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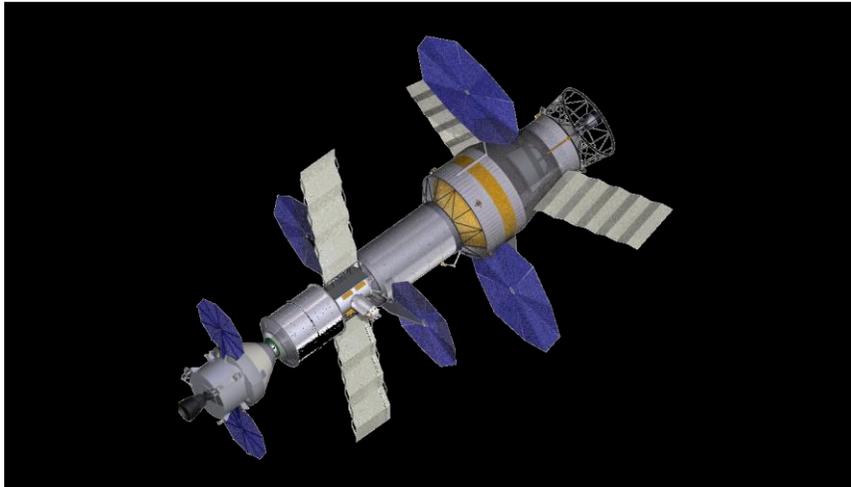
**DEEP SPACE HABITAT CONFIGURATIONS BASED ON  
INTERNATIONAL SPACE STATION SYSTEMS**

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**A Deep Space Habitat (DSH) is the crew habitation module designed for long duration missions. Although humans have lived in space for many years, there has never been a habitat beyond low-Earth-orbit. As part of the Advanced Exploration Systems (AES) Habitation Project, a study was conducted to develop weightless habitat configurations using systems based on International Space Station (ISS) designs. Two mission sizes are described for a 4-crew 60-day mission, and a 4-crew 500-day mission using standard Node, Lab, and Multi-Purpose Logistics Module (MPLM) sized elements, and ISS derived habitation systems. These durations were selected to explore the lower and upper bound for the exploration missions under consideration including a range of excursions within the Earth- Moon vicinity, near earth asteroids, and Mars orbit. Current methods for sizing the mass and volume for habitats are based on mathematical models that assume the construction of a new single volume habitat. In contrast to that approach, this study explored the use of ISS designs based on existing hardware where available and construction of new hardware based on ISS designs where appropriate. Findings included a very robust design that could be reused if the DSH were assembled and based at the ISS and a transportation system were provided for its' return after each mission. Mass estimates were found to be higher than mathematical models due primarily to the use of multiple ISS modules instead of one new large module, but the maturity of the designs using flight qualified systems have potential for improved cost, schedule, and risk benefits.**

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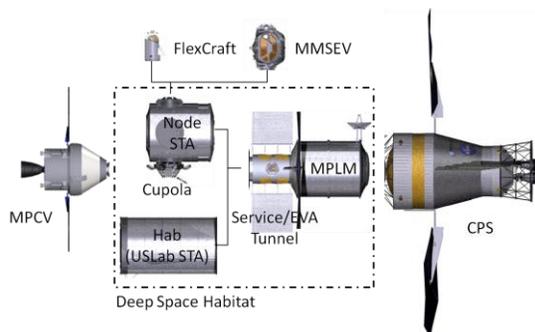
**I. INTRODUCTION**

A Deep Space Habitat (DSH) is the home and work place for astronauts on long duration missions beyond Earth orbit (BEO). Candidate destinations include asteroids, Mars and the Earth-Moon Lagrangian points. This study was conducted for the AES Habitation project to determine the feasibility of using systems from the International Space Station (ISS) and Multi-Purpose Crew Vehicle (MPCV) for the DSH. Potential benefits of this approach are a significant cost reduction, lower technical risk and schedule compression enabling early operations. Because of the differences in environment, mission duration, and technology maturation ISS systems were selected based on whether they were a good match for a deep space mission. Another important consideration is that most deep space missions do not have an emergency return capability. This played an important role in the selection and sizing of systems as well as creating a layout that enabled anytime maintenance by the crew.

The study used combinations of the ISS Node Structural Test Article (STA), the Multi-Purpose Logistics Module (MPLM), and the Hab (USLab STA) as the pressure vessels for the DSH. These elements were selected because the structural shells are on the ground and available. Configurations were designed to accommodate a crew of four for mission durations of 60 and 500 days.

**II. VEHICLE CONFIGURATION**

The DSH is part of an exploration vehicle designed to transport astronauts to the destination and return them to Earth. Other elements in the configuration (Fig. 1) included a Cryogenic Propulsion Stage (CPS), Multi-Purpose Crew Vehicle (MPCV), Service/EVA tunnel for mounting external equipment

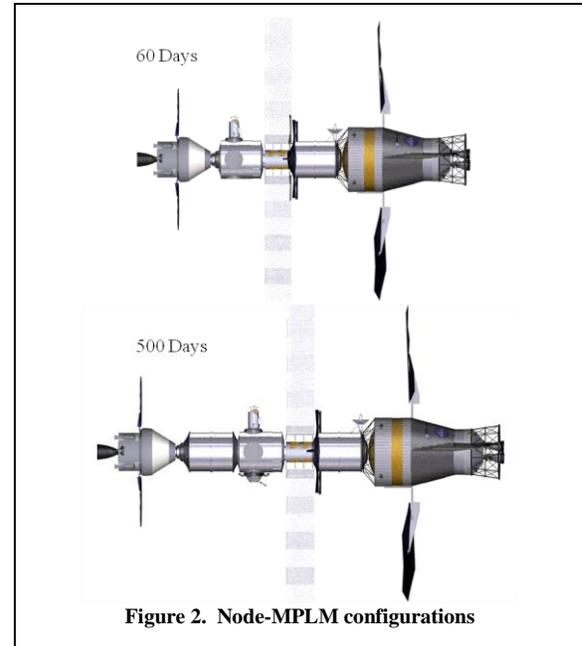


**Figure 1. Configuration elements**

such as solar arrays and radiators and FlexCraft, a single-person spacecraft or the Multi-Mission Space Exploration Vehicle (MMSEV) a two-person spacecraft. In addition, an ISS Cupola was included

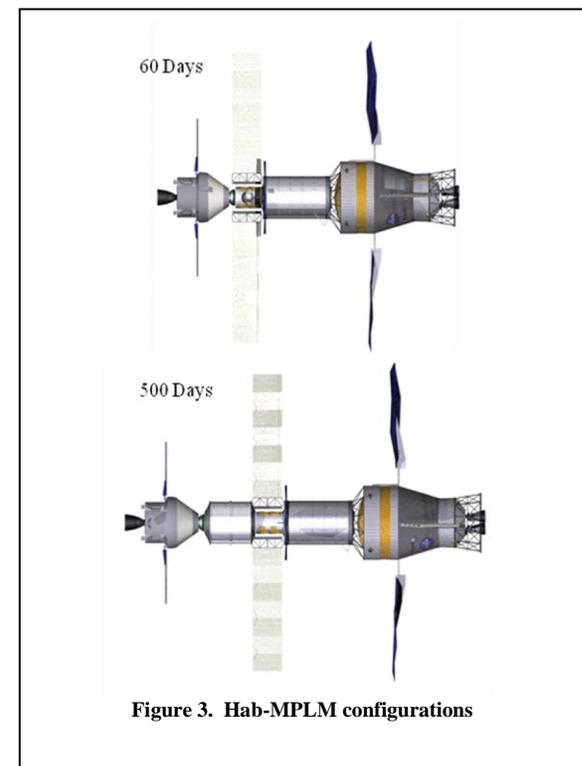
for configurations that used the Node because of the radial port needed for attachment.

