Ice Home Mars Habitat
Concept of Operations (ConOps)

Updated for the
FY17 LaRC CIF Risk Reduction Study

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December 2017

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Introduction/Overview

A realistic human mission to Mars requires an effective habitat where crews can operate on longs surface stays and are well protected from the environments. Galactic Cosmic Rays (GCRs) are a significant issue for human health on long duration Mars surface missions. Any effective habitat for Mars must provide shielding for crews. It is impractical to transport this shielding from Earth. Burial is an option but has many engineering and operational challenges. The Mars Ice Home is a deployable Mars habitat concept based on an inflatable structure that incorporates In Situ Resource Utilization (ISRU) derived water ice as GCR radiation shielding and as a structural component. The Mars Ice Home also provides a large, flexible, and cost effective workspace that can be used for many of the key activities that will be critical for the long term success of a human outpost on Mars.

Purpose, Scope, and Background

The Development of the Ice Home Concept of Operations (ConOps) document provides a vehicle for stakeholders to contribute to the design and expected use of an Ice Home structure to help ensure it will meet NASA's mission needs.

This ConOps document provides details on how the Mars Ice Home habitat could be deployed and operated so that follow-on study teams have a common starting point for future design iterations and concept development.

The ConOps document is a key systems engineering product that can be provided to external stakeholders to facilitate understanding of the concept and will be used to develop product requirements for the Ice Home System Requirements Document.

This document was originally produced as part of a 2016 NASA Internal Research and Development feasibility study (Ice Dome) using Center Innovation Funds (CIF). Significant support was provided through the collaboration of team members from the Clouds Architecture Office (Clouds AO) / Space Exploration Architecture (SEArch) team whose members had previously won a NASA Centennial Challenge on 3D printed habitats with their Ice House design concept (http://www.marsicehouse.com/).

This update incorporates changes based on the 2017 CIF Mars Ice Home Risk Reduction (MIHRR) Effort that focused on reducing the technical risks associated with the water ice cells. This includes material selection and testing, water cell configurations, filling methods, and initial radiation assessments. Detailed information on the results of the MIHRR can be found in the MIHRR Test Description.

Applicable Documents

1. Human Exploration of Mars Design Reference Architecture 5.0 (NASA/SP–2009–566-ADD) https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf
2. NASA SPACE FLIGHT HUMAN-SYSTEM STANDARD VOLUME 1, REVISION A: CREW HEALTH (NASA-STD-3001)
3. Radiation Shielding Optimization on Mars (NASA/TP–2013-217983TBD) 2013
4. Mars Science Laboratory (MSL) Environmental Requirements Document (JPL D-21382 9/27/2007)
5. Design factors (NASA-STD-5001B) https://standards.nasa.gov/standard/nasa/nasa-std-5001
6. The Mars Ice Home Risk Reduction Test Description – MIHRR-TR-001

References

1. Frontier In-Situ Resource Utilization for Enabling Sustained Human Presence on Mars – NASA/TM-2016-219282: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160005963.pdf
2. A Dual-Chamber Hybrid Inflatable Suitlock (DCIS) for Planetary Surfaces or Deep Space (AIAA 2011-5064): http://www.spacearchitect.org/pubs/AIAA-2011-5064.pdf
3. In addition to the Human Exploration of Mars Design Reference Architecture, the video at this link on “Mars Exploration Zones” provides a conceptual look at a recent Mars outpost design: http://www.nasa.gov/topics/journeytomars/videos/index.html
4. Mars Ice House: Using the physics of phase change in 3D printing a habitat with H2O: ICES-2016-222
5. Mars ISRU for Production of Mission Critical Consumables – Options, Recent Studies, and Current State of the Art: AIAA 2015-4458
6. Report of the Mars Water In-Situ Resource Utilization (ISRU) Planning Study; posted April, 2016: Abbud-Madrid, A., D.W. Beaty, D. Boucher, B. Bussey, R. Davis, L. Gertsch, L.E. Hays, J. Kleinhenz, M.A. Meyer, M. Moats, R.P. Mueller, A. Paz, N. Suzuki, P. van Susante, C. Whetsel, E.A. Zbinden, 2016, at http://mepag.nasa.gov/reports/Mars_Water_ISRU_Study.pptx

System Overview

The Ice Home System includes the softgoods Ice Home Inflatable Structure as well as Deployment and Access Subsystems. A notional concept of a deployed Ice Home is shown below.

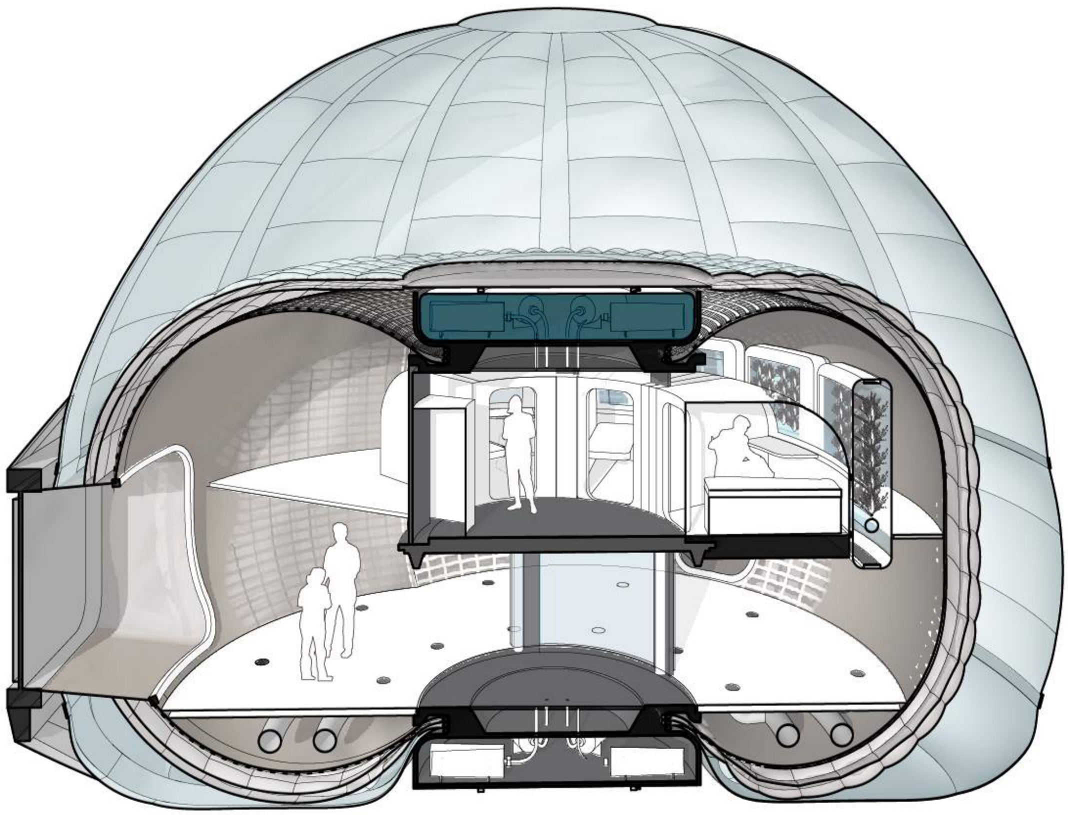


Figure 1: Simplified Cross section of Potential Ice Home Concept. (SEArch/ Clouds AO)

Figure 1 shows a large two level pressurized habitation area that is surrounded by a gas insulation layer and then a large amount of water ice within an external restraint layer. The habitation area is a tire shaped torus with upper and lower hubs that contain equipment used for deploying and maintaining the Ice Home.

Needs Goals and Objectives

NASA Need: NASA needs economical and effective habitats to enable future human missions to Mars.

What is the problem: Long term stays on the Martian surface (or other deep space destinations such as Ceres) require habitats that reduce launch mass and cost while providing an effective working environment with a high level of shielding from Galactic Cosmic Rays for mission crew members. Current habitat concepts do not address the GCR issue or they require burial by several meters of Martian Regolith which poses significant challenges for the deployment of an effective habitat. Also, current integrated habitat designs do not address the need for large pressurized workspaces to perform maintenance activities on critical equipment that must operate in severe conditions for long periods of time.

Measurable Goals:
Technical Goal: Provide a Mars habitat design concept that:

a) **Improves Mission Effectiveness**:
    i) Reduce GCR dose by >50% over habitats based on an aluminum structure (as depicted in the Humans to Mars Architecture: i.e. Aluminum shell with minimal shielding in the form of logistics storage above the crew)
    ii) Improve Human Factors (Large pressurized work area, Diurnal lighting, other uses such as recreation, plant growth, etc.)
    iii) Scalable design for supporting a wide variety of mission scenarios. Versatility for different mission types is an important consideration.

b) **Improves Mission Affordability** (Reduces Life Cycle Cost over existing habitat designs)
    i) Reduced Launch Mass per cubic meter of pressurized working space
    ii) Provides dual use functions (Replaces water storage systems, provides logistics storage, etc.)
    iii) Can be pre-deployed with only basic robotic systems (as opposed to habitats that must be buried under meters of regolith (typical geology is bedrock) to achieve the same level of shielding).
    iv) Minimize technology development risks (i.e. predeployed large scale excavation/regolith construction systems).

Team Goal: Enable an Ice Home follow-on effort that includes a subscale demonstration system to test how to deploy a subscale structure and fill with water ice under Martian Environments as well as evaluate different materials to be used as boundary layers.

System Description

System Context

Ice Home will be a component of a human Mars outpost. The Ice Home will be connected to one or more additional habitation areas to provide flexible work and living space with a high level of radiation shielding for Mars mission crew members. Ice Home will interface with external ISRU, Power, Command and Control, and possibly ECLSS systems. Ice Home will have three key elements: The Inflatable Structure Element, the Deployment Systems Element, and the Access & Delivery Element.

