Space Transfer Concepts and Analysis for Exploration Missions

Contract NAS8 - 37857

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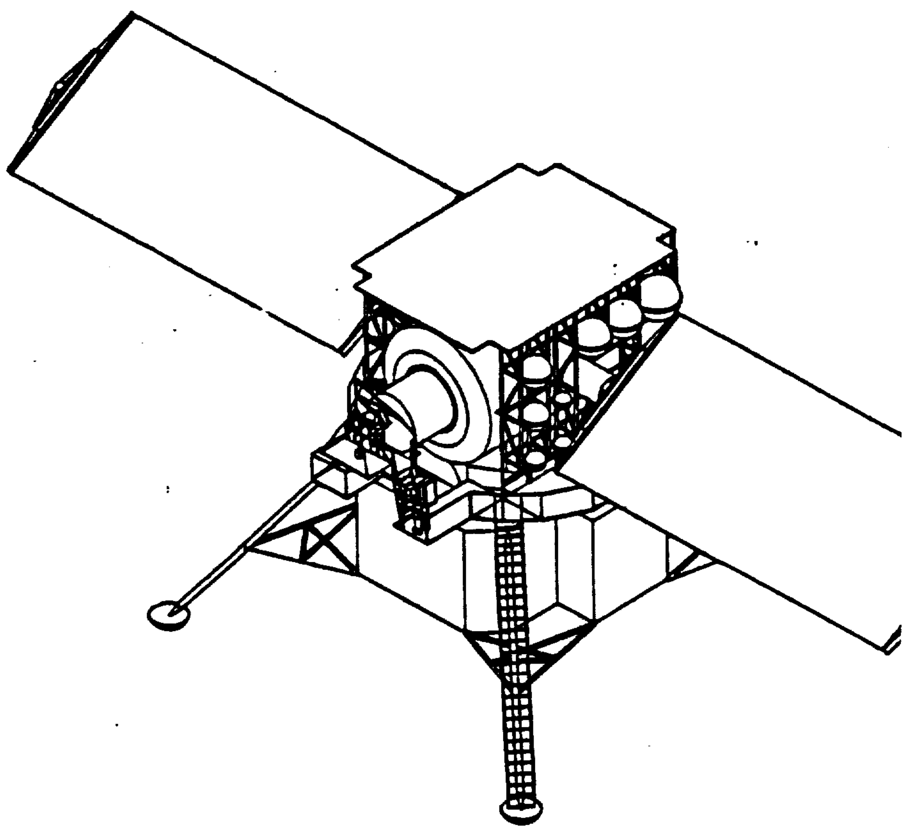
Final Report
Technical Directive 13
November 1992



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Advanced Civil Space Systems
Huntsville, Alabama

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Technical Directive 13

Final Report

November 1992

Boeing Defense & Space Group
Advanced Civil Space Systems
Huntsville, Alabama

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D615-10060

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FOREWORD

The study entitled "Space Transfer Concepts and Analyses for Exploration Missions" (STCAEM) was performed by Boeing Missiles and Space, Huntsville, for the George C. Marshall Space Flight Center (MSFC). The current activities were carried out under Technical Directive 13 during the period May 1992 through September 1992. The Boeing program manager was Gordon Woodcock, and the MSFC Contracting Officer's Technical Representative was Alan Adams. The task activities were supported by M. Appleby, P. Buddington, J. Burruss, M. Cupples, S. Doll, R. Fowler, K. Imtiaz, J. McGhee, T. Ruff, and L. Wiggins.

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ABBREVIATIONS AND ACRONYMS

A/B	Aerobrake
ACM	Atmosphere Composition Monitor
ACMA	Atmospheric Composition Monitoring Assembly
ACRV	Assured Crew Return Vehicle
ACS	Atmosphere Control and Supply
ADPA	Airlock Depressurization Pump Assembly
AIU	Audio Interface Unit
A/L	Air Lock
ALSPE	Anomalously Large Solar Proton Event
Al	Aluminum
AR	Air Revitalization
ARS	Atmosphere Revitalization System
ATU	Audio Terminal Unit
BFO	Blood-Forming Organs
BIT	Built-In Test
BMS	Bed Molecular Sieve
BOL	Beginning of Life
BREM	Boeing Radiation Exposure Model
BYRNTRN	Baryon Transport code
C&T	Communications and Tracking
C&W	Caution and Warning
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAM	Computer Anatomical Man Model
CBM	Common Berthing Mechanism
CCV	Common Crew Vehicle
CCWS	Command and Control Workstation
CDRA	Carbon Dioxide Removal Assembly
CETA	Crew and Equipment Translation Aid
c.g.	Center of Gravity
CHeCS	Crew Health Care System
CO_2	Carbon Dioxide
COA	Carbon Monoxide Analyzer
COP	Coefficient of Performance
CTB	Central Thermal Bus
CWU	Crew Wireless Unit
DCSU	Direct Current Switching Unit
DDCU	dc-to-dc Converter Unit
DDT&E	Design, Development, Test, and Evaluation
DMS	Data Management System
DSN	Deep Space Network
ECLSS	Environmental Control and Life Support System
ECWS	Element Control Workstation
ELF	Exercise Countermeasure Facility
EMAD	Emergency Monitoring and Distribution
EMCC	Eight Man Crew Capability
EMU	Extravehicular Mobility Unit
EOL	End of Life

ABBREVIATIONS AND ACRONYMS (Continued)

EPS	Electrical Power System
ETCS	External Thermal Control System
EVA	Extravehicular Activity
EVAS	Extravehicular Activity System
ExPO	Exploration Office
FBCC	Full Body Cleansing Compartment
FCW	Fuel Cell Water
FDDI	Fiber-Optic Distributed Data Interface
FEC	Forward Error Detection
FEM	Finite Element Model
FDS	Fire Detection and Suppression
FLO	First Lunar Outpost
F-MPAC	Fixed-Multipurpose Application Console
FSS	Fixed Servicing System
g	Acceleration in Earth Gravities (acceleration 9.80665 m/s^2)
1/6th g	One-sixth gravity (Lunar Gravity)
GaAs/Ge	Gallium Arsenide/Germanium
G/B	Glovebox
GCA	Gas Conditioning Assembly
GCR	Galactic Cosmic Radiation
GEO	Geosynchronous Earth Orbit
GFE	Government Furnished Equipment
GN&C	Guidance, Navigation, and Control
GTP	Geomagnetically Trapped Particles
h	hyperbaric
Hab	Habitation Module
Hab-A	SSF Habitation Module A
H/B	Hyperbarics
HBC	Hyperbaric Chamber
HECA	Hyperbaric Environmental Control Assembly
HGA	High Gain Antenna
HMF	Health Maintenance Facility
HRS	Heat Rejection System
HX	Heat Exchanger
I/F	Interface
IA/V	Internal Audio/Video
IAS	Internal Audio Subsystem
ICRP	International Commission on Radiation Protection
ILS	Integrated Logistics System
IMV	Intermodule Ventilation
IR	Infrared
ISPR	International Standard Payload Rack
ISMU	In-Situ Materials Utilization
ITCS	Internal TCS
ITA	Integrated Truss Assembly
IVA	Intravehicular Activity
IVS	Internal Video Subsystem

ABBREVIATIONS AND ACRONYMS (Continued)

NLS	National Launch System
nh	nonhyperbaric
O_2	Oxygen
ORU	Orbital Replaceable Unit
P/L	Payload
PBM	Pressurized Berthing Module
Pb V/W	Tank material performance factor (tank burst press/density)
PCWQM	Process Control Water Quality Monitor
PDGF	Power Data Grapple Fixture
PDOSE	Proton Dose Code
PDRD	SSF Program Definition and Requirement Document
PEP	Personnel Emergency Provisions
PEV	Pressure Equalization Valve
PHC	Personal Hygiene Compartment
PHF	Personal Hygiene Functions
PLE	Pressurized Logistics Element
PLM	Pressurized Logistics Module
PLSS	Personal Life Support System
PRLA	Payload Retention Latch Assembly
psia	pounds per square inch absolute
PV	Photovoltaic
QA	Quality Assurance
RCS	Reaction Control System
RFC	Regenerable Fuel Cell
R&MA	Restraints and Mobility Aids
RMS	Remote Manipulation System
RPCM	Remote Power Controller Module
RPDA	Remote Power Distribution Assembly
S&E	Sensor and Effector
SAFE	Solar Array Flight Experiment
SDP	Standard Data Processor
SEI	Space Exploration Initiative
SOTA	State of the Art
SPCU	Suit Processing and Check-out Unit
SPDA	Secondary Power Distribution Assembly
SPDM	Special Purpose Dextrous Manipulator
SPE	Solar Proton Event
SPS	Solar Power Satellite
SRD	System Requirement Document
SRS	Supplemental Reboost System
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSMB	Space Station Manned Base
STCAEM	Space Transfer Concepts and Analyses for Exploration Missions
STS	Space Transportation System (Shuttle)

ABSTRACT

The current technical effort is part of the third phase of a broad-scoped and systematic study of space transfer concepts for human lunar and Mars missions. The study addressed the technical issues relating to the First Lunar Outpost (FLO) habitation vehicle with emphasis on the structure, power, life support system and radiation environment for a baseline hab with specific alternatives for the baseline.

Boeing received task directives on the present contract to investigate the application of Space Station Freedom modules and variations thereof to the FLO habitat system. This report presents the results of one such technical directive that completed definition of a baseline concept and performed numerous trades departing from the baseline in various ways. A final report will be issued at the end of 1992 covering all the FLO technical directive results.

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requirements through more formal functional flow analyses. The TD13 baseline sought an integrated configuration to accommodate the SSF module, SSF Crewlock, internal and external systems, as well as access and logistics operations. This current habitat/airlock combination was selected based upon mission requirements (provided by NASA), including desire for hyperbarics capability and significant use of SSF hardware and systems. Once the baseline had been well defined, trades and analyses were identified with the main objective of reducing weight, which has resulted in candidate alternatives even to module configuration and materials. The results of these efforts may now support the classical functional flows to identify a set of derived requirements to meet mission goals. Discussions expanding each of these three study areas are addressed in this report.

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3.0 FLO HABITATION SYSTEM INTEGRATED BASELINE

3.1 INTRODUCTION

The integrated baseline has been developed to provide a traceable, internally consistent concept for the First Lunar Outpost Habitation System which will provide preliminary resource estimates, a basis for alternative trades and analyses, a scenario for operations studies, and a framework of configurations, issues, and requirements for more detailed design. As discussed under Design Approach, (section 2.2), the integrated baseline applies previous (TD11) strategies to the selected module/airlock combination (SSF Hab-A with SSF Crewlock) while improving the definition of all internal and external systems. The current work has afforded continued and maturing habitation concept definition in support of the overall FLO activity.

3.2 HABITAT CONFIGURATION

The First Lunar Outpost Habitat has been closely based on SSF Hab-A architecture, SSF systems, and SSF mass and power data. However, the needs of FLO require three hab functions in addition to those provided by the standard SSF Hab-A: (1) support of airlock operations and EVA systems; (2) internal science capabilities; and, (3) crew health care and monitoring. Accommodation of these additional functions in conjunction with perceived redundancy and operations needs requires changes to the topology and system selection for the FLO habitat module. The FLO habitation system concept represents a coordinated compilation of functions and configurations which are currently recognized as necessary to conduct a manned lunar mission; as a result, SSF and other existing/near-term hardware and technology have been applied to this concept in order to produce performance, operations, and resource profiles. This has been done assuming that these systems and elements will be available and sufficient for the FLO program to reduce schedule and DDT&E costs; however, much more detailed studies are needed to ultimately determine the requirements and capability for the First Lunar Outpost

3.2.1 Integration of Airlock to Hab Module

Formal work under the current task began with a short, focused trade study on the choice of hyperbaric airlock and its attachment to the habitat module. Under consideration were the SSF Crewlock or a new design, either of which would be located on the module cylinder or endcone. Due to maturity of the SSF Crewlock and the lesser impacts of mounting it onto the habitat endcone, this configuration was chosen as the baseline to be studied. Reservations which continue with this selection include: (1) the Crewlock is not designed for the lunar environment (less-than-optimal internal height, dust, thermal, and radiation concerns, etc.); (2) changes to the module endcone; and, (3) loss of four standard rack locations to accommodate the Crewlock within a 10 meter ETO shroud. In answer to these concerns, first, all of the systems and elements proposed for FLO will require some design changes to survive the lunar environment; at some point, the ultimate extent of these changes could be traded against "all-new, lunar-optimized" designs. Second, initial estimates have shown that enlarging the opening in the flat portion of the module endcone should allow placement of the Crewlock without affecting the basic endcone shape and without significantly reducing external or internal endcone packaging volumes and schemes; however, access to these areas, feedthrust to and from the Crewlock, and load requirements must still be considered. Third, alternatives to losing four internal racks were examined (including, moving the entire complement of racks aft, enlarging the payload shroud, and assuming deeper "pockets" within the 10 meter shroud); however, the assumption of an unnegotiable 10 meter dimension along with the need for cylinder, endcone, and adjacent rack access as well as the possible requirement for external viewing dictated a removal of the forward bay of four racks.

The choice of which four racks to remove is eased somewhat by a change in the Avionics Air System; namely, this change redesigns Av Air from a centralized to a distributed system. In so doing, this change also deletes the need for both Avionics Air Crossover Racks (which is assumed to account for 2 of the 4 racks to be removed). In accordance with NASA's emphasis on external lunar science with minimal internal capabilities, the other two rack deletions were realized by reducing internal science from (the TD11 number of) three dedicated racks to just one. This remaining science rack has been based upon the SSF Lab-A Maintenance Workstation (MWS) which would allow characterization studies, suit maintenance, etc. but would not strictly be an experiment rack. Additional stowage or equipment volume could still be available in the "lost" ceiling and floor locations (in addition, loose storage or EVA suits could be placed in front of the windows) as shown in the internal volume assessment discussed later in this report. Other aspects of internal configuration and systems selection are included in the next section.

3.2.2 Internal Systems Location

Given the need to accommodate different functions within the module as discussed above, the internal configuration and system complement shown in figures 3-1 and 3-2 were developed specifically for the FLO integrated baseline with the goal to provide these capabilities and yet maintain substantial heritage to the SSF Hab-A architecture

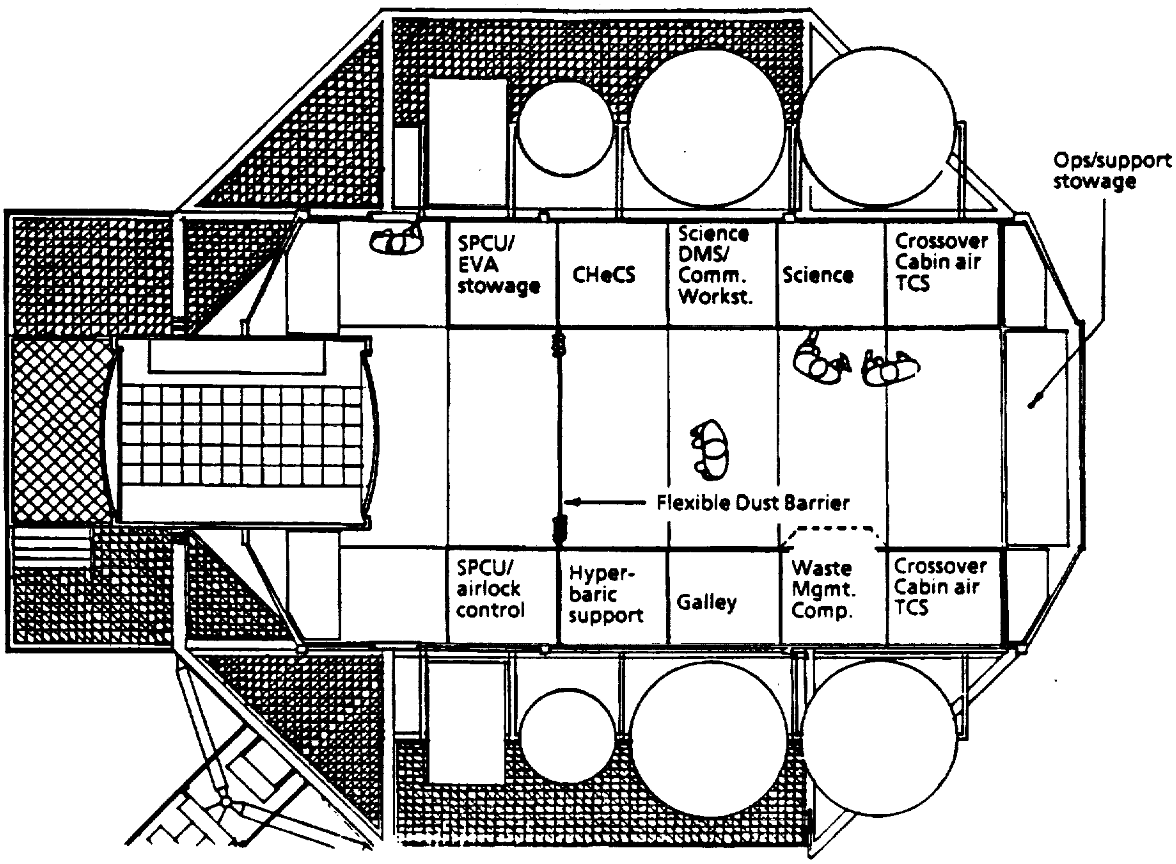

Figure 3-1. First Lunar Outpost Habitat, Plan View

and design. The internal outfitting for a habitation module must observe numerous requirements in order to provide an operational and ergonomic vehicle. FLO will share many of these constraints with SSF; for example, system layouts must obey adjacency requirements (both functional and physical), packaging limitations, access requirements, contingency needs and procedures, etc. The operating environment of FLO will also dictate additional constraints, including gravity, radiation, dust, and thermal concerns. Some of these considerations are discussed below and will ultimately be reflected in each of the internal systems which, due to both inter- and intradependencies, cascade into overall lunar habitation design.

Although the Outpost configuration does arrange the ECLSS tier, Crossovers, and Waste Management Compartment in the same relative position as they exist for SSF Hab-A, a major change is made by locating ECLSS operating equipment in the ceiling instead of the "floor" (as in SSF). This modification is suggested for several reasons: (1) lunar dust is certain to enter the module irrespective of any dust-off scheme; thus, it is deemed reasonable to avoid placing operating equipment in the floor (therefore, only

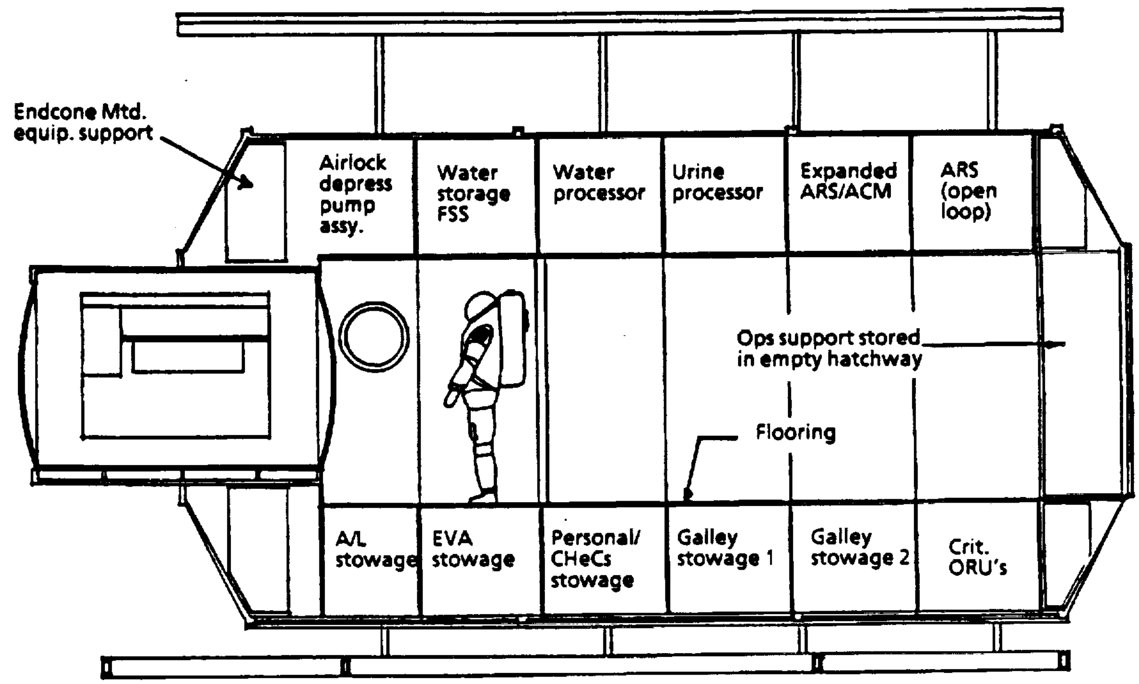

Figure 3-2. First Lunar Outpost Habitat, Section View

unpowered stowage is placed there); (2) solar and galactic radiation bombards the lunar surface with essentially no attenuation (except by the Moon itself); thus, placing massive equipment and especially water in the ceiling provides substantial benefit. However, in order to preserve the SSF ECLS system arrangement, water storage is no longer directly over the proposed storm shelter location (this and other changes will be discussed later in this section); (3) placement of non-ECLSS powered racks only on the walls is hoped to simplify standoff utility runs and services; and (4) maintaining SSF Hab-A relative positions for this equipment is hoped to reduce cost and design impacts (for example, the highly corrosive urine line from WMC to ECLSS processing is kept at its nominal length). However, this change also results in several potential impacts: (1) pumping of water and other fluids up to the ceiling is now required and may not be within the capabilities of currently designed SSF hardware; (2) simplifying utility services may require wall racks to interface with the standoffs at the top of the rack instead of at the bottom (which is potentially a substantial change to both internal rack packaging and rack pivoting design but may be advantageous with regard to dust mitigation, avoiding interference with the floor and crew activity, etc.); (3) ECLSS racks may need to interface both at the top and the bottom in order to feed and be fed from both adjacent standoffs (if this proves beneficial); and, (4) it is assumed but not known that the distributed Avionics Air Subsystem will not preclude packaging each functional rack as shown (better data on this subsystem are still forthcoming). Another change from the SSF Hab-A ECLS system is expansion of the second ARS rack to include redundant CO_2 Removal and Mass Constituent Analyzer assemblies (making these life critical functions one-failure tolerant) which are assumed to fit in this rack in place of the SSF laundry facility. Also, as described in reference 2-3, ECLSS water storage is reduced by half to better reflect Outpost needs; thus, the Fluid System Servicer (FSS) is assumed to be able to share this rack. ECLSS also includes make-up and emergency gas tanks which require accommodation external to the module.

Several system racks have been located in an attempt to satisfy adjacency requirements. EVA and airlock support racks (SPCUs, EVA Stowage, Depress Pump) are placed nearest the airlock (which, in conjunction with some type of flexible dust barrier like a zippered plastic curtain, will hopefully also serve to minimize dust transport throughout the module). As mentioned earlier, windows are placed in the vacated forward positions to assist in visual inspection and monitoring (actual visual requirements and analyses have yet to be identified). Also, the Hyperbaric Support, Crew Health Care System (CHeCS), and CHeCS Stowage racks are located near the airlock (an alternative may be to switch the Science rack, envisioned to be like a SSF Maintenance Work Station (MWS), and CHeCS rack locations to assist in suit maintenance activities). The Science/DMS/Comm Workstation is a shared resource comprised of central computing and crew interface hardware; this rack is located between the CHeCS and Science racks to support both life science and selenology activities (a concern may be that the workstation also provides IVA monitoring of EVA activities and may desire a location nearer a window or away from other internal activities). As previously discussed, the WMC and both Crossover racks are positioned as they are in SSF Hab-A, which locates the Galley rack as shown. Placing this rack next to the WMC does not result in an ideal solution, but this concern is not overcome with the current module volume. Another less than optimal arrangement is the location of Galley Stowage in the floor (close to the galley for convenience). These two racks will house most of the food and meal preparation equipment which will be frequently accessed. Another use for this food would be as a radiation attenuator during large natural radiation events; however, due to the presence of the Moon itself, protection is mainly needed on the module sides and ceiling. Thus, in forming the in-situ storm shelter, this food must be relocated from the floor as discussed later. Critical ORUs, located at the aft end, consist of equipment spares and emergency provisions (critical spares philosophy and needs remain unidentified; however, estimates based on SSF are included elsewhere in this report while the baseline ORU mass and volume allowance is meant as a placeholder only). Since the second hatch is normally not used, Operations Support equipment (housekeeping supplies, cameras, etc.) are stored in this empty hatchway. Other storage space may be available in the vacated sub-floor and ceiling in front of the airlock; also, some loose storage (to accommodate EVA suits, for example) may be possible on the floor in this area.

As discussed above, the forward bay of four racks were removed mainly to prevent access violations. Several other access issues exist both internal and external to the FLO hab: (1) even in the lunar gravity environment, some type of device(s) will be required to assist in lowering, raising, and/or moving racks to perform maintenance, arrange storm shelters, gain access to the module shell, changeout equipment, etc. (2) full access to the embedded Crewlock shell may still not be possible; (3) airlock pass-through of crew and equipment requires further study to identify volume, hatch, operations, etc. concerns; (4) access to the external endcone opposite the airlock will be difficult but may be necessary for equipment located there due to redundancy and separation requirements, offloading from the forward endcone, functional constraints (such as short external water lines), etc.; (5) likewise, access to much of the external equipment, including power generation and thermal control systems, must be possible but remains a challenge; and, (6) access to the surface in addition to airlock egress/ingress, dust removal, and resupply operations may require powered hoists/lifts, large platforms, etc. which result from the Operations/Logistics study discussed elsewhere in this report. This aspect of the hab system design is discussed below as part of the external configuration and will ultimately be driven by the requirements yet to be identified for the First Lunar Outpost.

Another consideration of the FLO habitation system which will help dictate its configuration is radiation protection. Although normal solar activity and cosmic radiation is not currently expected to be a significant crew hazard for short missions, the possibility of anomalously large solar proton events (ALSPEs or "solar storms") is a very real concern for all lunar missions. Our approach to deal with these events is to "build" a "storm shelter" as needed using available Outpost mass for shielding. This available mass consists of racks which may be relocated, external equipment which may be strategically pre-placed or possibly even moved upon initial storm warnings, and/or, if necessary, use of dedicated mass to provide additional protection where needed. Due to high lunar transportation costs, it is desirable to minimize the amount of dedicated shielding required and current preliminary analyses have shown dosage to be below assumed limits using inherent habitat mass only (see Section 5.0). The storm shelter must provide living volume capable of supporting 4 people for 3 days (during the most intense period of the ALSPE); for current study purposes, we have assumed this shelter will be formed around rack bays three and four by closing off the aisle with storage racks from the floor and aft hatchway. This volume provides approximately 8 cubic meters and is situated where the Galley, CHeCS, and control workstation are nominally located. Food and galley equipment would be used to "close off" one half of one aisle; the other aisle would be closed using Critical ORUs and Ops Stowage. This arrangement would place the Waste Management Compartment outside of the shelter; however, this is a less massive rack which would not provide significant protection and personal hygiene may be accomplished for these three days by means similar to that used during Earth-to-Moon transport. One concern is raised in how much food will be used during this time and possibly reducing protection afforded by its presence (one mitigation scheme proposes to replenish this "wall" with wastes). An updated radiation analysis to assess the environment corresponding to this new layout is included later in this report and provides some insight when compared to previous analyses, reference 2-3 (for example, how much the missing forward bay of racks affects crew dose). External configuration will also balance radiation protection with other concerns; thus, the location of power fuel cell reactants, ECLSS gas tanks, and other equipment will be a trade off between access, launch constraints, thermal considerations, and other factors including their possible use as radiation shielding.

3.3 EXTERNAL CONFIGURATION

In addition to the module and its internal systems, the FLO integrated baseline includes the external equipment and accommodations necessary to support the habitat and its crew. These external systems include power generation, storage, and distribution, thermal control, communications, ECLSS gas storage and management, and EVA support. While many of these systems could share hardware and operational burdens with the FLO lander, study assumptions have sized this concept for habitat needs only. As discussed above and as illustrated in figure 3-3 , external systems are very much related to the module and its systems as well as to each other; thus, configuration and selection of external systems must consider many of the same factors posed for internal systems.

3.3.1 Integration of External Systems to Hab Module

The habitat, its subsystems and supporting structure are treated as an integrated payload to be attached to the lander at several points. The habitat's external subsystems are integrated into a framework of vertical trusses and diagonal cross-bracing that extend from the base of the hab to the bottom of the radiator panel support structure, which support individual tanks, fuel cells, and other equipment, and transfer loads to the

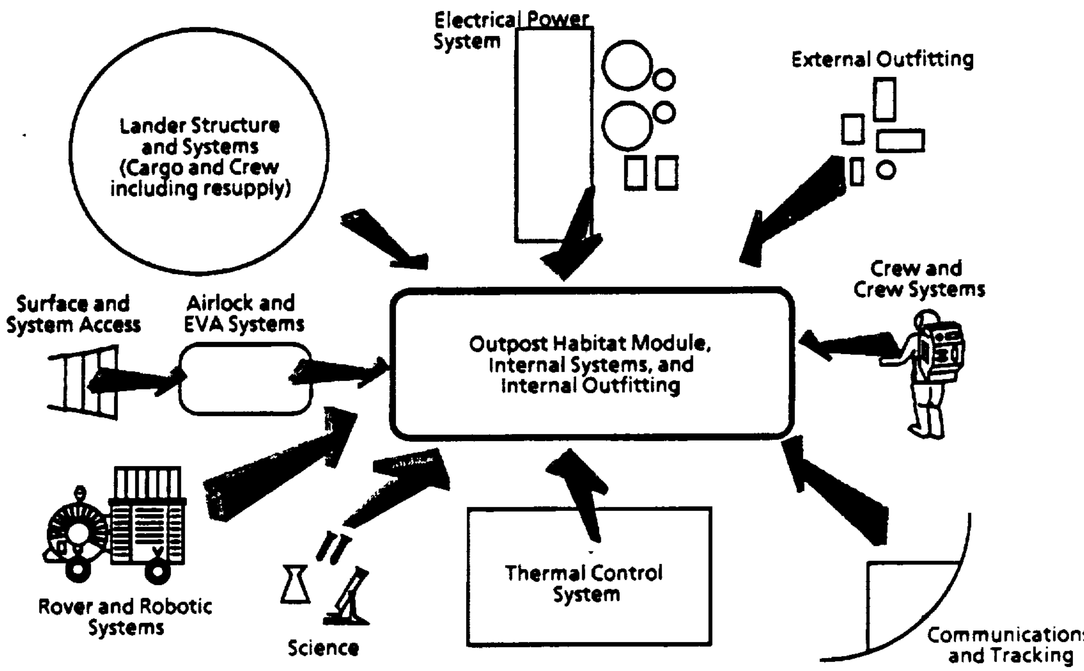

Figure 3-3. Outpost Hab External Interfaces

MR005

habitat support structure figure 3-4. This also has the benefit of minimizing any modifications to the lander, so that it it can function as a common lander stage for crew delivery, or for future cargo missions in support of lunar base buildup.

3.3.2 External Systems Location

The location of power and life support systems on the exterior of the lunar habitat is effected primarily by the limitations imposed by the launch shroud diameter of 10 meters. Equipment and storage tanks have been located on either side of the habitat, mounted in vertical frames that allow partial EVA access around the sides of the habitat, and also provide partial coverage of the habitat structure for radiation protection. Power system fuel, liquid hydrogen and oxygen, is located in a series of spherical tanks, split evenly on each side of the habitat. Fuel cells, electrolyzers and solar array structures are also split into two separate units, and located on either side of the hab. ECLS supplies, repress gasses and EVA sublimator water, are also divided evenly, and located on either side of the hab structure, figure 3-5.

3.3.3 External Access

During normal outpost operations, astronaut access to critical areas of the habitat for inspection, maintenance, and repair will be required. Access to fuel cells, electrolyzer, solar array deployment mechanisms and valving is achieved by placing a catwalk type of platform around the front and forward sides of the habitat. The catwalk, parts of which are deployed after the crew arrives, would be attached to the upper members of the lander structure, and would provide a safe working area for EVA personnel, figures 3-5 and 3-6.

Design Requirements

- 7 cubic meters of resupply weighing approximately 1700 kg must be brought into the habitat through the airlock
- Resupply packages must be lifted 8-9 meters from surface to airlock entrance
- The size of resupply packages may vary depending on the enclosed materials
- Externally stored resupply materials, such as repress gas, metabolic oxygen and EVA sublimator water, will not be required to be lifted to the habitat level of the lander for resupply operations

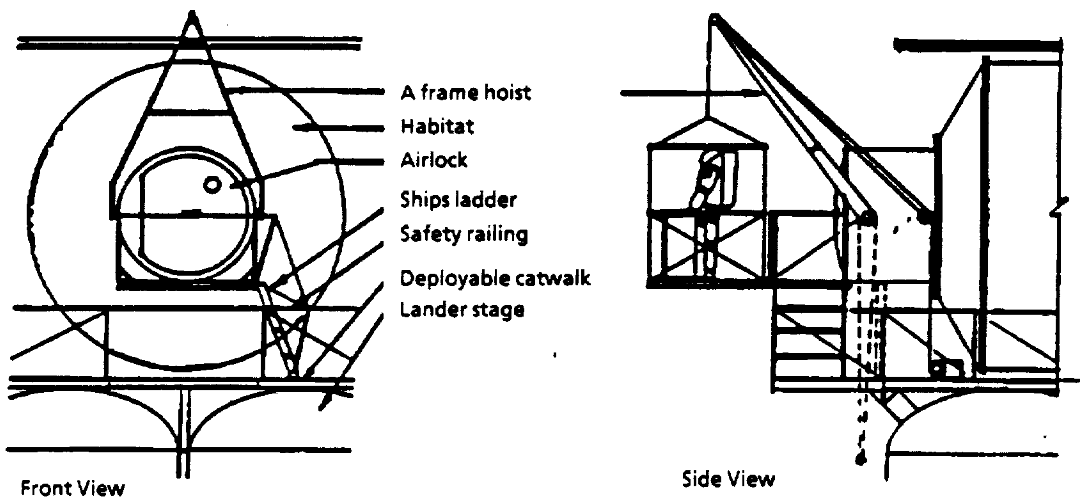

Figure 3-6. Resupply and Logistics AC5018

Access to the catwalk from the surface is by way of a ladder located on one of the forward lander legs. The long axis of the habitat/payload is oriented on the lander at a 45 degree angle to the landing legs, which allows the ladder to terminate at an open space on the catwalk, instead of directly beneath the airlock. This will enhance the safety of EVA operations by eliminating the need for a vertical ladder section connecting the "leg-ladder" and the airlock. The airlock entrance is located approximately two meters above the level of the catwalk, and has a smaller, deployable "threshold" platform of it's own. A ships ladder connects the catwalk and this smaller platform. Both platforms are surrounded with handrails.

Roughly five tonnes of resupply cargo will be offloaded from the crew lander on the second mission, and delivered to the airlock entrance for transfer into the habitat. The airlock entrance is seven to eight meters above the surface, and it will be difficult for a suited astronaut to deliver the required resupply packages to the airlock platform by hand. Therefore, methods were developed to minimize the amount of material lifted to the level of the habitat. Life support resupply gasses will be connected to the system

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through valving located at the base of the lander, after transfer from the crew lander on a trailer attached to a rover. Other noncritical resupply materials can be stored under a thermal protection blanket, under the habitat lander, and brought into the hab as needed. Those supplies that are required immediately would be hoisted directly to the airlock platform from the surface through the use of an "A" frame type hoist, figures 3-6 and 3-7. The hoist's capacity will allow 400 kilograms of cargo or personnel to be lifted directly to the airlock entrance.

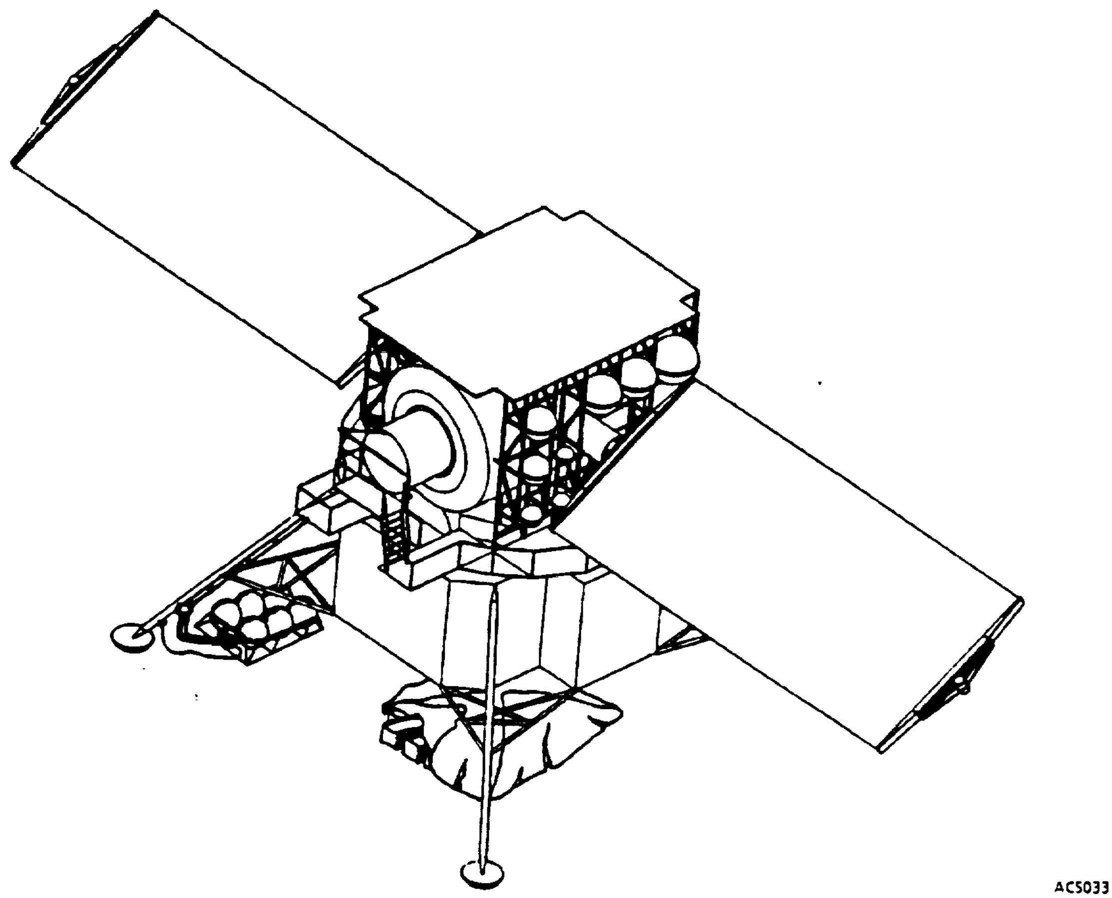


Figure 3-7. First Lunar Outpost Configuration

3.4 INTEGRATED BASELINE MASS SUMMARY

A mass summary for the Boeing FLO Integrated Baseline Habitation System is presented in figure 3-8. Appendix A gives a detailed breakdown of Boeing masses along with hardware locations, data sources, and assumptions. Appendix B includes lower level values of Boeing and MSFC mass estimates and associated rationale for any differences. Descriptions for specific baseline systems are included in the following paragraphs of this section.

Module Structure	**6345 kg**
Internal Systems	
ECLSS	2990 kg
Medical Support	668 kg
Crew Systems	1402 kg
DMS	687 kg
IAV	97 kg
Internal EPS	711 kg
Internal TCS	1262 kg
Internal Science	767 kg
Internal EVAS	535 kg
External Systems	
Support Structure	2064 kg
C&T	72 kg
External EPS	5451 kg
External TCS	520 kg
Airlock System	2175 kg
EVA Suits	with crew
Gas Conditioning Assembly	258 kg
Dedicated Radiation Protection	**Not Required**
Consumables	**2505 kg**
Contingency (15 - 28% of Ext Systems)	**1477 kg**
Total Landed Mass	**29,986 kg**

Figure 3-8. Integrated Baseline Concept Description, Mass Properties Summary

3.5 CONSUMABLES STOWAGE VOLUME ASSESSMENT

Internal volume is recognized as a valued commodity on SSF and may also be a significant constraint to FLO design. Earlier discussions have stated the assumption that systems currently contained within a SSF rack would continue to occupy this volume for FLO applications; thus, system volume estimates have been made mainly on a rack-to-rack comparison and the current internal configuration has been developed to accommodate these necessary functions. The FLO habitation system also contains a large quantity of consumables, the majority of which must be stored internal to the module. To evaluate the internal volume needs versus availability, a preliminary assessment was made of the volume required for 45 days worth of consumables. The obvious purpose of this study was to identify potential problems and solutions associated with internal volume storage requirements in support of habitat definition, operations/logistics analyses, and consumables philosophy development.