The study analyzed four vehicle configurations to cover all options. Using combinations of the Node and MPLM 60 day and 500 day configurations were developed (Fig. 2). Then, 60 and 500 day



**Figure 2. Node-MPLM configurations**

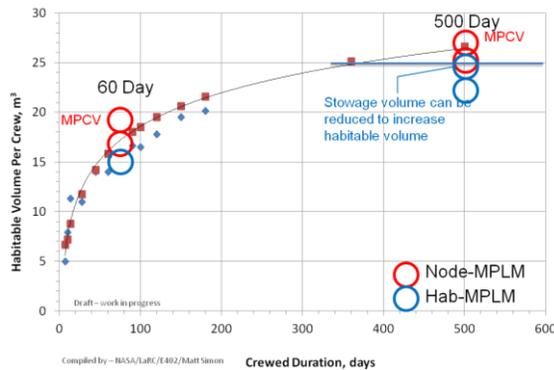
configurations Using the USLab STA and MPLM were created (Fig.3).



**Figure 3. Hab-MPLM configurations**

**Volume**

The challenge with using existing hardware is the efficient assembly of the elements. First, an internal layout tailored for deep space missions was developed, then subsystems and consumables were sized and packaged within the planned layout. This was an iterative process that relied on the input from subsystem engineers for preferred location, line length and accessibility. The initial design position assumed adequate volume for all the outfitting, but not until the modules were packaged could the habitable volume actually be determined. This is important because historical averages show volume increasing with mission duration and then leveling out at one year or 25 m<sup>3</sup>/crew member. Figure 4 shows that Node-MPLM configurations met or were



**Figure 4. ISS-derived habitable volumes compared to historical averages.**

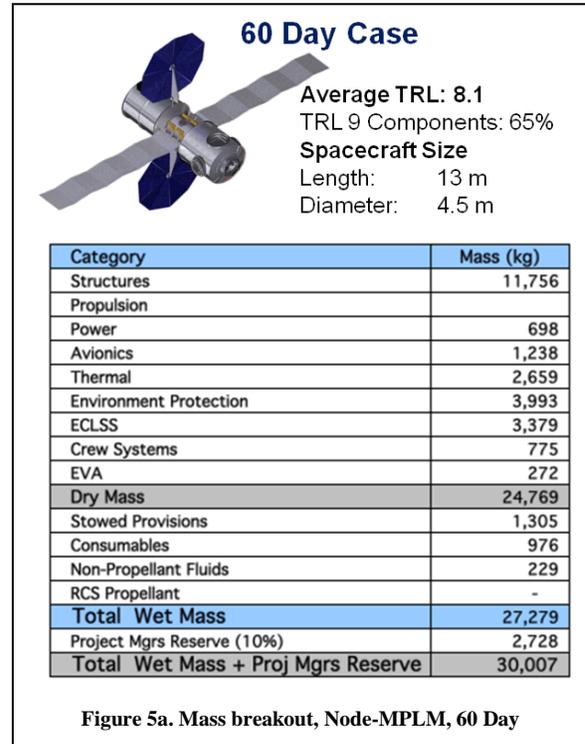
very close to the average, in particular when MPCV volume was included. The Hab-MPLM volumes were slightly lower but should increase because estimates for stowage volume were conservative.

**Mass**

Prior to this study, mass estimates were derived from parametric models. Because ISS systems have flown, the actual weights are available and to the extent possible, these were used for estimating the ISS-derived DSH weight. Subsystem engineers were responsible for defining their systems and assigning an appropriate technology readiness level (TRL). Using the AIAA convention, the TRLs provided the mass growth allowance for components and systems. To this, a Project Manager Reserve (PMR) of 10% of the dry and wet mass was added for the overall mass estimation. See Figures 5 a, b, c and d.

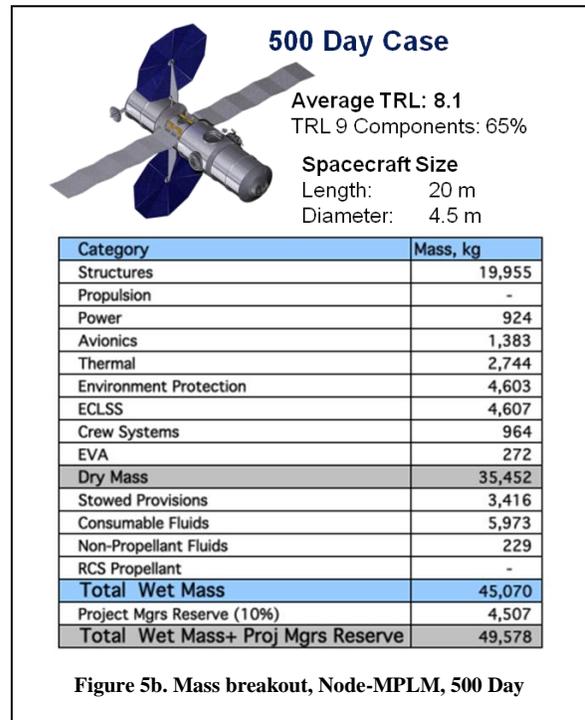
**Layout**

The philosophy for ISS build up and resupply was based on the delivery of many elements that were assembled and outfitted in low Earth orbit (LEO). The MPLM, Node and Hab are all designed to fly on the Space Shuttle which is no longer in service but the elements used to create a DSH still bear the



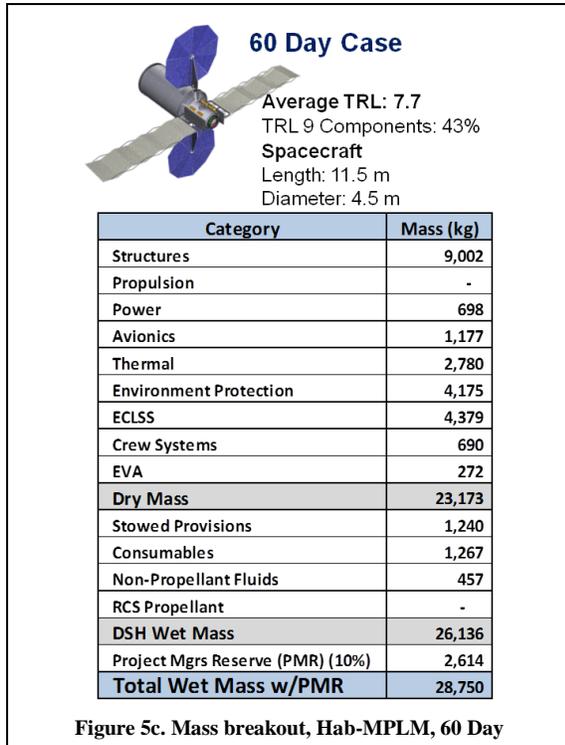
**Figure 5a. Mass breakout, Node-MPLM, 60 Day**

heritage of the Shuttle/ISS philosophy. Namely, this is a modular system of interchangeable racks attached to four utility standoffs. This turned out to be a