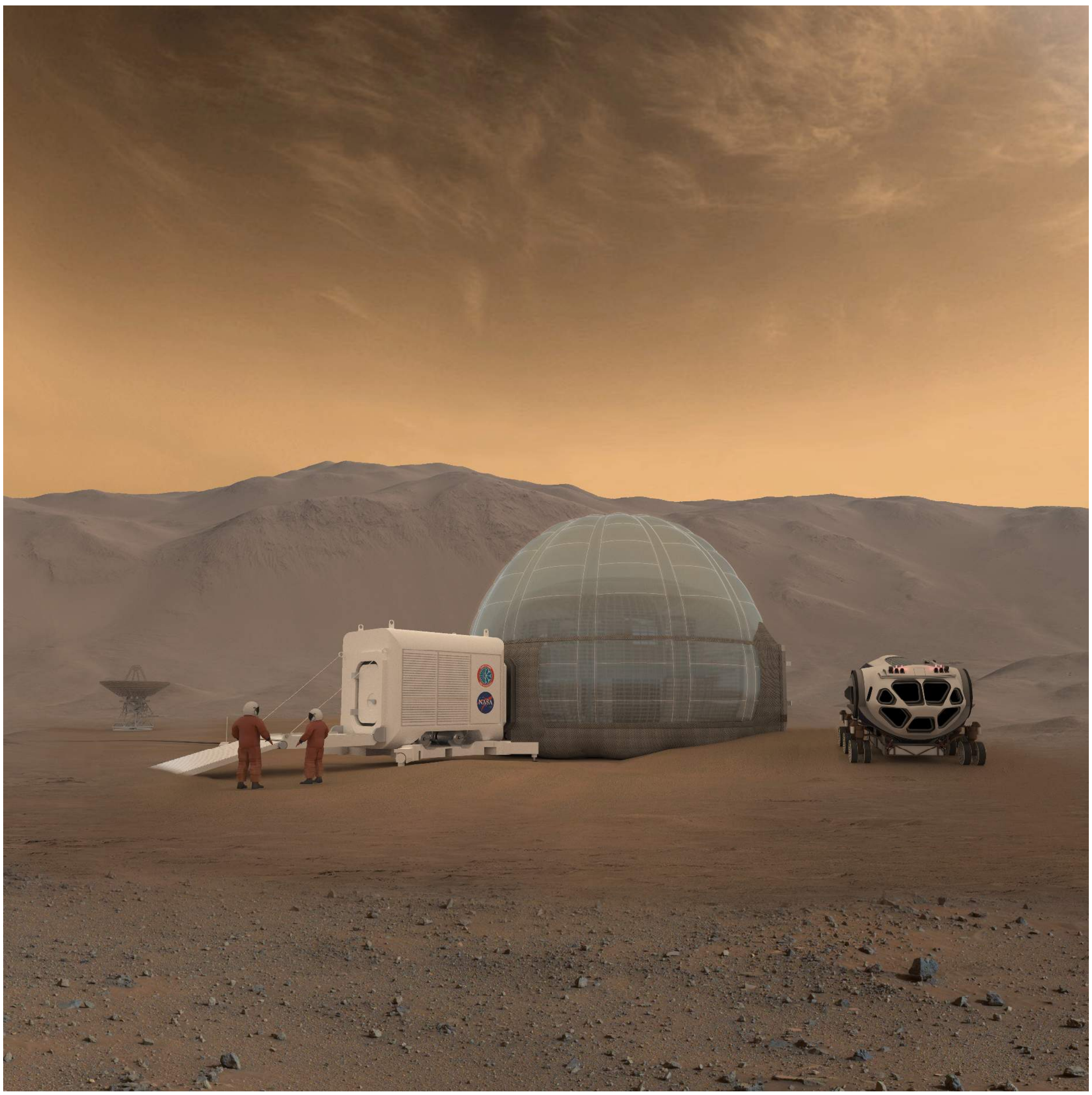


Figure 2: Crew Members Arrive At Their Pre-Deployed Ice Home (SEArch/ Clouds AO)

Basic Assumptions for the Ice Home Concept

1. Water will be available from an ISRU extraction system
   a. Water on Mars will be a precious resource for early human missions. The specific amount needed is a function of the desired radiation protection, the size and configuration of the structure, and external factors such a fuel needs for the Mars Ascent Vehicle (MAV). The water extraction rate is based on inputs from experts in Mars ISRU systems. Although water ice is plentiful on Mars, extracting it from subsurface ice or hydrated minerals will be severely limited in an early Mars outpost by power availability and ISRU system mass constraints.
      i. The water extraction system will have limited storage capacity per use or fill. The Ice Home design incorporates a water storage capability that is available immediately after inflation and can double as the ISRU water storage system.
      ii. Water will be extracted at low rates over long periods of time so the Ice Home deployment method must accommodate this. Per ISRU subject matter experts, the latest Mars architecture assumes a production rate of 1.25–2.0 kg/hr. This rate is based specifically on the propellant production needs for a Mars Ascent Vehicle. It should also be noted that this activity is expected to drive size of the power generation system. This rate is inadequate to support an Ice Home concept. A rate of 0.25 m^3/day (~10 kg/hr.) is recommended to support deployment to full operational capability in a reasonable time frame.
         a. Per the Mars Design Reference, which assumes water extraction from Hydrated Minerals: "*Based on mission consumable need estimates, Mars H_2O extraction that is to be used for propellant production for crewed missions requires that excavation and soil processing systems must be designed to excavate and process 77 kg (3% H_2O content) to 30 kg (8% H_2O content) every hour.*" (This was based on 300 days of operation.)
         b. The Report of the Mars Water In-Situ Resource Utilization (ISRU) Planning Study provides a great deal of information on water extraction options and constraints. http://mepag.nasa.gov/reports/Mars_Water_ISRU_Study.pptx. Significant work is being done to advance these technologies. An example is the Mars Ice Challenge where university teams develop rigs to extract water ice buried by simulated regolith (http://specialedition.rascal.nianet.org/).
      iii. Increases in the ISRU/power system mass to increase water production rates for the Mars Ice Home must be offset by mass savings over conventional habitats with similar dimensions and also account for the systems needed for different methods of radiation shielding.
         a. To accommodate realistic water production rates, an important feature of the Ice Home design is a configuration that will allow initial habitation with a reduced level of radiation protection early and this level of protection will continue to increase as water is added until fully filled. When fully filled the Mars Ice Home will provide several meters of water for radiation shielding. The

design also allows for large quantities of water to be periodically removed (i.e. for conversion into MAV propellant) when needed.

b. Water will be "reasonably" pure with a pH between 6 and 8 (since it will be used to make propellants (i.e. O_2) for the MAV for crew return.

iv. Ice Home will have one primary attachment point for the water resource that can be attached robotically or by a human in a pressure suit. Hoses will have appropriate heating systems to prevent freezing prior to reaching the Ice Dome water connection point. A backup attachment point will be included in the design. In addition to the heated water holding area, the Ice Home system will have integrated pumps, water manifold(s) with valves, heated water tubing, and various water management sensors for routing the water throughout the various water cells in the system.

   a. Given the Exploration zones concept (per latest Mars Architecture), it is expected that water will be transported to the Ice Home periodically via a carrier vehicle vice continuously via a hose from a remote water extraction site. This is likely needed to satisfy planetary protection requirements.

2. Power will be available from a pre-deployed power system prior to Ice Home deployment.
   a. Ice Home will have a standard power interface that is robotically connected prior to deployment (for sensor data collection, data communication, water pumps, valve controllers, blowers, heating, air pumps, and airlock mechanisms). Ice Home will require emergency batteries for key systems such as the Airlock and also have a backup external power connector.
3. The Ice Home system will be initially inflated with filtered Mars atmosphere (mostly CO_2) with onboard air pumps that run on external power.
4. An Environmental Control and Life Support System (ECLSS) will be installed later or will be available for connection to the deployed Mars Ice Home
   a. To provide conditioning of internal atmosphere (air circulation, condensate removal, filtering, etc.).
   b. The ECLSS may be provided via connection to a dedicated habitat module or provided by an internal system that may be installed after deployment or integrated if landing mass allows it.
   c. Linear softgoods seals will be considered between sections (i.e. between dry cooler lower work area and the warmer humid upper area for plant growth)
5. The deployment site will have some preparation.
   a. Limited slope (<5^{o}) (placeholder needs to be assessed in Phase 2). The foundation design will be self levelling.
   b. No large rocks (>4 cm)
   c. A ground cover protective layer may be placed prior to inflation or the structure may be deployed on an existing platform.
6. The Ice Home in the pre-deployed configuration will be mobile or transportable
   a. For safety reasons the habitation zone will be a significant distance from the landing zone especially to limit the hazard of debris ejected from rocket plumes during landing and takeoff.

7. A pre-integrated habitat module will be attached to the deployed Ice Home after it is landed on Mars.
    a. Since Ice Home must be outfitted after deployment, it is likely the crew will initially use a smaller traditional, integrated habitat module early in the mission stay until outfitting and set-up is complete.
    b. Attachment to an integrated habitat module is expected to be via a soft goods passage.
8. The Ice Home system should be less than 18,000 Kg.
    a. Based on discussions with Entry Descent and Landing (EDL) subject matter experts.
9. The Deployed configuration (including EDL systems) must fit within the 8 meter cargo shroud of a standard SLS launcher
    a. And also fit within the more stringent dimensional constraints of the aero shell used for landing on Mars.

System Phases

Launch and Transit: Ice Home must be packaged in a stowed configuration that can be accommodated (with any other systems being transported to the outpost) within the volume and dimension constraints of the EDL aero shell. After landing, the Ice Home deployment package will be transported from the Mars Landing Zone to the habitation zone via robotic transporters (as envisioned in official mars architectures). In addition to launch and landing loads, the system design must withstand the compression loads expected when the inflatable structure is packaged to reduce volume. The current packaging ratio is conservative (~ 2:1).

Placement and Site Preparation: Since Ice Home may be pre-deployed early on it may be landed directly in the habitation area and deployed in place. If needed, robotic assets will transport the Ice Home deployment package from the Landing Zone to the Habitation Zone where it will placed at its operating location. A likely delivery method to the deployment site would be on a trailered cart. The site may have some preparation to provide a level surface free of large obstructions. The design also allows for deployment from an integrated platform.

