores about 2 lb of oxygen, is provided upstream of the pressure differential valve. This 11-cu ft accumulator supplies pure oxygen through face masks (0.08 lb/man hour) for crew denitrogenation prior to a space-suit operation. It is also used to provide an oxygen flow of 2.0 lb/man-hour (helmet purge flow) to the astronauts during air-lock pumpout.

The accumulator also controls operation of the third electrolysis module. Whenever the accumulator pressure falls below 35 psig, the extra unit goes on until the accumulator is filled.

Two other methods of operating the electrolysis modules to meet the varying oxygen demand rates for MORL were considered. These are: (1) varying cell voltage to match the oxygen use rate, and (2) continuous operation through an accumulator. The first method was not used because the extremely wide variation of oxygen demand in two separate compartments would require a complex electrical control system. The second method was not used, because the size and weight of accumulator required would be excessive.

Task III analysis showed that with an 11 kWe power system, the experimental program was rarely limited by a lack of electrical power even though the EC/LS system uses an extra 1.48 kWe for operation of the electrolysis modules. In those cases where the laboratory is power limited, extra power is needed only for relatively short periods (usually minutes). In order to provide extra operating flexibility, the water electrolysis system is designed to provide normal oxygen requirements while operating only three of the installed modules. Thus, whenever additional power is required for experiments, all the electrolysis modules are simply shut down. Upon completion of the period of high power demand, four modules are restarted and operated until they catch up on oxygen production. The power demand will be 2000 W during this catch-up period which will naturally vary in length depending upon the number of hours the electrolysis cells were shut down.

During the down period, the crew lives upon the oxygen in the atmosphere of the compartment they are in. This is perfectly safe since the partial pressure of oxygen (PO_2) in the main laboratory would decrease less than 0.1 psi in 4 hours when the supply is stopped and the entire crew (six) is consuming oxygen at a normal rate. It is not expected that this additional electrical power will be required for more than 4 hours at a time, but if it is, this can also be accommodated. After 4 hours of operation, the laboratory PO_2 would presumably decrease from 3.5 to 3.4 psi. At this time, if 2 lb of gaseous oxygen from the recompression supply is bled into the laboratory

(2% of that available), the PO_2 would go back up to the normal 3.5 psi, and 4 additional hours of time are available.

2.3.1.3 Changes Required for a Nine-Man Crew Operating Mode

To accommodate a nine-man crew, it is not necessary to increase the capacity of the water storage tanks. The extra three men will arrive in a complete logistics spacecraft which will include a cargo module that contains all the extra expendables required on board for them. In the case of the water required for consumable oxygen, it will remain in the cargo module which is parked on MORL. When the on-board tanks are partially emptied, the extra water will be transferred from the cargo module to MORL. It should be noted that the Phase IIa system could not operate in this manner, because it was constrained by the cryogenic storage capacity launched with MORL. It would have been necessary to alter the resupply schedule whenever extra men were on board for long periods of time, because the oxygen would be used up faster. Extra cryogenic oxygen could not be brought and stored because of the inevitable boiloff.

The electrolysis system is designed to accommodate the nine-man crew by adding a fifth module to the four required for the basic system. Thus, when a nine-man crew is on board, all five modules are operated for about 20.4 hours per day at an average power demand of 2,120 W. It is even more important to have the capability to shut down water electrolysis during periods when a nine-man crew is on board, because it is during this time that the experimental power demand will be the greatest, and yet the operational power demand will be even higher. Therefore, the shutdown procedure described for the six-man crew (Section 2.3.1.2) will be the same except that the electrolysis power demand during the catch-up mode will be 2,500 W, instead of 2,000 W, and the cycle times will change.

The other functional elements of the atmosphere supply subsystem are not affected by crew size.

2.3.1.4 Changes Required for the Oxygen Regeneration Operating Mode

No changes are required to the atmosphere supply subsystem when the system is operating in the oxygen regeneration mode, because a Bosch-process hydrogenation system is used to convert the CO_2 into water, and the electrolysis cells are already sized to convert this water into oxygen. The only requirement is that the hydrogen output from the cells be rerouted to the hydrogenation reactor rather than dumped overboard.

If the oxygen regeneration mode is selected during the period of time when a nine-man crew is also required, the storage tanks will be filled with enough water to supply oxygen for the extra three men for the period of time they expect to be on board. This is necessary, because the CO_2 collection and hydrogenation subsystems are not designed for a nine-man crew (Sections 2.3.2 and 2.3.10).

2.3.2 Atmospheric Purification Subsystem

The following paragraphs present a discussion of the atmospheric purification system.

2.3.2.1 Phase IIa Subsystem

The Phase IIa atmospheric purification subsystem consisted of two, six-man, atmospheric purification circuits (one for the main laboratory and one for the hangar); a purification circuit for the Biological/Liquids (B/L) laboratory; and contamination detection equipment. The laboratory and hangar purification circuits consisted of a contamination removal loop, a humidity control loop, and a carbon dioxide removal loop. In normal operation, these loops purify the atmosphere in the compartment to which they are referenced. The B/L laboratory circuit consists of a fan, debris trap, ultraviolet light, charcoal filter, and a catalytic burner. A combination gas chromatograph-mass spectrometer is used for contamination detection.

The laboratory and hangar atmospheric purification circuits are identical and are interconnected so that either loop will purify the atmosphere for either compartment. This installed redundancy in separate compartments always makes another compartment available to the crew should either become uninhabitable for any reason. A contaminated compartment caused by a contaminant loop failure can be cleaned up by the other purification subsystem. Also, in a closed mode, these circuits can operate as intravehicular space suit loops which can be at cabin pressure or at suit pressure above cabin pressure.

2.3.2.2 Changes Required for the Basic Operating Mode

No changes are required to the atmospheric purification subsystem for the basic operating mode.

2.3.2.3 Changes Required for the Nine-Man Crew Operating Mode

No changes are required to the atmospheric purification subsystem in order to accommodate a nine-man crew. Since MORL is already equipped with two six-man purification circuits in each compartment, no performance degradation occurs as long as three of the men are always in the hangar. Since the purpose of increasing the crew is to increase the experimental output of MORL, it is most likely that the hangar will always be occupied in normal operation.

Even if more than six men were to occupy the main laboratory simultaneously, the effect on the performance of the atmospheric purification subsystem will be slight. The functions of trace-contaminant and atmospheric-bacterial control are relatively independent of the crew size and are sufficiently sized to accommodate nine men for other reasons. In the open mode, one purification circuit can handle the humidity control function for nine men, because the design condition for the condenser is the intravehicular space suit operating mode where the latent heat load is much higher than the sensible heat load, and the total metabolic rate is higher. Therefore, even with nine men in one compartment, the relative humidity will remain within the allowable level.

Carbon dioxide removal however, will be affected by the extra three men. Theoretically, the PCO_2 in the atmosphere would reach 6 mm Hg with nine men in one compartment. Actually, it is extremely unlikely that this level will be reached. It is reasonable to assume that some of the men will be sleeping and, thus, will produce less CO_2. Also, it takes many hours for steady-state conditions to be reached because of the large internal volume of the MORL compartments (6,700 and 3,300 cu ft). In addition, as the PCO_2 in the atmosphere increases, the molecular sieves tend to become more efficient so that they remove more CO_2 from the air. Finally, there is evidence that the crew could tolerate a PCO_2 of 6 mm of Hg indefinitely, without any ill effects.

The only function of the atmospheric purification subsystem that cannot be accomplished for a nine-man crew is the intravehicular space suit operating condition. If nine men were on the same suit loop, the PCO_2 and humidity levels would not be acceptable. However, the only time that all the men have to be suited is in an emergency, and, with a fully redundant purification loop in the other compartment, there is no requirement for the entire crew to be suited at the same time. If the atmosphere of both compartments was uninhabitable simultaneously and if the gaseous recompression supply were expended, the crew would have to abandon the laboratory.

2.3.2.4 Changes Required for the Oxygen Regeneration Operating Mode

Significant changes to the atmospheric purification subsystem were required to provide for an oxygen regeneration operating mode. Whereas the basic mode desorbs the molecular sieve beds by exposing them to the vacuum of space, in the oxygen regeneration mode, it is necessary to collect the CO_2 for subsequent processing. The Bosch hydrogenation reactor will be resupplied whenever it is deemed desirable to operate in an oxygen regeneration mode, however, it is not considered practical to revise the CO_2 removal units after launch; therefore, the CO_2 collection capability is included in the initial design.

In the collection system, the CO_2 is driven out of the molecular sieve beds mainly by means of thermal energy, and is then collected and held for further processing. The changes necessary to provide this capability are as follows:

1. Heating Coils in the Molecular Sieve Canisters--CO_2 desorbtion can be effected by exposing the beds to space vacuum without adding any

thermal energy. However, in order to collect the CO_2 at canister pumpdown pressure, it is necessary to drive the CO_2 out of the beds with heat. The amount of heat required is quite high (Appendix A. 2); therefore, thermal desorbtion with waste heat from the isotope power system is used rather than electrical heat. This requires the addition of heating coils to the molecular sieve beds. It should be noted that the use of the same fluid (water) for the heating and cooling functions simplifies the CO_2 collection system considerably, because the same heat transfer surface can be used for heating and cooling.

2. CO_2 Pumping--A vacuum pump is required to transfer the CO_2 from the bed to the accumulator. The pump provides a lower pressure (approximately 1 psia) in the bed to facilitate desorbtion.

3. Full-Flow Silica-Gel Desorbtion--In Phase IIa, bleed flow silica-gel bed desorbtion was used because it reduced the system pressure drop and lowered the overall equivalent system weight. Part of the flow from the adsorbing molecular sieve bed is passed through the desorbing silica-gel bed and then is recycled upstream of the condenser. For atmospheric purification with CO_2 collection, full-flow silica-gel bed desorbtion is better, because the process air coming from the hot molecular sieve bed is preheated, thus minimizing heating requirements and facilitating water desorbtion of the silica-gel bed. The entire flow from the adsorbing molecular sieve bed is passed through the desorbing silica-gel bed and then enters the cabin.

4. Cycle Time--The minimum molecular sieve bed cycle time is increased to 40 min. (as opposed to 30 min.) to lengthen the heating and cooling cycles and, by more efficient bed loading, to improve the purity of the delivered CO_2. High purity CO_2 (that is, free of oxygen and nitrogen), is required to achieve the required efficiency in the hydrogenation process. For this reason, the vacuum pump transfers the bed ullage back to the cabin immediately prior to bed desorbtion. Lengthening the cycle time also had the effect of reducing the desorbtion heat requirements which decreases the radiator size.

5. Variable Bed Cycle Time--Since the baseline system is designed with one, six-man CO_2 removal system in each compartment and the crew will be either six or nine men, it is obvious that the CO_2 beds will be partially loaded at times, depending upon the location of the crew and the metabolic rates. This was satisfactory with vacuum bed desorbtion, since no process downstream depended upon the amount of CO_2 being desorbed. With CO_2 collection, the system should have the capability of increased zeolite bed adsorption time when the CO_2 production in a single compartment drops below the design value. This would occur when several of the crew members are in the hangar area. Since the purity of the delivered CO_2 is effected by the anticipated atmospheric ullage, with a reduced amount of CO_2 adsorbed and delivered in a constant cycle

time, the CO_2 collected will be less pure. To ensure maximum purity, the adsorbing zeolite bed cycle time is lengthened until the quantity of CO_2 adsorbed is equal to the design quantity. The simplest means to accomplish this is to vary the cycle time with the compartment CO_2 partial pressure. When the partial pressure of CO_2 in a compartment is below 4-mm Hg, one CO_2 canister adsorbs, and switch-over occurs only when the partial pressure reaches 4 mm, because the timer in the unit will be controlled by the compartment CO_2 sensor. The minimum cycle time allowed by the timer would be based upon a basic desorption time requirement of 40 min. so that higher metabolic rates than anticipated would not alter the performance of the bed. All diverter valves, including those for directing heating and cooling water to the beds, are timer controlled to ensure that the CO_2 concentrator operates at the proper temperatures.

2.3.3 Water Management Subsystem

The following paragraphs present a discussion of the Water Management Subsystem.

2.3.3.1 Phase IIa Subsystem

The Phase IIa water management subsystem is designed so that the drinking water cycle is completely closed and drinking water resupply will not be required. Wash water is also purified and reused. Potable water is reclaimed from urine, perspiration, respiration, and wash water. Fecal water is not recovered.

Reclamation of this water is accomplished by two open-loop air evaporation systems, one designed to purify wash water and one designed to purify urine. The two systems are identical so that the wash-water system can serve as a back up to the urine system. The two evaporators are placed in parallel within the atmospheric purification air loop, utilizing this air flow for the evaporating media. The system is designed to process 1 day's supply of water in 18 hours so that, in the event of failure, the extra time can be used to reprocess the bad batch without requiring that washing be stopped. Four storage tanks are provided, each with the capacity of 1 day's total water usage; one tank is being filled, one is being used, one is a standby (in case of a bad batch), and one is undergoing a potability check. The stored water is constantly maintained at 160^oF to prevent the growth of bacteria. Cool water is provided for drinking.

The high efficiency of the air evaporation method of purification actually realizes an excess of 3.15 lb of water per day (excess metabolic water). This water is used for PLSS cooling and for experimental purposes. However, these requirements are small and the remaining water is jettisoned.

2.3.3.2 Changes Required for the Basic Operating Mode

No conceptual changes are required to the water-management subsystem for the basic operating mode. However, the excess metabolic water recovered is now diverted to the water storage tanks of the atmosphere supply subsystem, where it is converted into breathing oxygen. The 2.8 lb of oxygen obtained from this water supplies more than 20% of the total oxygen requirements, and resupply is accordingly reduced. Water required for PLSS extravehicular and experimental requirements can be included with the experiment hardware.

2.3.3.3 Changes Required for the Nine-Man Operating Mode

In order to accommodate the nine-man operating mode, the subsystem was revised to process a 1-day total water usage for a six-man crew in 16 hours, instead of 18 hours. This means that the subsystem has the capacity to process water for a nine-man crew when operated 24 hours a day. This change requires an increase in the size of the evaporators and the storage tanks. When the subsystem is operated 24 hours a day, it is still possible to reprocess a bad batch of water in case of a failure. This is accomplished by not processing the wash water and using that unit to repurify the bad batch. Denying the crew the ability to wash for 16 hours is considered a minimum inconvenience.

2.3.3.4 Changes Required for the Oxygen Regeneration Operating Mode

The basic water-management subsystem accommodates the oxgyen regeneration operating mode by making use of the excess metabolic water to close the oxygen cycle.

2.3.4 Waste Management Subsystem

The following paragraphs present a discussion of the Waste Management Subsystem.

2.3.4.1 Phase IIa Subsystem

The Phase IIa waste-management subsystem consisted of two sets of two waste processors, each sized to handle the expected wastes from a six-man crew. One set was located adjacent to each of the commodes. The extra capacity so provided was reserved for experimental wastes.

Each set of processors was operated on a daily basis, one being used as a collector while the other was being used as a processor. All wet wastes, including fecal matter, were manually transferred to the processors. After dehydration, the wastes were put into non-vapor-permeable bags and stored in empty food containers. Thermal energy from the isotope heat source was used to dehydrate the wastes. The sterilized vapors were dumped overboard. Each processor was sized to handle a 1-day quantity of waste so that it was necessary to switch processors daily.

2.3.4.2 Changes Required for the Basic Operating Mode

During Task III, it was determined that operation of the waste-management subsystem required about 15 man-min./day. In addition, the wastes had to be manually handled twice before storage. In the interests of reducing crew operating time to a minimum, a study was made of an integrated waste-collection, processing, and storage subsystem that utilizes expendable collectors. A detailed discussion of this analysis is contained in Appendix A, Section A.4. The results of this analysis indicated that the following subsystem should be used in preference to the baseline method.

The selected system for collection and storage of wet wastes consists of a commode in the form of a sphere. The sphere is vented to space vacuum to allow freezing and eventual dehydration of the fluids in the wastes. The sphere has an airtight lid which is removed for deposit of wet wastes or for use as a commode. When the lid is removed, a fan automatically circulates 5 cfm of air through the sphere. This flow establishes the necessary velocity to ensure that the feces are directed down into the sphere which is lined with a layer of screen and felt. Spacers are used to provide an air space between the felt lining and the outer sphere. The outlet for the airflow is connected to this air space so that all particles pulled into the sphere are held against the felt liner by the air velocity. The air goes from the sphere, through a charcoal and millipore filter, to the circulation fan, and back to the cabin. After use, the lid is replaced and the fan is shut off. A vacuum pump lowers the sphere pressure to 0.5 psia, after which a selector valve vents the sphere to space. Each sphere is sized for a 30-day use. Four additional spheres are to be brought up with the first resupply spacecraft to provide a 150-day waste-storage capacity. After the 30-day sphere is filled, it is replaced by an empty sphere. The filled sphere is evacuated, sealed, and stored, until it can be rejected with the empty logistics spacecraft. This system has been tested in a prototype design and was found to be satisfactory for space station usage. The cabin return air is odor free, and the vented vapors are sterile.

The new concept was chosen to replace the baseline method because of the following:

1. Approximately 15-man min. of crew time is made available for the experimental program.
2. The manual transfers of feces are eliminated. Other wastes must still be manually carried to the commode.
3. The system is similar to a conventional toilet.
4. No waste heat is required.

2.3.4.3 Nine-Man Crew Operating Mode

The basic waste-management subsystem can accommodate a nine-man crew without any conceptual changes. Since the collection spheres are sized for 180 man-days of operation, they will have to be changed every 20 days, instead of every 30 days. The extra spheres required will be brought up with the extra supplies the three additional men will bring.

2.3.4.4 Oxygen Regeneration Operating Mode

The new waste-management subsystem has no interface with the O_2 regeneration system except to accept the wastes (carbon) associated with the hydrogenation process. No changes are required.

2.3.5 Compartment Conditioning

The following paragraphs present a discussion of the Compartment Conditioning Subsystem.

2.3.5.1 Phase IIa Subsystem

Ventilation and air temperature control for the main laboratory was provided by a simple cooling air circuit and a system of distribution ducting. The amount of cooling air flow was determined by the air heat load and turned out to be more than adequate for zero-g ventilation requirements.

In the Hangar/Test area, the equivalent function was accomplished by using the atmospheric purification subsystem as a cooling circuit. To obtain sufficient cooling, it was necessary to double the air flow by turning on the redundant contaminant loop fan. With this system, the hangar air temperature will remain at 75° when occupied by two men if most of the electrical load is transmitted to the heat transport circuit rather than to the air. When occupied by six men, the hangar air temperature would rise to 80 to 85°F.

2.3.5.2 Changes Required for the Basic Operating Mode

In establishing the air heat load in Phase IIa, it was assumed that experimental electrical power would probably be air cooled. However, the air heat load could now become as high as 7 kWt because of the power availability from the isotope power system. With this air heat load, the cooling requirements on the ventilation circuit would be prohibitively high. Therefore, the MORL design requirements now state that all electrical components requiring active cooling, including experiments, are to be cooled by the liquid heat-transport circuit.

Even with the new design criteria for the main laboratory, the air heat load increases, because it must be assumed that about 10% of the electrical heat will still be dissipated into the air. This requires a ventilation circuit with a flow of 700 cfm at a temperature of 60°F.

One of the results of the Task-III analysis showed that the Hangar/Test area would be increasingly used as an experimental area because the configuration is such that Earth-oriented experiments are best handled there. Also Task II showed that the number of Earth-oriented experiments would be a significant portion of the total experimental program. It is then clear that the hangar will often be occupied by more than two men and that the air heat load may be significant. Using the hangar atmosphere purification subsystem as a cooling circuit under these conditions will be marginal at best. Therefore, a separate ventilation circuit was added to the hangar which has a 3,400 Btu/hour cooling capability. This system has been sized arbitrarily, since the exact cooling requirements are not known. 3,400 Btu/hour of cooling will maintain the hangar at 75°F when occupied by a crew of six men, with 4 kW of power being dissipated by liquid cooled electronics.

2.3.5.3 Changes Required for the Nine-Man Operating Mode

It is not necessary to make any changes to the ventilation circuits for the nine-man crew condition. It is not expected that the entire nine men will inhabit one of the compartments simultaneously except in transient conditions; even then, it is probable that the metabolic rates will be lower than the 500 Btu/hour-man design level. In the worst case, if all nine men were in the main laboratory at once at the design metabolic rate, the air temperature would reach a maximum of 79°F which is still within the allowable tolerance.

2.3.5.4 Changes Required for the Oxygen Regeneration Operating Mode

The main laboratory ventilation flow was increased from 700 (as required by the basic system) to 750 cfm to account for an increased air heat load. The increased air heat load is caused by the full-flow silica-gel bed water desorbtion method which is necessary for O_2 regeneration (Section 2.3.2.4).

2.3.6 Cooling Circuit

The following paragraphs present a discussion of the Cooling Circuit.

2.3.6.1 Phase IIa Subsystem

The Phase IIa cooling circuit used a fluid (FC-75) circulation loop to reject all the waste heat created in the laboratory to space. The subsystem consisted of a heat exchanger (where the waste heat was collected from the heat transport subsystem), redundant fluid pumps, redundant radiators, and a regenerative heat exchanger with a temperature control valve.

2.3.6.2 Changes Required for the Basic Operating Mode

All of the changes required to the cooling circuit are necessary to accommodate the isotope power system.

Parasitic Heat Load

In the design of the isotope power system, it is desirable to maintain a constant demand upon the power system alternator despite variable load demand resulting from intermittent operations on MORL. This is accomplished by including a parasitic-load control in the EC/LS cooling circuit. The parasitic-load control is part of the isotope power system, and a complete description of it may be found in Reference 2. It operates by dissipating electrical energy in the form of heat directly to the circulating fluid. The amount of energy transferred is equal to the difference between the power system design output electrical energy and that amount of electrical power demanded by the laboratory. Since all the electrical energy dissipated in the laboratory eventually reaches the cooling circuit via the heat-transport subsystem, the effect on the EC/LS circuit is that the radiator fluid inlet temperature remains constant at its design valve (118°F). There is no penalty for including the parsitic heat load in the EC/LS system, because the cooling circuit must be designed for the case where all the electrical energy output of the power system is delivered to the laboratory anyway. It is advantageous to do so, because the power system radiator does not have to be designed to reject the parasitic heat load.

Regenerative Heat Exchanger

The regenerative heat exchanger was included in the Phase IIa design, because the radiator outlet temperature could become so cold under conditions that the heat transport fluid could freeze. The control valve bypassed the radiator outlet fluid so that it was warmed by the inlet radiator fluid to prevent this from happening. However, with the parasitic-heat load maintaining a constant radiator inlet temperature, the regenerative heat exchanger is not required, and a simple bypass control on the radiator protects the heat transport fluid.

Radiator Area

Since the vehicle structure is a thermos-bottle design, no heat is transferred into, or out of, the vehicle except through the radiator. This also fixes the radiator heat rejection load, because it must always be equal to the sum of the metabolic heat produced by the crew, the thermal equivalent of the electrical energy delivered by the power system, and the power system waste heat, which is brought into the laboratory. The increase to an 11-kWe power system increases the radiator heat load over Phase IIa requirements.

In addition, the isotope power system requires a radiator to reject the heat from the isotope fuel block, which it cannot convert into electrical energy. It was decided to locate the power system radiator on the cylindrical section of MORL in the vicinity of the aft interstage in order to keep it close to the power-conversion equipment located there. This meant that the EC/LS radiator would have to occupy the forward cylindrical section. This location creates the following problems:

1. The parked logistics spacecraft interferes with the view of the radiator to space.
2. The radiator tubes and headers are between the meteoroid structure and the pressure shell, and are not as accessible for checkout and repair as in the aft interstage location.

Consistent radiator design criteria were also used in the design of the EC/LS power system radiators. This resulted in the following design criteria changes:

1. Design Surface (α_s/ϵ_t)--0.173 for Phase IIa and 0.25 for Phase IIb.
2. Design Heat Influx--Maximum for Phase IIa and 87% of maximum for Phase IIb.

$\alpha_s/\epsilon_t = 0.173$ is a reasonable value to use for a newly painted surface, while $\alpha_s/\epsilon_t = 0.25$ anticipates the degradation to the surface that is expected in 5 years of orbital life. The more conservative value increases the area required to reject a given amount of heat. However, designing for less than the maximum heat influx to the radiator because of the sun and Earth, has the effect of reducing the area required. This is justifiable, because the peak influx only occurs whenever MORL is directly in the subsolar position (in the line between the center of the Earth and the center of the sun). This only occurs for a few orbits of the year and for a few minutes of each of these orbits. However, the increased α_s/ϵ_t is more significant and the combination of these two changes and the shadowing effect of the parked vehicles results in increased radiator area for a given heat load.

When the new radiator area requirements were determined for both the EC/LS system and the power system, it was found that the required area exceeded the usable cylindrical area on MORL. Several methods of reducing the EC/LS radiator area were investigated, including the following:

1. Circumferential versus axial tubing.
2. Use of a heat pump to increase the average radiator surface temperature.
3. Combining the EC/LS and power system radiators.
4. Separation of the EC/LS heat loads into two radiators.
5. Confining the radiator to the cylindrical areas of least heat influx.

These analyses confirmed the fact that the Phase IIa radiator concept with cylindrical tubes results in the best and most practical design for the EC/LS radiator. After the radiator design concept was chosen, parametric curves for radiator weight versus area required to reject the heat load were prepared (Figure 2-2). The design point shown (900 sq ft) was chosen to minimize the area required. The cylindrical length required to provide 900 sq ft of surface area is 13.2 ft. A detailed discussion of all the radiator studies is contained in Appendix A, Section A.1.

One result of the radiator analyses was that the vehicle was lengthened approximately 5 ft to obtain sufficient surface area for both the power system and radiators. For a detailed discussion of this optimization see Reference 2.

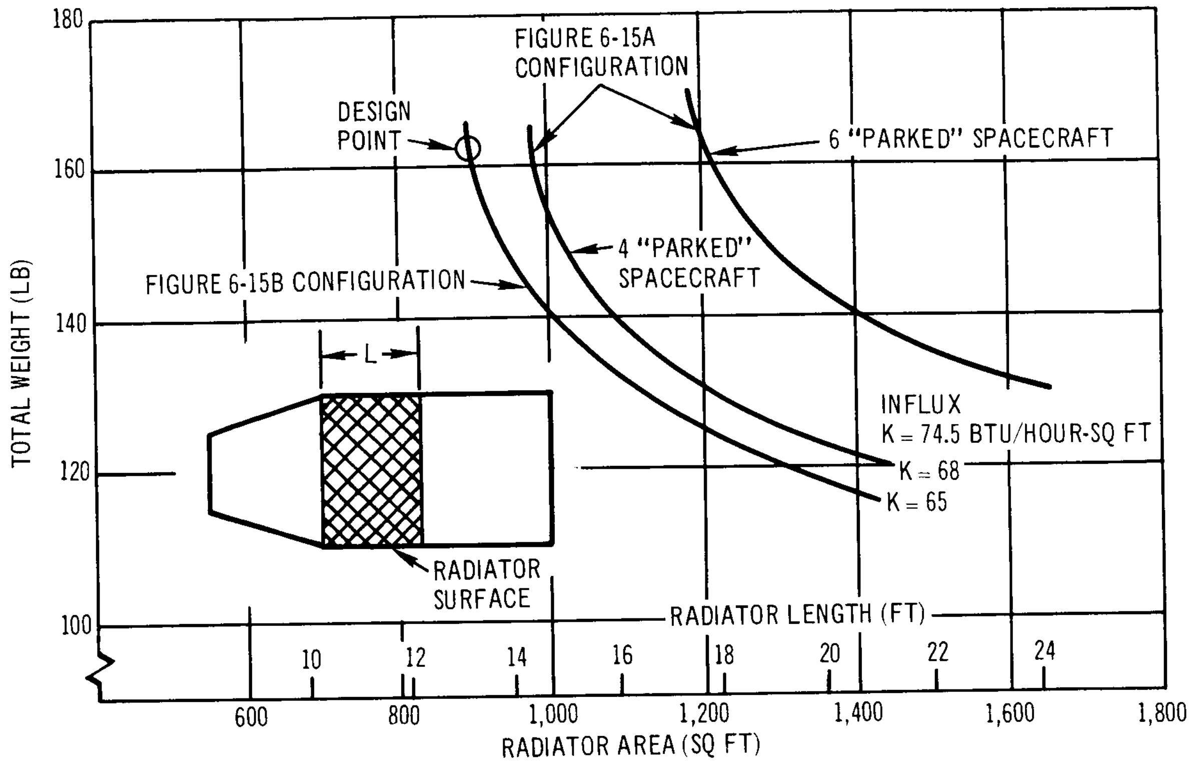


Figure 2-2. Radiator Area Requirements, Basic System, Q_L = 43,730 Btu /Hour

2.3.6.3 Changes Required for the Nine-Man Crew Operating Mode

No changes are required to cooling circuit subsystem in order to accommodate a nine-man crew. The metabolic heat for the extra three men is only about 3.5% of the design heat load, and the resulting degradation to system operation will be negligible.

2.3.6.4 Changes Required for the Oxygen Regeneration Operating Mode

Additional waste heat must be brought into the laboratory for the oxygen regeneration mode to desorb the molecular sieves at cabin pressure. The baseline system required an average of 7,740 Btu/hour while an O_2 regeneration system requires 13,630 Btu/hour (Appendix A, Section A.2). This additional heat directly affects radiator requirements. The parametric analysis of radiator weight as a function of area accomplished for the normal operating mode was repeated for the new design heat load. The results are shown in Figure 2-3.

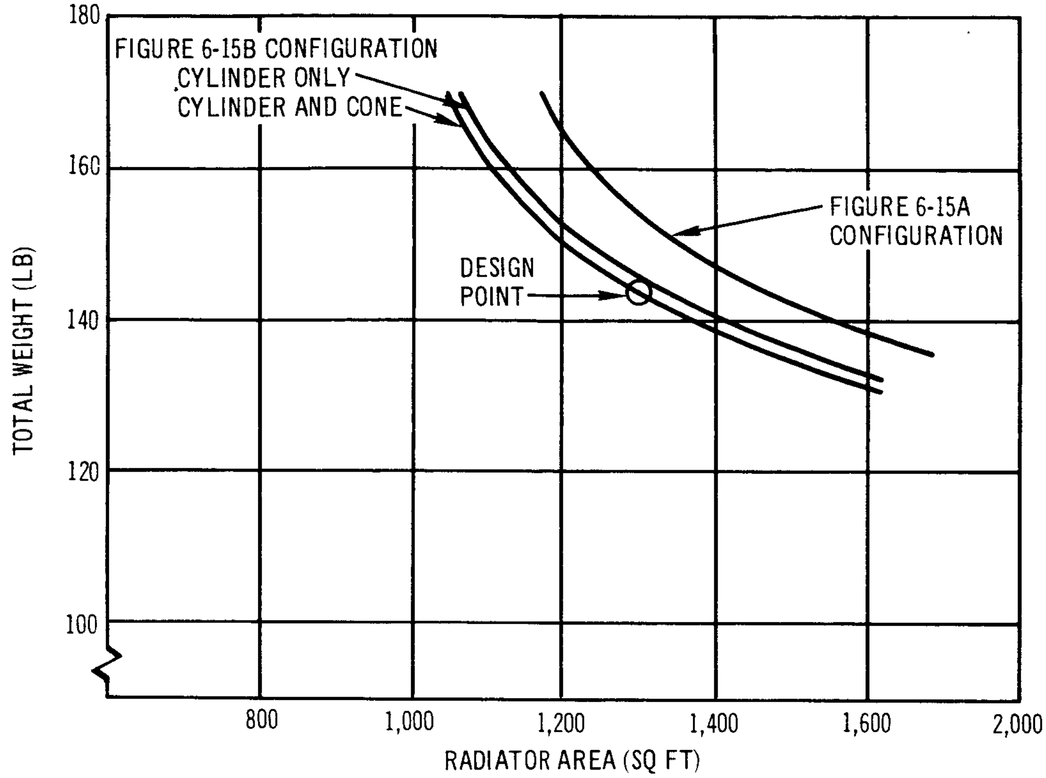


Figure 2-3. Radiator Area Requirements, O_2 Regeneration System, $Q_L = 49,630$ Btu /Hour

If the additional radiator area required is obtained by lengthening MORL in addition to that length already added to accommodate the isotope power system, the new radiator area would be 1,060 sq ft. This is 160 sq ft more than required for the normal operating mode and would require nearly 2.3 ft of additional cylindrical length. This was undesirable for structural and configuration reasons, so the parametric analysis was extended to utilize the conical section of MORL as a radiator. From Figure 2-3, it can be seen that the conical section of MORL is as good a radiator surface as the cylindrical section; therefore, this design was selected to provide the additional radiation surface required. The design point chosen (1,050 sq ft) is shown on Figure 2-3. The conical section provides about 400 sq ft of surface area suitable as a radiator surface after allowing for the unusable sections (caused by radial docking rings and experimental bay doors). Therefore, for the oxygen regeneration mode, the cylindrical radiator length will remain the same as that required for the normal operating mode, 13.2 ft, and the entire available area in the conical section will be utilized as a radiator. Utilizing all of this surface, even though only 160 sq ft is necessary, lowers the radiator weight, because it allows the radiator tubes to be spaced further apart. For an alternative method of providing radiator area for an oxygen regeneration operating mode see Appendix A, Section A. 1.

2. 3. 7 Heating Subsystem

The following paragraphs present a discussion of the Heating Subsystem.

2. 3. 7. 1 Phase IIa Subsystem

The Phase IIa heating subsystem consisted of a fluid circulation loop that obtained heat from a heat source and transferred this heat to the heat transport circuit. The subsystem consisted of a small radioisotope heat source, a fluid pump, and a control valve.

2. 3. 7. 2 Changes Required for the Basic Operating Mode

All heat required for the EC/LS system will be provided by using waste heat from the isotope power system. This eliminates the need for a separate heating subsystem.

2. 3. 8 Heat Transport Circuit

The following paragraphs present a discussion of the Heat Transport Circuit.

2. 3. 8. 1 Phase IIa Subsystem

The Phase IIa subsystem consisted of a fluid (water) circulation loop which collected heat from the heating subsystem and transported this heat to those components requiring it. It also collected waste heat from all components in the laboratory that required cooling and transferred this heat to the cooling subsystem. The subsystem consisted of redundant fluid pumps, a heat exchanger which interfaced with the cooling circuit, a heat exchanger which interfaced with the heating subsystem, a regenerative heat exchanger, and the fluid lines and valves required to distribute the circulating fluid.

2.3.8.2 Changes Required for the Basic Operating Mode

The heat transport subsystem assumes those functions formerly accomplished by the heating subsystem, because the isotope power system has sufficient waste heat available for the EC/LS system. As shown in Figure 2-4 a heat exchanger is placed in the Brayton cycle gas loop between the recuperator and the heat rejection heat exchanger. Fluid from the heat transport subsystem receives heat from this heat exchanger and then transfers it to those components requiring heating. A heat-dump exchanger and temperature-control bypass valve are also provided, so that the heat removal from the power system will be constant regardless of heating load fluctuations. This decreases the power system radiator heat load by the amount of waste heat delivered. The EC/LS system radiator must be designed for the peak load in any case. Thus, the inclusion of the heat dump exchanger minimizes total radiator area requirements.