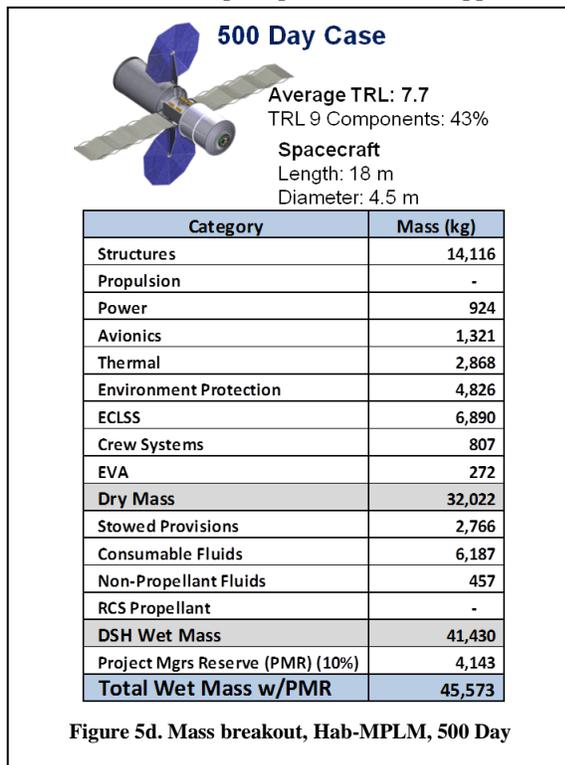
**Figure 5b. Mass breakout, Node-MPLM, 500 Day**

heavy solution because of the additional structure required for each rack and the complex distribution of utilities necessary to supply all racks. This interchangeable approach worked for ISS in LEO,



but imposes unnecessary mass penalties for a BEO DSH. For example, the ISS Lab (Destiny) could only be launched with 5 out of the required 24 racks.

Because ISS is close to Earth and within reach of the international partners launch systems, the crew, consumables, and spare parts can be resupplied on a



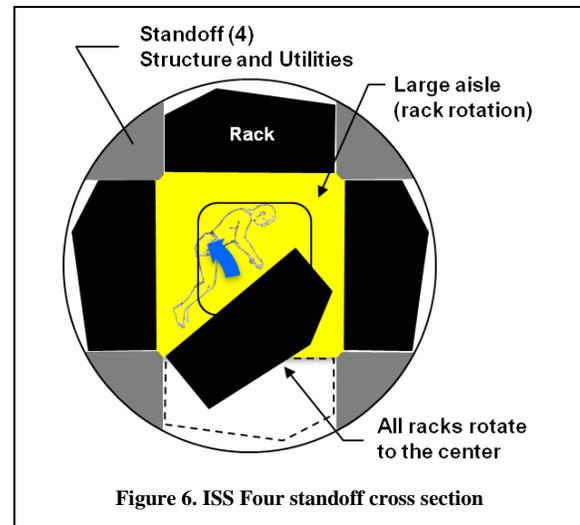
routine basis. In contrast, deep space missions must take all crew, consumables and spares for the entire duration without resupply. Furthermore, if there is an emergency on board ISS, the crew always has a rapid return capability. Because of the trajectory and propulsive energy requirements, deep space missions have no emergency return to Earth. This means that the crew must have the resources and parts to recover from emergency situations any time during the mission.

Another very important difference is that ISS does not have a Habitation Module. ISS serves more as a laboratory providing habitation functions across the pressurized elements. Because of the long transportation times, deep space missions are different requiring particular emphasis on habitation.

Tailored DSH Architecture

This study looks at keeping the high value ISS investments and repackaging them into a more efficient non rack-based configuration specifically tailored to the long duration missions. Orbital Replacement Units (ORUs) are the sub-rack assemblies designed for servicing and repair. The ISS-derived DSH uses ISS ORUs in a configuration created for long duration missions designed for greater autonomy. There is a “cost” for repackaging ORUs, but it is compensated by a more efficient and ultimately lighter DSH. For this study, repackaging ORUs was factored into the TRL assessment resulting in higher mass estimates.

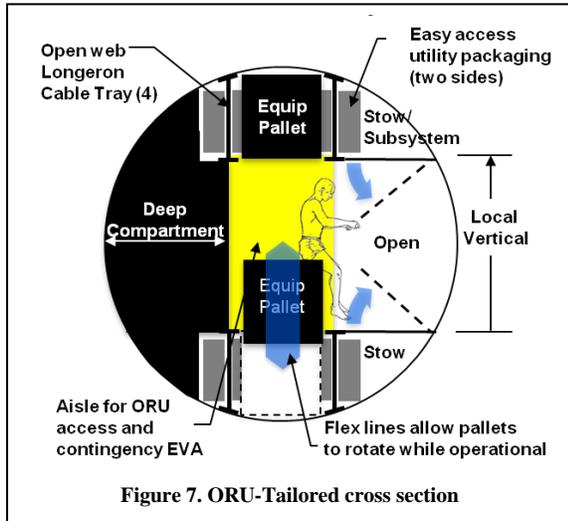
The ISS four standoff configuration places standardized racks end-to-end in a square around the circumference of the pressure vessel (Fig. 6). The racks are supported and restrained by a triangular



standoff structure which also encloses the air ducts, plumbing, electrical power and data cabling required to interconnect subsystems. The result is a large (~2m x ~2m) aisle way extending from one end of the

module to the other. Although it works as a laboratory, it is not an efficient habitat layout. The major issue is that the same size racks do not accommodate the varied habitation functions.

The ORU-Tailored configuration shown in Figure 7, provides a smaller (1.5m x 2m) multi-use aisle way



with emphasis on larger volumes for habitation functions such as private crew quarters, waste/hygiene, full body cleansing, group meals/meetings, and exercise.