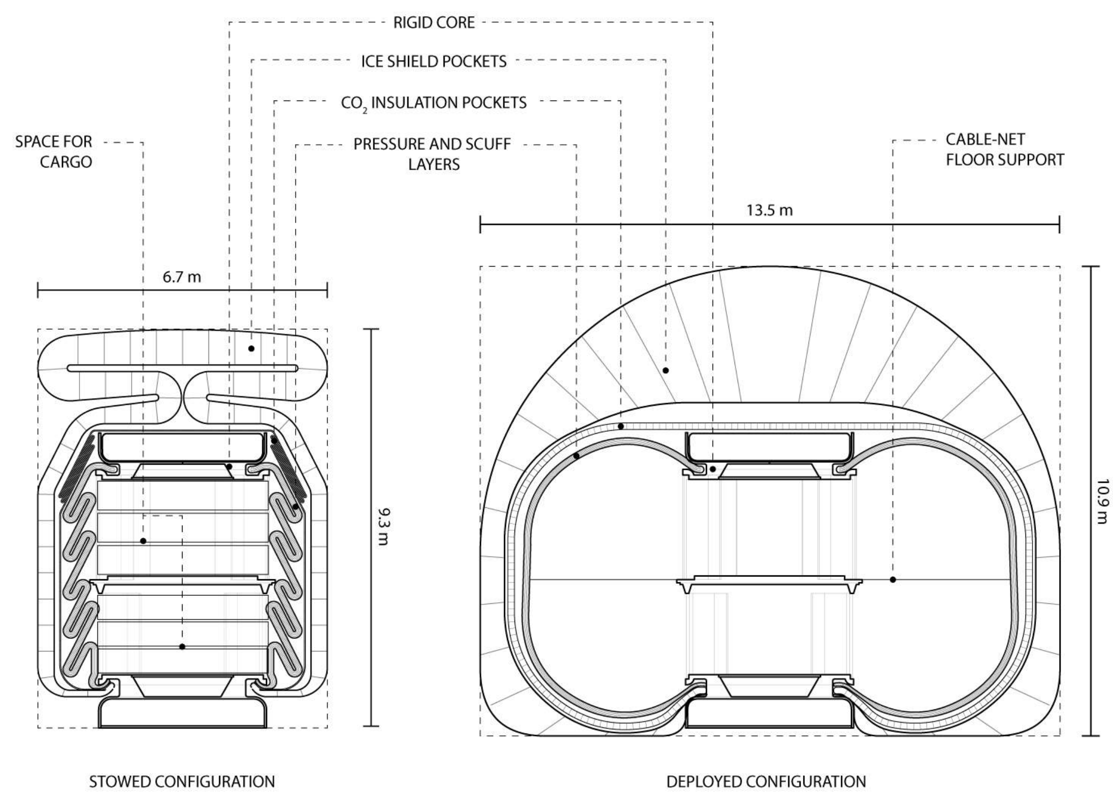


Figure 3: Concept of Ice Home deployment package (SEArch/ Clouds AO)

Deployment Phase: At this point, the Ice Home deployment package has been properly located in the Habitation Zone near where a landed integrated crew module and possibly other systems will eventually be attached.

The first activity will be to attach a power cable from a predeployed power system. A power cable is robotically connected to an interface panel which allows heaters to bring the system to needed temperatures and initiates the data system which allows ground operators to assess system status. A data cable will be attached or an RF link will be established to a to the outpost's communication system.

There will be some additional pre-inflation activities that occur such as deployment of a ground cover or external robotic visual inspection.

Initial pressurization will be performed with integrated air pumps that inflate the system with filtered air from the Martian atmosphere. If there is mass margin to allow integrated airlocks, the pumps for the airlock can double as the inflation pumps. The cargo hatch and the crew hatch may require some supporting mechanisms such as skids or wheels during inflation due to their structural mass.

The deployment will occur slowly with inputs from ground controllers who will verify the success of each operation by monitoring integrated pressure, temperature, and strain sensors (and likely cameras). Once it is established that the inflatable structure has been properly inflated to the desired pressure and temperature, ground controllers will command the sequences of ISRU water fills which will require the opening and closing of specific valves in the Ice Home Deployment Element. Water from the ISRU system will initially be accumulated and held in water cells within the gas insulation layer above the hub and kept heated to prevent freezing. Sensors to monitor the water level in the hub cells will allow ground controllers to control fill rates and volume for the various water cells in the Ice Home.

Once adequate water is stored within the Ice Home, sections will be filled and allowed to freeze in a sequential order. The sequence of fills will depend on the mission scenarios. It may be that the first crew will use a "short stay" mission scenario and if the water extraction rate is very limited it will optimally be placed overhead in the central holding cells and in a thinner layer above the pressurized habitation area to provide a reduced but still reasonable level of GCR protection. As shown in the figures, these water cells will be outside a layer of CO_2 gas insulation so that it will freeze regardless of the temperature in the habitable area. Water cells outside the insulation layer will be pressurized at low pressures to hold shape and then sequentially filled with water which will quickly freeze since Martian ambient temperatures are typically well below freezing. In between periods of habitation, the ISRU system will continue to add water as needed. Completely filling the Ice Home structure may take three or more years depending on water availability, the ISRU system that is deployed, and the agreed to requirements for GCR shielding. After the water cells are filled, the structure will undergo pressure and permeability test at higher pressures than used in normal operation. Also, any safety systems such as relief valves will be tested. Once this is successful the outfitting and checkout phase will begin. Note that since it may take several years to fully fill an Ice Home Structure the Deployment Phase will likely overlap the Outfitting Phase.

> **Per the Mars Ice Home Risk Reduction Water Cell Filling/Freezing Test Report:** *The ice in the Mars Ice Home water holding cells should consist of solid, clear water ice with sufficient strength to be self-supporting and with viscosity low enough to avoid creep of the structure throughout its operational lifetime. The mechanical properties and clarity of the ice are both functions of the size of the crystals in the ice matrix (the "grain size"). Grain size is determined by the rate of cooling of the water cells during freezing (specifically, grain size is initially set by the relative rates of nucleation and growth of ice crystals during freezing) and the temperature at which the cells are maintained following initial freezing (which affects annealing of the ice).*

Testing during the Mars Ice Home Risk Reduction study has shown that care must be taken to control the freezing of the ice cells to avoid failure due to the expansion of the water ice as it freezes. If performed correctly the water ice cell material will withstand many freeze that cycles with only a small degradation in material properties. The seams must not allow water to enter and pull apart as it freezes. In addition to fill and drain tubing, a network of temperature, pressure, and potentially sensors for monitoring fill status will be required. In addition heating elements will be needed around fill tubes to ensure water does not freeze prior to being delivered to the water ice cells. The entire fill operation must be done without human presence and must be highly repeatable.

<u>Outfitting and Checkout Phase:</u> After an integrated habitation module is located near the Ice Home, a soft goods passage will be connected to the crew airlock port to provide a pressurized path to transfer equipment and supplies. Large items will be brought in by robotic vehicles via the cargo airlock. The Mars atmosphere will be replaced with a human compatible atmosphere prior to crew arrival.

For outfitting, it is envisioned that robotic vehicles would bring palletized equipment in from the outside through a large external airlock. This can begin once the floor sections have been installed without fully pressurizing of the interior space. Large airlocks that can operate in the presence of dirt and dust will be a significant technical challenge along with the ISRU system for water production. These systems will be needed for any long term Mars outpost and are not unique to Ice Home. When the dedicated habitat module is attached via a second airlock, crew members can transfer smaller equipment directly to the Ice Home without donning pressure suits. Ice Home is not a substitute for a fully integrated habitat module that is landed separately. Ice Home is envisioned as a multipurpose crew space/workspace that can be configured for activities not better performed inside a fully integrated habitat module. The Ice Home can be configured for activities such as food production, crew quarters, equipment maintenance and logistics that require larger spaces. Providing crew quarters in the area of maximum shielding is was a key design consideration.

<u>Operations and Maintenance Phase:</u> The Ice Home is envisioned as a multipurpose workspace. Given its large volume, it may be used for a combination of science activities, vehicle maintenance, logistics storage, food production, recreation, and living area. Detailed use cases will be developed in later versions of this document.

The operational temperature inside the Ice Home structure is dependent on its use and the large Ice Home habitation area can be partitioned into multiple zones that have different operating temperatures and environmental conditions. The internal operating temperatures will affect the insulation requirements in the floor and walls. The primary insulation layer will be between the water cells and the ice cells. This insulation layer is expected to be a CO_2 gas layer which will help mitigate the impact of changes in volume of the pressurized habitation area from the thick rigid ice layer above. Very little insulation is needed on the outer layer since the temperatures on Mars do not rise above freezing for more than a few hours a day during the Martian summer. A reflective coating may be used to limit solar heating during worst case high temperature days. It should be noted that the ice is not critical for structural support unless there is a catastrophic loss of internal pressure inside the habitation area. Ice Home is essentially a pressure vessel and under Mars gravity the internal pressure will support tens of meters of water or ice.

Prior to crew departure, the propellant system will start converting the water in the water cells into fuel for the Mars ascent. If using a Mars "outpost" architecture, the water used for ascent propellant would be replaced over time after the crew leaves and will be in place for the next Mars mission crew to use.

External Interfaces to the Ice Home System

ISRU Water Interface: Water will be provided by a well-insulated flexible hose with a helical heating elements to prevent the water from freezing prior to reaching the Ice Home interface. The connector must be attachable robotically or by a human in a pressure suit.

Power Interface: Power for Ice Home will be connected to an external interface panel that provides power connector locations to the interior of the Ice Home. The connector must be attachable robotically or by a human in a pressure suit.

ECLSS Interface: This will be TBD until a specific use case is selected.

Command and Data Interface: Ice Home will need an extensive set of sensors to monitor deployment status. These will include multiple temperature, pressure, strain sensors and possibly visible cameras. This interface will likely be a robotically attached data cable to a pre-deployed communications system. A backup RF based command and data interface would be included. During deployment, the Ice Home will also need to accept commands to operate mechanisms such as valves, pumps, heaters, blowers, and airlock mechanisms over this interface.

Interface to other habitats: A flexible softgoods passage is shown in the Mars Exploration Zone video as a potential connection method between habitat modules. An attachment ring will likely be used although it is not known if these will be robotically attached or will require human assistance to perform.

> **Notes on Potential Airlocks:** Currently, airlocks for long term use in the Mars environment must be developed. Given the dust and contaminants brought in by humans and possibly vehicles this will be a major technical challenge that must be worked as a future technology development project. If integrated into the structure, a significant volume must be allocated around the airlock to accommodate their subsystems. The Ice Home study will help provide use cases for

future airlock design trades. One Airlock reference that was used was: A Dual-Chamber Hybrid Inflatable Suitlock (DCIS) for Planetary Surfaces or Deep Space (AIAA 2011-5064) from Scott Howe & Kriss Kennedy at JSC. Below is a graphic from this paper that appears to be scalable and compatible to the Ice Home ConOps.