The results of this evaluation and comparison of the volume available in the current module layout to the estimated volume needed for internal consumables is given in figure 3-9. These initial findings suggest the baseline layout offers a potential 12.4 cubic meters of stowage volume; however, 3 m^3 of this potential volume is located in front of the windows and may not be usable due to access needs and viewing operations but may be suitable for hanging EVA suits (and possibly allowing all four suits to be attached to the SPCUs simultaneously). Currently, 7.9 m^3 of internal consumables have been identified and may suggest changes to the present layout; for example, Personal/CHeCS

Stowage Volume Identifier	Racks or Rack Equivalents	Volume Available (m^3)*	Consumables to be Included	Volume Needed (m3)*	
EVA Stowage Rack	1.0	1.5	• EMU expendables • EMU Spares • Dust Control	0.72 0.31 0.67	1.70
Personnel/CHeCS Stowage Rack	1.0	1.5	• Clothing • Personal Hygiene • Off Duty • CHeCS Supplies	1.77 0.21 0.19 0.50	2.67
Galley Stowage Racks	2.0	3.0	• Food • Galley Supply	0.58 0.34	0.92
Critical ORUs Rack	1.0	1.5	• Internal System Spares (placeholder)	1.5 (assumed)	
SPCU/EVA Stowage Rack	0.25 (assumed)	0.375	• Stowed Suits (?)		
Volume available in ADPA Rack	0.25 (assumed)	0.375	• ECLSS Expendables	0.40	
Volume available under floor at end near Crewlock	0.25 (assumed)	0.375	• Stowed Suits(?)		
Open area in front of windows (must consider access)	2.0	3.0 (maybe?)	• Standing Suits (?)		
Volume available in back-up hatchway	0.5 (assumed)	0.75	• Operations • Maintenance • Science	0.43 0.14 0.16	0.73
Totals	**8.25**	**12.375**		**7.92 +**	

* Usable volume in 80" rack approximately 1.5 cubic meters

Figure 3-9. Study Results

Stowage will probably require more than one rack but Galley Supplies and Food take up only a third of its allocated space (although trash and waste storage is still unknown). Other unknowns include actual system spares and expendables needs, furniture stowage schemes, and science/sample stowage requirements. Assuming that the empty space in front of the windows is used for suits only, volume needed approaches 85% of volume available. Continuing definition of the quantity, size, and scheduling of consumables is necessary to verify packaging densities, to identify resupply operations and changeout needs, to help establish repair/replace and redundancy schemes, to define both dormancy and manned requirements, and to develop the optimal consumables manifest mix between that burdened on the initial habitat and that brought by the first visiting crew. FLO development should closely consider both SSF volume allocation history and ongoing refinement to ensure reasonable planning for its own internal volume.

3.6 STRUCTURAL ANALYSIS

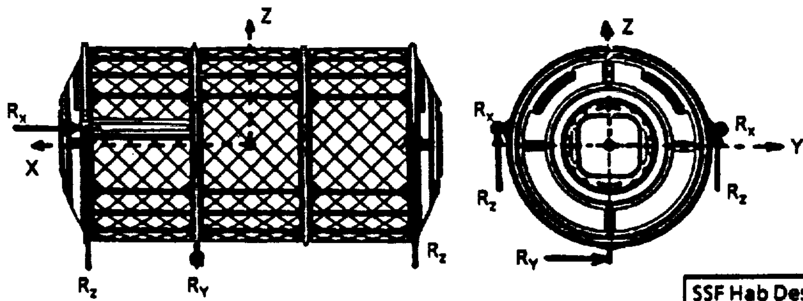
3.6.1 Summary of Previous Work

The previous study (TD11) included a preliminary structural evaluation of the Space Station Freedom (SSF) Hab module to be utilized as the First Lunar Outpost (FLO). The effects of SSF Hab-A mass change on trunnion loads and reactions were calculated, possible weight reductions issues were addressed, and a trade study on the selection of an airlock was conducted. A brief summary of the work accomplished is as follows;

a. Loads And Reactions. SSF Hab launch and abort-landing loads/reactions were re-evaluated for FLO 'g' loading and launch configuration (which is similar to the SSF hab landing configuration). Total hab mass was varied and, using Orbiter/Booster dynamics, resulting trunnion reactions were calculated. Launch loads and reactions are summarized in figure 3-10. The graph in this figure shows that the dynamic reaction loading on the hab is non-linear with mass increase. Severe loading increase on the hab module observed by increasing the mass above the SSF Hab design mass of 17.5mt will require structural changes to the SSF Hab. A more detailed analysis must be performed as the launch vehicle and Lunar Hab launch configuration are better defined. Realistic forcing functions for the launch vehicle are required in order to calculate accurate dynamic amplification factors for hab internal/external structure and hardware attachments.

b. Weight Reduction Issues. In order to find ways to reduce the structural mass of the SSF Hab, a detailed breakdown of the SSF Hab structural mass and payload was performed and those areas were identified that showed a potential for weight reduction. New semi-elliptic bulkheads were proposed which could save as much as 250 kg. Changing the pressure vessel material from 2219/7075 aluminum to aluminum-lithium will also result in approximately 10% weight saving.

   Storage racks seemed to be another candidate for a potential weight savings. Being an add-on structure, racks could be modified without redesign of hab primary structure. The present total weight of the racks is 2335 kg (74% as heavy as the hab primary structure). The driving factors for the rack design are the frequency requirements of 25Hz minimum, and loads resulting from two very conservative Space Shuttle Orbiter "Pseudo Forcing Functions". These pseudo forcing functions account for 40% to 60% increase in rack loads. It was proposed that the pseudo forcing functions which are specific to Orbiter/Booster dynamics, not be considered when calculating dynamic loads for the Lunar Hab racks. Instead the final design



Launch/Landing Design Load

	X (g's)	Y (g's)	Z (g's)
SSF Hab Design Requirements	-3.40	-1.10	3.70
FLO Design Requirements	-2.70	-1.00	4.00

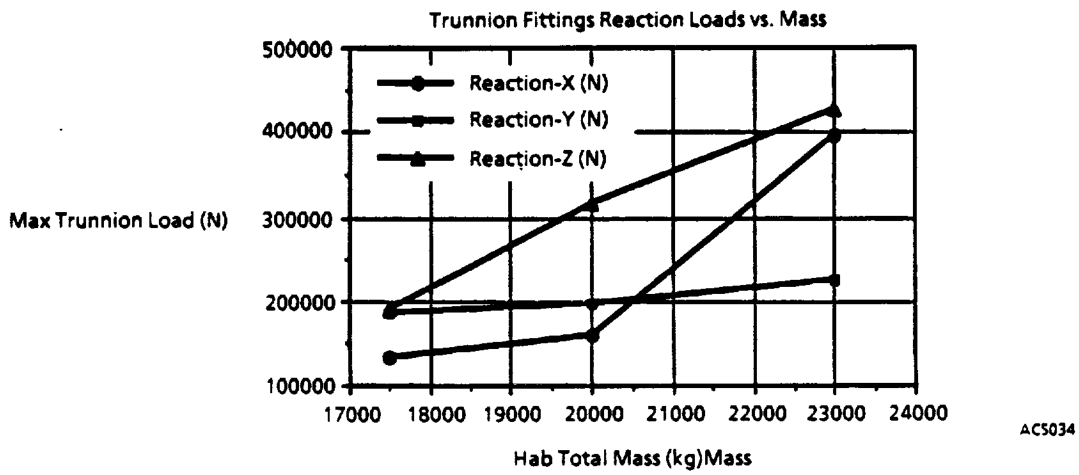


Figure 3-10 Lunar Hab Module Summary of Launch Reaction Loads

and sizing of the rack should be accomplished as the Lunar Hab expendable launch vehicle is better defined. Penalizing Lunar Hab racks by imposing Space Shuttle forcing functions is not appropriate in the conceptual design phase. Forcing functions other than pseudos may still be considered as usual. There is a potential of of about 20% to 30% (approximately 700 kg) weight savings. (This savings is reflected in the mass properties of figure 3-8.)

c. Airlock. A trade study was conducted to identify concerns and features of several FLO Habitat/Airlock configurations in order to arrive at an optimal baseline. Internal and external airlocks were evaluated for hyperbaric and non-hyperbaric operations. These configurations are shown in figure 3-11. External airlocks included the Orbiter airlock, SSF Crewlock mounted on the endcone or skin, and a new airlock mounted on the endcone and designed to fit within the 10m payload shroud. Internal airlocks included addition of an internal bulkhead creating a chamber providing hyperbaric or non-hyperbaric operations. Preliminary analysis showed that internal airlock is not an efficient design. Mass penalties of up to 80% of total hab structural weight will be realized with internal bulkhead designed for hyperbaric operations. Configuration 'D' with SSF Crew lock was evaluated to be the optimum choice with hyperbaric capabilities and about 12% higher mass than the baseline non-hyperbaric Orbiter airlock configuration 'A'.

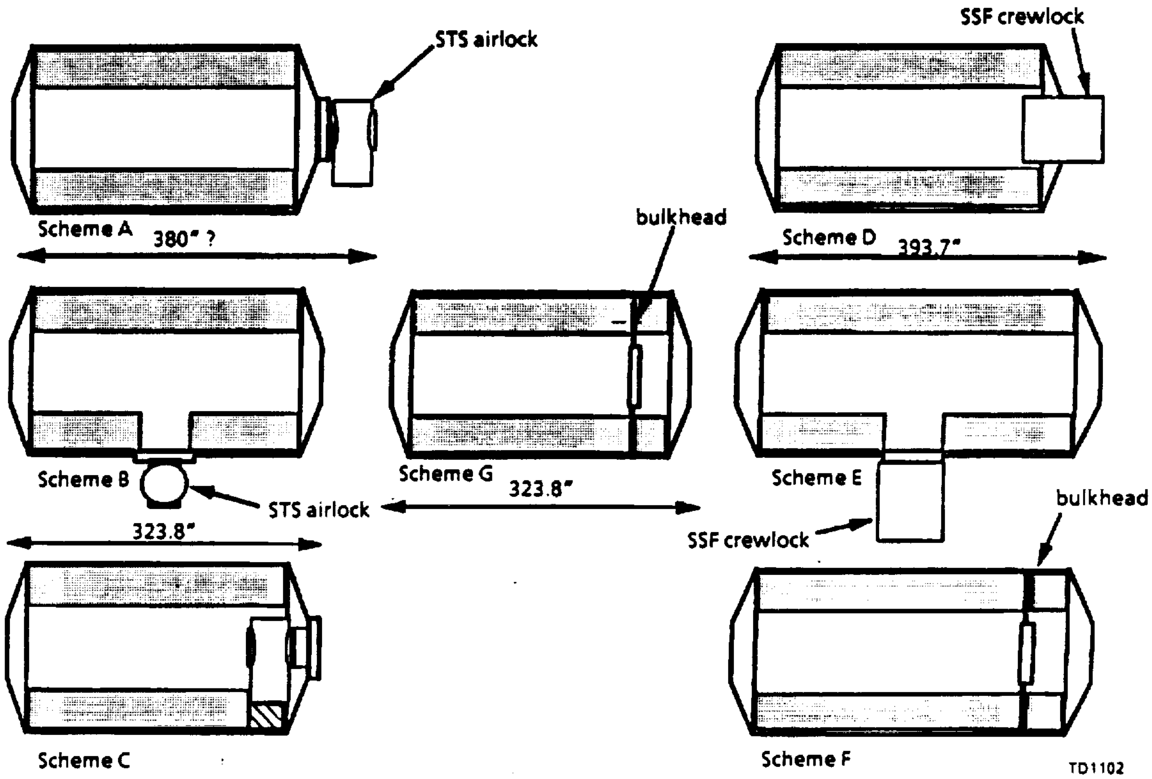


Figure 3-11. Lunar Hab Airlock Configuration Options

Once the SSF Crewlock was selected, structural analysis was performed to evaluate the impact of adding it to the SSF hab module. Two configurations, bulkhead mounted airlock and skin mounted airlock were evaluated. Mass savings and mass penalties were calculated. Supporting the airlock entirely by the hab would require major structural changes to the hab. It was assumed that the weight of the Crewlock will be supported by some external structure such as lander platform, etc. The analysis reflected hab modifications due to cutouts and reinforcements.

For the bulkhead mounted Crewlock configuration, a new and more efficient semi-elliptic end cone was considered. Stress analysis for the end cone with a cutout for the Crewlock was performed. This configuration resulted in approximately 275 kg of structural mass savings. A drawback to this configuration is that four racks could be lost. Skin mounted Crewlock required a 77in diameter cutout on the side of the hab. Stress analysis for this skin cutout was performed and required doubler thickness and stiffener sizes were calculated. This configuration does not affect the end cones. Outcome of the analysis was a net mass gain of ~50 kg with the loss of two rack spaces.

A new hyperbaric airlock was was also evaluated which would take advantage of the excess volume of the 10m payload shroud. The mass of new airlock was calculated to be ~1700kg. With this configuration no modifications to the hab were required and there was no impact to the existing racks. The new airlock is approximately 1000 kg *heavier* than the SSF crewlock but provides two to three cubic meter additional volume. Based on technical and programatic criteria, the configuration utilizing a SSF crewlock embedded in the endcone of the hab was chosen.

3.6.2 FLO External Structure

A preliminary structural mass estimate for the FLO external structure was carried out. External structure is defined as all the structure which is outside the Hab and Airlock, and is not a part of the Lunar lander. This includes the support structure for tanks, arrays, crewlock, and other exterior equipment, hab to lander platform, catwalks, and hoist and lift structure.

Structural masses were calculated for those elements which had a defined configuration. These included hoist and lift structure, catwalks and beams, and radiator secondary support structure. Mass for the remaining structural elements was estimated. Support structure for solar array is included with external power system summary. A summary of external structure mass is shown in figure 3-12.

Hoist and lift structure	=	25 kg
Catwalks and Beams	=	500 kg
Radiator secondary support structure	=	49 kg
All other external structure	=	1490 kg
Total	=	2064 kg

Figure 3-12. External Structure Mass Estimate

An update to the mass calculations and estimates will be performed as the configuration is solidified.

hardware; however, internal EVA system racks and the active CHeCS rack incorporated mass, power, and volume numbers for their primary function which were available from WP02 but had their rack housing and generic rack support systems (including ECLSS) based on the SSF Hab-A Urine Processor Rack. One Atmosphere Composition Monitoring Assembly (ACMA) and one Trace Contaminant Control Subsystem (TCCS) along with all of the original sampling lines are included in the FLO habitat as they exist in SSF Hab-A. Also, the FLO baseline maintains both Cabin Air assemblies in the same locations in SSF Hab-A. Each of the Water Storage and Water Processor Racks contain one water storage tank to allow use from one while filling the other (this total is sized for FLO needs, which are approximately half that of SSF due to removal of shower and laundry facilities). Fire Detection and Suppression equipment is identical to that of SSF Hab-A and sized for the 17 powered racks in the FLO baseline layout. One additional carbon dioxide removal assembly and one additional major constituent analyzer assembly are provided to make these life-critical Subsystems one-failure tolerant. Intermodule ECLSS hardware has been removed except for that needed between the habitat and Crewlock. External ECLSS gas thermal and pressure control estimates have been based on the SSF Gas Conditioning Assembly (GCA) and use one O_2 and one N_2 conditioning strings.

The FLO habitat has baselined a 10.2 psia internal atmosphere, primarily in order to facilitate EVA operations by matching pre-breath time to EMU donning time and reducing risk of decompression sickness. SSF also intends to operate at 10.2 psia during Manned-Tended Capability (MTC) before increasing to 14.7 psia at PMC. However, some of the ECLSS equipment may not be optimally designed for the 10.2 psia condition and will be modified prior to its use on FLO. Other design and safety concerns associated with less than standard atmosphere operations are contained within the Alternative Internal Pressure Trade to be discussed later in this report.

3.8 MEDICAL SUPPORT

The mass and complement of the Crew Health Care System have remained essentially the same as documented in the previous final report, reference 2-3. This medical support included with FLO is intended to provide some basic surgical/dental and emergency first aid capabilities in addition to modest test equipment and minimal countermeasures facilities. Our philosophy has been to enable monitoring of crew health in order to learn about lunar environment effects but to limit response to those problems that seem reasonable for a 45-day, anytime-abort mission. As with most of the FLO concept, more detailed scenario development and risk analyses are needed to arrive at the appropriate CHeCS manifest.

3.9 CREW SYSTEMS

Crew accommodations and crew-related equipment are spartan in keeping with the "campsite" philosophy but are closely related to the SSF Hab-A Man-Systems hardware and/or mass. A mass summary of the crew systems envisioned for the FLO integrated baseline habitation system is given in figure 3-14. The Endcone/Standoff Support includes the mass for restraints and mobility aids (R&MA) used on SSF which has been kept as an analog to the furniture and other accommodations necessary for the Moon's one-sixth gravity field; also, contained in this support equipment are rack and endcone closeout masses which have been increased by 50 kg over SSF Hab-A numbers to account for additional dust containment needs. Crew bunks are assumed to be constructible cots which would be stretched across the aisle and "plugged-in" to seat tracks on a rack face. Stowage drawers are assumed identical to those used on SSF. The Galley is based on its SSF Hab-A counterpart but includes the addition of a handwash (for a total of two in the FLO habitat) and deletion of the convection oven (microwave has been retained). A deployable table is added to the active Galley Rack to serve as a "wardroom" area in contrast to the more elaborate accommodations afforded by SSF. No refrigerator or freezer is included with the FLO baseline but several unpowered storage options may exist for providing fresh or frozen foods (see logistics discussion later in this report) if necessary. The SSF Hab-A waste management hardware mass is assumed to be analogous to a corresponding system for use on the Moon. Currently, no shower is included for FLO; however, through careful water management and design of a combination waste management/cleansing compartment, periodic showers (which seem to be highly desirable) may be possible. A mass representing Critical ORUs for internal systems has been included equaling approximately 5% of the active internal systems mass, but this serves as a placeholder only until more detailed analyses are performed (refer to "spares" discussions later in this report). Consumables stowage needs are addressed above under Internal Volume Assessment.

FLO Crew Systems	Boeing Mass (kg)
Endcone/Standoff Support	127
Rack Support/Stowage	471
Workstation Support	28
Galley/WR Functions	220
PHS Functions	126
Critical ORUs	429
Total Internal Crew Systems Mass	**1402**

Figure 3-14. FLO Habitation System, Crew Systems Masses

3.10 COMMUNICATIONS AND DATA MANAGEMENT SYSTEMS

Communications hardware consist of both internal and external systems which provide both audio and video capabilities within the module, between the module and crew or equipment on the lunar surface, and between FLO and Earth. A schematic of the FLO external Communications and tracking (C&T) system along with interfaces to internal audio/video (IAV) and internal data management system (DMS) is given in figure 3-15. The S-Band Earth links may utilize the Deep Space Network (DSN) rather than requiring additional orbiting relay satellites or new ground stations. Requirements for voice and data rates are not yet finalized but will have substantial effect on final systems design. Internal Audio and Video have been modeled directly on the hardware and masses included for SSF Hab-A and specific rack needs with one external camera added to facilitate EVA viewing operations.

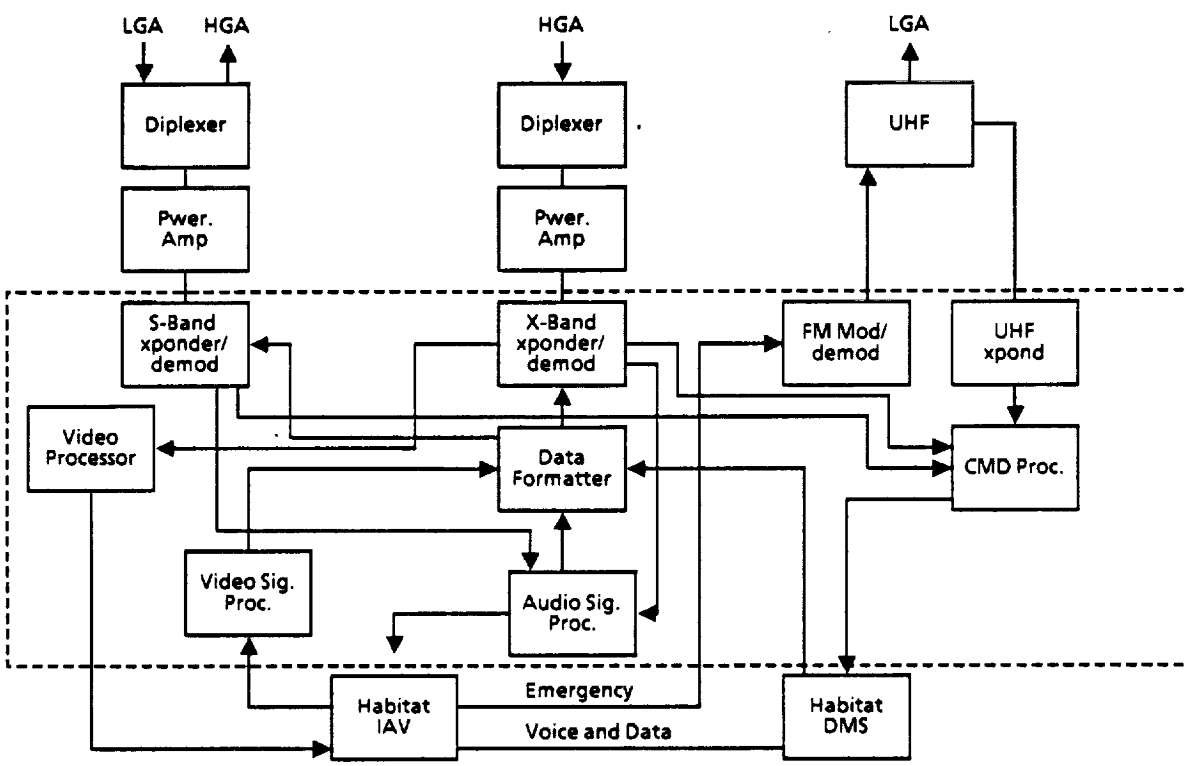


Figure 3-15. FLO Communication and Tracking

The Data Management System has also been based on SSF Hab-A and specific racks with the addition of Standard Data Processors (SDPs) and Mass Storage Units (MSUs) found from SSF Lab-A numbers. The Element Control Workstation (ECWS) from SSF Lab-A has also been included as the main command and control center and the primary computer interface for the crew. Portable Multipurpose Applications Consoles

3.11.2 POWER REQUIREMENTS

The reference power budget described in reference 2-3 included all systems outlined in the SSF habitat module summary of the report, along with additional power requirements associated with the laboratory science racks LAS1 and LAS2 (the ECWS and science/workbench racks). The science/glovebox power was derived from an older SSF power summary, since it is no longer included in the baseline SSF design. SSF power growth derived numbers were also included in the total. This power budget was modified as the FLO concept became better defined. The first change to the reference power budget was the addition of necessary DMS, airlock, and external equipment, which was not included in the earlier summary. A summary of these changes is shown in figure 3-16.

Addition	Power Level	Duty Cycle	# Units	Total Power
Standard Data Processor	138 W	100%	2	276 W
Mass Storage Unit	160 W	100%	2	320 W
Misc. Science Equip.	500 W	10%	1	50 W
Airlock Vacuum	500 W	10%	1	50 W
Airlock Lights	20 W	10%	1	2 W
External Cameras	88 W	100%	1	88 W
External Comm. Equip.	150 W	100%	1	150 W
Total delta	1556 W			936 W

Figure 3-16. Power Summary Changes

A reference power budget was produced for the unmanned dormancy period, in order to more accurately size the RFC system (drives fuel cell reactant, fuel cell, electrolyzer, radiator, and array requirements). All non-necessary equipment was deactivated, including the CO_2 removal unit, and other equipment (ARS, TCS, av. air, cabin air, heat pump, etc.) were scaled down for the lower unmanned loads. The dormancy budget was derived from the reference power budget and available knowledge of both FLO requirements and SSF derived subsystems. A summary of this power budget is shown in figure 3-17, and the complete breakdown is included in Appendix C. The reference power budget was modified to reflect the additional power required for redesigned fans to operate at 10.2 psi, since SSF fan power requirements are prohibitive for long term 10.2 psi operation (designed for nominal 14.7 psi). A brief summary of these changes is shown in figure 3-18.

The next change to the power system summary was a resizing of the airlock pumps using a compressor power computer code developed under IR&D. Along with the other power budget changes, new heat pump and hab growth power levels were determined. These changes resulted in a power system mass increase to approximately 5000 kg, and an array area increase from ~182 m^2 to ~195 m^2. The reference system is sized to provide 9.912 kW average (including 10% fuel cell capacity margin) and 13.52 kW peak (1.5 x average power) nighttime power, and 13.32 kW average and 19.98 kW peak (1.5 x

All Loads in Watts

		Connected Load	Av. Load
EPDS/DMS/SPI/IVA		2471	1927
TCS/THC/ACS		2257	1976
Galley/Wardroom		1629	443.6
Science		2019	727
Water stor./Proc.		1125	292
Air Revt. System		1298.6	796
Crew Health		911	91
Fire Det./Suppression		838	40
External Comm. Equip.		150	150
Waste Management		205	27
M/S Hygiene		516	108
Hab Growth		342	342
Gas Cond. Assy.		240	240
Heat Pump	- Day	3787	3787
	- Night	300	300
Airlock	- Day	6674	2371
	- Night	6674	1551
Grand Totals	- Day	24463 W	13318 W
	- Night	20976 W	9011 W

Figure 3-17. FLO Reference Power Budget Summary

Pressure (psi)	Avionics air fan	Cabin air fan	Crossover air fan	Total fan pwr	Delta power
14.7	520 W	360 W	220 W	1100 W	NA
10.2	749 W	519 W	317 W	1585 W	485 W

Figure 3-18. Fan Power Requirement Deltas for Reference FLO

average pwr) daytime power manned, and 2.525 kW nighttime dormancy power. The detailed power budget summary is included in Appendix D.

The reference power budget served as a baseline for all additional system level trade support activities.

3.11.3 POWER AND HEAT REJECTION SYSTEM SIZING

After the reference manned and dormancy power budgets were finalized, the sizing of the reference power and external heat rejection systems was initiated. The power system was sized based on the following:

a. Solar PV system utilizes GaAs/Ge (8 mil) arrays; nominal efficiency ~ 18%

b. Nighttime average power increased 10% to provide power/reactant margin; Peak power = 1.5 x average power + electrolyzer power (day)

c. Fuel cell capacity "stretched" 1 day at 11 kW to provide mission abort window in case of solar PV system malfunction at beginning of lunar day

d. ~14.9% temperature induced array degradation at lunar "noon"; 10% radiation degradation added (see degradation assessment information below)

e. Electrolyzer and array sized to provide nominal charging rate at worst case array performance; Nominal rate = dormancy requirements + 1/5 average manned nighttime power (kW-hr)

Fuel Cells	135 kg
Electrolyzer	88 kg
Radiator	0 kg*
Hydrogen Reactant	152 kg
Hydrogen Residual	5 kg
Oxygen Reactant	1218 kg
Oxygen Residual	32 kg
Hydrogen Tank(s)	1763 kg
Oxygen Tank(s)	800 kg
Water Tank	69 kg
Solar Array	435 kg
Support Equipment (cables, converters, etc.)	305 kg
Solar array support structre	449 kg
Total Mass:	5451 kg

* Included in HRS mass

Figure 3-19. Reference Top Level Power System Mass Summary

especially effective method for increasing radiator heat rejection efficiency (W/unit area). Additionally an increase in the emissivity of a radiating surface will have roughly a linear effect on heat rejection capability. For this study, a heat pumped augmented system was chosen, based on its flexibility to performance degradation, reduced radiator area requirements, and mass. The assumptions for the heat rejection system were: .

a. SSF derived internal heat acquisition/transport system design

b. Radiator rejection load:

   $P_{rej} = 1.5 \times (P_{hab} + P_{A/L}) + P_{electrol} \times (1 - h_{electrolysis}) + Q_{metabolic}$

c. Horizontal radiator utilized; heat pump augmented rejection

d. Heat pump motor/pump assembly rejects waste heat at condenser temperature (conservative assumption - probably 20° - 50°C higher)

e. Compressor isentropic efficiency = 0.6 (terrestrial sys data); Pcomp/Prej = 0.529 (R-11)

f. Heat pump system mass ~ 31.83 x Q (from terrestrial systems data)

g. Heat pump power provided by main arrays

h. rad = 0.25 (absorptivity) fin efficiency = 0.85

   εrad = 0.8 (emissivity) radiator rejection temperature = 360K

   radiator specific mass ~ 5.2 kg/m

i. Single phase pump efficiency ~0.30 (used to determine nighttime pump power)

j. Minimum fluid operating temp (nighttime) = 165 K (T.P. = 162 K)

k. Qmetabolic = 132 W/person x 4 crew

During the sizing process for the heat rejection system, several issues were raised. These issues were considered in the derivation and sizing of the reference heat rejection system concept. The major issues derived and considered:

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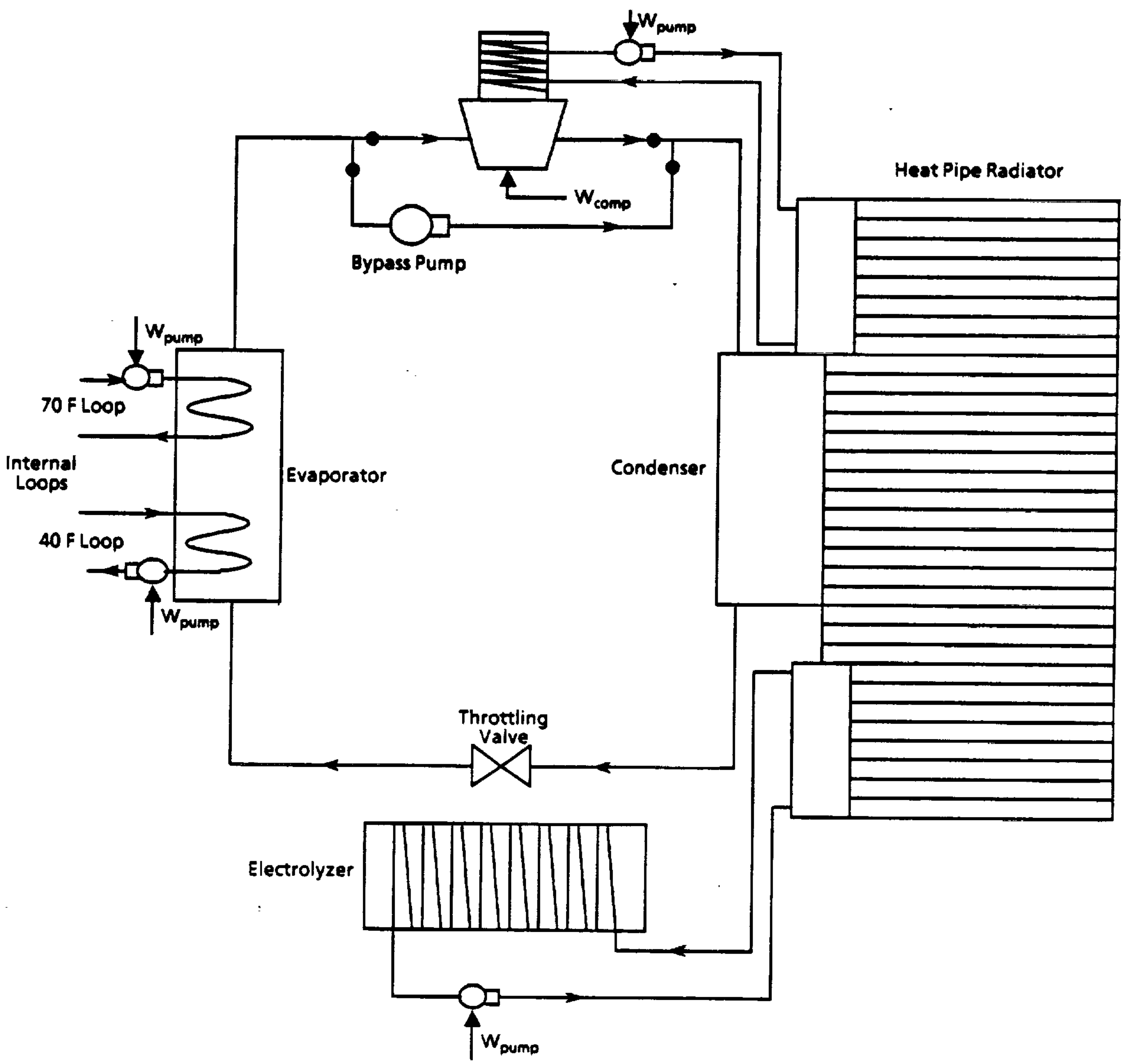

Figure 3-20. Reference Heat Pumped System Functional Schematic

lander can be positioned far enough away to protect the outpost from the initial lower velocity dust disturbed by the lander at higher altitude, no reasonable distance (<1-2 km) will completely spare the Outpost from the higher velocity particles (ejected just before touch-down). These particles will not only cover surfaces facing the Lander, but may "sand-blast" them as well. Operational considerations such as pointing or stowing the arrays, stowing the radiator (thermal energy storage required), or regular surface cleaning will be investigated as this study continues. Finally, the effects of scattered dust from the natural effects on the lunar surface (i.e., terminator line ionization/ deionization, and micrometeoroid impact scattering) were investigated. Although the

Fluid	Triple Point (K)	Pressure (high/low - psi)	Liquid Sp. ht kJ/kg K	kWhp/kWrej
Ammonia	195.5	750/125	4.815	0.643
R11	162	110/12	0.88	0.529
R12	115	380/70	0.98	0.782
R21	138	Not Avail.	1.07	Not Avail.
R22	113	580/110	1.22	0.77
R113	238	45/5	0.925	0.61*
R114	179	175/25	0.996	0.85
R142b	<205	235/30	1.12	0.61
R152a	<<177	400/58	1.60	0.71

Figure 3-21. Heat Pump Working Fluid Options

thermal balance. The habitat TPS consisted of 18 layers of MLI (αsurf = 0.30, εsurf = 0.40 - M/D shield outer surf). The worst case heating was determined to be at lunar "noon", where Qleak < 1 kW (with 3 SSF sized windows). Worst case habitat heating during the day assumed complete lunar dust coverage of the hab shell. It was assumed that the windows would be kept relatively clean (shields, cleaning, etc.). Covering the windows when not in use will reduce the transmitted solar radiation (i.e., heat leak) by as much as 200 - 300 W. A portion of the waste heat produced during lunar night can be utilized to maintain the habitat heat balance, although it may require separate heat transport loop. Additional TPS can be added to the habitat shell if the 700 W to 1 kW heating rates are deemed too high. It should be noted that no shielding effects were included for any external equipment, and therefore the heat flux is relatively conservative. A mass, rejection load, and radiator area summary for the reference external heat rejection system is shown in figure 3-22.

Rejection load:	22.61 kW
Radiator Area:	63 m^2
Radiator mass	327 kg
Heat pump mass	108.5 kg
Insulation mass	25 kg
Aux. pump mass	60 kg
Total HRS Mass:	520.5 kg

Figure 3-22. External Heat Rejection System Mass Summary

3.11.4 Subsystem Level Trade Studies Support

Several system level trades assessments were completed for power and thermal system impacts. The majority of these were in support of the FLO alternate subsystems task. In an early trade, the reference heat pumped heat rejection system was traded against a non heat pumped system. The savings in power system mass for the non heat pumped system was compared to the area and mass sensitivity of the heat rejection discussion of hyperbaric treatment requirements is included in the reference 2-3. Mass and power estimates have been derived from current SSF WP02 data; however, a persistent difficulty has been the interpretation of these data. The SSF WP02 mass report provides an itemized breakdown of the SSF Airlock (which includes both an Equipment Lock and the Crewlock) but is not clear as to where each of these components belong (inside, outside, Equipment Lock, Crewlock, or elsewhere). This ambiguity has led to differing weight estimates for the Crewlock and EVA systems; unfortunately, without better definition from SSF WP02, the correct numbers will remain unknown. The Boeing airlock system mass summary given in figure 3-23 combines internal habitat EVA systems (535.1 kg) with airlock and extended EVA systems (2174.8 kg) for a total of 2710 kg.

FLO Crewlock/EVAS Component	Boeing Mass (kg)
• **Structures and Mechanisms**	**1532.7**
Crewlock cylinder section	152.9
Crewlock EVA bulkhead ring	264.0
Crewlock IVA bulkhead ring	326.6
Longerons and struts	40.6
Isogrid panel/support angles	93.0
MM/D shield	79.2
EVA/IVA hatches/mech	228.1
Non-rack/rack support struct	17.8
Crewlock rack	58.3
1/6 g internal/external struct	
Pass-thru lock	
IV yoke	
Keel trunnion ftg and pins	
Transportation pins (2 keels)	
1/2 Equip Lock end dome	
Hab/Crewlock interface (est)	272.2
• **Internal EVA Systems**	**656.3**
Crewlock hyperbaric supp	121.2
Hab EVAS (SPCU, H/B, pump)	535.1
• **Other Distributed Hardware**	
• **Crewlock EVA Hardware**	**428.9**
• **External EVA Equipment**	**92.0**
Total Mass	**2709.9**

Figure 3-23. FLO Habitation System, Crewlock/EVAS Status

The internal EVA systems burdened onto the hab (as shown in the baseline layout) include Suit Processing and Checkout Units (SPCUs), Airlock Depressurization Pump Assembly (ADPA), and Hyperbaric Support which have been based on a similar SSF Equipment Lock complement. The use of these systems assumes lunar suit operations to be similar to the STS EMU; however, JSC has proposed a new, regenerable suit which

FLO Consumables Mass	Boeing Mass (kg)
• **Crew Accommodations**	**1134.0**
Crew Quarters	0.0
Clothing	245.0
Off Duty	84.2
Photography	182.8
Workstation	
Food & Galley Supply	463.0
Personal Hygiene	45.8
Housekeeping	113.2
• **Life Support**	**735.2**
Water (Closed Loop)	in hab
Oxygen	305.2
Nitrogen	259.0
ARS expendables	20.6
WRM expendables	129.4
WM expendables	11.0
THC expendables	10.0
• **Health Maintenance**	**80.0**
• **Science**	**50.0**
• **EVA**	**505.7**
EMU expendables	166.3
EMU spares	74.8
Dust Control	97.0
EVA Sublimator Water	167.6
• **Spares**	**in hab**
Total Consumables Mass	**2504.9**

Figure 3-24. FLO Habitation System,Consumables

for example), and to support life science experiments. Also included in this list is a Fluid System Servicer (FSS) and leak detection equipment which are based on SSF numbers and bookkeeping (actual use and location of this equipment remains unknown). With a major feature of FLO being the support of human presence to conduct missions on the Moon, it is expected that internal science capabilities will be a significant consideration of habitation system design.

FLO Internal Science Support	Boeing Mass (kg)
Science Workbench	300
Science Equipment	365
Fluid System Servicer and leak Detection Equipment	102
Sample Prep Instruments	
Imaging Instruments	
Spectrometers	
Total Internal Science Mass	**767**

Figure 3-25. FLO Habitation System,Internal Science Support Mass

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used where available, and other parameters were calculated or derived. Alternatives which trade better than the baseline system may be explored in more detail for inclusion into concept in the future.