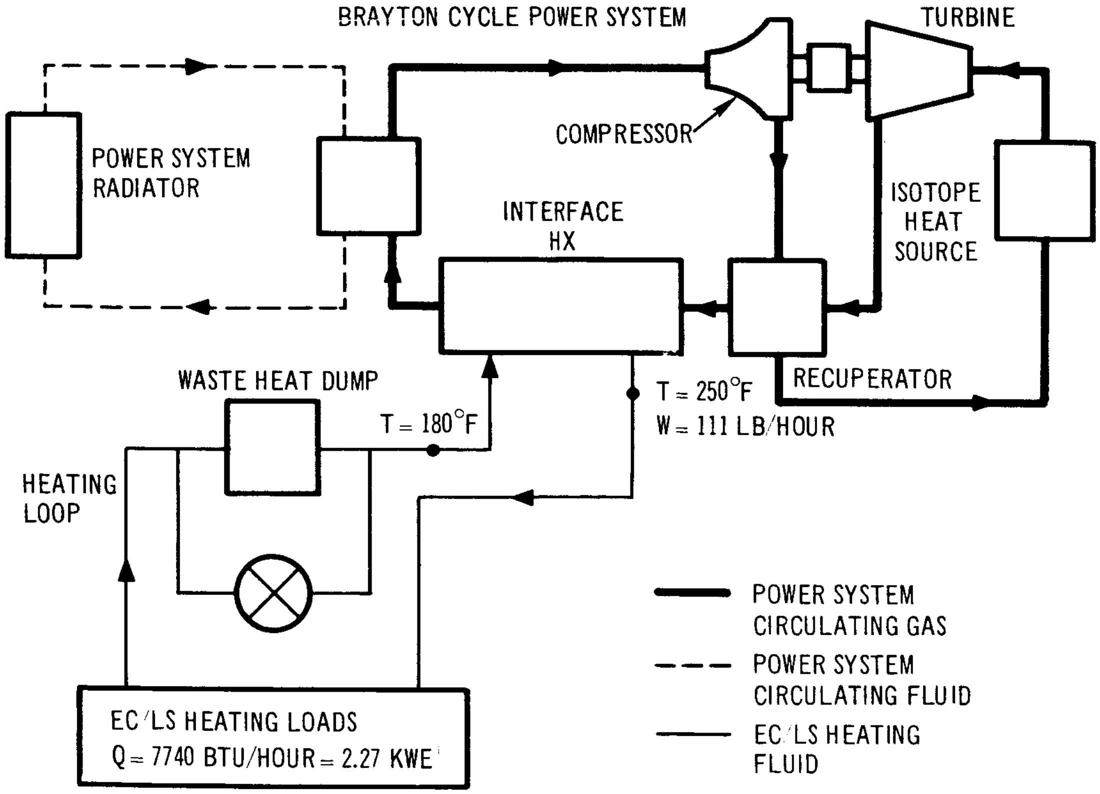


Figure 2-4. Integration of Power and EC/LS Systems Basic Operating Mode

The cooling loop of the heat transport circuit is conceptually the same as the Phase IIa subsystem, except that some loads are eliminated and some new loads are added due to other subsystem changes. These are discussed separately in the subsystems affected. The total load is also increased to 43,730 Btu/hour because of the growth to an 11-kWe power system.

2.3.8.3 Changes Required for the Nine-Man Crew Operating Mode

No changes are required to accommodate a nine-man crew. The additional cooling load due to the metabolic heat of three men has a negligible effect on the subsystem performance.

2.3.8.4 Changes Required for the Oxygen Regeneration Operating Mode

Thermal desorbtion of the molecular sieves not only requires additional waste heat, 13,630 Btu/hour versus 7,750 Btu/hour, but also the fluid temperature must be 360°F, rather than 250°F (required to desorb the silica-gel beds). In order to prevent the heat transport fluid from boiling at this temperature, the circuit pressure must be maintained at 300 psi. At this pressure and temperature, the water circuit presents a safety problem in the case that a line or fitting fails. Therefore, separate heating and cooling circuits are provided within the heat transport subsystem. The heating circuit, which operates at 360°F and 300 psi, will be a hard installation with high reliability. The cooling circuit, which operates at 120°F and at low pressure, can then consist of hard lines with flexible sections and quick disconnects for certain components (cold plates and experiments). Water is still retained as the circulating fluid in both circuits.

To obtain the waste heat at 360°F, it is not possible to provide all the waste heat in the same manner as described in Section 2.3.8.2 because of temperature limitations within the power system gas loop. The additional heat is obtained by passing the fluid through a heat exchanger in the isotope fuel block radiation shield (see Figure 2-5). About 90% of the thermal energy withdrawn from the fuel block by this method would normally be lost by heat leakage. The rest must be made up by addition to the fuel block (Reference 2). It should be noted that if molecular sieve bed desorbtion is possible at lower

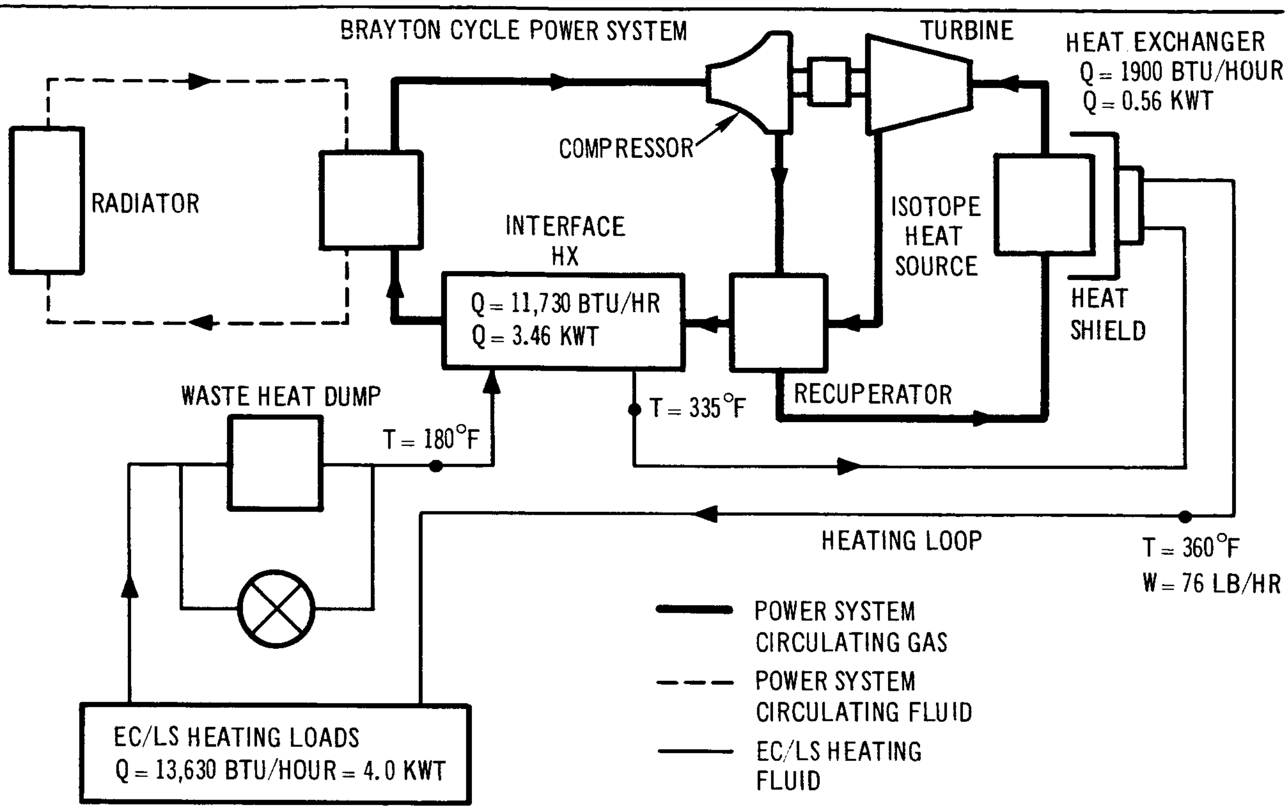


Figure 2-5. Integration of Power and EC/LS Systems, O_2 Regeneration Operating Mode

temperatures, the additional weight and complexity required by passing fluid through the radiation shield would be eliminated. It is possible that this can be accomplished by designing the bed in accordance with this requirement. Test data on bed desorbtion at lower temperatures is required. This problem is discussed in Appendix B.

The heat transport subsystem is operated as though the EC/LS system is in the oxygen regeneration operating mode regardless whether the Bosch reactor is operating or not. The heating loop withdraws the increased amount of waste heat at the higher temperature and the molecular sieves are heated and cooled, even though they are being desorbed to vacuum. Since the system is designed to operate in this mode, there is no penalty in allowing it to do so, even though the hydrogenation reactor is not operating, and there is an advantage in the fact that the design is simplified because only one operating mode is necessary.

2.3.9 Atmospheric Pump Down Subsystem

The following paragraphs present a discussion of the atmospheric pump down subsystem.

2.3.9.1 Phase-IIa Subsystem

The Phase-IIa subsystem was used to minimize atmospheric losses because of planned decompressions of the man air locks, the experimental equipment air lock, and the Hangar/Test area. The subsystem consists of a single stage compressor, intercoolers, a two-stage compressor, and a storage tank. The single-stage compressor is used to pump air from the man lock and equipment lock back to the cabin or hangar. All three stages are required to pump the hanger atmosphere into the storage tank.

2.3.9.2 Changes Required for All Operating Modes

The pump down subsystem is not affected by nine-man crew occupancy or by oxygen regeneration. However, it was necessary to increase the size of the storage tank, because the volume of the Hangar/Test area increased from 2,150 to 3,300 cu. ft. because of the structural change to a flat bulkhead between the laboratory and the hangar.

2.3.10 Carbon Dioxide Reduction Subsystem

The oxygen regeneration operating mode requires the addition of a carbon dioxide reduction subsystem to the EC/LS functional system. However, since this subsystem will not be added to MORL until after launch to save launch weight, it is not included as part of the new baseline system. The concept of adding this subsystem to MORL after launch is rationalized as follows:

1. It is unlikely that oxygen regeneration will be required during at least the first year of orbital operations. Crew rotation because of biomedical experimental requirements, automatically ensures sufficient resupply capability without oxygen regeneration because of the combined ferry-resupply spacecraft concept. Later, in MORL operations, better established resupply requirements and crew rotation schedules will determine the desirability of permanently operating in an O_2 regeneration mode.

2. Even if O_2 regeneration is never used as a prime operating mode, the addition of this capability is considered a valuable experimental development task to establish a technology which is necessary for future space programs that do not have resupply capability.
3. The modular design approach which has been implemented in the EC/LS system design allows the addition of a hydrogenation reactor with a minimum of retrofit problems. Thus, no risk is assumed in converting to oxygen regeneration, because the "open" oxygen mode is still available. An additional advantage is obtained because the basic system allows the use of other, more advanced, methods of carbon dioxide reduction as experiments.

Two methods of providing the capability for oxygen regeneration from carbon dioxide were considered: the Bosch hydrogenation process and the Sabatier process with methane breakdown. The hydrogenation process operates as follows:

$$CO_2 + 2H_2 \rightarrow C + 2H_2O \qquad (2\text{-}1)$$

$$2H_2O \rightarrow 2H_2 + O_2 \qquad (2\text{-}2)$$

The first reaction occurs in the Bosch reactor at a temperature of approximately 1,300°F. The water produced is delivered to the atmosphere supply subsystem where it is then electrolyzed (Equation 2-2) to form hydrogen and oxygen; the H_2 is recycled to the Bosch process reaction, and the O_2 is transferred to an accumulator for delivery to the vehicle atmosphere. This system has been selected for MORL, because it is the most proven process available.

The closely related Sabatier process is similar to the Bosch process.

$$CO_2 + 4H_4 \rightarrow CH_4 + 2H_2O \qquad (2\text{-}3)$$

$$2H_2O \rightarrow 2H_2 + O_2 \qquad (2\text{-}4)$$

However, as can be seen from Equation 2-3, twice the amount of hydrogen is required and, thus, requires its storage and resupply throughout the mission. The hydrogen may be resupplied in the form of water; however, the cycle would not be completely closed. For the Sabatier process, the waste product is methane (CH_4). In order to close the cycle for this system, the methane may be broken down as follows:

$$CH_4 \rightarrow 2H_2 + C \tag{2-5}$$

Thus the Sabatier process requires two steps to accomplish the function of the Bosch reaction. Considerations such as catalyst materials, heating requirements, and simplicity further support the choice of the Bosch system.

The subsystem consists of a CO_2 accumulator, a Bosch reactor, and a condensing loop. The carbon dioxide pumped from the CO_2 concentrator is stored in the CO_2 accumulator. This carbon dioxide and hydrogen from the electrolysis unit are combined by a flow controller and directed to a recirculating gas stream which is composed of carbon dioxide, hydrogen, water vapor, methane and nitrogen. This recirculating gas then proceeds to a condenser where the water vapor forms into droplets. Collection of the water is accomplished by a separator which pumps the condensed water to the water storage tanks where it is subsequently electrolyzed. The recirculating gas then passes through a compressor where the pressure is increased. The compressor forces the recirculating gas through a regenerative heat exchanger where it recovers heat from the return flow. The hot gas then enters the reactor where hydrogen and carbon dioxide are converted to water and fine carbon particles. This mixture flows through a specially designed regenerative heat exchanger which can pass the carbon particles, where much of the gas heat is transferred to the reactor inlet flow. The recirculating gas then passes through a low temperature collection unit where the carbon particles are trapped. The collection unit serves as a filter and collector, and is serviced by temporarily shutting down the unit. This type of a Bosch hydrogenation reactor has been successfully tested in conjunction with the Langley Research Center Integrated Life Support System.

Removal of all the processed CO_2 is accomplished by closed-loop recirculation of the carrier flow gas. Although the reaction of hydrogen and carbon dioxide is exothermic, the small quantities reacting require supplemental heating to make up for system heat losses.

In an oxygen regeneration operating mode, it is even more desirable that provisions be made to shut down the electrolysis modules temporarily so that this power may be used for experiments. It is not desirable to shut the reactor down because of its high operating temperature. This subsystem is kept operating, and only the electrolysis modules are shut down. A hydrogen accumulator is required to feed hydrogen to the reactor during this period. It is possible that a quiescent or dwell mode of operation of the Bosch reactor can be developed which would make startup and shutdown more simple. With this capability the hydrogen accumulator may be eliminated, and some of the 388 W used to operate the reactor could be diverted to the experiments. This problem is also discussed in Appendix B.

2.3.11 Summary of Physical Characteristics

Table 2-5 shows a summary of the Phase-IIb EC/LS system weight and power, broken down by subsystem. The Phase IIa system weight is also shown for reference. The average power is defined as the rated power multiplied by the estimated percent operating time.

Table 2-6 shows a summary of the expendables to be supplied to the laboratory. The system is launched with 20 days of expendables on board for a six-man crew. Heat transfer fluid weights are included in the launch weight, because they do not normally require further resupply.

2.4 LOGISTICS SPACECRAFT REQUIREMENTS

The following paragraphs present a discussion of the logistics spacecraft requirements.

2.4.1 Phase-IIa System

The logistics spacecraft consists of an Apollo spacecraft and a cargo module. Some minor changes to the Apollo Environmental Control System were required in order that it be compatible with MORL operations. The cargo module EC/LS requirements consisted of a ventilation circuit and a cryogenic oxygen and nitrogen transfer system.

Table 2-5

EC/LS SYSTEM--WEIGHT, VOLUME, AND POWER SUBSYSTEM SUMMARY

	Phase IIb					Phase II a
			Average Power (W)[1]			
Subsystem	Dry Weight (lb)	Volume (in.^{3})	Basic	Nine-Man	O_2 Regen.[2]	Dry Weight (lb)
Atmospheric supply	847.0	108,687	1,480	2,120	1,480	913
Atmospheric purification	665.5	22,982	745	745	792	546
Water management	228.4	19,882	1	1	1	160
Waste management	44.7	10,490	10	14	10	23
Compartment conditioning	129.0	2,397	333	333	333	124
Cooling circuit	131.0	8,244	32	32	32	273
Heat transport circuit	67.5	9,480	107	107	107	136[3]
Atmospheric pumpdown	392.9	314,250	--	--	--	314
Totals	2,506.0	496,412	2,708	3,352		2,489
Launch expendables (20 days + fluids)	934.1					871
Total launch weight	3,440.1					3,360
CO_2 reduction subsystem (resupplied)	(255)				388	
					3,143	

[1]Assumes continuous occupancy of the Hangar/Test area and B/L laboratory.
[2]For a six-man crew.
[3]Includes heating subsystem weight.

Table 2-6

EC/LS SYSTEM--EXPENDABLE SUMMARY

		Weight (lb)		
Item	Description	Launch Six Men--20 Days	Basic Resupply Six Men--90 Days	O_2 Regen. Resupply Six Men--90 Days
115	Oxygen, gaseous, PLSS	14	14	14
116	Oxygen, gaseous	105	-	-
117	Nitrogen, gaseous	203	120	120
228	Charcoal	11.9	11.9	11.9
233	Charcoal	3.0	3.0	3.0
305	Complexing agent	2.8	16.1	16.1
306	Wick	3.0	20.2	20.2
316	Potable water	165.0	-	-
911	Electrolysis water	229.0	1,030*	-
701	Waste disposal sphere	-	22	22
-	Urine bags	18.8	89	89
-	LiOH cannisters	-	60	60
-	Heat transport fluid	70.5	-	-
-	Cooling circuit fluid	108.1	-	-
		934.1	1,386.2	356.2

First resupply only

*Electrolysis water 1,585
PLSS backpacks 128

2.4.2 Changes Required for the Basic Operating Mode

The cryogenic oxygen and nitrogen transfer system is eliminated, because oxygen is supplied by the electrolysis of water, and nitrogen is supplied as a gas. For the new system, the nitrogen gas tanks are merely added to the bulk cargo and are transferred to the laboratory manually. The water is resupplied by an automated transfer system similar to that previously used for the liquid oxygen, except that the water is at low pressure and normal ambient temperature (which is well above the freezing point of water). The water is contained in two 36.5-in. diam. tanks which can hold 1,585 lb of water. Each tank is bisected by a double diaphragm. Application of pressure will separate the diaphragms and will expel the liquid to the laboratory storage tanks. Almost 100% removal efficiency can be obtained. The operation will be automated, so that transfer can be accomplished by remote control.

It is obvious that the reliability of the water transfer system will be higher than that for the cryogenic transfer system. In addition, a back-up mode of transfer will be provided for the water system that was not possible with the cryogenic system.

2.4.3 Changes Required for the Nine-Man Crew Operating Mode

The cargo module used to transfer the extra three men must also supply all the expendables required especially for them. In the case of water for breathing oxygen, the cargo module storage tanks will be off loaded to contain only enough water for the three men for the period of time which they intend to spend on MORL. This water is stored in the cargo module and is not transferred to MORL until the on-board tanks are sufficiently emptied to receive the extra water. It may be necessary to insulate or environmentally control these tanks, so that the water will not freeze during this period.

Section 3
SYSTEM OPERATION

3.1 PERFORMANCE

The design point performance of the EC/LS system is presented in the form of system operation charts. These charts are divided into two functional areas of thermal analysis: (1) the circulating gas subsystems, and (2) the circulating liquid subsystems. Gas-loop charts are provided for two cases: six men in the main laboratory in shirt sleeves for one case, and six men in a pressurized hangar in space suits for the other case. These charts apply to the basic operating mode or to the oxygen regeneration operating mode. The liquid-loop chart is applicable only to the oxygen regeneration operating mode.

3.1.1 Atmosphere Conditioning

The design performance chart for the laboratory area is presented in Figure 3-1. Laboratory temperature is maintained at 75°F by a temperature control heat exchanger and fan combination. A volumetric flow of 750 cfm at 7 psia is necessary to provide laboratory ventilation and adequate cooling. As the air-cooled electronics load is variable, the coolant fluid flow through the heat exchanger is throttled as necessary to maintain cabin temperature. The total heat load at the design point of this subsystem consists of the heat leak from the CO_2 removal system, the laboratory metabolic sensible heat load (less the quantity of heat removed by the atmosphere purification loop), and the assumed air cooled electronics heat load of 1 kWt.

Contaminant removal and humidity control is accomplished by directing 90 cfm through the contaminant control system at a temperature of 75°F. The flow passes through the debris trap and pressure is increased by 4.2 in. of water using one of the two centrifugal fans. The other fan is redundant. Trace contaminants are removed by the chemisorbent bed and catalytic burner. Power supplied to the catalytic burner is 20 W which raises the temperature

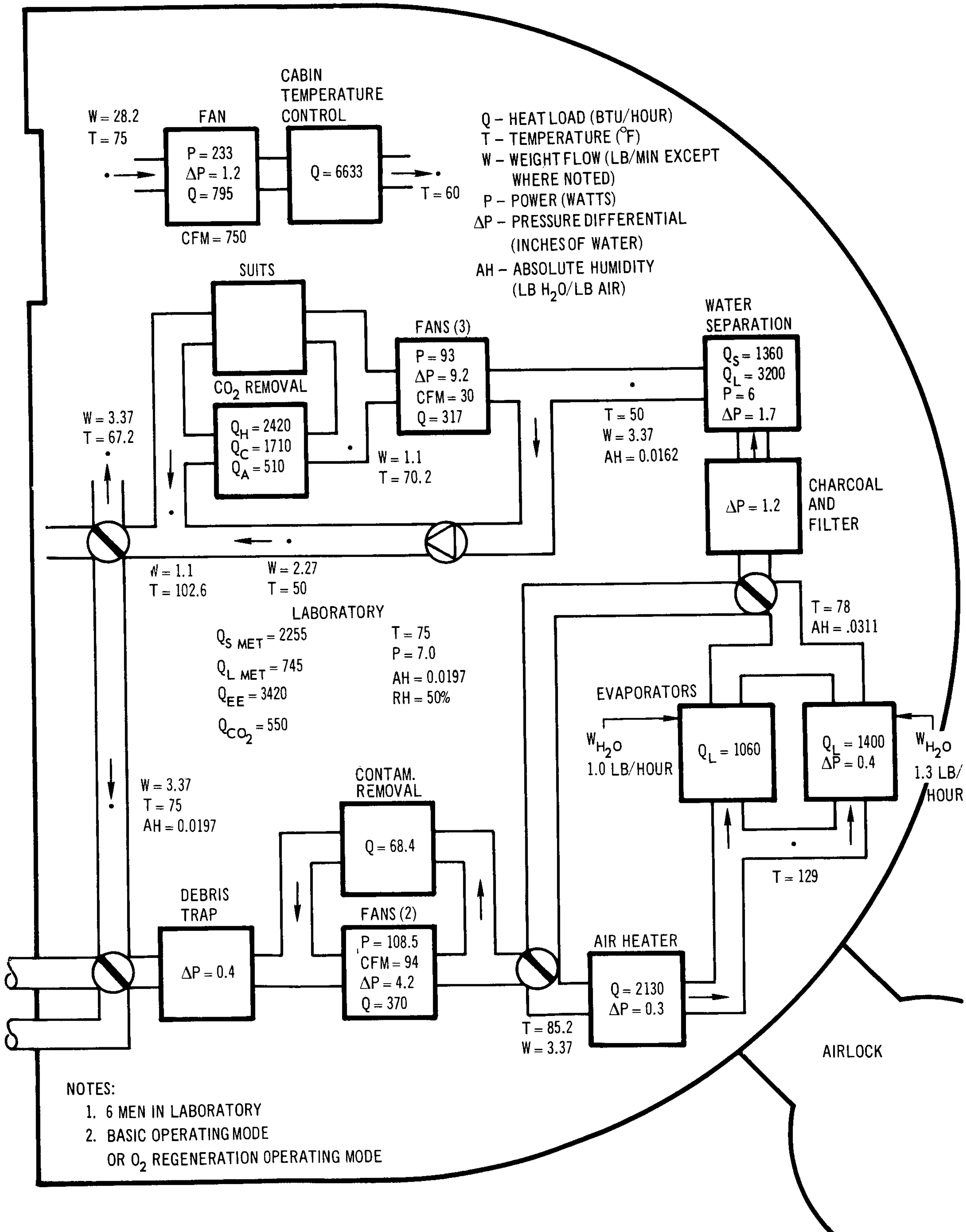


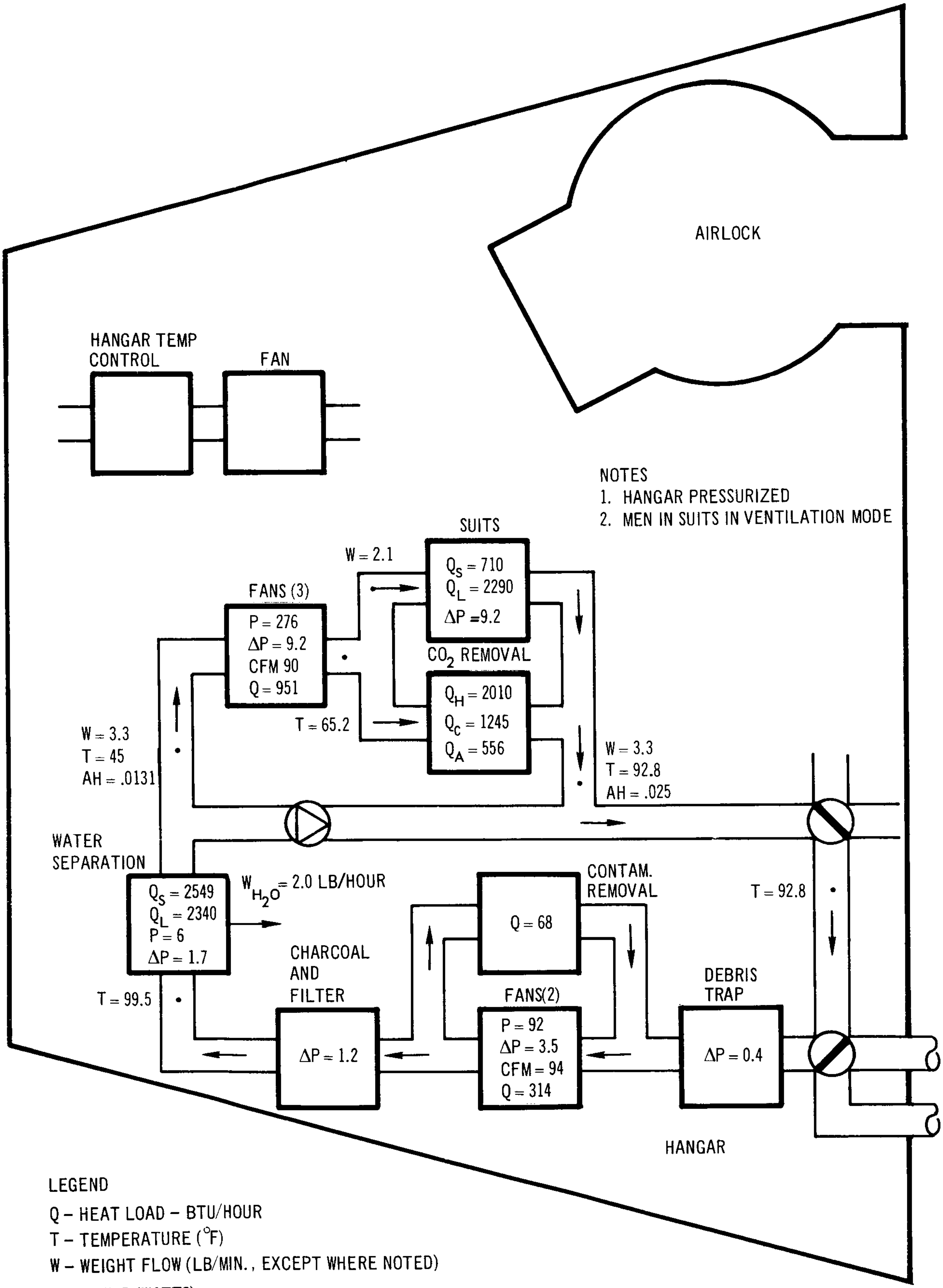
Figure 3-1. Laboratory Atmosphere Heat Balance

of the air to 550°F. A regenerative heat exchanger transfers heat to the incoming flow to minimize heat loss.

Downstream from the fan, the air heater supplies 2,130 Btu/hour to raise this air flow temperature to 129°F before the flow enters the evaporators used for processing urine and wash water. A maximum absolute humidity of 0.0311 lb H_2O/lb air, at a temperature of 98°F, is acquired by the air stream in the evaporators. The water is then separated and removed by the condensing heat exchanger and water separator. The air leaving the water separator is saturated at 50°F. After water separation, about one-third of the flow is circulated through the CO_2 removal system by the suit loop fan. This flow passes through the adsorbing silica gel bed, the adsorbing molecular sieve bed, and then is directed through the other silica gel bed (desorbing) to remove the water vapor. Since an equal amount of water is removed and then added, the final CO_2 concentrator outlet air dew point is approximately the same as at the inlet. The CO_2 removal flow then is mixed with the bypassed flow and enters the laboratory at 67°F. In the laboratory, the water production of the crew creates a relative humidity of 50%.

3.1.2 Suit Loop Operation

The suit loop operation flow chart (Figure 3-2) was prepared for Hangar/Test area suit operation with six men in suits at 7 psia. With all three suit loop fans in operation drawing 3.3 lb/min. to the suits and to the CO_2 removal system, the suit flow is 10 cfm/man. A total metabolic rate of 500 Btu/hour/man is assumed with a sensible-latent split of 146 Btu/man-hour and 354 Btu/man-hour respectively, based on a suit inlet dew point of 45°F. The total flow from the contaminant loop is drawn to the suits and CO_2 system. Even though the system is identical to the laboratory system, in this application the flow will increase because the pressure drop of the wick evaporator is not existent in the hangar system. Since detail data on this fan is not available, the flow was assumed to be the same; however, the power was reduced accordingly. The metabolic rate of 500 Btu/hour is based on a 7 psia operating pressure, where the atmosphere circulates freely between the suit and the cabin through an open faceplate.



LEGEND
Q – HEAT LOAD – BTU/HOUR
T – TEMPERATURE (°F)
W – WEIGHT FLOW (LB/MIN., EXCEPT WHERE NOTED)
P – POWER (WATTS)
ΔP – PRESSURE DIFFERENTIAL (INCHES OF WATER)
AH – ABSOLUTE HUMIDITY (LB H_2O/LB AIR)

Figure 3-2. Hangar Suit Loop-Heat Balance

Loop heat rejection is done in the condensing heat exchanger, which absorbs the suit fan and contaminant fan heat as well as the metabolic heat. The water gained from metabolic production (2 lb/hour) is transferred to the water management subsystem by the centrifugal pump.

Metabolic loads up to 1,020 Btu/hour/man may be accommodated by the suit loop flow at the 7 psia pressure. When operating in a depressurized laboratory at a suit loop pressure of 3.5 psia, the maximum metabolic rate the system may tolerate is 920 Btu/hour/man, the difference being the sensible capacity of the gas flow.

Suit operation differs from design point operation in that a 45°F dew point is required in the flow entering the suits. In the design case, the exit dew point of the condenser is 50°F. This condition is the design point for the CO_2 removal system silica gel beds with the highest bed heating and cooling requirements. Although the thermal requirements of the system are based primarily on the design case, the suit operation case imposes the requirement of the lowest sink temperature of the system, requiring the lowest inlet humidity to the suit.

3.1.3 Performance of the Liquid Circuits

The average design point operation of the liquid thermal conditioning subsystems is shown in Figure 3-3. The operational description, by subsystems, is presented below.

3.1.3.1 Heat Transport Subsystem

The heat transport subsystem cools equipment in the Laboratory and the Hangar/Test area. The inlet temperature of this water loop is 40°F and is determined by humidity control requirements for the suited condition. The three parallel paths of the loop maintain the proper temperatures in each of the components conditioned. For the design point operation, the sources of heat are the crew, laboratory EC/LS components, and electronics cooling loads. As components and subsystems are activated in the hangar, the sources of heat shift from laboratory to hangar. A throttling valve, controlled by cabin and fluid temperature sensors upstream from the laboratory

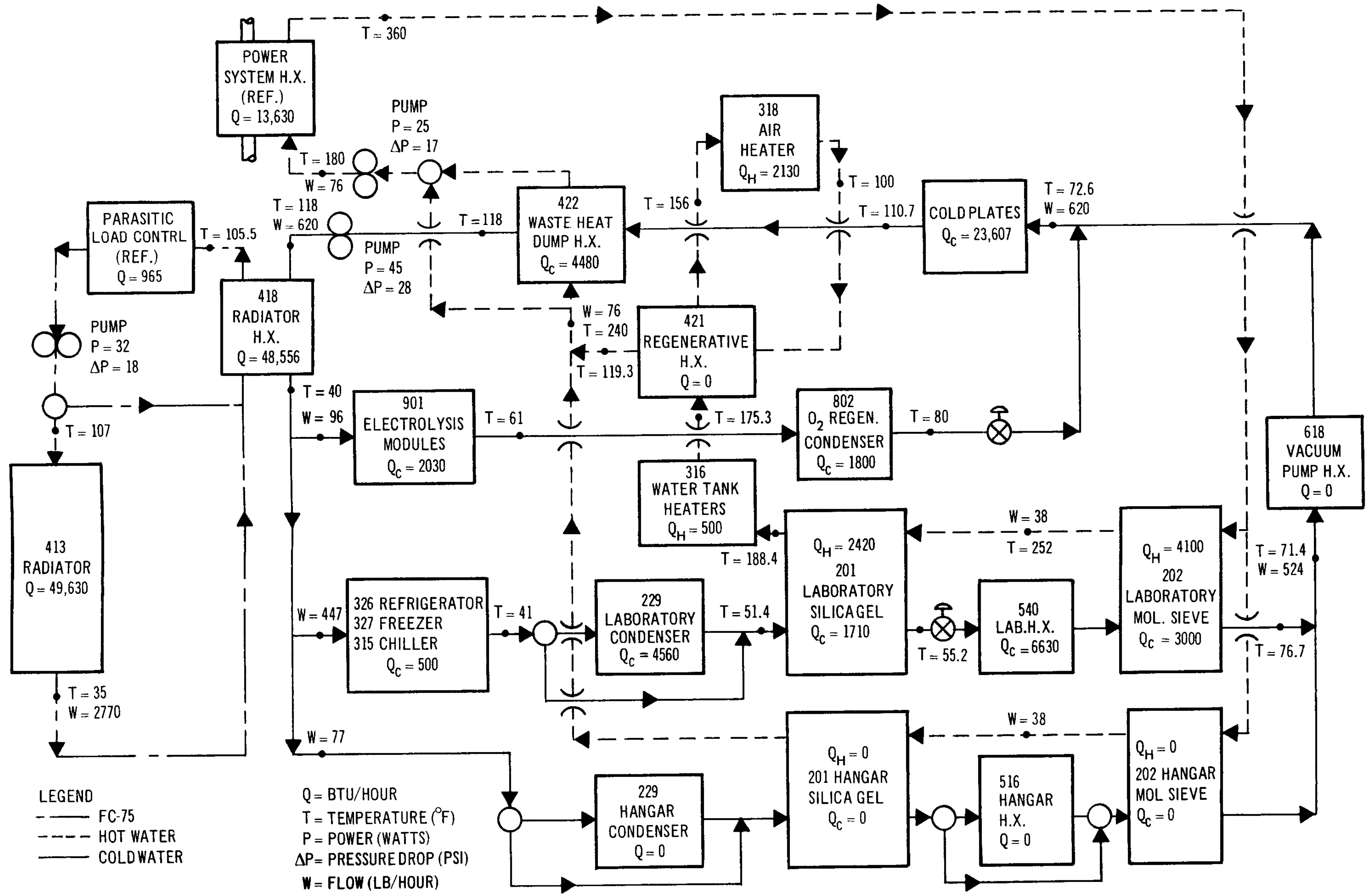


Figure 3-3. Heat Balance – Liquid Loops

heat exchanger, senses a decrease in laboratory air temperature and throttles the flow in the line. (The fluid temperature sensor will not allow further flow decrease when the fluid temperature reaches 70°F.) Since the pump provides a constant flow, more coolant water is directed to the hangar loop. The flow through the electrolysis cell is controlled in a similar manner. The total cooling and temperature requirements of the system (including electronics) allow 77 lb/hour to pass through the hangar portion of the loop with no load. With no change in laboratory heat load, this flow alone is sufficient to accommodate activation of the EC/LS electrical equipment and heating circuit loads. With the given flows, none of the loops will be starved even with a large load in one branch.