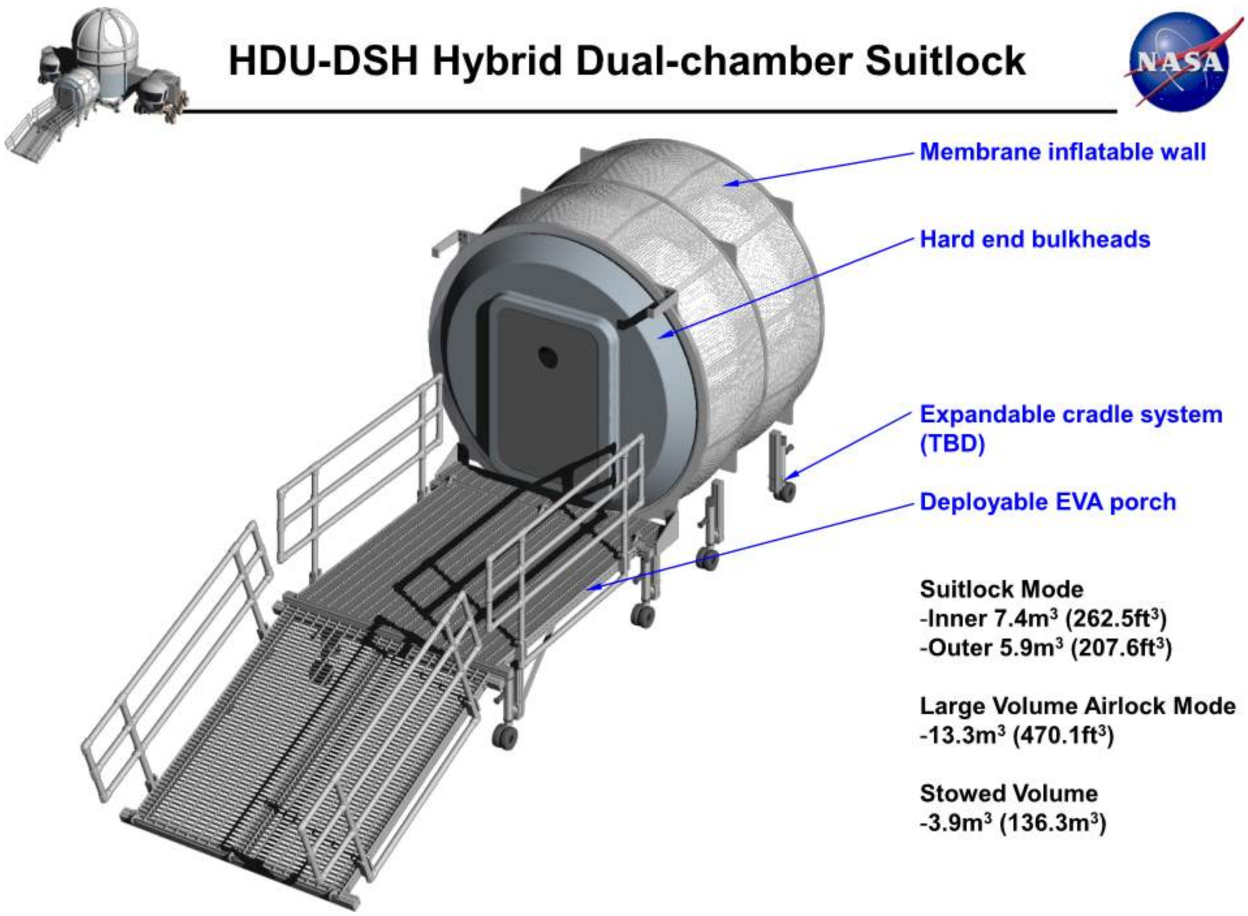


Figure 4: Potential Airlock configuration from AIAA 2011-5064

Due to Mass Constraints it may be necessary to attach separately to the existing hatch. If performed robotically, it would allow outfitting to be performed prior to human occupation. No mass estimates were provided in the material for the version shown.

Day in the Life

Based on the Mars Architecture Documents the Ice Home is best utilized as part of the nominal surface mission scenario as described below in the Human Exploration of Mars Design Reference Architecture 5.0:

> *"The nominal surface mission scenario that was adopted for this Reference Architecture would have a centrally located, monolithic habitat, two small pressurized rovers, and two unpressurized rovers (roughly equivalent to the LRV that was used in the Apollo missions to the moon) (figure 4-8). Power for these systems would be supplied by a nuclear power plant (40 kW at last report) that would have been previously deployed with the DAV and would be used to make a portion of the ascent propellant. Traverses would be a significant feature of the exploration strategy that is used in this scenario, but these traverses would be constrained by the capability of the small pressurized rover. In this scenario, these rovers have been assumed to have a modest capability: notionally a crew of two, 100 km total distance before being resupplied, and no more than 1 week duration. Thus, on-board habitation capabilities would be minimal in these rovers. However, these rovers are assumed to be nimble enough to place the crew in close proximity to features of interest (i.e., close enough to view from inside the rover or within easy EVA walking distance of the rover). Not all of the crew members would deploy on a traverse, so there would always be some portion of the crew in residence at the habitat. The pressurized rovers would carry (or tow) equipment that would have the capability to drill to moderate depths – 100's of meters – at the terminal end of several traverses.*
> *The primary habitat would have space and resources allocated for on-board science experiments. The pressurized rovers would carry only the minimal scientific equipment that is deemed essential for field work (in addition to the previously mentioned drill); samples would be returned to the primary habitat and its on-board laboratory for any extensive analysis."*

A typical day for the Ice Home crew will begin when the crew wakes up to their view of the garden through windows in their crew quarters and leave their well shielded crew quarters at the center of the Ice Home and go to through the airlock to the Integrated Surface Habitat (SHAB) to fix a hot breakfast and have a morning team briefing. Since many of the daily tasks will occur inside the Ice Home they will soon return to begin work.

Figure 5: Crew members wake up with diurnal light and a view of the plants in the greenhouse (SEArch/ Clouds AO)

Crew members will go to the greenhouse section to perform routine garden tasks…

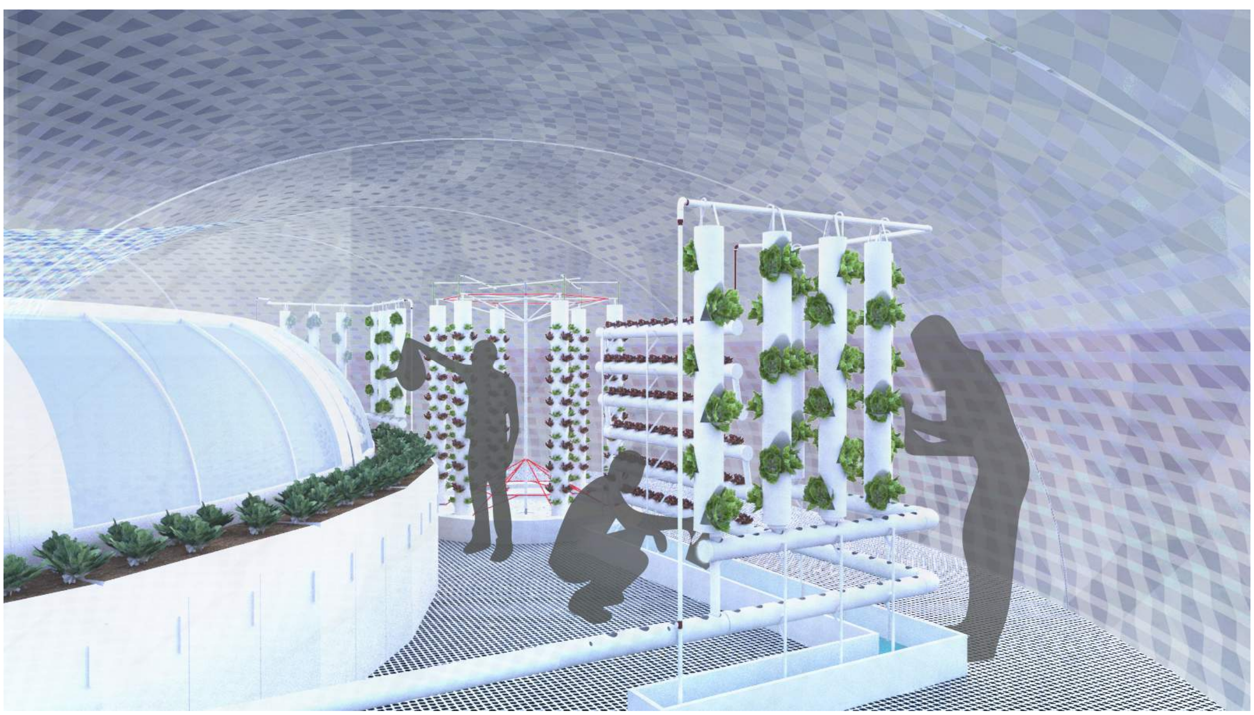


Figure 6: Crew members go to work in the garden section of their Ice Home (SEArch/ Clouds AO)

Another will enter the Ice Home to begin implementing another set of mission science sessions. This includes remotely operating robotic vehicles on the Martian surface and analyzing materials that have been returned…

Another will don an environmental suit to begin performing routine maintenance on external systems brought into the repair and maintenance section the previous day…

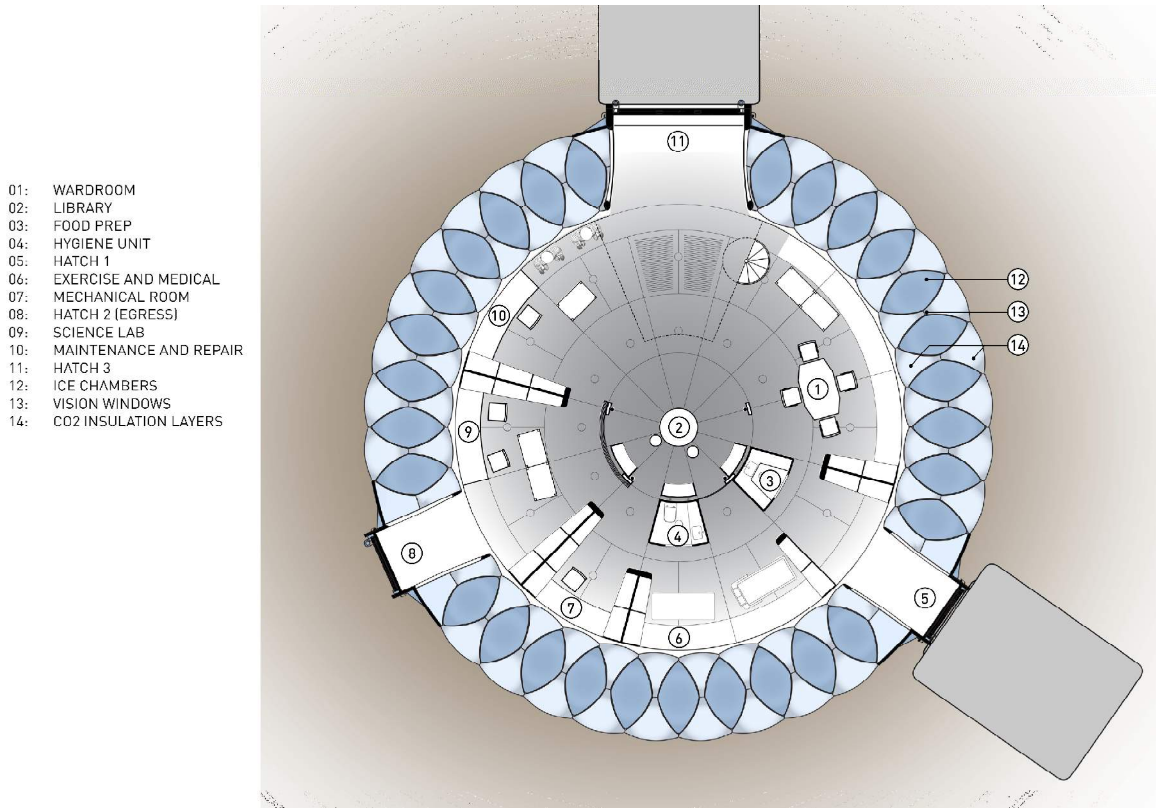


Figure 7: Notional Ice Home 1st Floor Layout (Clouds AO)

The first floor provides a significant amount of workspace that can be tailored to the specific needs of an early Mars outpost.

