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SLS-Derived Lab
Precursor to Deep Space Human Exploration

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Plans to send humans to Mars are in the works and the launch system is being built. Are we ready? Transportation, entry, landing, and surface operations have been successfully demonstrated for robotic missions. However, for human missions, there are significant, potentially show-stopping issues. These issues, called Strategic Knowledge Gaps (SKGs), are the unanswered questions concerning long duration exploration Beyond low Earth Orbit (BEO). The gaps represent a risk of loss of life or mission and because they require extended exposure to the weightless environment outside of earth's protective geo-magnetic field, they cannot be resolved on Earth or on the International Space Station (ISS). Placing a laboratory at a relatively close and stable lunar Distant Retrograde Orbit (DRO) provides an accessible location with the requisite environmental conditions for conducting SKG research and testing mitigation solutions. Configurations comprised of multiple 3 m and 4.3 m diameter modules have been studied but the most attractive solution uses elements of the human Mars launch vehicle or Space Launch System (SLS) for a Mars proving ground laboratory. A shortened version of an SLS hydrogen propellant tank creates a Skylab-like pressure vessel that flies fully outfitted on a single launch. This not only offers significant savings by incorporating SLS pressure vessel development costs but avoids the expensive ISS approach using many launches with substantial on-orbit assembly before becoming operational. One of the most challenging SKGs is crew radiation protection; this is why SKG laboratory research is combined with Mars transit habitat systems development. Fundamentally, the two cannot be divorced because using the habitat systems for protection requires actual hardware geometry and material properties intended to contribute to shielding effectiveness. The SKGs are difficult problems. The solutions to these problems are not obvious; they require integrated, iterative, and multi-disciplinary development. A lunar DRO lab built from SLS elements enables an early and representative transit habitat test bed necessary for closing gaps before sending humans on a 1,000-day Mars mission.

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Nomenclature

AES	=	Advanced Exploration Systems
AMO	=	Autonomous Mission Operations
BEO	=	Beyond Low Earth Orbit
C	=	Speed of light ($\approx 3.00 \times 10^8$ m/s)
CAD	=	Computer Aided Design
CMG	=	Control Moment Gyro
CPH	=	Crew Health and Performance
DRO	=	Distant Retrograde Orbit
EM1	=	Earth-Moon Lagrangian point 1
EM2	=	Earth-Moon Lagrangian point 2
EMC	=	Evolvable Mars Campaign
GCR	=	Galactic Cosmic Radiation
ISS	=	International Space Station
LEO	=	Low Earth Orbit
MEL	=	Master Equipment List
SKG	=	Strategic Knowledge Gap
SLS	=	Space Launch System
SME	=	Subject Matter Expert
SPE	=	Solar Proton Event
TRL	=	Technology Readiness Level
DDT&E	=	Design, Development, Test, and Evaluation

I. Introduction

THIS paper introduces key Strategic Knowledge Gaps (SKGs) associated with human exploration Beyond low Earth Orbit (BEO), then describes the urgency for gap resolution, and finally offers a concept for a deep space laboratory that provides the resources and environment for early testing to support NASA's plans for Mars exploration.

II. Why a SKGLab?

A. Next Step for Human Exploration beyond Low Earth Orbit

Preparation for human exploration into the solar system is in progress. A phased approach to build and test needed capabilities based on technological and human responses to the deep space environment beyond Earth's protective magnetosphere is critical to mission success. SKGs serve as guides to determine and weigh the need for explicit activities and technologies to be incorporated within this phased approach. Among the NASA teams investigating technology gaps, the two that directly apply to human exploration are supporting Advanced Exploration Systems (AES) and the Evolvable Mars Campaign (EMC). The EMC Systems Maturation Team (SMT) has analyzed technology gaps presenting a schedule and test location for maturation. (Fig. 1). From this analysis, Subject Matter Experts (SMEs) identified that 34% of exploration technologies should be tested beyond low-earth orbit in the relatively close cis-lunar environment. Not shown in the table but equally important are the gaps in understanding behavioral health and performance, exploration medical capability, human health countermeasures, space human factors and habitability, and space radiation mitigation techniques necessary for long-term deep space exploration.

System Maturation Team	GAPS	Gaps tested in cis-lunar
AMO	30	100%
CHP-Radiation	—	—
Comm/Nav	34	38%
ECLSS-EM	23	0%
EDL	7	43%
EVA	26	0%**
Fire Safety	7	0%
ISRU	19	21%
Power	17	29%
Propulsion	24	29%
Robotics	12	42%
Thermal	16	38%
TOTAL	215	34%

**15% need to be tested in Cis-lunar if testing does not occur on ISS

Figure 1. Cis-lunar environment is required for 34% of exploration technologies.

B. Cross Cutting SKGs

In recent years and months, NASA has been assessing SKGs for destinations associated with potential human spaceflight missions. These include the Earth's Moon, deep space, small bodies and asteroids, and Mars.

SMEs with knowledge of these environments and operational considerations have contributed to identifying SKGs and identifying what is needed to fill in the gaps. A multi-disciplinary approach with breadth and depth is most productive to revealing the gaps and provides opportunities to form efficient integration solutions to fill the gaps (Fig. 2).