The hangar and laboratory flows join to cool the hangar vacuum pump (not activated in the design case) and pass to the liquid-cooled electronics. The maximum allowable liquid temperature at the outlet of the electronics is 120°F. An outlet temperature of 112.6°F is shown, and is the result of the average value of the bed heating loads. Downstream from the electronics is the waste-heat-dump heat exchanger which absorbs heat not used in the heating circuit. Calculations show heat transferred in this exchanger because of the use of average bed heating loads instead of maximum. The flow is returned to the radiator heat exchanger for heat transfer to the cooling circuit.

The heating circuit (shown in dotted lines) transfers waste heat from the power system, for use by the air heater, the silica gel beds and the molecular sieve beds. The water in this loop is at 300 psia. This waste-heat-dump heat exchanger is controlled by a temperature sensor providing a constant 180°F fluid temperature to the power system heat exchanger. The constant load of 13,630 Btu/hour from the power system is removed during all phases and cycles of heating requirements of the EC/LS, regardless of the operating mode actually chosen.

The calculations shown in Figure 3-3 are for the oxygen regeneration operating mode. If the system is operated in the basic mode, some of the temperatures will be slightly different because of the absence of the Bosch reactor.

3.1.3.2 Cooling Circuit

The cooling circuit transfers heat from the heat transport circuit to the space radiator. Shown in the performance chart is 965 Btu/hour to the parasitic load, because the hangar fans were assumed to be off for this calculation. Since the power system generates a constant power level, unused power is absorbed by this load dump. The design point of the radiator is 49,630 Btu/hour between temperatures of 107° and 35°F. The fluid in this loop is FC-75 pressurized to 50 psia.

3.2 OPERATION AT LAUNCH

The cooling circuit fluid will be conditioned by ground equipment during prelaunch operations. In this mode, the radiators are bypassed because of the location of the ground connections. This is necessary so that the surface of MORL does not become covered with moisture when the ambient dew point is above the fluid operating temperature.

Immediately prior to launch, the ground connections are removed and the bypass valve that will divorce the heat transport loop from the cooling loop is activated. This is necessary because the radiator is ineffective until orbit is achieved, and the precooling and thermal mass of heat transport circuit is expected to cool the laboratory components that operate during launch. Since this load is less than 1 kW, this type of environmental control is satisfactory. The cooling loop is bypassed so that the aerodynamic heat which will raise the radiator surface temperature to over 200°F is not pumped into the laboratory. As soon as orbit is achieved, the heat transport loop bypass valve is switched back to the normal operating mode.

During launch, the parasitic heat load is receiving energy from the power system, because the power system is activated and the laboratory requires relatively little power. The cooling circuit is allowed to absorb this heat which, in conjunction with the aerodynamic heat, will raise the fluid and structure temperature to about 300 to 350°F. The cooling circuit system is designed to withstand this condition.

The laboratory atmosphere is premixed to an oxygen nitrogen mixture at 14.7 psi during prelaunch operations. During launch, the compartment relief valves open to bleed the pressure down to 7 psia. This eliminates the necessity of launching oxygen and nitrogen for the initial supply of atmosphere.

All other EC/LS systems are dormant during launch and are not activated until MORL is occupied.

3.3 MONITORING AND FAULT ISOLATION

The EC/LS system performance is determined by the measurement of the basic parameters of temperature, pressure, quantity, and flow. The instrumentation of the EC/LS system is divided into two broad categories: (1) controlling sensors, and (2) indicating sensors. The controlling sensor is that which produces an actuation of a remedial control when a condition exists beyond normal limits. The indicating sensor is that which informs the crew of a given condition with no remedial action. In many cases, a controlling sensor also serves as an indicating sensor. A list of indicating sensors is included in the item list of Figure 2-1. The sensors and subsequent indicators will display a given condition upon the laboratory panel. Normal monitoring and fault isolation monitoring requirements are shown in Tables 3-1 and 3-2 respectively.

Table 3-1 (page 1 of 3)

EC/LS SYSTEM DISPLAYS - NORMAL MONITORING

NAME	Instr. (Ref. 1)	Oper	Use		Type		Alarm		Control		Tele-metered
			Monitor	Test	Cont.	Demand	Warning	Caution	Remote	Local	
Pressure, total laboratory	I 11		X		X		X		X	X	X
Pressure, total laboratory suit loop	I 11	X (2)	X		X		X			X	
Pressure, part., lab O_2	I 24		X		X		X		X	X	X
Pressure, total, hangar	I 11	X (2)	X		X		X		X	X	X
Pressure, total, hangar suit loop	I 11	X (2)	X		X		X			X	
Pressure, partial, hangar O_2	I 24	X (2)	X		X		X		X	X	X
Pressure, differential, H_2O separation pump, laboratory	I 18		X		X			X		X	
Pressure differential, H_2O separation pump, hangar	I 18	X (2)			X			X		X	
Pressure, differential, FC-75 pump	I 18		X		X		X		X	X	X
Pressure, total, cooling circuit	I 12		X		X		X			X	
Pressure, differential, heat transport circuit pump (2)	I 18		X		X		X		X	X	X
Pressure, total, heat transport circuit (2)	I 12		X		X		X			X	
Pressure, partial, laboratory CO_2	I 26		X		X			X		X	
Pressure, partial, hangar, CO_2	I 26		X		X			X		X	
Pressure, total, water electrolysis cell (5)	I 12		X		X			X		X	
Pressure, total, oxygen, electrolysis cell (5)	I 11		X		X			X		X	

Table 3-1 (page 2 of 3)

NAME	Instr. (Ref. 1)	Oper	Use Monitor	Test	Type Cont.	Demand	Alarm Warning	Caution	Control Remote	Local	Tele-metered
Pressure, total, hydrogen electrolysis cell (5)	I 11		X		X			X		X	
Pressure, total, nitrogen electrolysis cell (5)	I 11		X		X			X		X	
Temperature, cooling water electrolysis cell inlet	I 16		X		X			X		X	
Temperature, cooling water electrolysis cell outlet (5)	I 16		X		X			X		X	
Temperature, water electrolysis cell (5)	I 16		X		X			X		X	
Temperature, laboratory	I 16		X		X			X	X	X	X
Temperature, hangar	I 16		X		X			X	X	X	X
Temperature, B/L laboratory	I 16		X		X			X		X	
Temperature, H_2O, radiator HX outlet	I 16		X		X		X		X	X	X
Temperature, H_2O, H/T circuit HX outlet	I 16		X		X		X		X	X	X
Temperature, H_2O H/T circuit HX inlet	I 16		X		X			X	X	X	
Temperature, water, electrolysis unit inlet	I 16		X		X		X			X	
Temperature, water, electrolysis outlet (5)	I 16		X		X			X	X	X	X
Flow rate, laboratory N_2	I 15		X		X			X		X	X
Flow rate, hangar N_2	I 15		X		X			X		X	X
Flow rate, B/L laboratory vent air	I 10		X		X			X		X	
Quantity, accumul., heat transport water (2)	I 20		X		X		X			X	
Quantity, FC75 accum. radiator No. 1	I 22	X (2)	X		X		X			X	

Table 3-1 (page 3 of 3)

NAME	Instr. (Ref. 1)	Oper	Use Monitor	Test	Type Cont.	Type Demand	Alarm Warning	Alarm Caution	Control Remote	Control Local	Tele-metered
Quantity, FC75 accum. radiator No. 2	I 22	X (2)	X		X		X			X	X
Quantity, potable H_2O tanks (4)	I 20	X			X			X		X	
Quantity, urine storage tank	I 20	X			X			X		X	
Quantity, urine process tank	I 20	X			X			X		X	
Quantity, wash water storage	I 20	X			X			X		X	
Quantity, wash water process	I 20	X			X			X		X	
Quantity, complex agent (2)	I 20	X			X			X		X	
Conductivity, H_2O sep. outlet	I 28		X		X			X		X	

Note:

1 - Refer to Figure 2-1

2 - Operational during mode selection

Table 3-2 (page 1 of 2)

EC/LS SYSTEM DISPLAYS - FAULT ISOLATION MONITORING

NAME	Instr. (Ref. 1)	Use		Type		Alarm		Control		Tele-
		Oper	Monitor	Test	Cont.	Demand	Warning	Caution	Remote	Local	metered
Pressure, total GO_2 tanks (3)	I 13		X			X		X		X	
Pressure, total GN_2 tanks (5)	I 13		X			X		X		X	
Pressure, total, laboratory airlock	I 11	X				X		X		X	
Pressure, total, hangar, airlock	I 11	X				X		X		X	
Pressure, total, laboratory zeolite bed	I 11			X		X				X	
Pressure, total, hangar zeolite bed	I 11			X		X				X	
Pressure, total, hangar storage tank	I 12	X				X				X	
Temperature laboratory catalytic burner	I 17		X			X		X		X	
Temperature hangar, catalytic burner	I 17		X			X		X		X	
Temperature, B/L laboratory catalytic burner	I 17		X			X		X		X	
Temperature, laboratory vent air	I 16		X			X				X	
Temperature, air, evap. outlet (2)	I 16			X		X				X	
Temperature, laboratory condenser outlet	I 16		X			X		X		X	
Temperature, hangar condenser outlet	I 16		X			X		X		X	
Temperature, potable water tanks (4)	I 16		X			X		X		X	
Flow rate, laboratory vent air	I 10		X			X		X		X	

Table 3-2 (page 2 of 2)

NAME	Instr. (Ref. 1)	Oper	Use Monitor	Use Test	Type Cont.	Type Demand	Alarm Warning	Alarm Caution	Control Remote	Control Local	Tele-metered
Flow rate, hangar vent air	I 10		X			X		X		X	
Flow rate, laboratory purification air	I 10		X			X		X		X	
Flow rate, hangar purification air	I 10		X			X		X		X	
Flow rate, laboratory suit loop	I 10		X			X		X		X	
Flow rate, hangar suit loop	I 10		X			X		X		X	
Relative humidity, laboratory	I 23			X		X				X	
Relative humidity, hangar	I 23			X		X				X	
Relative humidity, B/L laboratory	I 23			X		X				X	
Humidity, laboratory zeolite bed	I 23			X		X				X	
Humidity, hangar zeolite bed	I 23			X		X				X	
Pressure, partial, NH_3, CH_4, H_2, CO	I 25		X			X		X		X	
Trace contaminants	I 27			X		X				X	

Notes:

1 - Refer to Figure 2-1

2 - Operational during mode selection

NOMENCLATURE

EC/LS	Environmental control life support
AAP	Apollo applications program
CO_2	Carbon dioxide
PCO_2	Partial pressure of carbon dioxide
kWt	Kilowatts--thermal
kWe	Kilowatts--electrical
O_2	Oxygen
GO_2	Gaseous oxygen
PO_2	Partial pressure of oxygen
N_2	Nitrogen
GN_2	Gaseous nitrogen
PLSS	Portable life support system
B/L	Biological/liquids
Btu	British thermal units
cfm	Cubic feet per minute
FC-75	Fluorochemical manufactured by Minnesota Mining and Manufacturing Co.
α_s	Solar absorptivity coefficient
ϵ_t	Thermal emissivity coefficient
CH_4	Methane
MAC	Maximum allowable concentration
PDP	Predevelopment phase

REFERENCES

1. Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept. Vol. XIV, Laboratory Mechanical Systems Environmental Control/Life Support, Douglas Report No. SM-46085.

2. Preliminary Design of a Pu-238 Isotope Brayton Cycle Power System for MORL.

   Vol. I--Technical Summary, Douglas Report No. SM-48832.

   Vol. IV, Book 3--Technical Appendix, Douglas Report No. SM-48837.

Appendix A
SUBSTANTIATION DATA

A. 1 COOLING SUBSYSTEM

Because of the increased cooling load and the resultant increase in radiator area requirements, considerable analysis was conducted on the cooling subsystem. It may be noted that some of the ground rules and design criteria used in the following analyses are not consistent. This is unavoidable in the iterative method of optimization which was used throughout this study. However, these inconsistencies were always minor and the final design criteria established did not invalidate the conclusions reached during a preceding analysis.

A. 1. 1 Radiator Configuration

The following paragraphs discuss the radiator for MORL as it is affected by surface characteristics, heat influx, tube configuration, and fin effectiveness.

A. 1. 1. 1 Surface Characteristics

An evaluation of available radiator coatings was completed in conjunction with the study on the design of an Isotope Brayton Cycle power system for MORL (Reference 2). Since the EC/LS and power systems radiators have the same design requirements regarding the surface optical properties, the same radiator coating will be used for both radiators. The results of this work is summarized below.

Fifty-three commercially available temperature control coating materials were evaluated. The best performance is obtained from a potassium silicate-zinc oxide material (Z-93), that was developed by ITT Research Institute (formerly Armour Research Foundation). This material shows a high degree of stability when exposed to ultraviolet radiation in a hard-vacuum environment. Table A-1 lists the pertinent data on this radiator coating.

Table A-1

CHARACTERISTICS OF RADIATOR COATING Z-93

Type	Inorganic
Vehicle	Potassium Silicate
Pigment	Zinc Oxide
Solar absorptivity (α_s)	
Initial	0.147
After*	0.159
Thermal emissivity ($_t$)	
Initial	0.925
After*	0.925
α_s / ϵ_t	
Initial	0.159
After*	0.172

*After exposure to 5 hours of ultraviolet radiation at one solar constant in a 1 x 10^{-7} Torr vacuum.

Additional exposure tests were conducted in an attempt to obtain more data on the life expectancy of the Z-93 coating. Results of these tests are given in Table A-2.

Table A-2

LIFE DATA--RADIATOR COATING Z-93

Characteristic	Initial	After*
αs	0.165	0.179
t	0.909	0.902
α_s / ϵ_t	0.181	0.199

*After exposure to ultraviolet radiation at 10.6 times sun intensity in Earth orbit.

It was assumed that the above test was equivalent to 4, 200 hours or approximately 6 months of extraterrestrial operation. Figure A-1 shows the degradation of the optical characteristics of Z-93 with time. The dashed section of the curve is a linear extrapolation to the 5-year point (MORL mission life). Based on the above data, an actual design point of $\alpha_s/\epsilon_t = 0.25$ was arbitrarily selected. The conservative value of 0. 25 was chosen because of the obvious inadequacy of existing data.

A. 1. 1. 2 Radiator Heat Influx

An orbital radiant heat transfer computer program was used to calculate the radiator heat influx resulting from direct solar energy, Earth-emitted energy, and Earth-reflected energy (albedo). These factors are variable with orbit inclination, orbit altitude, vehicle orientation, and radiator surface characteristics.

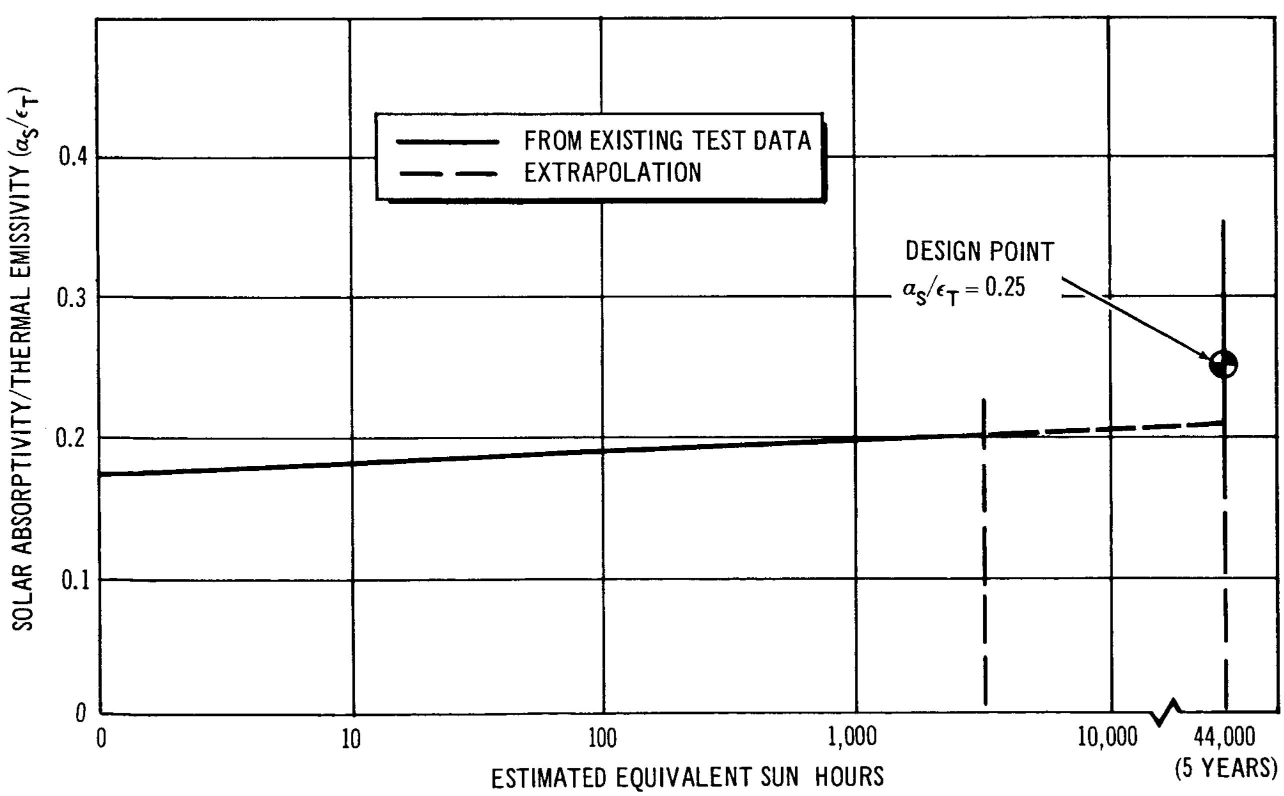


Figure A-1. Degradation of Z-93 Radiator Coating

Figures A-2 and A-3 show the average heat influx as a function of orbit position for the three orbits of interest for α_s/ϵ_t of 0.20 and 0.25. The heat influx is obtained by assuming that the MORL cylinder was actually a hexagon and calculating independently the heat influx for each of the six planar surfaces. The average heat influx is the arithmetic average of these six influxes.

Average heat influx can be related to equivalent sink temperature by the expression

$$\frac{Q_{in}}{A} = \sigma_t T_s^4$$

Where

σ = Stefan - Boltzman Constant, 0.1714×10^{-8} Btu/sq ft-°R^4

ϵ_t = surface thermal emissivity

A = radiating area, sq ft

T_s = equivalent sink temperature °R

Q_{in} = total heat influx Btu/hour

T_s represents the average temperature (around the circumference) "seen" by the radiator. Figure A-4 shows the effect of increasing α_s/ϵ_t on radiator area requirements.

A.1.1.3 Circumferential and Axial Tube Configurations

The basic radiator configuration recommended in Phase IIa was one where the radiator tubes were integrated with the meteoroid shield and were circumferential. In a circumferential design, each tube is as long as the circumference of MORL (68 ft) and the inlet and outlet headers are adjacent to each other and parallel with the axis of the vehicle. Since the radiator was confined to the cylindrical section of MORL, radiator length refers to the distance along the cylinder required by the radiator to dissipate the design heat load.

The configuration chosen for the Isotype Brayton Cycle power system radiator was one where the tubes are axial and the headers are circumferential.

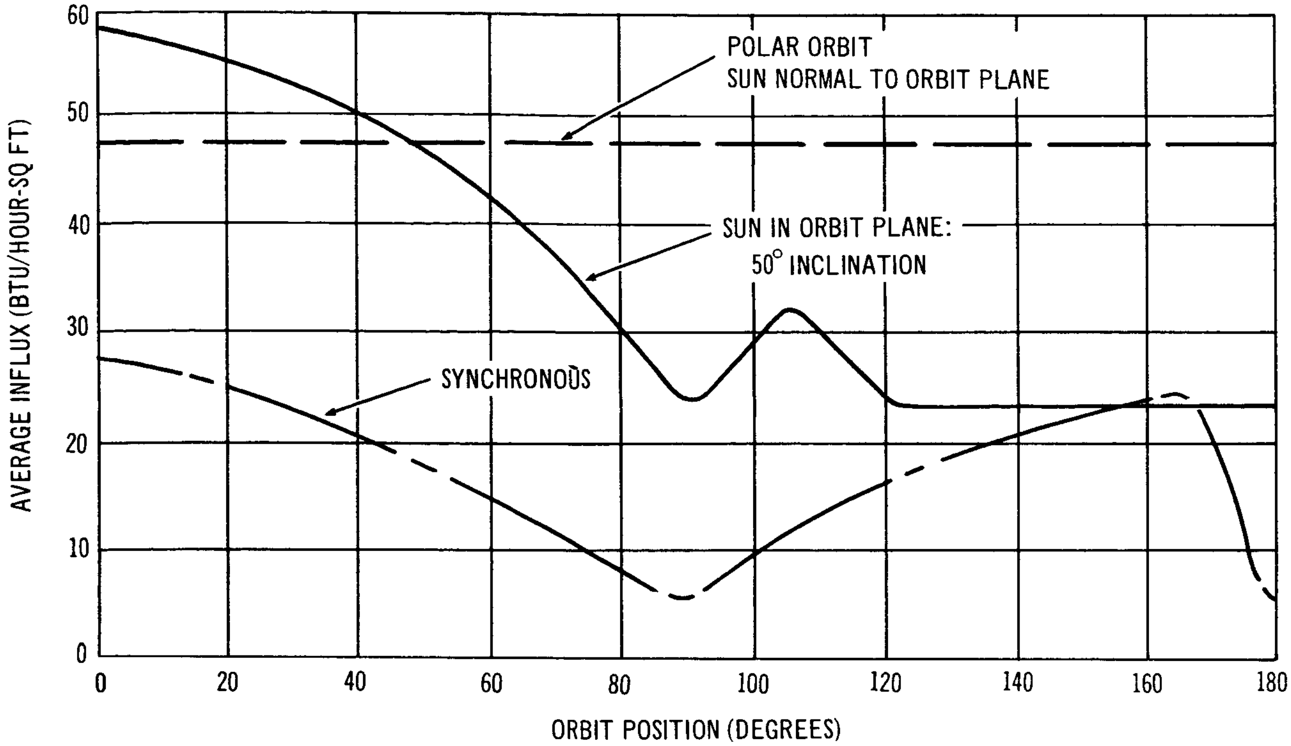


Figure A-2. Radiator Heat Influx as a Function of Orbit Position (Belly-Down Orientation, $\alpha_S/\epsilon_T = 0.20$, Albedo = 0.35)

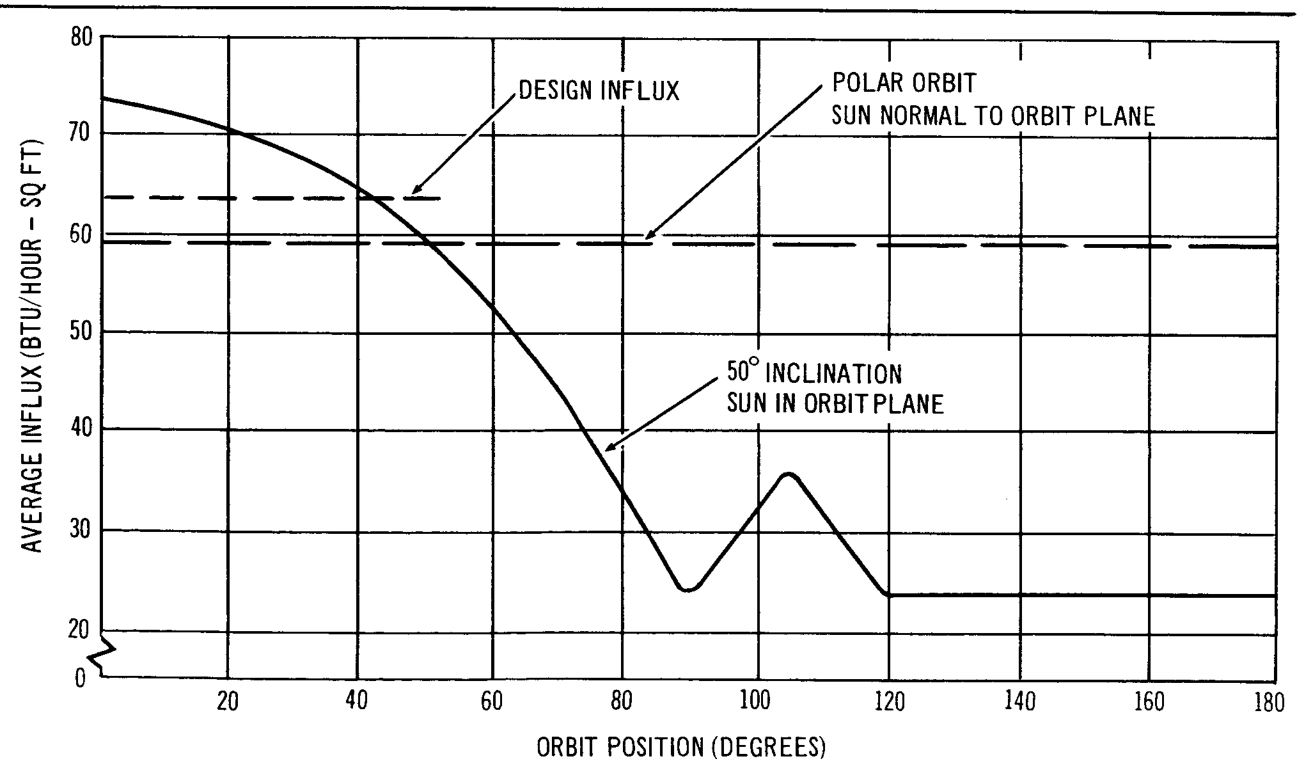


Figure A-3. Radiator Heat Influx as a Function of Orbit Position (Belly-Down Orientation, $\alpha_S/\epsilon = 0.25$, Albedo = 0.35)

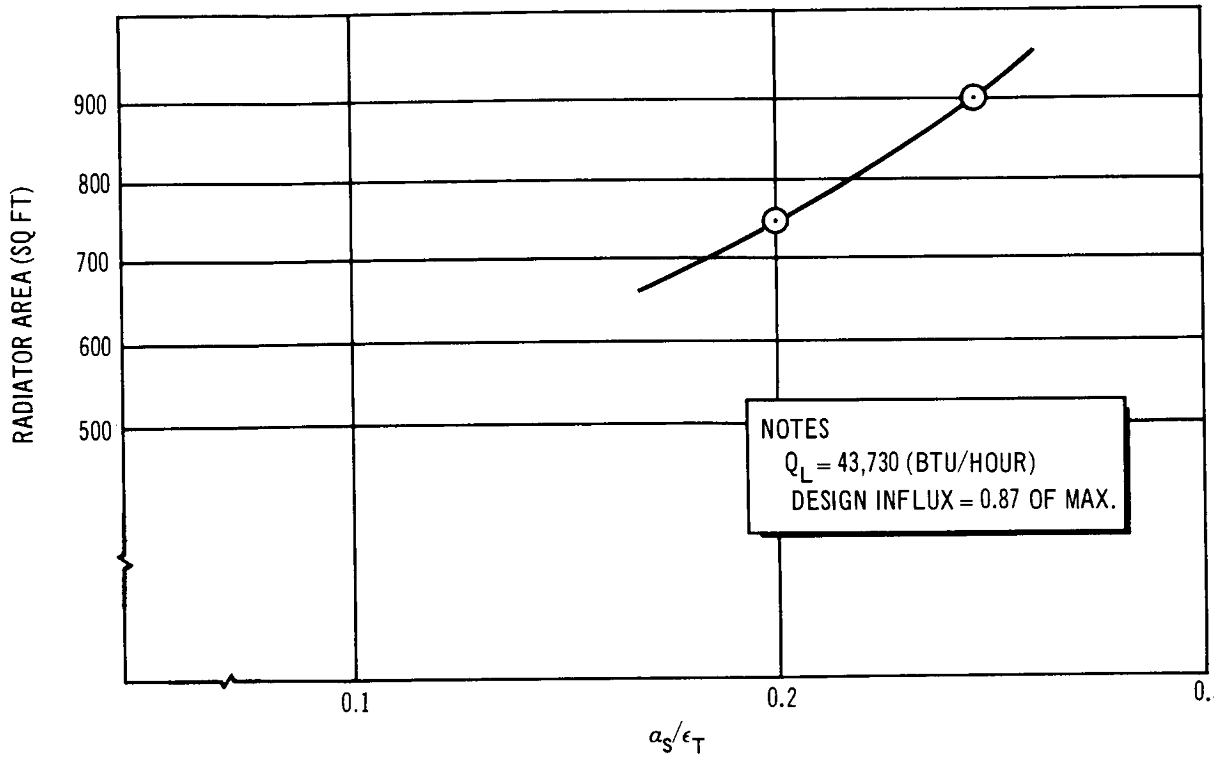


Figure A-4. Variation of Radiator Area with α_S/ϵ_T

To attempt to derive a single design common to both the EC/LS and power system radiators, a comparative study of the two configurations to reject the EC/LS heat load was performed. The results of this analysis are shown in Figure A-5. The figure shows that the circumferential configuration results in increased tube spacing for a given radiator length. Increased tube spacing means that fewer tubes (therefore a lighter radiator) are required. This can be understood by remembering that, in an axial configuration, the total fluid flow must be divided so that the flow per tube is small enough that the required outlet temperature (35°F) is reached at the end of the tube. In a circumferential configuration, the tube length is one circumference (68 ft); therefore, fewer tubes are required because of the length of the flow path. The circumferential configuration could possibly be lighter for axial tubes 70 ft long; however, this was not investigated because long axial tubes are unrealistic for MORL.

Since a circumferential radiator allowed the choice of a smaller radiator, and minimum radiator area was the primary requirement (See Section A. 1. 1. 3), this configuration was retained for the EC/LS system radiator.

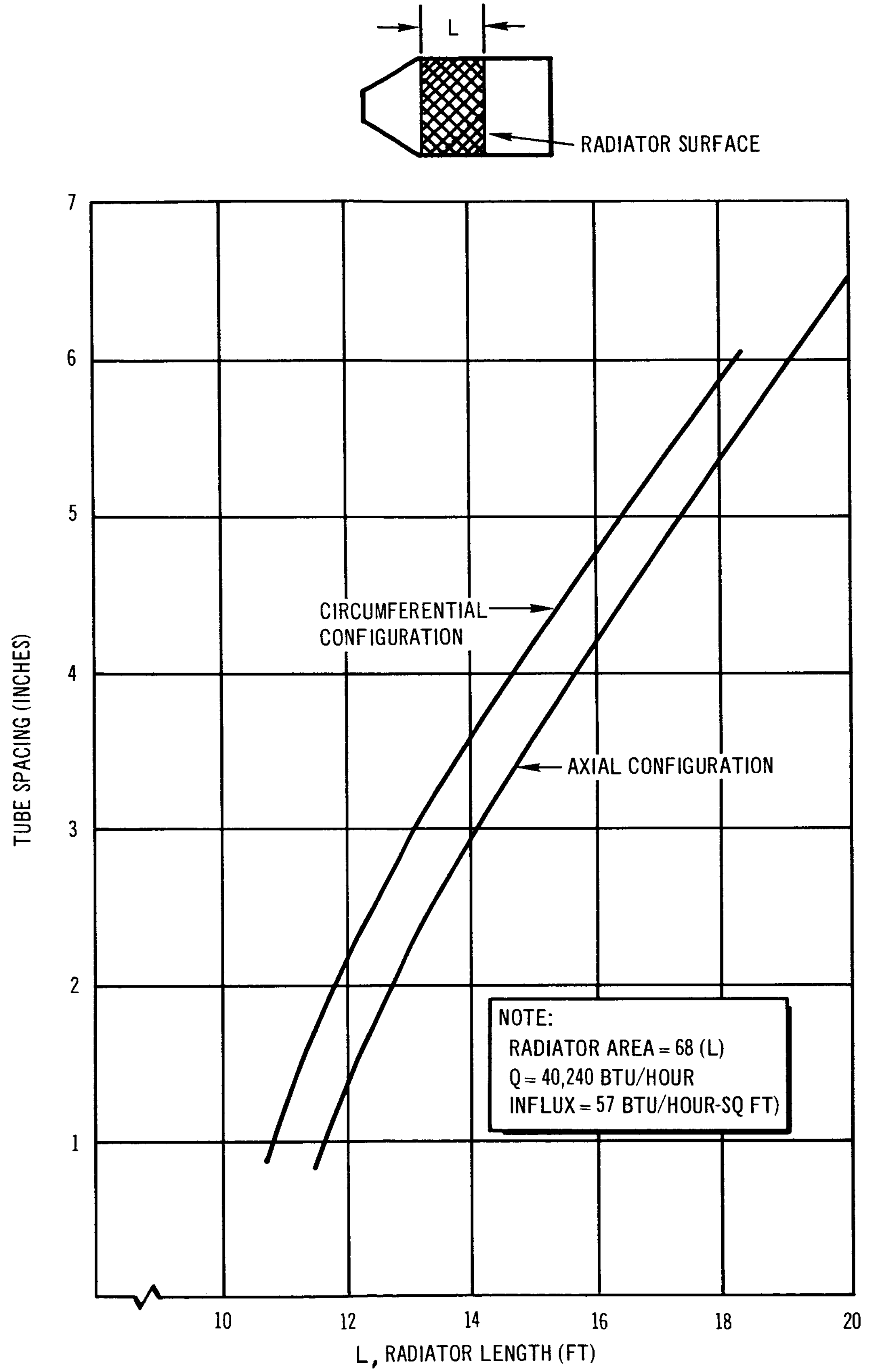


Figure A-5. Tube Spacing as a Function of Radiator Length

Another reason for selecting a circumferential configuration is that the variation of heat influx caused by direct solar and Earth albedo energy is averaged because each tube "sees" all the external heat sinks in a single pass. In an axial tube configuration, a tube on the sun side "sees" the maximum heat influx, whereas a tube on the space side "sees" zero influx. This variation of heat influx would result in large temperature differences in the fluid at the outlet of the tubes. If the flow would remain constant in each tube, the total mixed fluid temperature would be as predicted. However, as a result of the accompanying viscosity difference, the flow would increase in the hot tube and decrease in the cold tube. As the flow in the cold tube decreases, less heat is transferred, and the fluid in that tube becomes colder. In some cases, the flow distribution becomes unstable and virtually ceases on the cold side, making that portion of the radiator ineffective. Orificing the tubes to even out the flow is possible for a given orientation. However, since the radiator must be effective in all orientations, because of experimental requirements, this approach is not satisfactory.

The axial tube configuration is also awkward from an installation standpoint because the inlet and outlet headers must then be circumferential. The header nearest the aft interstage would be in a satisfactory location because it is exposed from the interstage area. However, the forward header must be between the pressure shell and the meteoroid shield, and is inaccessible for inspection and repair. It would be necessary to have an even-numbered multiple-pass configuration so that the headers would be on the same side. A multiple-pass configuration is not as efficient as a single-pass configuration because the returning cool fluid is warmed by the inlet fluid on the return pass. In the circumferential configuration, the headers are axial and the structural design is such that the headers can be exposed and examined at any time.

A.1.1.4 Fin Effectiveness

A Douglas computer program was used to determine the effectiveness of the MORL interstage structure when the heat is transferred from the fluid to the external skin surface. This computer program predicts three-dimensional convection, conduction, and radiation heat transfer in structures. The analysis had the following objectives:

1. Determine the fin effectiveness of the radiator.
2. Determine whether or not axial tubes (parallel to structural corrugations) contribute a significant heat transfer advantage over circumferential tubes (perpendicular to structural corrugations).
3. Determine the required heat-transfer contact at the assembly joints.