Access to utilities is another important difference. ISS utilities are densely packed in standoffs making inspection or repair difficult and time consuming. To improve the design, utilities are arranged one layer

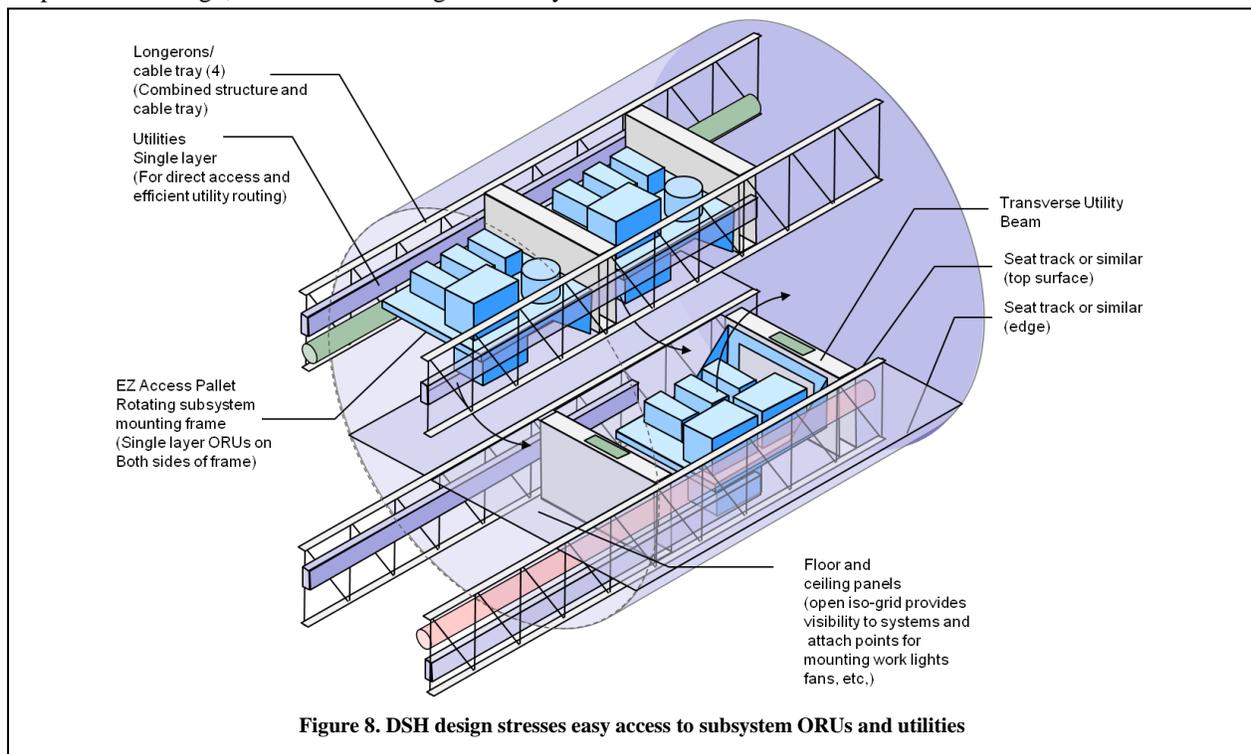
deep attached to an open web longeron that doubles as a cable tray. This configuration gives both direct visual and physical access to utilities.

ISS racks are enclosed which makes getting to the ORUs difficult. For repair and maintenance, DSH crews will need to see and get to hardware without removing or disconnecting other hardware. The Tailored concept features rotating, double-sided equipment pallet with ORUs mounted to both sides. This design was specifically created to allow easy access to components which is an essential feature for keeping life-critical systems operational for up to five hundred days.

The ORU-Tailored approach provides direct access to operating systems, utilities, and the pressure vessel wall. Four open truss longerons support the subsystems and outfitting hardware. For normal inspections and servicing it is important to get to hardware quickly without disruption to other systems. For this, the trusses double as cable trays with single layer packaging for direct access without having to remove or go around other hardware.

Pallets are designed for mounting subsystem ORUs on either side of a rotating frame. The purpose is to double the layout area while providing the same single layer accessibility as the utility trays. Pallets swing into the aisle way for access to both sides providing access to the pressure vessel hull. Flex lines connect the pallet to the utility tray allowing the system to remain functional during inspections.

Transverse utility beams connect the longerons



providing structural stiffness, pivot points for the pallets, utility cross over, and mounting surfaces for lights, diffusers and filters.

Internal Layout including Crew Systems

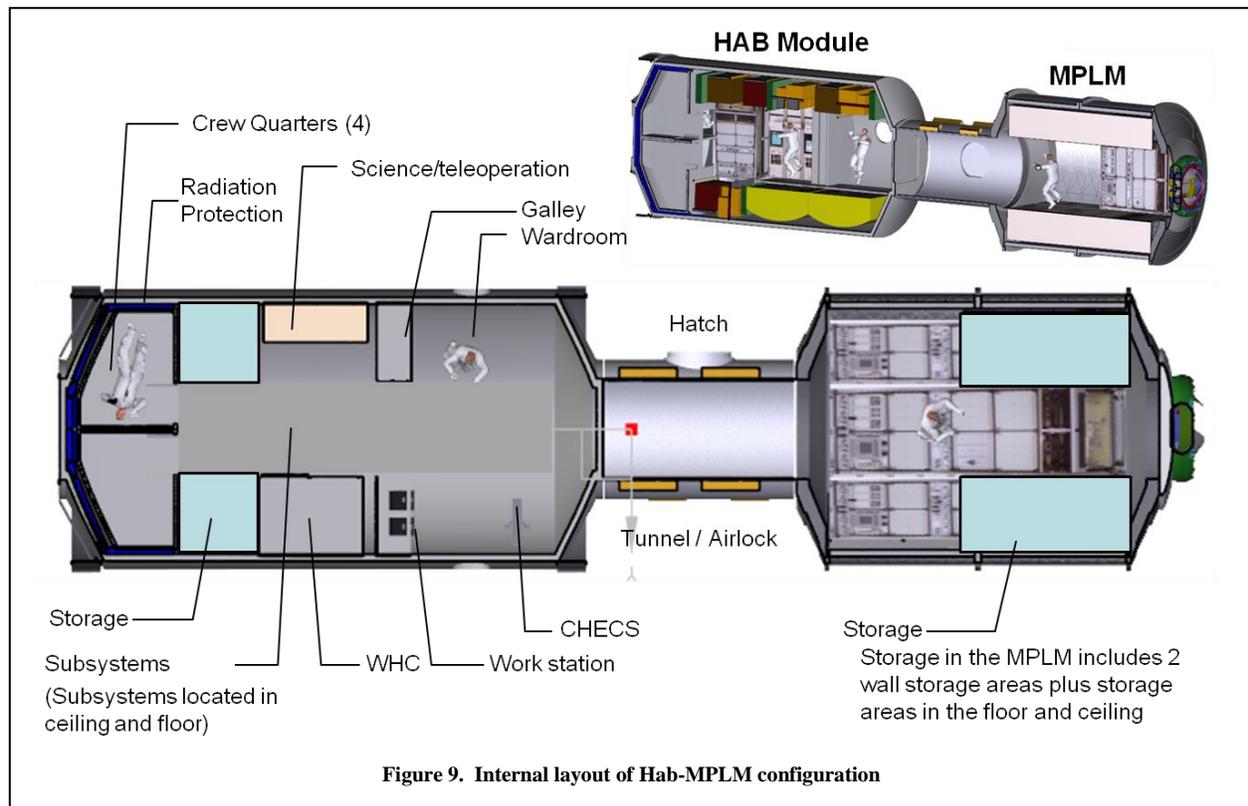
The DHS layout shown in Figure 9 includes all subsystems and outfitting for long duration habitation and science for a crew of 4. Even in the weightless environment, habitats are designed with a local vertical orientation. Accordingly, the ISS-derived DSH configuration positions the active subsystems in the floor and ceiling maintaining a consistent orientation in the wall location for the habitability functions such as the galley/wardroom. The local vertical is further reinforced by overhead lighting, a consistent orientation for labeling and displays, and a head-to-toe airflow. The exception is the crew quarters. They are located at the dead-end of the module to take advantage of the additional end cone volume and to separate them from the more active and noisy activities at the opposite end. With this arrangement, each crewmember gets about twice the volume as the ISS crew quarters. Because the planned sleep time is 8 hours, the crew quarters will be the single place where each astronaut spends the most time. Therefore, this area is provided with 11 cm of radiation shielding to provide passive protection and to weather out solar proton events. Storage is placed adjacent to the crew quarters to provide acoustic insulation and add to radiation