STRATEGIC KNOWLEDGE GAP	CROSS-CUTTING DISCIPLINES
Environmental Effects - Ionizing/Non-Ionizing - Thermal Radiation - Dust - Micrometeoroids - Plasma	▪ Crew Accommodations, Food Systems ▪ Crew Health and Medical, Medications ▪ ECLSS ▪ Extravehicular Activity ▪ Logistics ▪ Planetary Protection ▪ Research Payload Systems
Logistics Management - Relationship of resupply with habitat and logistics vehicle volume - Trash management strategy - EVA Maintenance scheme - Human-tended versus human-occupied schemes	▪ Architecture and Vehicle Configuration ▪ Crew Accommodations, Food Systems ▪ ECLSS ▪ Human Factors ▪ Logistics
Autonomous Systems and Communications Latency - Choreography of communication between payload, crew, vehicle, ground, remote locations; immediacy of information - System reliability for critical systems - Human-tended versus human-occupied schemes - Rendezvous and docking real-time processing calculation	▪ Avionics and Software incl. Communication ▪ Crew Health and Medical ▪ ECLSS ▪ Human Factors ▪ Logistics ▪ Operations ▪ Power ▪ Research Payload Systems ▪ Telerobotics
Relationship between tolerable workspace/space, reconfigurability, adaptation, and customization	▪ Architecture and Vehicle Configuration ▪ Crew Accommodations ▪ Crew Health and Medical ▪ Human Factors ▪ Structure

Figure 2. Strategic Knowledge Gaps (SKGs) cut across many space disciplines.

III. Human Exploration Risk Reduction

A. Unique Test Environment

SKGs form the basis for understanding and testing to reduce risks for human exploration. Key among these risks is exposure to radiation from both solar and galactic sources. Recognizing the significance to human health, The National Research Council ranked space radiation 5 of the top 10 priorities for technology development (Fig. 3).

Solar Proton Events (SPEs), occur when the Sun produces flare events that inject an unusually large population of particles into space. These particles are largely protons moving at relatively slow speeds (<<C); unprotected exposure to these events is life threatening, but the mass of the particles and their relatively slow speed make shielding, particularly in a large spacecraft, a matter of relatively straightforward engineering. The latter, in the form of Galactic Cosmic Rays (GCRs), consist of fast- moving (fractions of C) heavy particles as heavy as Fe nuclei, whose dynamic nature makes shielding, as we presently understand it, difficult to impossible. On the International Space Station (ISS), the Earth's magnetic field greatly reduces the effects of each of these radiation sources, although crewmembers are still exposed to a radiation environment more significant than that present on the Earth's surface. In particular, understanding the ultimate effect of GCRs on biological systems during a long duration voyage outside the Earth's magnetosphere remains a key knowledge gap. Managing the risk from this source will be problematic without additional information.

Table 8. *NRC Prioritization of TA06 Level 3 Technologies*

Title	Comment(s)
(Radiation) Monitoring Technology	High Priority
(Radiation) Protection Systems	High Priority
(Radiation) Risk Assessment Modeling	High Priority
Habitation	High Priority
(ECLSS) Waste Management	High Priority
Long-Duration (Human) Health	High Priority
(ECLSS) Water Recovery and Management	High Priority
(EVA) Pressure Garment	High Priority
Radiation Prediction	High Priority; renamed from Space Weather Prediction
Radiation Mitigation	High Priority
Fire Detection Suppression	High Priority
(ECLSS) Air Revitalization	High Priority
(EVA) Portable Life Support System	High Priority; the NRC Panel originally scored this as Medium Priority but re-designated it after further consideration
Remediation	High Priority; the NRC Panel originally scored this as Low Priority but re-designated it after further consideration
(EVA) Power, Avionics and Software	Medium Priority
Behavioral Health and Performance	Medium Priority
Sensors: Air, Water, Microbial, etc.	Medium Priority
Human Factors and Performance	Medium Priority
Medical Diagnosis/Prognosis	Low Priority
Protective Clothing/Breathing	Low Priority

Figure 3. Radiation is high priority in 5 of top 10 NRC Panel priorities.

Another key risk element for long duration spaceflight is exposure to microgravity. Without the earth's gravitational force, complications will arise in human systems. This has been known since the beginning of human spaceflight; in fact, Skylab and the ISS have conducted long duration studies into the effects of long duration microgravity on the human system. Although managing human long duration exposure to microgravity is becoming better understood, there are still neurological issues such as intracranial pressure and degraded visual acuity that remain enigmatic. Many of these issues can be addressed in Low-Earth Orbit (LEO), but there is rising concern for understanding the interrelated effects of microgravity and the deep space environment. For this, a laboratory in cis-lunar space is ideal.

The question of logistics on a long duration, deep space voyage also represents a critical risk issue. A human Mars mission, regardless of duration, will represent a multi-year voyage away from any terrestrially-based logistical support. All food, spare parts, and medical supplies will need to be onboard the vehicle or pre-positioned at Mars if the mission is to be successful. It is presently unclear if medications will maintain their potency on this mission, particularly in the light of the deep space radiation environment. It is also unclear if food supplies will provide the necessary nutritional value and if medications will sustain adequate efficacy for the duration of the mission.