4.2 ALTERNATE SUBSYSTEMS TRADE SUMMARY

4.2.1 Open vs Closed Water Trade

A trade was performed to assess ECLSS water supply options for the FLO mission. An open system which requires resupply of all necessary ECLSS water was compared to a closed system utilizing SSF derived water processing equipment. Mass summaries developed for the current reference system (closed), and the open system option are shown in figures 4-1 and 4-2, respectively. The total mass of the reference system was found to be approximately 626 kg lower than the open system, with the total system masses diverging for each manned mission. The resupply requirements for either system would consist of expendables and any spares needed, but the open system would also require ~1 mt of water and tanks for each manned visit. The overall system mass for the closed system was found to be 1568.8 kg, while the system mass for the open system was 2194.7 kg. The increased thermal and power systems mass for the closed system water processor operation was estimated to be only ~146 kg, since the power system mass is much more sensitive to average power than peak power levels (increase in average power required for water processor less than peak power increase). The required resupply for expendables for either system may be assumed similar since a complete spares assessment cannot be completed until more is known about the respective systems, although expendable requirements may be higher for the closed system. The EMUs will also require water but the PLSS may be regenerable, so EMU water requirements were not included in the trade (an overall system level water balance may also leverage this trade for either option). Both the "Closed" and the "Open" Water Systems require 3 rack spaces inside the module, although plumbing and other utilities may require slightly less volume for the "open" version. The conclusion reached as a result of this trade was that the closed version is preferred over the 'simpler' open system for the following reasons:

a. Closed water system should be proven by SSF.
b. FLO is intended for multiple missions.
c. Both initial and resupply masses are significantly lower for closed water option.

Alternative	System Description	Mass (kg)	Power (W)
Current Baseline Concept (SSF "Closed Water" System	• Water Storage Rack (with 1 tank)		
	- basic utilities and rack	159.7	
	- water storage assembly	157.0	70W Peak
	- water (1 tank)	110.4	14W Avg
	- valves, etc.	15.3	
	• Water Processing Rack (with 1 tank)		
	- basic utilities and rack	171.0	
	- water processor assembly	312.9	700W Peak
	- water (1 tank)	110.1	200W Avg
	- process cntrl wtr qual monitor	30.8	
	- valves, etc.	26.4	
	• Urine Processor Rack		
	- basic utilities and rack	187.9	355 W Peak
	- urine processor assembly	146.7	
	- valves, etc.	11.2	77.8 W Avg
	• Expendables	129.4	
	• Spares	?	
	Total System Mass and Power	**1568.8**	**1125W/291.9W**

Figure 4-1. Mass and Power Summary for Referenced Closed Water Loop System

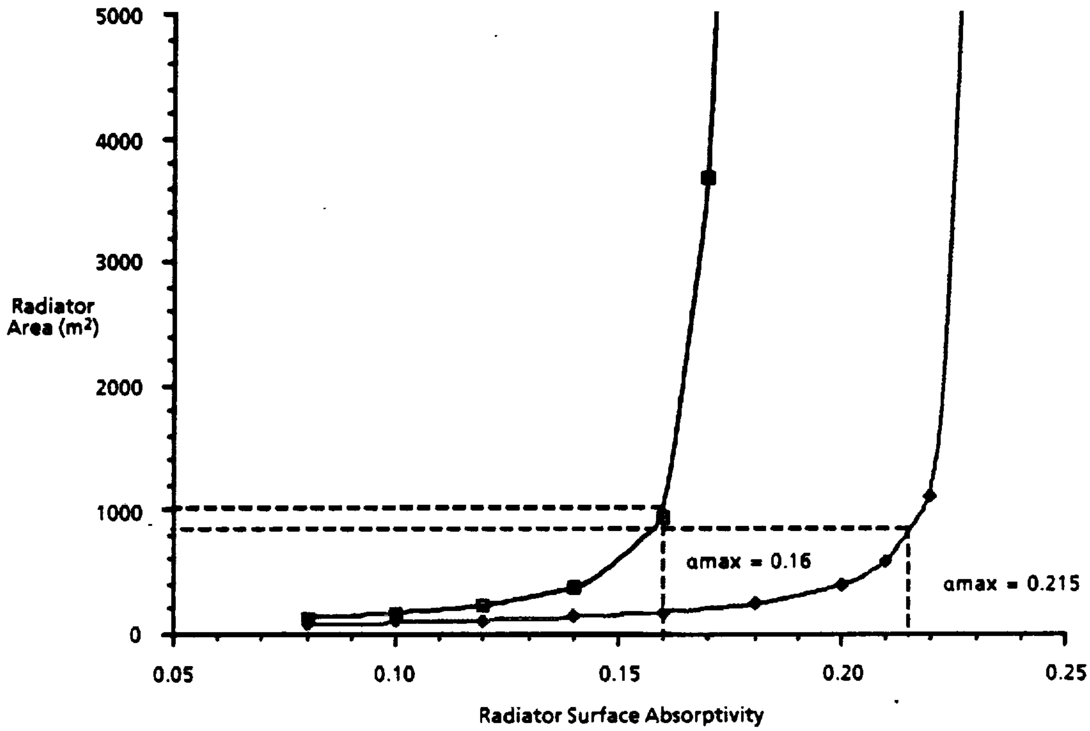
Alternative	System Description	Mass (kg)	Power (W)
Specification Candidate ("Open or Stored Water" System	• Crew Water Needs: **between** 4.65 kg/p-d x 4 people x 45 days = 837 kg *(hydrated food, handwash, urinal)* **and** 5.45 kg/p-d x 4 people x 45 days = 981 kg *(add 1 shower/week)*		
	• Water System Capabilities		
	- 3 Water Storage Racks (w/3 tanks each) *(with 5% tank fraction, will provide 945.9 kg of water total)*	2013.6	(3x70) W Peak
	- PCWQM	30.8	(3x14) W Avg
	- MDM	20.9	
	- Additional tankage for urine/condensate *(assume use of emptied water tanks for storage of waste water - tanks switched out for resupply)*	0.0	
	• Expendables *(assumed)*	129.4	
	• Spares	?	
	Total System Mass and Power	2194.7	210W/42W

Figure 4-2. Mass and Power Summary for Open Water Loop System Option

4.2.2 Heat Pumped vs Non-Heat Pumped Heat Rejection System (HRS) Trade

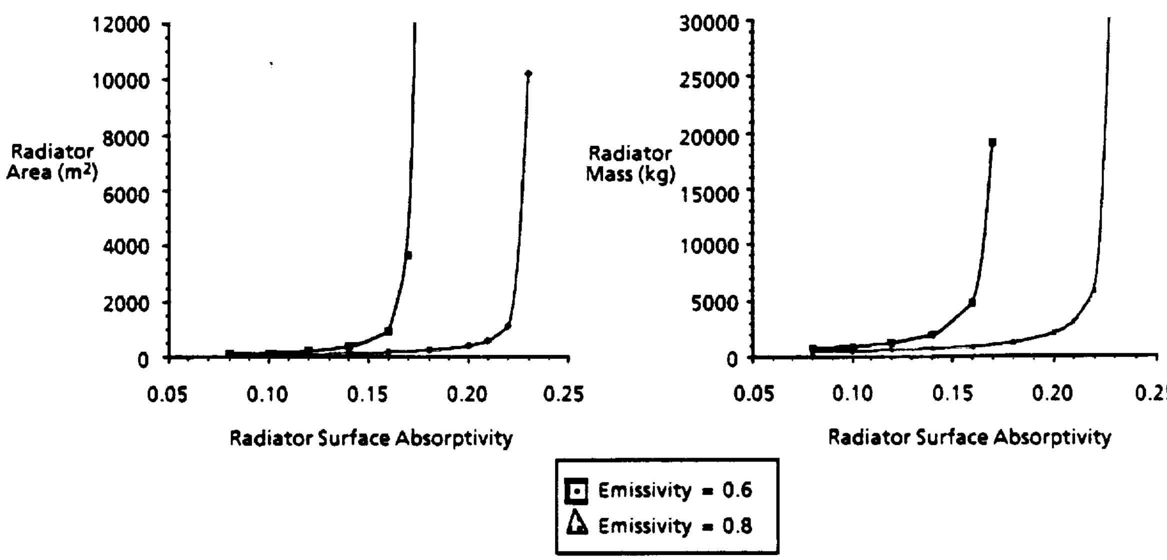
A trade was performed to assess the sensitivity of the performance of the reference heat rejection system to the presence of a heat pump to augment the rejection temperature of the FLO radiator. Power system mass impacts of the heat pump power requirements were also assessed to quantify the mass impacts of the heat pump. The radiator area required to reject a representative FLO habitat waste heat (~16 kW) for a range of radiator absorptivities, and for surface emissivities of 0.6 and 0.8 is shown in figure 4-3. The two emissivity curves are shown to illustrate that the radiator area vs absorptivity trends are similar for different emissivity levels. The solar absorptivity of the radiator will probably be the most effected by the lunar environment, since lunar dust (which is likely to become deposited on the radiator) has a rather high emissivity (>0.9). As can be seen from the graph, the radiator is much more sensitive to the surface absorptivity than emissivity in the area of interest. The 5% offsets were shown for illustration only, to give a reasonable point where the surface area goes asymptotic to a given absorptivity. Even at these values, however, the required radiating areas are ~850 and 1000 m^2, for emissivities of 0.6 and 0.8, respectively. The same area trend, along with the radiator mass vs surface absorptivity is illustrated in figure 4-4. Top level assumptions made for the trade are also shown on the figure. The radiator area and masses were derived for a horizontal orientation at worst case conditions (lunar "noon"). The radiator was assumed to be insulated on the back to limit lunar surface heating effects. As can be seen in the figures, the non-heat pumped thermal control system (TCS) was very sensitive to radiator optical properties (absorptivity and emissivity).

Although the heat pumped system will likely be slightly more complex than a non-heat pumped option, and would require heat pump technology development, the non-heat pumped TCS will pose several challenges in the development phase. The absorptivity range (including expected degradation) should be kept away from the mass and area asymptotes in order to increase system reliability given the uncertainties in dust and erosion effects on performance. Current state-of-the-art radiator coatings have some difficulty to provide required α/ε values over the FLO operational life (frequent changeout may be necessary). If absorptivity approaches the asymptotic value, small increases in degraded optical values would make required radiator size and mass unworkable. SSF degraded α and ε values used to size the heat pumped radiator ($\alpha = 0.25$ and $\varepsilon = 0.8$), would cause the radiator mass and area to become prohibitively large for the non-heat pumped system. Since the heat pump is only required during the day, the reference power system impact in mass for delivering heat pump power during the lunar daytime is only ~159 kg (mainly due to increased solar array area required). The heat



• Selected maximum α corresponds to 5% offset from asymptotic value

Figure 4-3. Radiator Area vs. Optical Surface Properties ACS023



• Trad (effective) = 289 K
• Insulation Thickness = 1.27 cm.
• Fin (effective) = 85%
• Heat Load = 16.064 kW

Figure 4-4. Radiator Mass and Area vs. Optical Surface Properties ACS024 pump mass is approximately 110 kg, which is more than offset by the additional radiator mass of the non-heat pumped system. Due to its lower area, the heat pumped radiator may be pre-integrated so as to require little or no deployment after landing. The heat pumped TCS should be inherently more flexible than the non-heat pumped TCS in that the power level input to the heat pump compressor can be altered to raise the evaporator (i.e., radiator) rejection temperature. The primary conclusion of this trade was that the heat pumped system was preferable due to its operational flexibility, greater rejection efficiency, and lower overall external HRS mass.

4.2.3 Possible Uses of Crew Lander Fuel Cell Water Trade

A trade was performed to investigate the possibility of utilizing the crew lander fuel cell water for the FLO habitat system. The crew lander power level is estimated to be ~4 kW in active mode, and ~1 kW in standby . Fuel cell water (FCW) will be produced at 8.736 kg/kW-day at these power levels. Assuming 5 days active mode on lunar transfer, and 42 days on standby, the crew lander generates 541.6 kg of water by the end of FLO mission. The FLO lander may also produce fuel cell water during its active mode, depending on the lander power system architecture, and its relationship to the FLO power system.

The fuel cell water has two major uses in the Outpost Habitation System: (1) to meet crew water needs in an open water ECLS system, and (2) to meet crew oxygen needs via electrolysis (utilizing FLO external power generation equipment to split this water into O_2 and H_2). Either of these uses require fuel cell water to be transported from the crew lander to the FLO habitat, so several small lander water tanks would probably be necessary. Removal and transport operations for the water to be integrated into the appropriate habitation system would take place very near the end of the mission, in order to capture the most water. The crew lander TCS is not yet defined, but it may require fuel cell water for sublimator cooling, potentially leaving no excess for FLO uses. If it is not used for onboard TCS, the crew lander fuel cell water may be used to meet crew water needs: the 541.6 kg of water generated by the crew lander would provide 50 - 60% of the necessary ECLSS water for a typical FLO mission. As shown earlier in this section, without the use of fuel cell water, the ECLSS water trade showed that the open water system mass is 480.3 kg greater than closed version, and that open resupply requirements may be ~1 mt higher. With the use of fuel cell water, the first FLO must still pay the 480.3 kg penalty (to accommodate the first manned visit needs) and the open resupply requirements would still be ~400 kg higher, so the use of crew lander fuel cell water does not overcome the mass benefits associated with a closed water system, although it may be very useful in meeting other needs, such as for EMU sublimators. Another area of use for crew lander water could be to meet crew oxygen needs, utilizing the electrical power system electrolyzer. At the end of the first mission, lander fuel cell water would be introduced to the product water storage of the FLO external power generation system, and electrolyzed into hydrogen and oxygen during the interim lunar daylight periods between manned missions. The excess 541.6 kg of water would produce 481.4 kg of oxygen, which would be more than adequate for oxygen resupply (42 day metabolic load and makeup/repress requires 225 kg). Resizing the FLO product water tanks to hold a full 541.6 kg of water, enlarging the oxygen reactant tanks to hold an additional 225 kg, and increasing the array and electrolyzer mass needed to split this water results in a ~164.5 kg impact to FLO power system. It is assumed that the remaining water is utilized by EMU, etc., but the hydrogen is lost, unless it becomes valuable for later ISRU or other uses.

There will likely be several negative impacts to the initial FLO habitat relating to the utilization of the lander fuel cell water. The complexity of the FLO system will likely be higher with delivery of oxygen from the reactant storage subsystem, introduction of crew lander water into the fuel cell product storage, etc. Fuel cell water utilization may result in a ~165 kg mass penalty for the first FLO mission, above the requirement of supplying the first mission oxygen needs (later lessened resupply requirements may offset this initial impact). The main discriminator in this trade will be the amount of water available, if any, from the yet to be defined crew lander. A final set of recommendations cannot be made until the crew lander is better defined.

4.2.4 Inflatable Hyperbaric Chamber Concept

All FLO concepts provide hyperbaric treatment capabilities that meet current understanding of the NASA Exploration Program Office (ExPO) requirements. The reference SSF crewlock concept is near-term hardware which combines airlock and hyperbaric chamber functions.The crewlock mass is high, however, (mass estimates for the crewlock system range from 2700 to 4200 kg), and the crewlock intrudes into the habitat volume in order to fit within the 10m launch vehicle shroud. An inflatable hyperbaric chamber in conjunction with a smaller dedicated airlock may significantly reduce airlock system mass and size. The airlock could be designed for optimal egress/ingress and equipment pass-thru only, potentially reducing its size and mass significantly. A hyperbaric chamber would stow and deploy inside the habitat module when required. ILC Dover has constructed, tested, and delivered a one-person collapsible hyperbaric chamber prototype to the United States Air Force, reference 4-1.

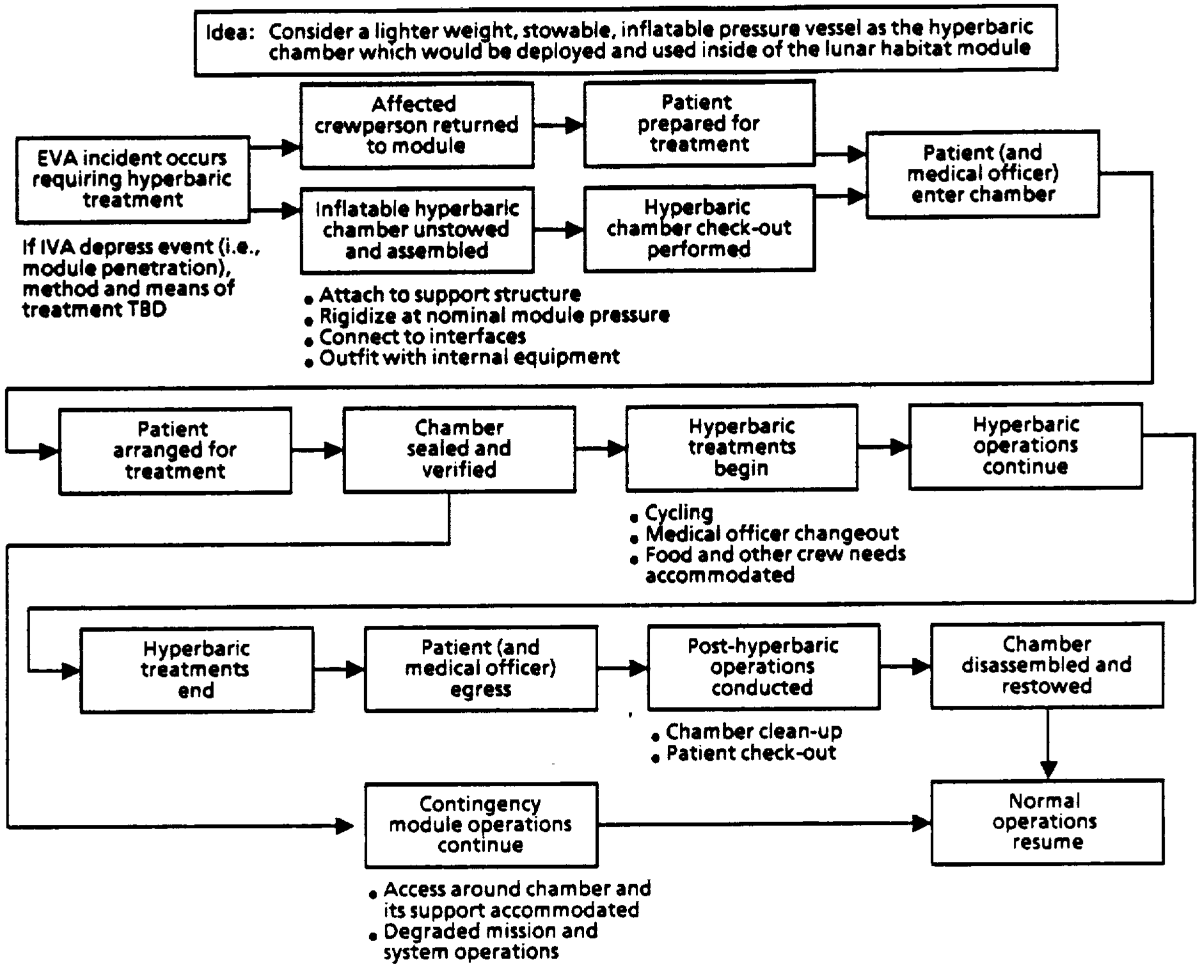


Figure 4-5. Operational Scenario for Inflatable Hyperbaric Chamber

reactants leaving electrolyzer are at ~60°C or higher). The initial reactant supply must satisfy a 6 month dormancy period, and the first crew mission (~3595 kg of reactants and ~723 kg of tankage). Each crew must bring the same amount of reactants for each 6 month dormancy period and 42 day mission. The fuel cell product water is available for other uses (open water system, EMU PLSS use, etc.), or must be disposed of to provide storage space for next mission. Using the above scenario, the mass for the open power system for the first FLO mission is about 637 kg higher than the baseline. In addition, the open system would require an additional 4317 kg of resupply every visit (including the first). Based on this brief assessment, the closed, or regenerable fuel cell electrical power system was the preferred option.

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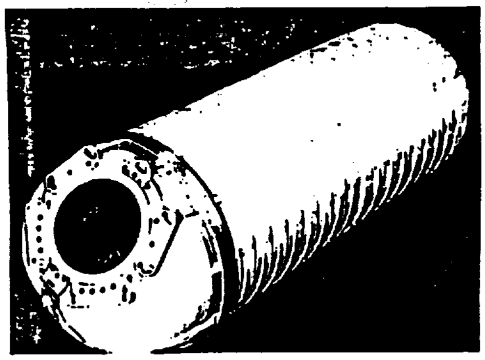


- **NORMAL OPERATING PRESSURE: 26.5 PSIG**
- **BURST PRESSURE: 60 PSIG**
- **77" LONG X 24" I.D.**
- **SOFTGOODS WEIGHT: 14.5 LBS.**
- **PACKAGING DIMENSIONS: 26" X 26" X 3 1/2"**
- **POLYESTER RESTRAINT/URETHANE COATED NYLON BLADDER**

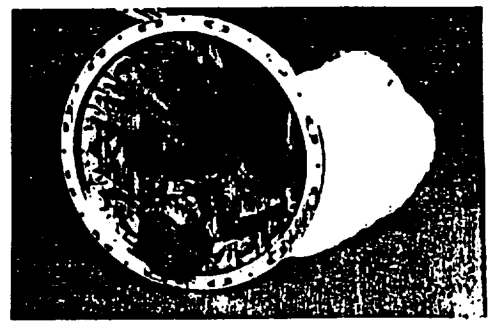


Figure 4-6. ILC Dover Collapsible Hyperbaric Chamber

- Technology maturity
  - Materials
  - Pressure differential
- Interfaces and connections
  - Data/Power/Thermal
  - Hyperbaric Support
  - Gas Storage and Delivery
  - Medical Support
- Egress/Ingress
- Storage and deployed volume requirement
  - Where
  - Getting around
  - What's blocked, what's not
  - Size
  - Mass (any savings?)
  - Chamber distributed systems and hyperbaric support system
  - Drivers?
- Pass-through lock possibilities
- Dedicated hyperbaric support rack?
- Method of deployment
- Need for attendant medical officer inside or size for patient only (ILC design)?

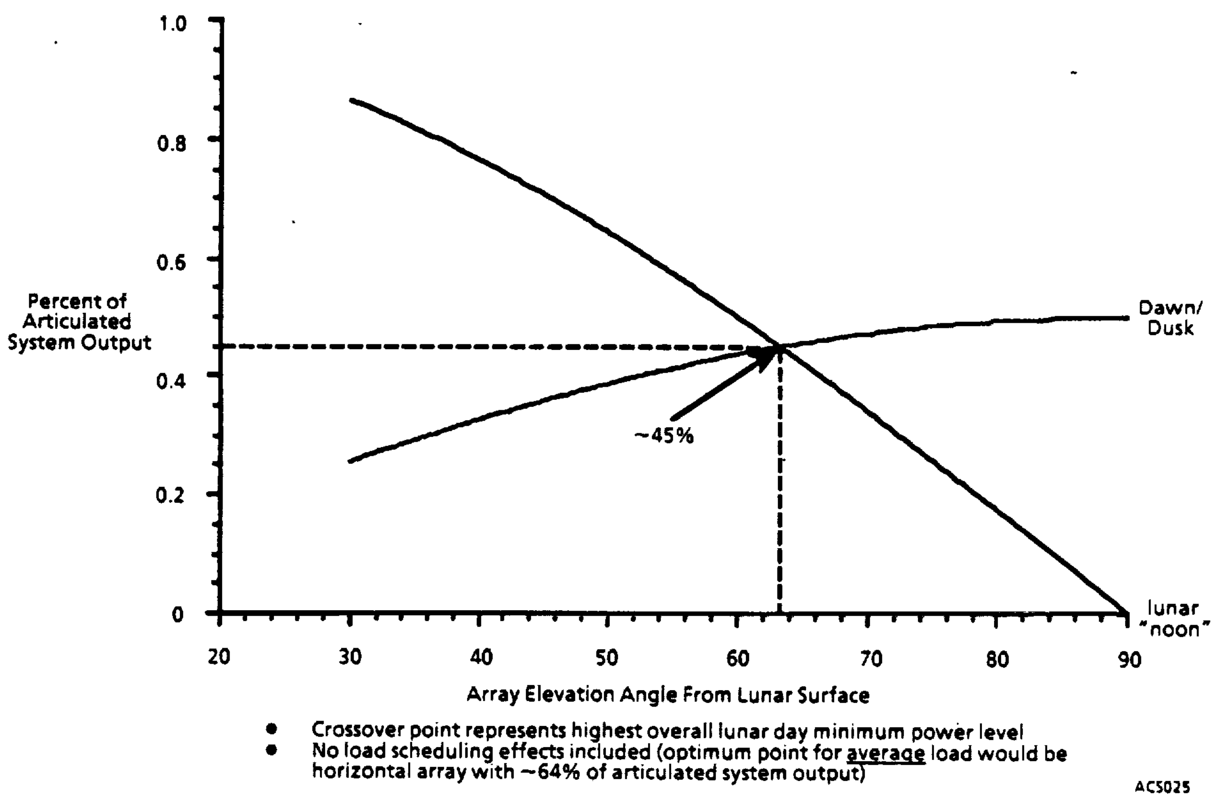
Figure 4-7. Inflatable Hyperbaric Chambers Issues to be Addressed

4.2.6 Reduced Power Processing Levels

An effort to identify possible areas of simplification for the SSF derived power system architecture was completed on a qualitative basis. A schematic of the reference power system is shown in figure 4-8. The schematic is similar to the current SSF architecture, with the exception of the electrolyzer/fuel cell system (SSF utilizes batteries). The power coming from the solar arrays requires conditioning, since it is delivered from the array in a range between ~160 - 200 V, depending on array orientation, solar flux, surface temperature, etc. A sequential shunt unit, which "bleeds" off excess power from the array, is used for overload protection. A DC switching unit is used to control fuel cell discharge and electrolyzer recharge, and main bus switching units are utilized to control the flow of external and internal power to and from the habitat. A DC to DC conversion unit (DDCU) in the habitat converts power from the unregulated nominal 160 V, to a regulated 120 V. The secondary power distribution assembly units (SPDA) provide power at the module level, and are equivalent to a main "breaker box". The remote power distribution assembly units (RPDA) provide power at the rack level for user loads, and further regulation of 120 V (down to 28 or 15 V) power is executed at ORU level within individual racks.

Qualitative assessments were made regarding possible avenues of simplification to the FLO EPS architecture. The fuel cell output requires relatively small amount of conditioning as compared to the array output, so conditioning equipment can probably be bypassed during lunar night, increasing end-to-end power delivery efficiency. Reduced levels of power conditioning would result in increase in power system efficiency, although significant component level redesign would be required to standardize voltage level to 28 or 120 V, in order to accomplish this need. The required redesign of SSF derived components to standardize electrical power requirements could be a significant cost driver, however. If system standardization proves prohibitively complex or costly, the amount of electronic equipment requiring off nominal power conditioning (currently 120 V after first DDCU) should be minimized to reduce power losses, complexity, and mass. Control and stability issues may be less severe for FLO solar array, due to its 14/14 day charge/discharge cycle compared to the 57/35 minute cycle for SSF. Utilizing single stage DDCU's with multiple voltage outputs at the rack level may decrease conversion losses and complexity, although system mass may increase slightly. Until more is known regarding the design and integration issues mentioned above, the reference FLO system (i.e., SSF EPS architecture) was preferred due to its compatibility with SSF derived hardware, and lack of design data on the associated costs of common power conditioning. A more detailed assessment of design environments and issues would also be required for a more accurate assessment of an optimal power conditioning system.

articulating arrays, the fixed arrays were sized to provide peak power at worst case: 0° and 90° solar angle (noon and dawn/dusk). As can be seen in the crossover graph, and in the array area versus array elevation graph (figure 4-10), the fixed array performance is ~45% of articulating system levels, and the required area is ~435 m^2. A possible configuration of the fixed array system, along with a summary mass statement, is shown in figure 4-11. As shown, the size and orientation of the array result in a significant mass penalty over the reference system. A preliminary deployment scheme for the fixed array concept is shown in figures 4-12 and 4-13. The frame would deploy in two parts. First, structural "runners" would deploy to the surface, to provide support for the deployment of main array support structure, which could unfold in "accordion" fashion. The array would roll or unfold along the support structure, and then expand to its full length of ~15 meters (second "lengthwise" folds necessitated by 10 meter launch shroud allowance). The advantages and disadvantages of the fixed array concept as compared to the reference are summarized in figure 4-14. Although it will likely be more complex than the fixed array system, the articulating system was preferred for the reference FLO concept due to its significantly lower mass (885 kg vs 2575 kg) and area (190 square meters vs ~435 square meters).



- Crossover point represents highest overall lunar day minimum power level
- No load scheduling effects included (optimum point for average load would be horizontal array with ~64% of articulated system output)

Figure 4-9. Percent of Articulated Solar Array System Power Output vs. Array Elevation Angle

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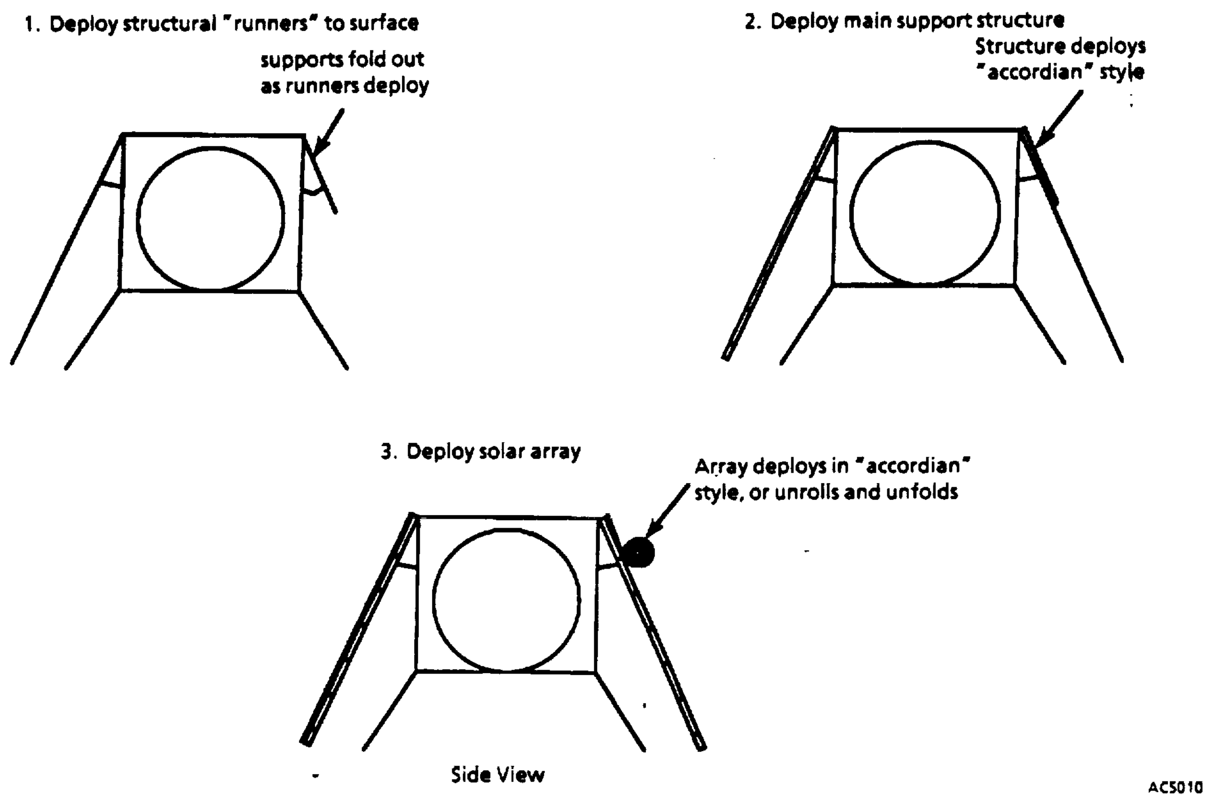

Figure 4-12. Deployment Scheme for Fixed Array Structure

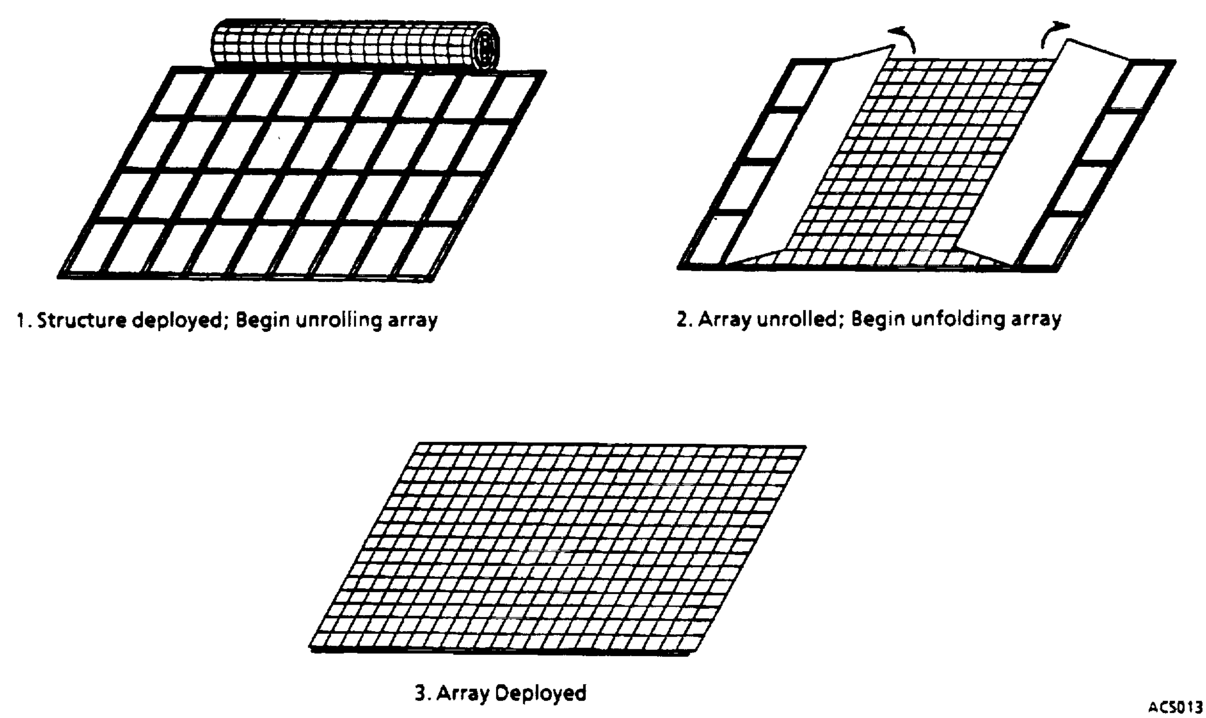

Figure 4-13. Array Blanket Deployment Scheme for Fixed Concept

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Advantage	Disadvantage
• Can be fully deployed before manned landing; operational reliability high	• Articul. system can also be fully deployed before manned landing; lifetime operational reliability somewhat lower than fixed
• Dust impingement on rotating mech. of greatly reduced concern	• Array dust buildup/shielding more difficult; cannot stow array during crew arrival/depart.
• Nominal operation is routine and relatively simple	• Autonomous deployment more difficult; system mass much higher
• Not sensitive to sun inclination angle array alignment	• As sensitive to sun azimuth alignment with array; design limits flexibility of system to correct for off nominal landing

Figure 4-14. Summary of Advantages and Disadvantages of Fixed Solar Array Concept

4.2.8 Offload Some First Visit Consumables to Crew Lander

The option of offloading some first visit consumables to the crew lander, rather than carrying them on the unmanned FLO, which currently burdens all consumables necessary for the first 45 day stay against the habitation system mass, was investigated. Since this mass must be brought by the second crew to sustain their visit, the crew lander and surface operations must be designed to accommodate these items. Depending upon manifest needs, the first crew could also bring a substantial amount of their initial supplies. In fact, most of the consumables are only needed by the crew (food, etc.), or can only be utilized by the crew (internal spares/expendables, etc.), with the exception of make-up gas, which has not yet been fully burdened for unmanned operations. If crew-specific items only, were off-loaded from the habitat, including food, clothing, EMU expendables and spares, CHeCS supplies, personal hygiene articles, operations gear, and off-duty items, 1238.9 kg of consumables could be removed from the habitat system mass. A consumables Stowage Volume study contained elsewhere in this report, discusses current volume estimates, and the need for significant additional investigation into this potentially enhancing area of operations modifications.

4.2.9 Deferral of Full Power Capability Until Arrival of First Crew

The reference FLO lander/habitat employs external systems which automatically deploy and activate after the habitat comes to rest on the lunar surface. Means of reducing the requirements on the various deployment systems have been examined. A heat pump augmented radiator system reduces radiator size, allowing it to be pre-integrated without deploying, or at least significantly decreasing the level of deployment required (see heat pumped vs non-heat pumped HRS trade). The fixed vs articulating solar array trade explores alternatives to the baseline deployment and tracking scheme, at the expense of the difficulties involved in deploying (either automatically or manually) a very large array. The self-activation of both internal and external systems require significant further study and development before activation methods and operations can be defined and selected. Options to the reference must consider system survival and verification both prior to each crew arrival, and after each crew departure. This trade examined the possibility of equipping the initial FLO habitat with power sufficient only for unmanned operations with the remainder of the reactants, tanks, and solar arrays brought and emplaced by the crew.

The baseline FLO dormancy average day/night power needs are 7.85 kW, and 2.525 kW, respectively, compared to the manned requirements of 13.32 kW/9.91 kW. This difference may allow some power system mass to be deferred by equipping the initial FLO for dormancy power generation only, with full power capability delivered by the first crew. Such a scheme would remove ~3100 kg (including reactants, tanks, and additional arrays) from the habitation system mass, and add it to the Crew Lander, which would also incur an additional ~100 kg impact, for added valves, lines, etc., due to the splitting of the reactants into smaller tanks for transport on the two vehicles. Crew-delivered power system augmentation supplies could be emplaced on the surface near the habitat lander, and "plugged into" the existing systems. As with the consumables offloading trade, any mass offloaded from the habitat and burdened onto the crew lander must consider the latter's own mass limitations, as well as the required surface operations to be conducted by the crew. Related studies have been conducted on this subject, and discussions are presented elsewhere in this document to aid in the selection of optimal payload splits for habitat and crew lander manifests.

4.3 SSF DEVIATION - FLO HABITATION SYSTEM TRADES

A SSF deviation study was carried out to investigate ways, independent of SSF design, to reduce current FLO baseline costs and weights by simplifying design, reducing operations, and/or proposing alternate and innovative approaches of achieving FLO mission goals. The SSF deviation study addressed alternate internal pressures, alternate materials, alternate structural configurations, alternate subsystems, and inflatable structures.

4.3.1 Alternate Internal Pressures

To arrive at an optimal pressure which satisfies FLO mission goals, the effects of operating the FLO Habitation module with internal pressure lower than the current baseline of 14.7 psia were investigated and advantages and disadvantages associated with lower internal pressures were assessed. The FLO Hab is based on SSF Hab-A which is designed and optimized for 14.7 psia and operates at the following internal pressures;

a. 14.7 psia nominal pressure-Permanently Manned Capability (PMC)
b. 10.2 psia operating pressure - Man Tended Capability (MTC).

Alternate internal pressures of 10.2, 8.0, and 5.0 psia are evaluated in this study. Typical advantages associated with lower internal pressures are;

a. Improved EVA operations by decreasing or eliminating pre-breathe requirements, decreasing decompression risk, and accommodating lower pressure suit to increase mobility and reduce fatigue.
b. Reduce leakage rate resulting in lower resupply air mass and smaller tank sizes.

Keeping O_2 partial pressure constant, a change in internal pressure results in a change in oxygen concentration as indicated, figure 4-15.

Internal Pressure (psia)	O_2 Partial Pressure (psi)	O_2 Concentration %
14.7	3.1	21
10.2	3.1	30
8.0	3.1	38
5.0	3.6	70

Figure 4-15. Variation in Oxygen Concentration

Change in O_2 concentration and pressure impacts several areas as follows;

a. Change in *Oxygen Concentration* affects
   1. Flammability
   2. EVA Operations
   3. Physiological factors
b. Change in total *pressure* affects
   1. Pressure Vessel Structure
   2. Material Outgassing
   3. Physiological Factors
   4. EVA Requirements and Operations
   5. ECLS Systems
   6. Heat Rejection System (avionics cooling & cabin air systems)
   7. Power Requirements
   8. Leakage Rate (Resupply Air Mass & Tank Sizes).

Some of these issues are discussed in the following sections.