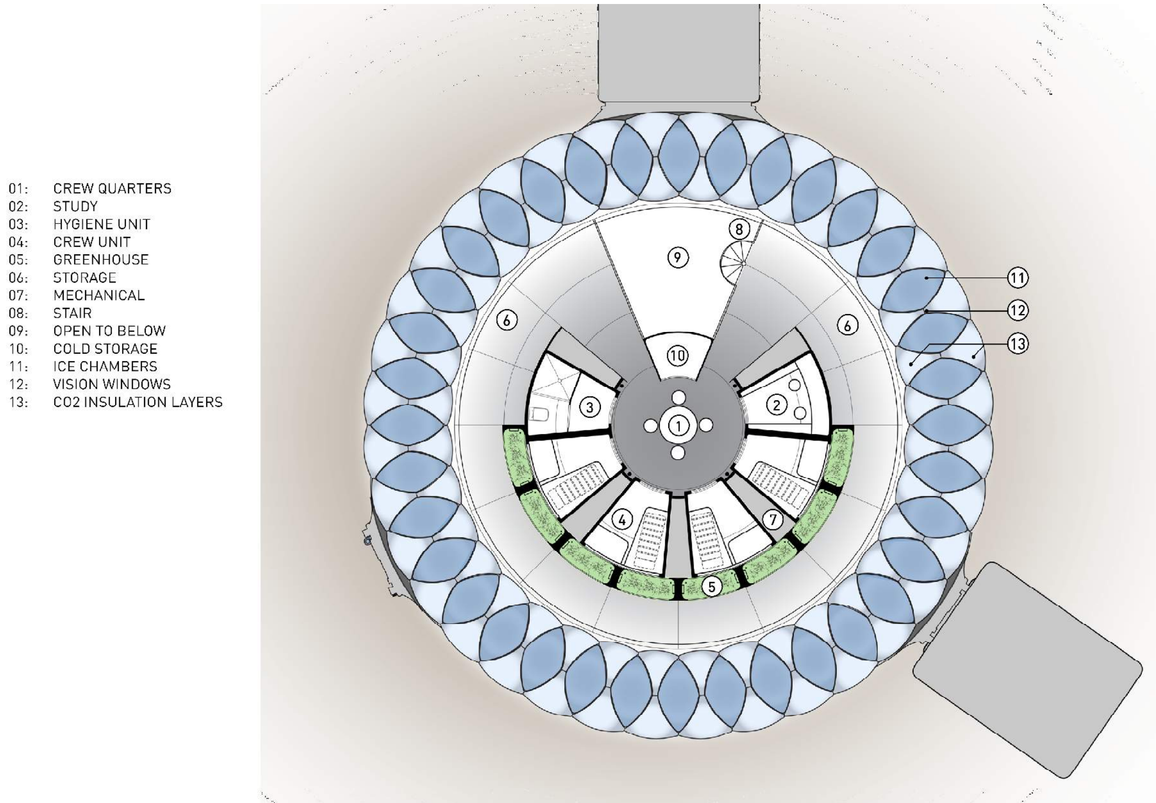


Figure 8: Notional Ice Home 2nd Floor Layout (Clouds AO)

The second floor can be used for logistics storage or as in this example an area to grow fresh food. A greenhouse derivative of the Mars Ice Home has been proposed. The greenhouse would be attached to one of the access ports so that crews could easily perform crop maintenance with a selectable level of GCR shielding.

Allowing some level of diurnal lighting to penetrate the Mars Ice Home is a design goal. If achievable, it takes advantage of the similarity of Martian day night cycles to those of Earth to make living on Mars a little more like home. Maintaining Earthlike circadian rhythms can promote human health.

Figure 8a: Diurnal lighting for crew well-being on long stays (Clouds AO)

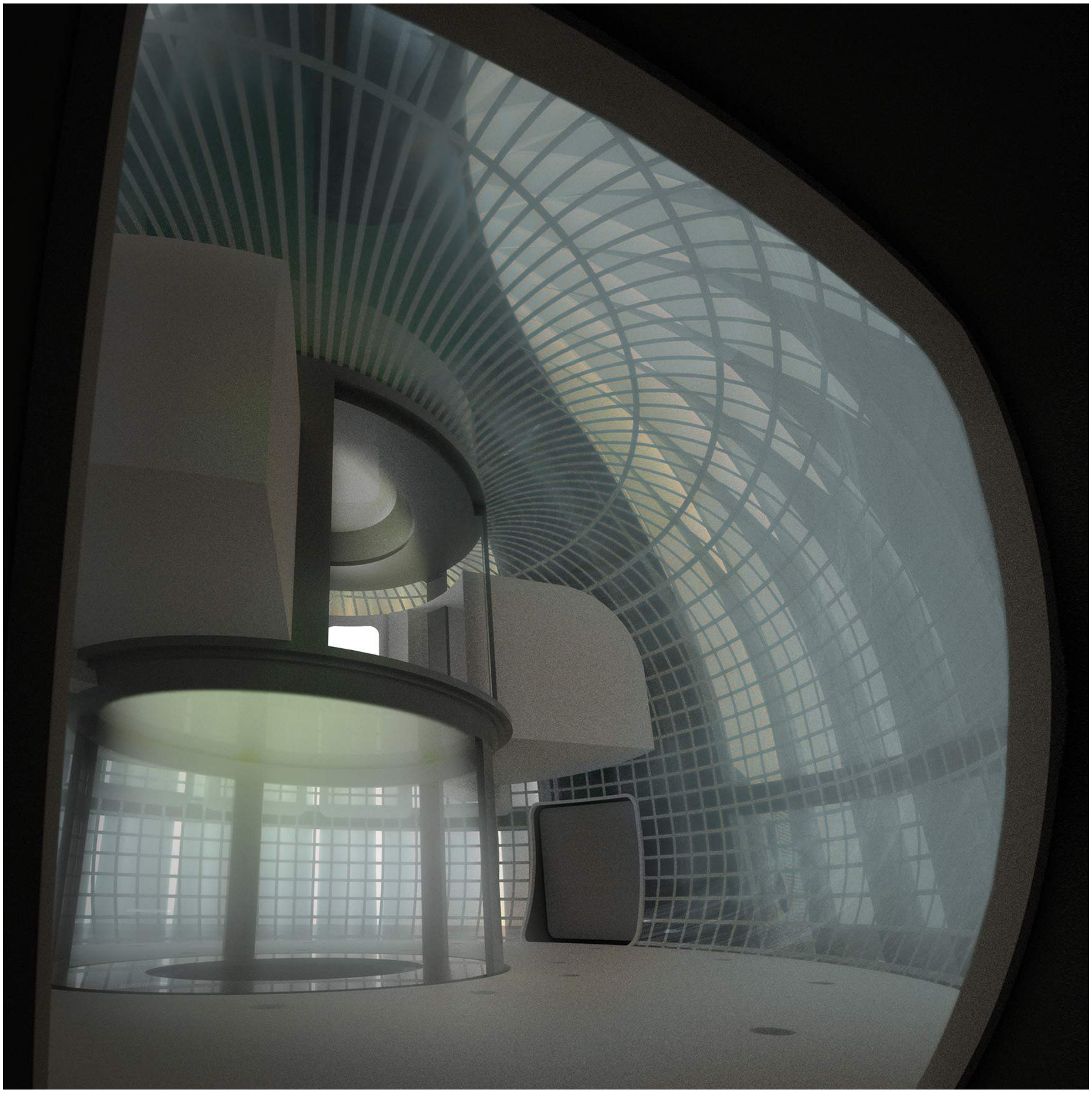


Figure 8a: Operational potential of a large well shielded pressurized workspace (Clouds AO)

The hemispherical design maximizes interior workspace for a given surface area which minimizes landed mass and water requirements.