B. Radiation Protection and Countermeasures

Radiation protection for humans BEO remains untested, however there is a broad and creative range of proposed protective countermeasures. Some propose an energized field around the spacecraft; others use the mass and atomic properties of materials to either shield the entire spacecraft or create a dedicated storm shelter. There are also concepts for protective garments and sleep restraints. Still others have looked into mitigating effects through pharmacological therapy. Research and testing at a deep space laboratory (called the SKGLab) may reveal the most effective solution to be one of the above, a combination of the above, or a concept yet to be discovered.

Most studies recognize that shielding against the ever-present GCR is mass prohibitive. As a result, design solutions tend to provide for SPE protection with a crew exposure limit of 180 days for GCR. These solutions may work for missions that do not exceed 180 days but are insufficient for the 1000-day Mars missions.

For decades, physicists and physiologists have been at odds over radiation protection while design engineers just want a "requirement" for shielding thickness. It is a complex problem and solutions are not intuitive. Because consumable propellant is required to push spacecraft around the solar system, mission planners strongly resist the idea of adding propellant for dead mass. This is why there is an incentive to subsystem and stowage mass double as radiation protection. This approach is a good goal but because of radiation scattering from the packaged systems, the intended protection may in fact make the threat worse. There are analytical methods to assess the effectiveness of protection concepts but they do not provide early answers because they require accurate geometry and material properties rendered in Computer Aided Design (CAD) models. Because radiation is a safety issue, negative analytical results will necessarily translate into costly redesign with repeated radiation analyses to assess the effectiveness of the changes. Furthermore, the only way to verify analytical results is to test them in the actual operating environment which is why a deep space laboratory is needed. In this laboratory a broad range of concepts can be instrumented for simultaneous testing to measure their effectiveness and refine analytical processes.

IV. Human-Tended Laboratory

A. Requisite Environment

The SKGLab in cis-lunar space provides the opportunity to complete the last step on the Technology Readiness Level (TRL) scale: *Actual technology proven through the successful use in an operational environment*. Cis-lunar space offers the unique radiation environment not available on Earth or in LEO. Being outside Earth's geomagnetic field it receives virtually the same SPE and GCR exposure as astronauts in transit to the Moon or Mars.

To avoid radiation risk to astronauts, the SKGLab in cis-lunar space is intended to initially be human-tended. The lab is instrumented for tele-operation to control and monitor onboard systems and experiments. In the crew absence, science would continue. Outfitted for life-science research using plants and animals specimens would remain onboard under experimental control for long periods of time. Then, during their visits, astronauts would use the onboard equipment, supplies and gloveboxes to take samples for on-orbit analysis and possible Earth return.

B. Reasonable Earth Transit Times

Because of its proximity to Earth, Cis-lunar space offers attractive sites for the SKGLab. Shown in Figure 4

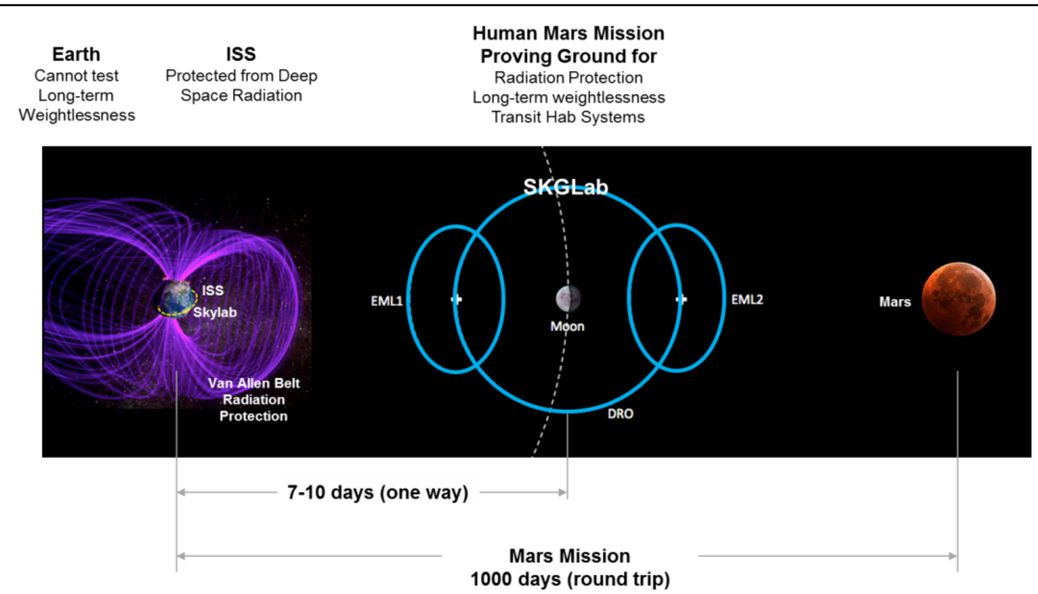

Figure 4. The lunar Distant Retrograde Orbit is ideal for SKG testing.

these include the Earth-Moon Lagrangian (EML) points EML1 and EML2 and the lunar DRO. Each is approximately 7-10 days from Earth, which is within the 21-day capability of an Orion crew transfer vehicle. Both the Lagrangian points and the DRO have been studied as sites for the deep space habitats. However, the DRO location is favored because it is a very stable orbit, meaning the SKG Lab would not require a propulsion system for orbital stability. Furthermore, the lab provides near-continuous access to sunlight for electrical power, only requiring control moment gyros (CMGs) to maintain a solar inertial orientation