4.3.1.1 Flammability

NASA manned program requirements state that all materials must pass NASA's Upward Propagation Flammability Test, reference 4-2. All space qualified ("A" rated) materials must pass the NASA Upward Flammability Test at or above 30% O_2 concentration. The following fact must be remembered when evaluating materials for flammability:

a. Risk of Flammability is directly proportional to Oxygen concentration
b. For a constant partial pressure of O_2, flame propagation rate increases with decrease in total pressure. This is true even with normal O_2 partial pressure

Flammability tests on frequently used spacecraft engineering materials indicate that:

a. ~ 76% of the materials tested pass at 14.7 psia / 21% O_2
b. ~ 52% of the materials tested pass at 10.2 psia / 30% O_2
c. ~ 28% of the materials tested pass at 5.2 psia / 70 % O_2
d. ~ 18% of the materials tested pass at 5.2 psia / 100 % O_2

Materials used on SSF Hab-A are qualified to approx. 30% O_2 concentration. Several high usage materials have failed the flammability test at 33% O_2, such as:

a. Polyimide foam insulation
b. Silicon rubber coating used as fire barrier
c. Fabric used in Orbiter crew uniforms
d. Outer fabric of EVA suits
e. Woven composite material used in SSF racks
f. Various paints

The results from NASA's flammability tests are shown in figure 4-16. It should be noted that flammability tests at 33% O_2 were conducted on 244 materials used in the Orbiter.

Test data indicates that a knee exists in the data at about 33% O_2 concentration. Less than 50% materials passed flammability test above 33% O_2 concentration. Materials that pass at 33% concentration usually pass at 100% as well. If an increase in O_2 concentration above 33% is desirable, material re-qualification and/or extinguishing methods must be investigated.

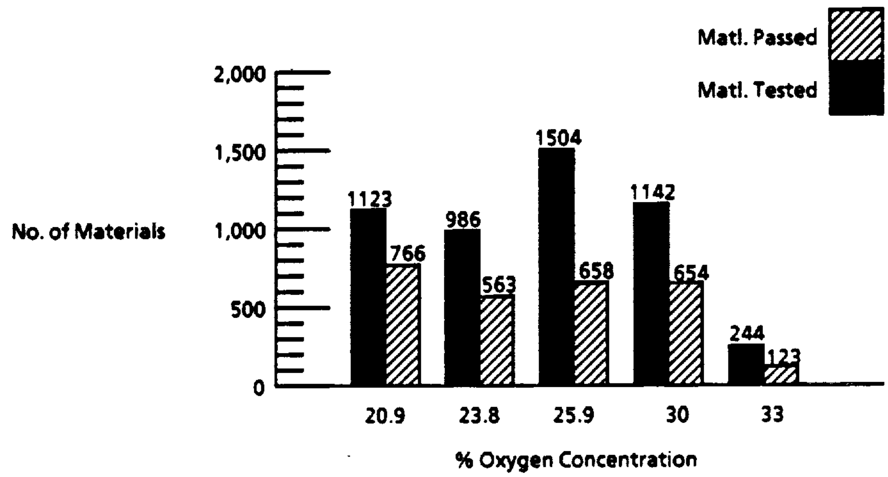

Figure 4-16. NASA Flammability Test Results

4.3.1.2 Toxic Outgassing due to lower pressure

The SSF Materials and Processes Group was consulted on the issue of outgassing due to reduced pressures. It was pointed out that:

a. Material outgassing is roughly the same at any internal pressure being considered (14.7, 10.2, 8, or 5.0 psia). Significant increase in outgassing does not occur until near-vacuum pressures are reached. Pressure as low as 0.5 psia will be sufficient to keep the outgassing problem under control (dictated by gas theory). Major outgassing will be produced only when there is complete vacuum (dictated by theory of molecular dynamics).

b. At lower internal pressures, normal outgassed products form a larger percentage of atmosphere. Contamination control system may require redesign and/or increased maintenance to cope with higher concentration

c. As internal pressure goes down, outgassed products become difficult to scrub.

Outgassing was not considered to be a major concern. A more thorough investigation of all of the materials involved must be carried out before a final conclusion on outgassing is arrived at. Materials must be selected such that outgassed products (especially at higher concentrations) do not increase flammability (volatiles) or toxicity risks. SSF is presently examining the impact of new 180-day hard vacuum requirements (operations and survivability). Results of this study may affect design and material selection of SSF Hab.

4.3.1.3 Structures

SSF hab structural sizing is not a function of internal pressure only. Skin sizes are primarily driven by Space Shuttle launch/landing loads and by LEO meteoroid/debris shielding requirements. Minimum required skin thickness for the SSF hab module is 0.125 in. Longerons and rings are designed to carry launch/landing loads as well as localized rack loads.

Lunar surface has no man made debris protection requirements. Meteoroid and secondary ejecta requirements are also different than those in LEO. Structural analysis may be performed to resize the skin with lunar launch loading, FLO pressures, and lunar particle/meteoroid shielding requirements. There is a potential of up to 200kg mass savings.

4.3.1.4 Summary

As a result of reduced internal pressures, EVA operations and module leakage rates are improved; however, physiology, flammability, and power system concerns require additional work.

4.3.2 Alternate Materials

In order to optimize weight, a preliminary investigation was carried out to find alternate materials for FLO hab module primary and secondary structures. State-of-the-art metallic, non-metallic composite, and hybrid metal-matrix composite materials were reviewed as a replacement for materials currently used on SSF Hab-A. included in this review were aluminum-lithium, titanium, graphite/epoxy, boron/epoxy, silicon-carbide/aluminum, silicon-carbide/titanium etc. Candidate materials selected for final evaluation were;

a. Metals - aluminum-lithium
b. Non-metals - graphite/epoxy composite
c. Hybrid - silicon-carbide/aluminum metal-matrix composite.

The current FLO Hab structure is based on SSF Hab-A. Materials used on the SSF Hab-A primary and secondary structure are summarized to establish a baseline for investigation in figure 4-17.

Part	Material	Weight (kg)
Cylinder Skins	2219-T87 Al	1542
End Cones	2219-T87 Al	1113
Longerons	2219-T87 Al	347
Fittings	7075-T73 Al	217
Stand-Off	7075-T73 Al	1042
M/D Shield	6061-T6 Al	747
Racks	Gr/Epoxy Comp	2308

Figure 4-17. SSF Structural Materials

4.3.2.1 Material Selection Criteria

Material selection for space applications is based on the following criteria:

a. Higher specific strength
b. Higher specific modulus
c. Fatigue and damage tolerance characteristics
d. Corrosion resistance properties
e. Degradation due to temperature extremes and thermal cycling
f. Fabrication and weldability
g. Flammability characteristics in O_2 rich environment
h. Toxicity and outgassing characteristics for livable areas
i. Resistance to UV and other types of radiation
j. Inspection and maintainability
k. Design, Development, Test, and Evaluation (DDT&E) costs
l. Miscellaneous environmental effects

4.3.2.2 Metals - Aluminum-Lithium

a. Advantages. Advantages of aluminum lithium (2090/8090, or Weldalite 049) are as follows;
   1. Fully commercialized alloy, readily available (listed in MIL-HDBK 5F)
   2. 8% to 10% lower density than other aluminum alloys
   3. 10% higher modulus than other aluminum alloys
   4. Higher corrosion resistance properties
   5. Excellent weldability
   6. Comparable fatigue and damage tolerance properties
   7. Superior high temperature strength
   8. Currently used in aerospace applications (A330/340, C17, Atlas, Titan)
   9. Direct replacement for currently used aluminum alloys

4.3.2.4 Hybrid Materials - Silicon-carbide/Al Metal Matrix Comp.

a. Advantages

1. Space qualified material available (currently being used on NASP and ATF)
2. Higher specific strength than aluminums (almost 300% higher)
3. Higher specific modulus than aluminum alloys (up to 300% higher)
4. Density equivalent to aluminum (0.103 lb/cu. in.)
5. Strength and stiffness retained at elevated temperatures (up to 500 deg F)
6. Strength can be tailored to desired load paths by orienting the fibers
7. Superior fatigue strength over aluminum alloys
8. Welded joints are possible (but weld strength of that of baseline aluminum)
9. Corrosion resistance properties comparable to baseline aluminum material
10. No outgassing concerns
11. Overall weight savings of over 30% over current materials

b. Disadvantages

1. Relatively new technology - lacks a comprehensive data base for space applications
2. Redesign of FLO hab structure required
3. Requalification of the structure required
4. New tooling to be developed
5. Long term space application effects not understood as of today
6. Thermal/mechanical cycling effects due to mismatch in thermal expansion coefficients between matrix and fiber need to be investigated
7. Radiation, outgassing, and flammability qualification testing required
8. Higher costs of Design, Development, Test, and Evaluation

4.3.2.5 Conclusions

Of the three candidates, aluminum-lithium appears to be the most desirable alternate material for FLO structure for the following reasons;

a. Commercially available
b. A direct replacement for 2219 and 7075 aluminum
c. Requires minimum DDT&E
d. Current tooling applicable
e. No impact to schedules
f. Lowest cost alternative

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4.4 INFLATABLE STRUCTURES

An investigation was carried out to study the feasibility of using inflatable structures for space applications. The study included the history and past experiences, inflatable structure design concepts, materials used, and feasibility of inflatable structures in lunar environments.

4.4.1 Advantages and Potential Applications

Typical advantages of using inflatable structures are that large volumes may be launched in smaller packages and a possible weight saving depending on application. Inflatable structures may be utilized for the following applications;

a. Living and storage areas
b. Airlocks
c. Landing aids
d. Connecting tunnels
e. Surface enclosures for thermal and dust protection
f. Antennas
g. Insulation of cryogenic or other temperature critical materials
h. Hyperbaric chambers
i. Other structures (radiator or solar panel support, landing area, debris shields and emergency shelters etc.)

4.4.2 History of Inflatables for Aerospace Applications

The concept of using inflatables for space applications has been around since mid sixties. An exhaustive literature search revealed the following aerospace related applications of inflatable structures. Most of these applications were never realized.

a. Lunar shelter developed by Goodyear Aerospace Corp. (GAC) in 1965. To support a crew of two for 8-30 day periods with radiative thermal control and micrometeoroid protection. The shelter was 7 ft in diameter and 15 ft long and constructed of nylon/vinyl foam/nylon sandwich. Total weight of the shelter-148 kg.
b. Apollo Lunar Stay-Time Extension Module - hab volume addition, 1965
c. Airlock developed for U. S. Skylab by Goodyear Aero. Corp (GAC), 1967 5.2 ft diameter, 6.2 ft long airlock was developed through a joint NASA-DOD venture, constructed of composite bladder, steel wire structure, polyurethane foam micrometeoroid barrier, and fabric film laminate thermal coat. Total weight -85 kg.
d. Space habitat developed by GAC in 1968. A prototype of a 110 ft habitat was developed. Prototype, dubbed "Moby Dick" was 12.8 ft in dia. and 37.5 ft long. It was

made of Dacron bladder sealed with PVC foam. The entire structure was covered with polyurethane foam and covered with thermal controlled nylon film-fabric laminate. Total weight 737 kg.

e. Shuttle/Spacelab connector tunnel fabricated in 1979 by GAC. 4 ft dia., 14.2 ft long flexible tunnel between Orbiter's crew cabin and the Spacelab module was constructed using Nomex fabric coated with Viton B-50 elastomer wrapped around steelbeads. Debris shield was constructed of Kevlar 29. Total weight 344 kg.

f. GAC and LaRC research including Toroidal Space Station.

g. Soviet developed airlock demonstrated in Mar 1985 on Vostok 2 spacecraft.

4.4.3 Available Materials and Construction

Inflatable structure for space application are constructed in layers. A multi-layered base material (fabric) is the member carrying all the pressure loading. An elastomer coating or a layer of vinyl is applied to seal the base material. Steel wire or another form of expandable structure is provided to act as reinforcement. Thermal protection is provided by a thermal control coating or a layer of thermal controlled fabric. Micrometeoroid/debris protection is achieved by using an outer layer of foam or Kevlar. The following materials have been used in the past or have a potential for use in the construction of an inflatable aerospace structure;

a. Base Material
   1. Nomex fabric coated with an elastomer
   2. Nylon layered with vinyl foam
   3. Dacron fabric coated with PVC foam
   4. Kevlar 29 or Kevlar 49 coated with an elastomer

b. Reinforcement
   1. Steel wire
   2. Composite framework

c. Thermal protection:
   1. Thermal controlled film fabric
   2. Thermal controlled paint

d. Meteoroid Protection:
   1. Kevlar
   2. Polyurethane/vinyl foam

4.4.4 Disadvantages and Concerns Regarding FLO Application

Disadvantages and concerns regarding the use of inflatable structures for FLO specific applications are as follows:

a. Subsystem integration must be performed after or during inflation process
b. Internal support structure may have to be assembled on lunar surface
c. Greater DDT&E required due to unique application (impacts cost/schedule)
d. Inflation of structure may be complex operation. Difficulty in complying with campsite autonomous deployment and subsystem deployment and activation requirement, for example;
   1. Access to equipment
   2. Time required for deployment and system checkout
e. Limited commonality with SSF and other existing hardware
f. Integration of exterior systems with inflatable structures
g. Flame resistant properties of inflatable structural materials
h. Particle impact shield requirements (micrometeoroid and lunar surface ejecta)
i. Life of structural materials in lunar environment
j. Outgassing of toxic materials into habitable areas
k. Checkout and test of subsystems prior to launch

4.4.5 Simplified Comparison of Inflatable vs. Aluminum Structure

For evaluation purpose *Kevlar 29* was chosen as the inflatable material and a direct mass comparison with aluminum was performed.

a. Density - Kevlar(k) is 50% lighter than Aluminum(A)

$$\rho_{kevlar} = (0.50 * \rho_{Alum})\ kg/m^3$$

b. Strength - Kevlar is 67% stronger than Aluminum

$$\sigma_{kevlar} = (1.67 * \sigma_{Alum})\ Pascals$$

c. Thickness - Skin thickness(t) required based on purely internal pressure loading

$$t_{kevlar} = (0.60 * t_{Alum})\ mm$$

d. Mass - For same pressure loading and internal volume, an inflatable structure mass ($m_{inflatable}$) in terms of aluminum (m_{Alum}) would be

$$m_{kevlar} = (0.30 * m_{Alum})\ kg$$

$$m_{inflatable} = m_{kevlar} + m_{misc.} = m_{kevlar} + 1.0 * m_{kevlar}$$

$$m_{inflatable} = (0.30 * m_{Alum}) + 1.0 * (0.30 * m_{Alum})$$

$$m_{inflatable} = 0.60 * m_{Alum}\ kg$$

where,

$m_{misc.}$ is the sealant/coating and secondary support structure mass.

The above relationships show a 40% mass savings over aluminum structure. It must be noted that launch loads and packaging for inflatables have not been considered in this analysis. Actual mass savings may be less than 40%.

4.4.6 Conclusions and Recommendations

In order to establish the usefulness and advantages of inflatable structures for FLO, further research is required. Since the early applications of 60's and 70's, materials technology as well as analysis methodology and computing power has greatly increased. Inflatable structures have potential for use in the lunar environments. More research, and testing is required to space qualify the newer materials. New requirements for FLO must be established that would reflect the use of inflatables. Following remarks are based on the technology used on previous applications;

a. First Lunar Outpost requirements of self deployment and use of SSF derived hardware will make using an inflatable habitat difficult.

b. Inflatable structure DDT&E costs may be higher than a metallic structure.

c. Chemically rigidized structures offer advantages but could impose added mass and complexity. They will need further investigation.

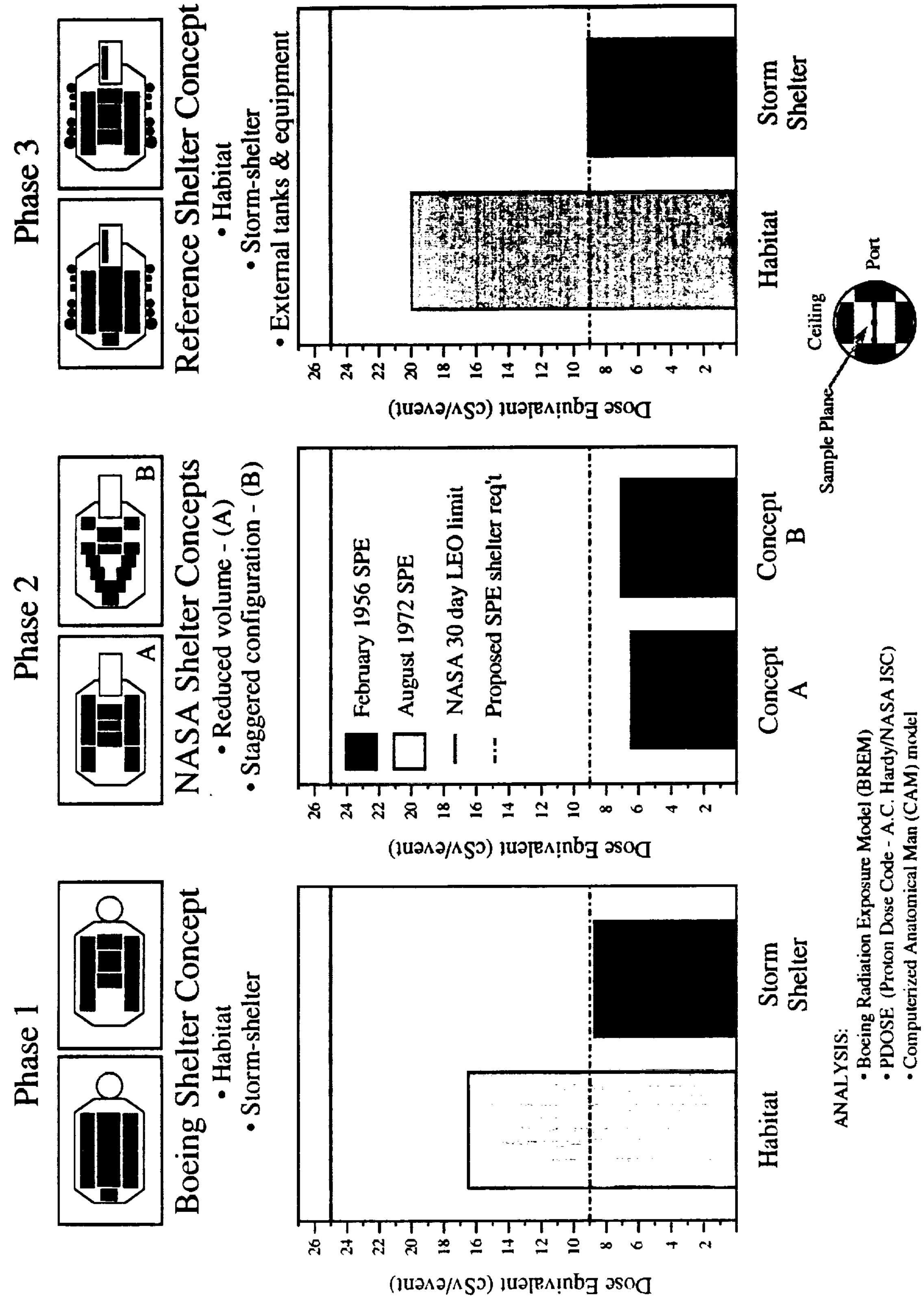

Figure 5-1. Solar Proton Event Radiation Analysis Results, Blood Forming Organs

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5.2.1 Natural Radiation Environment Models

Storm-shelter analyses were completed by estimating the exposure resulting from three large reference Solar Proton Events (SPEs). During the course of the roughly eleven year solar cycle, several tens of solar flares will produce sufficient energy to release elevated charged particle fluxes. Historically, an average of 2 to 4 flares per cycle release tremendous amounts of energy and particles and are classified as Anomalously Large Solar Proton Events (ALSPE). The cumulative fluence resulting from proton events during the solar cycle are dominated by the occurrences of ALSPE. Large solar proton events can deliver debilitating or lethal doses to unprotected astronauts.

Three such ALSPE were used in the FLO analyses; the February 1956, August 8, 1972, and October 19, 1989 events. All three are considered reference events and each has unique spectral qualities. Unlike the Earth, which has an atmosphere and intrinsic magnetic field, the Moon has no natural radiation protection other than its own shadowing effect. Therefore the free space radiation environment proceeds unhindered to the lunar surface over the upper hemisphere. The free-space differential flux of the reference events have been reduced by a factor of 2 to account for the 2π shielding provided by the mass of the Moon. A comparison between the cumulative differential proton spectra is provided in figure 5-2.

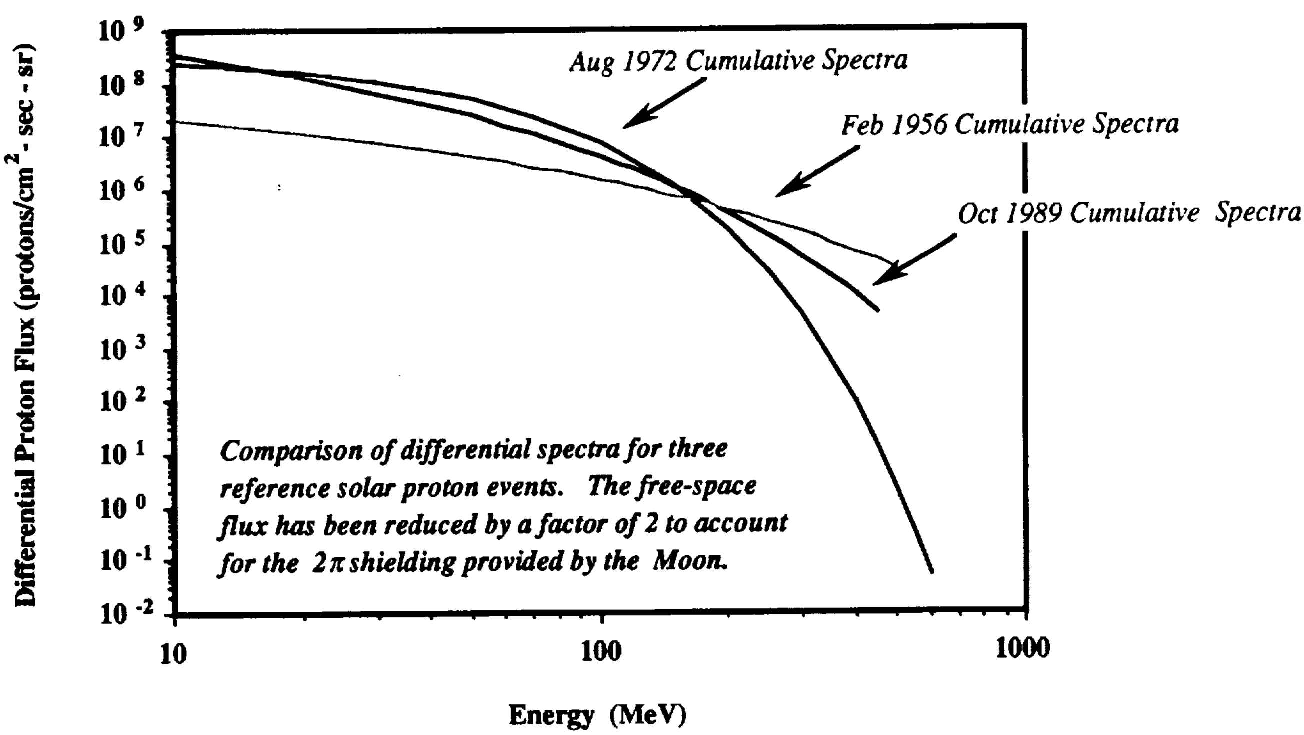

Figure 5-2. Differential Lunar Spectra Comparison, Feb '56, Aug '72, Oct '89 SPE's

5.2.2 The Boeing Radiation Exposure Model

FLO analyses were performed using BREM. BREM combines Computer Aided Design (CAD) capabilities with established NASA transport codes. Complete detail descriptions of BREM and its applications have been reported previously in a number of final reports and contributed papers, reference 2-3.

Transport analysis was performed using PDOSE (Proton Dose code developed by A.C. Hardy; NASA/JSC) PDOSE has adopted a continuous slowing down approximation to calculate the attenuation and propagation of particles in various shield materials. Secondary particles generated by nuclear interactions are ignored in PDOSE. Results from PDOSE have been extensively compared against Shuttle measurements by NASA's Radiation Analysis Group, JSC, and has been found to be fairly accurate. Organ dose calculations were performed using a detailed mathematical anthropomorphic phantom called the Computerized Anatomical Man model (CAM). CAM provides a more realistic shield distribution for the blood forming organs, ocular lens and skin rather than the simple (and conservative) water sphere geometry. PDOSE uses quality factors from ICRP-26 to calculate dose equivalent results.

5.2.3 Solid Modeling

One of BREM's attributes is its use of CAD technology to produce the spacecraft shield distribution, providing savings in time and cost, and increasing functionality and accuracy. BREM has been developed so that engineering data bases created by design groups can be accessed to provide an accurate solid model, thereby avoiding the need to duplicate modeling efforts. As was the case with FLO, detailed engineering Space Station solid models were used to perform habitat analysis.

5.3 ANALYSIS RESULTS

Crew dose and dose equivalent quantities have been determined as a result of simulated exposure to the previously noted reference solar proton events. The purpose of the study was to estimate exposure to astronauts for early lunar missions and make comparisons of these results with current NASA limits. The National Council on Radiation Protection and Measurements (NCRP) has recommended career, annual and monthly limits for NASA to use in planning manned missions. These limits are shown in figure 5-3. The limits presented have been established for missions taking place in Low-Earth-Orbit but have been adopted by NASA for planning early lunar missions. The 30-day and annual exposure limits are based on considerations of deterministic effects, whereas career limits are based on an increase in cancer mortality of three (3) percent. Re-evaluation of the LEO 30-day and annual limits has yielded no change, however, the new career dose equivalent for both male and females has been reduced by as much as a factor of two. The higher limits given to astronauts are based in part on risk versus gain and a relative comparison to other potential mission risks such as vehicle system failure. The results of the analysis have been presented previously in figure 5-1 where they can be compared to previous shelter options evaluated in TD-11.

All values presented in cSv - (cSv = rem)

Time Period	BFO*	Lens of Eye	Skin
30 day	25	100	150
Annual	50	200	300
Career	See table below	400	300

* Blood forming organs. This term has been used to denot the dose at a depth of 5cm

Career whole body dose equivalent limits based on a lifetime excess reisk of cancer mortality of 3%

Age (years)	Female	Male
25	100	150
35	175	250
45	200	320
55	300	400

* Data from Guidance on Radiation Received in Space Activities, NCRP Report No. 98

Figure 5-3. NASA Limits

Analysis was performed using modified Space Station engineering solid CAD models. Degradation of the proton spectrum is a function of the spectral characteristics and the thickness and composition of the material traversed. To determine the shield distribution, VECTRACE divides the solid angle surrounding the detector into a number of equal solid angles. For this analysis 512 were used to determine the habitat shielding. Radiation transport is performed following the conversion of all materials to an equivalent aluminum form. A list of materials used in building this model is provided in figure 5-4. Conversions of these materials to equivalent aluminum is based on the ratio of stopping powers for a 50 MeV/nucleon proton of the defined material and aluminum. Rack densities were assigned in accordance with individual rack mass and volumes specified in figure 5-5. Utility stand-offs, ducts, fluid lines, and cabling were modeled in the same manner as the racks. In phase 3, the radiation analysis was performed taking into account external equipment and tanks. The external equipment modeled is shown in figure 5-6.

Rack Volume = 1.872 m^3

Rack Location	Mass (kg)	Density (g/cm^3)
C1	443.4*	a
C2	662.2*	b
C3	356.8	0.190
C4	588.9	0.314
C5	446.9	0.238
S1	428.2∞	0.223
S2	864.4	0.455
S3	330.4	0.171
S4	1019.8	0.539
S5	450.2	0.235
F1	444.9	0.232
F2	655.6	0.344
F3	418.8	0.218
F4	562.3**	c
F5	800.2	0.427
P1	669.1∞	0.357
P2	314.0	0.162
P3	410.6	0.219
P4	340.3	0.181
P5	428.1	0.228
E1	193.8	0.103
Depress	222.1	0.474
CL	192.8	0.352

* Includes 105 kg water
** Includes 360 kg food
∞ Includes 208 kg for EMU stowage

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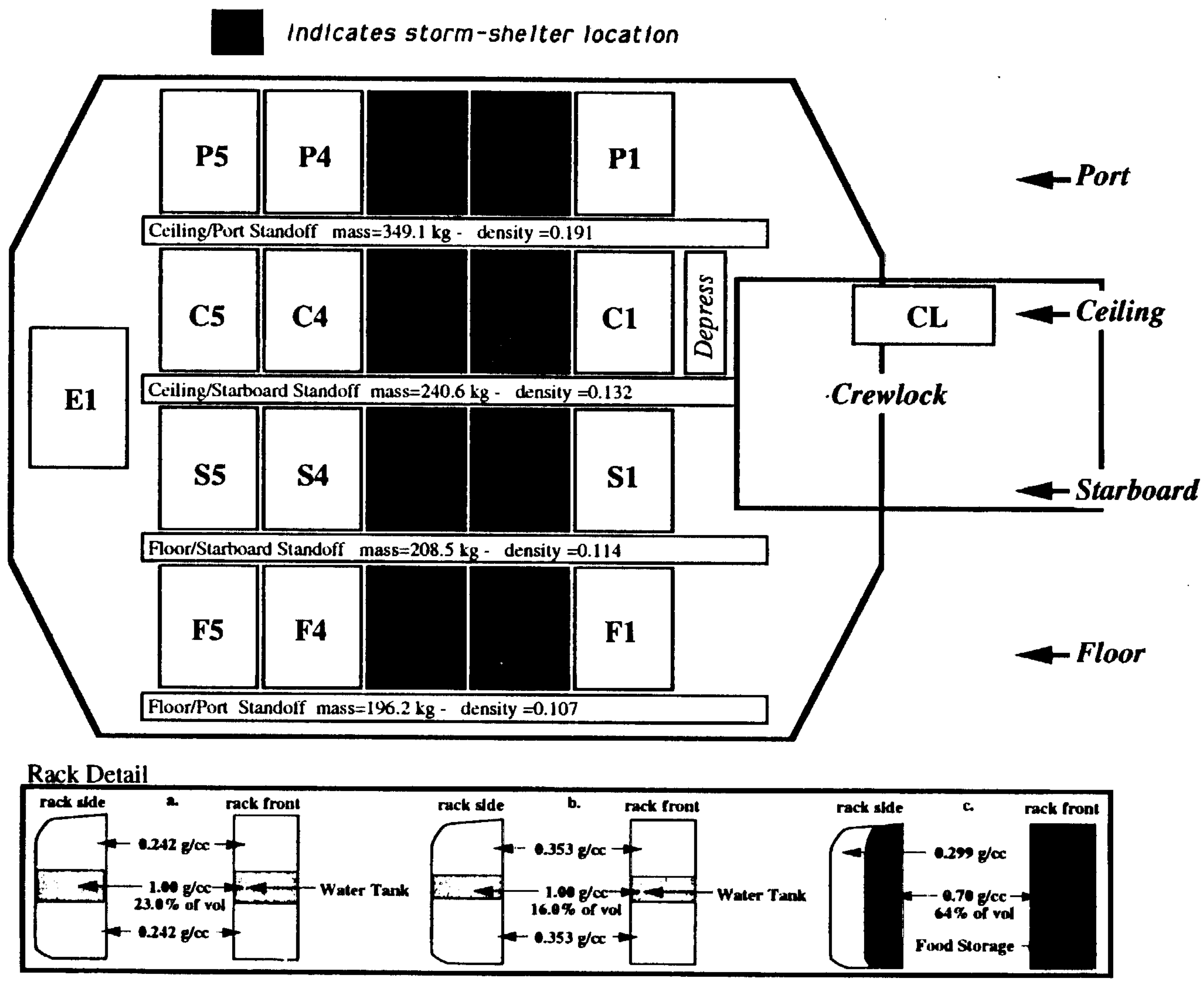


Figure 5-5. Rack Densities

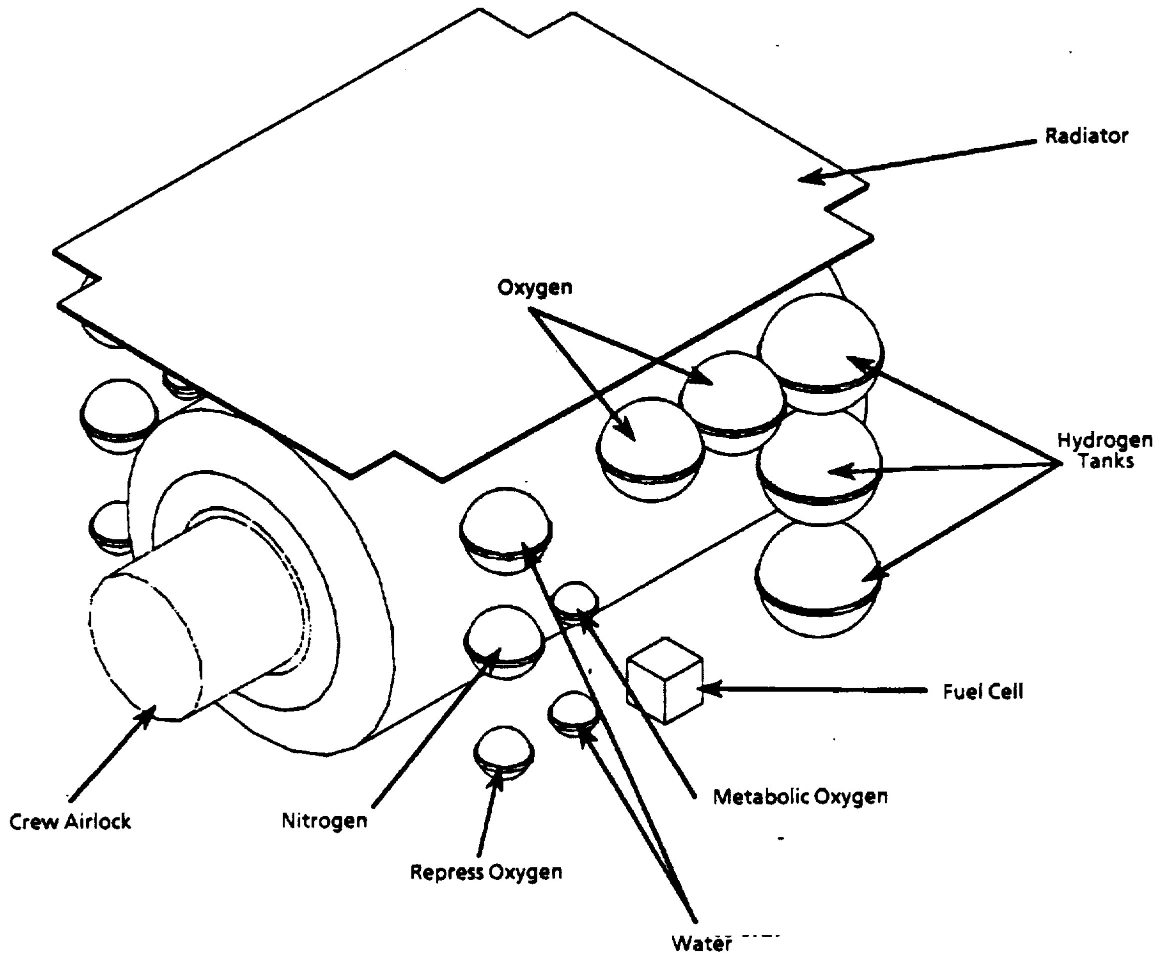


Figure 5-6. Radiation Analysis Model Exterior ACS020

120 MeV. The smallest reduction in the spectra occurs for the February 1956 SPE. As noted in the results all maximum doses recorded within the storm-shelter to the blood forming organs were the result of exposure to this event. However, the largest dose equivalent to the skin inside and outside the storm-shelter was the result to exposure from the August 1972 SPE. The higher energy nature of the February 1956 event allowed particles to penetrate deeper into body even with additional storm-shelter shielding. Integrating over the 4π solid angle about the detector point, the cumulative transmitted spectrum at the dose point is produced. This flux is then assumed to be isotropic and is then transmitted through the organ distribution. Any orientational effects of the astronaut relative to the spacecraft shield distribution are removed.

The dose equivalent results of the analysis are show in figure 5-11 for the blood forming organs and the skin. The current 30-day limits for the BFO (25 cSv) and skin (150 cSv) are indicated on each of the graphs. In addition, 9 cSv (described as a Proposed

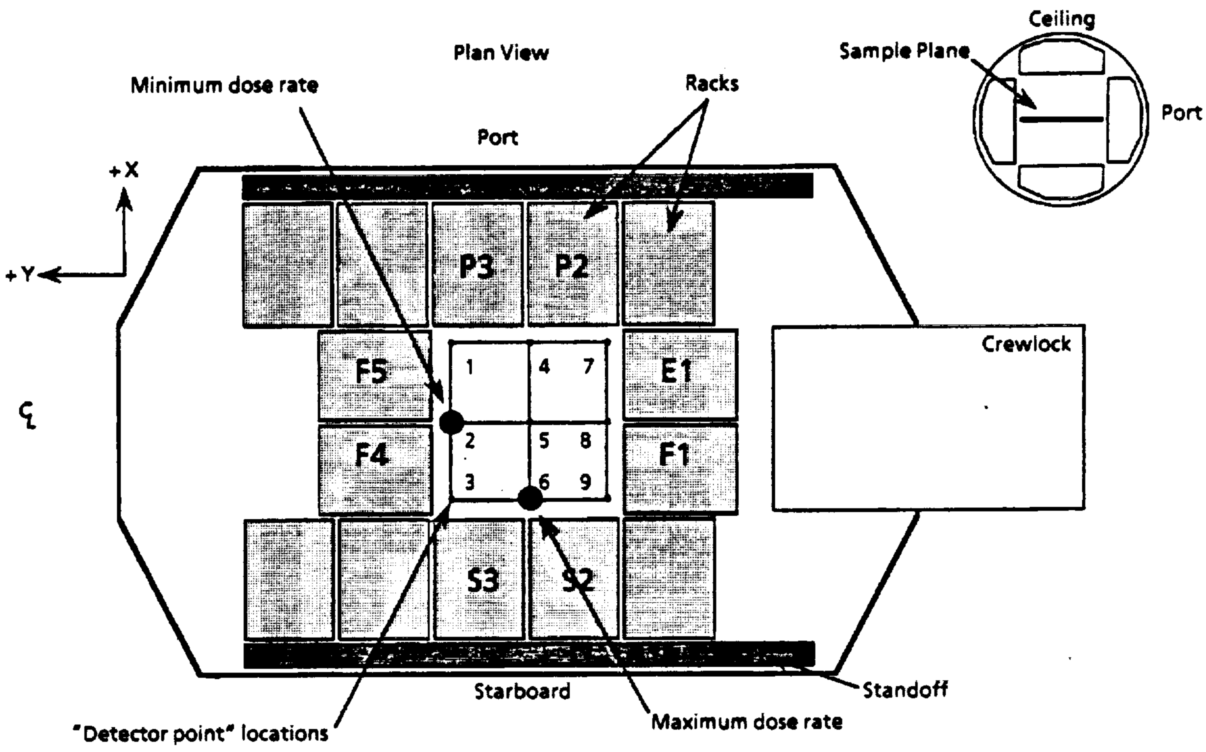
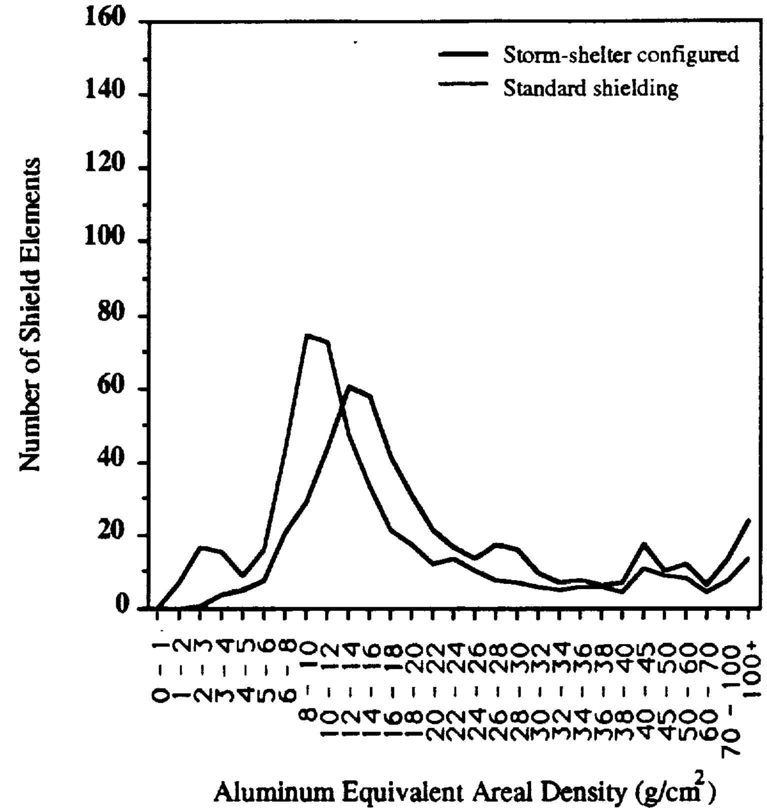


Figure 5-8. Lunar Habitat Radiation Storm-Shelter Configuration ACS021

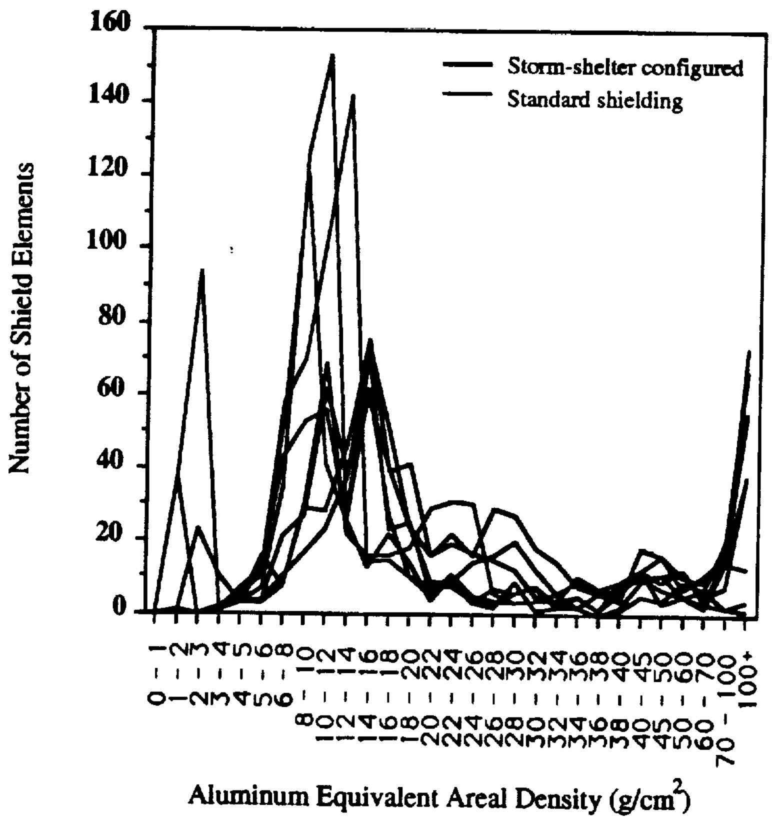
the protection method employed within the habitat should use as much on-board equipment and mass as possible.