…and then the crew members kicked back for some well-deserved R&R in their Martian Ice Home after a hard day of work and back to their cozy (and highly shielded) Ice Home bunks…

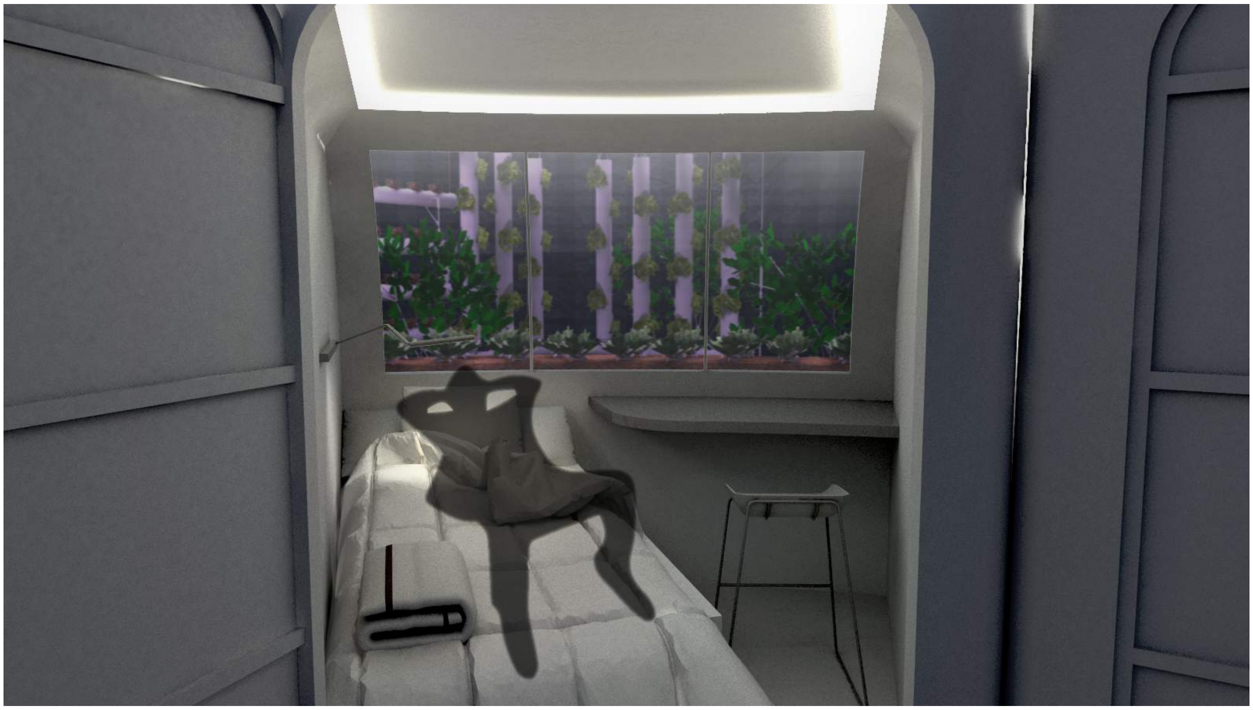


Figure 9: Time to Recharge (SEArch/ Clouds AO)

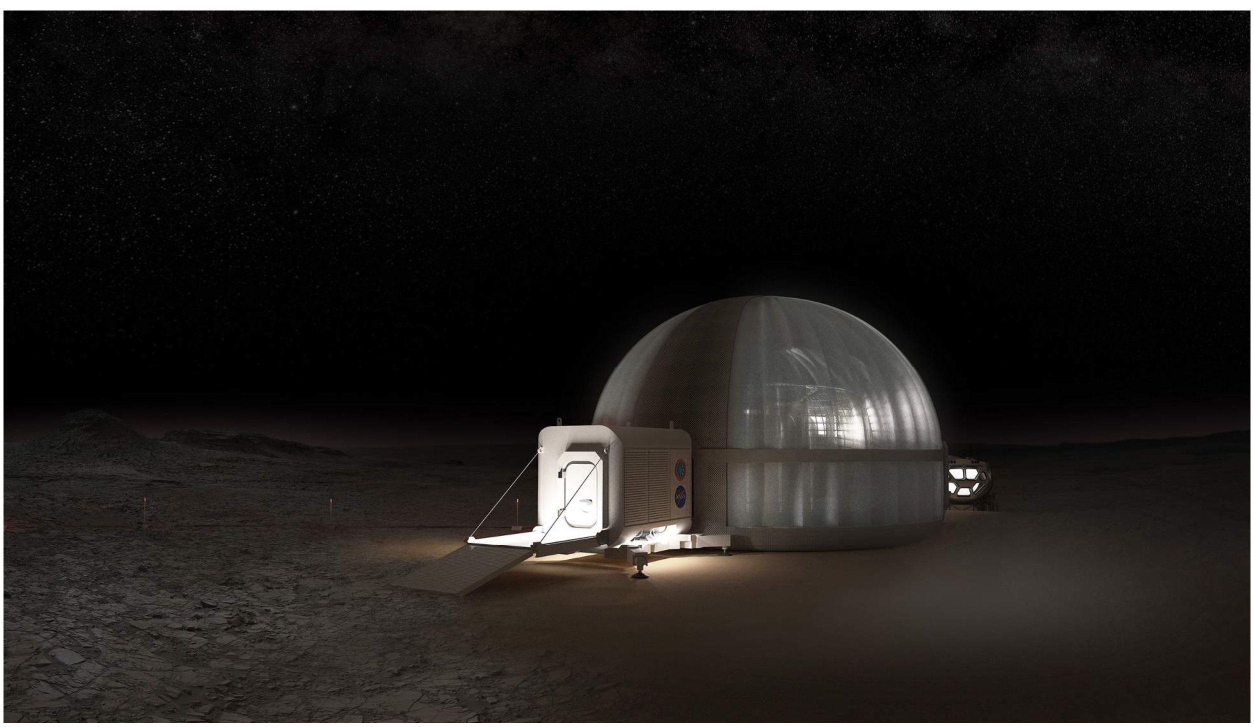


Figure 10: A Beacon of Light in the Martian Evening (Clouds AO)

Design Trades

1. **Size: Deployed Diameter** - Since Ice Home is envisioned as a flexible workspace for a crew of 4 during a long duration surface stay, maximizing the useful volume has been a key consideration. Potential uses include a pressurized area for the maintenance of tele-operated vehicles, food production, recreation, and logistics. For workspace flexibility the larger the better. The current 12 meter diameter two level torus provides about 198 m^2 of floor space (~2131 ft^2).
    - The limiting factor when selecting the size of the Ice Home is based on the amount of water that can be collected in a reasonable time frame to provide shielding from GCRs. Size is also limited by the mass that can be landed on the surface of Mars.
    - Given a constant pressure the hoop stress on the material increases linearly with the torus radius thus doubling the radius would require the restraint material to be twice as thick. Given that the working area goes up by the square and volume goes up by the cube it may be a reasonable tradeoff in many cases.
    - The payload fairing diameter for the SLS cargo version is currently 8.4 meters. The EDL aero shell configuration constrains the volume even more. The Ice Home System must be designed with significant margins so that it can be accommodated within that volume.
    - If the MSL is used as a reference point for a tele-operated vehicle, an airlock that can accommodate it is 3 meters long, 2.7 meters wide, 2.2 meters high (and supports a mass of 899 kg). This is roughly the size of a garage door. For outfitting, the capability to have tele-operated vehicles place palletized material and equipment racks inside the Ice Home would be highly desirable.
    - The recommended living space of at least 25 cubic meters/crew member is easily accommodated by the addition of an Ice Home habitat and does not impact the design solution.

    Given these constraints, the study team selected an internal habitation space that was 12 meters across based on a torus that is 6 meters in diameter and is split into two levels.

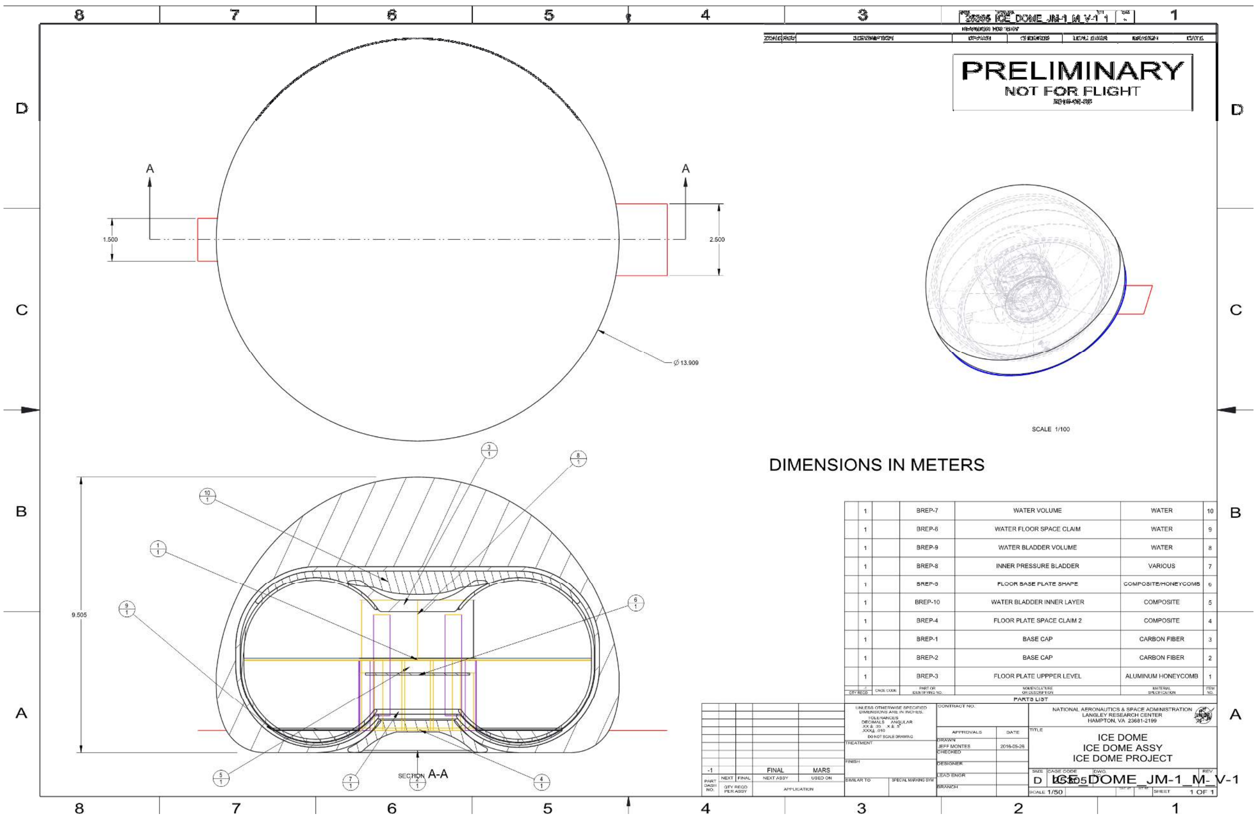


Figure 11: Early Ice Home Concept Drawing with Selected Dimensions

2. **Size: Height** - What is a reasonable height? Can the structure be deployed with multiple levels? Will maintenance be required on top of the structure? May want to integrate external attachment feature adding items after deployment

   Since the design is based on a torus shaped habitation area approximately 6 meters high with at least three meters of ice above in addition to insulation and water cells, the deployed height is approximately 10 meters.