C. Test Early

Sending humans to the vicinity of Mars by the 2030s may seem like the distant future, but according to the SMEs this date is only possible if technology investments are made now. Figure 5 superimposes the recommended start date for closing gaps on the EMC timeline. Of the 215 gaps, 91% of them should start to be developed within

Campaign Timeline — Gap Start Date

System Maturation Team	GAPS	Gaps in progress or starting in the next 5 years	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
AMO	30	100%							10		10	10										
CHP-Radiation																						
Comm/Nav	34	76%																				
ECLSS-EM	23	91%						2	3	6	1	7		2			1	1				
EDL	7	100%				6					1											
EVA	26	92%				4		5	3	1		7		3	1*		2					
Fire Safety	7	100%							2	2	3											
ISRU	19	100%	2		4	2	1	2	3	1	1	1	1		1							
Power	17	71%				3	1		2	1		3*	1		1*			1		4*		
Propulsion	24	96%			4						4		11		4*	1*						
Robotics	12	92%																				
Thermal	16	94%					2	4	2*			1	1	1	4*		1					
TOTAL	215	91%	2		8	15	4	13	25	11	20	29	14	6	11	1	4	2		4		

Figure 5. Evolvable Mars Campaign technologist recommend 91 percent of gap testing should begin in the next 5 years.

the next 5 years. This urgency is driven by the fact that it takes time to devise experiments; design, build and test hardware; transport experiments to the test site; conduct the test, analyze the results; and, if promising, incorporate the lessons learned into the design. Ideally, to avoid excessive costs, this information is available during the concept design phase. Amongst the possible candidates for a SKGLab, an SLS-derived solution is the most attractive because it offers ready access to a propellant tank pressure vessel that not only provides sufficient test volume, but is also designed to take launch loads. Schedule is critical to closing the gaps and because the SLS is in production there is a savings of at least 2-3 years of government acquisition alone. In addition, most of the Design, Development, Test, and Evaluation (DDT&E) is complete further compressing the schedule and thus allowing the early testing required for NASA's Mars exploration plans.

V. Why SLS-Derived Lab is a Good Option

Like the original Skylab, the SLS-derived lab uses sections of the launch vehicle propellant tank for the pressure vessel. There are five compelling reasons why the propellant tank is a good option. First, SLS is being built so that it can support early SKG testing; second, no on-orbit assembly is required because it flies fully integrated on a single launch; third, it mimics the Mars transit habitat and is therefore ideal for deep space radiation data gathering; fourth, no new upper stage is required because it uses a modified existing Delta IV Interim Cryogenic Upper Stage (iCPS) and fifth, the large 8.4 m diameter allows centrally located crew quarters to double as a radiation storm shelter protected by surrounding equipment and stowage (Fig. 6).

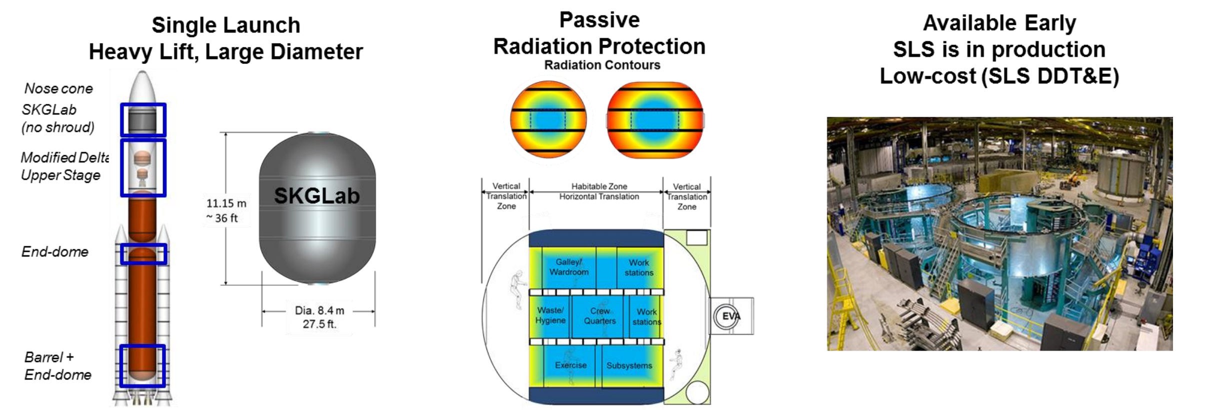

Figure 6. Using the Space Launch System (SLS) propellant tank minimizes costly Design, Development, Test, & Evaluation (DDT&E) while providing large diameter lab for testing passive radiation concepts.

Since 2011, NASA has looked at a variety of options for deep space habitats through the NASA Advanced Exploration Systems (AES) Program. Studies through the AES Deep Space Habitat and Exploration Augmentation Module projects have provided detailed analysis for modules and configurations that begin to show the advantages of large, single-module designs for future deep space habitats. Several module sizes have been investigated, including ISS module diameters of about 4.5 m, a 5.5 m diameter common to Orion elements, and the SLS diameter at 8.4 m (Fig. 7).

The Mars habitat sizing was held common for these designs to support four crewmembers for 1,000 days, with the habitat departing from and returning to the lunar DRO so it could be refurbished for multiple missions.