Astronauts realize a great advantage in being on the surface of the Moon. Even though the radiation environment is the same as that found in free-space and proceeds unhindered to the lunar surface from the upper hemisphere, the isotropic flux of both galactic cosmic and solar proton event radiation can be reduced by a factor of two due to the shadowing effect of the Moon itself.

Although the results are less than the current recommended limits for the BFO and skin, they should not be misinterpreted. There still remains a large number of uncertainties regarding the determination of crew exposure. The fundamental causes of these uncertainties include, transport theory, nuclear cross-section determination, and environment modeling. As a result , exposures can potentially be in error by as much as a factor of two (2). Additions to the exposure will come from trapped particles during lunar and Earth transfers, the occasional "ordinary" solar proton events, galactic cosmic radiation and its generated secondary particle effects, and man-made sources such as small reactors. Protection of the astronaut will vary during the course of the mission from the relative safety of the habitat to the protection provided only by a space suit during EVA.

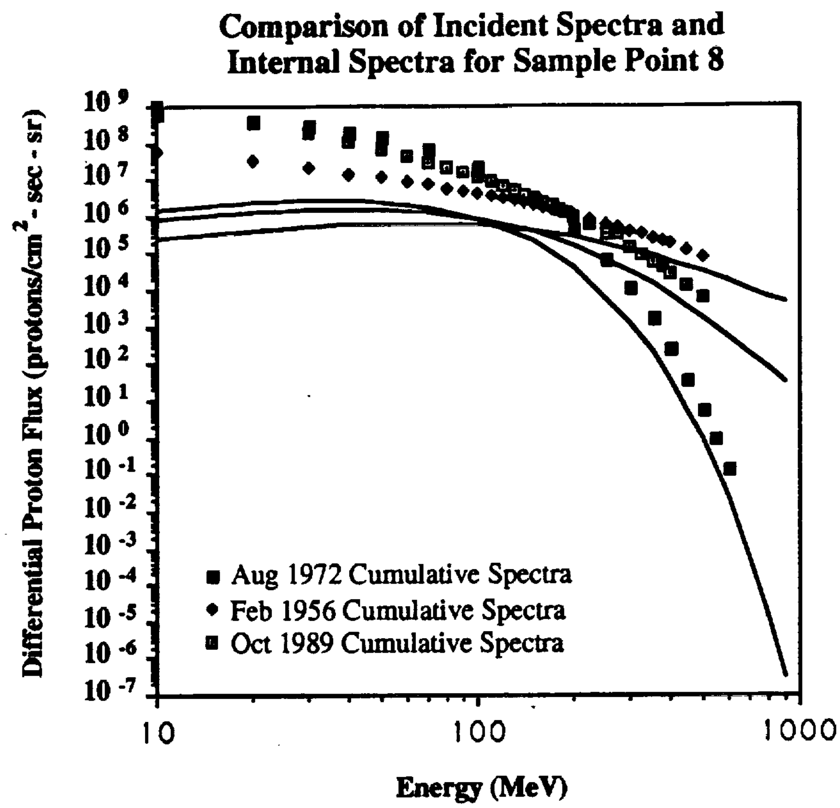


Comparison of Average Shielding With and Without Storm-Shelter



Differential Shield Distribution for Longitudinal Sampling Locations

Figure 5-9. Equivalent Aluminum Differential Shield Distribution



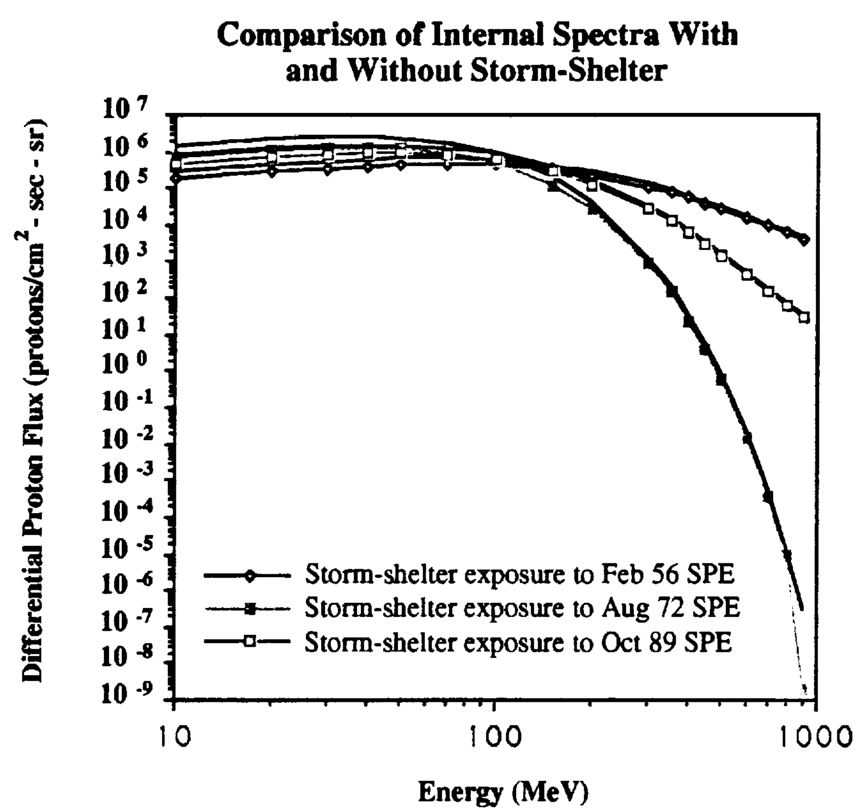


Figure 5-10. Differential Incident and Calculated Internal Spectra

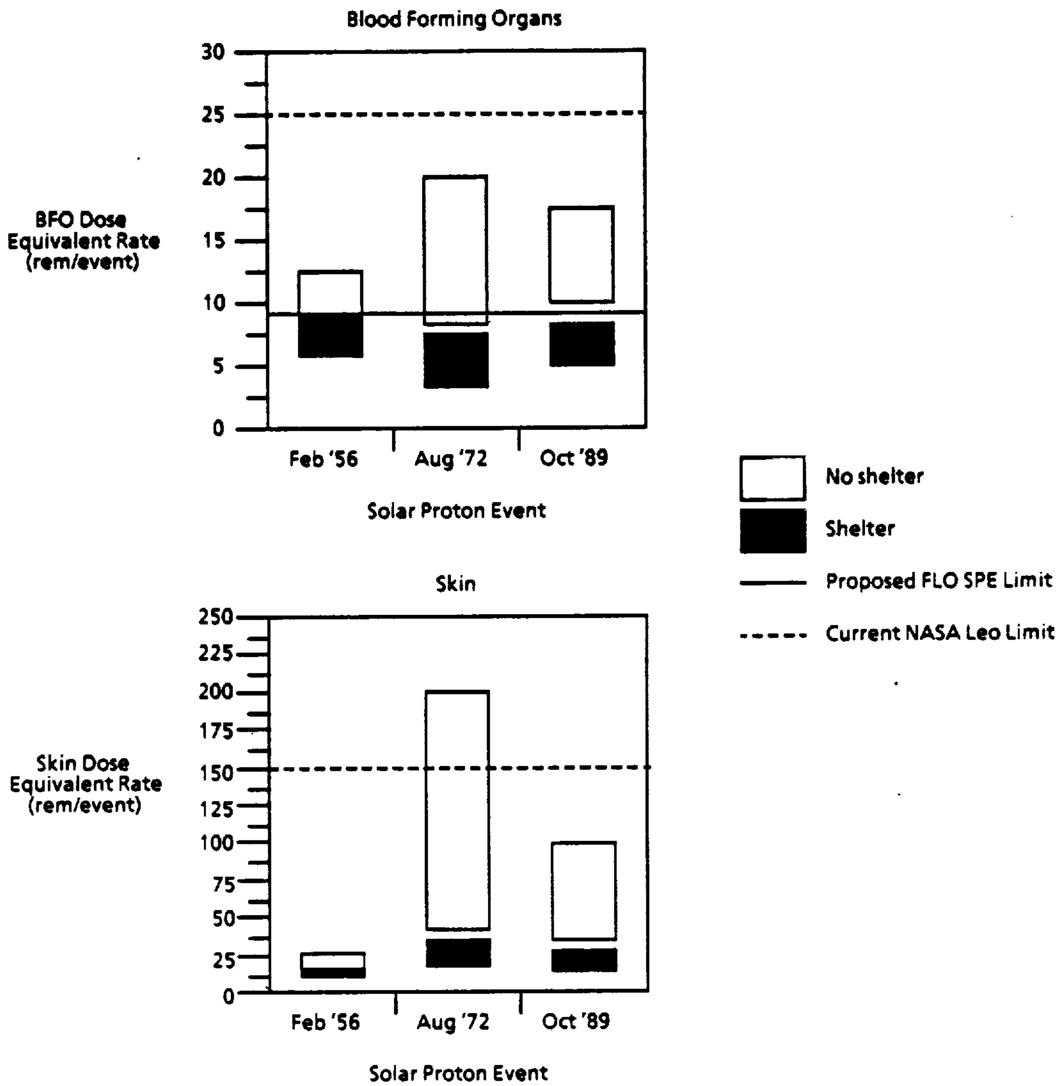


Figure 5-11. Analysis Dose Equivalent Results

Finally, the use of an on-board active SPE warning system is seen as a critical need. SPE warning and detection will be the result of solar X-ray telescope that continuously monitors the visible solar disk. In addition SPE detection and warning, crew dosimeters will be used to warn of solar proton event exposure concerns. Two threshold dose rates are needed with such a detection and warning system. The first threshold warns of an enhanced proton flux that is tied to a detected solar flare and the second threshold dose rate warns the of the criticality they face in seeking enhanced shielding. The first threshold has been established to remove the problem of false alarms, the second to provide maximum protection for crew. It is critical that work in determining solar proton event propagation and cumulative dose versus time continue.

6.0 RESUPPLY AND LOGISTICS

6.1 INTRODUCTION

At present the plan for surface operations begins with the Outpost lander containing all the expendable items for the first 45 terrestrial day mission on board. The first manned mission proceeds using these on-board expendables with a rover brought on the manned vehicle. The rovers, this one and one brought on the subsequent mission is an LOR unpressurized rover with improved drive train and tires. They are capable of carrying 4-crew or 2-crew and 500 kg packaged material in a towed cart. Their maximum speed is 8 km/hr against a target (around obstacles to a specific point).

The second manned mission brings the next crew plus 5 t of resupply for a nominal 38 day surface mission staytime. The supplies stored both internally and externally are given in figure 6-1. The second mission lander is to land approximately one kilometer away from the FLO. All these expendables are to be transported to the FLO area for storage either internally or externally. The first set of transported items will be those that are deemed critical and cannot take external storage, such as canned or moist food, CHeCS (medical), some personal hygiene and necessary clothes, EVA expendables and dust control (approximately 500 kg total) and critical externally stored items such as repressurization gases (they come carted ready for transport). These critical stores are shown in figure 6-2. Other supplies will be brought to the Outpost and stored externally until needed. These supplies will be brought in as a regular part of the normal operations, reducing the need to expend additional airlock repressurizations specifically to get supplies. The amount of supplies were limited to the available volume for storage in the habitat, about 6.5 cubic meters. (This is less than the 9 cubic meters of supplies in an early NASA estimate.)

Currently it is estimated that each manned mission will land with no less that ten terrestrial days of sunlight before the lunar night (to ensure the correct angle of sunlight for landing and avoiding obstacles). The first manned transport done on each mission is currently scheduled to be with Shuttle IVA suits. The normal lunar EVA suit will be good for eight hours of external operations for each surface venture and needs to be refurbished before each excursion.

6.2 SMALL PACKAGE LOGISTICS

With this information the surface mission timelines is given in Appendix E for both a single EVA operation of two crew on the surface and two in the habitat and a double EVA operation of all four crew on the surface for eight hours of operations. It is during this time that all supplies are transported and stored or attached and all external science has been deployed on the surface. The logistics flow is illustrated in figure 6-3. The

	A	B	C	D	E	F
1	Outpost Resupply Packaging					6/9/92
2						
3			Mass (kg)	Volume (m^3)	# Packages	Package Volume
4	Interior	Food	360.0	0.58	7.2	0.08
5		Clothing	245.0	1.77	4.9	0.36
6		Galley Supply	103.0	0.34	2.1	0.17
7	ECLSS	ARS	20.6	0.05	0.4	0.12
8		WRM	129.4	0.22	2.6	0.09
9		WM	11.0	0.10	0.2	0.46
10		THC	10.0	0.03	0.2	0.13
11	EMU	Expendables	166.3	0.72	3.3	0.22
12		Spares	74.8	0.31	1.5	0.21
13		Dust Control	97.0	0.67	1.9	0.35
14		CHeCS	80.0	0.50	1.6	0.31
15		Pers. Hygiene	45.8	0.21	0.9	0.23
16		Operations	182.8	0.43	3.7	0.12
17		Off Duty	84.2	0.19	1.7	0.11
18		Maintenance	113.2	0.14	2.3	0.06
19		Science	50.0	0.16	1.0	0.16
20	Exterior	N2 make-up	259.0	0.67	5.2	0.13
21		O2 make-up	119.8	0.26	2.4	0.11
22		Met O2	185.4	0.15	3.7	0.04
23		Eva sub. water	167.6	0.16	3.4	0.05
24		Science	2390.0	7.96	47.8	0.17
25		Spares	17.0	0.09	0.3	0.26
26						
27						
28						
29	# Packages					
30	Total resupply volume		83.6			
31	Total resupply mass		14.5			
32	Package Mass (ea.)		4911.9		Note: shaded area not included	
33	Avg Package Volume, m^3		50.0		in packaging estimates	
34	# Interior packages		35.5			
35	Interior package volume		6.4			
36	Interior package mass		1773.13			
37	Exterior resupply volume		9.3			
38	Exterior resupply mass		3138.8			

Figure 6-1. FLO Resupply Packaging

single EVA requires eleven days of operations to complete all resupply and deployment tasks; the double EVA requires seven days. Pie charts were developed for the total (all suit usage) available EVA task time over the life of the mission using single EVAs, except as noted and double EVAs. For a single EVA of two crew per EVA, 21.4% of the available EVA time is devoted to storage, figure 6-4. These data can be compared to using a double EVA of all four crew outside at one time in which case 15.7% of the available EVA time is devoted to resupply, figure 6-5.

Note: All Sets use a 500kg capacity cart for transport

First Package Set:

Item	Mass	Volume	# of Packages
Food*:	260.0 kg	0.42 m^3	5.2
CHeCS:	80.0 kg	0.50 m^3	1.6
(1/4) EMU resupply:	84.5 kg	0.43 m^3	1.7
Personal hygiene:	45.8 kg	0.21 m^3	0.9
(1/12) clothing:	29.7 kg	0.21 m^3	0.6
Total:	500.0 kg	1.93 m^3	10.0

* food consists of moist, canned goods (temperature sensitive) or frozen food; dry goods come in the third set

Second Package Set: Make up Gases -

Nitrogen	259 kg	
Oxygen	120 kg	
Total:	379 kg	+ connection hardware

Third Package Set:

Metabolic Oxygen	185.4 kg	
EVA Sublimator Water	167.6kg	
Subtotal	353.4 kg	+ connection hardware
+	100 kg dry food	
Total:	453.4	+ connection hardware

Figure 6-2. Critical Items for Early Transport

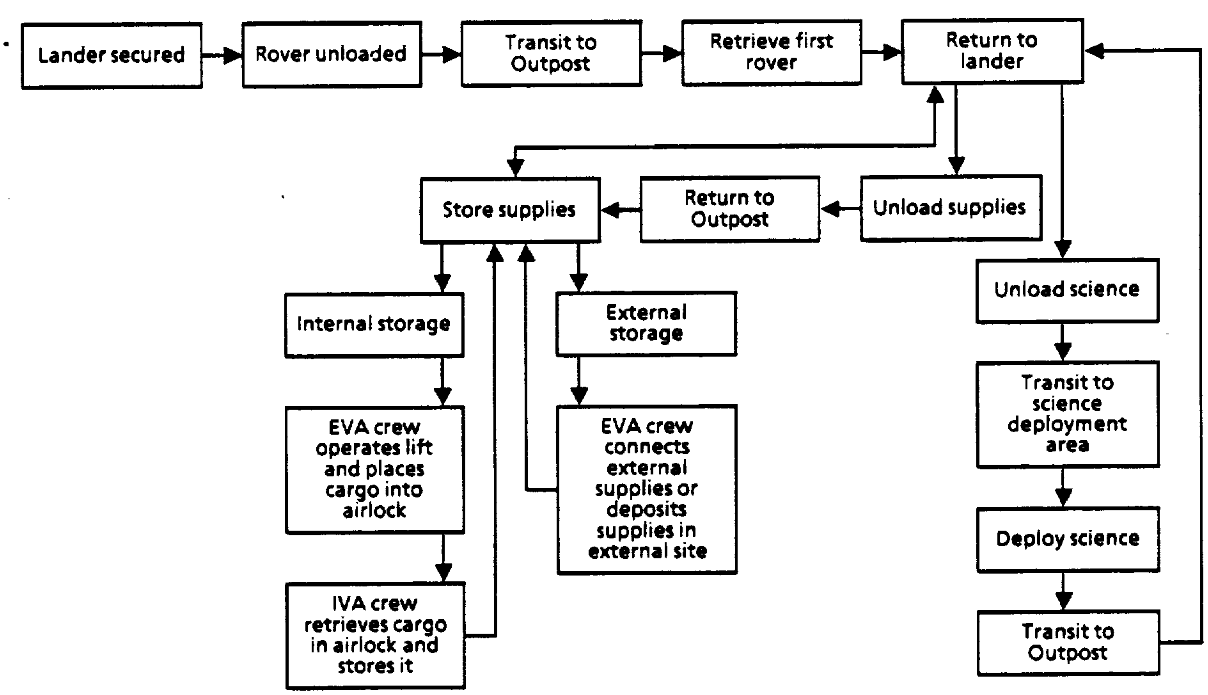


Figure 6-3. Initial Resupply Logistics Flow

6.3 LOGISTICS MODULES AND SPARES

A preliminary examination was made of logistics modules and an assessment for maintenance and spares. Data from ALENIA SPAZIO S.P.A. on the Mini-Pressurized Logistics Module was acquired and this planned module and two reduced weight versions of it were examined for lunar resupply use, reference 6-1. The resultant weight reduction and implications are given in figures 6-6 to 6-9.

Basic "Requirements"
- Must contain 1800 kg of resupply - 3 to 4 racks
- Must be able to be transported
- Must contain a pressure

Using Mini-PLM as it is now designed

Provides
- Contains 8 racks - 7 for users (2 refrigerator/freezer, 5 stowage), 1 for utilities
- Has active pressure, thermal control, fluids, power, avionics, man systems
- Size is 4.3 m long by 4.4 m diameter
- Has standard SSF connections

Impacts
- Requires an additional SSF hatch
- Requires crane or ramp to offload and onload
- Requires a ground transport mechanism
- Requires an additional to the outpost lander platform and a bulkhead in the habitat

Disadvantages
- Will not use the full capacity of the Mini-PLM
  - Uses ~1800 kg of ~4000 kg capacity
- Basic structural weight with systems provided is 3765 kg
  - Combined with the internal stores the total mass is ~5.5t and completely uses the allotted resupply capacity on the manned lander (no additional rover, no external resupply or science, no ground transport vehicle)

Figure 6-6. Lunar Logistic Module from Mini-PLM

Using a "stripped down" Mini-PLM

Provides
- Contains 8 racks - all for users, no utilities
- Has passive pressure and thermal control, but no utilities, man systems, or avionics
- Size is 4.3 m long by 4.4 m diameter
- Has standard SSF connections

Impacts
- Requires an additional SSF hatch
- Requires crane or ramp to offload and onload
- Requires a ground transport mechanism
- Requires an additional to the outpost lander platform and a bulkhead in the habitat

Disadvantages
- Will not use the full capacity of the Mini-PLM
  - Uses ~1800 kg of ~4000 kg capacity
- Basic structural weight with rack supports provided is 2773.4 kg
  - Combined with the internal stores the total mass is ~4.5t and uses the most of allotted resupply capacity on the manned lander (rover mass not used in resupply, therefore it can be flown with this cargo, 453 kg external resupply or science, no ground transport vehicle)

Figure 6-7. Lunar Logistic Module from Mini-PLM (Continued - 1)

Using a shortened "stripped down" Mini-PLM

Provides
- Contains 4 racks - all for storage, no utilities
- Has passive pressure and thermal control,but no utilities, man systems, or avionics
- Size is 3.2 m long by 4.4 m diameter
- Has standard SSF connections

Impacts
- Requires an additional SSF hatch
- Requires crane or ramp to offload and onload
- Requires a ground transport mechanism
- Requires an additional to the outpost lander platform and a bulkhead in the habitat

Disadvantages
- Basic structural weight with rack supports provided is 2461.3 kg
  - Combined with the internal stores the total mass is ~4.24t and uses the most of allotted resupply capacity on the manned lander (rover mass not used in resupply, therefore it can be flown with this cargo, 764 kg external resupply or science, no ground transport vehicle)

Figure 6-8. Lunar Logistic Module from Mini-PLM (Continued -2)

Mini-PLM Subsystem	Mass (kg)		
	MPLM	Stripped	Shortened
Structure	3116.4	2773.4	2461.3
ECLS	266.2	—	—
ITCS	209.3	—	—
Avionics	124.1	—	—
Man Systems	18.0	—	—
Fluids	55.0	—	—
Total	3789	2773.4	2461.3

Figure 6-9. Mini-PLM Mass Summaries

A set of maintenance issues that are yet to be resolved were examined along with some parts failure rate information obtained previously, reference 6-2. Data on maintenance and spares was acquired, reference 6-3. The principal critical spares (class 1C and 1) for the SSF habitat was examined. This was an incomplete list but gave some indication of the magnitude of the "spares problem" to the lunar surface. A preliminary reduced list for FLO is included in Appendix F.

Major maintenance considerations that have to be addressed include:

a. A minimum of 2% of all active items should be available for maintenance covering habitat internal and external systems all active deployed science packages and all mobile equipment.

b. Failure rates must be addressed over both the time the crew is present and in the "dormant" conditions between missions.

c. Commonality of parts (not systems) must be addressed and a priority on cannibalization established.

d. Spares and maintenance rates will have an impact on the amount of material to be transported.
e. Maintenance performance tools required and the access to equipment must be determined.
f. Review of "Lessons Learned" from previous space programs should be initiated.

An initial cursory review of these "Lessons Learned" revealed several methods that should be incorporated in the FLO logistics and design. Redundant systems should not necessarily be identical. The backup system could fail in the same manner as the primary, leaving the whole non operational. Systems should be designed for rapid detection and isolation of the malfunctions. Time is more critical the further away from home you are. Human engineering principals must be applied to reduce the time at the task and the potential errors in correcting a problem for safety considerations. Interdependent systems should be avoided to prevent cascading failures. It must be recognized that some repair functions will have to be done in a space suit, both IVA and EVA activities must be taken into account. Hardware should be standardized and traceable to avoid "reworking" the part during the mission or the possibility of a non fit. As many tasks as possible should be mechanized to reduce the crew time involved in the task with the resultant fatigue. Intense tasks will "key up" the crew and should not be done prior to a rest period Palatable excess consumables should be provided both as a reassurance and to provide selection for the crew.

6.4 IMPACTS TO OUTPOST DESIGN AND OPERATIONS

Possible concept design and schedule recommendations may include the following:

a. If the single EVA crew schedule is used, it is likely that the last supply transport mission will be done in the lunar night or that the remaining supplies will be left at the lander until lunar day returns. Recommend that the lighting at the lander, the path back to the Outpost, and the Outpost be revised for work in Earthshine or darkness.
b. Active suit time is critical to the time to complete the resupply from the lander. It should be as long as possible without stressing the surface crew.
c. With a set cargo limit, use of a lunar logistics module will either limit the amount of external resupply or science that can come with a manned mission or require a separate resupply flight. The alternative is to live with the EVA time consumed in using small transportable packages, or design a new lunar logistics module. Use of a logistics module for resupply must still be considered. It may not be feasible to start with a logistics module, but to go to it as the activity at the FLO becomes more regular and expands.

CONCLUDING REMARKS

The current study is a continuation of the "First Lunar Outpost" study that was initiated under Technical Directive 11. For the selected baseline hab-airlock (with hyperbaric capabilities), systems were chosen to meet the 45 day stay-time. Space Station Freedom heritage was an important factor in the selection of the systems for the baseline hab. Studies were also conducted to examine deviations from the baseline hab on habitat configuration, materials, internal pressure and inflatables. To meet the mission constraints of the 45 day stay-time, the baseline hab mass was approximately 30 mt. Some changes in this mass would occur with the incorporation of items examined in the "deviations" study. Further work is necessary to quantify these impacts.

Appendix A

Boeing Mass Breakdown Details

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Sub				~~5323.98~~ 4826.63		As a note, there appears to be a discrepancy in the Mass Properties Report of 13.18 lbs in FWD/INT Endcone. We will assume here that the masses are correct.
Dist Sys - Endcone/ Standoff-Mounted Equipment and Utilities						
EP1	Endcone - fwd/ext	EPDS		0.00		SSF HAB A Mass Properties Report (12/15/91)
EP2	Endcone - fwd/int	EPDS	Remote switch	0.71		"
			Cable Assy	12.47		"
			Sensor/Effector cable	2.26		"
			SPDA struct. and integ.	32.15		"
			Feedthru(DDCU)	2.19		"
			RPDA utility rails	4.25		"
			RPC's	47.85		"
			DC-DC converter	50.00		"
	Sub			151.88	5%	
EP3	Endcone - aft/ext	EPDS		0.00		"
EP4	Endcone - aft/int	EPDS	Remote switch	0.71		"
			Cable Assy.	12.47		"
			Sensor/effector cable	2.26		"
			SPDA	32.15		"
			Feedthru, DDCU	2.19		"
			RPDA Utility rails	4.25		"
			RPC Modules	47.85		"
			Converter, DDCU	50.00		"
		Sub		151.88	5%	
EP5	S/off - ceiling/ starboard	EPDS	Lighting	21.44		"
			Cable Assy.	13.97		"

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			cable, sensor effector	~~2.26~~ 0.00		• This mass is associated with intermodule ventilation (IMV) and deleted
		Sub		~~25.65~~ **0.00**	5-28%	Total IMV mass deleted is 144.6 lbs - including portions in AFT/INT Endcone and a small part of one Av Air/Crossover rack
		ECLSS-ACS	Pres. equal. valves	~~9.09~~ 0.00		• This mass deleted since no berthing vestibule exists for integrated baseline; O2/N2 feeds between A/L & module should suffice;V&R also available
			Vent & relief assy	8.76		•
			O2/N2 control and dist.	~~24.66~~ 13.71		• Portion which incl inter-module O2/N2 blkhd feeds deleted (connection between module & A/L maintained at other end) - alt. atmos resupply prov. by hyperbaric A/L
			Plumbing	~~12.05~~ 0.00		• This plumbing assumed to be part of inter-module O2/N2 bulkhead feeds, which have been deleted as discussed
			cable, sensor effector	5.66		•
		Sub		~~60.22~~ **28.13**	5-28%	
		ECLSS-FDS	Flame detector	1.52		•
			Portable fire extinguisher	5.23		•
			Fluid CO2	2.72		•
			Sensor/effector cable	0.90		•
		Sub		**10.37**	5-28%	
		ECLSS-ARS	Sensor/effector cable	2.26		•
			CO2 vent system	2.93		•
		Sub		**5.19**	5-28%	
		ECLSS-WRM	Sensor/effector cable	**2.26**	5-28%	•
EC3	Endcone - aft/ext	ECLSS-WRM	Bulkhead penetration	~~1.42~~ 0.00		• This mass is associated with water venting which is deleted assuming that no excess water will be present or
~~44.59~~ 0.00			Vents	~~33.65~~ 0.00		• This mass is associated with water venting which is deleted assuming that no excess water will be present or

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Feed-thru	1.45		•
		Sub		**4.36**	5-28%	
		ECLSS-FDS	Flame detector	1.52		•
			Portable fire ext.	5.24		•
			Sensor/effector cable	0.90		•
			CO2-fluid	2.72		•
		Sub		**10.38**	5-28%	
		ECLSS-WRM	Sensor/effector cable	2.26		•
			plumbing	4.00		•
		Sub		**6.26**	5-28%	
EC5	S/off - ceiling/ starboard	ECLSS-THC	Fan	5.19		• Fan assumed needed for circulation to smoke detectors in packed standoffs
~~159.35~~ 153.50			Ducting	~~145.14~~ 139.29		• Portion of this mass is associated with extended module delta (8") which is deleted since no need is assumed for
			Insulation	5.52		•
		Sub		~~155.85~~ **150.00**	5-28%	Total extended module delta (8") mass deleted is 17.22 lbs - including portions in Floor/Starboard Standoff
		ECLSS-FDS	Sensors	1.63		•
			CO2 release valve	1.19		•
			Sensor/effector cable	0.68		•
		Sub		**3.50**	5-28%	
EC6	S/off - floor/ starboard	ECLSS-THC	Fan	5.19		• Fan assumed needed for circulation to smoke detectors in packed standoffs
~~91.3~~			Valves	8.47		•
89.34			Ducting	28.80		•
			Sensor/effector cable	5.60		•
		Sub		**48.06**	5-28%	
		ECLSS-ARS	Plumbing	**0.54**	5-28%	•
		ECLSS-FDS	Sensors	1.63		•
			Valves	1.19		•
			Plumbing	9.14		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Fluid	~~13.60~~ 9.48		* Portion of this mass is associated with STS Fuel Cell Water transfer and deleted (but may be there if water
		Sub		~~49.95~~ 43.73	5-28%	....
EC8	S/off - ceiling/port	ECLSS-THC	Fan	5.19		* Fan assumed needed for circulation to smoke detectors in packed standoffs
72.14			Ductwork/Insulation	22.43		*
			Sensor/effector cable	6.11		*
		Sub		33.73	5-28%	
		ECLSS-ARS	plumbing	0.67	5-28%	*
		ECLSS-FDS	Sensors	1.63		*
			plumbing	15.10		*
			Sensor/effector cable	0.45		*
		Sub		17.18	5-28%	
		ECLSS-WRM	Sensor/effector cable	13.60		*
			plumbing	6.96		*
		Sub		20.56	5-28%	
EC9	Cylinder	ECLSS-ACS	Module atmosphere	147.40	5-28%	*
	ECLSS Sub			~~846.19~~ 691.19	5-28%	....
DM1	Endcone - fwd/ext	DMS	none	0		SSF HAB A Mass Properties Report (12/15/91)
DM2	Endcone - fwd/int	DMS	Cabling	16.38		*
			Feedthrus	1.81		*
			Transducer	0.54		*
			Acoustic sensor	2.06		*
			Ring Concentrator	22.67		*
			Display panel	2.26		*
			MDM-large	20.86		*

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			EMADS	9.07		•
			Signal processor	16.66		•
			SDP "A" populated chassis	16.78		SSF LAB A Mass Properties Report (12/15/91) - SDPs don't seem to exist in Hab A mass properties, but will be needed for Outpost (SDP "B" also included on other end)
			Mass storage unit (2)	62.60		SSF LAB A Mass Properties Report (12/15/91) - MSUs don't seem to exist in Hab A mass properties, but will be needed for Outpost (2 exist on SSF Lab A and both are
	Sub			171.69	5-28%	
DM3	Endcone - aft/ext	DMS		0.00		•
DM4	Endcone - aft/int	DMS	Cabling	16.38		•
			Feedthrus	1.81		•
			Transducer	0.54		•
			Acoustic sensor	2.06		•
			Ring Concentrator	22.67		•
			Display panel	2.26		•
			MDM-large	20.86		•
			EMADS	9.07		•
			SDP "B" populated chassis (2)	16.78		SSF LAB A Mass Properties Report (12/15/91) - SDPs don't seem to exist in Hab A mass properties, but will be needed for Outpost (SDP "A" also included on other end; both SSF Lab A SDP "B"s are included here)
		Sub		92.43	5-28%	
DM5	S/off - ceiling/ starboard			0.00		•
DM6	S/off - floor/	DMS	Cable	19.33		•
			Fiber distribution/data	6.27		•
			Time dist. bus	4.99		•
		Sub		30.59	5-28%	
DM7	S/off - floor/port	DMS	Cabling and Dist. bus	61.20	5-28%	•
DM8	S/off - ceiling/port	DMS	Cabling and Dist. bus	30.60	5-28%	•
DM9	Cylinder		Thermographic scanner	19.05	5-28%	•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Berth vestibule	1.90		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
		Sub		**10.71**	5-20%	
MS2	Endcone - fwd/int	Man-Systems	Handrail assy.	1.02		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Closeouts	23.15		•
		Sub		**24.17**	5-20%	
MS3	Endcone - aft/ext	Man-Systems	Handrail	6.55		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Slidewire	2.26		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Berth vestibule	1.90		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
		Sub		**10.71**	5-20%	
MS4	Endcone - aft/int	Man-Systems	Handrail assy.	1.02		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Closeouts	23.15		•
		Sub		**24.17**	5-20%	
MS5	S/off - ceiling/ starboard	Man-Systems	Closeouts	**2.30**	5-20%	•
MS6	S/off - floor/	Man-Systems	Closeouts	2.30		•
			Sensor/effector cable	4.53		•
		Sub		**6.83**	5-20%	
MS7	S/off - floor/port	Man-Systems	Closeouts	2.30		•
			Sensor/effector cable	22.67		•
		Sub		**24.97**	5-20%	
MS8	S/off - ceiling/port	Man-Systems	Closeouts	2.30		•
			Sensor/effector cable	4.53		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Valve	1.31		•
			Cold plate	24.42		•
			Bulkhead penetration	3.23		•
			Sensor effector cable	4.53		•
			Heater	1.05		•
			Fluid (water)	10.88		•
			Paint	2.04		•
			Insulation	4.49		•
		Sub		102.19	5%	
TC5	S/off - ceiling/ starboard	TCS	Plumbing	6.66		•
			Insulation	6.42		•
		Sub		13.08	5%	
TC6	S/off - floor/	TCS	Plumbing	10.29		•
			Sensor/effector cable	9.07		•
			Insulation	5.90		•
			Fluid (water)	13.60		•
		Sub		38.86	5%	
TC7	S/off - floor/port	TCS	Plumbing	39.50		•
			Insulation	6.42		•
			Sensor/effector cable	15.87		•
			Fluid(water)	13.60		•
		Sub		75.39	5%	
TC8	S/off - ceiling/port	TCS	Plumbing	16.93		•
			Insulation	6.42		•
			Sensor/effector cable	15.87		•
			Fluid(water)	36.28		•
		Sub		75.50	5%	
TC9	Cylinder	TCS	Insulation blanket	216.98		•
			Paint	13.74		•
		Sub		230.72	5%	
	TCS Sub			718.82		

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Rack attachments	23.20	11%	*
	Sub			95.80		
Floor2	Personal/ CHeCS Storage	Pack	Rack Structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) - Personal contents of this rack are included in consumables; CHeCS included within total for CHeCS rack
			Rack attachments	26.85		*
		M/S	Closeouts	3.12		*
		90.11	Drawers	86.99		*
	Sub			189.58		
Floor3	Galley Stowage #1	Pack	Rack structure	72.62	16-17%	SSF HAB A (based on Galley/Wardroom Storage Rack) Mass Properties Report (12/15/91) - Contents of this rack are included elsewhere as part of food and galley
			Rack attachments	26.85		*
		M/S	Foot restraints	0.58		*
		92.09	Handrail	1.40		* This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Closeouts	3.12		*
			Drawers	86.99		*
	Sub			191.56		
Floor4	Galley Stowage #2	Pack	Rack structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) - Based on Galley Storage (food for crew included under consumables)
			Rack attachments	26.85		*
		Man-Systems	Handrail	1.72		* This mass will be retained but assumed part of 1/6th-g furniture and accommodations
		91.84	closeouts	3.12	5-15%	*
			Drawers	87.00		*
	Sub			191.31		

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Floor5	Critical ORUs	Pack	Rack Structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) - Necessary and desired spares for Outpost not yet defined - this acts as a placeholder only
			Rack attachments	26.85		"
		M/S	Closeouts	3.12		"
		518.71	Drawers	86.99		"
			ORUs (?)	428.60	5%	" This bogey mass is equivalent to SSF Hab-A ORU
	Sub			618.18		
Starboard1	SPCU/ EVA Stowage	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Generic rack utilities and structure based on Urine Processor as analog
			Rack attachments	95.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
		EVA	SPCU - suit drying assy #1	7.67	25%	SSF WP02 Mass Properties Report (Jan 91) - One of the two SPCUs is captured here (other SPCU and controls sets are located across the aisle)
		31.25	SPCU - rack ventilation assy #1	4.85	25%	"
			SPCU - don/doff assy #1	17.01	25%	"

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			SPCU - cable set	1.72	25%	"
	Sub			209.23		
Starboard2	CHeCS	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Generic rack utilities and structure based on urine processor as
			Rack attachments	35.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-ACS	O2 jumper assembly	7.14		This O2 jumper assembly has been added in anticipation of oxygen needs at the CHeCS rack (N2 assumed not
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
		Medical Support	MTC ALS pack	13.20	5-12%	SSF WP02 Mass Properties Report (Jan 91) - This complement and volume assumed sufficient and appropriate for Outpost mission
		668	Med restraint sys	9.60	5-12%	"
			Ventilator	11.60	5-12%	"
			Defibrillator	11.40	5-12%	"
			Hydrocarbon analy	4.10	5-12%	"
			Organic analy	25.30	5-12%	"
			Organic sampler	2.80	5-12%	"
			Ion sel electrodes	5.00	5-12%	"
			Optical water q. analy	47.90	5-12%	"
			Water sampler	4.50	5-12%	"
			Fungal sport monitor	3.70	5-12%	"