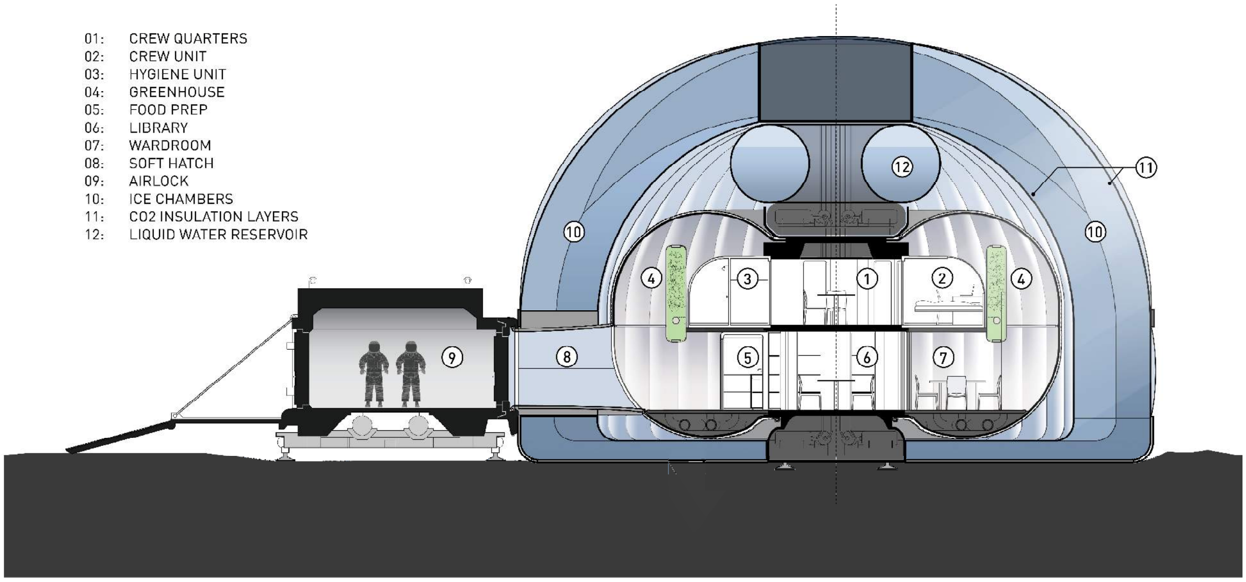


Figure 12: Enhanced Ice Home Cutaway with Dimensions (Clouds AO)

3. **Operational Life:** Along with a 550 day operational phase, the deployment phase for Ice Home may be two years or more primarily due to the ability of the ISRU systems to collect water and fill the Ice Home structure. Thus the minimum operational life would be ~4 years on the Martian surface. The nominal operational life would be much greater that if an "outpost mode" is assumed as described below. The Evolvable Mars Campaign (EMC) describes an outpost life cycle of 3 crew rotations.

Per Mars Architecture: <u>A 550-day surface mission</u> (Long Stay Option)

- "Sortie mode vice outpost mode: The **outpost mode** assumes that each of the human missions to Mars will integrate its elements and materials with those from previous missions, building up to a greater capability for future missions."
- "The first phase of the long-stay mission architecture begins with the pre-deployment of the first two cargo elements, the Direct Ascent Vehicle (DAV) and the Surface Habitat (SHAB)."
- "Pre-deployed and operated surface elements include the SHAB, power system, thermal control system, communications system, robotic vehicles, and navigation infrastructure."
- "Pre-deploying assets, by definition, requires that the assets remain fully functional for longer periods of time (in some cases, double the total lifetime compared to the all-up option) to complete the entire mission. This introduces reliability issues and associated risks to both crew safety and mission success."

- o "Long-Stay Mission (fast transit) **-** similar to the minimum energy Long-Stay profile, this mission profile provides long surface stay times. With sensible increases in propulsive energy, the travel times to and from Mars can be reduced by up to 100 days each way (one-way travel times range from 120 to 180 days), resulting in an increase in surface stay times to a total of 600+ days."
- o 15 years of Mars Environments on Materials.
  - Consider material creep
  - Thermal expansion of water
  - Material degradation due to Mars Chemistry and radiation
  - Etc.

Based on recommendations from Mars Architecture experts, the required operational life is 15 years.

4. **Number of Crew members**: The Human to Mars Architecture recommended a crew of 6. The Evolvable Mars Campaign has recommended a crew of 4.

   Based on recommendations from Mars Architecture experts, the expected crew size will be 4.

5. **Purpose of Facility:** What will be the primary purpose of Ice Home? Habitation, Vehicle Servicing, Food Production, Logistics, Other.
   - "Mobile robots are used on the surface to reduce astronaut workload and risk and to enable exploration objectives."
     - Mobile robotics and ISRU equipment will likely require periodic maintenance that would greatly benefit from a working environment where pressure suits are not required.
   - Bio regenerative food production has gained significant interest recently to reduce long term logistics. Most Mars outpost concepts include plant based food production infrastructure.

   The current concept incorporates a sleep area, a food production area, a logistics area, a recreation area, and a work area.

6. **Applicable Martian Latitudes:** Equatorial, > 30 degrees
   - o Higher latitudes are more challenging for EDL due to the benefit of Mars rotation on low latitude landings to reduce relative velocity. Higher Latitudes have more water resources but are generally colder. The northern hemisphere is generally better in some ways due to lower elevations providing slightly higher atmospheric pressures (and more time to slow down). The Southern hemisphere has more interesting geography in general. Specific landing site selection is outside of the scope of the feasibility study. The temperature profile will be based on the MSL environmental requirements where it will generally get above freezing for only a few hours per day (measured just above the surface due to solar heating) in the summer and worst case cold temperatures are well below minus 100^{o} C for long

periods. There may be a significant desire to store various types of equipment inside the Ice Home to mitigate damage from dust and the extreme temperatures.

The landing site will be between +/-30^o Latitude

7. **Crew Operational Environment:** Shirt Sleeve, Environmental Suit, other
   - If robotic systems are to be maintained inside the Ice Home it would be necessary to partition sections from one another to minimize contamination from Martian soil. Positive pressure and filtering systems may be used to mitigate this issue.
   - Condensation will be a significant concern if the external water cells are much colder than the interior pressurized space. Additional insulation layers may be needed.

The crew operational environment inside the Ice Home will be shirt sleeve compatible.

8. **Internal Pressure (Habitation Area):** 8 psi, 10.2 psi, 14.7 psi, other
   - 10.2 psi seemed like a good compromise for the Ice Home feasibility study.
   - The conservative choice is to use 14.7 psi for structural design loads, which will provide significant margin if the internal pressure requirement is relaxed.

Based on recommendations from Mars Architecture experts, the assumed pressure inside the habitation area will be 14.7 psi.

9. **Internal Pressure (Ice Cells):** 1 psi, 2 psi, other
   - 3 psi is the starting assumption. A typical Martian atmospheric pressure is only 0.09 PSI (as opposed to Earth's 14.69 PSI). Although there is much uncertainty in the overall habitat design and the ambient pressure that the cells will be subject to, it is expected that the water holding cells would not require a differential pressure greater than 3 PSIG to maintain the desired shape when initially inflated. This pressure is typical of inflatable structures that do not have to carry significant loads. It is also expected that a differential pressure of less than 0.5 PSIG will be inadequate to maintain a good shape when filling is being performed.
   - During the Mars Ice Home Risk Reduction study tests demonstrated that solid clear ice with large grain sizes can be produced in water cells at pressures below 1 psi. Specific procedures must be developed to optimize the filling and freezing of the water.
   - Using 3 PSI with a NASA standard Factor of Safety allows calculations to be performed that will determine material thickness and mass.

Based on the results of risk reduction studies, the assumed pressure inside the water cells area will be 3 psi.

10. **Internal Temperature:** 72 degrees F
    - Per an ESA ECLSS document for the ISS (http://wsn.spaceflight.esa.int/docs/Factsheets/30%20ECLSS%20LR.pdf): Cabin

Temperature nominal range: T = 65 to 80˚F (18.3 to 26.7°C). Also Note: *"Airborne particulate and microbes removal and disposal: CCAA Filters"* so it may be prudent to consider flexible ductwork into the design so that blowers and filters are integrated into the structure. Will assume 72 degrees F for design of insulation between crew are and structure.

- It is likely that the Ice Home will be partitioned into different sections and the internal temperature and humidity levels may be different in each. Custom ECLSS systems will need to be designed for the specific configurations and use cases.

For thermal calculations, the temperature inside the pressurized habitation area will be 22.2° C (72° F)

11. **Assumed Fill material:** Pure Water, Water/Regolith Slurry, Combination
    - A slurry mix of regolith and water would add strength and resistance to slumping to the lower areas at the expense of system complexity and reliability.
    - Water in the various water holding cells will need to be occasionally emptied, filtered and refilled to maintain purity and reduce potential biological contamination (algae, microbes, etc.).
    - Desalination capability may be needed over time.

    Pure water ice will be assumed as the fill material for shielding and structure.

12. **Assumed Water Generation Rate:**
    - The selected rate is based on the quantity needed for various design concepts, feedback from ISRU experts, and the expected deployment and use scenarios from the Mars Architecture experts.
    - Assessments of the effective dose on crewmember at the center of a hollow sphere of ice (Using TARIS 4.0) shows that a two meters of water shielding will provide a reduction of well over 50%.

Shield Geometry	Effective Dose (mGy/Year)	Difference over Unshielded Crew Member
No Shielding	178	Baseline
Thin Aluminum shell	Small increase	Small increase
Water sphere 1 meter thick	107	-40%
Water sphere 2 meters thick	**75**	**-58%**
Water sphere 3 meters thick	50 High Uncertainty	-72% High Uncertainty
More than 3 meters	Very High Uncertainty	Very High Uncertainty

Table 1: Effective Dose Reduction Based on Shield Thickness

- If the radius of the internal habitation area is 6 meters and it is surrounded by a gas insulation layer that is 0.5 meters thick then the inside diameter of the ice shell will be 13 meters.

Shield Thickness (Inside	Water Volume with a	Time to fill at 0.25 cubic

diameter of 13 meters)	1 meter thick Floor	meters per day
1 meter	~441 m^3	~1764 days
2 meters	~844 m^3	~3376 days

Table 2: Water Volume and Fill Time Based on Shield Thickness

- Clearly a two meter thick hemisphere in not a practical option at 0.25 m^3/day. Water can be placed strategically such that there is more near the top and less on the sides to make the shielding more effective on the Martian surface. This will help reduce water volume requirements to obtain a dose reduction of greater than 50%. Future analysis will allow optimization of the water placement. Also, reducing the diameter of the habitation area will greatly reduce the water collection requirements.
- Low energy launch opportunities to Mars occur about every 26 months (1560 days)
- This very basic assessment suggests that an Ice Home with a habitation area 12 meters in diameter would need to be pre deployed at least two launch opportunities ahead of the crew if the maximum extraction rate is 0.25 m^3 per day and we want the effective dose to be reduced by 50%. Many options are available for mission designers.