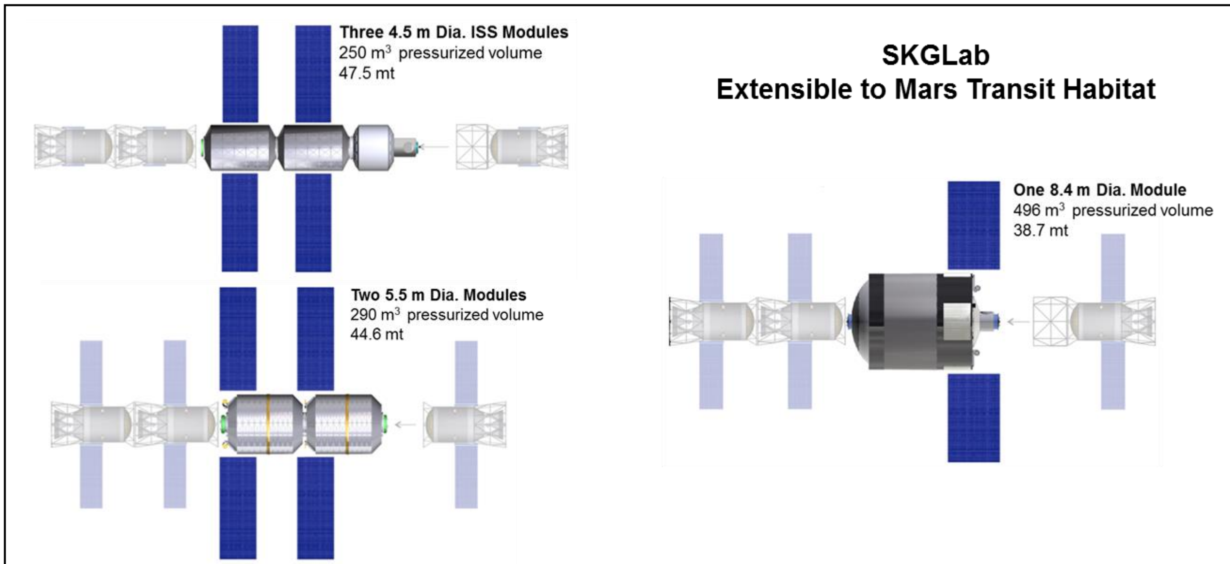

Figure 7. SLS-derived Habitat Mars offers more volume for less mass than smaller diameter options.

Propulsion elements depict a scenario where the return stage is delivered to Mars orbit in advance.

Several studies have been done looking into the use of the ISS 4.5 m modules for deep space missions. This configuration uses two habitat modules that are each 7.2 m long and one logistics module that is about 5.5 m in length (not including the attached airlock). The interior is similar to ISS but uses some built-in systems with fold out pallets for easy access to stowage and habitat subsystems. The configuration is sufficient, but minimal at about 24 m^3 per crewmember, which is close to the 25 m^3 of habitable volume per crewmember recommended for long duration missions. Total pressurized volume is about 250 m^3 and the total habitat mass is about 48 mt.

A new module was recently investigated that uses the diameter of the stage adapter connecting Orion to SLS. It is 5.5 m in diameter, with each module being about 7.5 m long, yielding a total habitat length of about 15 m. The interior is laid out on two deck levels with two crew quarters in each module common spaces and gathering areas concentrated toward the center. The configuration is more comfortable, with about 30 m^3 of habitable volume per crewmember, a total pressurized volume of 290 m^3, and a total habitat mass of about 45 mt.

A large single module design was also considered using the 8.4 m diameter SLS core stage elements. The overall length is about 13.5 m with an interior layout on three deck levels using the end domes for crew translation between decks. The habitable volume comes in at a comfortable 69 m^3 per crewmember with an overall pressurized volume of 486 m^3 and a total habitat mass of 39 mt.

Figure 8 depicts some of the advantages realized for the large, single-module habitat design. Note first the mass and volume comparison between Skylab and the ISS. The designs and configurations are different primarily because Skylab was put in place with one launch from a Saturn V rocket and ISS was put in place by over 100 launches from the Space Shuttle and other international launch vehicles. Today, the Space Shuttle is no longer available and the SLS under development is more suitable for a single large module delivery capability like that of Skylab. The last 3 columns depict the mass and volume of the 4.5m, 5.5 m, and 8.4 m diameter habitats moving from three module designs to two and then one respectively. Note that as the number of modules is decreased, the total mass goes down even with increased volume.