protection.

The active end of the DSH opens to the full 4.3 m diameter and includes a galley/wardroom on one side with accommodations for Crew Health Care (exercise) on the other. This large open area is a multi function space and also includes storage for Crew Health Care medical provisions and a work station for flight operations. Events in this area are time shared so that exercise does not interfere with the common meal time.

In the middle of the module are the waste/hygiene compartment (WHC) and the science/maintenance work station. The WHC is convenient to both the active and passive ends of the module without the interference of being directly adjacent. The science/maintenance station is outfitted for the mission or task at hand. In other words, it may contain a glove box for sample inspection or be the processing center for a telescope.

ISS utilities in standoffs run continuous down the length of the module. This means those utilities that need to return to the source for reconditioning must cross over at one end of the module. For example, the supply air that comes out of the overhead standoffs is collected in the lower standoffs and must be routed to the end and back to the source for moisture and carbon dioxide removal. This solution results in long ducts that require more power to move the air. Limited real estate in the standoffs



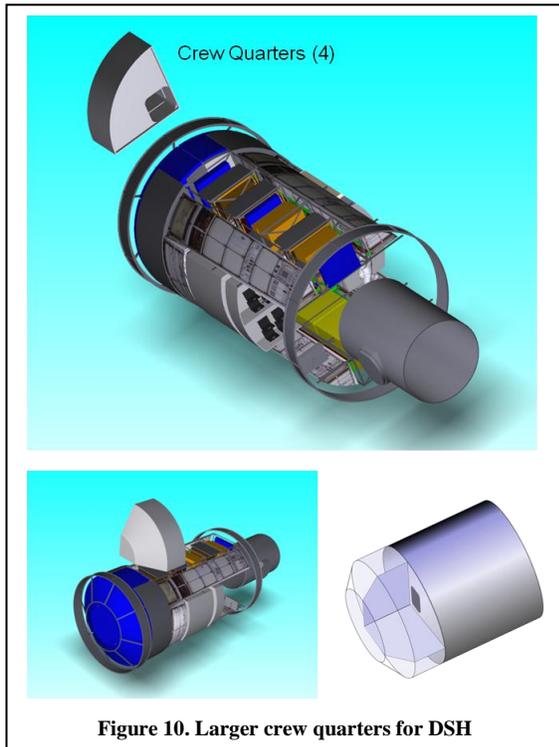
encourages smaller ducts which increase noise.

The ORU-Tailored concept allows utilities to cross over in the middle of the module which reduces line length, power requirements, and noise. Furthermore, rather than having interchangeable rack stations which complicate utility distribution, the ORU-Tailored solution provides for simple direct connections.

ISS standoffs are used for lights, diffusers, and filters. The ORU-Tailored concept uses transverse utility routing, the lights, diffusers, and filters positioned in the center of the aisle way providing efficient distribution of light and air.

**Crew Quarters**

With an emphasis on habitability, the DSH crew quarters are designed for long duration missions (Figure 10). They provide about twice the volume as ISS US crew quarters and are equipped with sleep restraints, power and data ports, and controls for



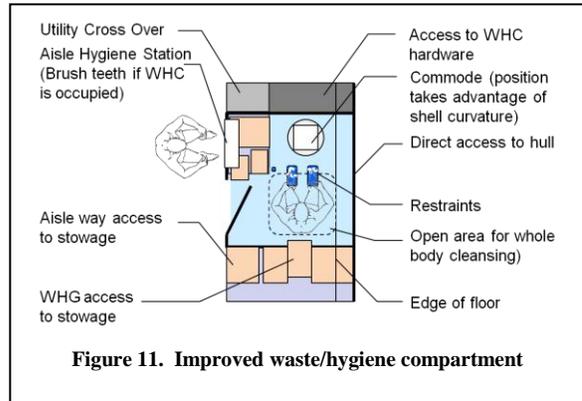
**Figure 10. Larger crew quarters for DSH**

lighting, temperature, and air flow. In addition to sleeping, crew quarters are used for changing clothes, private communications, and off-duty activities.

**Waste Hygiene Compartment**

Rack packaging of the ISS waste/hygiene compartment (WHC) means that users have to extend privacy partitions into the aisle way. The ORU Tailored architecture offers a much improved design that includes adequate internal volume for waste management as well as whole body cleansing (Figure 11). If the compartment is occupied, crew members use the aisle way hygiene station to brush teeth or

wash hands. The configuration allows easy access to both the hull and commode hardware for servicing. Rather than take up internal volume, hygiene provisions are in the adjacent stowage rack, yet

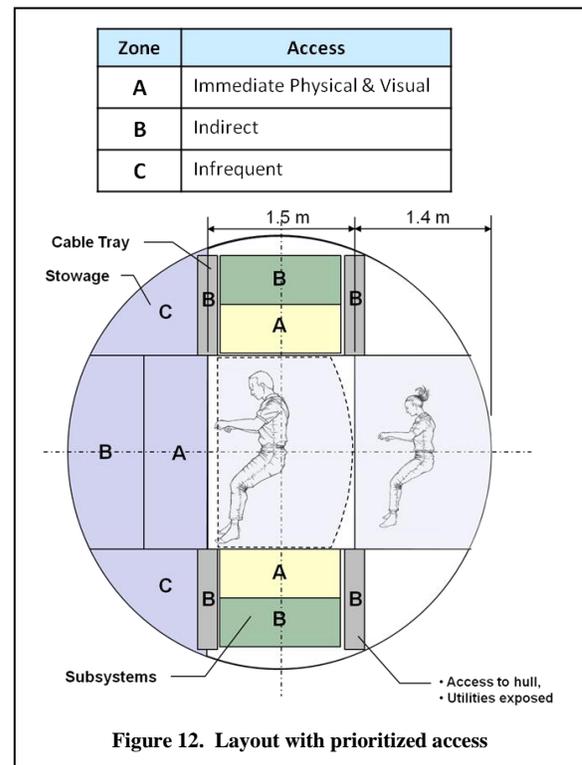


**Figure 11. Improved waste/hygiene compartment**

accessible from inside the compartment. Like the crew quarters, the compartment has controls for lighting, temperature, and air flow.