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Tubing	0.88		•
			Fluid - water	6.80		•
			Insulation	0.88		•
		ECLSS-THC	Valves, sensors, diffusers	4.78		•
		ECLSS-FDS	sensor, disconnect, line	2.02		•
		3.89	Fire indicator panel	0.68		•
			CO2 release valve	1.19		•
		Man-Systems	Task light	3.10		•
		39.49	IMS bar code reader	11.91		•
			A/V tapes, etc	9.75		•
			Restraints/handrails	6.42		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Closeouts	5.07		•
			Single drawer	3.24		•
	Sub			319.41		
Starboard4	Science	Rack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Based on SSF Lab A Maintenance Workstation
			Rack attachments	22.43		•
		EPDS	Cable Assy.	3.96		•
		24.51	converter	1.96		•
			RPC	14.06		•
			RPDA	4.53		•
		DMS	MDM	20.86		•
		IAV	Fiber optics	0.16		•
		TCS	Flow control assy.	6.81		•
		25.37	cold plate	3.37		•
			Heat exchanger	10.71		•
			plumbing	0.88		•
			Fluid(water)	2.72		•
			Insulation	0.88		•
		ECLSS-THC	Valve	3.37		•
		3.81	ductwork	0.44		•
		ECLSS-FDS	Sensor	0.81		•
		3.31	CO2 valve	1.19		•
			Fire indicator panel	0.68		•
			CO2 diffuser line	0.63		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		Man-systems	Restraints, handrails	6.41		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
		18.95	closeouts	5.06		•
			Drawers	7.48		•
		FSS	Fluid system serv & leak test equip.	101.7	18%	•
		Experiment	Maintenance Workstation	279.10	5%	•
		665.07	Local controller	20.90	5%	•
			Test eq, meters, etc.	51.00		•
			Autoclave	34.90		• This particular instrument serves as analog to appropriate lunar LSE
			Battery charger	10.00		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Cleaning equip	18.10		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Oscilloscope	24.00		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Dosimeter	29.90		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Etching equip	6.00		• This particular instrument serves as analog to appropriate lunar LSE
			Fluid handling tools	65.00		• This particular instrument serves as analog to appropriate lunar LSE
			Gen purpose hand tools	59.00		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Mass measurement devices	39.90		• This particular instrument serves as analog to appropriate lunar LSE

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Specimen labeling	5.00		• This piece of equipment assumed still needed for Outpost and mass retained as is
			Surgery dissection tools	20.00		• This particular instrument serves as analog to appropriate lunar LSE
			Wipes, etc.	2.27		•
	Sub			958.79		
Starboard5	Crossover/ Cabin Air/ MT TCS	Pack	Rack structure	102.10	5-28%	SSF HAB A Mass Properties Report (12/15/91) - PEP mass and complement are unknowns that were not identified in SSF report
			Rack attachments	29.68		•
		EPDS	Cable Assy.	3.96		•
		12.79	RPC	7.03		•
			RPDA	1.80		•
		TCS	Flow control assy.	6.81		•
		145.77	cold plate	3.15		•
			plumbing	8.14		•
			Fluid(water)	2.72		•
			Insulation	0.96		•
			Plumbing	16.26	5-23%	Internal TCS taken from previous AV Air/TCS/Crossover TCS Mass
			Pump assy.	74.16		•
			Controls	18.01		•
			Cold plate	3.15		•
			Regenerative HX (8000W)	10.72		•
			Fluid (water)	2.72		•
			Insulation	0.97		•
		ECLSS-THC	Cabin Air assy.	106.00	5%	• Water separator mass included as portion of this assembly (centrifugal separator may be replaced by passive 1/6 g system)
		139.2	Valves, ducts, etc.	33.20	5%	•
		ECLSS-FDS	Sensor	0.81		•
		3.88	CO2 valve	1.19		•
			Fire Indicator panel	0.68		•
			Quick disconnect	0.57		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Ceiling1	ECLSS Water Storage	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Outpost assumed to require less water than SSF
			Rack attachments	35.57		"
		EPDS	Cable Assy.	3.96		"
		12.79	RPC	7.03		"
			RPDA	1.80		"
		TCS	Flow control assy.	6.81		"
		16.51	cold plate	3.15		"
			plumbing	4.31		"
			Fluid(water)	1.36		"
			Insulation	0.88		"
		ECLSS-THC	Valves	4.23		"
		6.11	Sensors	0.09		"
			Ductwork	1.79		"
		ECLSS-ACS	N2 rack-user I/F assy.	2.38		"
		7.13	Feedthru assy.	1.42		"
			N2 S/O to rack jumper assy.	3.33		"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63		"
		ECLSS-WRM	Water assy	~~165.00~~ 157.03	~10%	" Reduced by deletion of 2 of 3 "3-way elect. act valve"s assoc with change below; Press ORU mass kept along with existing pump (functions unclear)
		~~511.53~~ 282.76	Water (assumed to include tanks)	~~331.20~~ 110.40	~10%	" Reduced by deletion of 2 of these 3 water tanks (Outpost water needs are much lower than SSF, due mainly to no laundry and no every-day shower)
			Valves, etc.	15.33	~10%	"
		Man-systems	Closeouts	5.06		"

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Valves, etc.	26.43	~13%	•
		Man-systems	Closeouts	5.06		•
		5.45	Handrails	0.39		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
	Sub			~~689.42~~ 651.23		Pump for moving water in gravity assumed to be handled by combination of existing press ORU and existing pump (TBD)
Ceiling3	ECLSS Urine Processor	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Assumed that SSF-sized processor appropriate for 4-person Outpost (latest SSF topologies show this function now requiring a full rack; 2nd ARS/ACM functions expanded
			Rack attachments	44.54		•
		EPDS	Cable Assy.	3.96		•
		14.75	converter	1.96		•
			RPC	7.03		•
			RPDA	1.80		•
		DMS	MDM	20.86		•
		TCS	Flow control assy.	6.81		•
		19.78	cold plate	3.15		•
			plumbing	6.14		•
			Fluid(water)	2.72		•
			Insulation	0.96		•
		ECLSS-THC	Valves	4.22		•
		6.43	Sensors	0.09		•
			Ductwork	2.12		•
		ECLSS-FDS	Sensor	0.81		•
		3.88	CO2 valve	1.19		•
			Fire indicator panel	0.68		•
			Quick disconnect	0.57	5%	•
			CO2 diffuser line	0.63	5-23%	•
		ECLSS-WRM	Urine processor assy.	146.67		•
		~~158.3~~	Valves	1.43		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			2nd Sample line	0.05	5%	"
			2nd CO2 Removal assy	148.80	5%	"
			2nd valves, etc.	7.25	5%	"
		Man-systems	closeouts	5.06		"
	Sub			577.97		
Ceiling5	ECLSS ARS (open loop)	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachments	38.65		"
		EPDS	Cable Assy.	3.96		"
		24.51	converter	1.96		"
			RPC	14.06		"
			RPDA	4.53		"
		DMS	MDM	20.86		"
		TCS	Flow control assy.	6.81		"
		30.93	cold plate	11.72		"
			plumbing	5.17		"
			Fluid(water)	6.35		"
			Insulation	0.88		"
		ECLSS-THC	Valves	4.22		"
		6.44	Sensors	0.10		"
			Ductwork	2.12		"
		ECLSS-ACS	Plumbing	0.71		"
		ECLSS-ARS	TCCS assy	75.78	5%	"
		231.83	CO2 Removal assy	148.80	5%	"
			Valves, etc.	7.25	5%	"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63		"
		Man-systems	closeouts	5.06		"
		5.45	Handrails	0.39		" This mass will be retained but assumed part of 1/6th-g furniture and accommodations

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Sub			435.88		
Port1	SPCU/ Airlock Controls	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Generic rack utilities and structure based on urine processor as analog
			Rack attachments	35.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
		EVA	SPCU - power supply and battery charger	18.10	25%	SSF WP02 Mass Properties Report (Jan 91) - Second of the two SPCUs as well as controls are captured here (other SPCU located across the aisle; SSF has these two racks adjacent - impact unknown)
		272.09	SPCU - battery storage locker	10.21		"
			SPCU - oxygen reg & distr	25.54		"
			SPCU - H2O reg & distr	74.84		"
			SPCU - rack ventilation assy #2	4.85		"
			SPCU - umbilical I/F panel	36.88		"
			SPCU - hose set	8.53		"
			SPCU - cable set	11.93		"
			SPCU - suit dryer assy #2	7.67		"

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			SPCU - don/doff assy #2	17.01		•
			SPCU - maintenance kit	19.87		•
			NSTS EMU launch fixtures	8.53		•
			Umbilical set	19.60		• Assumed adequate to provide any functional interconnects between the two SPCU racks (across aisle from one another) during use
			Depress/repress console	8.53	25%	•
	Sub			450.07		
Port2	Hyperbaric Support	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Rack and generic Utilities based on Urine Processor rack; hyperbaric support functions derived from WP02 data
			Rack attachments	44.54		•
		EPDS	Cable Assy.	3.96		•
		14.75	converter	1.96		•
			RPC	7.03		•
			RPDA	1.80		•
		DMS	MDM	20.86		•
		TCS	Flow control assy.	6.81		•
		19.78	cold plate	3.15		•
			plumbing	6.14		•
			Fluid(water)	2.72		•
			Insulation	0.96		•
		ECLSS-THC	Valves	4.22		•
		6.43	Sensors	0.09		•
			Ductwork	2.12		•
		ECLSS-FDS	Sensor	0.81		•
		3.88	CO2 valve	1.19		•
			Fire indicator panel	0.68		•
			Quick disconnect	0.57	5%	•
			CO2 diffuser line	0.63	5-23%	•
		Hyperbaric Support	Hyperbaric Gas and Pressure Control Assy	66.10		SSF WP02 Mass Properties Report (Jan 91) - This is the hyperbaric support burdened onto the hab module; airlock rack contained within airlock mass
		115.1	Pass-thru chamber	38.20		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			C&W panel	9.10		
			C&W panel mounting H/W	1.70		•
		Man-systems	closeouts	6.06		•
	Sub			303.02		
Port3	Galley (Oven/ DD/ Handwash)	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) - Based on Galley/ Oven/ Drink Dispenser rack plus new Handwash (based on handwash in WMC)
			Rack attachments	17.89		•
		EPDS	Cable assy	3.97		•
		14.78	Converter	1.97		•
			RPC	7.03		•
			RPDA	1.81		•
		TCS	Plumbing	5.17		•
		18.73	Flow control assy.	6.81		•
			Cold plate	3.15		•
			Insulation	0.88		•
			Fluid(water)	2.72		•
		ECLSS-THC	Valves	4.23		•
		4.76	Sensor	0.09		•
			Ductwork	0.44		•
		ECLSS-FDS	Sensor	0.81		•
		3.88	CO2 valve	1.19		•
			Fire indicator panel	0.68		•
			Quick disconnect	0.57		•
			CO2 diffuser line	0.63		•
		ECLSS-WRM	Valve	0.47		•
		2.81	Plumbing	2.34		•
		Man-systems	Oven	~~63.80~~ 50.15	15%	• Reduced by estimate of convection portion of the oven (30.10 lbs); microwave portion is retained - this change chosen for its reduction in power req'ts, too
		~~277.79~~	Water dispenser	74.80	15%	•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		264.14	Handwash	36.20	5%	•
			I/F structure	21.70	15%	•
			Wardroom table and I/Fs	45.20		•
			Stowage	28.10	15%	•
			Restraints/handrails	2.93		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			closeouts	5.06		•
	Sub			~~413.26~~ 399.61		
Port4	Waste Management Compartmen	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachments	17.89		•
		EPDS	Cable assy	3.97		•
		12.81	RPC	7.03		•
			RPDA	1.81		•
		TCS	Cold plate	3.15		•
		ECLSS-THC	Valves, sensor, diffuser	4.78		•
		ECLSS-FDS	Sensor	0.82		•
		ECLSS-WM	Commode/urinal assy	121.36	19%	• Commode/Urinal urine fan/separator mass included as portion of this assembly (centrifugal separator may be replaced by passive 1/6 g system)
		Man-Systems	Waste Mgmt Compartment	52.39		•
		95.83	Handwash	36.24	5%	•
			Local controller	1.43		•
			Handrail	0.70		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
			Closeouts	5.07		•
	Sub			329.26		

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Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Port5	Crossover/ TCS/Cabin Air	Pack	Rack structure	102.10	5-28%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachment	29.68		•
		EPDS	Cable assy	3.97		•
		12.81	RPC	7.03		•
			RPDA	1.81		•
		TCS	Fluid disconnects	15.26		•
		115.26	ITCS pump assy	74.16		•
			System flow control assy	11.19		•
			Rack flow control assy	6.81		•
			Cold plate	3.15		•
			Tubing	1.00		•
			Fluid - water	2.72		•
			Insulation	0.97		•
		ECLSS-THC	Cabin Air assy	105.99		• water separator mass included as portion of this assembly (centrifugal separator may be replaced by passive 1/6 g system)
		140.45	Valves, sensor	4.33		•
			Diffuser	0.36		•
			Ducts and welds	29.77		•
		ECLSS-ACS	N2 rack-user I/F assy	2.38		•
		7.14	N2 rack feedthru	1.43		•
			N2 jumper	3.33		•
		ECLSS-FDS	Sensor	0.82		•
		3.89	CO2 release valve, disconnect, line	2.39		•
			Fire indicator panel	0.68		•
		Man-Systems	Handrail	0.70		• This mass will be retained but assumed part of 1/6th-g furniture and accommodations
		5.77	Closeouts	5.07		•

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Sub			417.10		
Ops1	Ops storage (located in endcone of Outpost)					SSF HAB A Mass Properties Report (12/15/91) - All mass associated with Ops Storage included in consumables below (assumed to be stored sans rack in empty hatchway)
Rack-based Sub				~~9997.47~~ 8816.70		
Habitat Sub				~~17047.13~~ 16114.01		
Radiation Protection				TBD		Awaiting further requirements definition; current analysis shows doses below artificial limits for
Airlock	Airlock			1818.30		Best guess at Crewlock mass from WP02 data (see 3/27 breakdown and 6/22 comparison with Dave Kissinger's/JSC numbers for more details)
	Hab-to Airlock Adapter			272.20		Estimate for adaptation hardware
	Tools and Toolbox			~~553.20~~ 57.20		From SSF WP02 Mass Properties Report (toolbox itself masses 344.7 kg, which is hefty; Δ2 reductions include only minimal tool complement with 15% mass fraction for toolbox))
	Dust Mitigation and Removal			15.00		This bogey includes 15 kg for vacuum (w/ filter and recirculation) and/or electrostatic removal (assume 1 kW peak, 2 % duty cycle) - other dust control mass under expendables

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	External Lights			12.00	15%	Estimated mass for two EVA lights to be used for near-module activity during lunar night (power estimated at 0.2 kW, 5% duty cycle)
Sub				~~2670.70~~ 2174.70		
External Support Systems						
	External System Support Structure			2064.00		Estimate for stairs, platforms (catwalks), A-fram hoist and elevator platform, integration structure for ECLSS and RFC tanks, radiator support, etc.
	C&T			40.00		
	External IA&V		External cameras (2)	31.70		Estimate based on AFT/INT Endcone IAV (microphone mass retained but assumed to be mass for dust control
	Thermal Control System		External transport	60.00		Sized for using a heat pump during the lunar day
			Radiator	435.00		
			Radiator insulation	25.00		
	Sub			520.00		
	Power		Reactants	1406.60		High pressure (3000 psi) stored O2/H2 reactants for regenerable fuel cell operation
			Tanks	2632.20		
			Arrays, fuel cells, etc.	963.00		All power and thermal masses based on needs of reference layout (thermal includes metabolic load from
			Array deployment and support structure	449.00		Calculated from estimated loads and by scaling from SAFE
	Sub			5450.80		

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Gas Conditioning Assembly			257.90		Based on one O2 string and one N2 gas conditioning strings from SSF GCA (without any structure, tanksets, fluid, or insulation - assumed provided elsewhere)
Sub				8364.40		
Consumables						
	Crew water					Closed system needs included in above ECLSS numbers
	Food			360.00		4 people for 45 days (2 kg/p-d)
	Clothing			245.00		3 lbs per person-day
	Galley/ Wardroom (non-food)		Wipes, bags, etc.	103.00		
	ECLSS expendables		AR	20.60		
			WRM	129.40		
			WM	11.00		
			THC	10.00		
	Sub			171.00		
	Make-up gas		Repress, Airlock loss, module leakage	378.80		2 represses, 10% airlock loss for 22 EVAs, standard leakage; includes hi-pressure tankage
	Metabolic oxygen			185.40		This assumes cryo storage (high pressure storage would mass much higher). These numbers include tanks.
	EVA sublimator water			167.60		16 lbs/EVA for 2 people for 7 hours (22 EVAs per mission)
	Suit expendables			166.30		Based on JSC's 3/6/92 value

Integrated Baseline FLO Hab Module and Systems Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Suit spares			74.80		Based on JSC's 3/6/92 value
	Dust Control			97.00		This bogey includes 90 kg for disposable coveralls, 5 kg for brushes, and 2 kg for double-sided contact paper
	CHeCS			80.00		Based on JSC information
	Personal Hygiene			45.80		From HAB A Mass Report ?
	Ops storage		Camera, cleaning, etc.	182.80		From HAB A Mass Report ?
	Off Duty			84.20		See 2/5/92 report from JSC
	Maintenance			113.20		See 2/5/92 report from JSC
	Science			50.00		Assumed number for internal science
Sub				2504.90		
Growth				1477.20		Contingency growth will be based on : for power, 15% of tanks, 15% of array, 28% of all else (incl 28% on array deployment and support structure), 0% on reactants; 28% for external structure;
						28% on external TCS; and 28% on external C&T; with no growth on consumables

Appendix B

Boeing and MSFC System Mass and Rationale

FLO Habitation System

Structures and Mechanisms

FLO Habitation System

Environmental Control and Life Support System

FLO Habitation System

ECLSS - Subsystem Masses

FLO ECLSS Subsystem	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
THC	*811*	*520*	Mass for new distributed system not defined (old centralized numbers used)
ACS	*263*	*279*	Boeing number includes internal only (GCA, at 258 kg, and make-up/metabolic gases bookkept separately)
ARS	*650*	*583*	Both MSFC and Boeing include redundant MCA; Boeing includes 1 ACMA (MSFC: 0); Boeing inlcudes 1 TCCS (MSFC: 2); Boeing includes all original sampling H/W (MSFC: 0)
FDS	*120*	*136*	Boeing incl for 17 powered racks (MSFC: 12)
WRM	*1025*	*1078*	Boeing includes two full water storage tanks, one each in Water Storage and Water Processing Racks in order to allow use from one while the other is being filled (MSFC: 1)
WM	*121*	*121*	
Total Internal ECLSS Mass	**2990**	**2717**	MSFC also includes 282 kg for high pressure tanks for a total ECLSS mass of 3000 kg

FLO Habitation System

Medical Support/Radiation Protection

FLO Habitation System

Crew Systems

FLO Habitation System

Crew Systems - General Description

- Crew System masses are based on SSF Hab-A :
  - masses for restraints and mobility aids are kept as analog to one-sixth gravity furniture and accommodations
  - rack and endcone closeout masses are increased by 50 kg to account for additional dust containment needs
  - stowage drawers are assumed the same as used on SSF
  - waste mgmt hardware mass is assumed identical to lunar system
  - galley has been modified by the addition of a handwash (for a total of two in the FLO habitat) and deletion of convection oven (microwave remains) with only a table acting as a "wardroom"

- Internal systems Critical ORUs are included under Crew Systems and represents approximately 5% of the internal systems mass (placeholder only - maintainability analyses TBD)

- Crew bunks are envisioned to be constructible cots which "plug-in" to rack seat tracks

- Stowage needs and assessment are currently being examined

FLO Habitation System

Crew Systems Masses

FLO Crew Systems	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
Endcone/Standoff Support	*127*	*88*	Boeing mass based on SSF Hab-A numbers (R&MA mass to represent 1/6th g accommodations)
Rack Support/Stowage	*471*	*234*	Boeing mass based on SSF numbers in accordance with reference FLO layout (overall stowage assessment still pending)
Workstation Support	*28*	*380*	Boeing mass based on SSF Lab-A numbers
Galley/WR Functions	*220*	*497*	Boeing mass based on SSF Hab-A numbers (inlcudes deployable table; handwash added to active Galley rack; convection oven deleted with microwave remaining)
PHS Functions	*126*	*in ECLSS*	Boeing mass based on SSF Hab-A numbers
Critical ORUs	*429*	*within each system*	Boeing mass for Critical ORUs represents bogey for spares (~5% of active int sys)
Total Internal Crew Systems Mass	**1402**	**1694**	MSFC total from July report (known individual masses do not equal total)

FLO Habitation System

CDMS

FLO Habitation System

Power and Thermal Control Systems

FLO Habitation System

Power and Thermal Control Systems Comparison (cont)

FLO Thermal Systems Mass	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
Thermal System - External			
External transport	*60*	*89*	Boeing number does not include power system penalty (~ 7 kg)
Radiator	*435*	*619*	Boeing number includes heat pump
Radiator insulation	*25*	*60*	Heat pumped radiator smaller **Radiator areas (m2):** **Boeing 62.8 (22.6 kW cap)** **MSFC 110 (10 kW cap)**
Thermal System - Internal	*1262*	*1222*	Includes both active and passive internal TCS subsystems. Boeing mass based on SSF numbers in accordance with reference FLO layout
Thermal System Total	**1782**	**1990**	

ADVANCED CIVIL SPACE SYSTEMS

FLO Habitation System

Crewlock/EVAS Status

BOEING

FLO Crewlock/EVAS Component	Boeing Mass (kg)	JSC Mass (kg)	Rationale for Difference
• ***Structures and Mechanisms***	***1532.7***	***1819.0***	
Crewlock cylinder section	*152.9*	*140.0*	*Unknown (different data ?)*
Crewlock EVA bulkhead ring	*264.0*	*264.0*	
Crewlock IVA bulkhead ring	*326.6*	*330.0*	
Longerons and struts	*40.6*	*41.0*	
Isogrid panel/support angles	*93.0*	*67.0*	*JSC removed 35% (?)*
MM/D shield	*79.2*	*52.0*	*JSC removed 35%*
EVA /IVA hatches/mech	*228.1*	*232.0*	
Non-rack/rack support struct	*17.8*	*52.0*	*Unknown (different data ?)*
Crewlock rack	*58.3*	*58.0*	
1/6 g internal/external struct		*59.0*	*Boeing incl overall 1/6g# w/hab*
Pass-thru lock		*38.0*	*Boeing incl in hab EVAS*
IV yoke		*152.0*	*Function of item not clear*
Keel trunnion ftg and pins		*46.0*	*Similar est. for 3 marked items*
Transportation pins (2 keels)		*16.0*	
1/2 Equip Lock end dome		*64.0*	*Function of item not clear*
Hab/Crewlock interface (est)	*272.2*	*208.0*	
• ***Internal EVA Systems***	***656.3***	***1103.0***	*Unknown*
Crewlock hyperbaric supp	*121.2*		*Boeing incl HECA /h/b ltg assy*
Hab EVAS (SPCU, H/B, pump)	*535.1*		*Boeing incl internal EVAS only*

FLO Habitation System

Crewlock/EVAS Status (continued)

FLO Crewlock/EVAS Component	Boeing Mass (kg)	JSC Mass (kg)	Rationale for Difference
• *Other Distributed Hardware*		*585.0*	*This H/W assumed part of hab burden (incl racks, dist systems, etc.) necessary to support internal EVAS; thus, incl as part of Boeing hab systems*
• *Crewlock EVA Hardware*	*428.9*	*396.0*	*This hardware assumed to include distributed systems, umbilicals, plumbing, insulation, and airlock controls which are located within Crewlock*
• *External EVA Equipment*	*92.0*	*333.0*	*Included in Boeing estimates are tools and toolbox (reduced in Δ2 from 553.2 kg to 57.2 kg), small internal dust vacuum, external lights, and R&MA*
TOTAL MASS	**2709.9**	**4236.0**	

ADVANCED CIVIL SPACE SYSTEMS

FLO Habitation System

Consumables

BOEING

FLO Consumables Mass	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
• *Crew Accommodations*	***1134.0***	***883.0***	
Crew Quarters	*0.0*	*30.0*	*No Crew Quarters on FLO ?*
Clothing	*245.0*	*244.0*	
Off Duty	*84.2*	*40.0*	*Boeing mass based on JSC 2/5/92 rpt*
Photography	*182.8* (Photography + Workstation)	*15.0*	*Boeing mass based on SSF Hab-A "Ops Storage" number* (Photography + Workstation)
Workstation		*0.0*	
Food & Galley Supply	*463.0*	*464.0*	
Personal Hygiene	*45.8*	*15.0*	*Boeing mass based on SSF Hab-A*
Housekeeping	*113.2*	*75.0*	*Boeing mass based on JSC 2/5/92 rpt for "Maintenance"*
• *Life Support*	*735.2*	*332.0*	***MSFC mass for initial charge only; Boeing mass includes 45 day supply***
Water (Closed Loop)	*in hab*	*61.2*	*Boeing mass incl 220.5 kg (incl tanks) initial charge in habitat ECLSS mass*
Oxygen	*305.2*	*30.0*	*Boeing mass: 119.8 kg (make-up for 2 represses, airlock loss, leakage) + 185.2 kg (metabolic) incl tankage*
Nitrogen	*259.0*	*68.5*	*Boeing mass incl make-up (w/ tanks)*
ARS expendables	*20.6*	*172.3* (ARS + WRM + WM + THC expendables)	
WRM expendables	*129.4*		
WM expendables	*11.0*		
THC expendables	*10.0*		

FLO Habitation System

EVA Suits/Contingency Factor

FLO Habitation System

EVA Suits/Contingency Factor

FLO Mass	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
Total EVA Suit Mass	Suits With Crew	635	Boeing approach assumes that primary EVA suits will necessarily be brought by Crew due to: 1) need for EMUs during transit between Earth and Moon, Crew lander and FLO; 2) special sizing for individual crewperson; 3) importance of ensuring availability and performance of suits. Boeing consumables numbers do include suit spares and other suit needs for FLO mission.
Total Contingency Mass	1477	2477	Boeing contingency based on : for power, 15% of tanks, 15% of array, 28% of all else (incl 28% on array deployment and support structure), 0% on reactants; 28% for external structure; 28% on external TCS; and 28% on external C&T; with no growth on consumables. All SSF growth allowances are maintained but not increased in Boeing numbers. MSFC contingency represents 10% of total habitat mass.

FLO Habitation System

Internal Science Support

FLO Habitation System

Internal Science Support Mass

FLO Internal Science Support	Boeing Mass (kg)	MSFC Mass (kg)	Rationale for Difference
Science Workbench	*300*		Boeing mass based on Maintenance Workstation (MWS) in SSF Lab-A. The MWS chosen as analog to generic glovebox or workbench for conducting internal science (examination, sampling, etc.)
Science Equipment	*365*		Boeing mass based on Lab Support Equipment from SSF Lab-A to represent generic materials/life sciences instruments
Fluid System Servicer and Leak Detection Equipment	*102*		Boeing mass based on SSF numbers and bookkeeping (location and function of FSS remains TBD)
Sample Prep. Instruments		*18*	
Imaging Instruments		*24*	
Spectrometers		*20*	
Total Int Science Mass	**767**	**62**	

Appendix C

Power Budget

Dormant Operation

ADVANCED CIVIL SPACE SYSTEMS

Lunar Campsite Internal Systems Power Budget Summary - Dormancy

BOEING

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Electrical Power Distribution System (EPDS)			
Lights	360	0	0
Cable power losses	114	100	114
Data Management System (DMS)			
Ring concentrators	48	100	48
C&W control panel	7.5	0	0
EMADS	10	100	10
Multiplexer-demultiplexer (MDM)	156	100	156
Standard Data Processors (SDP)	276	100	276
Mass Storage Unit (MSU)	320	25	80
Signal Processor Interface			
Data acquisition signal proc.	40	100	40
Internal Audio & Video			
Crew wireless unit batt.	22.5	0	0
Camera body	34.3	1	0.34
Zoom lens	9.2	0.2	0.02
Audio bus coupler	39.9	0	0
Video switching unit	104.5	1	1.05
Audio terminal units	56	0	0
Portable video monitor	155	0	0
Totals:	1753 W		725 W

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ADVANCED CIVIL SPACE SYSTEMS

Lunar Campsite Internal Systems Power Budget Summary - Dormancy (Cont.)

BOEING

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Thermal Control System (TCS)			
Rack flow control assy.	91	25	23
Crossover assy.	56	~0	~0
ITCS pump assy.	150	100	150
System flow ctrl. assy.	14	50	7
Temp. & Humidity Ctrl. (ECLSS-THC)			
Isolation valves	100	~0	~0
Rack air ctrl. valves	28	0.025	0.01
Avionics air fan	260	100	260
Av. air - I/F box	10	100	10
Cabin air - electrical I/F	25	100	25
Cabin air fan	90	100	90
Fan, ceiling ventilation	22	~0	~0
Atmosphere control (ECLSS-ACS)			
Isolation valve	2.4	100	2.4
Line press. sensor	1.8	100	1.8
Line temperature sensor	0.02	100	0.02
O2/N2 discharge diffuser	6.8	100	6.8
PCA firmware controller	14	100	14
Vent & relief subassembly	1	100	1
Totals:	872 W		591 W

Lunar Campsite Internal Systems Power Budget Summary - Dormancy (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Galley / Wardroom			
Handwash			
Diverter motor	1.8	0	0
Local control	1.6	0	0
Signal cond.	6	0	0
Temp. meas.	0.5	0	0
H2O supply	309	0	0
H2O dispenser			
Chiller	280	0	0
Electronic control	16	0	0
Flow control assy.	144	0	0
Heater assy.	210	0	0
Insertion/dispensing	57	0	0
Elec. converter (120 -28 VDC)	2.9	0	0
Microwave oven	600	0	0
Science/workbench			
Bar code reader	20	0	0
Light fixture	50	0	0
Converter	9.6	0	0
Local controller	68	~0	~0
Control electronics	31.3	0	0
Control panels (2)	25	0	0
Delta press sensors (5)	50	0	0

Lunar Campsite Internal Systems Power Budget Summary - Dormancy (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Science/workbench (Cont.)			
Press. transducers / sensors	31.5	0	0
Temp. sensors	0.4	0	0
Vacuum cleaner	237.5	0	0
Misc. Science Equipment	500	0	0
Water Storage	70	20	14
Water Processing			
Water processor	600	0	0
Process ctrl. H_2O quality	100	~0	~0
Urine processing			
Distillation assy.	175	0	0
Embedded ctrl.	30	0	0
Fluid ctrl. assy.	5	0	0
Fluid pump ORU	70	0	0
Pressure ctrl.	5	0	0
Purge pump	70	0	0
Totals:	3777 W		14 W

Lunar Campsite Internal Systems Power Budget Summary - Dormancy (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Air Revitalization System (ECLSS - ARS)			
CO2 vent valve	40	0	0
Atmos. comp. monitor	531	25	133
CO2 removal assy.	523.4	0	0
Converter	7.2	100	7.2
THC supply valve	20	100	20
Heater	150	25	37.5
TCCS - elec. I/F assy.	10	25	2.5
TCCS - flow ctrl. assy.	15.4	25	3.9
Flow meter & cable	1.6	100	1.6
Science / DMS / Comm. / Workstation	996	27	265
Crew Health (CHeCS)	911	0	0
Fire Detection / Suppression			
Flame detector	14	100	14
CO2 release valve	800	0.25	2
Sensors, smoke - duct & area	23.8	100	23.8
Totals:	4043 W		511 W

ADVANCED CIVIL SPACE SYSTEMS

Lunar Campsite Internal Systems Power Budget Summary - Dormancy (Cont.)

BOEING

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Waste Management			
Commode/urinal assy.			
C/U - commode fan	50	0	0
Compactor	130	0	0
User panel	25	0	0
M/S Hygiene			
Waste management compartment			
Cabin air fan	30	10	7
Cabin air heater	100	8	8
Cabin air temp. sensor	10	10	1
Lighting system	30	0	0
Local controller	27	0	0
Handwash			
Diverter motors	1.8	0	0
Local control	1.6	0	0
Signal cond.	6	0	0
Temp. meas.	0.5	0	0
H2O supply	309	0	0
Totals:	721 W		16 W

Lunar Campsite Internal/External Systems Power Budget Summary - Dormancy

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Hab Growth (scaled from SSF: ~5.4% Pavg)	164	100	164
Gas Conditioning Assembly (GCA)			
GCA - N2			
N2 cond. assy.	113.6	20	22.7
N2 growth	9.1	20	1.8
GCA - O2			
O2 cond. assy.	108.8	20	22
O2 growth	8.7	20	1.7
RPC Modules	156	100	156
External Communication Equip.	150	100	150
Rad. Ht Pump (for avg.+10%) (day/nt)	1474 / 150	100	1474 / 150
Totals:	2184 / 860 W		1992 / 818 W

Lunar Campsite Overall Power Budget Summary - Dormancy

- All Loads in Watts -

	Connected Load	Av. Load
EPDS/DMS/SPI/IAV	1753	725
TCS/THC/ACS	872	591
Galley / Wardroom	1629	0
Science	2019	265
Water stor. / Proc.	1125	14
Air Revit. System	1298.6	206
Crew Health	911	0
Fire Det. / Suppression	838	40
RPC Modules	156	156
External Comm. Equip.	150	150
Waste Management	205	0
M/S Hygiene	516	16
Hab Growth	164	164
Gas Cond. Assy.	240	48
Heat Pump - Day	1474	1474
- Night	150	150
Grand Totals: - Day	13351 W	3849 W
- Night	12027 W	2525 W

Note: Airlock Power (average and connected) = 0 W

Appendix D

Power Budget Details

Crew Onboard Operations

ADVANCED CIVIL SPACE SYSTEMS

Lunar Campsite Internal Systems Power Budget Summary - Δ2

BOEING

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Electrical Power Distribution System (EPDS)			
Lights	360	50	180
Cable power losses	196	100	196
RPC modules	312	100	312
Data Management System (DMS)			
Ring concentrators	48	100	48
C&W control panel	7.5	100	7.5
EMADS	10	100	10
Multiplexer-demultiplexer (MDM)	480	100	480
Standard Data Processors (SDP)	276	100	276
Mass Storage Unit (MSU)	320	100	320
Signal Processor Interface			
Data acquisition signal proc.	40	100	40
Internal Audio & Video			
Crew wireless unit batt.	22.5	10	2.25
Camera body	34.3	10	3.5
Zoom lens	9.2	2	0.18
Audio bus coupler	39.9	40	16
Video switching unit	104.5	10	10.5
Audio terminal units	56	30	17
Portable video monitor	155	5	7.75
Totals:	2471 W		1927 W

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Thermal Control System (TCS)			
Rack flow control assy.	91	25	23
Crossover assy.	56	~0	~0
ITCS pump assy.	300	100	300
System flow ctrl. assy.	14	50	7
Temp. & Humidity Ctrl. (ECLSS-THC)			
Isolation valves	100	~0	~0
Rack air ctrl. valves	28	0.025	0.01
Avionics air fan	749	100	749
Av. air - I/F box	10	100	10
Cabin air - electrical I/F	25	100	25
Cabin air fan	519	100	519
Fan, ceiling ventilation	22	~0	~0
Standoff fans	317	100	317
Atmosphere control (ECLSS-ACS)			
Isolation valve	2.4	100	2.4
Line press. sensor	1.8	100	1.8
Line temperature sensor	0.02	100	0.02
O2/N2 discharge diffuser	6.8	100	6.8
PCA firmware controller	14	100	14
Vent & relief subassembly	1	100	1
Totals:	2257 W		1976 W

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Galley / Wardroom			
Handwash			
Diverter motor	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
H2O dispenser			
Chiller	280	0.7	196
Electronic control	16	100	16
Flow control assy.	144	16.7	24
Heater assy.	210	0.7	147
Insertion/dispensing	57	16.7	9.5
Elec. converter (120 -28 VDC)	2.9	100	2.9
Microwave oven	600	2	12
Science/workbench			
Bar code reader	20	75	16
Light fixture	50	10	5
Converter	9.6	32	3.1
Local controller	68	~0	~0
Control electronics	31.3	33	10.3
Control panels (2)	25	33	8.25
Delta press sensors (5)	50	33	16.5

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Science/workbench (Cont.)			
Press. transducers / sensors	31.5	33	10.3
Temp. sensors	0.4	40	0.16
Vacuum cleaner	237.5	5	11.9
Misc. Science Equipment	500	10	50
Water Storage	70	20	14
Water Processing			
Water processor	600	33	200
Process ctrl. H2O quality	100	~0	~0
Urine processing			
Distillation assy.	175	16.5	29
Embedded ctrl.	30	100	30
Fluid ctrl. assy.	5	100	5
Fluid pump ORU	70	17	12
Pressure ctrl.	5	17	0.83
Purge pump	70	1.4	1
Totals:	3777 W		861 W

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Waste Management			
Commode/urinal assy.			
C/U - commode fan	50	2.5	1.25
Compactor	130	0.55	0.72
User panel	25	100	25
M/S Hygiene			
Waste management compartment			
Cabin air fan	30	70	21
Cabin air heater	100	8	8
Cabin air temp. sensor	10	100	10
Lighting system	30	20	6
Local controller	27	100	27
Handwash			
Diverter motors	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
Totals:	721 W		135 W

Lunar Campsite Internal/External Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Connected Load	Duty Cycle(%)	Av. Load
Hab Growth (scaled from SSF: ~5.4% Pavg)	342	100	342
Gas Conditioning Assembly (GCA)			
GCA - N2			
N2 cond. assy.	113.6	100	113.6
N2 growth	9.1	100	9.1
GCA - O2			
O2 cond. assy.	108.8	100	108.6
O2 growth	8.7	100	8.7
External Communication Equip.	150	100	150
Rad. Ht Pump (for avg. pwr.)	3787 / 300	100	3787 / 300
Totals:	4519 / 1032 W		4519 / 1032 W