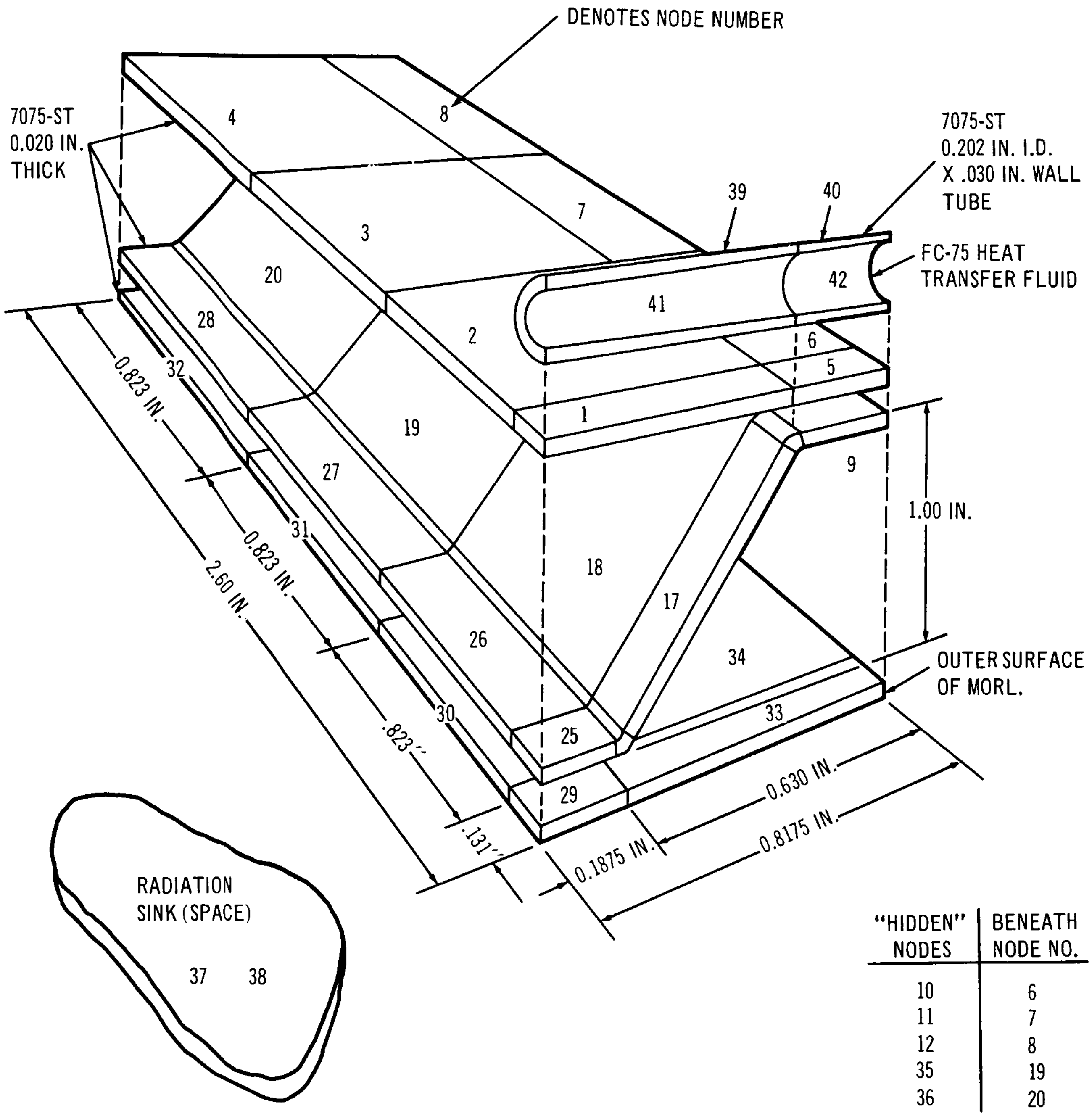
Figure A-6 shows the thermal model that was used in the computer program. Figure A-7 shows the radiator effectiveness as a function of bulk fluid temperature for two conditions. The conditions for Curves A and B are as follows:

1. Turbulent flow for T_{BULK} = 75°F; contact conductance = 500 Btu/hour-sq ft-°F.
2. Turbulent flow assured at all temperatures; contact conductance = 5,000 Btu/hour-sq ft-°F.

The results indicate that an effectiveness of 80% or better is obtained for all conditions. Where turbulent flow is established in the tubes, the effectiveness of the fin approaches 90%, an achievement that is difficult to improve, even if the structure were designed strictly as a radiating surface. This analysis led to the following two conclusions:

1. The use of the MORL interstage structure as a radiator fin does not penalize radiator effectiveness and, since there is no weight charge for this structure, the lowest possible radiator weight results.
2. Normal manufacturing methods will provide sufficient heat-transfer contact between the surfaces; because a contact conductance on the order of 5,000 Btu/hour-sq ft-°F can be achieved with a good seam weld.

The analysis was repeated for the axial tube configuration (Figure A-8). The results were essentially the same as shown in Figure A-7. This led to the conclusion that both configurations have comparable heat-transfer capability through the structure. The circumferential configuration was selected for reasons stated in Section A.1.1.3.



"HIDDEN" NODES	BENEATH NODE NO.
10	6
11	7
12	8
35	19
36	20

Figure A-6. Thermal Model for Circumferential Tubes

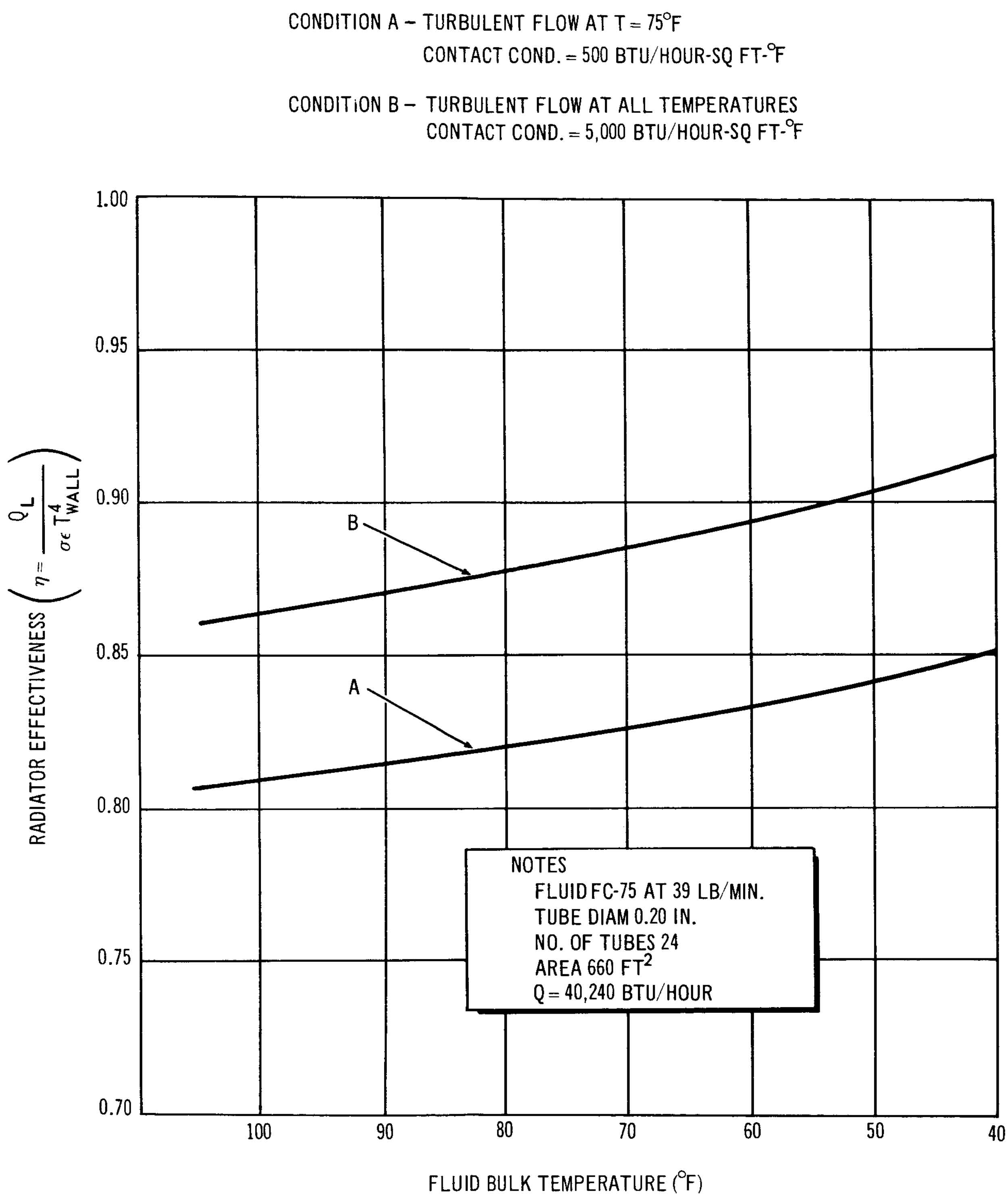


Figure A-7. Radiator Effectiveness as a Function of Fluid Bulk Temperature

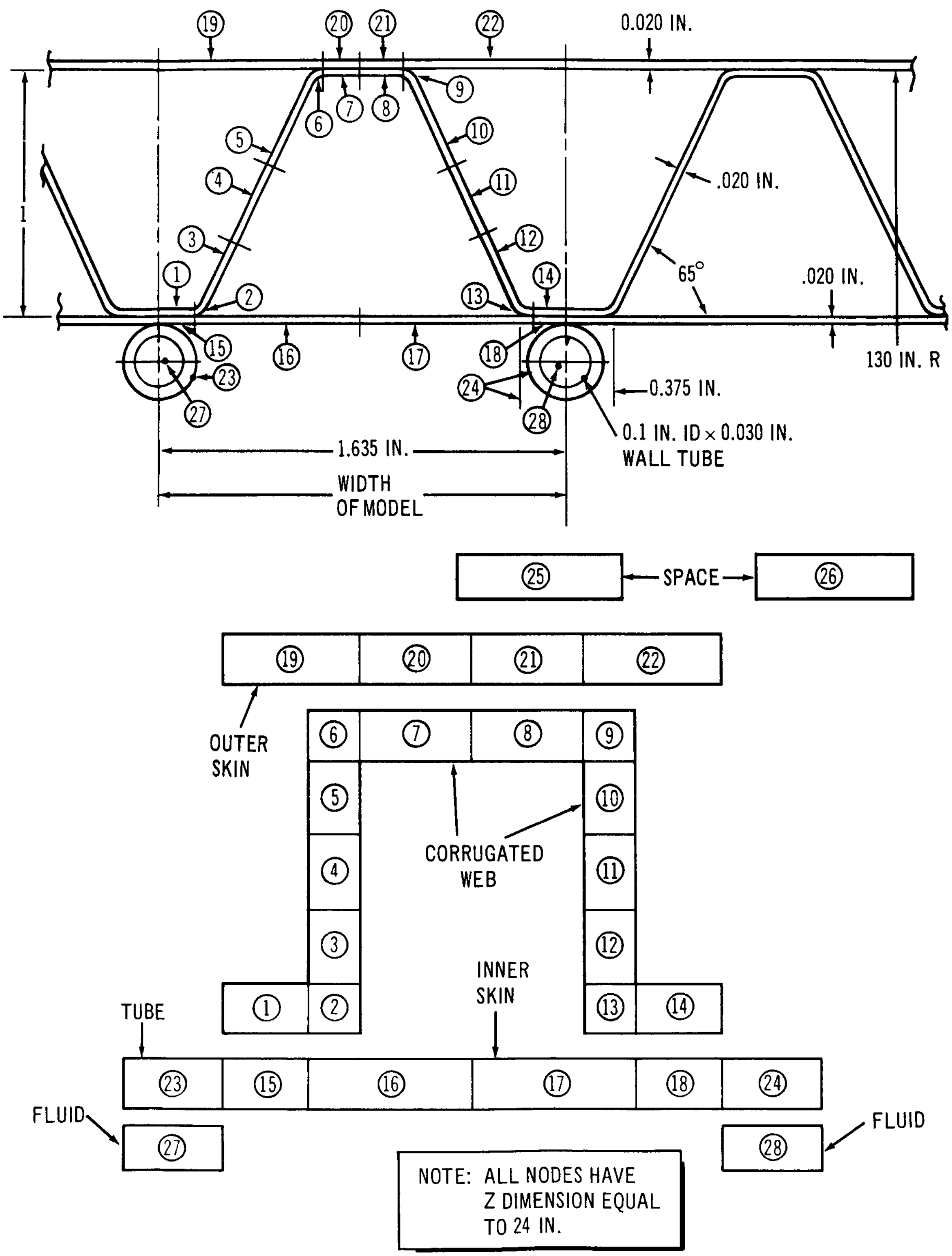


Figure A-8. Thermal Model for Axial Tubes

A. 1. 1. 5 Turbulent Versus Laminar Flow

In the design of the radiator, the following parameters are fixed by other design considerations: (1) heat load (Q_L), (2) fluid inlet temperature (T_{in}), and (3) fluid outlet temperature (T_{out}). Therefore, the total fluid flow (W_T) is fixed, because

$$W_T = \frac{Q_L}{C_P(T_{in} - T_{out})}$$

where C_P is the fluid specific heat.

Radiator weight decreases as the tube size decreases because the tube is lighter and contains less fluid. However, since the total fluid flow and surface area are fixed, the pressure drop and pumping power increase as the tube becomes smaller. Therefore, for a given power equivalent weight penalty, there must be an optimum tube diameter. This can be determined as follows:

$$\begin{aligned}\text{Equivalent weight} &= \text{tube weight} + \text{fluid weight} + \text{pumping power weight} \\ &= f(N, D) + f(N, D^2) + f(N^{-2}, D^{-5})\end{aligned}$$

Where

N = the number of tubes

D = the tube diameter

The pumping power function is further defined by choosing a flow velocity to ensure turbulent flow in the tube. The relationship between the Reynolds number (R_e) and N and D is as follows:

$$R_e = \frac{\text{Constant}}{ND}$$

By choosing a Reynolds number, a relationship between N and D is determined which can be inserted into the equivalent weight formula. The resulting equation is differentiated to determine the tube diameter that results in minimum weight.

A radiator design computation is necessary to determine whether this tube spacing provides a high enough fin effectiveness to reject the total heat required. An iterative procedure may be necessary to arrive at the optimum design.

This procedure was followed in the design of the radiator and the results are shown in Figure A-9. This indicates that it is clearly advantageous to establish turbulent flow in the tubes; as a result of this analysis, a turbulent flow Reynolds number was chosen as a design requirement for the radiator.

A. 1. 1. 6 Radiator Mechanical Design

The actual radiator tube cross-section used is detailed in Figure A-10. This shape was selected after considering weight, heat transfer, and manufacturability. The tubes are attached to the meteoroid structure as shown in Figure A-11. The square cross-section ensures a weld contact area of three to four times that which is indicated as a minimum requirement by the heat-transfer analysis discussed in Section A. 1. 1. 4.

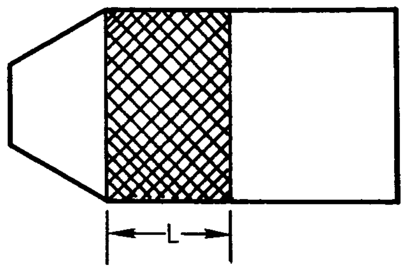
A. 1. 2 Radiator Area

A problem of major concern during Phase IIb was that of providing sufficient radiating surface on MORL to accommodate the requirements of both the EC/LS and power system radiators. The basic MORL orbiting vehicle did not have sufficient surface area for optimally sized radiators. Several methods of minimizing the area requirements were investigated as follows:

1. Raise the radiator inlet temperature with a heat pump.
2. Combine the EC/LS and power system radiators.
3. Provide separate EC/LS radiators for high-temperature electronic loads and low-temperature air loads.
4. Confine the radiator to the vehicle sections with minimum heat influx.

At this point in the study, the radiator design requirements were as follows:

Electrical power load	10 kW
Influx	57 Btu/hour-sq ft
Maximum electronics cooling temperature	105°F
Radiator outlet temperature	35°F
Maximum available area	12 ft of vehicle length



CIRCUMFERENTIAL TUBES
FLUID FC-75
RADIATOR CAPACITY -40,240 BTU/HOUR
$T_{IN} = 105°F$ $T_{OUT} = 35°F$
$\alpha_S/\epsilon = 0.25$, INFLUX 87% OF PEAK
RADIATOR AREA = 68 × L

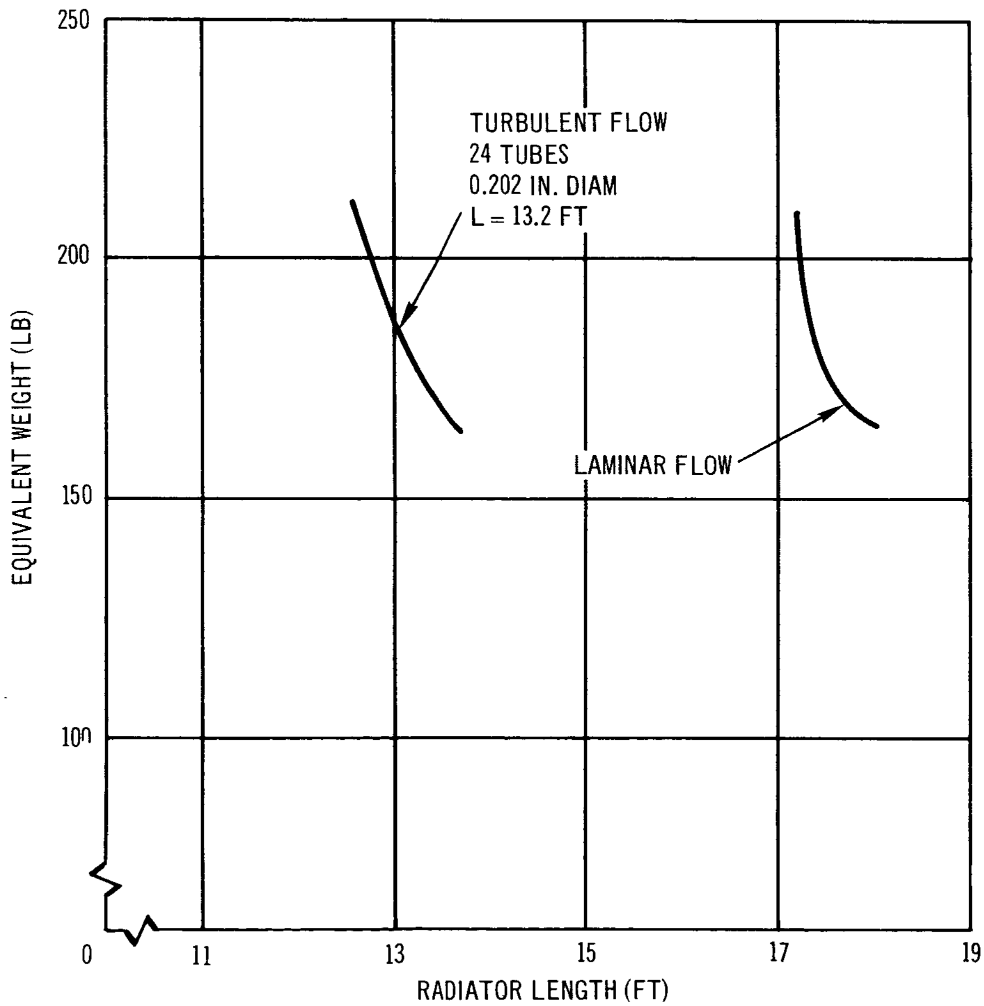


Figure A-9. Total Weight Penalty as a Function of Radiator Area

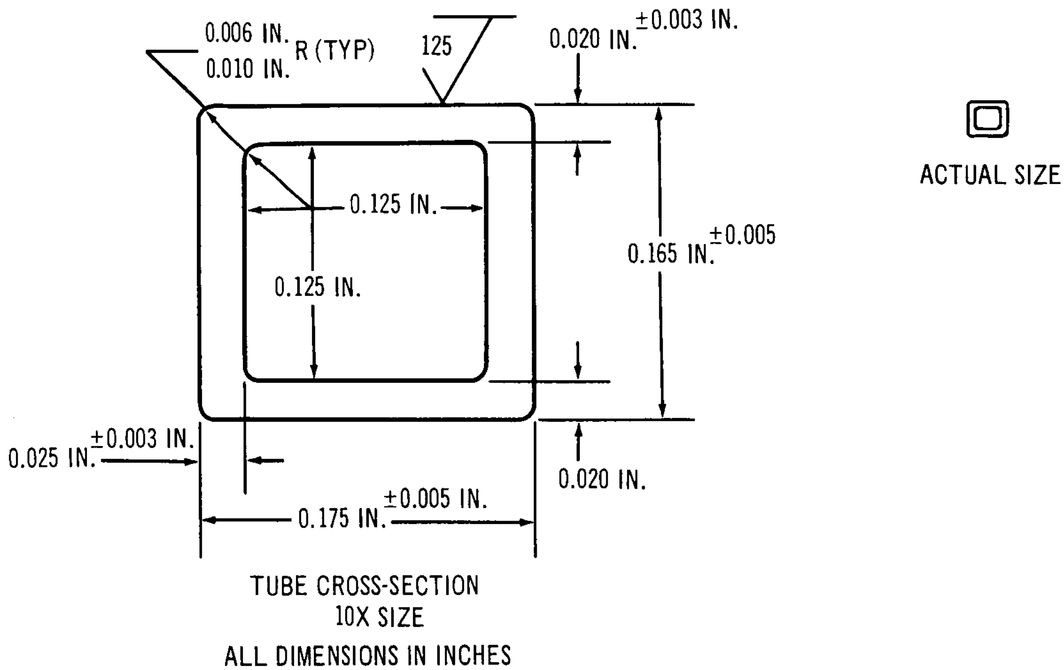


Figure A-10. Radiator Tube Details

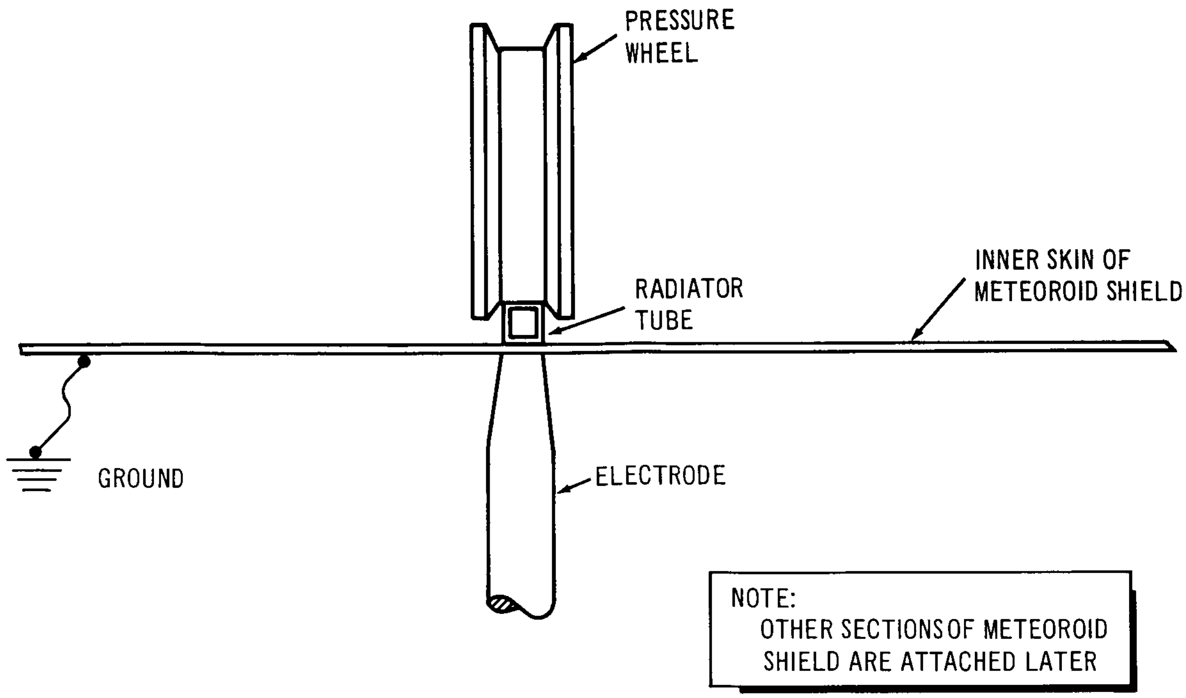


Figure A-11. Radiator Tube Attachment

Although the problem was solved by other methods (Section A. 1. 3) the results of these studies are presented below.

A. 1. 2. 1 Heat Pump

A method of reducing radiator area requirements for a given heat load is to raise the average radiating temperature by a vapor-compression heat cycle installed as shown in Figure A-12. Freon 11 is the fluid in the vapor-cycle loop and FC-75 is the fluid in the cooling circuit loop. In the MORL application, the vapor-cycle system lifts only a portion of the total heat load to a higher temperature. For a given radiator area (12 ft of vehicle length) there is an optimum load split between the evaporator and the heat exchanger caused by the established temperature levels and flow rate in the cooling circuit. For this system, approximately 2/3 of the load must be raised to a radiator inlet temperature of 125°F. This is accomplished at a cost of 1.5 kW in compressor power. The remaining 1/3 of the system load is transferred directly into the cooling circuit fluid by a heat exchanger.

This solution was not considered acceptable because 15% of the total available electrical power would be used up by the vapor cycle compressor.

A. 1. 2. 2 Combining EC/LS and Power System Radiators

The purpose of combining the EC/LS and power system radiators was to attempt to increase the average radiator surface temperature. In this system, the combined heat load would be 42 kWt.

The integrated cooling circuit is shown in Figure A-13. The fluid used is FC-75. Proper temperatures to each system would be provided by mixing valves between the inlet and outlet radiator fluid paths. Normal operating temperatures are shown.

The results indicated that the combined radiator did not offer any area advantage over separate radiators. Therefore, this solution was also rejected.

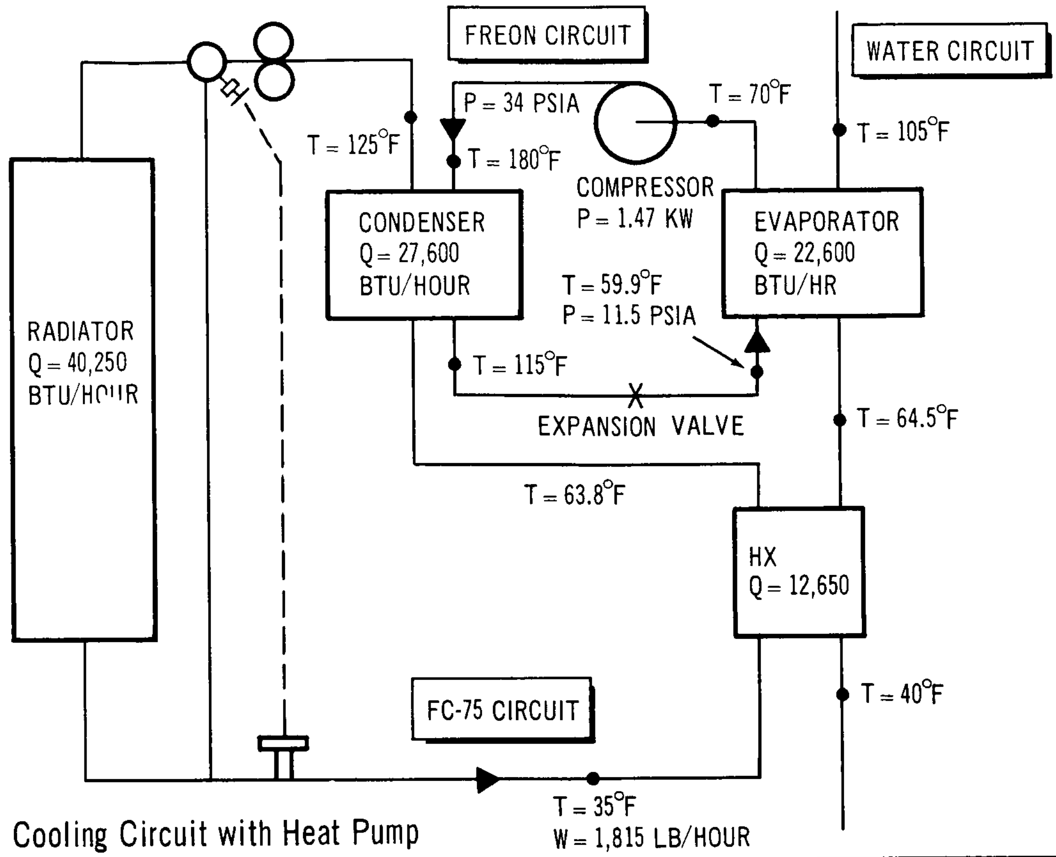


Figure A-12. Cooling Circuit with Heat Pump

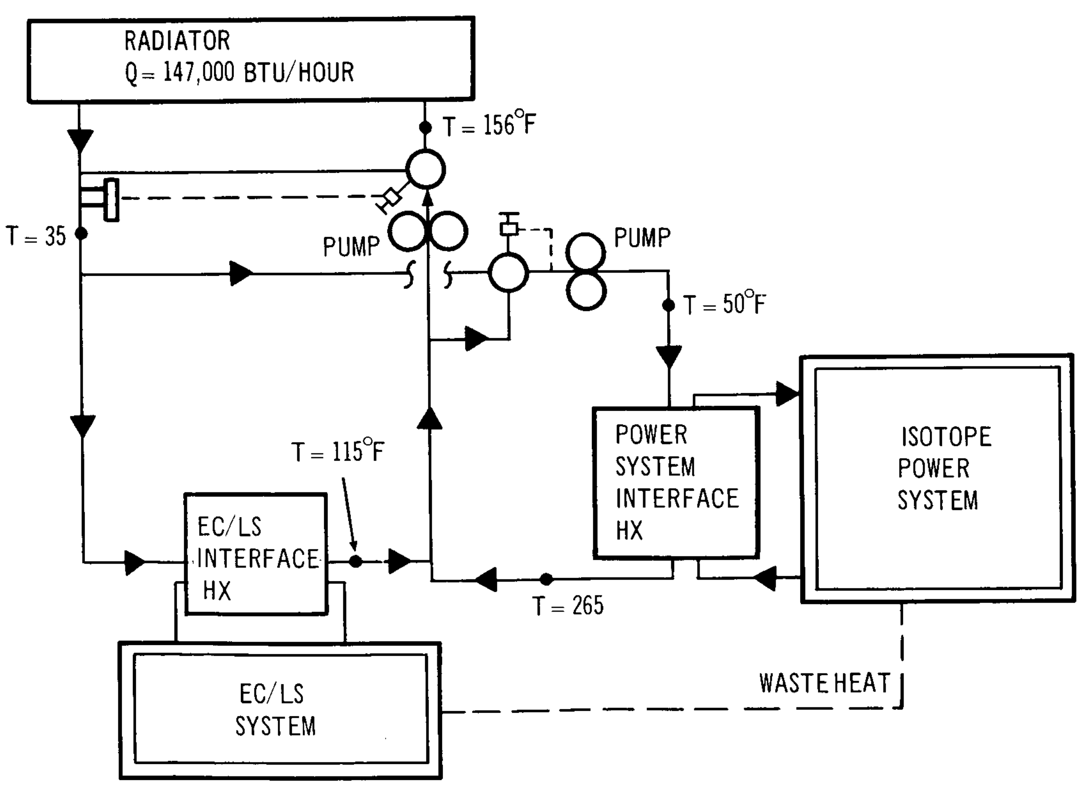


Figure A-13. Integrated Cooling Circuit for Power and EC/LS Systems

A. 1. 2. 3 Separation of EC/LS System Heat Loads

There are two general classes of heat loads in the EC/LS system: (1) the higher temperature electronics cooling loads, and (2) the lower temperature air loads. The purpose of this study was to determine whether separate radiators, each operating at an average temperature more optimum for its load, would result in a net area decrease. The split radiator schematics are shown in Figure A-14.

The results of this study indicated that the area reduction obtained by this design was negligible and not worth the increased weight and complexity.

A. 1. 2. 4 270°-Circumferential Radiator

For a circumferential radiator, one segment receives a maximum influx because it faces the sun directly. The purpose of this study was to determine whether a more efficient radiator would result of the 90° segment facing the sun were not part of the radiating surface.

The results of this study were also negative. This method would require a longer vehicle because the area that would be lost by this design would be greater than the area reduction as the result of decreased influx. This also confirms that the best design is a radiator which completely surrounds MORL.

A. 1. 3 Parametric Radiator Analysis--Basic EC/LS System

The final conclusion drawn from the analyses of Sections A. 1. 1 and A. 1. 2 was that the original circumferential radiator design is the most optimum for the EC/LS radiator. If additional radiating surface is required to accommodate the EC/LS and power system radiators, then the interstage length should be increased as required. The structural weight penalty for increasing the interstage length is approximately 75 lb/ft of extension (up to a maximum of 5 ft).