**Prioritized Access**

The ORU-Tailored configuration provides zoning for accessibility. As shown Figure 12, items that require immediate physical and visual access are placed in zone A. These may include frequently used hardware or emergency items. Zone B provides indirect access for items that may include filters or clothing. Items used only on the return leg of the mission or spares could be located in Zone C. Locating stowed items is always a challenge, so the



**Figure 12. Layout with prioritized access**

goal is to use an RF identification system with a tailored software search engine to find items even if they are misplaced. Dimensionally, the aisle way is wider than the compartment partitions. This allows the partitions to be transported down the aisle way without disassembly.

## SUBSYSTEMS

### Structures

Using ISS elements for the DSH means the pressure vessel primary structure is provided by either a Structural Test Article or an MPLM ground unit. The properties of each element are shown in Figure 13. Initially, the Shuttle Airlock was



	STA Hab/Lab	MPLM	Tunnel		ISPR
<b>Length</b>	8.5m (27.4 ft)	6.5m (19 ft)	3.2 m (10.5 ft)	<b>Height</b>	2 m (6.1 ft)
<b>Cylindrical section length</b>	7.2 m (25.6 ft)	4.9m (15 ft)	3.2 m (10.5 ft)	<b>Width</b>	1.05 m (3.4 ft)
<b>Diameter</b>	4.3 m (14 ft)	4.3 m (14 ft)	2.5 m (7.6 ft)	<b>Max. depth</b>	.86 m (2.8 ft)
<b>Pressurized volume</b>	107 m <sup>3</sup>	76.4 m <sup>3</sup>	10 m <sup>3</sup>	<b>Volume</b>	1.57 m <sup>3</sup>
<b>Mass of shell incl. CBMs and hatches</b>	3833 kg (8450 lbs)	2502 kg (5516 lbs)	1284 kg (2204 lbs) ~25 kg/m <sup>2</sup> areal mass	<b>Mass of 6-post rack</b>	105 kg (230 lbs)

Figure 13. Characteristics of ISS elements

considered a candidate for the tunnel, but there are only two hatches and these are designed for EVA, not mating to the ISS Common Berthing Mechanism (CBM). More importantly, the tunnel serves as a strongback for mounting external equipment such as radiators, solar arrays and batteries. The Shuttle airlock was too short to accommodate ISS radiators therefore a simple, right-sized connecting tunnel was created for attaching external deployable elements and performing contingency EVA. For direct access to space without the EVA overhead, a FlexCraft or MMSEV would be docked to the hatch. Pressurized elements use ISS CBMs for structural and utility connections. One is added to an MPLM to provide through-translation and one CBM is removed from the crew quarter end of the Hab.

The secondary structure uses four open-web longerons that double as cable trays for single-layer utility mounting. Subsystem pallets are attached to transverse beams allowing them to be rotated into the aisle way for direct two-sided access to the ORUs. The weight of the secondary structure was

conservatively estimated at twenty percent of the supported load.

Floor and ceiling closeout panels span from the shell to the longeron and between longerons helping to control air flow and support crew translation.

### Environmental Control Life Support System

The Environmental Control and Life Support System (ECLSS) is responsible for the air, water, food, waste management, and fire detection/suppression for the crew. Because it is possible to conduct the 60 day mission with an open-loop ECLSS, the important decision for the DSH was the degree of system closure for the 500 day mission. The open loop system has a high TRL, is less complex, and requires considerably less power. But, considering the system should ultimately support the long duration missions, a closed loop ECLSS was selected for the DSH. This means that the ECLSS is the same for all missions except for the quantity of expendables, consumables, and spares.

For best utilization of ISS ECLSS systems, it was determined that water processing would use the Urine Processing and Water Processing Assemblies positioned under the floor in their ISS rack configuration (Figure 14). Air handling ORUs are



Figure 14. ISS water processing rack

mounted to pallets in the ceiling. These locations were determined according to adjacency efficiency, minimal utility line length, and noise reduction in the quiet zone.

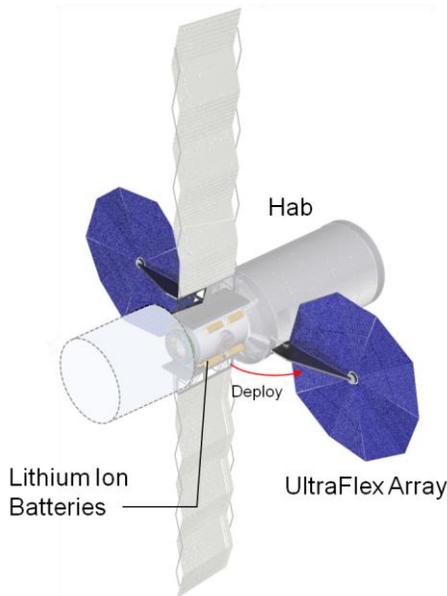
The water balance can be achieved in a number of different ways. If food with 63% water were carried on long missions, less water would be needed to meet the closed loop water requirement. But, dehydrated food is projected for the five hundred day mission to allow for easier long-term food storage and the

utilization of stored water. Instead of adding hardware redundancy to water recovery and management, extra water is carried. In addition, this is expected to contribute to radiation protection.

The operational experience of ISS ECLSS provides important lessons for hardware reliability and on-orbit maintenance. Furthermore, before the DSH launches, the ECLSS systems will benefit from ongoing development offering potential mass reduction for long duration missions.

**Electrical Power**

The electrical power system is one area where using the ISS systems was not the best choice. Instead, more efficient UltraFlex solar arrays used on the MPCV were selected for the DSH (Figure 15).



**Figure 15. UltraFlex solar array for DSH.**

Similar to using ISS hardware, the investment for developing the arrays has been made by another program resulting in a lower cost for the DSH. The UltraFlex arrays use high efficiency Inverted Metamorphic cells that were sized to accommodate a 14,136 W load for the sixty day mission and 18,824 W for the five hundred day mission. The arrays are mounted to the endcone of the Hab and for launch they are stowed in the void between the tunnel/airlock and launch vehicle shroud.

Likewise, a 120V MPCV compatible bus was used for power conversion along with MPCV heritage VME electronics boards and enclosures (Figure 16).

Unlike LEO missions that pass in and out of the Earth’s shadow, deep space missions will have direct access to sunlight. This means that the solar arrays provide near continuous power to the DSH, however



**Figure 16. Heritage hardware used for DSH.**

for periods of shadowing, off-the-shelf, 122.4 V high-capacity lithium ion cell batteries are provided.