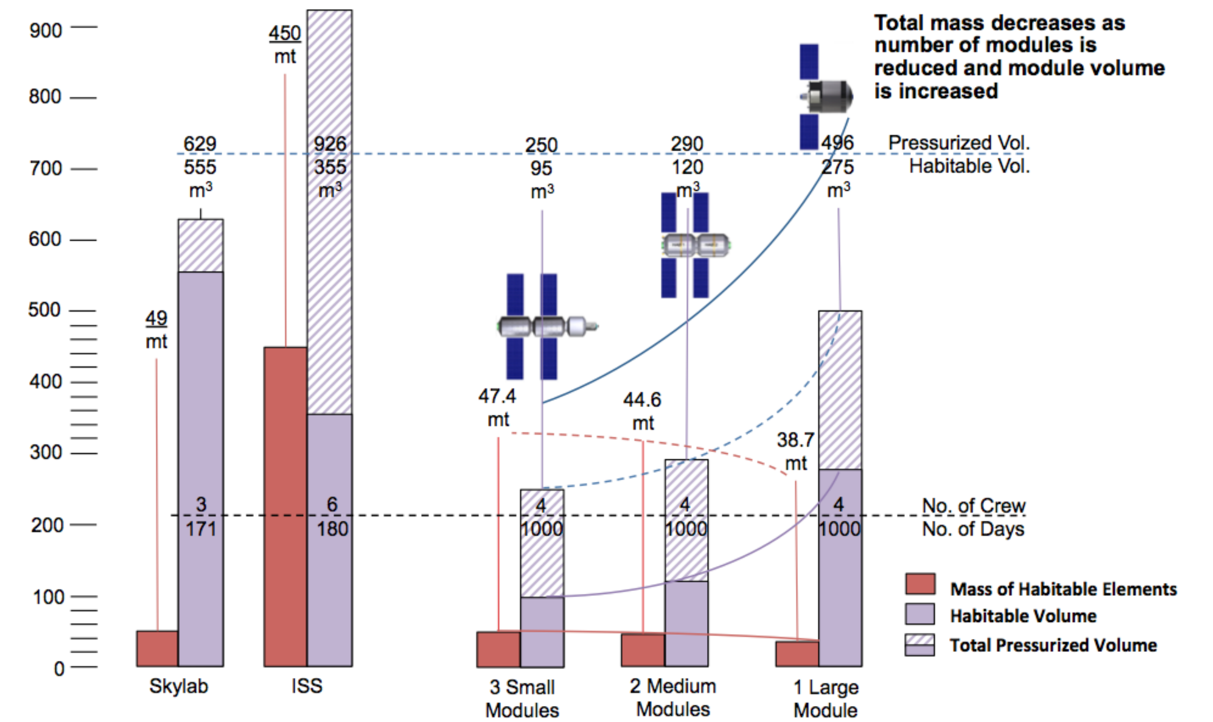

Figure 8. Comparison of mass and volume between Skylab, ISS, and the various Mars transit vehicle configurations.

Mass-to-volume improvement is not the only advantage to a single-module large volume habitat design approach. By placing the crew quarters in the center of the habitat, all of the subsystems and stowage required for long duration missions can be placed around the perimeter, acting as natural radiation protection. Smaller diameters inevitably end up with crew quarters along the exterior wall requiring dedicated polyethylene panels for radiation protection. The large volume allows more flexibility too, such that many more research stations can be put into the habitat while in its testing phase in lunar DRO and later replaced with stowage for the long duration missions. In other words, larger volume provides a certain level of flexibility that simply cannot be accommodated in smaller diameter modules.

VI. Research Objectives and Equipment

Figure 9. ISS type glove-boxes for *in-situu* analysis.

The SKG Lab is key in answering critical questions about human and system performance during the trans-Mars and trans-Earth phases of a human Mars mission. SKGs may be fulfilled through research over the course of exploration capability development. In other terms, research objectives correspond with SKGs using proposed gap fillers. Research incorporates acquiring and applying the data. The data is applicable to deep space habitation and extensibility to follow-on vehicles and surface missions, e.g. Mars transit/surface, habitation ramifications, and research results are applied to operations and engineering decisions and end-to-end processes.

Some of the greater challenges posed by deep space habitation and operations, are system reliability and limited logistics exchange. Additionally, research will be conducted continuously, remotely, and autonomously, with or without the crew for both internal and external experiments. There will be limited return sample capability which means that when the crew is there, they will perform procedures that transmit data electronically to scientists on the ground. Complementing the laboratory equipment, gloveboxes similar to the one on ISS will be used for life science research (Fig. 9). This allows the visiting crew to dissect animals that have had long-term exposure to the deep space environment selecting only the most important samples for earth return.

Research Workstations reside within the SKGLab and are the hubs that provide the functionality needed to control, interact with, and monitor research of all types on and from the lab and habitation modules. A Research Payload Subsystem, in tandem with the Research Workstations, provides the functionality to support and hold internal and external research payloads, including physical interfaces. Payloads will reside within a Research Workstation or be remote from the Workstations elsewhere within the SKGLab, habitation module, or external to the module. External accommodations are modeled after successful ISS operations on the Japanese External Platform. Services and functions provided to the workstation, platforms, and research payloads include power, data/telemetry, gases, environmental control, light, vacuum, venting, and handling.

VII. Multi-Purpose Configuration

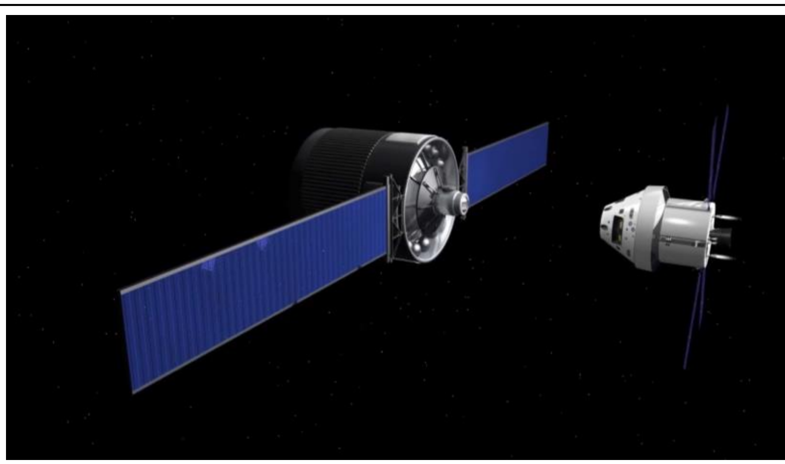

Figure 10. The crew visits the SKG Lab in lunar DRO.