To determine how much interstage length should be added to MORL to accommodate the EC/LS and power system radiators, it was necessary to analyze parametrically the variation of EC/LS radiator weight as a function

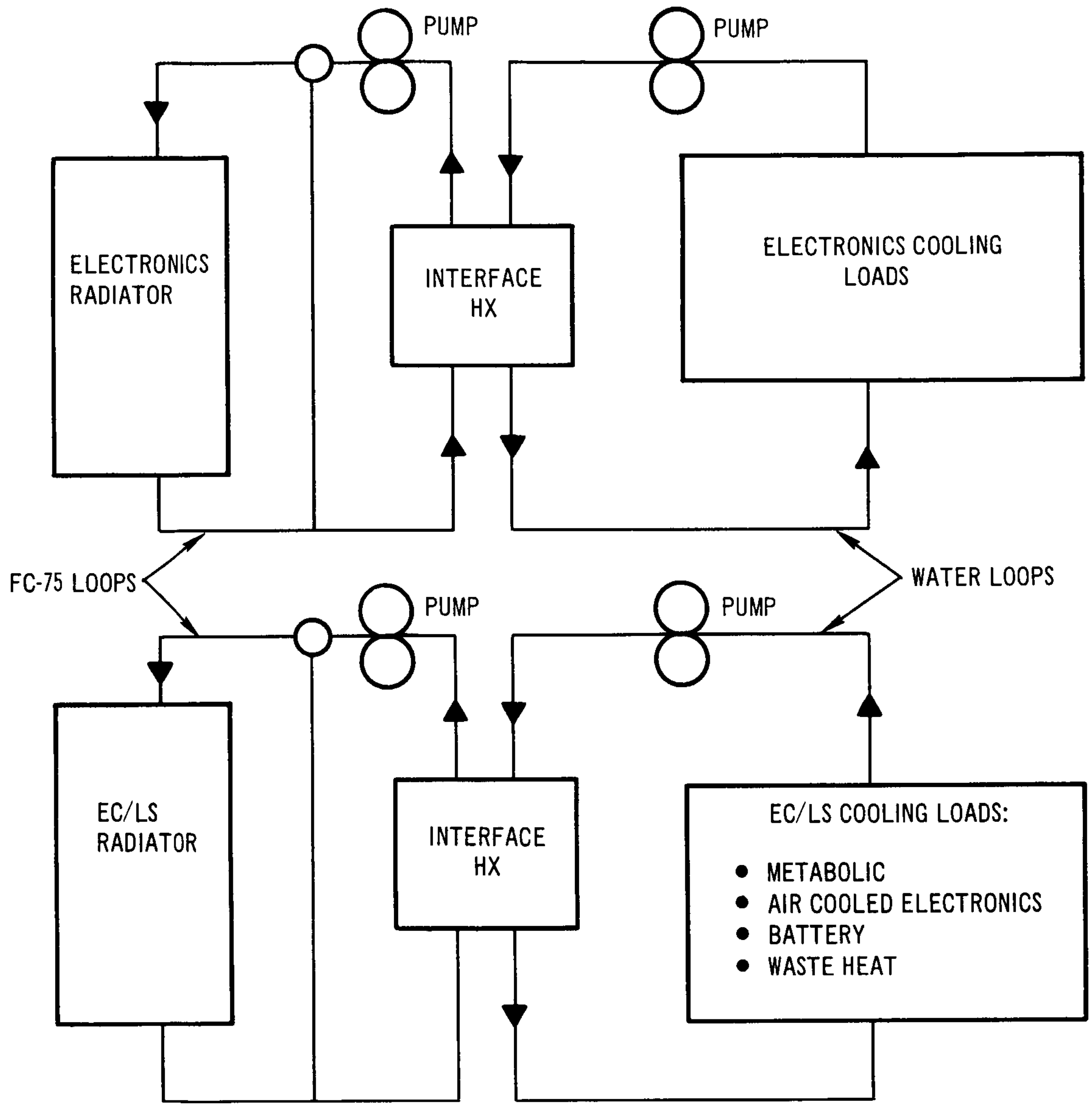


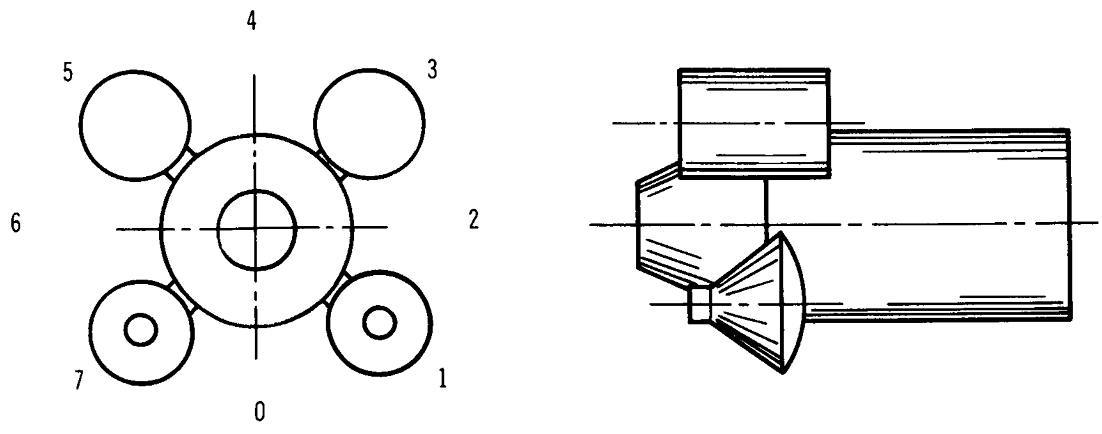
Figure A-14. Split EC/LS Cooling Circuit Configuration of area required. If the radiator tubes are spaced closer together, the average surface temperature will be higher; therefore, less area is required. However, the weight of the radiator increases with a larger number of tubes. This weight increase can be traded off against the weight required to increase the interstage length. To minimize the radiator area requirements, it was decided to allow the liquid temperature at the outlet of the electronics cooling loop to reach a maximum of 120°F, rather than 105°F, for the following radiator sizing studies.

A. 1. 3. 1 Effect of Parked Spacecraft on Radiator Design

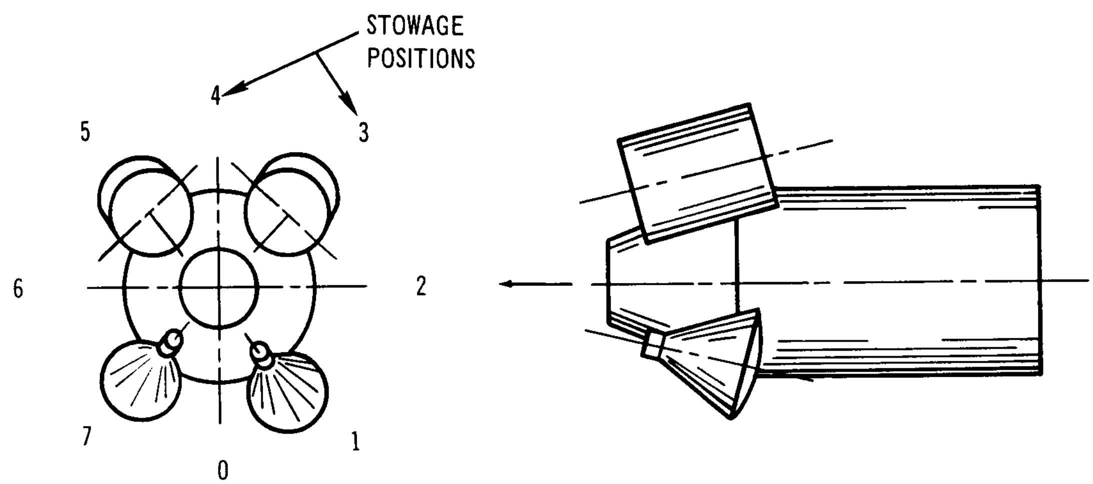
Throughout the mission, logistics-spacecraft and experimental modules will be parked on MORL. These spacecraft interfere with the radiator's view to space and will, therefore, reduce the efficiency of the radiator. In Phase IIa, this effect was considered negligible because the radiator was located in the aft interstage area and the shadowing effect was small. With the advent of the isotope power system, the EC/LS radiator was assigned the cylindrical area of MORL, toward the conical section. In this position, the effect of these parked logistics spacecraft is significant.

Two methods of stowing parked spacecraft vehicles were considered: (1) the Phase IIa baseline stowage configuration, and (2) the two-arm axial-stowage configuration (Figure A-15). The two-arm axial-stowage method was under consideration for adoption in Phase IIb during the Task IV studies.

The number of parked spacecraft around MORL at any time will vary, depending on mission requirements. At least two Apollo spacecraft (crew return vehicles) will be on board the MORL at all times. As many as six (three Apollos, one cargo module, and two experimental modules) may be accommodated at one time. The latter case is doubtful. However, to assess the effect of the number of parked spacecraft on the MORL, cases of four and six spacecraft were studied. In the case of four spacecraft, positions one, three, five, and seven were chosen as shown on Figure A-15. For the case of six spacecraft, it does not matter whether positions two and four or four and six are used as the additional parking areas.



A. TWO-ARM AXIAL CONFIGURATION



B. PHASE IIa. CONFIGURATION

Figure A-15. Logistics Spacecraft Stowage Configurations

A. 1. 3. 2 Parametric Results

The resulting radiator weight as a function of required radiating surface is shown in Figure A-16. The distance L refers to the length required from the conical section aft to the end of the radiator. The case of the six parked spacecraft was studied for the two-arm configuration only. The curves in Figure A-16 show that the total influx increases because the parked spacecraft act as reflecting surfaces. The increased influx requires a larger radiator. From the results of this study it was concluded that the two-arm axial-stowage configuration is undesirable because it resulted in excessive radiator area requirements. It was also decided that the design of the radiator would be based on the requirement for four parked spacecraft (two Apollos and two cargo or experimental modules) as shown on Figure A-15, Part B. The other conditions, where more spacrcraft are parked are considered transient; degradation to the radiator performance that will result from this increase will be accepted.

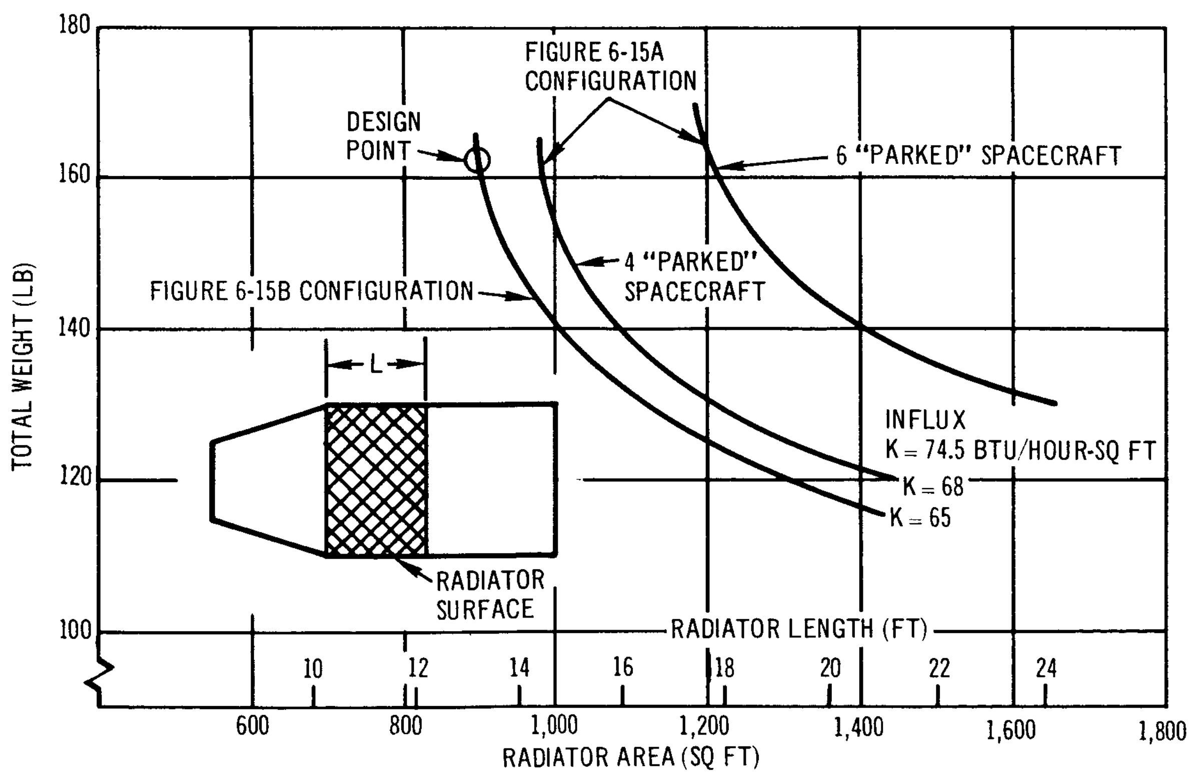


Figure A-16. Radiator Area Requirements, Basic System, Q_L = 43,730 BTU/Hour

The curve for Figure A-15, Part B configuration was used in the final radiator design for the basic operating mode of the EC/LS system. The optimum EC/LS radiator design point was determined from this curve, taking into account a similar analysis for the power system radiator and lengthening of the MORL interstage (for a detailed discussion of this optimization see Reference 2). As a result of this optimization, the design point of the EC/LS radiator in Figure A-16 was chosen. To accommodate this radiator and the power system radiator, the interstage length of the MORL was increased by 5 ft.

A. 1. 4 Parametric Radiator Analysis --0_2 Regeneration Operating Mode

For the oxygen regeneration operating mode, the total radiator load increases to 49, 630 Btu/hour because of the additional waste heat obtained from the power system to desorb the molecular sieves (Section A. 2). Therefore, the parametric analysis of the previous section was repeated and the results are shown in Figure A-17. However, since it was already known that this additional heat load could not be rejected without lengthening the interstage again, the possibility of using the conical section of MORL as a radiator was also investigated. The middle curve represents the same design conditions as the design curve of Figure A-16. The lower curve assumes the use of the conical section, plus whatever additional cylindrical area is required. Since the curves are almost identical, it can be concluded that the conical surface of MORL is as good a radiating surface as the cylindrical section. This result was surprising because the parked spacecraft more completely cover the conical section. The reason for this condition is that, in the Belly Down orientation, the parked spacecraft block out a significant amount of sun and Earth influx, while the oblique conical surface still "sees" dark space in the direction of the arrow shown in Figure A-15, Part B.

The conical section provides a minimum of 400 sq ft of surface which is available as a radiator (Figure A-18). The conical area and the cylindrical area which are available (13. 2 ft) total 1, 300 sq ft (400 + 13. 2 x 68). This is the point that was chosen for the design of the radiator for the oxygen

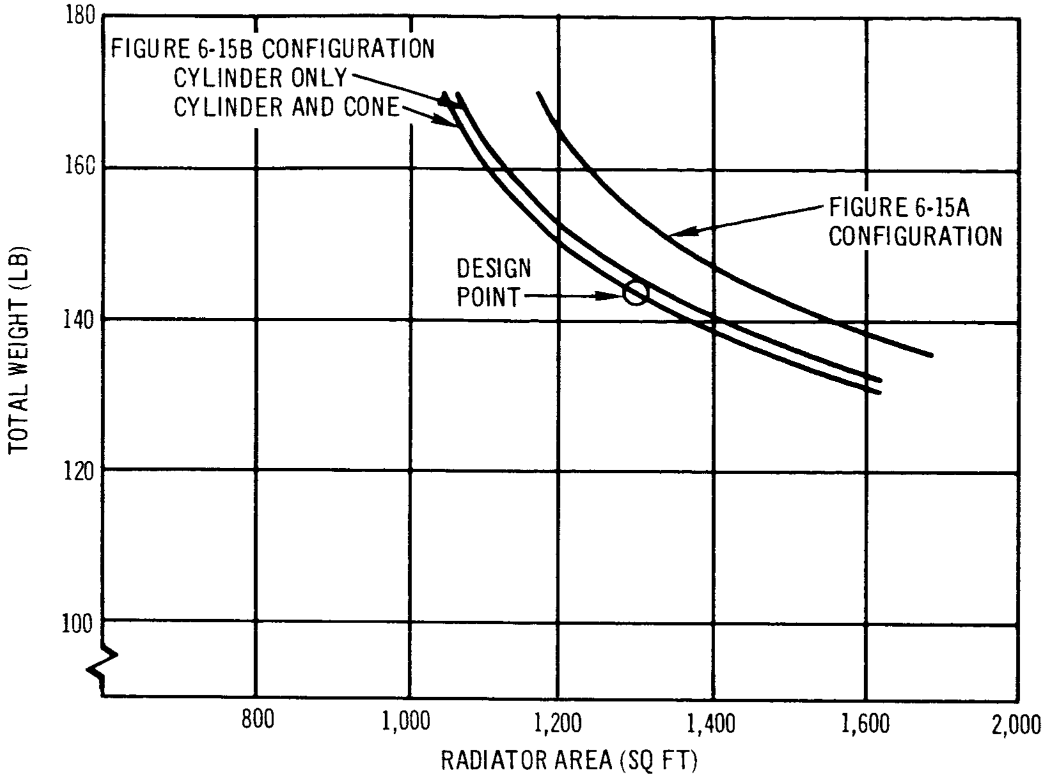


Figure A-17. Radiator Area Requirements, O_2 Regeneration System, Q_L = 49,630 BTU/Hour

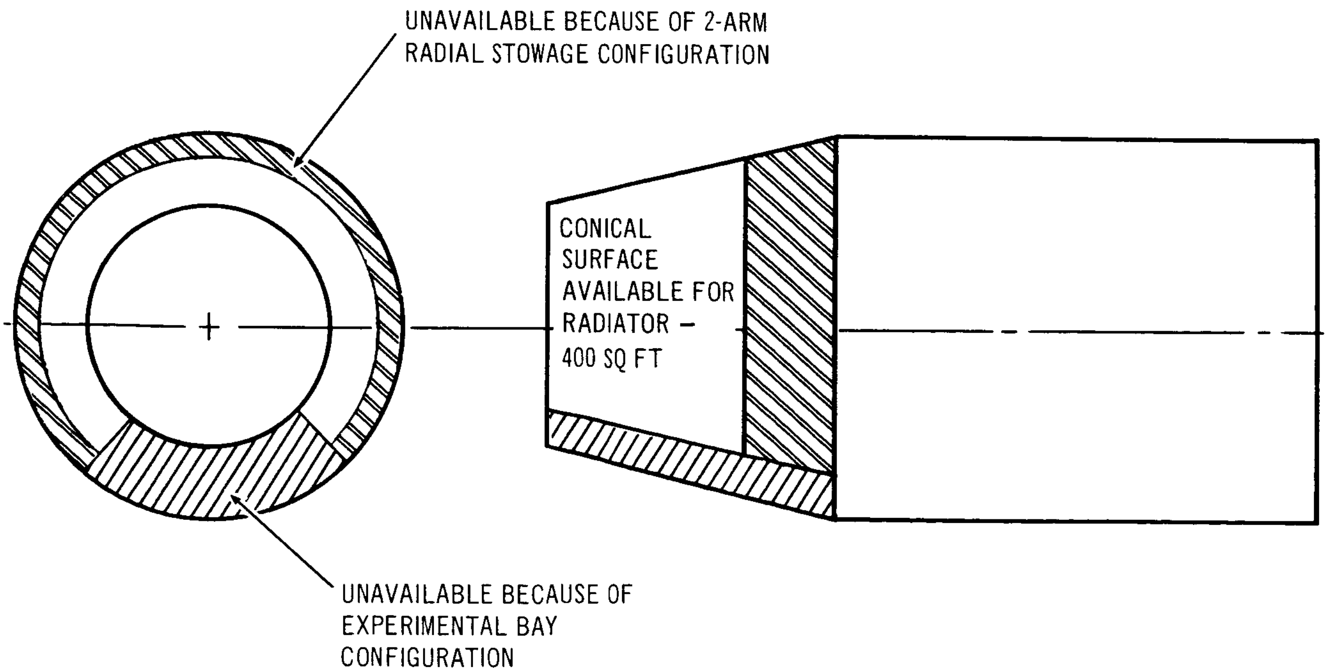


Figure A-18. Conical Surface Area Available as Radiator regeneration system. It should be noted that the use of all the available cone area reduces the weight of the radiator because it allows the tubes to be spaced farther apart.

After the above analysis was completed, a new stowage configuration was considered (which eventually became baseline) wherein the spacecraft are arranged around the conical section with their axes perpendicular to the conical surface (two-arm radial stowage). Time was insufficient to analyze the effect of this configuration on the radiator. However, from inspection, it is felt that this stowage method is at least as satisfactory as the Phase IIa baseline configuration (Figure A-15, Part B) because the conical section is still shaded from the sun and is also open to space from the end view. It also causes less interference with the cylindrical surface. The 400 sq ft of the conical surface area assigned to the radiator do not include that area which would be used for radial stowage structure or for the experimental bay structure (Figure A-18).

A. 1. 5 Cooling Subsystem for Larger Power Sources

A preliminary analysis was completed to determine the maximum size power system that could be accommodated on MORL. This analysis took into account the limiting factor that the radiator area could present in the use of advanced power systems for MORL. This study applies to any type of power source as long as the only radiator that must be accommodated by the fixed MORL surface is for the EC/LS system. That is, if a radiator is required by the power source, it is provided by some means other than the MORL surface.

The following design criteria were established for this study:

Maximum skin temperature of vehicle	250°F
Maximum electronics cooling water temperature	120°F
Low temperature electronics cooling water inlet temperature	70°F
Radiator fluid outlet temperature	90°F

Radiator tube spacing	1.6 in.
Cooling water for EC/LS air loads	40 °F
Total available radiator surface area	1,500 sq ft

Results of the analysis showed that approximately 25 kW is the maximum capacity of a power source that could be accommodated by the 1, 500 sq ft of radiating surface area available. In the analysis, it was assumed that a heat pump/refrigeration system could be used when necessary to provide a more efficient radiator. Figure A-19 shows the heat rejection system schematic. For each power source load to be rejected by the radiator, there is a single heat lift required by the heat pump system. The power required by the heat pump is shown in Figure A-20 as a function of the total capacity of the heat source that can be rejected by a 1, 500 sq ft radiator. This curve shows the amount of power required by the heat pump system to still be capable of rejecting the total heat in a 1, 500 sq ft radiator, as the power is increased to above 25 kW. Usable power is defined as the total

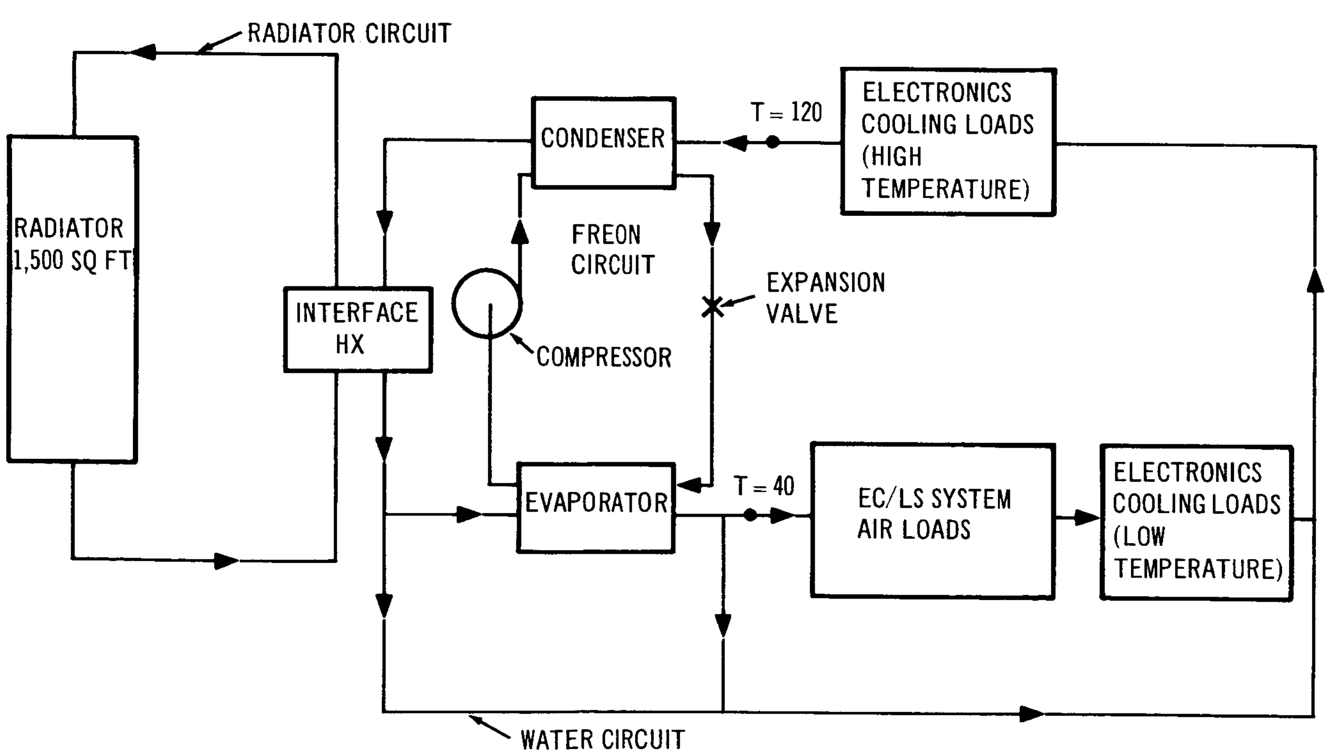


Figure A-19. Heat Rejection Circuits

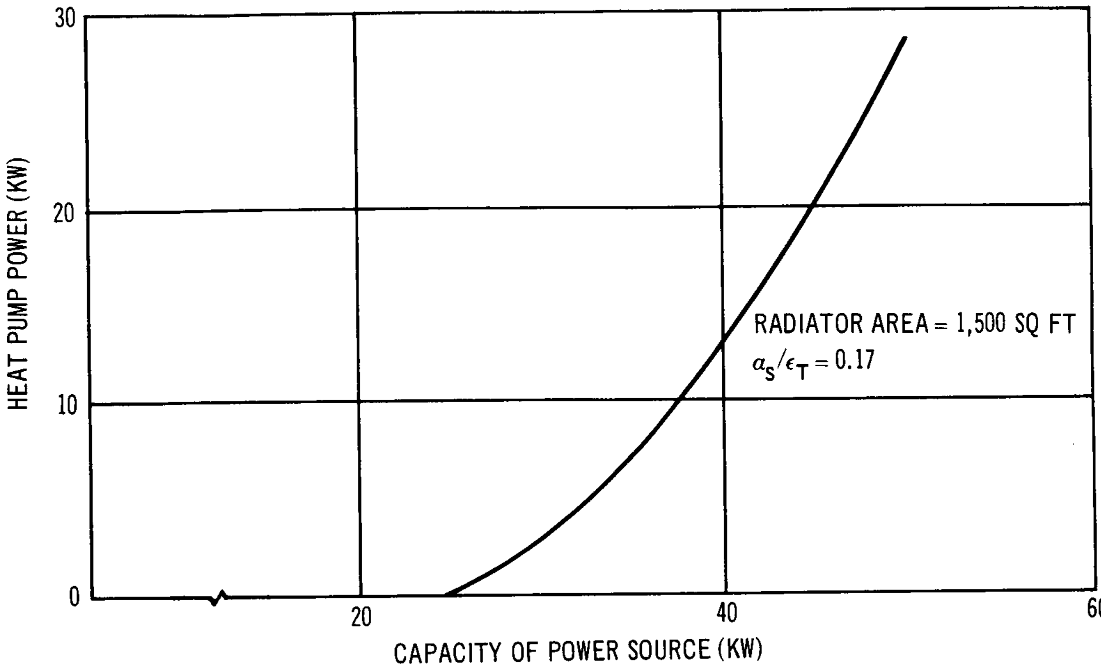


Figure A-20. Heat Pump Power Requirements

capacity of the power source less the heat pump power. Figure A-21 plots usable power as a function of the total capacity of the power source. It shows that approximately 30 to 35 kW is the maximum power source that would be considered for MORL. At this point, the rate of power increase required by the heat pump is greater than the rate of increase of the power source and the usable power decreases.

For this study, an α_s/ϵ_t of 0.17 and the peak influx were used to determine the heat rejection capability of the 1,500 sq ft radiator. Also, the radiator was confined to the cylindrical section of MORL. If the conical section were used, or if less than peak influx were assumed, the maximum power source that could be accommodated would increase (Section A.1.6).

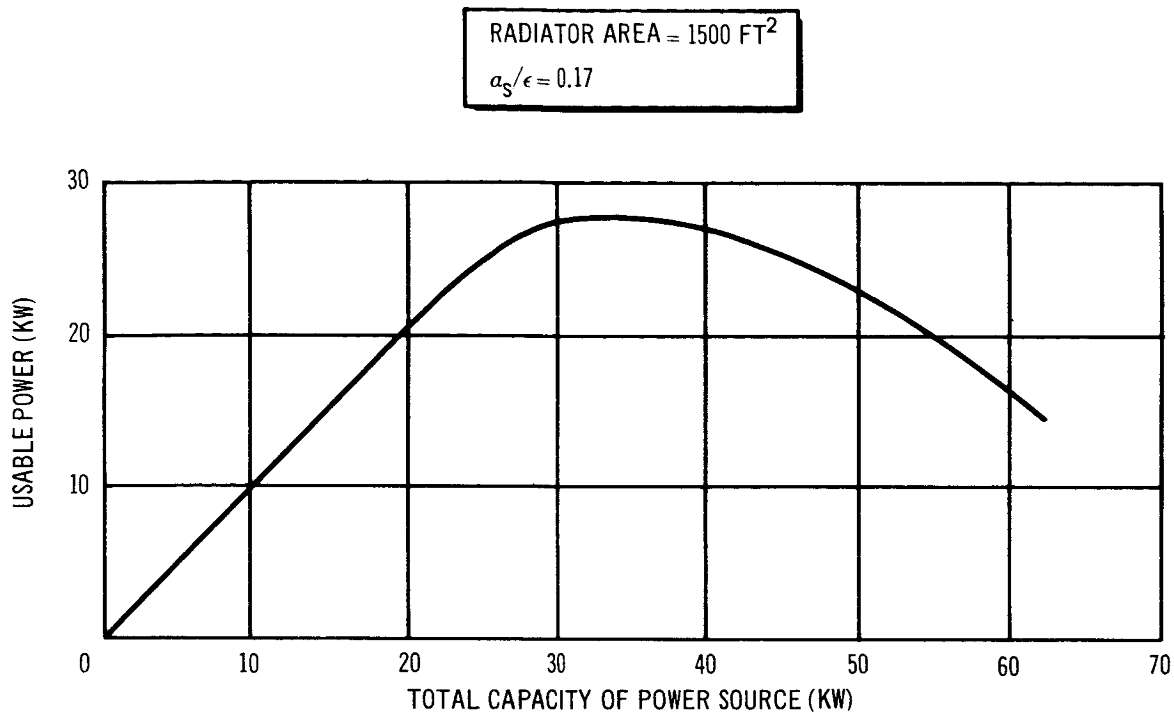


Figure A-21. Usable Power as a Function of Power Source Capacity

A.1.6 Alternate Radiator Design

The techniques and assumptions used in the design of the MORL EC/LS radiator are conservative estimates of the radiator environments and the capabilities of such a system. Variations of the design criteria can have a direct influence on the area required for a radiator. The following were assumed:

Solar constant:	442 Btu/hour-sq ft
Earth albedo:	0.35
Orbit inclination:	50°
Orbit height:	200 nmi
Orbit attitude:	Belly down
Solar absorptivity:	0.231
Emissivity:	0.925
Tube orientation:	Circumferential
Tube material:	Aluminum

Fluid:	FC-75
Inlet temperature:	107° to 120°F
Outlet temperature:	35°F
Capacity of peak influx:	87%

In the design of the radiator, absorptivity, emissivity, and heat influx are the criteria which most greatly affect the required radiator area.

The MORL radiator was designed assuming that the radiator surface has an absorptivity-to-emissivity ratio (α_s / ϵ_t) of 0.25. This value is conservative. It represents the estimated value at the end of the 5th year of orbital life. This means that, for the other years, the radiator is overdesigned. Figure A-4 shows the effect of α_s / ϵ_t on the radiator area requirements. Large area savings can be realized by designing the radiator for a lower value of α_s / ϵ_t.

The heat influx caused by direct sun radiation, Earth emission, and Earth reflection varies around the orbit as shown in Figures A-2 and A-3. The peak influx only occurs at 0° in the orbit and only whenever this position is directly between the sun and the Earth (that is, at the subsolar point). MORL will pass over the subsolar point only a given number of times/year. At all other times, the peak influx is lower and the radiator is over designed. The design value for influx, 87% of the peak, was assumed rather arbitrarily from inspection of the influx curves. It is entirely possible that this percentage may be lowered, depending on the thermal lag of the radiator and the time constants of the components that are affected by the radiator performance.

When it is considered that the power system radiator is designed in a manner similar to that described above, it can be seen that the total radiator surface required for MORL can be reduced by changing these design criteria. The analysis required to determine the new radiator design criteria was beyond the scope of this study, but is recommended for future work.

A. 2 WASTE HEAT STUDIES

Several EC/LS components require heat in performing their functions. In the Phase IIa baseline system, there was no heat available at the required temperature levels for use in these components, and a separate isotope heat source was provided to supply the necessary heat. With the Phase IIb change in power system (from the solar cells to the Isotope Brayton Cycle System), waste heat became available at high temperatures. This negated the requirement for an isotope heat source in the EC/LS system. The following studies were performed during the integration of the EC/LS system and Isotope Brayton Cycle power system.

A. 2. 1 Waste Heat Requirements

A. 2. 1. 1 Basic System Operating Mode

In the basic system, the following items need heat to accomplish their functional requirements:

1. Air heater: evaporation of urine and wash water.
2. Tank heater: pasturization of potable water.
3. Silica gel beds: desorption of water.

A maximum temperature of 250° F is required in the silica gel canisters. The heat is absorbed in a cyclic manner in the beds. To minimize the total heat requirements, the heating cycles are phased between the laboratory and hangar silica gel beds. The optimum combination occurs when the cycles are 15 min. out of phase. The air and water tank heaters use a constant amount of heat.

As was noted in Section 2. 3. 8. 2, it is desirable to withdraw a constant amount of waste heat from the power system to minimize the area requirements of the power system radiator. This is accomplished by providing a waste heat dump heat exchanger in the heating loop. When the peak heat requirement occurs in the cycle, the heat exchanger is by-passed completely. A constant temperature (and subsequent constant load of 7, 740 Btu/hour) is maintained by a temperature sensor and bypass valve. Figure A-22 shows the waste heat requirements for the basic system operating mode as a func-

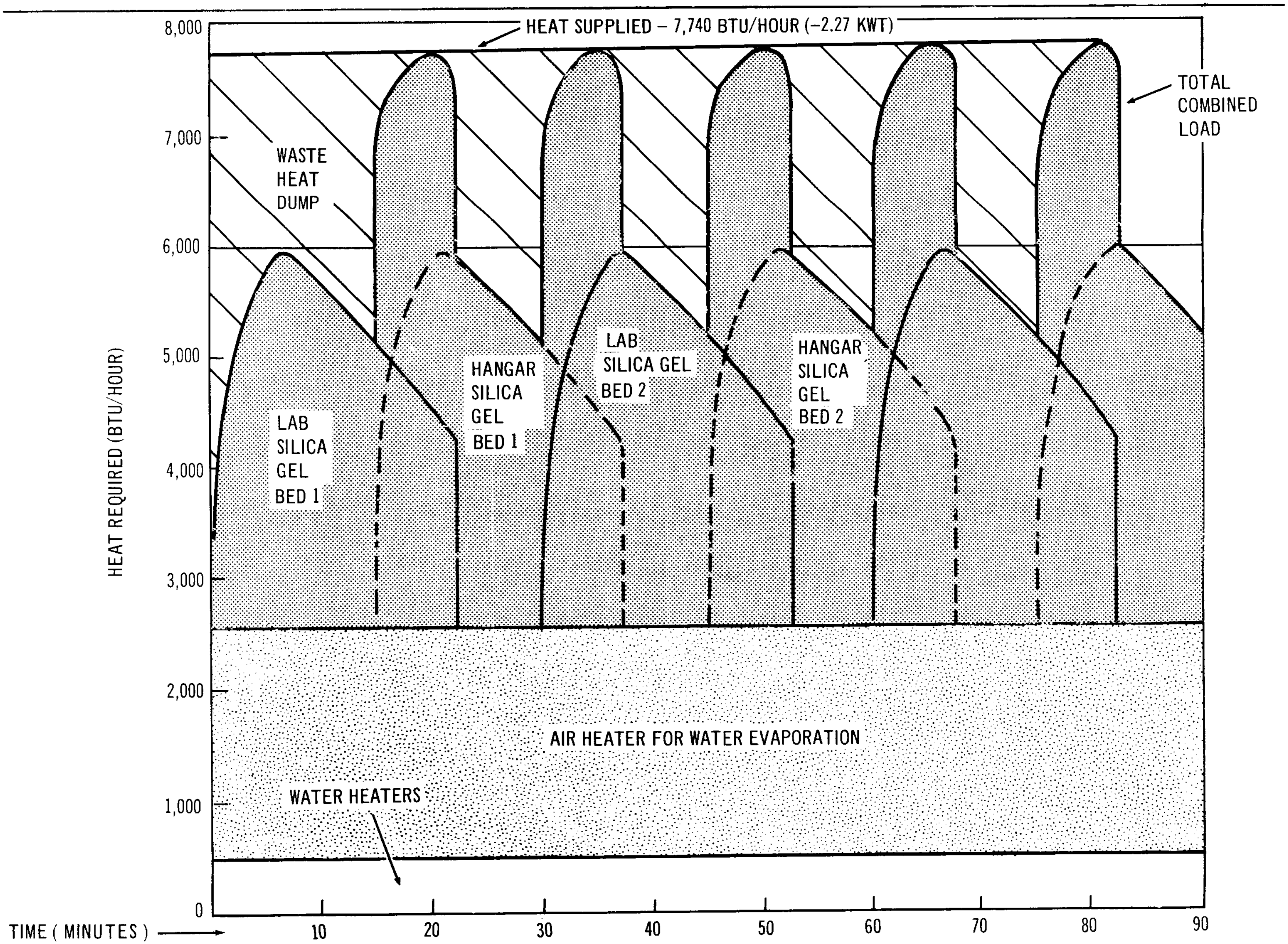


Figure A-22. Waste Heat Requirements, Basic System tion of time. In the figure, the cross-hatched area is the load added to the heat transport subsystem by the waste heat dump. This analysis was made using a typical heat load distribution and assumed no thermal lag in the system.