**Thermal Control**

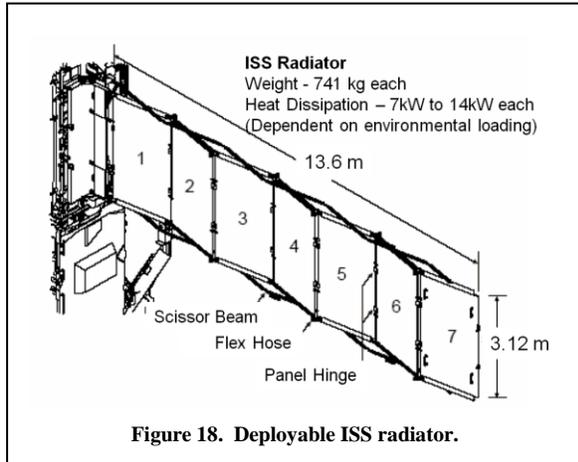
Although the thermal environment for the DSH is different than LEO, the ISS radiators were selected as a cost-effective human-rated solution. The system uses ammonia as an external working fluid interfacing with an internal water loop at endcone mounted heat exchangers. Both the internal and external loops are redundant and pump fed using cold plates and heat exchangers. The system was sized for an equipment and metabolic waste heat load of

60/500-Days	
Item	Total Heat Dissipation (W)
C&DH, Instrumentation	1024
Displays & Controls	452
Communications	525/625
Intercom / Video	292
Cabin Lighting	200/240
Circulation Fans	350/450
Heat Transport Pumps	700
Refrigerator/Freezer	540/1080
ECLSS	6373
Metabolic (4 crew)	544
Power Systems	970/1145
<b>Totals</b>	<b>11,970/12,925</b>

**Figure 17. Heat dissipation for thermal control.**

11,970 W for the sixty day mission and 12,925 W for the five hundred day mission (Figure 17). Like ISS, the DSH uses electrical shell heaters and external multi-layer insulation around the Hab, MPLM and tunnel.

The radiator ORU (Early External Active Thermal Control System Radiator/Photovoltaic Radiator ) is a direct flow, deployable and retractable radiator system with two independent cooling loops. The radiator consists of seven radiator panel, the deploy/retract mechanism, support structure, and the necessary plumbing (Figure 18). The radiator has two



channels (A&B) that acquire heat from the low temperature loop and medium temperature loop Interface Heat Exchanger (IFHX) via liquid anhydrous ammonia. The independent loops were designed so that a failure in one would not take down the entire external cooling system. The ammonia flows from the Pump and Flow Control System (PFCS) to the associated IFHX, to the power systems and avionics cold plates, to the radiator manifold tubes, across the radiator panels and back to the PFCS. The radiator panels reject the excess heat to space via two non-articulating radiator ORUs.

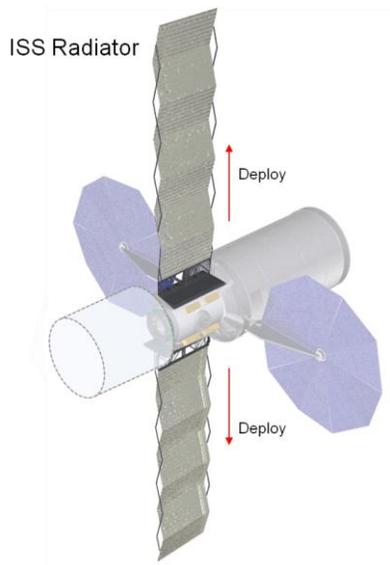


Figure 19. Radiators mounted on the tunnel.

Another important feature of the ISS radiators is that they are designed to be deployed (Figure 19). This allows them to be mounted on the smaller diameter tunnel/airlock for launch and then extended on-orbit.

Avionics Systems

The avionics system provides all command, control, data handling, and communications systems for the habitat (Figure 20). Because avionics technology has improved significantly since ISS, the DSH system is based on the newer MPCV. This was judged to be a practical approach since the MPCV vehicle is largely a habitat vehicle with all the electronics required to operate ECLSS systems and provides a robust communications system with good ground link and local communication capabilities. None of the MPCV propulsion or GN&C capabilities are included in the habitat

It is basically a single hardware redundant system with dual or triple fault tolerance provided by complementary systems. For example, the S-band system can provide the same communication functions as the Ka-band with some reduced

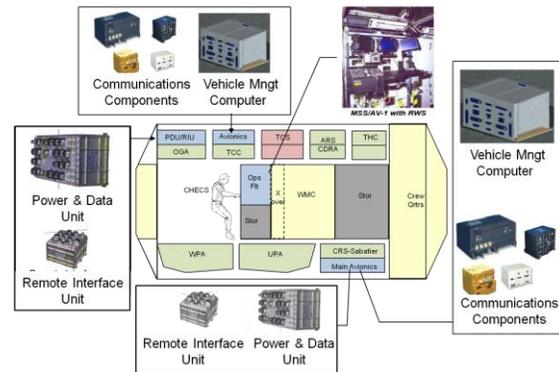


Figure 20. DSH internal avionics.

performance. The two main computers are each a self checking pair system, making each one single fault tolerant itself, providing triple fault tolerances for the complete system.

The avionics system is partitioned and distributed into different locations. The main avionics compartment in the floor contains one of the Vehicle Management Computers (VMC) and most of the data handling components (video processor and recorder, audio control unit, mass memory unit), two Power control and Data bus Units (PDU), a Remote Interface Unit (RIU) for instrumentation, and most communication components like the Ka and S band transceivers and amplifiers. A second location on a side wall of the CHECS area contains control panels and displays for the primary human-machine interface and the robotic control station to work with a Flexcraft, MMSEV, or EVA. This area is the primary habitat control center. It is assumed that

laptop computers will be used by the crew to interface with habitat functions also. The laptops will communicate commands and receive status data from the VMCs. With this capability, for example, a crew member could monitor ECLSS health and status from any location within the habitat, or pan an external camera around while relaxing in the crew quarters.

The redundant set of avionics equipment is located in the ceiling area to physically separate components. Proper distribution of instrumentation and power control functions minimize cabling mass and congestion. Therefore, additional PDUs and RIUs are strategically located throughout the habitat. For this distribution, a small portion space is used. Intercom boxes are also distributed throughout the habitat for the crew to communicate with each other or plug in headphones.

The 500 day and 60 day avionics are the same except for a couple of extra intercom units in the MPLM.