Designed as a multipurpose facility, the SKGLab shown in Figures 10 and 11 serves as both a deep space laboratory and habitat. As a laboratory, it provides the resources and equipment needed to conduct experiments toward understanding the effects of the deep space environment and assessing risk mitigation techniques. As a habitat, it provides temporary lodging for the visiting crew, and while there, offers SPE storm shelter protection. More importantly, because the SKGLab design mimics the Mars transit habitat, it has the correct materials and geometry required for accurate radiation measurements over the reference 1000-day mission. Between crew visits, the instrumented SKGLab continuously sends data to ground stations for analysis by scientists and engineers thereby minimizing crew exposure and is the safest approach to acquiring data that is available early enough to be included in the development of the actual transit habitat.

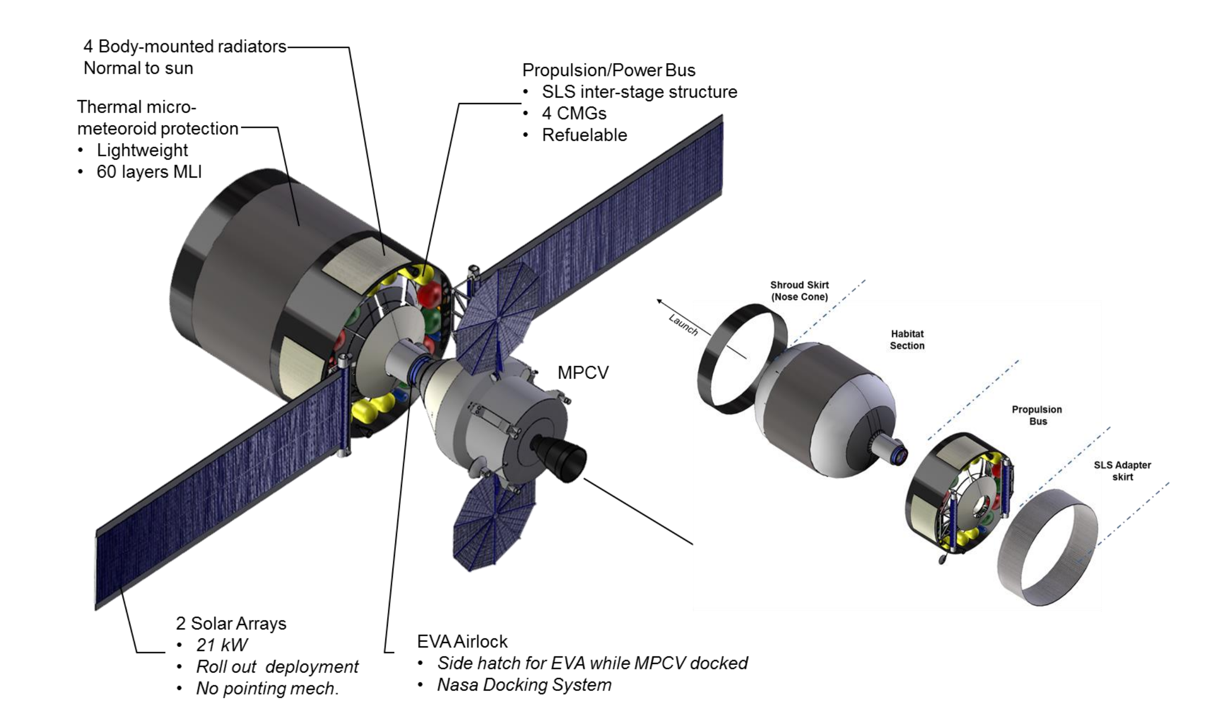

Figure 11. The SLS-derived laboratory provides the necessary volume and resources for SKG testing.

Currently, a lot of educated guess work goes into radiation protection for deep space habitats. In an attempt to avoid the additional mass[1] of dedicated protection, the incentive is to position existing subsystems or stowage to act as insulation for the crew during an SPE. An instrumented SKGLab would provide an ideal test environment for measuring protection concepts. This is why data gathered from a representative design is needed to refine the predictive analytical models for design guidance during concept development.

Although other configurations are possible, the internal layout for the Skylab Gen II created during a previous deep space habitat study was used as the foundation for the SKGLab (Fig. 12). Using the organizing principles