A. 2. 1. 2 Oxygen Regeneration Operating Mode

To provide for thermal desorption of the molecular sieve beds for the oxygen regeneration operating mode, additional waste heat is required at an inlet temperature of 360°F rather than the 250°F required for the basic system.

The total heating requirements for this operating mode are shown in Figure A-23. The figure shows that the molecular sieve bed desorption adds another cycle to the heating loop. The molecular sieve bed cycle time is designed for 40 min. so that the laboratory and hangar cycles are phased 20 min. apart. This spreads the application of the waste heat over a longer period, but decreases the total heating requirements. The molecular sieve bed becomes bigger and heavier; however, the tradeoff is still advantageous because of the resulting reduction in radiator area.

Since the silica gel bed cycle time is 30 min. and the molecular sieve bed cycle time is 40 min., the combined heating load repeats every 120 min. Figure A-23 shows that a short spike occurs at 36 min. However, this is ignored because the thermal lag of the system will even out this peak. The resulting waste heat requirement is, therefore, established at 13,630 Btu/hour.

Provisions for waste heat dump are even more important in this system because the total waste heat withdrawal from the power system is higher. In the figure, the cross-hatched area shows how the waste heat dump system evens out the total heating load.

A. 2. 2 Integration With the Isotope Power System

The following paragraphs discuss the integration of the EC/LS and isotope power system for the basic operating mode and the oxygen regeneration operating mode.

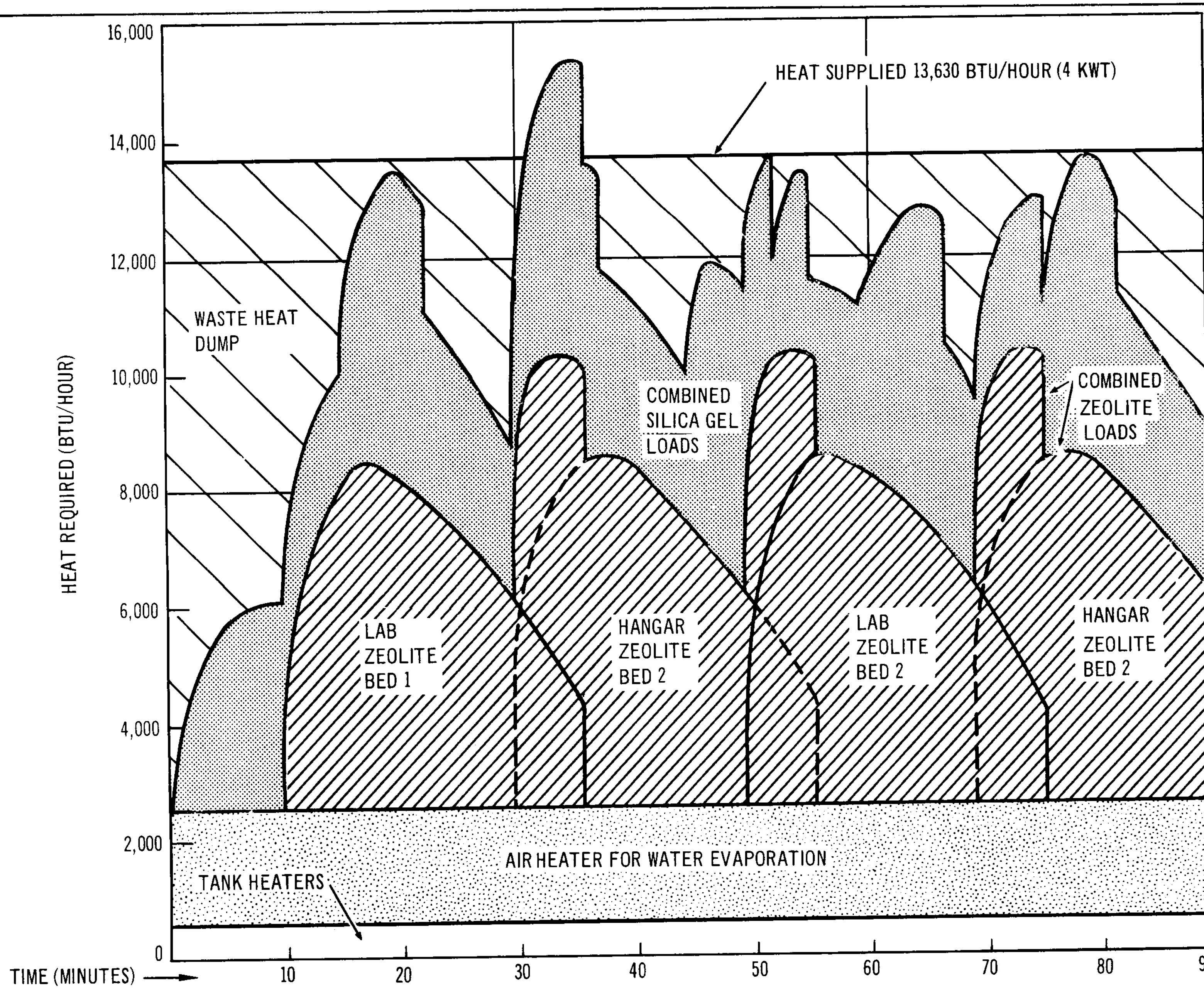


Figure A-23. Waste Heat Requirements, O_2 Regeneration System

A. 2. 2. 1 Basic System Operating Mode

As established in the previous section, the waste heat required for the basic EC/LS system operating mode is 7,740 Btu/hour (2.27 kW) at 250°F. Figure A-24 shows how this waste heat is transferred from the power system to the EC/LS system. Water from the heating loop of the EC/LS heat transport subsystem is passed through a heat exchanger in the gas loop of the Isotope Brayton Cycle power system. The water is heated to 250°F and returns to the EC/LS system, where it gives up this heat. Before the cooler water is returned to the power system, it passes through the waste heat dump exchanger. This operation ensures that the fluid inlet temperature to the gas heat exchanger

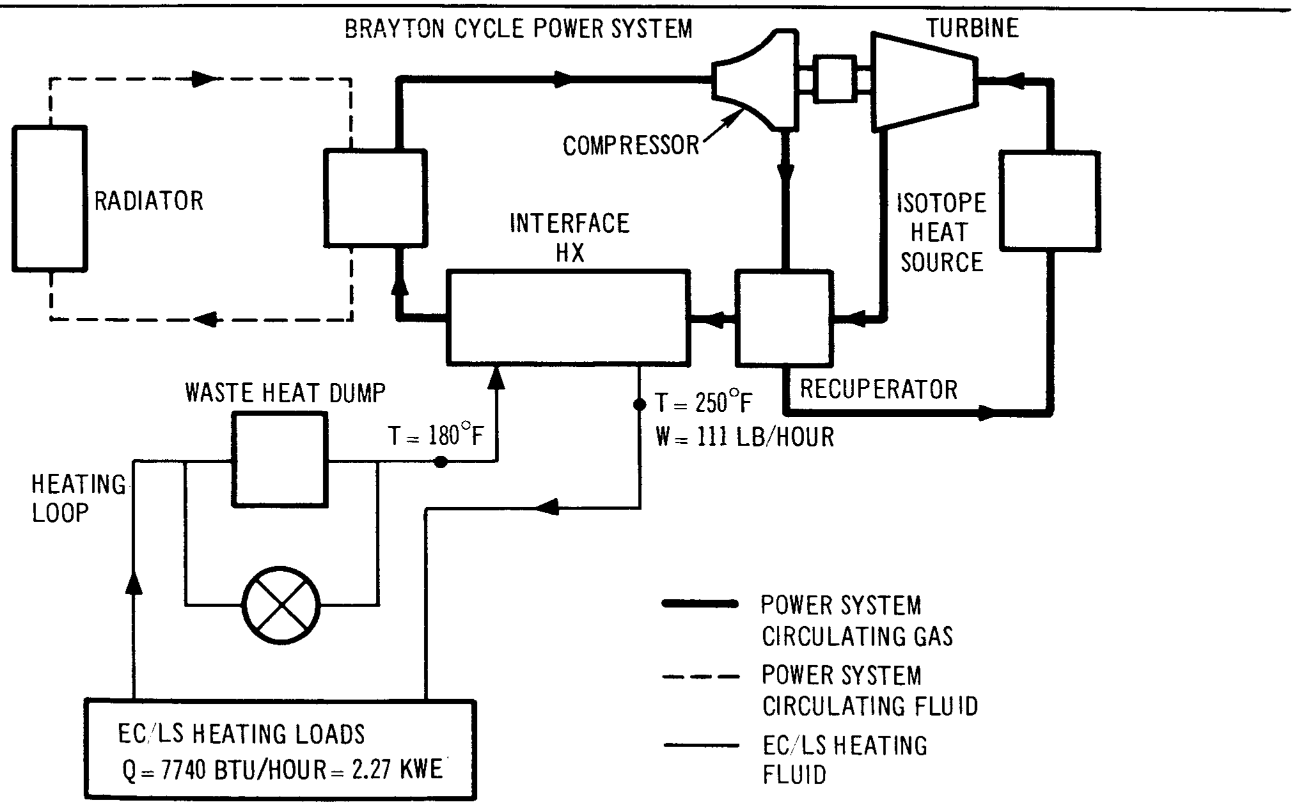


Figure A-24. Integration of Power and EC/LS Systems Basic Operating Mode will not exceed 180°F when the EC/LS heating loads decrease. The gas heat exchanger is place downstream of the recuperator so that the heat transferred is truly waste heat, and directly reduces the amount of heat which must be transferred in the power system heat rejection loop.

A. 2. 2. 2 Oxygen Regeneration Operating Mode

For the oxygen regeneration operating mode, the waste heat requirements increase to 13,630 Btu/hour (4 kW) at 360°F. Figure A-25 shows how this heat is obtained from the power system. In this case, the maximum temperature available from the gas heat exchanger, downstream of the recuperator, is 335°F. The fluid must pass through the isotope fuel block heat shield, where it picks up the additional heat required to increase its temperature to 360°F. This, again, is mostly waste heat because the heat shield would ordinarily radiate this energy into space anyway. Approximately 10% of the heat thus obtained is not truly waste heat. Reference 2 contains a detailed discussion

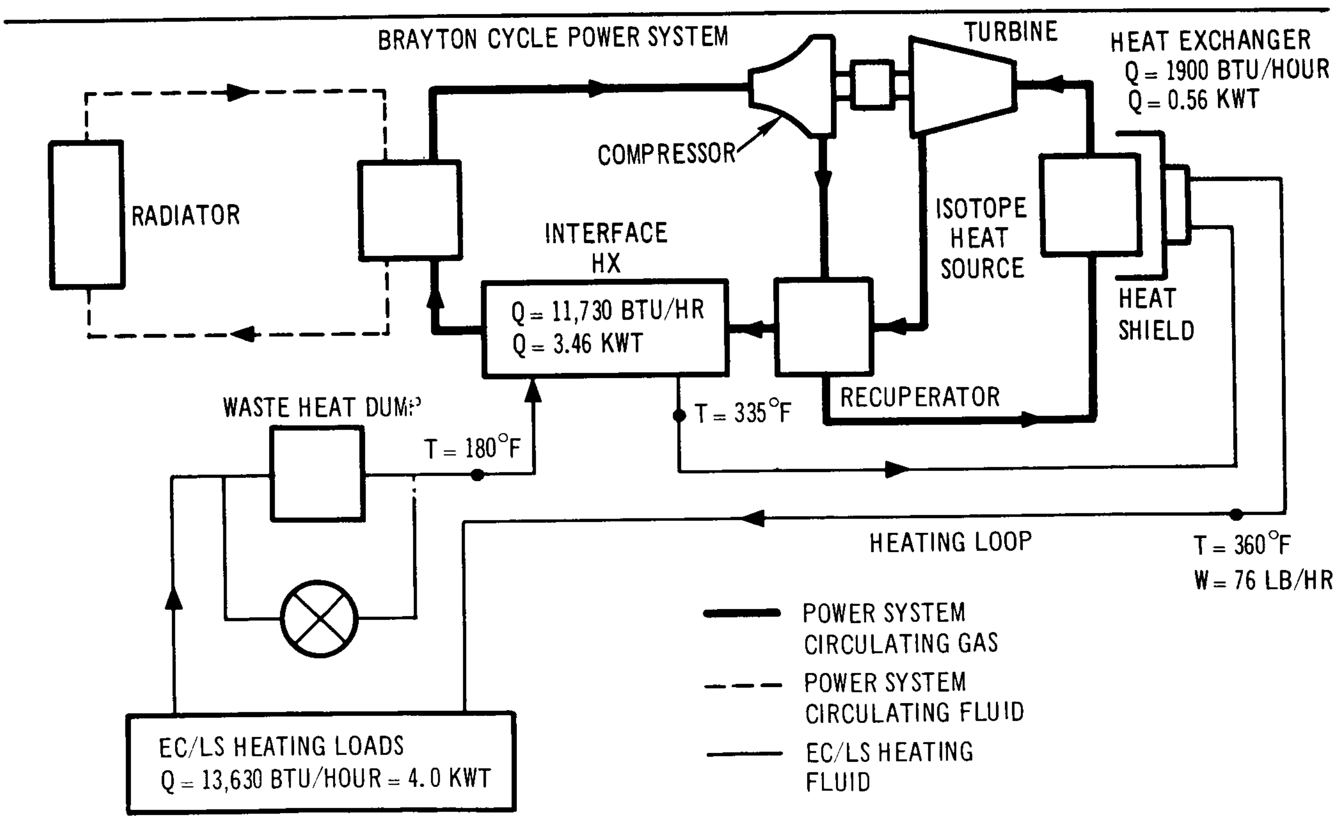


Figure A-25. Integration of Power and EC/LS Systems, O_2 Regeneration Operating Mode of this problem. Section B. 2. 2. 8 presents a method of eliminating the need for heat obtained from the heat shield. In this system, water is still the EC/LS heat transport fluid. The operating pressure of this circuit is increased to 300 psia so as to avoid boiling. The waste heat dump exchanger operation is the same as that for the basic operating mode.

The waste heat circuit must be designed and installed for the oxygen regeneration operating mode at launch, although this mode of operation will not be used until later in the mission. It is unnecessary to make special provisions for this circuit to accommodate this requirement. The waste heat required for oxygen regeneration will be transferred regardless of the operating mode selected by the EC/LS system. The waste heat dump will ensure a constant load even when the EC/LS system heating load is low. Therefore, the power system and the EC/LS heating circuit are each designed for one operating condition, thus simplifying their design and operation.

A. 3 SPACE SUIT OPERATION STUDIES

The following paragraphs discuss the space suit operation studies.

A. 3. 1 Liquid Cooled Space Suit

During the MORL mission, space suits will be used for required intravehicular and extravehicular operations and experiments. The original Apollo space suit provided cooling by an air flow over the body. Metabolic heat was rejected by evaporation of water from the body. For high metabolic rates and extended duration, this method tends to cause dehydration of the body of the astronaut. In the basic Apollo mission, there is not sufficient time for rest and replenishment of water in the body. It was, therefore, concluded that the basic cooling concept had to be changed to prevent excessive dehydration of the body.

A liquid-cooled undergarment has been developed. This undergarment is capable of removing high metabolic heat loads by sensible cooling. This is accomplished by a circulating coolant fluid passing through plastic tubes in direct contact with the body. Dehydration is thus prevented because sweating is not required for this cooling process. A gas flow of approximately 6 cfm is required for CO_2 removal and oxygen supply; however, this is approximately half of the flow required without a liquid undergarment.

Liquid-cooled suit operation is particularly appropriate when metabolic loads are high, such as during extravehicular operation. Accordingly, this method of cooling is used in the Apollo mission during extravehicular operation, and the liquid flow undergarment is integrated with the portable life-support system (PLSS) back pack. During intravehicular operation, when metabolic loads are relatively low, the gas-cooling method of heat removal is retained.

The anticipated metabolic loads during operation inside the MORL are low enough so that the gas-cooling method of heat rejection can be employed, as it is during the Apollo mission. There is no need for the liquid-cooling concept in this intravehicular operation.

It is assumed that the metabolic loads may be high during extravehicular operation and, accordingly, the liquid-cooled undergarment should be used in connection with the PLSS, as it is with the basic Apollo system.

It would be possible to provide liquid cooling by an umbilical line connection with the vehicle heat transport subsystem with the liquid undergarment. Such a system would only be recommended if it was determined that extravehicular excursions were planned which exceed the allowable operating time of the PLSS anticipated for use during the MORL mission.

A. 3. 2 Integration of Space Suits and Molecular Sieve Bed Operation

During operation of the closed-suit loop in the laboratory, the switchover of the molecular sieve canisters from an on-line bed to an off-line bed produces a momentary drop in system pressure. The drop occurs because the off-line bed, which is evacuated during desorption, is suddenly introduced into the closed loop. The worst condition involves 3.5 psia operation during which one crew member is suited. The calculated loop pressure drop is 0.15 psi.

For aircraft pressurization systems, the design values* for comfortable pressure changes are as follows:

1. Depressurization: 0.25 psi/min.
2. Pressurization: 0.15 psi/min.
3. Step change: 0.05 psi

The drop in pressure caused by this operation may be controlled to the above limits by governing pressure decay time. If it is assumed that no oxygen inflow is recovered, flow into the evacuated bed must take 36 sec or longer. This bleed rate is obtained by controlling the speed of the switchover valving and by proper design of the size of the orifice of the valves.

A.4 WASTE MANAGEMENT SUBSYSTEM DESIGN

In space missions of long duration, such as the MORL, the system for handling, processing, and storing human fecal wastes must meet requirements other than the standard requirements of minimum weight, volume, power, and maximum reliability. Physiological and psychological considerations must be evaluated in the final selection of system hardware. Operating time, maintenance, sanitation procedures, spare parts, and resupply requirements are other considerations.

A.4.1 Combined Waste Collection and Storage

The Phase IIa waste management concept has two main disadvantages: (1) manual transfers of wastes to the waste dehydrator and to the storage containers are required, and (2) the time required by the crew to accomplish these transfers is excessive. For these reasons an outhouse waste management concept* was studied. This concept is essentially a combination waste collector, processor, and storage container. The container is a sphere which has a removable cover and seat. During defication, air flows past the seat area and into the sphere to ensure movement of feces into the collection sphere (Figure A-26). When the system is not in use, an airtight

*MIL-P-18927B (Aer) Oct. 15, 1957. Pressurizing Systems, Cabin Aircraft General Requirements.

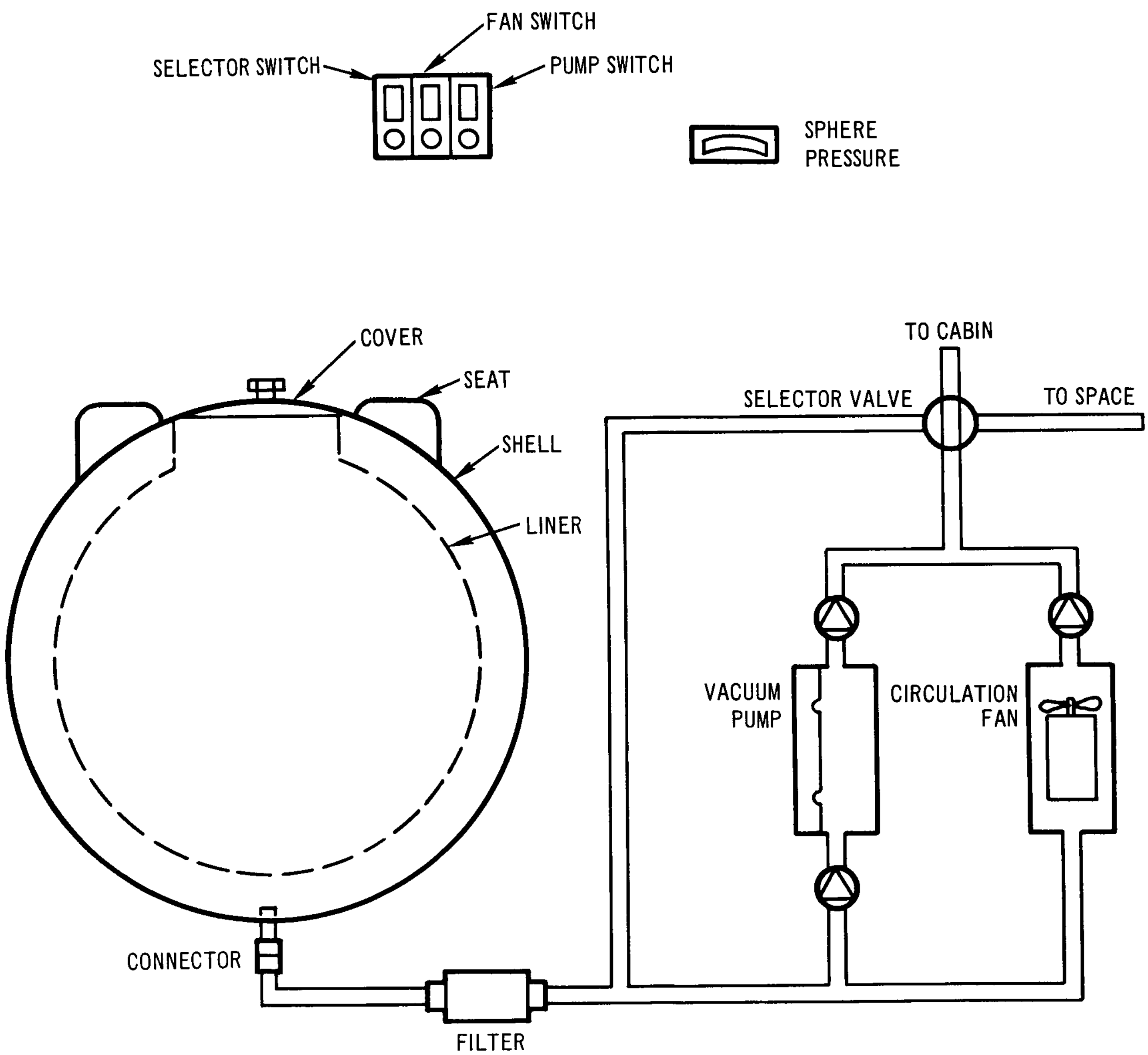


Figure A-26. Combined Waste Collection and Storage cover is installed and the sphere is opened to vacuum for dehydration of the latest wastes collected. When a sphere is filled, it is disconnected from the system and an unused sphere is installed in its place. The only expendables required are the collection spheres (including a cover and connector), a charcoal filter cartridge, and a millipore filter cartridge. The last two items are mounted externally from the sphere and upstream from a blower which, during commode use, pulls air through the sphere and returns it to the cabin. Allowance is made for a separate urine collection device.

A breadboard model of the collector showed no problems in three particular areas of concern: (1) there was no pressure buildup in sealed spheres from partially dehydrated feces, (2) recycled air was odor free, and (3) bacteria were completely removed from gases vented to vacuum.

A. 4. 2 Collection Size

For MORL, a 30-day, six-man sphere was sized. Five of these spheres will fulfill the 147-day operating capacity requirement. Three spheres accommodate a 90-day resupply period, and four spheres accommodate a 120-day resupply period.

A. 4. 3 Collector Weight

A six-man, 30-day collector is estimated to weigh approximately 9. 8 lb. This weight is for the expendable sphere and does not include system valves, blower, fittings, filters, and lines. These items are estimated to weight 25 lb. The fixed weight for a 150-day capacity system (five spheres) is estimated as 74. 1 lb.

A. 4. 4 Air Losses

A primary concern with this type of waste management system is the amount of air lost overboard when a collection sphere is evacuated to space. The effect of a vacuum pump (Figure A-26) to lower sphere pressure from 7 to

*J. Dodson and H. Wallman. Research on a Waste System for Aerospace Stations. AMRL-TDR-64-33, May 1964.

0.5 psia prior to evacuation was studied. Figure A-27 shows the breakeven point in time when the weight of a vacuum pump will equal the weight of atmosphere lost by a sphere without pumpdown. For the MORL mission, pumpdown will save weight for any sphere of a practical size.

Figure A-28 presents a parametric curve of total system weight penalty for the use of collection spheres of various sizes for a 150-day mission. The curve shows that the best way of reducing system weight is by increasing the size of the collection sphere. It must be pointed out that the curve is theoretical because only the 15- and 30-day-size collection spheres actually fall on the curve shown. Other sizes which are not even multiples of 150 have excess capacity. Figure A-29 shows the weight penalty for 15- and 30-day sphere sizes and various mission lengths. This curve presents a more realistic view of system weight penalty as more spheres are needed for longer missions and as air is vented overboard.

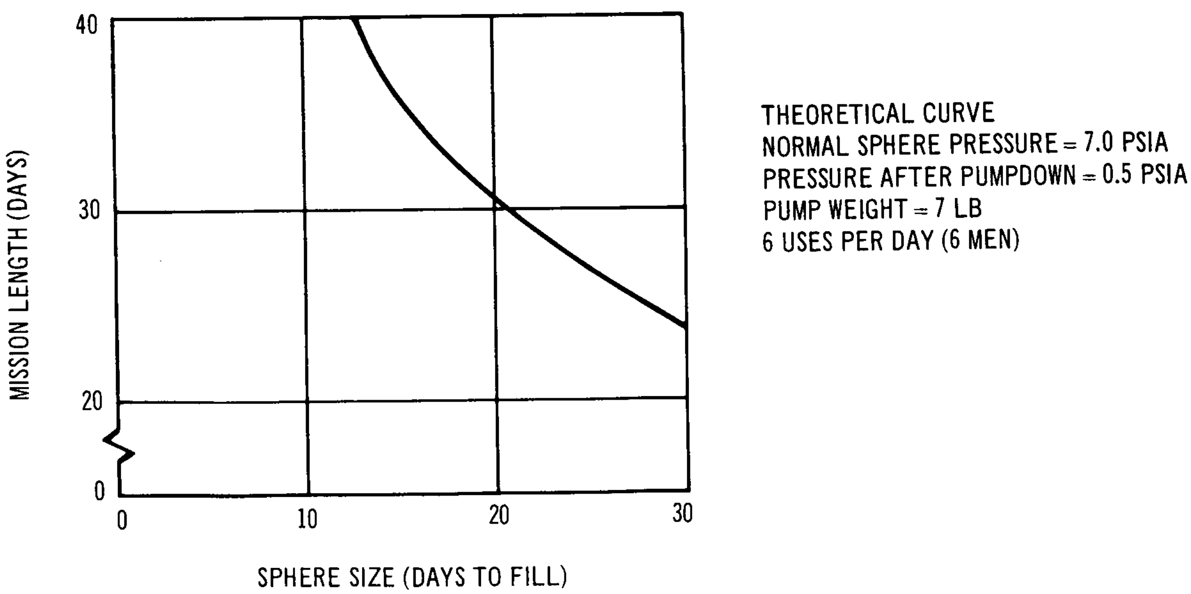


Figure A-27. Breakeven Point in Time When Vacuum Pump Should be Used in Waste Collector System

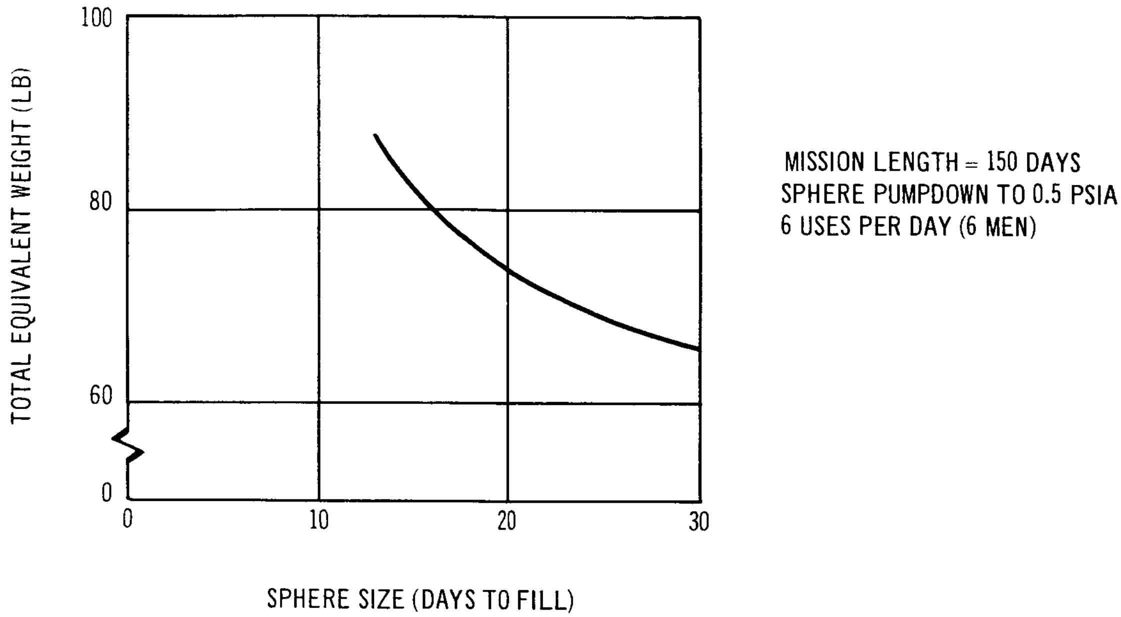


Figure A-28. Theoretical System Weight for Solid Waste Collector System

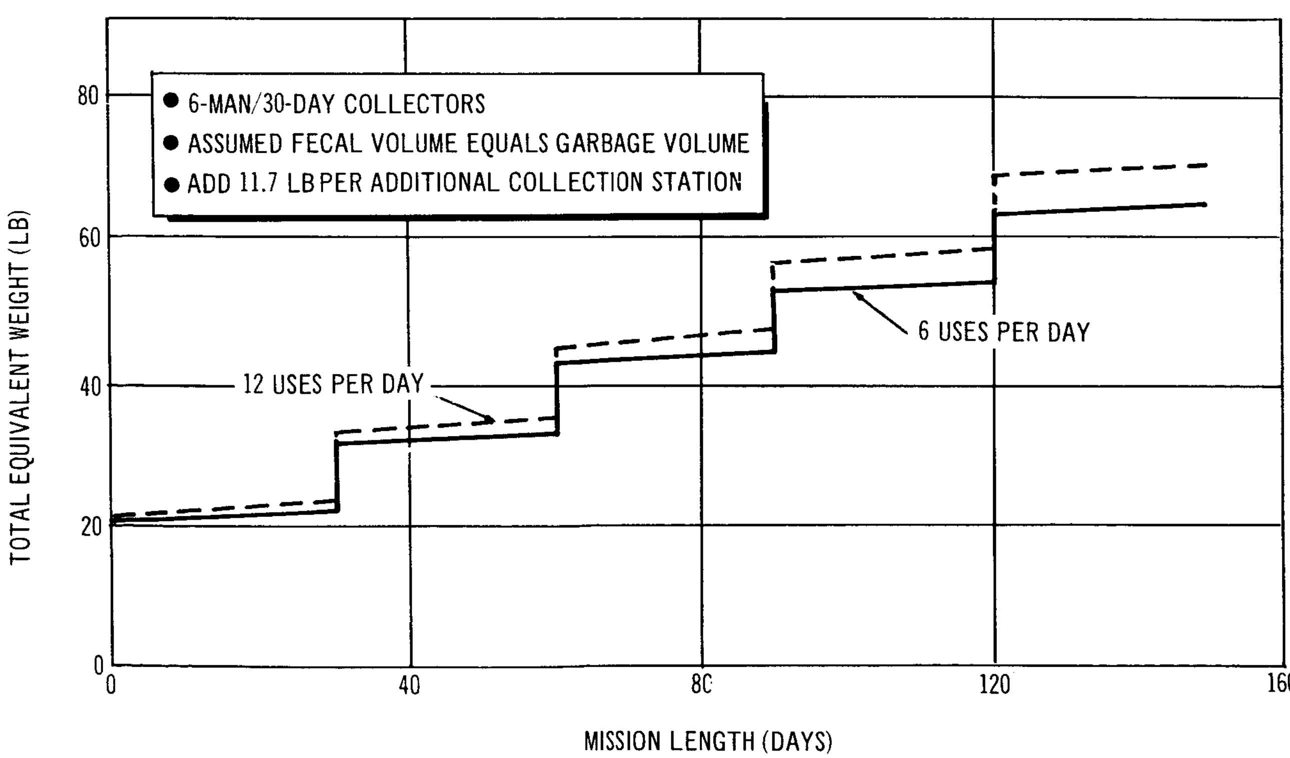


Figure A-29. System Weight as a Function of Use Rate for Combined Waste Collection/Storage

The power required for the air blower is 18 W. This blower will operate only during commode use to pull 5 cfm of air through the sphere and return it through filters to the cabin. The total estimated use is 2 hours/day, which will only require an average power of approximately 1.5 W. The power required for the vacuum pump is nominally 50 W and its estimated use is 4 hours/day, an average power demand of 8.3 W.

A.4.5 Number of Uses

If the system is equipped with a vacuum pump to recover most of the air normally lost during evacuation, increasing the number of uses adds little weight penalty/day. Figure A-30 shows the additional weight penalty for using this system for other laboratory wastes besides fecal matter. The total added weight penalty at the end of 150 days is approximately 6 lb.

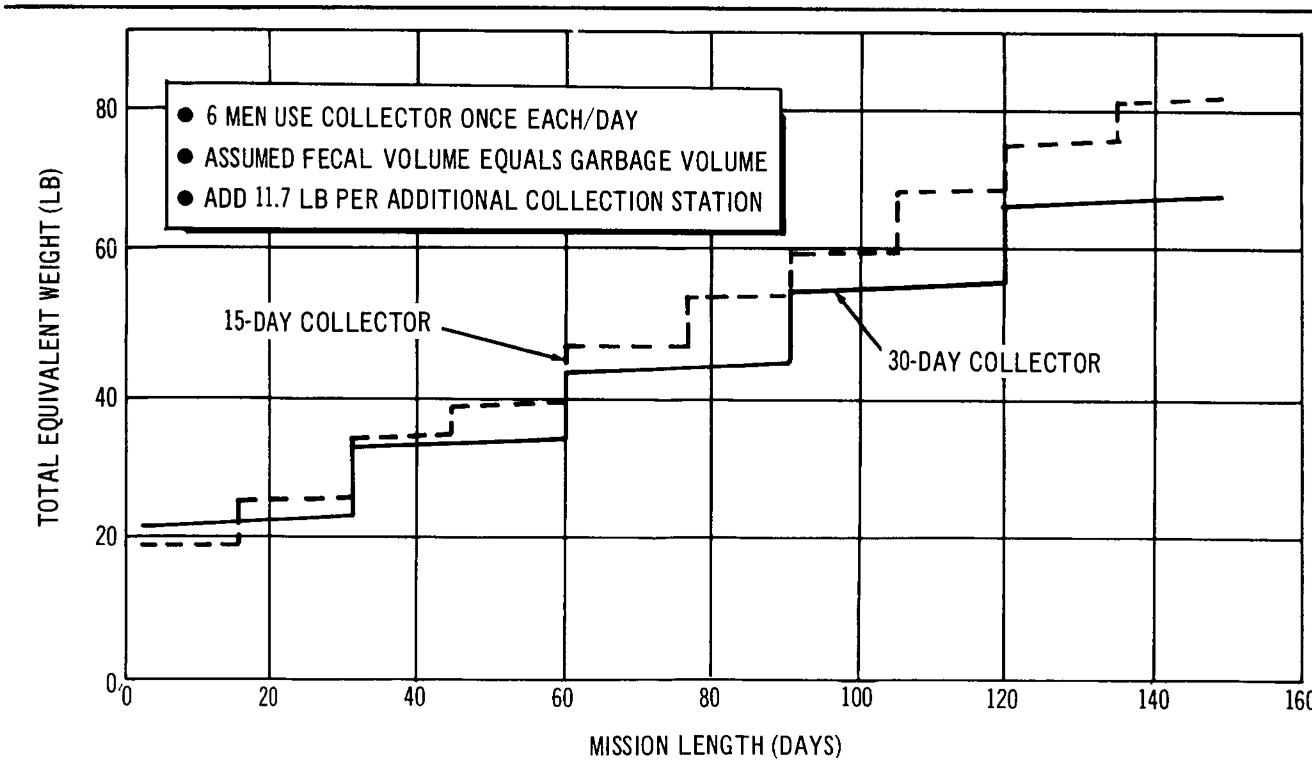


Figure A-30. System Weight as a Function of Collector Capacity for Combined Waste Collection/Storage

A. 4. 6 Other Factors

The following paragraphs list other factors concerning waste collection and storage.