Lunar Campsite Overall Power Budget Summary - Δ2

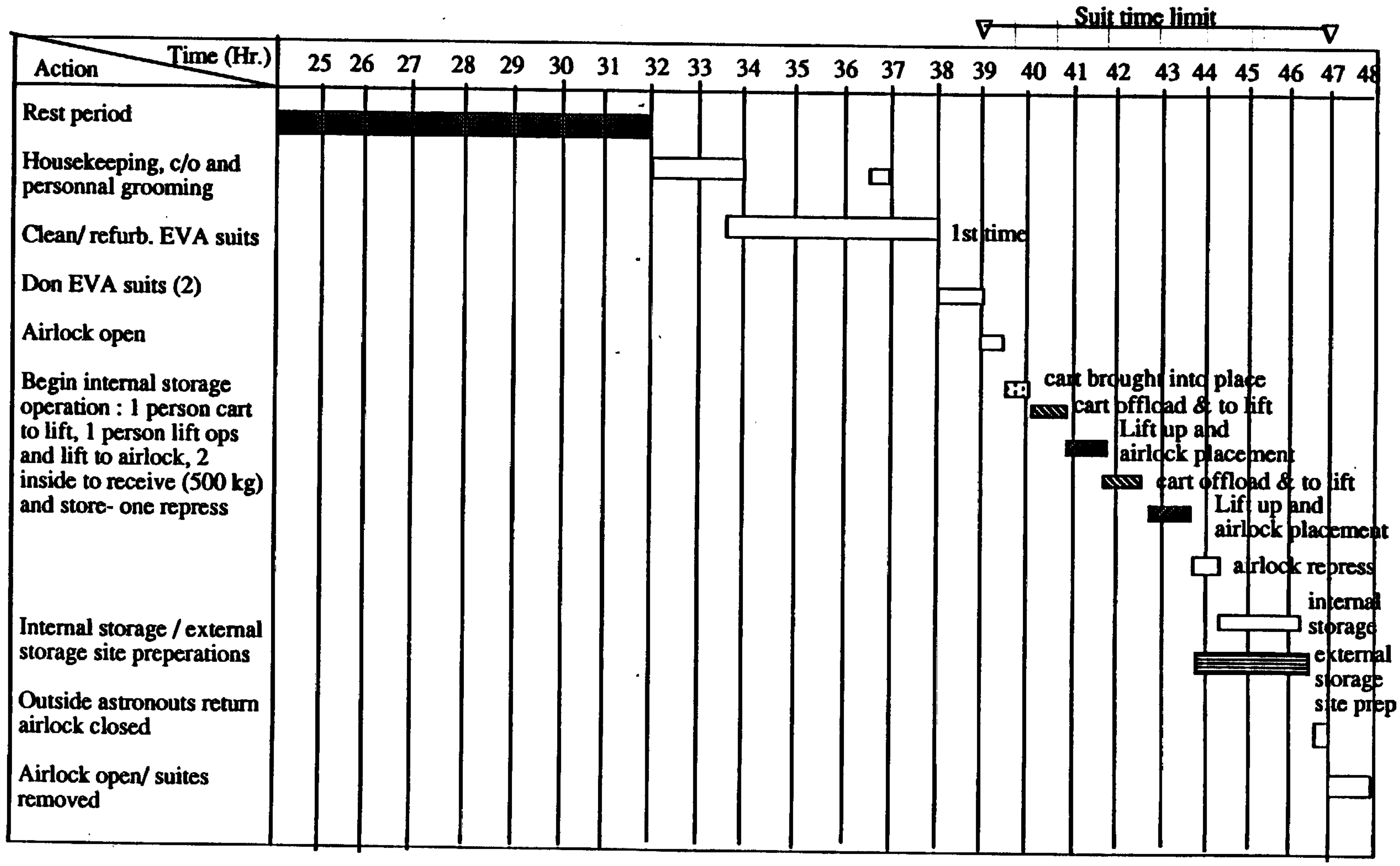
- All Loads in Watts -

		Connected Load	Av. Load
EPDS/DMS/SPI/IAV		2471	1927
TCS/THC/ACS		2257	1976
Galley / Wardroom		1629	443.6
Science		2019	727
Water stor. / Proc.		1125	292
Air Revit. System		1298.6	796
Crew Health		911	91
Fire Det. / Suppression		838	40
External Comm. Equip.		150	150
Waste Management		205	27
M/S Hygiene		516	108
Hab Growth		342	342
Gas Cond. Assy.		240	240
Heat Pump	- Day	3787	3787
	- Night	300	300
Airlock	- Day	6674	2371
	- Night	6674	1551
Grand Totals:	- Day	24463 W	13318 W
	- Night	20976 W	9011 W

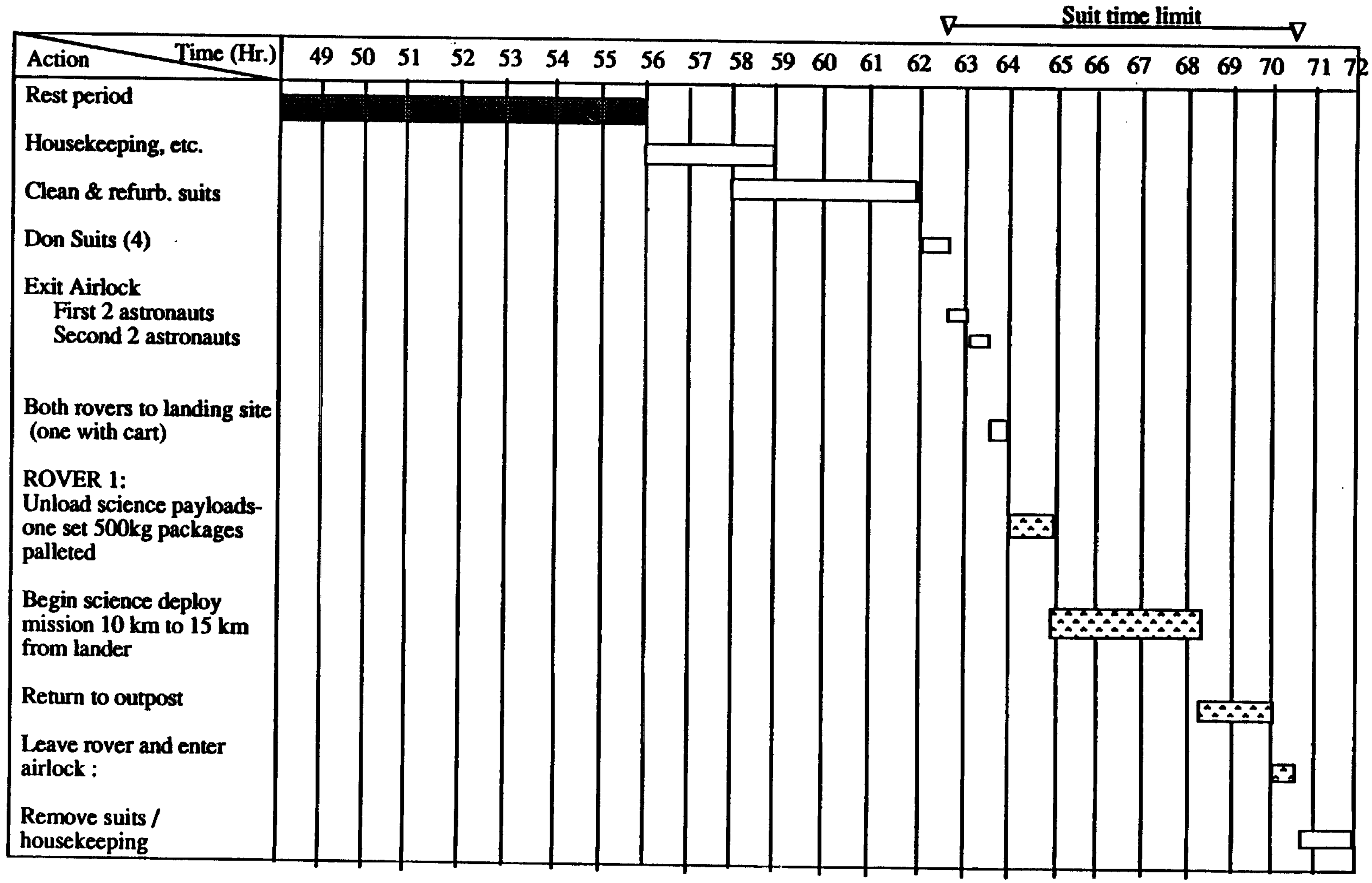
Appendix E

Surface Mission Timeline

2nd Manned Surface Mission Timeline
page 2



2nd Manned Surface Mission Timeline
page 3



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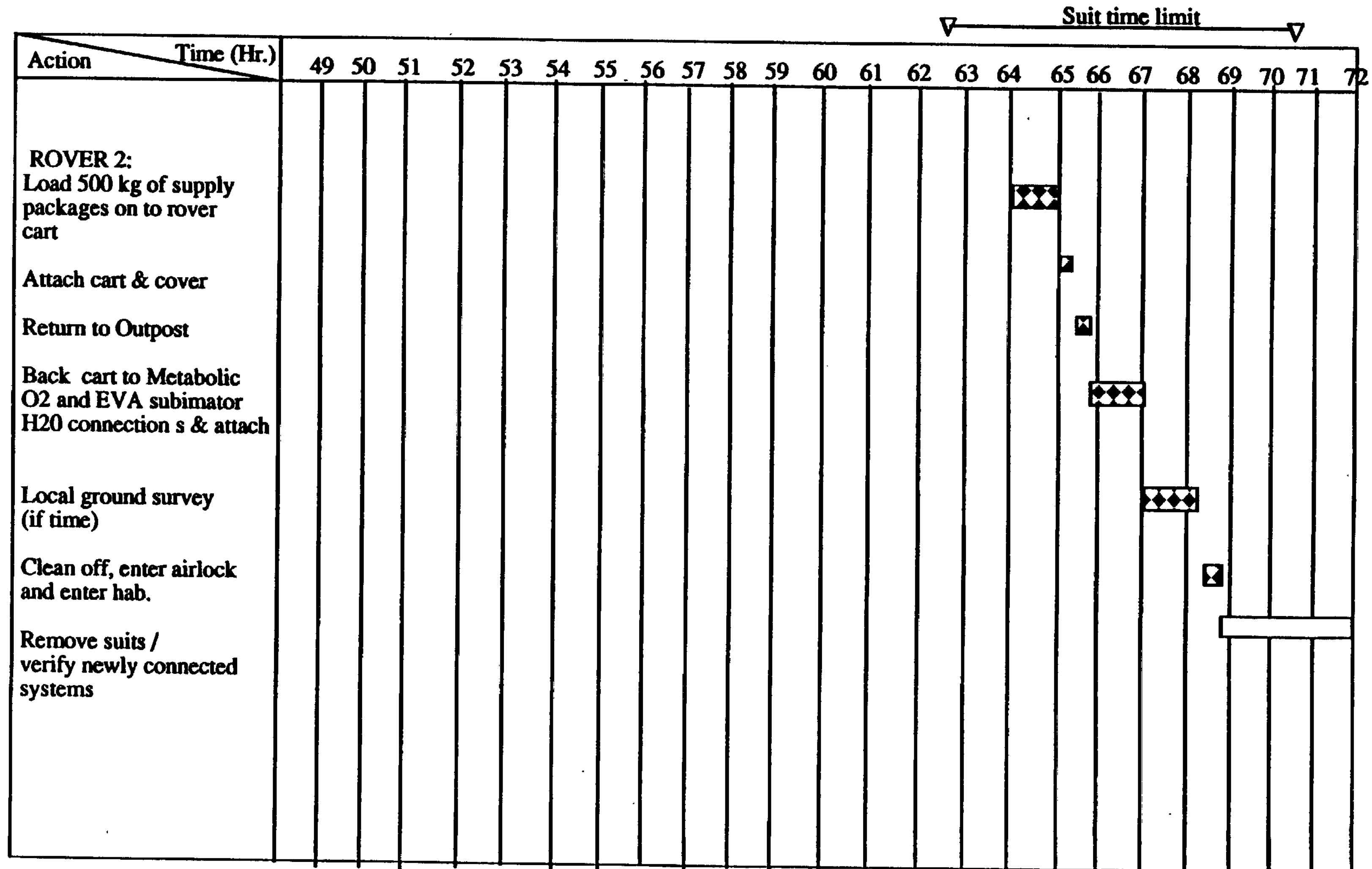
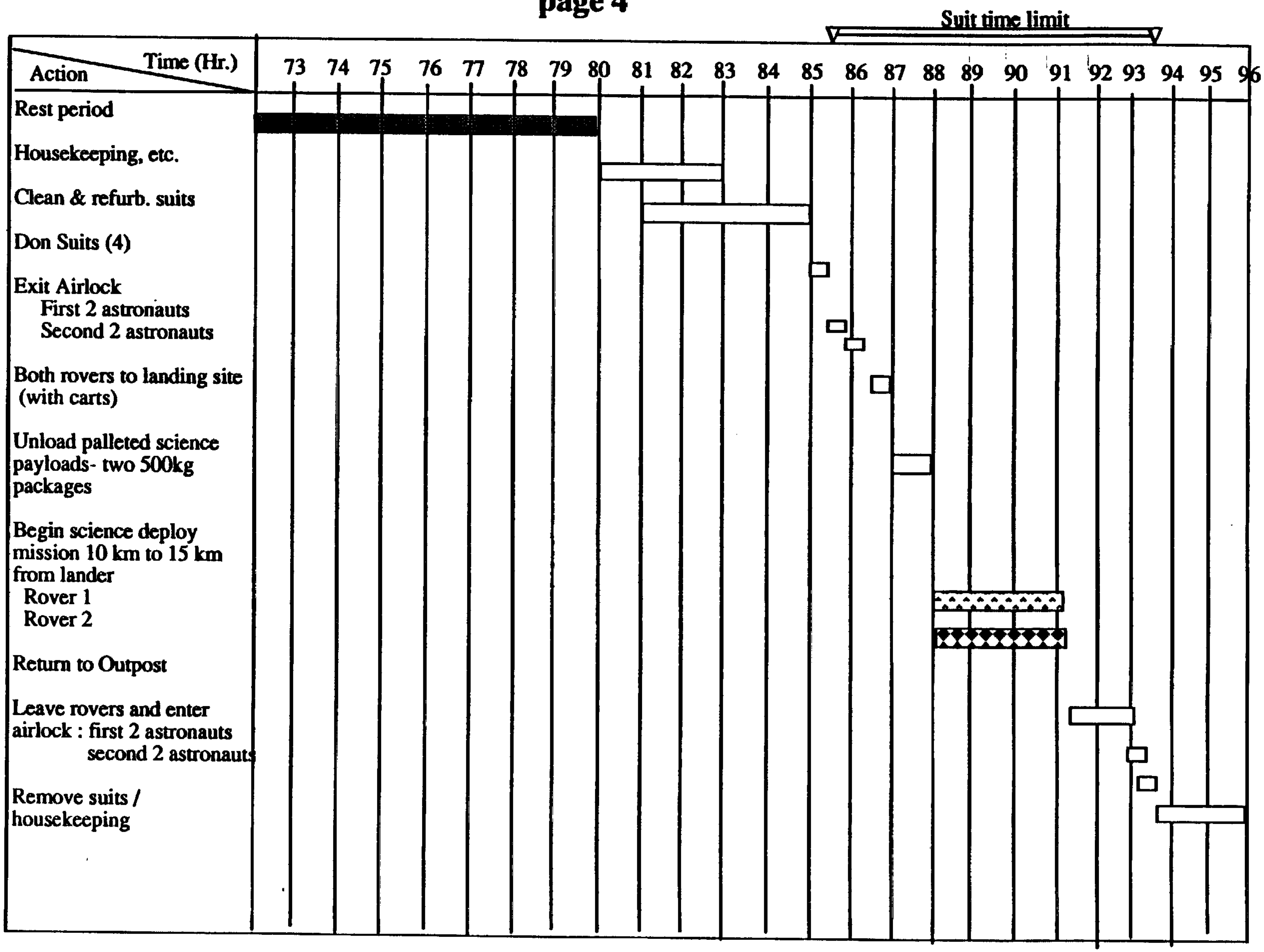
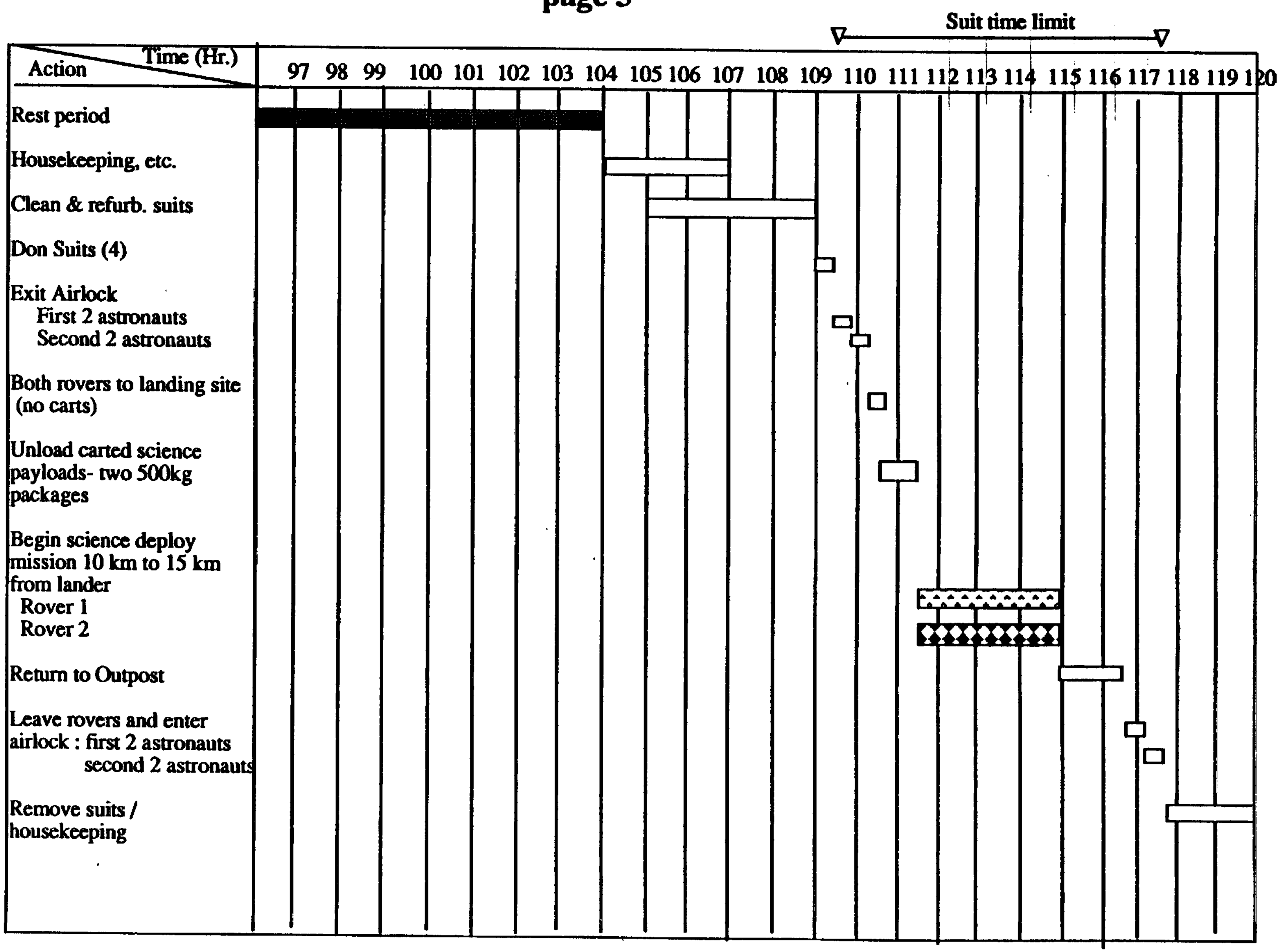


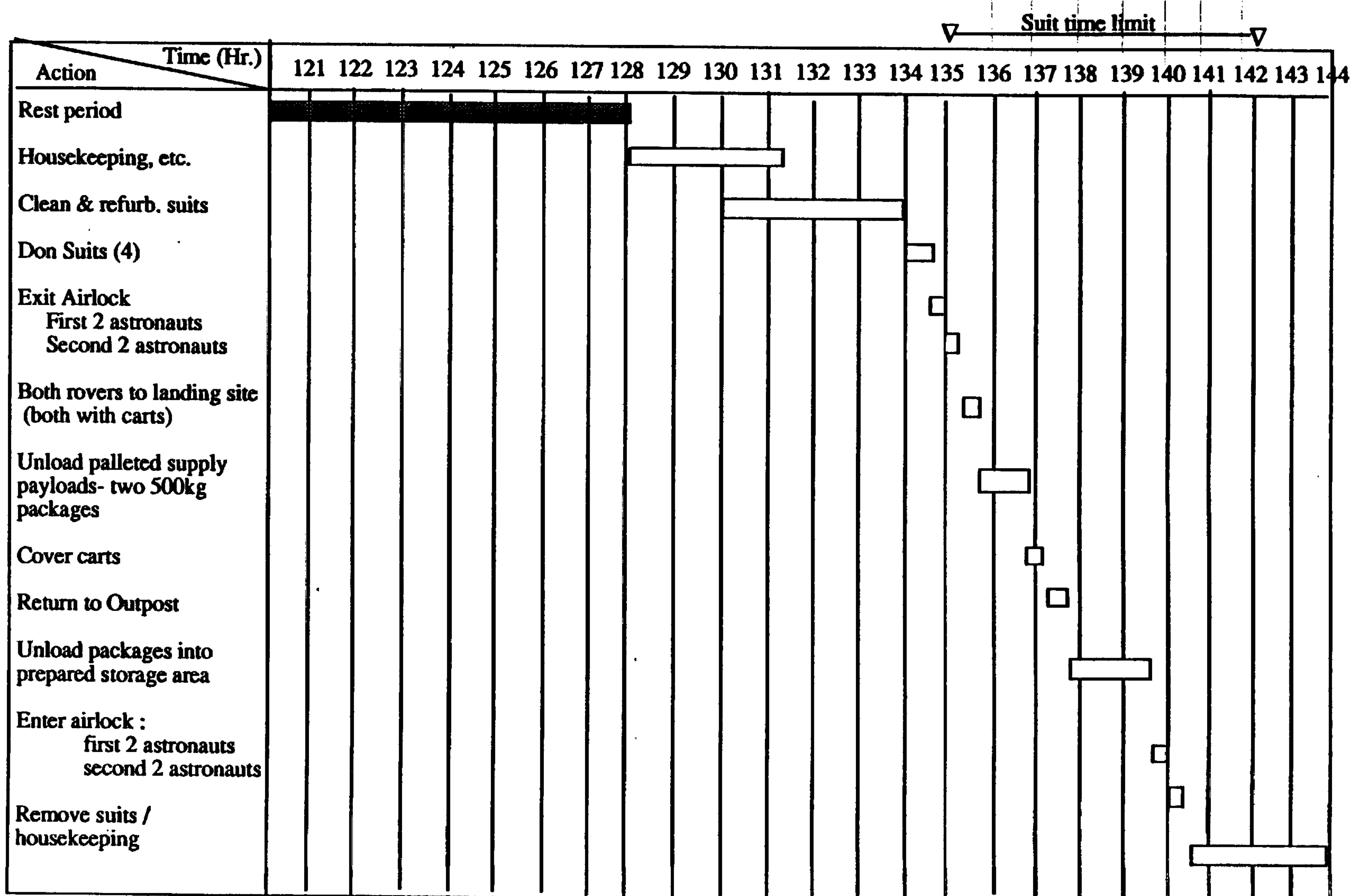
2nd Manned Surface Mission Timeline
page 4



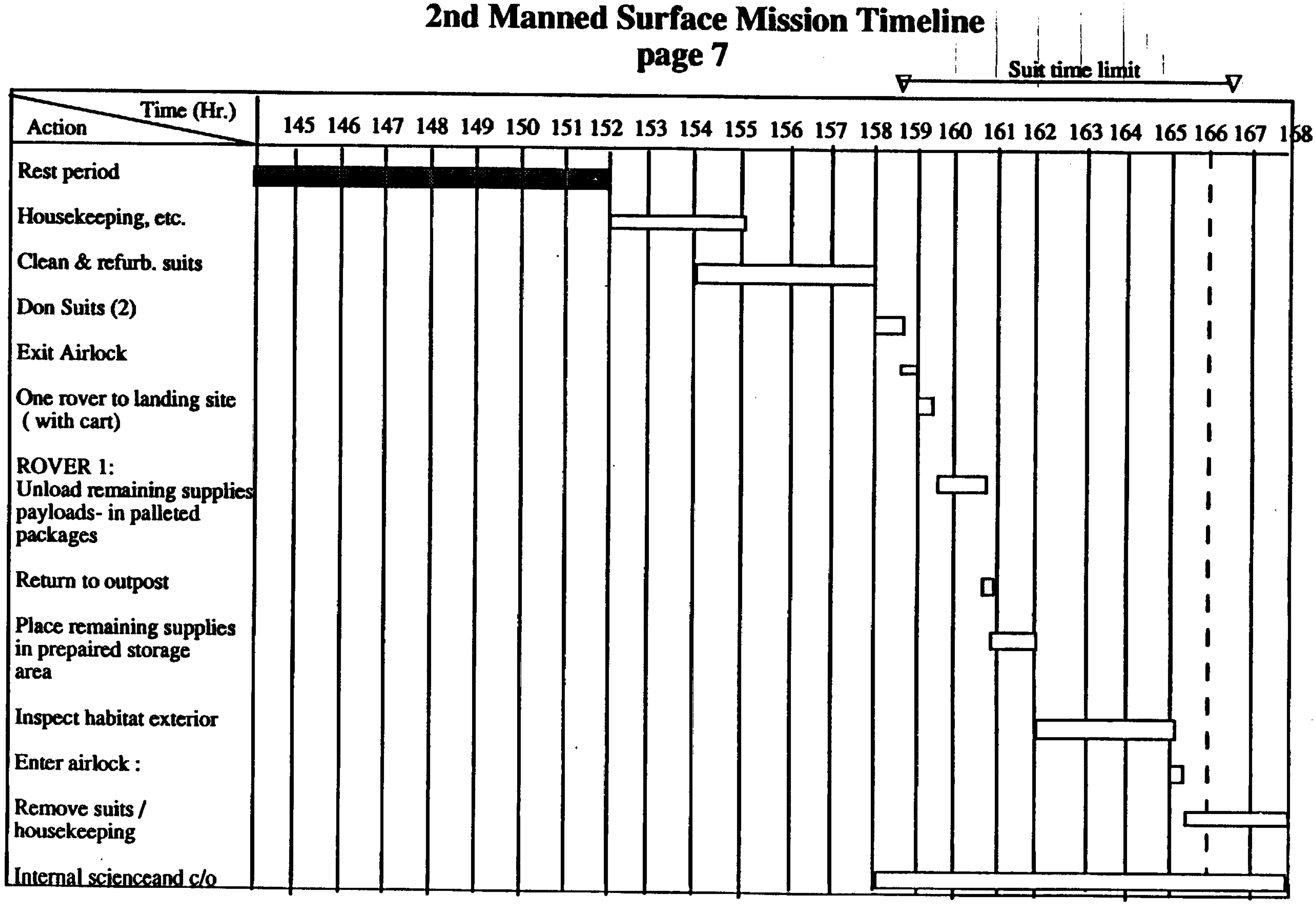
2nd Manned Surface Mission Timeline
page 5



2nd Manned Surface Mission Timeline
page 6



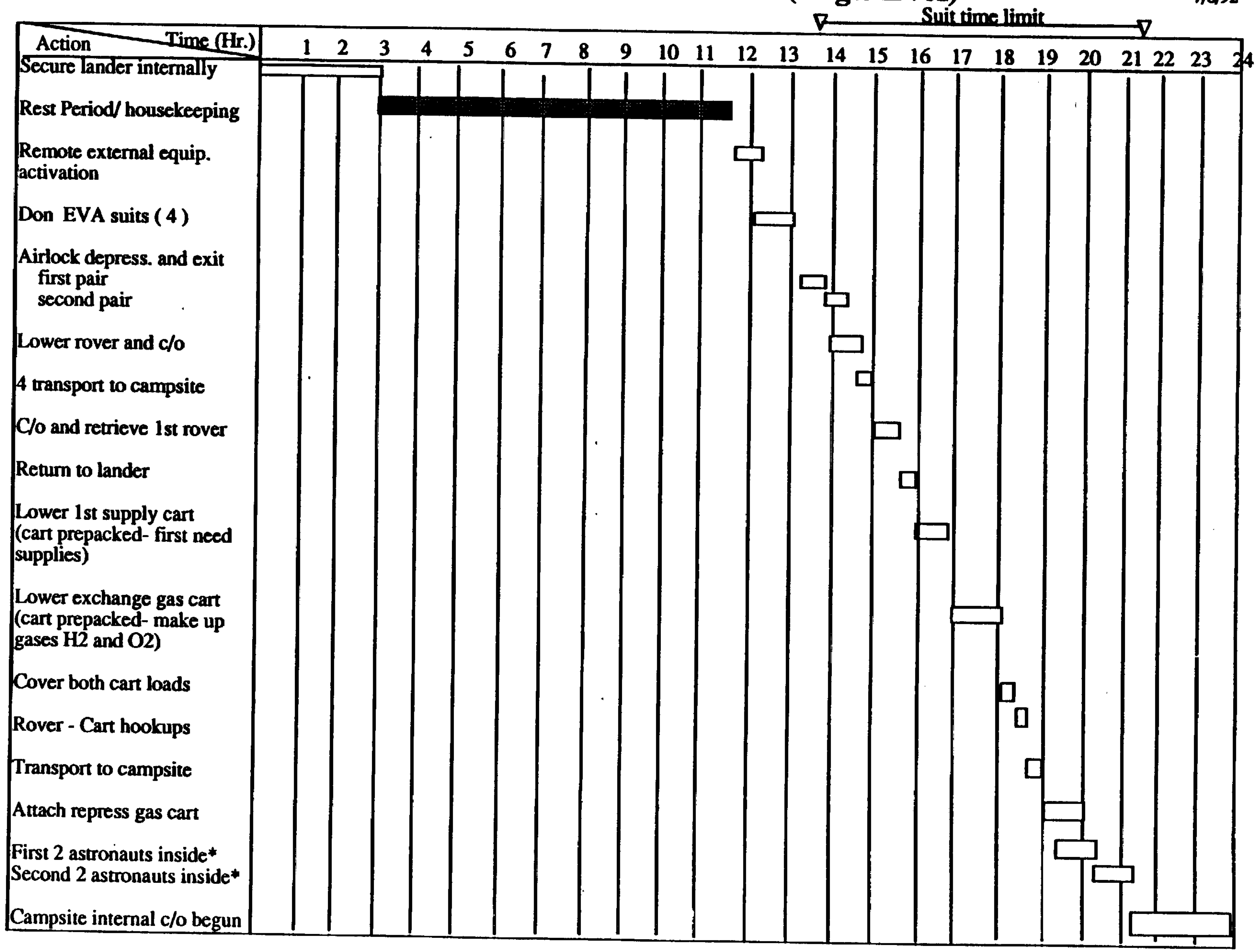
2nd Manned Surface Mission Timeline
page 7



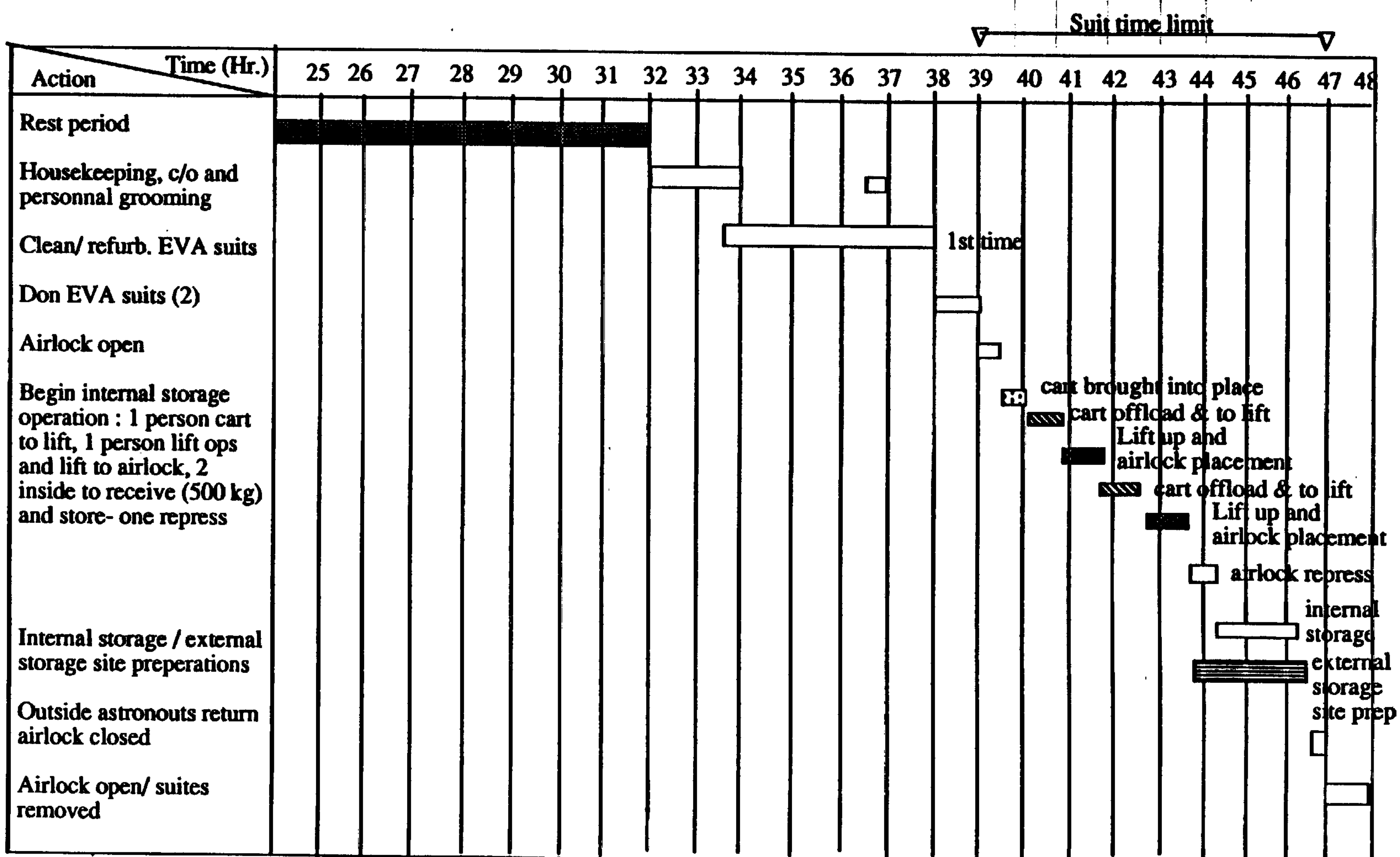
* includes dust off time

2nd Manned Surface Mission Timeline (single EVA)

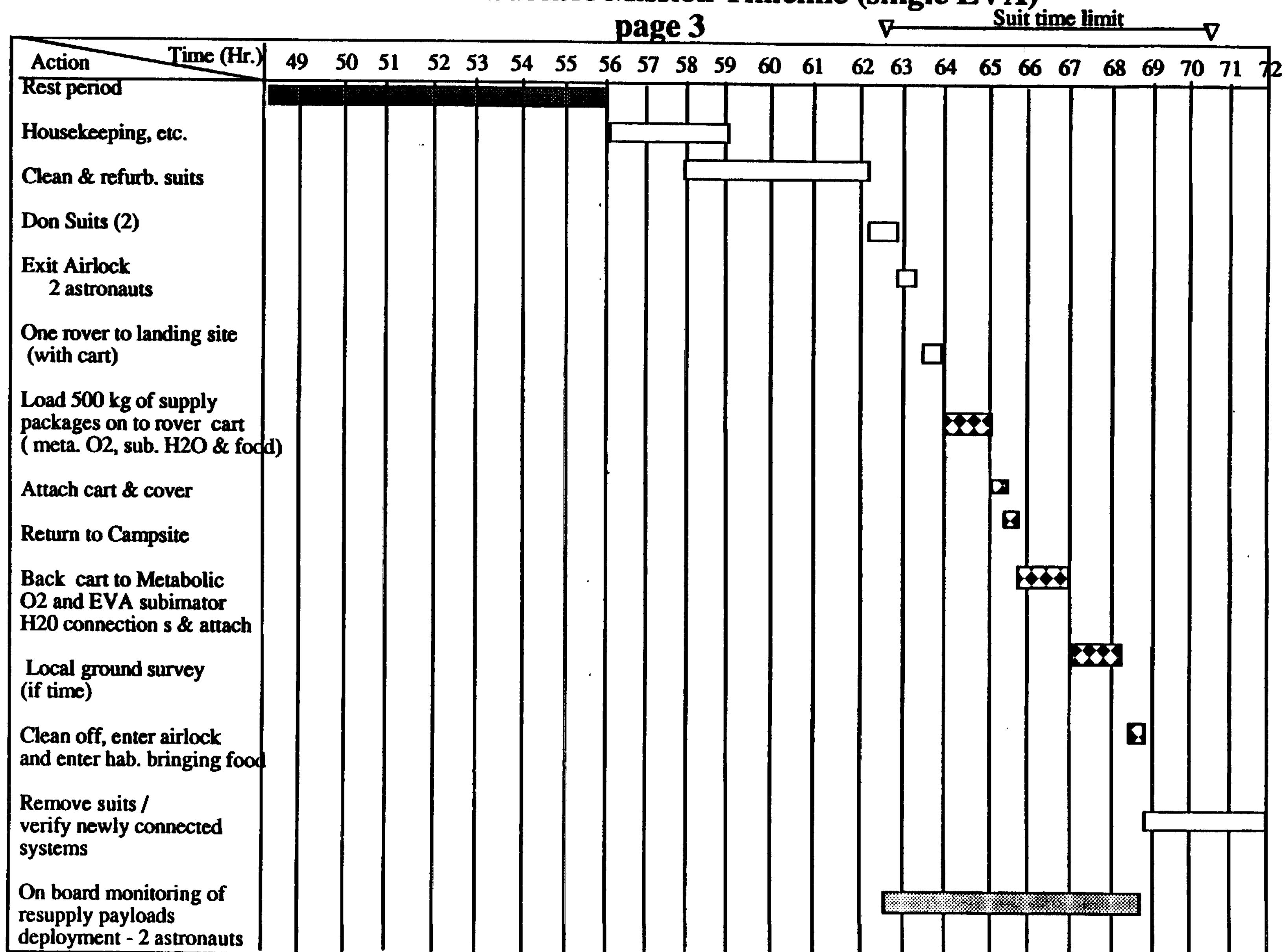
7/6/92



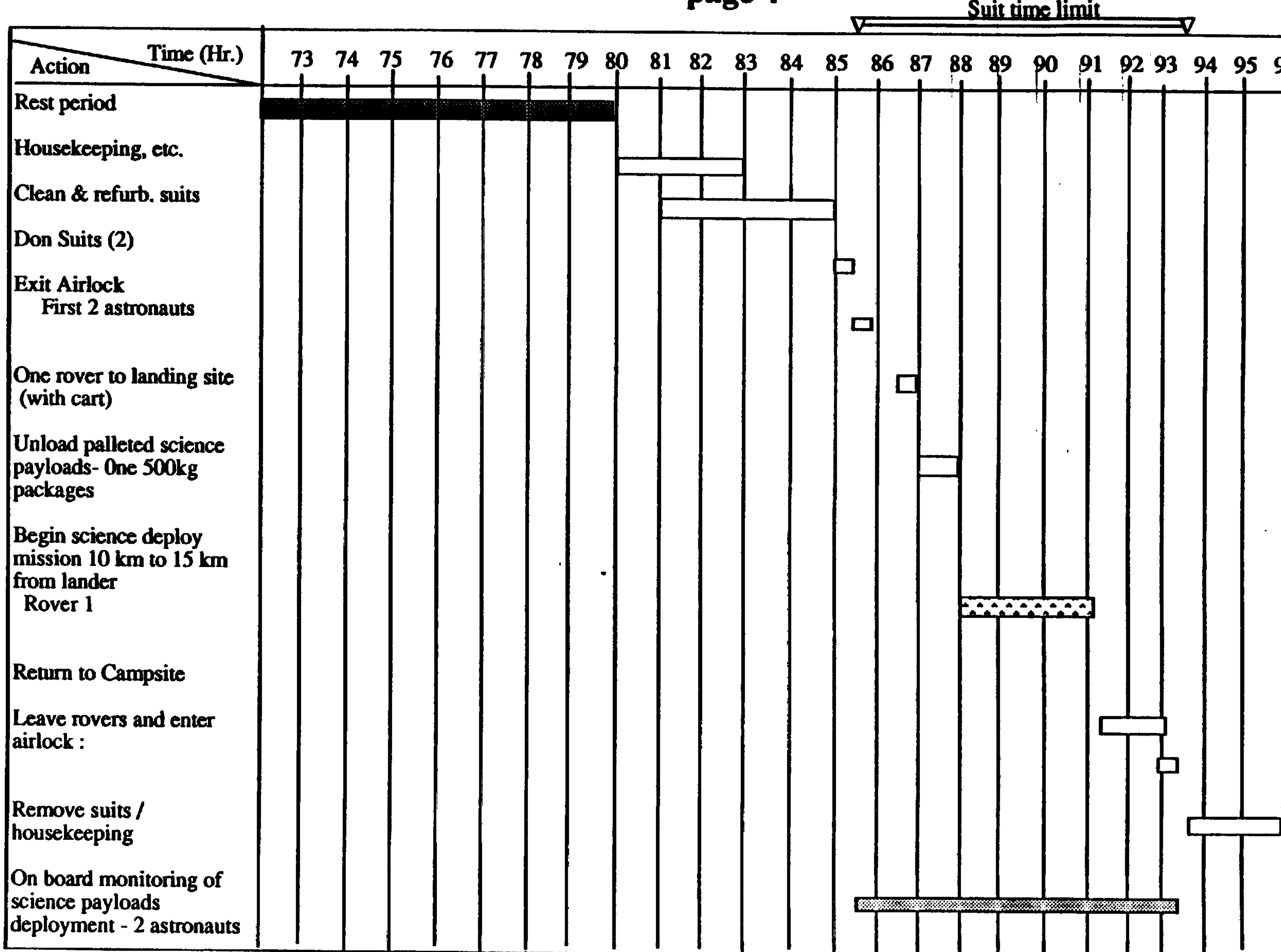
2nd Manned Surface Mission Timeline (Single EVA)
page 2