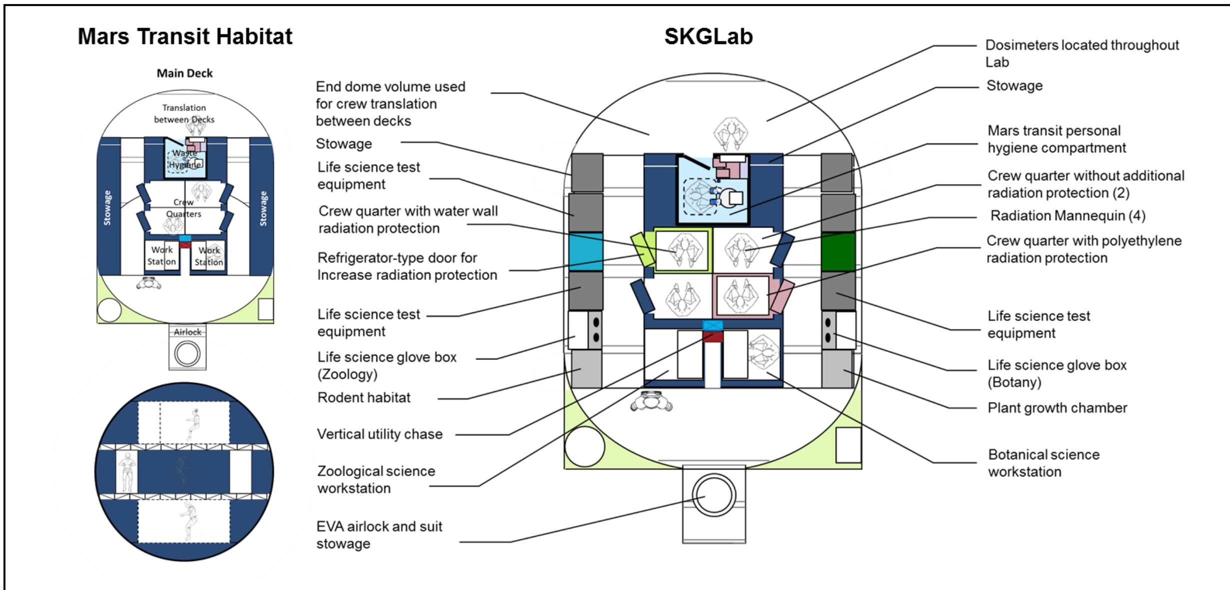

Figure 12. Example layout of how the SKGLab mimics a Mars transit habitat.

[1] 330 kg per crew, Cucinotta, F.A., Kim, M.Y., Chappell, L.J., "Evaluating Shielding Approaches to Reduce Space Radiation Cancer Risks," NASA TM-2012-217361, p.8, May 2012.

mentioned above, the layout attempts to provide SPE radiation protection without additional mass. The SLS diameter allows a three deck longitudinal layout with two double-loaded corridors on the main deck. This arrangement allows the crew quarters to be positioned in the very middle of the lab providing an opportunity for passive radiation protection. The crew quarters would double as a SPE storm shelter benefiting from the surrounding subsystems and storage mass. This is a logical and attractive strategy, but does it work? The SKGLab would measure effectiveness by having different versions of the crew quarters each configured with alternative protection concepts. In the crew's absence, mannequins instrumented with dosimeters (Fig. 13) would occupy the

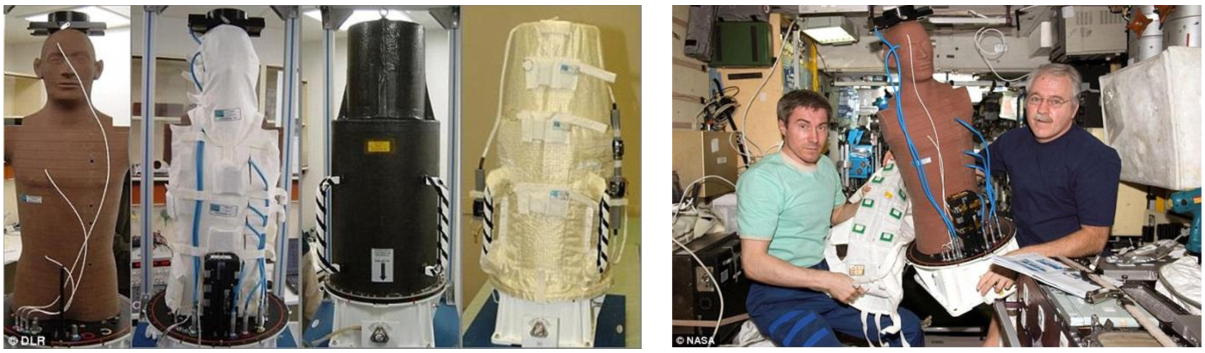

Figure 13. Mannequins serve as radiation test subjects collecting data without risk to astronauts.

crew quarters collecting data on the concept effectiveness.

Another function of the SKGLab is to conduct engineering analysis on itself. With ISS and Apollo, the astronauts were never more than three days away from Earth. For Mars, there is no early return so the crew is committed to the nearly 1,000-day trip, even if something goes wrong. The years of continuous operation for the transit habitat combined with periods of dormancy for the surface habitat introduce new reliability and maintainability requirements for life-critical systems. Although extensive testing can and should occur on the Earth or in LEO, the SKGLab provides an ideal, integrated test habitat for verifying system operations and maintainability in the relevant environment.

VIII. Conclusions

If humans are to visit Mars by the 2030s, there is an urgent need to begin SKG testing now. EMC technologists have recommended that a little over a third of the gaps be tested in cis-lunar space. The DRO is an ideal location because it offers a stable orbit within close proximity to Earth for crew visits and logistic resupply. Using portions of the SLS hydrogen tank as the SKGLab pressure vessel is an attractive solution because it offers an integrated, single launch solution representative of a Mars transit habitat. Furthermore, because the SLS is currently in production, the acquisition schedule can be compressed by an estimated 3-5 years allowing early testing.

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