A. 4. 6. 1 Cost

The system is simple and no complex development or qualification tests are anticipated. Costs are both reasonable and competitive with other systems.

A. 4. 6. 2 Reliability

The system design is simple and there are few operating parts. Mechanical reliability that is equal to other fecal collection systems should be achieved, especially if a redundant motor and selector valve are added.

A. 4. 6. 3 Psychological and Physiological Desirability

The system design has minimized the difference between this concept and a conventional toilet. For this reason, this concept is assumed to have maximum psychological and physiological desirability. Urine collection is disregarded in this evaluation because it is part of the water management subsystem.

A. 4. 6. 4 Sanitation

No sanitation problems are anticipated with this concept because the fecal wastes are not handled by personnel. The tested breadboard model showed that the circulated air was free of bacteria and odors. The changing of spheres presents no opportunity for accidents that could cause contamination. Daily antiseptic cleaning of the seat area will probably be desirable as a general sanitation procedure.

A. 4. 6. 5 Space Contamination

Positive standards of space cleanliness have not yet been established; however, the following arguments have been presented against venting materials from a space vehicle:

1. Effects on vehicle speed, direction, and attitude may be unknown and/or unacceptable.
2. Solid matter released can become missiles against other space vehicles.
3. Solids which ionize may set up electromagnetic fields which interfere with communications.
4. Solids released over a long period may build up in large enough quantity to interfere with vision or camera operation.
5. The release of matter to space often involves releasing valuable cabin atmosphere.
6. Because vacuum alone will not kill some microorganism for several weeks, a suitable atmosphere for reproduction may exist in areas where the vehicle provides shadowing from solar heat and radiation.

The combined collection and storage system allows only uncontaminated gaseous products to be vented to space. Of the above comments, only Items 1 and 5 apply to this system. As far as releasing cabin atmosphere is concerned, the amount lost is known and acceptable. As for Item 5, simple measures will be taken to eliminate undesirable thrust effects or to use them for useful purpose in orbit keeping.

A. 4. 7 Conclusions

The combined waste collection and storage waste management subsystem described above is superior to the Phase IIa method because it eliminates the manual transfers of wastes; approximately 15 man-min. are thus saved. A 30-day size collection sphere is selected. Each sphere is sized to handle twice the amount of fecal waste of six men for 30 days. The extra capacity is used for other laboratory wastes. A vacuum pump is installed to minimize the loss of air vented overboard during sphere evacuation.

A. 5 FREEZER CONCEPTS

A low-temperature freezer is required on MORL for the storage of specimens and samples required by the experimental program. In Phase IIa, a CO_2 vapor compression system was recommended for this storage requirement. In Phase IIb, a detailed study was performed of the various candidate subsystems to ensure that the selected concept represented the optimum method of providing the desired storage conditions. From the results of the study it was concluded that the CO_2 vapor cycle was still the best approach available to meet this requirement.

The following concepts of refrigeration were investigated for the freezer application:

1. Radiator cooling.
2. Thermoelectric cooling.
3. Open system boiling.
4. Gas absorption.
5. Vapor compression.

The analysis performed on each of these systems was based on a freezer with a volume of 2 cu ft, a controlled temperature of 0°F, and a freezing capability of 2 lb of water in 1 hour.

A. 5. 1 Radiator System

Figure A-31 presents a concept using a space radiator rejection from the freezer. The heat from the freezer is removed by a circulating coolant which has an inlet temperature to the unit of -5°F. The theoretical power requirement for this method is 2 W, and as can be noted in Table A-3, this value is low with respect to the other candidate approaches. The main disadvantages of this system are: (1) the requirement for a separate radiator which will operate at a lower temperature than the EC/LS radiator, (2) the contamination of the cabin atmosphere if any coolant (FC-75) should leak from the system, (3) the shortage of available space for a radiator, and (4) the necessity of providing for the repair of damaged radiator tubes. A minor deficiency of this system is an inability of the coolant to reach the

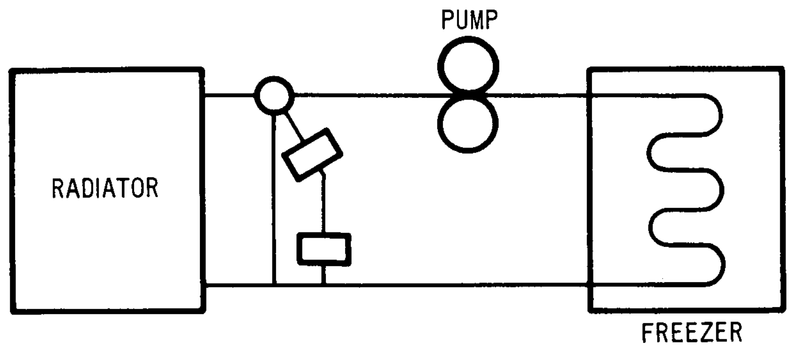


Figure A-31. Radiator/Freezer Concept

freezer sink-temperature of -5°F during certain periods of belly down orbit orientation. This shortcoming is probably not detrimental to freezer performances, because the increase in freezer temperature is slight, and each occurrence is of short duration. The radiator area required is approximately 30 sq ft and the total system weight is 26 lb.

A. 5. 2 Thermoelectric System

A thermoelectric system which is constructed by staging semiconductor junctions integrally with the freezer wall was studied, and is shown schematically in Figure A-32.

The selected junction material, Bismuth telluride (Bi_2Te_3), is a common semiconductor and is used for both p and n junctions. The voltage drop

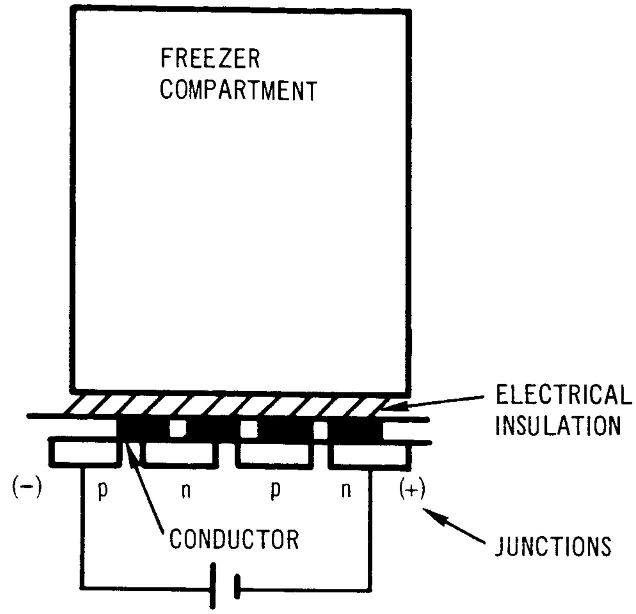


Figure A-32. Thermoelectric Freezer

across a junction necessary for optimum cooling is determined by the physical properties of the semiconductor and the temperature difference between the freezer and the cabin. For this freezer concept, in which the cabin temperature is 75°F and the freezer temperature is 0°F, the optimum potential for Bi_2Te_3 is 0.87 V. With an optimistic coefficient of performance (Q cooling/power supplied) of 0.50, approximately 280 W are required during the peak cooling period. If only one junction is used, the current required for 280 w of power consumption is 3,220 amps. As this is beyond the capability of the power supply system, a number of junctions must be staged. With a 28 Vdc power supply, 322 junctions will lower the current required to 10 amps.

Electrical insulation between the junctions and the freezer wall is required. Unfortunately, the most favorable electrical insulators are likewise good thermal insulators. This makes the choice of a suitable insulation material difficult.

The unit weight for the thermoelectric freezer is only 22 lb, and it has the advantage of having no moving parts. The main disadvantages are its high power consumption and difficult fabrication. The joining of semiconductors must be done with extreme care to prevent changing the thermoelectric properties of the material. The overall development status of high efficiency thermoelectric refrigerators is still in the experimental stage.

A. 5. 3 Open Boiling Systems

The principle of operation of an open boiling system (Figure A-33) is to provide a low sink temperature by giving up heat to a fluid being vaporized to space at a prescribed pressure. The sink temperature in the freezer of 0° F requires that a fluid with a low boiling point be used. The quantity of expendable fluid needed in this concept is excessive and eliminates this system as a contender. For example, the amount of expendables required using freons is approximately 1 lb/hour at the average freezer heat load. Ammonia, the

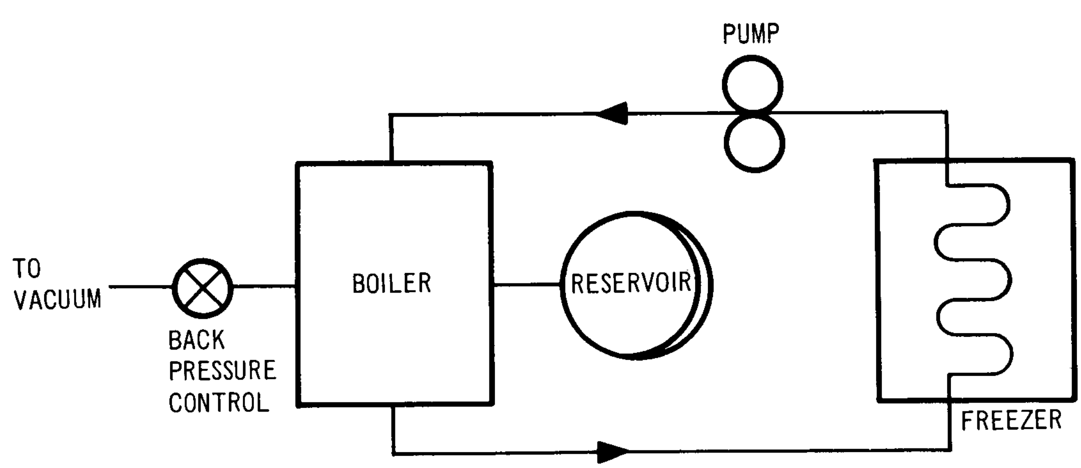


Figure A-33. Open Boiling Concept

best of the fluids, would require approximately 0.2 lb/hour. The use of either type fluid could present possible contamination problems to the cabin atmosphere.

A. 5. 4 Absorption System

An absorption cooling process, such as shown in Figure A-34 utilizes the basic change-of-phase method of the vapor compression system; however, the power requirement is lower. The system requires a carrier fluid (absorbent) to absorb the vaporized refrigerant. The power saving is realized by compressing a liquid (the refrigerant in solution with the absorbent) rather than compressing a vapor, as is done in a standard refrigeration cycle. After compression, waste heat must be added to separate the refrigerant from the absorbent. Upon separation, the refrigerant is passed through a condenser and then through an expansion valve and into the freezer.

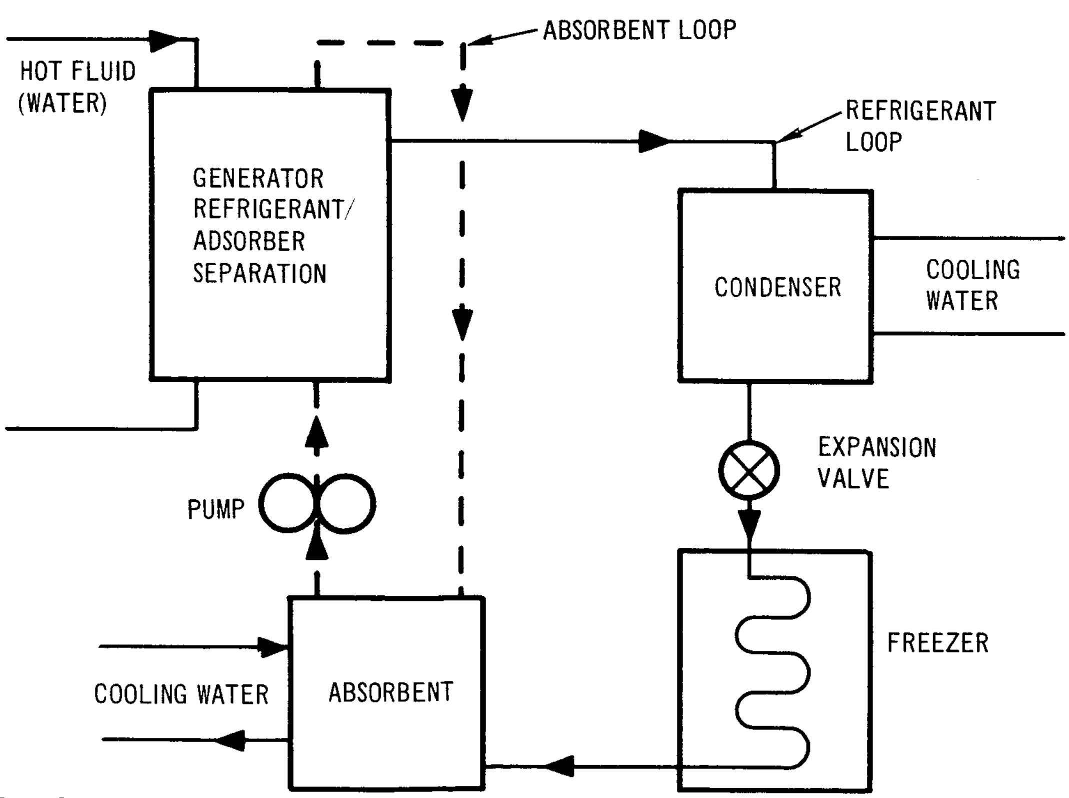


Figure A-34. Absorption Concept

This system was not recommended for two reasons: (1) the possibility of contamination problems, and (2) the problem of providing for the separation of the refrigerant from the absorbent in zero g.

A. 5. 5 Vapor Compression System

Figure A-35 shows a vapor compression system and its interface with the EC/LS water loop. Because previous systems were penalized as the result of the possibility of refrigerants causing atmosphere contamination, the refrigerants most commonly used in vapor compression systems were excluded from consideration. CO_2 is one refrigerant that can easily be removed from the laboratory environment if a leak in the freezer coolant system should occur. Although the coefficient of performance using CO_2 (5.4) is slightly less than with the use of freons, the power requirement of 26 W is not excessive. The weight of the unit plus the interface hardware is 24 lb.

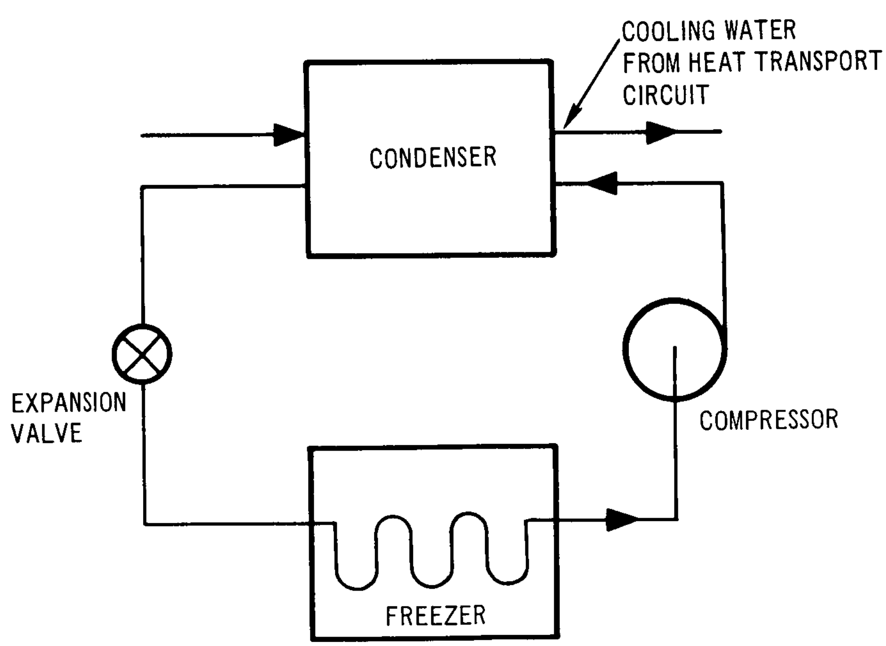


Figure A-35. Vapor Compression Freezer

Carbon dioxide is a commonly used refrigerant in industrial applications, particularly for low temperatures. The required 500 psi condensing pressure will not severely penalize the system because only small volumes are involved.

A. 5. 6 Summary of Concepts

A tabulated comparison of the systems discussed is presented in Table A-3.

A. 6 GASEOUS REPRESSURIZATION STORAGE

A study in the early portion of Phase IIb was performed to determine the penalty of repressurization of the vehicle if the storage was in a cryogenic subcritical form. Since the new Phase IIb EC/LS system eliminates cryogenic storage, this study is obsolete but is included in the report for reference.

In the Phase IIa baseline system, 121 lb of oxygen and 107 lb of nitrogen were stored in a gaseous state for cabin repressurization. Four tanks were used (two oxygen and two nitrogen), and their combined weight was 305 lb. If the 121 lb of oxygen were to be split up among the five subcritical O_2 storage tanks, the required capacity per tank would increase from 353 to 377 lb. The 107 lb of nitrogen would have approximately doubled the capacity requirement of the subcritical nitrogen tank to 219 lb. The result would have been an addition to subcritical tankage weight amounting to 14 lb for the five oxygen tanks, and 20 lb for the nitrogen tank (a total of 34 lb). This provided a 271 lb weight saving over the gaseous storage method.

The major problem incurred with the use of subcritical fluids for repressurization, is the requirement for large amounts of heat (38, 700 Btu) to provide gaseous delivery of the cabin refill charge at cabin pressure and temperature.

One method of reducing the electrical power requirement for heat is to increase the tank heat leak from the surroundings. When vacuum dependent insulation is used with cryogenic tanks, it is possible to increase the termal

Table A-3

SUMMARY OF FREEZER CONCEPTS

Method	Fixed Weight (lb)	Power (W)	Expendable Weight (lb)	Total Equivalent Weight (lb)	Notes
Radiator cooling	26	2	-	26	Radiator requires 30 sq ft of vehicle area. Possible atmosphere contamination. Cooling is a function of radiator orientation.
Thermoelectric cooling	22	280	-	64	Requires excessive power.
Open boiling	32	2	1 lb/hour	2,192 (90 days)	Possible atmosphere contamination. Weight of required expendables is excessive.
Absorption	30	5	-	31	Possible atmosphere contamination. Zero-g gas/liquid separation a problem.
Vapor concentration	24	26	-	27.8	Contamination problem is minor if CO_2 is used. Power required is higher than other systems.

conductivity of the insulation by letting air into the vacuum at the ambient pressure of the hangar. An increase of pressure from 10^{-5} to 10^{-1} mm Hg would raise the conductivity from $3.5 \times 10^{-5} \frac{\text{Btu}}{\text{sq ft/hour °R}}$ to approximately two orders of magnitude higher.

As the pressure is increased further, the thermal conductivity of the insulation approaches that of air. This will provide a significantly reduced power requirement in supplying oxygen. There will be relatively little effect upon the nitrogen tank power requirement caused by the smaller amount of total surface area per unit of nitrogen. Figure A-36 presents the power requirement for refilling the cabin with increased heat leakage taken into account.

During the repressurization period, it is assumed that the major power consuming equipment in the cabin will be dormant. If this is the case, repressurization may be accomplished in relatively short periods. If the crew could remain in the hangar over somewhat larger pressurization periods, the power penalty would be reduced even further.

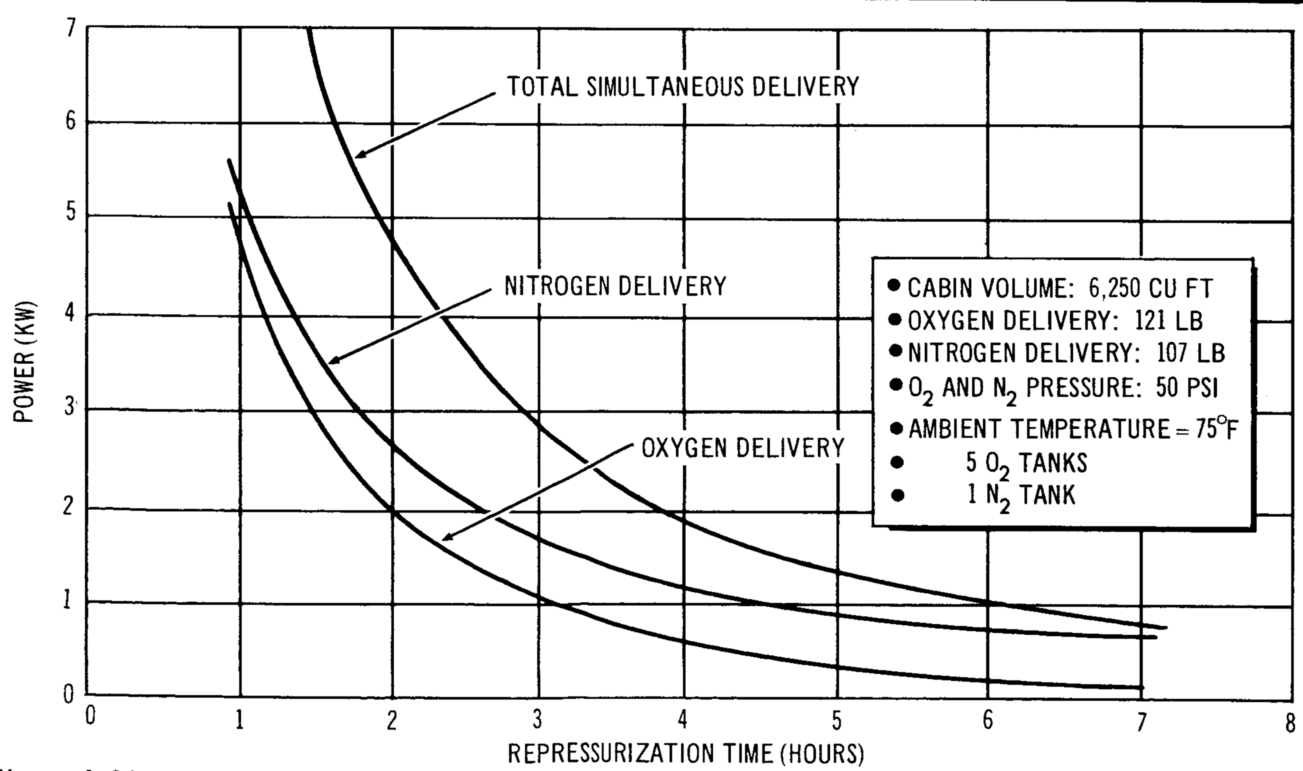


Figure A-36. MORL IIA Baseline, Repressurization Heating Power Penalty – Subcritical Storage of Oxygen and Nitrogen

A.7 ATMOSPHERE SUPPLY RELIABILITY

An analysis was conducted to determine the effect on subsystem reliability of obtaining oxygen by the electrolysis of water rather than from cryogenic oxygen.

A.7.1 Analytical Procedure

In Phase IIa, a reliability analysis of the complete atmosphere supply subsystem was completed with estimated failure rates for each subsystem component. To determine the system reliability without cryogenic O_2 equipment, the failure rates of the cryogenic O_2 equipment were subtracted from the sum of all baseline component failure rates according to the following procedure:

P_{MS} (Atmosphere supply system/without cryogenic 0_2)

$$= e^{-(\Sigma\lambda_{baseline} - \Sigma\lambda_{0_2\ equipment})\ t}$$

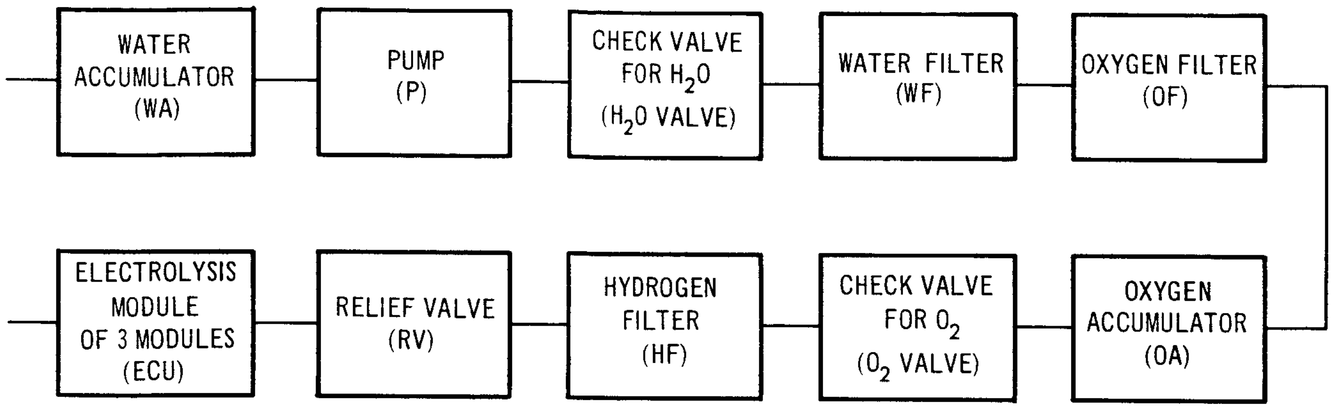
P_{MS} for 90 days = 0.854

P_{MS} for 1 year = 0.530

The reliability of the generation of 0_2 by electrolysis is given in Figure A-37 and the reliability of the electrolysis module is given in Figure A-38. The only reliability data available are for a single electrolysis module. These reliabilities are adjusted to include the equipment of the entire oxygen generation process indicated in Figure A-37. Therefore, Figure A-39 indicates the methodology used to determine the reliability of the electrolysis process based on available data.

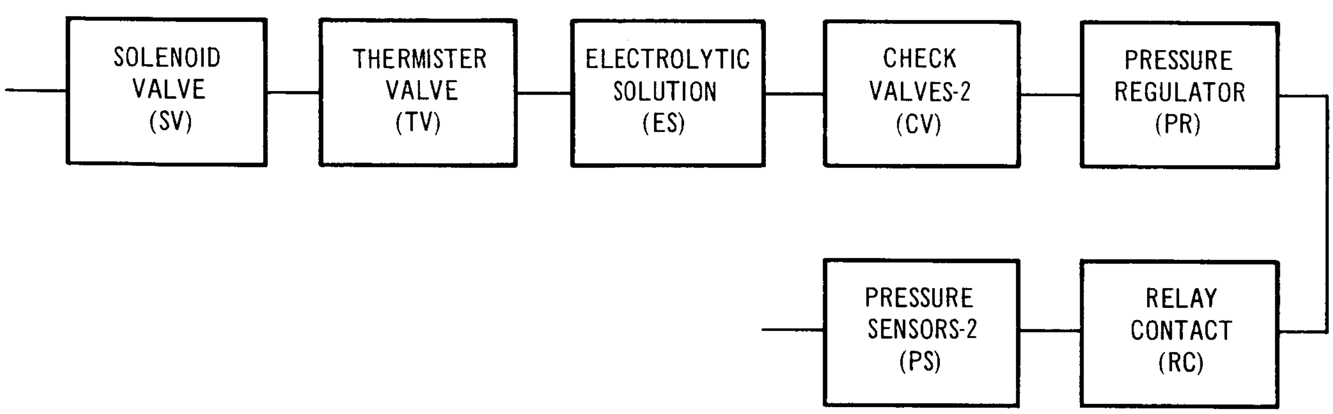
A.7.2 Reliability Comparison, Alternate 0_2 Supply Methods

The reliability of the Phase IIa Atmosphere Supply subsystem based on cryogenic 0_2 is 0.26782 for a 1-year period. An atmosphere supply subsystem based on water electrolysis has (for the same period) a reliability of 0.524--an improvement of 100%. The addition of redundant electrolysis modules and the elimination of the relatively high failure rates associated with cryogenic 0_2 storage and transmission (tanks, regulators, valves, sensors, and so forth) are the main reasons for this increase in reliability.



$$P_{MS}\text{(ATMOSPHERIC SUPPLY)} = P_{MS}(\text{WA}) \cdot P_{MS}(\text{P}) \cdot P_{MS}(H_2O\text{ VALVE}) \cdot P_{MS}(\text{WF}) \cdot P_{MS}(\text{OF}) \cdot P_{MS}(\text{OA}) \cdot P_{MS}(O_2\text{ VALVE}) \cdot P_{MS}(\text{HF}) \cdot P_{MS}(\text{RV}) \cdot P_{MS}(\text{ECU – MINIMUM OF 3})$$

Figure A-37. Reliability Model – Oxygen Generation



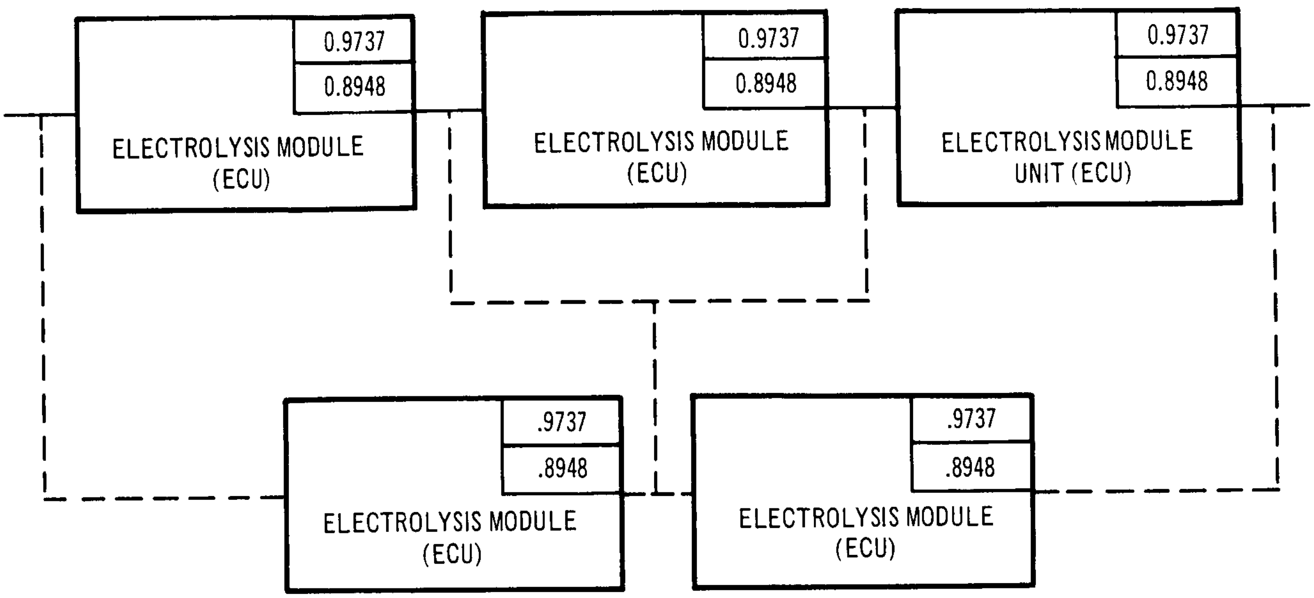
P_{MS} (ELECTROLYTIC CELL UNIT) $= e^{-(\Sigma\lambda)\,t}$,

WHERE $\Sigma\lambda$ = SUM OF FAILURE RATES $= \lambda_{SV} + \lambda_{TV} + \lambda_{ES} + 2\lambda_{CV} + \lambda_{RC} + 2\lambda_{PS}$

t = NORMAL OPERATING TIME

$$P_{MS}\text{(ELECTROLYTIC CELL UNIT – MINIMUM OF 3 OUT OF 5)} = 1 - P_F^{\,5}(\text{ECU}) - 5P_S(\text{ECU}) \cdot P_F^{\,4}(\text{ECU}) - 10P_S^{\,2}(\text{ECU}) \cdot P_F^{\,3}(\text{ECU})$$

Figure A-38. Reliability Model – Electrolysis Module



P_{MS} (ECU) FOR 90 DAYS = 0.9737*

P_{MS} (ECU) FOR 1 YEAR = 0.8948*

P_{MS} (ECU – MINIMUM OF 3) FOR 90 DAYS = 0.9998

P_{MS} (ECU – MINIMUM OF 3) FOR 1 YEAR = 0.9901

P_{MS} (ECU – MINIMUM OF 3 OUT OF 5) = P_S^3 (ECU) + $3P_F$ (ECU) · P_S^2 (ECU) [1 – P_F^2 (ECU)] + $3P_F^2$ (ECU) · P_S^3 (ECU)

*BASED ON ESTIMATED DATA FROM THE HARDWARE MANUFACTURER

Figure A-39. Modified Reliability Model – Oxygen Generation

Appendix B
RESEARCH AND TECHNOLOGY REQUIREMENTS

B. 1 INTRODUCTION

This appendix presents a summary of the research and technology development required by the recommended EC/LS system. Problems range from relatively minor hardware feasibility or improvement tests which can be resolved after PDP, to major critical problems requiring test programs up to a 12-month duration. Most problems can be resolved by ground test development. Flight test requirements are discussed in Section B. 3.

B. 2 RESEARCH AND TECHNOLOGY SUMMARY

Figure B-1 shows the logic diagram from which the research and technology requirements were evolved. The diagram shows specific hardware requireing development, how this hardware is related to the EC/LS subsystem, present status of the hardware development, and type of development required. If no entry is made under any of the test columns for a particular item of hardware, that item can be designed with existing technology. If an entry is made, a separate discussion of the particular problem follows, categorized by subsystem. An overall priority listing is contained in Table B-1. Some entries are indicated as being part of the Support category. This means that a specific AAP experiment is not required. However, it is felt that the AAP program will automatically provide flight-test data useful in the design of that particular item of hardware. A separate discussion for each of these entries is not provided. A summary and discussion of this support is contained in Table B-2.