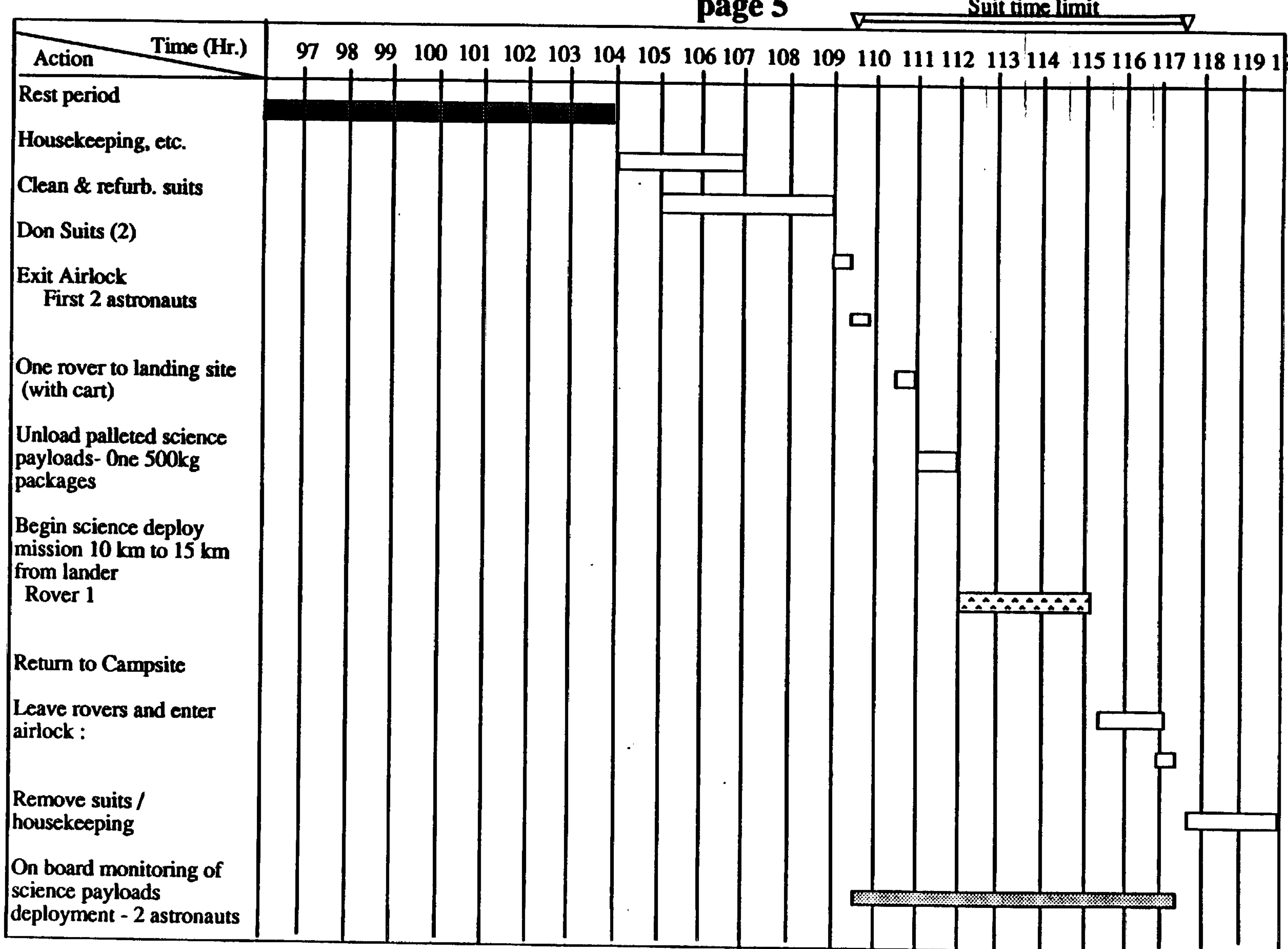
2nd Manned Surface Mission Timeline (single EVA)
page 3



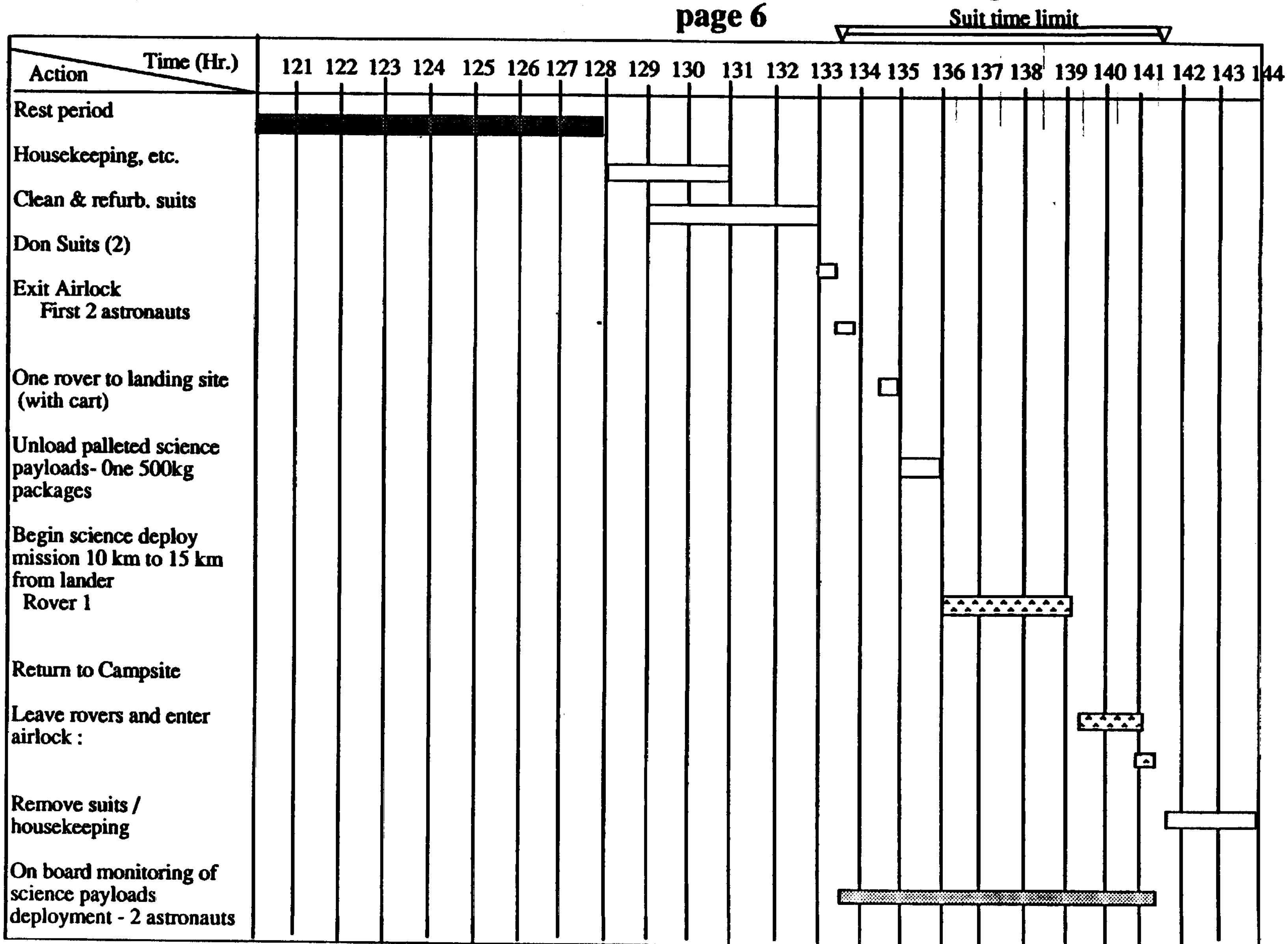
2nd Manned Surface Mission Timeline (single EVA)
page 4



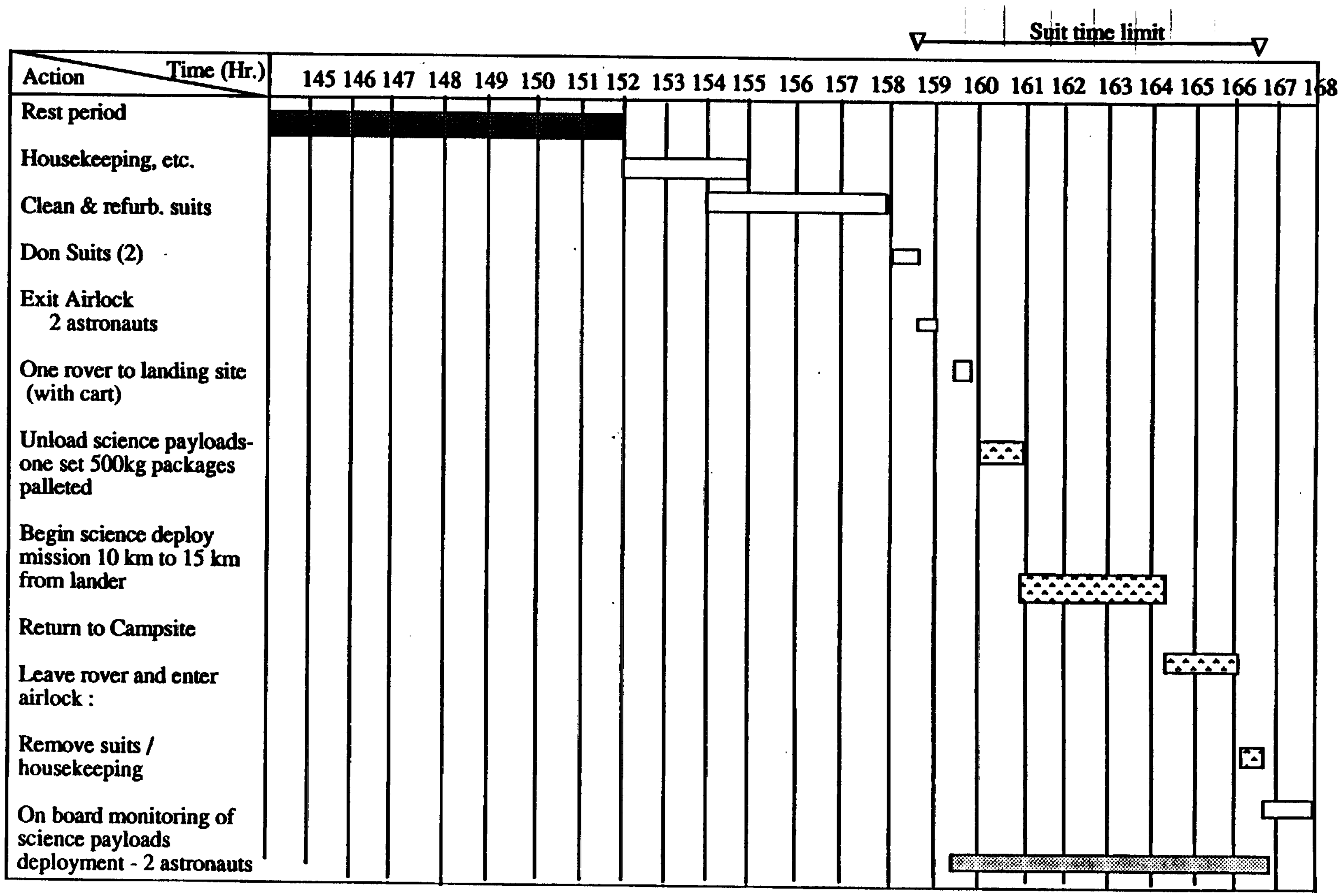
2nd Manned Surface Mission Timeline (single EVA)
page 5



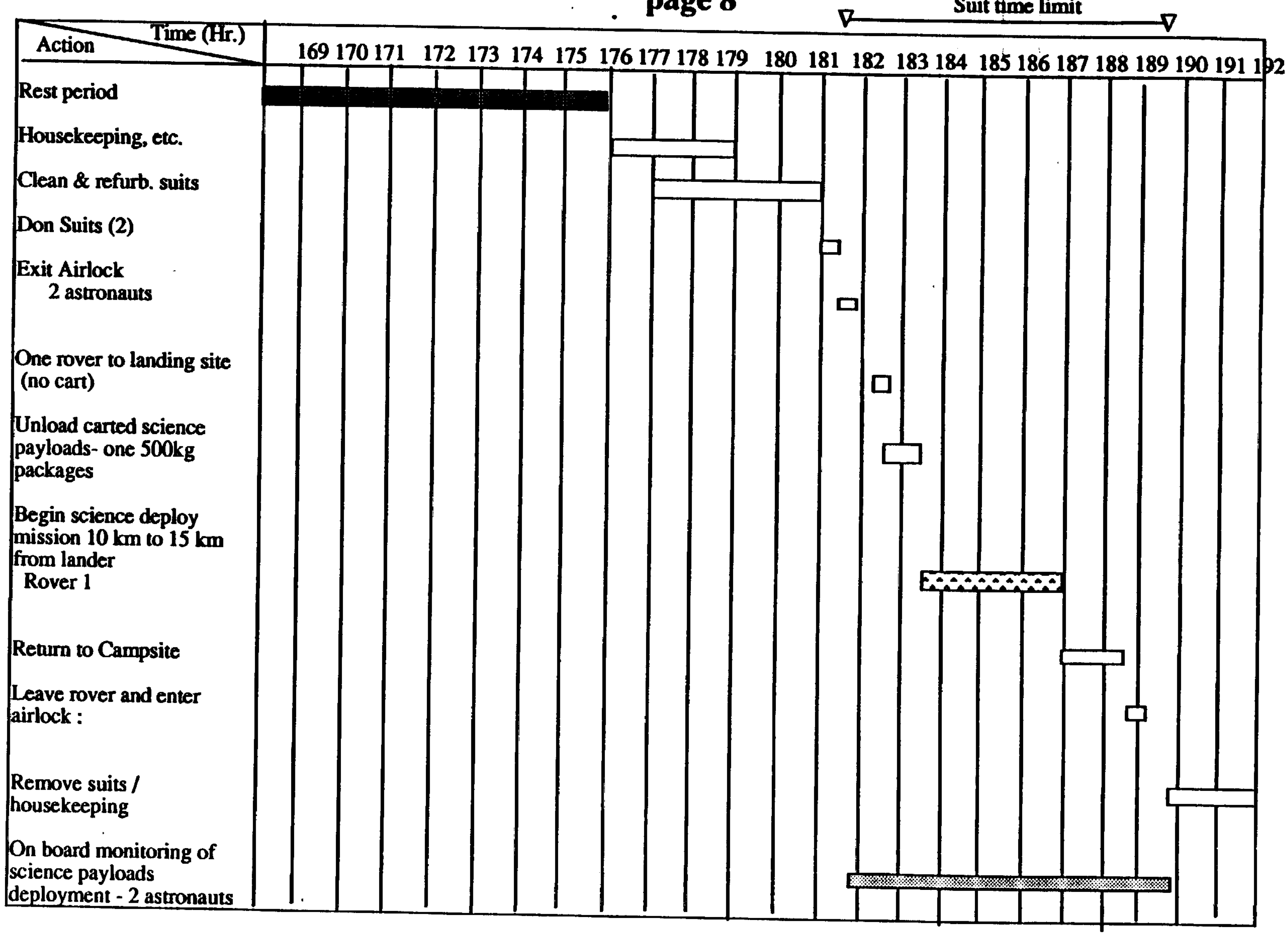
2nd Manned Surface Mission Timeline (single EVA)
page 6



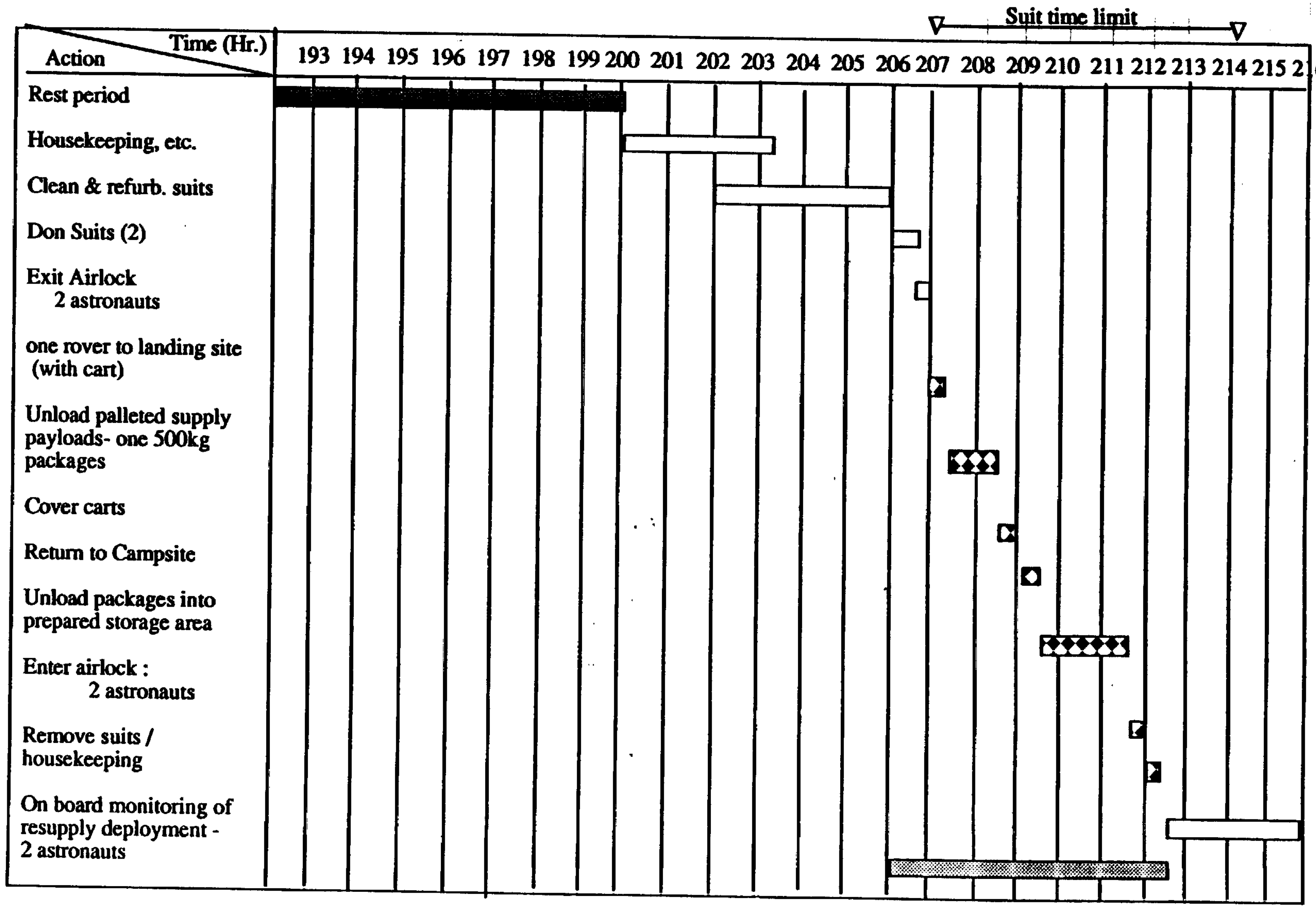
2nd Manned Surface Mission Timeline (single EVA)
page 7



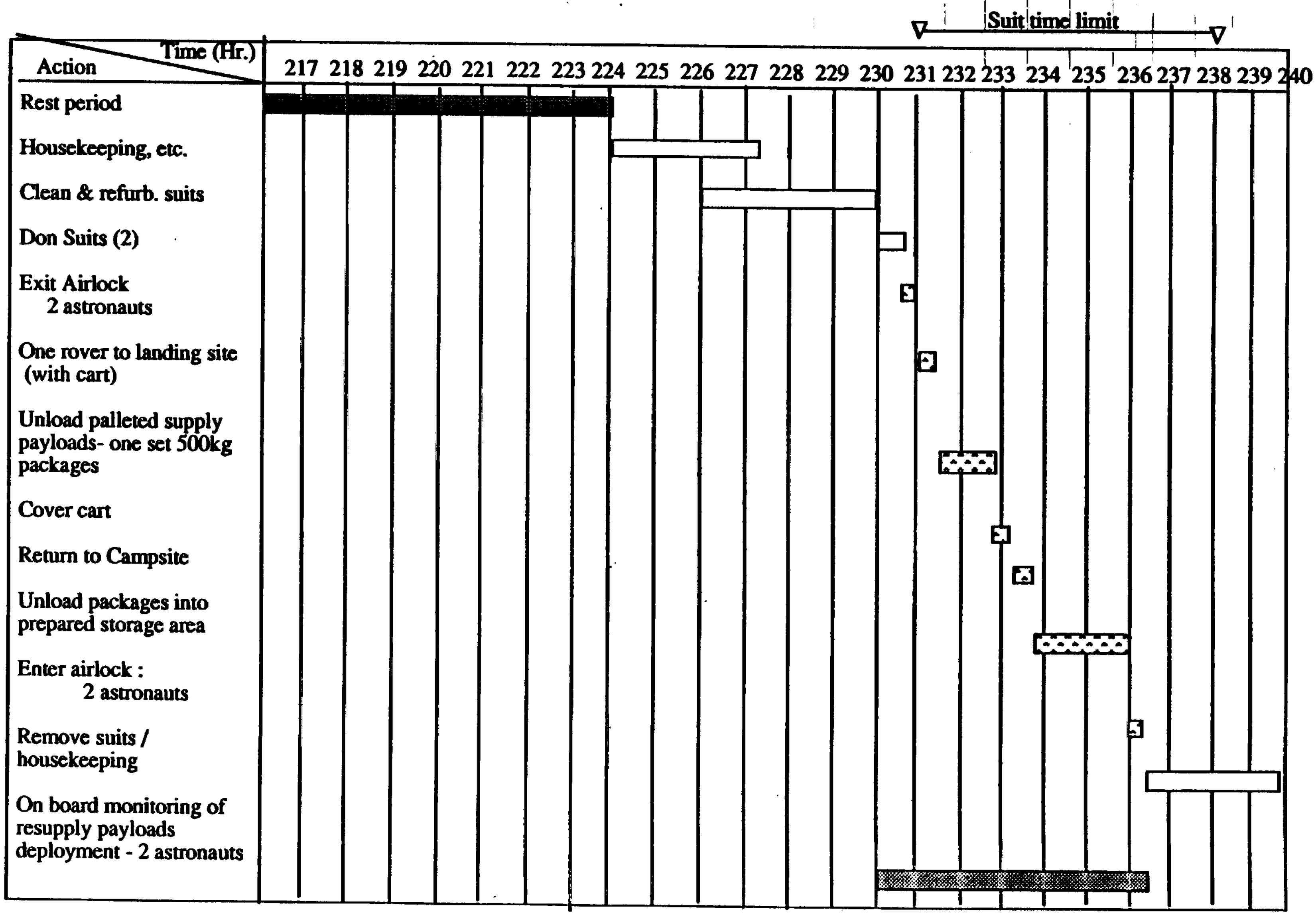
2nd Manned Surface Mission Timeline (single EVA)
page 8



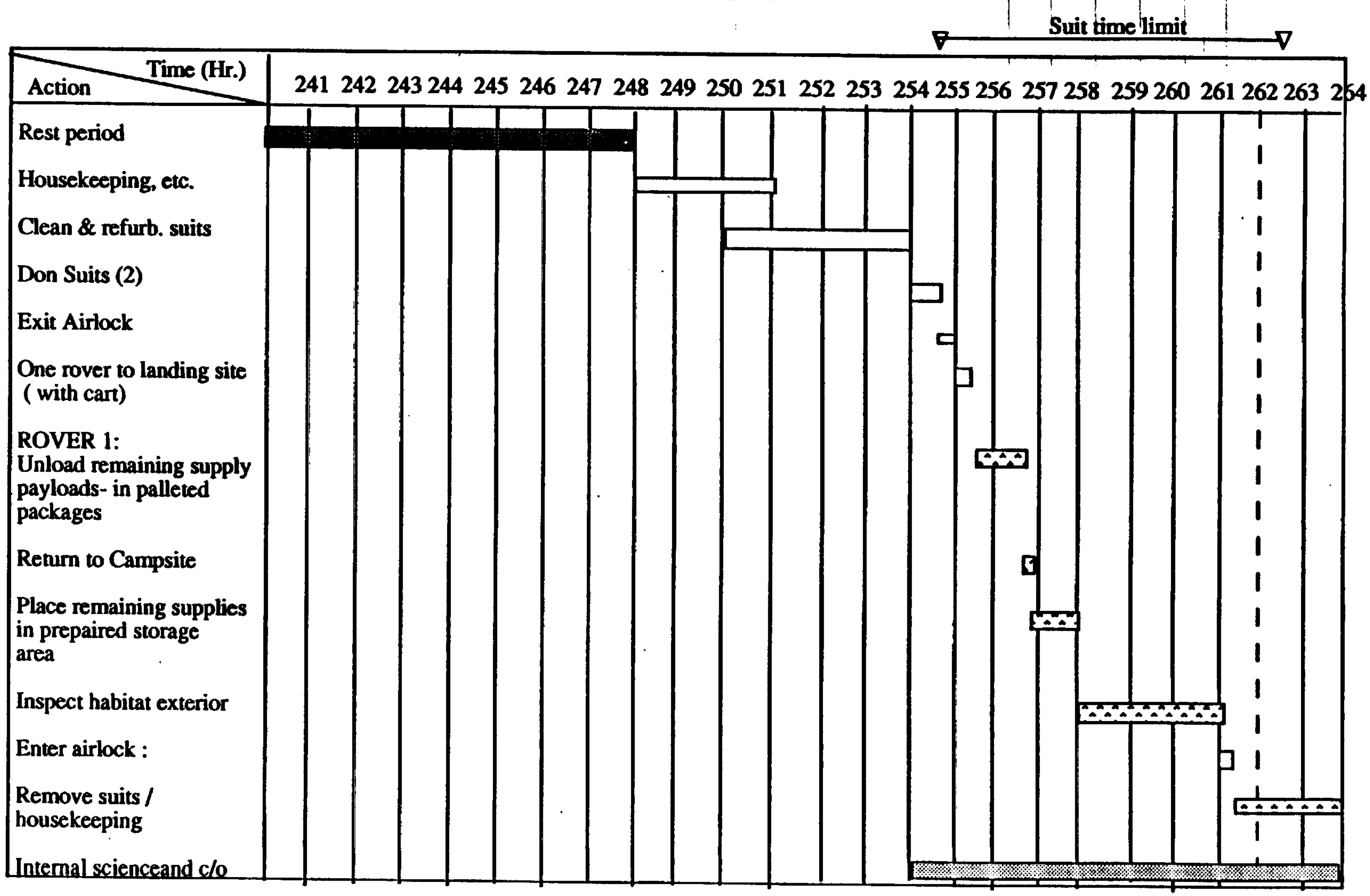
2nd Manned Surface Mission Timeline (single EVA)
page 9



2nd Manned Surface Mission Timeline (single EVA)
page 10



2nd Manned Surface Mission Timeline (single EVA)
page 11



Preliminary Estimate of EVA Task Time Single EVA

- Estimated total available suit time - 38 day mission total time
  - 7 days of total dark (no Earthshine)
  31 days with potential EVA time

31 days at 16 hr./day EVA + 2 days of double EVA (32 hr.) on landing and leaving = 528 hr. EVA

- Estimated task time and percentage of available time:

Task	Time description	Task Time	% total EVA
Crew mission initiate & terminate	initiate= 4(3.5 hr.), terminate= 4(5 hr.)	34 hr.	6.4%
Total airlock time including dust off & suit covering	first day= 4(2.17 hr.), last day= 4(2.17 hr.) 29 hr. at 0.5 hr. per ingress and egress for 2 suits	46.36 hr.	8.8%
Resupply Operations includes - loading carts - preparing sites - storing resupply - resupply transfer to and from outpost - take out garbage/ bring in supplies - cart attachment at outpost	4(4.5 hr.) initial, 2(4(7 hr.)) normal transfer, 2(4.9 hr.) final transfer, 14 hr. at 30 min. / day for 28 days in & out for 2 suits	112.8 hr.	21.4%
Science Deployment	5 (3.1 hr.) for 2	31 hr.	5.9%
Exploration traverse	5 (3.9 hr.) for 2	39 hr.	7.4%
Unallocated time		264.84 hr.	50.1%

Preliminary Estimate of EVA Task Time Double EVA

- Estimated total available suit time - 38 day mission total time
  - 7 days of total dark (no Earthshine)
  31 days with potential EVA time

16 days at 16 hr./day EVA + 15days of double EVA (32 hr.) = 752 hr. EVA

- Estimated task time and percentage of available time:

Task	Time description	Task Time	% total EVA
Crew mission initiate & terminate	initiate= 4(3.5 hr.), terminate= 4(5 hr.)	34 hr.	4.5%
Total airlock time including dust off & suit covering	first day= 4(2.17 hr.), last day= 4(2.17 hr.) 4(15 x 0.5 hr.) ingress and egress for 4 suits, 2(16 x 0.5 hr.) for 2 suits	63.36 hr.	8.4%
Resupply Operations includes -loading carts - preparing sites - storing resupply - resupply transfer to and from outpost - take out garbage/ bring in supplies - cart attachment at outpost	4(4.5 hr.) initial, (4(7 hr.)) normal transfer, 3(2(7hr.)) split, 2(4.9 hr.) final transfer, plus 30 min. / day for 15 days in & out for 4 suits	118 hr.	15.7%
Science Deployment	2 (3.1 hr.) for 4 + 2 (3.4)	31.6 hr.	4.2%
Exploration traverse	2 (3.9 hr.) for 4 + 2 (2.5)	36.2 hr.	4.8%
Unallocated time		468.84 hr.	62.4%

STCAEM/PAB/22AUG92

Appendix F

Reduced Spares

FLO Habitation System

Critical Spares Assessment - Overall

- Critical items for the First Lunar Outpost will eventually be defined and analyzed in accordance with classical parameters :
  - criticality classification due to failure modes and effects (FMEA)
  - mean time between failures (MTBF)/mean time to repair (MTTR)
  - redundancy philosophies and schemes
  - degraded modes and scenarios
  - maintenance and logistics operations

- Identification of spares needed for critical functions will use these same criteria in addition to :
  - overall ORU definition (pertinent to FLO and lunar environment)
  - volume allocation studies (especially for pre-positioned ORUs)
  - other spares needed for routine, non-critical changeout

- Spares studies must be developed for the full set of FLO systems :
  - habitat and internal systems (incl airlock, EVA systems, EMUs)
  - external systems (including landers)
  - payloads (including rovers)
  - crew return vehicle

FLO Habitation System

Critical Spares Assessment - Overall (continued)

- Current assessment is preliminary and focused on spares identified to support crew survival or FLO survival functions :
    - SSF functional failure tolerance categories 1C or 1 (per req'ts)
    - SSF H/W criticality defined by failure modes and effects analysis

- Several SSF references are available for habitat systems :
    - SSP 30000 (PDRD), Sec 3.0, Rev K contains SSMB Functional Failure Tolerance Req'ts (however, critical ORUs remain TBD)
    - D683-10318-1 (Resupply/Return Analysis, ORU Candidates List, Volume 1) contains statistical data from ORU logistics analyses
    - D683-10318-2 (Volume 2) contains reliability and maintainability data to complement Volume 1
    - D683-10220-1 (Critical Items List) contains critical items as identified by FMEA for each of the SSF systems

- SSFP is currently defining its critical spares needs with results expected in the CDR timeframe (~April 1993)

- External and other systems critical spares needs will be estimated from reference concepts

FLO Habitation System

Critical Spares Assessment - Overall (continued)

Some questions to be answered

- Guidelines are needed to establish a reasonable preliminary spares list :
  - SSF ORU requirements are not available
  - limited payload volume and mass are available on FLO
  - FLO is not permanently manned, but only tended for 45 days
  - ensuring operability during unmanned periods may drive system redundancy as much as or more than manned requirements

- "Hot" vs "cold" spares must be considered (balancing on-line redundancy with in-situ repair capability)

- Differences between FLO and SSF failure tolerance requirements, system design, and mission focus must be addressed in developing critical spares estimates

- Is SSF MTC or PMC failure tolerances or some other scheme more appropriate for FLO ?

ADVANCED CIVIL SPACE SYSTEMS

FLO Habitation System

Critical Spares Assessment - Habitat

BOEING

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
1. Respirable Atmosphere	*1.1 O2/N2 Storage (external?)*	*1C / 1R*	• Make-up/Metabolic O2	119.8 / 185.4	0.26 / 0.15
		1R	• Make-up N2	259	0.67
		1R	• Gas conditioning assy	O2 / N2 292.5 / 292.5	O2 / N2 2.37 / 2.37
	1.2 O2/N2 Distribution	*1C / 1R*	• Isolation valve assemblies	O2 1.13 | N2 1.13	O2 0.001 | N2 0.001
		1R	• Jumper assemblies	8.84 | 8.84	0.001 | 0.001
		1R	• Transducers	0.68 | 0.68	.0001 | .0001
		1R	• Check valves	0.68 | 0.68	0 .001 | 0.001
	1.3 O2/N2 Pressure Control	*1C / 1R*	• Pressure control panel	8.35	0.054
		1R	• Press. equalization valves	2.31	0.003
	1.4 CO2 Removal	*1C / 1R*	• Desiccant/sorbent bed	36.28	0.177
		1R	• CO2 pump	7.26	0.005
		1R	• Selector valve	1.36	0.002
		1R	• Wire harness	1.36	0.011
		1R	• Temperature sensor	0.32	0.0003
		1R	• Blower/precooler unit	4.54	0.019
		1R	• Pressure transducer	0.32	0.0003

Page Total minus external stores: 84.76 0.278

External spares : 1,149.2 5.8.2

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
1. Respirable Atmosphere	*1.5 Air Particulate & Microbial Control*	*1C / 3*	• Cabin air bacteria filter assy	5.08	0.019
		1R	• Supply rack air cntrl valve	3.18	0.010
		1	• Cabin air/IMV bact filter	2.54	0.009
		1R	• Return rack air cntrl valve	1.13	0.007
		3	• IMV bacteria filter assy	13.61	0.059
	1.6 Cabin Air Temp and Humidity Control	*1C / 1R*	• Heat exchanger	72.47	0.336
		1R	• Fan group	20.50	0.040
		1R	• Temperature cntrl chk vlve	8.21	0.025
		1R	• Outlet temperature sensor	0.77	0.0005
		1R	• Water separator	18.87	0.088
		1R	• Electrical interface box	17.51	0.041
		1R	• Inlet temperature sensor	0.77	0.0005
		1R	• Liquid sensor	2.09	0.007
		1R	• Inlet	2.27	0.035
	1.7 Circulation	*1C /*	see above - may be enough		
	1.8 Vent and Relief	*1C /*	• Vent & relief subassembly	8.35	0.009

Page total : 177.35 0.686

ADVANCED CIVIL SPACE SYSTEMS

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

BOEING

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
1. Respirable Atmosphere	*1.9 Atmosphere Composition Monitoring*	*1C / 1R*	• MCA data & cntrl assembly	8.12	0.025
		1R	• Mass spectrometer assy	10.34	0.018
		1R	• COA assembly	10.52	0.005
		1R	• Low voltage pwr supp assy	3.22	0.004
		1R	• MCA/TCM series pump	1.36	0.004
		1R	• MCA sample distr assy	2.04	0.003
		1R	• EMI filter	1.72	0.002
		1R	• TCM data and control assy	8.12	0.002
		1R	• Gas chromo/mass spec assy	30.98	0.029
		1R	• TCM heater controller assy	7.53	0.005
		1R	• PCM assy	17.87	0.005
		1R	• PCM 100 micron filter assy	9.98	0.001
		1R	• TCM parallel pump assy	1.72	0.001
		1R	• TCM sample distr assy	2.90	0.001
		1R	• TCM oxidizer evaporator	4.76	0.001
		1R	• 2µ PCM filter assy	0.09	0.001
		1R	• Verification gas assembly	2.36	0.011
		1R	• MCA chassis assembly	17.87	0.005
		1R	• TCM chassis assembly	17.87	0.005
			Page Total:	**159.37**	**0.126**

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
1. Respirable Atmosphere	*1.10 Trace Contaminant Monitor*	*1C / 1R*	*See MCA ORU data above*		
	1.11 Trace Contaminant Control	*1C / 1R*	• Charcoal bed	33.96	0.076
		1R	• Post-sorbent bed	3.66	0.008
		1R	• Catalytic oxidizer	12.06	0.024
		1R	• Electronic interface assy	4.54	0.004
		1R	• Flow meter	0.95	0.0002
		1R	• Blower	------	-------
	1.12 Avionics Air Temperature and Humidity Control ??		*Assumed part of internal thermal control ORU data*		
2. Food	*2.1 Food Storage*	*1C /*	MREs or 45 day supply - listed separatly	360.0	0.58

Page total minus food: 55.17 0.112

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
4. Personal Hygiene	*4.2 Urine Storage*	*1C /*	TBD		
	4.3 Fecal Waste Collection	*1C / 1*	• Fecal odor/bacteria filter	1.64	0.003
		1	• Fecal fan	3.01	0.006
		1	• Plenum bacteria filter	0.10	0.002
		1	• Compactor	7.70	0.001
		1	• Transport tube	9.95	0.011
		1	• Seat	2.33	0.007
		1	• Waste storage canister	0.91	0.012
		1	• User service panel	1.96	0.001
		1	• Electrical interface box	4.93	0.017
	4.4 Fecal Waste Storage	*1C /*	TBD		
5. EVA Capability	*5.1 Ingress to Habitat & Repressurization*	*1C /*	TBD		
	5.2 Crew Retention	*1C /*	*May not be applicable*		

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Page Total : 32.53 0.060

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
7. Power	*7.2 Provide Power to Category 1C Functions*	*1C / 1R*	*See ORU list above*		
8. DMS	*8.1 Data Management for Category 1 Functions*	*1 /*	TBD		
	8.2 Data Management for Category 1C Functions	*1C /*	TBD		
9. TCS	*9.1 Power Generation Heat Acquisition, Transport, and Rejection*	*1 /*	• External Systems		

FLO Habitation System

Critical Spares Assessment - Habitat (continued)

Resource	Function	Functional Category/ Criticality	Implementing ORU	Mass (kg)	Volume (m3)
9. TCS	*9.3 Thermal Support to Category 1C Functions*	*1C /*	*See TCS ORU data above*		
	9.4 Thermal Mgmt and Control	*1 /*	• External Systems (?)		
10. Health and Status Monitor	*10.1 Health and Status Monitor for Category 1 Functions*	*1 /*	**TBD**		
	10.2 Health and Status Monitor for Category 1C Functions	*1C /*	**TBD**		

Other resources and/or associated functions have less critical failure tolerance requirements

FLO Habitation System

Critical Spares Assessment - Issues

- Several of these ORUs currently identified as critical seem questionable :
    - Food storage (what does this mean - amount or locations ?)
    - Fecal/urine collection
    - Portions of the power system
    - Portions of the thermal control system

- Some critical functions specific to SSF have not been included :
    - Provide interface to Space Shuttle
    - Assembly and Checkout
    - Command and control (orbit, attitude, navigation)

- Critical spares for some FLO functions not yet identified :
    - non-WP01 items (DMS, DDCUs, etc.)
    - airlock and EVA systems
    - CHeCS
    - external systems
    - lander systems
    - payloads
    - crew vehicle

Known Spares Needs

	Mass kg	Volume m^3
External gases and distribution systems	1,149.2	5.82
Food	360.0	0.58
Known internal	1,179.6	3.79

- Not all outpost spares are addressed
- Lander spares not addressed
- Failure rates for continuously active critical items undefined (number of copies of critical items not known)

Spares Assessment Consequences

- Forces a gleaning of the known spares and a cannibalization strategy on common parts

- Forces decisions on abort scenarios
  - After what devices fail does an abort automatically occur?
  - Decision criteria needed for when to replace, replace & repair or escape and return

- Forces a decision on what spares should be "on hand" and stored at the outpost and which ones can be replaced by the next mission

- Demands that the conditions when the return vehicle fails be addressed (stuck on surface)