The main avionics components external to the habitat are the antennas and cameras (Figure 21). For

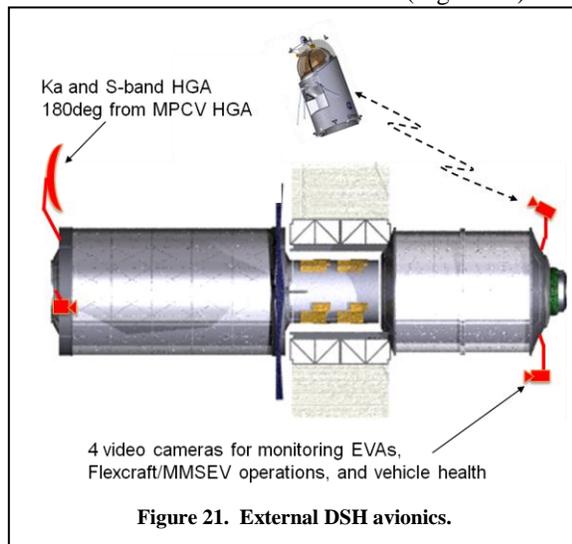


Figure 21. External DSH avionics.

the 60 day configuration, a 0.75 meter dish provides 100 Mbps ground link to the deep space network from lunar locations. A 1.5 meter dish is provided on the 500 day habitat to maintain 1 Mbps from distant locations like Mars. Real-time video will not be possible from these great distances, with up to 20 minutes signal travel time delays. However, most Mars reference missions include an orbiting communication satellite which improves data rate capabilities. The habitat dish is 180 degrees phased from the MPCV dish to provide complimentary viewing angles. Four video external cameras are provided for health and status monitoring of the habitat and attached elements. The cameras can be used to assist in Flexcraft/MMSEV mission operations or EVAs. The cameras are also phased

from each other to provide complete viewing capability of the habitat.

#### Environmental Protection

Exterior Micrometeoroid Debris Protection System (MDPS) is used to protect the pressure vessel from puncture. For the DSH it is the same system used on the MPLM.

The exterior MDPS includes:

- 0.8 mm AL alloy bumper shield
- 127.6 mm multi-layer insulation (MLI) with Nextel ceramic fiber

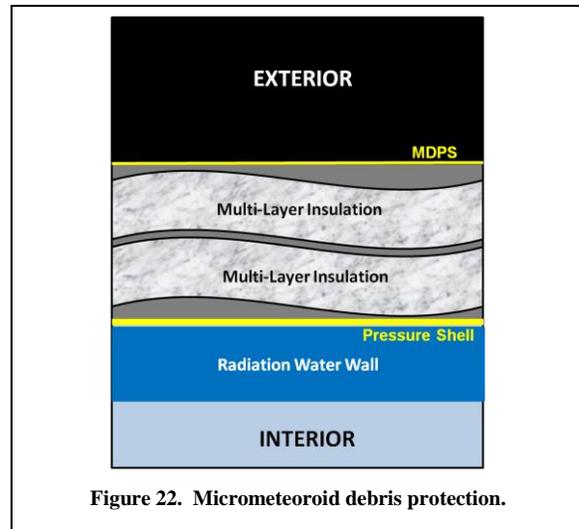


Figure 22. Micrometeoroid debris protection.

The molecular properties of water and polyethylene provide a physical advantage for radiation protection. The thickness of the water serves as a storm shelter during a solar particle event (SPE) to keep the crews' exposure limits within the National Council for Radiation Protection (NCRP) recommended levels (Figure 23). The water thickness for sixty and five hundred day missions is ~11 cm which provides sufficient protection for the crew exposed to SPEs. To date, there is no agreed approach for long term galactic cosmic radiation (GCR); this design does not provide GCR protection.

#### Radiation Water Wall

- 0.55 cm thick polyethylene tanks
- 9.9 cm thick wall of water

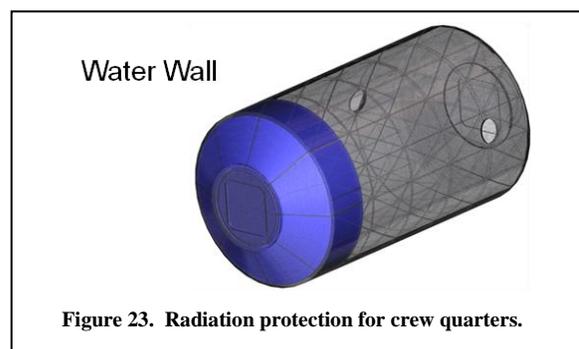


Figure 23. Radiation protection for crew quarters.

### III. FINDINGS

This analysis determined that a DSH could be assembled using combinations of ISS and MPCV systems. The configuration provides adequate overall volume, large crew quarters, improved waste/hygiene provisions, and SPE radiation protection for a crew of four for up to five hundred days. Because multiple ISS elements are required to provide the DSH volume, there are additional bulkheads and berthing mechanisms that contribute to a higher mass than a single element solution.

The ORU-Tailored (non-rack) layout works well for the deep space missions. It provides the benefit of hardware development and simplified utility distribution without the mass and packaging penalty of a rack-based layout. Furthermore, and equally important, it will weigh less and provide improved accessibility to ORUs, utilities, and the hull.

The objective of this approach is to reduce cost, schedule and program risk however, without a detailed cost analysis, it is uncertain whether the perceived economy is real. Important issues to still be considered are:

- Flight worthiness of the structural shells
- Launch vehicle accommodations
- Transfer stage requirements/availability
- Availability of subsystem hardware
- Supplier availability
- Hardware/software compatibility

### IV. FUTURE WORK

During the course of this study it was noted that there are opportunities for additional analysis that suggest alternative approaches or addresses issues not resolved with an ISS derived DSH. These include:

- Launch Vehicle Derived DSH
  - Outfitting an empty upper stage SLS hydrogen tank as the DSH.
  - Explore using the SLS shroud as a DSH
- Radiation Protection
  - Investigate using the contingency water for radiation protection
  - Assess the GCR protection provided by having 2 m of water in the space between ISS Hab module placed inside the SLS upper stage hydrogen tank.
- Artificial Gravity
  - Investigate ISS derived elements configured for artificial gravity
- Reusability
  - Explore concept of operations for returning the DSH to LEO or Earth-Moon Lagrangian points

### • Configuration

- Assess an ISS derived Hab-Node assembly
- Explore commercial and international partner involvement

### V. ACRONYMS

AES	Advanced Exploration Systems
AIAA	American Institute of Aeronautics and Astronautics
BEO	Beyond Earth Orbit
CBM	Common Berthing Mechanism
CHECS	Crew Health and Exercise Care System
CPS	Cryogenic Propulsion Stage
DSH	Deep Space Habitat
ECLSS	Environmental Control and Life Support System
EVA	Extra Vehicular Activity
GCR	Galactic Cosmic Ray
GN&C	Guidance Navigation and Control
IFHX	Interface Heat Exchanger
ISS	International Space Station
LEO	Low Earth Orbit
MDPS	Micro-meteoroid Debris Protection System
MLI	Multi-Layer Insulation
MMSEV	Multi-Mission Space Exploration Vehicle
MPCV	Multi-Purpose Crew Vehicle
MPLM	Multi-Purpose Logistics Module
MSFC	Marshall Space Flight Center
NCRP	National Council for Radiation Protection
ORU	Orbital Replacement Unit
PDU	Power control and Data bus Unit
PMR	Project Manager's Reserve
PFCS	Pump and Flow Control System
RIU	Remote Interface Unit
SPE	Solar Particle Event
STA	Structural Test Article
TRL	Technology Readiness Level
VMC	Vehicle Management Computers
WHC	Waste Hygiene Compartment