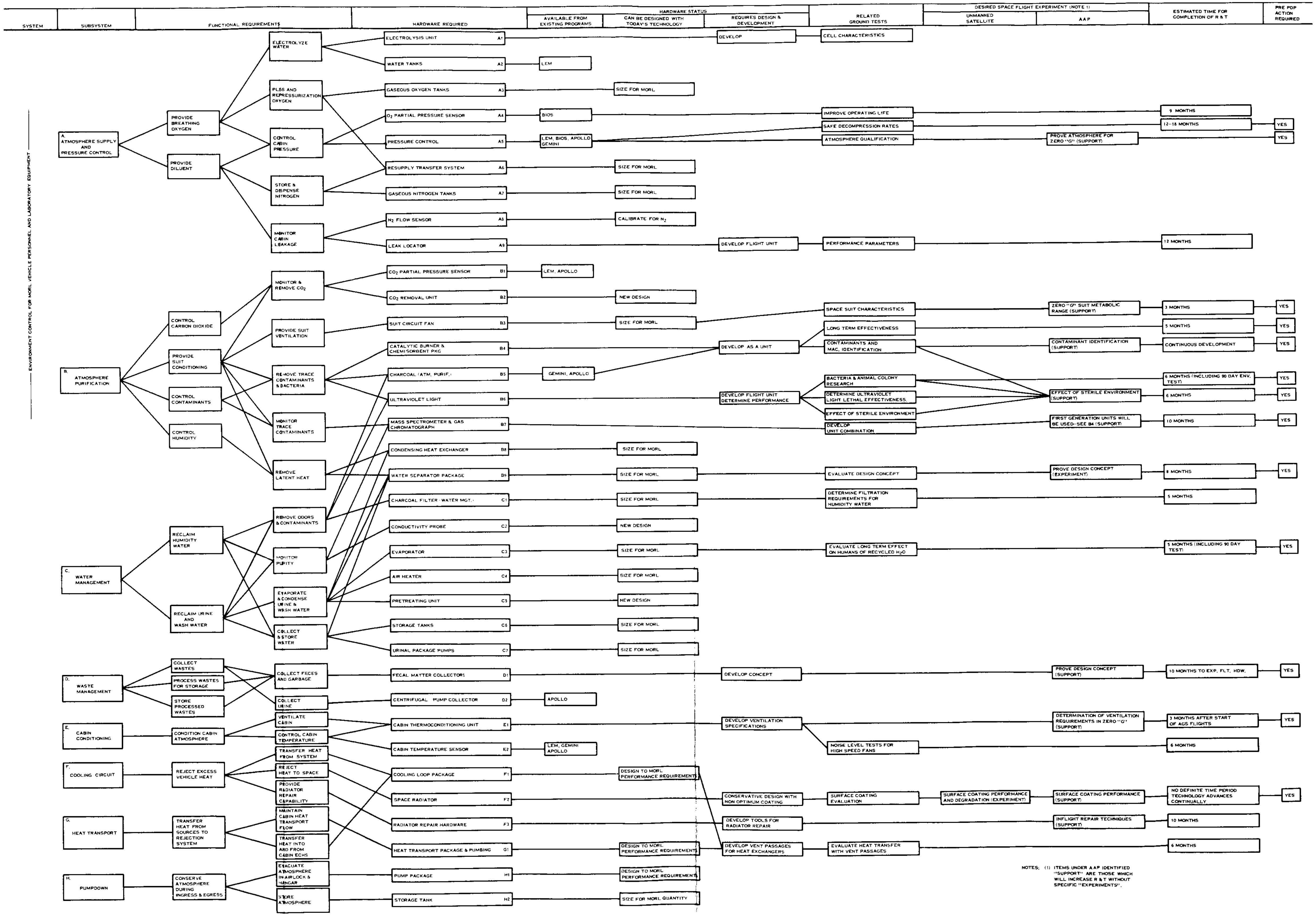


Figure B-1. Research and Technology Summary

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Table B-1 (page 1 of 2)

PRIORITY OF EC/LS RESEARCH AND TECHNOLOGY

Group A--Highest priority within EC/LS system development. Results will increase confidence that overall schedules can be met.

Priority	Problem	Reference Paragraph	SRT Category*
1	Selection of atmospheric composition	B. 2. 1. 4	R
2	Identification of and tolerance to trace contaminants	B. 2. 2. 2	R
3	Contaminant monitoring accuracy	B. 2. 2. 1	R
4	Electrolysis cells	B. 2. 1. 1	AD
5	Long-term water potability	B. 2. 3. 2	R
6	Bacteriological research	B. 2. 2. 6	R
7	Animal colony experiments**	B. 2. 2. 5	R

Group B--Desirable because significant improvements to the EC/LS system will result, such as: increased reliability, decreased weight, or increased operating convenience.

Priority	Problem	Reference Paragraph	SRT Category*
1	Radiator coatings	B. 2. 6. 1	AT
2	Trace contaminant removal effectiveness	B. 2. 2. 3	AD

*NASA-defined supporting research and technology categories

**Priority is decreased if animal colony experiments are not mandatory on MORL

Table B-1 (page 2 of 2)

Priority	Problem	Reference Paragraph	SRT Category*
3	Humidity water processing	B. 2. 3. 1	AT
4	Molecular sieve bed desorbtion	B. 2. 2. 8	AT
5	Bosch hydrogenation reactor operation	B. 2. 8	AT
6	Water separator development	B. 2. 3. 3	AD
7	Solid waste collection	B. 2. 4. 1	AT
8	In-flight radiator repair	B. 2. 6. 2	AT

Group C--Lowest priority within EC/LS system development. Development can wait until ATP because risk is low. However, advanced development would relieve a tight development schedule and reduce development cost.

Priority	Problem	Reference Paragraph	SRT Category*
1	Metabolic rates in space suits	B. 2. 2. 7	AT
2	Heat exchanger leakage	B. 2. 7	AD
3	Flight-qualified ultraviolet lights	B. 2. 2. 4	AD
4.	Oxygen partial pressure sensor life	B. 2. 1. 3	SD
5	Noise generation by fans	B. 2. 5. 1	AT
6	Atmospheric leak location	B. 2. 1. 2	AT

*NASA-defined supporting research and technology categories

Table B-2 (page 1 of 2)
SUMMARY OF EXPECTED AAP SYSTEM SUPPORT

Area	Problems	AAP Applicability
1. 50-50 N_2/O_2 7.0 psia atmosphere	a. Safety in the event of a fire b. Air velocity required for crew comfort and equipment cooling effects c. Physiological effects on man d. Tolerance over extended time period e. Safe decompression rates	a. It is expected that at least one long-term AAP vehicle will use this atmosphere b. This atmosphere will likely be ground tested prior to long-term AAP flights
2. Astronaut physical capabilities	a. Use of welding and other equipment for vehicle and radiator repair b. Design of detailed components to allow for ease of repair/ replacement	a. Tests are anticipated which will indicate 1. maneuverability 2. level of work effort 3. physical strengths 4. control of movements
3. 90-day spacecraft environment	a. Desirability of completely sterile atmosphere b. Daily work, sleep, eat, exercise, diet, and recreation schedules to more	a. 90-day AAP missions are a possibility

Table B-2 (page 2 of 2)

Area	Problems	AAP Applicability
	accurately determine systems EC/LS requirements c. Tolerance to long-term water recycling (over 90 days)	
4. Ventilation in zero-g	a. Air movement properties/requirements	a. Can be evaluated in all AAP flights
5. Space suit EC/LS requirements in zero-g	a. Air-flow requirements over complete metabolic range	a. Can be evaluated in any AAP flight with significant suited operation
6. Atmosphere purification	a. Identify trace contaminants and production rates	a. Will probably be evaluated in all AAP flights to provide backup to ground test data
7. Feces collection system	a. Simple and comfortable design for long-term mission b. Reliable operation	a. Various designs can be tried in AAP flights until satisfactory solution is found
8. Radiator coatings	a. Degradation over time b. Performance	a. Will be determined to some degree in all AAP flights

B. 2. 1 Atmosphere Supply Subsystem

The following paragraphs discuss the atmosphere supply subsystem.

B. 2. 1. 1 Electrolysis Cells

The basic supply of oxygen for MORL is obtained from the electrolysis of water. In normal operation three modules, each consisting of a stack of cells, are connected in parallel. If one module fails, an in-line spare is activated. The system is designed so that any one of the modules can be started and stopped to meet the varying oxygen production design requirements, and to control the PO_2 pressure.

The type of electrolysis cell recommended for development is the reverse Gemini fuel cell (manufactured by General Electric Corporation). It is the most advanced in the present level of technology. The problems with this cell in the type of operation described above are as follows:

1. Membrane Life -- Inadequate data exists on the operating life of the individual cell membrane. Limited test data indicates that a life of 45 days is probably available with existing technology. Because of this limited membrane life, the MORL design requires installed redundancy, membrane spare parts, and the capability to replace membrane stacks in zero g.
2. Membrane Replacement -- If a membrane fails, three choices are available: (1) replace the failed membrane, (2) replace the entire membrane stack, or (3) replace the module. The first alternative was rejected because it was considered to be a maintainance operation too complex for MORL. The third alternative, while not impossible from a logistics standpoint, is not desirable because of excessive resupply weight. This leaves the second alternative, and if follows that the module must be designed so that the membrane stacks are replaceable. A special design is required so that the acid electrolyte can be separated safely from the cells in zero g. (This feature has not been incorporated into those units already built.)
3. Start-Stop Operation -- Although the existing modules are not specifically designed for start-stop operation, the manufacturer feels that cycling as often as once every 24 hours will not present a problem. However, in view of the limited membrane life available, it is felt that tests should be conducted to confirm this assumption.

Alternate

An alternative would be to develop one of the newer type electrolysis systems which are presently in laboratory or feasibility development stages. The so-called dry electrolysis concepts would be preferable from a space station standpoint because it would eliminate the need for a chemical electrolyte. It is recommended that the most promising of these alternate electrolysis concepts be developed as a backup.

Development Status

The existing prototype design is not specifically designed for membrane replacement or start-stop operation. The maximum number of operating hours on a membrane stack has reached 1,500 hours.

Schedule Considerations

If the discussed problems are not resolved, they will not prevent development of this subsystem in the post ATP development program. However, a pre-PDP solution to these problems would permit a more accurate definition of operating and spares requirements, and would eliminate the risk involved in solving these problems during development. An estimated 18-month program would be required.

B.2.1.2 Atmospheric Leak Location

The leakage of atmosphere from the MORL vehicle caused by penetrations of the pressure shell, is classified into two general categories, known and unknown. Included in the first category are seals around penetrations by liquid lines, air lines, and hatches. The area of concern is the second category, the leakage caused by micrometeoroid penetrations. Leaks are detected by a higher than normal consumption of atmospheric stores. Leaks are located visually if possible; however, the problem of locating minute leaks must be resolved. An ultrasonic leak detector which locates a leak or discontinuity by means of a pulse-echo system is recommended. The problem is that a portable flight unit suitable for this application has not been developed.

Alternate

Since the need of such an instrument is not great because of the low probability of meteoroid penetration, fatigue from launch, and so forth, the alternate solution would be to have no leak location device and resort to visual detection. If the portable locator were not employed, the quantities of oxygen and nitrogen would be necessarily increased to compensate for unknown leakage.

Another alternate concept is the use of an ionization-type vacuum gage which would be used as a sniffer by an astronaut on the exterior of the vehicle. If the sniffer probe covers or is near a leak, the vacuum gage will indicate a higher pressure. This approach is questionable as the outside of the presure skin is not accessible in many locations.

Development Status

The development of a leak-location device is within present capabilities. Although a unit has not been fabricated for space flight applications, the principles of operation are found in commercial equipment. The location of holes down to a 0.003 -in. diameter by this technique is questionable and must be demonstrated. If the concept does not adequately perform the function desired, other concepts should be tested.

Schedule Considerations

The development of a leak detector can start as late as 1 year before deployment of the MORL. It is desirable to start the development of a leak detector earlier because the probability of mission success will be lower if a technique cannot be developed. It also may be necessary to design the atmospheric storage system for greater capacity, as discussed earlier.

B.2.1.3 Oxygen Partial Pressure Sensor Life

The partial pressure of oxygen in each compartment is monitored by an oxygen partial pressure sensor which actuates the oxygen inflow control. The selected sensor in the baseline system is of the polarographic type, in which the solubility of oxygen in a fluid is proportional to the partial pressure. The main problem is the evaporation of this fluid over extended periods of time, necessitating periodic replacement of the sensing element.

Alternate

The alternative for developing a long-life sensor would be to use presently developed sensors in the system. With the use of present sensors, instrument replacement must be made at regularly scheduled intervals. There would not be any significant weight penalty; however, crew time required to replace the sensors is a penalty to crew experiment time.

Development Status and Requirements

The present expected life of polarographic sensors is approximately 30 days. Development to reduce the evaporating tendency of the fluid or, possibly, investigation of a completely new concept is needed.

Schedule Considerations

The development of a sensor should be completed before MORL final hardware design is started. It is estimated that a 9-month research program will be required to develop a new O_2 sensor concept.

B. 2. 1. 4 Selection of Atmospheric Composition

For the baseline system, an atmospheric composition of oxygen and nitrogen (50% by volume) at a pressure of 7 psia was selected. It is necessary to qualify the selected atmosphere by manned tests for at least a 90-day period before acceptance may be made. In addition, decompression rate tests must be made from 7 to 3. 5 psia pure O_2 suit atmosphere to determine aeroembolism effects on crew members.

Alternate

The alternative to qualification of the 7 psia atmosphere would be to use a sea-level atmosphere. A 14. 7 psia atmosphere would impose significant penalties as a result of greater structural requirements and leakage for higher pressures. The physiological effects of a higher atmospheric pressure would result in longer decompression time to the suit pressure and, with a lower pressure, possible decreased vehicle occupancy periods.

Another alternative would be to use helium as a diluent rather than nitrogen if the nitrogen decompression problems prove insoluble. However, the unknown effects of helium may present even greater problems. Decompression problems should not be critical on MORL, however, because two independent compartments are available.

Development Status

Manned tests of a 7 psia atmosphere have been conducted for periods of 30 days. These tests are not considered adequate for determination of long-term effects on a crew (up to 270 days). Extensive ground base testing for periods of 90 days (as a minimum) is required.

Limited decompression tests have been conducted; however, as a result of variations between individuals, the results have been inconclusive. Additional tests using larger numbers of test personnel are required.

Schedule Considerations

The atmosphere for the MORL must be established prior to PDP because of the major impact that the atmospheric pressure has on the design of the EC/LS system. Approximately 5 months will be required to run a 90-day confinement test assuming that chamber facilities are available, such as the Langley Integrated Life Support System (ILSS) facility. Tests conducted for other programs, such as the MOL or AAP programs, may provide some of the data needed to verify the atmosphere selection.

B.2.2 Atmospheric Purification Subsystem

The following paragraphs discuss the atmospheric purification subsystem.

B. 2. 2. 1 Contaminant Monitoring Accuracy

The contaminants in the MORL atmosphere are to be identified and monitored by a mass spectrometer-gas chromatograph combination. At present, the accuracy is not sufficient for an adequate knowledge of the atmospheric constituency. The problem is to develop a flight-qualified mass spectrometer-gas chromatograph combination that is capable of measuring contaminants 10 times below the continuous exposure maximum allowable concentrations (MAC), and 100 times below the intermittent exposure MAC (once the MAC values have been determined).

Alternate

The alternative to the problem is to use the presently developed individual mass spectrometer-gas chromatograph with sufficient over design in the contaminant removal units. The will decrease the possibility that contaminant levels will reach the MAC values. The use of an individual mass spectrometer and gas chromatograph would then be a quantitative measurement of the general condition of the vehicle atmosphere. As a result, a lower probability of mission success will exist.

Another alternative would be to deliberately change the cabin atmosphere at regular intervals (possible every 30, 60, or 90 days). This could impose a weight penalty up to 1, 000 lb for every scheduled repressurization.

Development Status and Requirements

The gas chromatograph is presently undergoing development for flight qualification for the Apollo program. The capability of readout is approximately 35 channels. The mass spectrometer has been flight qualified for a limited capability. The combination of both, with an increase in accuracy, must be developed for the MORL application.

Schedule Considerations

This problem should be resolved before the completion of PDP to eliminate the risks noted above. It is anticipated that 10 months will be required to develop a flight prototype combination unit.

B. 2. 2. 2 Identification of and Tolerance to Trace Contaminants

The contaminant removal equipment was sized on the basis of an assumed contaminant presence and generation rate. Likewise, the MAC were based on assumed values derived from industrial standards. The main problem is determining all anticipated contaminants in the MORL atmosphere and the maximum concentration limits for the crew.

Alternate

The alternative to the solution is an ultraconservative design approach to the contaminant removal units. The present MAC values are based on a limited exposure time, such that crew time may be unnecessarily penalized in contaminant monitoring. The weight penalties involved are the oversizing of equipment and the possible dumping of cabin atmosphere on a periodic basis (up to 1, 000 lb per repressurization).

Development Status and Requirements

The identification of the trace contaminants used in the tests should be determined by an evaluation of all materials to be used in the MORL, including chamber testing of these materials to determine off-gassing rates. Also included in these tests must be the contaminants generated by man.

Closed chamber testing has been conducted on men for periods up to 30 days. It is desirable that manned tests be performed for a 270-day test duration. Before performing manned tests, the trace gas MAC values for animals should be determined by testing many animals at various concentrations for 90-day periods. The results from the animal testing should be used to predict MAC values for man, and the manned closed-chamber tests should have trace-gas concentrations controlled at these values.

Schedule Considerations

This problem area should be resolved before the completion of PDP to eliminate the program risk noted above. A total test program of approximately 1 year is anticipated to resolve this problem, assuming facilities are available, such as Langley's ILSS.

B. 2. 2. 3 Trace Contaminant Removal Effectiveness

The removal of trace contaminants in the MORL atmosphere is accomplished by charcoal, chemical sorbents, and a catalytic burner. Although the design of these components is in a highly developed state, long-term effectiveness is unknown. Selection and quantity determination of catalysts and sorbents materials must be made with regard to MORL's long-mission duration.

Alternate

The alternative to developing a long-term contaminant removal system would be the use of presently available technology for short-duration missions. The impact of this alternative will be the requirement for excessive spares and additional crew time for monitoring and/or unit replacement. It may be required to dump the cabin atmosphere at periodic intervals at a penalty of up to 1, 000 lb for each repressurization.

Development Status and Requirements

Contaminant removal equipment for spacecraft is undergoing development at the present time. Sorbents for contaminant removal are being developed for Apollo and LEM. Further development and selection of catalysts and sorbents must be made when identification of anticipated contaminants is made. Ground tests for extended periods are necessary for solutions to these problems. The testing planned for Langley's ILSS facility will satisfy these test requirements.

Schedule Considerations

The determination of a solution to this problem is desirable before the completion of the PDP, although not compulsory. The expected contaminants in the MORL atmosphere and the maximum allowable concentration should be determined. Approximately a 5-month test program in the Langley ILSS test facility will be required. This test can be conducted in conjunction with other tests.

B. 2. 2. 4 Flight-Qualified Ultraviolet Lights

The baseline system utilizes ultraviolet lights for the control of atmospheric bacteria. Two problems exist for the employment of such lights: (1) accurate determination of bacteria killing performance, and (2) breakage of the lights. Data are necessary to size the units so that bacteria removal (consistent with the bacteriological research study results) will be accomplished with units of minimum power and weight. The second problem to be solved is to ensure that a lethal contaminant will not be introduced into the atmosphere if a lamp is broken because existing lights contain mercury vapors.

Alternate

The alternative to the problem is to eliminate the ultraviolet lights and resort to the high temperature of the CO_2 removal system silica gel beds, as well as any additional heat required to provide bacteria kill. The impact of this solution may be assessed when the results of the bacteriological research study (Section B. 2. 2. 6) are available.

Development Status and Requirements

Although ultraviolet lamps have been developed for bacteria killing purposes, performance data are limited in scope. Accurate performance must be determined and a flight unit design must be developed. Ground testing is adequate for qualification of such a unit for MORL flight.

Schedule Considerations

The solution to this problem should be defined before the end of the PDP, otherewise a conservative design approach must be used. Approximately 6 months of research testing would be required to resolve this problem.

B. 2. 2. 5 Animal Colony Experiments

The risks and problems associated with the conduction of animal colony experiments are severe as result of possible bacteria release and contamination to the crew. Testing is required with typical animal colonies to determine the type of EC/LS system required for the animals, and the amount of integration possible between the animal EC/LS and crew EC/LS systems.

Testing is required to develop atmospheric purification/water management subsystems that can be used with animals. Ground testing is sufficient for the determination of requirements in this area. Areas such as purification of the atmosphere and reclamation of water after contact with contamination (inevitable in animal bedding) are of greatest concern.

Alternate

The impact upon the mission if the purification is not performed could have serious consequences to crew safety. The alternative may be total isolation of the animal colony with no interface between the two EC/LS systems. This would involve inefficient use of crew time, either in donning suits or masks, or in taking extreme precautions in animal handling.

Development Status and Requirements

There has been essentially no development of EC/LS systems for unconfined animals or animal colonies to data.

Schedule Considerations

Testing with animals must be done before final experiment hardware design is started if the alternative mentioned above is to be relaxed. Approximately a 9-month period is required to build prototype equipment and perform tests using animals.

B. 2. 2. 6 Bacteriological Research

In MORL, the atmosphere will be relatively sterile. The effect on a human of a sterile environment must be determined before flight. Since the bacteriological balance of man will be changed, his resistance to infection or disease may be seriously lowered. The research problem in this area may also include the establishment of an artificial bacteriological balance in the vehicle.

Alternate

If the problem is not investigated and the flight is made with a bacteria-free environment, as in the baseline approach, it may be necessary (if stay times are not shortened) to immunize the crew after they return until they have restored their normal resistance to disease. Experimentation with animals may be severely compromised as a result of the contamination effect upon the crew. All resupplies may have to be sterilized.

Development Status and Requirements

Several manned chamber tests have been performed for short durations, up to 30 days. Although data have been obtained, it is necessary that longer duration experiments be run because a crew member may remain in MORL for extended periods of time. Only ground testing is required, but flight experience is expected to be obtained from the AAP program. It is unlikely that the duration of AAP flights will be as long as desired.

Schedule Considerations

A solution to the problem should be obtained prior to the end of the PDP to eliminate the program risk noted above. Approximately a 6-month period will be required to conduct a 90-day tests, assuming test facilities are available.

B.2.2.7 Metabolic Rates in Space Suits

Sizing of the fans that provide air flow for suited operations must be made to satisfy the air flow requirements of the suits, but still not be oversized such that electrical power is wasted. Present metabolic rates for the MORL vehicle are 1,000 Btu/hour per man. Whether this value is accurate is in question and may ultimately change suit operation air flow requirements. The fan pressure drop is a function of suit characteristics and as such must be corrected as suit designs change.

Alternate

If fan power is excessive, liquid-cooled thermal garments may be used to lower air flow requirements.

Development Status and Requirements

The development of space suits is constantly increasing and valuable data are continually developed pertaining to work levels as a function of air flow requirements. Because the air flow in a suit is a forced convection situation, there is high confidence in curves generated which show cooling capacity and carbon dioxide removal from the helmet. The largest problem that exists is estimating long- and short-term metabolic requirements under zero-g conditions. The research and technology requirements in this area consist of continuing present programs of suit development plus testing human levels of effort under suited zero-g conditions.

Schedule Considerations

This problem need not be resolved prior to the PDP.

B. 2. 2. 8 Molecular Sieve Bed Desorbtion

Existing test data indicate that a 360°F temperature is required for thermal desorbtion of the molecular sieves. To get waste heat of 360°F from the Isotope Brayton Cycle power system designed for MORL, it is necessary to use the isotope fuel block as a heat exchanger. This is undesireable because it is an additional complexity and not all of the heat obtained at this location is truly waste heat. If thermal desorbtion were possible at 300° to 325°F, then all the waste heat required would be obtainable downstream of the power system recuperator in a single heat exchanger.

Alternate

If thermal desorbtion is necessary at the higher temperature, the existing method must be used. Another possibility is to obtain the maximum waste heat downstream of the power system recuperator and use electrical power to raise the fluid temperature to the level required.

Development Status and Requirements

From a feasibility standpoint, it does not appear to be a technical problem to obtain thermal desorbtion at temperatures in the 300° to $325^{\circ}F$ range. Testing accomplished to date did not investigate this possibility. The resulting bed will probably be bigger and heavier than an optimum one designed by CO_2 removal requirements. Tests to determine the increase in bed size, as a function of desorbtion temperature, are required.

Schedule Considerations

This problem need not be resolved prior to the PDP because the first alternative solution can be implemented.

B.2.3 Water Management Subsystem

The following paragraphs discuss the water management subsystem.

B.2.3.1 Humidity Water Processing

Purification of humidity vapor is achieved by filtration of the water vapor through a charcoal bed in the contaminant-loop air stream. Testing of this method is required to determine if atmospheric contaminants will appear in the condensed himidity water. If contaminants are permitted through the filtration process, it will be necessary to define a post filtration process to eliminate carry-over.

Alternate

If this problem is not resolved, a major design change in the water management system will be required. The open-loop urine processing unit would be replaced by a closed system, handling urine and a portion of the wash water. Humidity condensate could be used for the balance of the wash water, depending on the degree of contamination encountered.

Development Status and Requirements

Filtration tests with humidity water processing have shown promise. Further ground testing is required in a manned MORL simulation vehicle so that the performance with the pertinent contaminants may be developed. Use of the

Langley ILSS facility would be satisfactory for this research effort; however, all materials to be used in the MORL should be included in the chamber.

Schedule Considerations

The solution to this problem is desirable prior to MORL PDP because of the major effect on the water management subsystem. This test should be conducted in conjunction with other 90-day tests in the ILSS facility. Testing will require approximately a 5-month period.

B. 2. 3. 2 Long-Term Water Potability

A long-term test must be performed (90 days) to determine the effect on the crew of using recycled water for drinking and food reconstitution. Also, psychological effects of drinking reclaimed urine for long periods of time should be determined.

Alternate

This problem must be determined before long-duration flights may be made. Failure to prove the concept and qualify the water cycle would require severe redesign, resupply, and fixed weight penalties. The weight required for drinking water is 3,330 lb for 90 days, not including wash water.

Development Status and Requirements

The reclamation of water compatable with all known acceptability standards is within the present level of technology. Ground testing in a long-term mission simulation test has not been done. Present tests on monkeys have been performed by feeding them water reclaimed from human urine for a 55-day period with no adverse effects. Even with this experience it is still considered necessary that a 90-day test be conducted in a facility such as Langley's ILSS.

Schedule Considerations

Since there is essentially no alternative solution, the determination of the effect of the water cycle on the crew is desirable before MORL PDP to eliminate this element of program risk. Approximately 5 months would be required to conduct a 90-day test in the ILSS facility. The subsystems for recycling water have been included in the ILSS facility.

B.2.3.3 Water Separator Development

Prior to installation in the MORL vehicle, the water separator must be tested to ensure its satisfactory performance under all operating conditions. Carry-over of water droplets into the CO_2 removal system will reduce the efficiency of the silica gel beds. Excess humidity in the air-purification loop will allow only reduced levels of work during suited operations.

Alternate

If the baseline water separator fails to perform a different water separator concept can be used. A number of other concepts are available for use, but they have various penalties in weight, reliability, and power.

Development Status and Requirements

The two-stage water separator (scupper plus a liquid/vapor separator pump) has been proven in concept through various applications on Earth. A development model of the total two-stage concept must be designed and tested on Earth and, eventually, in zero g. The basic design can be laboratory tested for general design approach and reliability of operation. Zero-g tests should be conducted with the developed unit to determine its operating characteristics under all flow rates, as well as start-up and shutdown characteristics.

Schedule Considerations

By the PDP, a proven water separator should have been tested both on Earth and in zero g. Because a water separator of some design is vital to the MORL, the sooner a concept can be proven, the less likely a water separator will become a pacing item in the design of the MORL.

B.2.4 Waste Management Subsystem

The following paragraphs discuss the waste management subsystem.

B. 2. 4. 1 Solid Waste Collection

The present baseline system for solid waste collection serves the dual purpose of both commode and garbage collector. The unit was designed for collection and storage of fecal wastes, and only tests of fecal collection have been made. The unit consists of a sphere, an air-tight cover, a felt material liner within the sphere, and a means of evacuating the sphere in to space. After each collection of feces, the unit is evacuated. This serves to freeze the feces and also dry them through sublimation. The result is a storage environment which retards the production of gases from the feces and the growth of bacteria. Using the collection spheres for the storage of laboratory and solid food wastes has not been attempted. While no distinct problems are foreseen, some testing must be done to determine the following: (1) the volume of laboratory and food wastes to be expected, (2) the expected density which will result from these wastes after freezing and drying has taken place in the collection sphere, and (3) the complete compatability of the fecal wastes with food and laboratory wastes, as well as the compatability of both of these with the materials used in the collection sphere.

Alternate

With inaccurate knowledge of storage density there is a necessity to carry a conservative number of reserve collection spheres on the vehicle. This will result in unnecessary weight and volume penalty. Noncompatability between solid wastes may result in a pressure buildup in a sphere which has been filled and stored. A pressure relief valve in the sphere could prevent the sphere from failing, but noxious gases of an unknown variety are not acceptable in the vehicle. Should a problem develop, there is a possibility that a chemical additive may be placed in the sphere after it is filled to retard biological or chemical activity in the sealed sphere.

Development Status

Only laboratory prototype testing of the sphere collection concept has been performed. Although limited in scope, these tests indicated that the feces could be collected easily in a system requiring a minimum of operating procedures and maintenance, and that pressure buildup in sealed containers of fecal wastes was very small. Further indications were that during collection the air passing through the sphere and returning to the cabin, via a fan and dust system, was free of odor and bacteria. In the tests a charcoal and a Millipore filter were used for the purpose of cleaning this circulation air.

Schedule Considerations

A 12-month test program is considered adequate for this problem. It need not be resolved prior to the PDP; however, early test results would eliminate schedule problems during development.

B. 2. 5 Compartment Conditioning Subsystem

The following paragraphs discuss the compartment conditioning subsystem.

B. 2. 5. 1 Noise Generation by Fans

Noise generation by the EC/LS rotating machinery and air ducts must be minimized for the MORL system. Development is required to achieve high-efficiency, low-specific-speed fans to reduce the noise generated. The duct configuration within the vehicle must be determined such that minimum sound propagation is present.

Alternate

The alternative to achieve low noise generation levels would be to use conservatively designed low-speed fans and sound attenuating media within the ducting. The result of this method would be higher fan power and added weight caused by the sound damping provision.

Development Status and Requirements

The development of rotating machinery is advanced at this time; however, precise noise characteristics are not known. Ground tests on simulated ducting systems incorporating the fans are required to optimumly reduce noise.

Schedule Considerations

The determination of a minimum-power/minimum-noise system must be done before final hardware design is started; otherwise, an alternative conservative design approach must be taken. Approximately a 9-month research test program will be required to test various fan duct combinations.

B.2.6 Cooling Circuit Subsystem

The following paragraphs discuss the cooling circuit subsystem.

B.2.6.1 Radiator Coatings

The heat rejection capability of the MORL radiator is directly dependent on its surface characteristics. To determine the required area for an optimum radiator, it is necessary to obtain the optimum surface coating available and provide a coating with the least property degradation with time in a space environment.

Alternate

If testing is not conducted, the alternative solution would be an oversized radiator for the MORL heat rejection requirement. The consequences of coating degradation would be the inability to reject rated heat loads from the vehicle. As a result, all mission objectives could not be achieved. Depending on eventual flight, some of the necessary data required may be obtained without additional tests.

Development Status and Requirements

Work is presently being done to determine the performance of radiator coatings. It is required that the candidate coatings for the MORL vehicle be flight tested in a space environment for long periods of time to determine degradation. A period of at least 1 year would be required to determine the rate of degradation in a space environment.

Schedule Considerations

The existing MORL design uses an estimated 5th year degradation value for the radiator coating; it may be an overly conservative estimate. If a smaller radiator is to be used, the test data must be available by the PDP.

B. 2. 6. 2 In-Flight Radiator Repair

The EC/LS radiator of the baseline system is designed with a partially redundant radiator to provide backup heat rejection in the event of a radiator tube puncture. The redundant tubes eliminate the necessity for laboratory abort, which is necessary if heat rejection cannot be accomplished. The status of the mission after a radiator puncture is subject to immediate abort if a second puncture occurs. This problem may be avoided if techniques and equipment for radiator repair are developed. The radiator would always have a backup in the event of a failure.

Alternate

If the problem is not solved, the reliability for mission success would be lowered. The alternatives would be to incorporate greater redundancy in the radiator, at a penalty of 40 lb for each redundant set of tubes, or to be satisfied with a .9999 reliability. If repair is possible, the reliability is .999999.

Development Status and Requirement

The equipment and techniques for in-flight repair would consist of valving, welding, pinching, or patching tools adapted to space-suit operation under zero-g conditions. Although the hardware development may be ground tested, actual in-flight qualification of the selected techniques should be made.

Schedule Considerations

It is desirable to determine radiator repair capability before the completion of the PDP. However, it is not mandatory because the risk that it will be possible to repair the radiator may be taken. If, for example, packless valves are used on each tube, the risk may not be great; however, valves would reduce the reliability of the entire radiator.

B. 2. 7 Heat Transport Circuit Subsystem--Heat Exchanger Leakage

The interface heat exchanger between the cooling circuit and the heat transport circuit contains FC-75 and water. The interface heat exchange between the power system and the heat transport circuit contains water and gas. If the water in the heat transport subsystem is allowed to leak into the other loops undetected and unchecked, severe problems would results, such as heating-loop boiling and cooling-loop freezing. Conversely, if cooling fluid leaks into the water, a contaminant is introduced into the water thermal transport system which may get into the cabin atmosphere and drinking water supplies. Leak prevention has been obtained in incorporating internal vent passages between the two fluids.

B. 2. 7. 1 Alternate

At present there is no acceptable alternative solution to this problem.

B. 2. 7. 2 Development Status and Requirements

Heat exchangers, incorporating vent passages between the fluid passages in the heat exchanger, have been used in aircraft; however, available data on performance characteristics are insufficient. Ground testing is required to achieve maximum performance from this type of heat exchanger.

B. 2. 7. 3 Schedule Considerations

The test effort required to define the performance characteristics of this type of heat exchanger must be completed before final hardware design begins. A 6-month test program should resolve the problem.

B. 2. 8 Carbon Dioxide Reduction Subsystem--Bosch Hydrogenation Reactor Operation

The electrical power required to operate the oxygen regeneration modules (the hydrogenation reactor and the water electrolysis units) on MORL total nearly 2 kW. It is desireable to design them so that they can be shut down for short periods of time when the power is required for experiments. It does not appear to be difficult to restart the electrolysis modules; however, the hydrogenation reactor operates at 1,300°F and it will not be desireable to start and stop it often. The existing design calls for a hydrogen accumulator for hydrogen storage so that the reactor can continue operation. If the Bosch system could be operated in low-output mode, it is possible that this hydrogen accumulator would not be required. It may be possible to reduce some of the power requirement of the reactor (400 W), making more power available for experiments.

B. 2. 8. 1 Alternate

An alternative would be to design the reactor so it can be restarted simply, or to use the method described above.

B. 2. 8. 2 Development Status and Requirements

The units developed to this date have not explored the restart possibility. It appears that operation of the Bosch reactor without hydrogen feed would be possible using the Langley Research Center ILSS facility.

B. 2. 8. 3 Schedule Considerations

This problem need not be resolved until approximately 18 months before MORL is scheduled to be retrofitted with the hydrogenation reactor.

B. 3 FLIGHT TESTS

B. 3. 1 Unmanned Satellite Test

B. 3. 1. 1 Cooling Circuit Subsystem--Radiator Coating

The problem noted in Section B. 2. 6. 1 probably requires orbital test to be sure that a solution has been found. Ground testing alone will not be satisfactory because of the difficulty of duplicating the orbital environment. Also, the cost of space chamber ground tests for extremely long periods of time is high.

B. 3. 1. 2 Recommendation

A long-term, unmanned satellite coating exposure test program should be accomplished in the MORL orbital environment for the required time period. Ground tests should be used to develop candidate coatings. Flight tests should be used to determine coating life.

B. 3. 2 AAP Experiment

B. 3. 2. 1 Atmospheric Purification Subsystem -- Water Separator Performance

The problem noted in Section B. 2. 3. 3 cannot be resolved without risk unless the chosen concept is tested in zero-g. This is the result of the concept's operation being directly related to gravity forces.

B. 3. 2. 2 Recommendation

An AAP experiment could be devised to run as a closed system, with varying air flow rates. The location of the droplet scupper could be made variable to determine the most effective location. The resulting data would be used for the final MORL design.