250 kg/day (i.e. 0.25 m^3/day) is assumed. However this is 5X the production rate that was estimated to support fuel production for the MAV.

13. **Materials:** Identify materials to be used in the Ice Home inflatable structure
14. An important design consideration for the Ice Home team was Human Factors over a long duration mission. A key design goal for the team was to allow some level of external light to pass through the structure to provide diurnal lighting. Significant effort went into the selection of materials that offered high strength with low creep as well as high resistance to the Martian environment that also have high light transmission.
15. Environmental considerations included:
    - External abrasion by windblown dust
    - External degradation by radiation
    - External degradation by perchlorates
    - External degradation by atomic oxygen
    - Internal abrasion by crew activities
    - Internal abrasion by water ice movement
    - Internal outgassing into the crew area (in accordance to ASTM E595)
    - Flexibility, creasing, and degradation at extremely low temperatures
    - It is expected that the large dimensions of the bladder layer for the habitation area along with the low permeability required will be a significant manufacturing challenge. Interior abrasion layers have been designed to be removable to allow access to the internal bladder layer in the event repair is needed.
    - Planetary Protection: If unable to wipe down, a hot soak to kill microbes will likely be required to meet planetary protection requirements (Dry Heat Microbial Reduction (DHMR)). This is typically done at ~125^{o}C.

- Possibly consider antimicrobial coatings for materials that have a risk of damage in a DHMR.

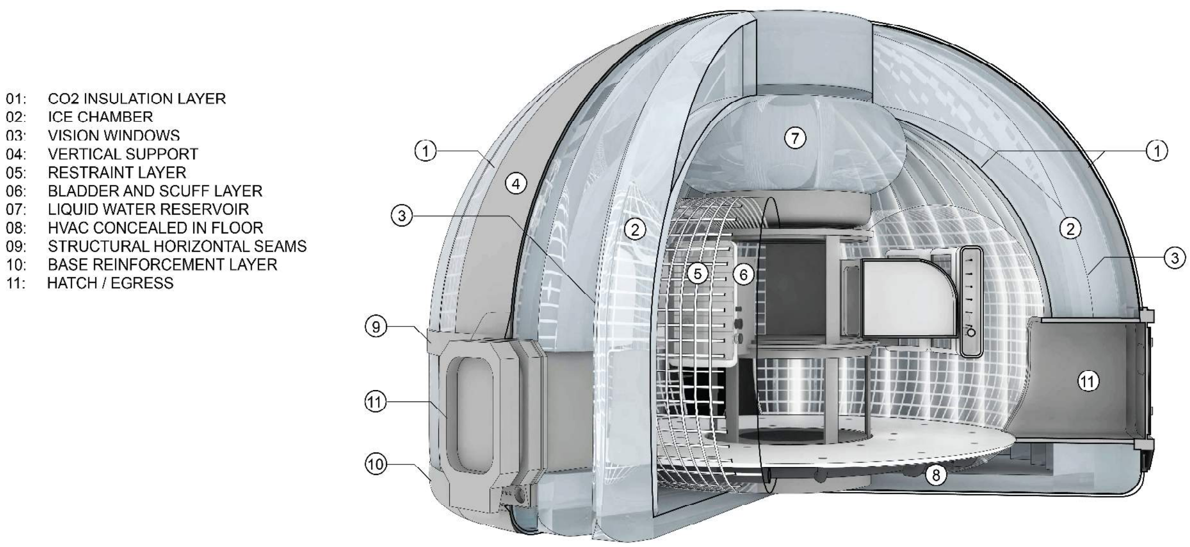


Figure 13: Ice Home Material Layers (SEArch/ Clouds AO)

The following image shows the potential of natural lighting inside a translucent ice structure if the restraint layer(s) and insulation is sufficiently transparent. The designer's attempted to allow as much natural lighting to enter the Ice Home as is reasonably practical. This may also be achieved via parabolic solar collectors and fiber optics if needed.

Figure 14: Example Ice Structure showing potential benefit of light transmission

Material	Description	Thickness cm(in)	Weight g/cm2 (oz/yd2)	Density gm/cm3	Rationale	Comments	Reference
Outer Cover							All references files are pasted in One Note on Materials page
Beta Cloth	woven glass fiber coated in Teflon	.020 (.008)	.0237 (7)		loosely woven outer AO and environmental protection	Might be able to loosely weave the beta cloth (lower AO protection) if TOR underneath	
COR (Clear Oxygen Resistant)	polyarylene ether phosphine oxide (polymer film)				good AO and UV protection	invented at LaRC; made by Triton Systems, Inc.	
Ice Bag Mylar		.026 (.010)		1.39	excellent gas barrier		
Insulation Bag (CO2 inside) Mylar	clear film	.013 (.005)		1.39	excellent gas barrier	good gas barrier, high strength, transparent	
Water Bag Mylar	clear film	.013 (.005)		1.39	excellent gas barrier		
Structural Layer Woven Fiberglass Cloth	E glass S-2 glass	.015 (.006) .023 (.009)	0.0205 (6) .0303 (9)		strong, translucent, low creep low moisture absorption	might need fiber placement sealer	
Inner Bladders HDPE (3 layers)		.008 (.003)			low Tg; puncture resistant; flexible at large range of temps; ok gas & vapor barrier		
Scuff Layer Nomex	white cloth (mats not a full layer	.018 (0.007)					

Table 1: Ice Home Material Information

For the restraint layer, material experts selected high grade fiberglass webbing over other materials for its low creep properties, wide temperature range, high resistance to chemical and UV degradation and its good light transmission properties.

The operational life of the Mars Ice Home is expected to be 15 years. The material used for the water holding cells must provide trouble free operation in the Martian environments during that period. The water cell material must also allow for trouble free packaging and deployment. This task will identify potential materials that meet the environmental and operational requirements.

Tensile Strength: Although this will be refined during follow-on design iterations, the initial assumption is that the water cells will be pressurized to 20 kPa (3.0 PSI) to allow water to be distributed to the water cells and frozen into solid clear ice. Given the above and a Factor of Safety of 2 a minimum tensile strength would be in the range of 40 to 50 MPa. (Note as a reference point DuPont Tedlar film has a tensile strength of 90 MPa).
Maximum Temperature: Since the water cells will be inside a gas insulation layer the primary heat loads will be from solar induced heating on the upper surface of the water cells. To be conservative the maximum expected temperature during operations will be 90 degrees F (~32.2^{o}C) caused by the greenhouse conditions in the gas insulation cells. Higher temperatures may be encountered while in the payload shroud awaiting launch or from solar heating of the payload while in transit. For most materials this is not expected to be an issue.
Minimum Temperature: It is expected the payload will have thermal control during transit to mitigate deep space temperature swings. While on Mars the outside temperature may drop to -100 degrees F. Although the water cells will be inside a gas insulation layer there is the potential that a loss of power will allow the material to be exposed to the minimum Martian temperature of -100 degrees F (-73.3^{o}C). Note that the structure will not be deployed (initially inflated from a packed configuration) without being heated to a minimum recommended temperature that is preset for deployment. The material should not become brittle and crack at these low temperatures while under loads.

Resistance to UV Light: The thin atmosphere of Mars does not filter UV light as effectively as Earths thick atmosphere with its ozone layer. Although the total UV flux is equivalent (since Mars is twice the distance from the sun) much of the UV flux on Mars is in the shorter UV wavelengths which are more damaging to materials. An outer layer of clear Teflon with some coatings such as micron sized zinc oxide, could greatly reduce the UV exposure on the water cells at the cost of reduced visible light transmission. The Ice Home Water Cell material must meet its other requirements after 15 years (15 Earth Years is about 8 Martian Years) operating on the Martian surface.
Thermal Cycles: There are a little more than 5000 Martian days (AKA Sols) in the estimated 15 Earth years of operations. Since Mars has a wider day/night temperature range than Earth these diurnal cycles will be important in material selection even though the water ice cells will be insulated to some extent by the external layer of gas insulation.
Visible Light Transmissivity: As high as reasonably achievable
Freeze/Thaw Cycles: Three full freeze/Thaw cycles for each material based on three crew rotations. Filling procedures will be a key factor. Cells cannot be overfilled since water expands as it freezes. Freezing rates, fill methods, and surface coatings are also critical to expansion and loads on the material.
Resistance to Perchlorates: It is unclear what concentration of perchloric acid will be in the water provided by the ISRU system but since perchlorates are relatively common on Mars, the material should have a high resistance to them. Material resistance to perchlorates will drive water purity requirements for the ISRU systems. In general, the less restrictive the purity requirements, the better.
Resistance to Atomic Oxygen: UV light can break up water molecules to produce atomic oxygen, which although short lived can damage materials. Materials selected should have good resistance to degradation by atomic oxygen.
Resistance to Chemical Leaching into Water: Harmful contaminates from the material itself should not leach into the water which may have multiple uses during the mission.
Resistance to High Energy Radiation: The surface of Mars gets ~40% the Galactic Cosmic Ray flux as deep space. In addition High Energy Protons from solar events are not attenuated to the extent they are on Earth.
Maximum Creep at under expected loads: The water cells will be filled with gas for up to two years prior to being filled with water ice. After filling and freezing it is important that the water boundary layer does not continuously creep under load which would cause the water cells to slump. For the vertical water cells a restraint webbing or fibers may be incorporated in the material to add strength and reduce material creep.
Resistance to abrasion while under compression: The water cells will be separating large masses of ice that may have some movement during thermal cycles. The material must resist self-abrasion while under high compressive loads.
Resistance to degradation at creases: The material will be folded and compressed for launch and transport to Mars. This process will form creases in the water cell material. Upon deployment, these creases must not affect material performance.

Commercial and custom Tedlar and Teflon bags were extensively tested during the Mars Ice Home Risk reduction effort. By using proven procedures for filling and freezing, these materials withstood multiple fill and freeze cycles with only minor degradation. The materials were also tested for degradation due to exposure to acid, ionizing radiation, and abrasion with encouraging results. The top water cell material candidates are:

Clear Teflon (Teflon™ FEP) – This material has exceptional UV resistance, high acid resistance, high strength and durability as well as extreme cold temperature tolerance (cryogenic to high temperature condition, -400 to 400 °F). In addition it can allow more than 95% of the incident light to pass through.

Clear Tedlar – Like Teflon, this material has exceptional UV resistance, and high acid resistance. Tedlar has higher strength than Teflon. It has very good durability as well as cold temperature tolerance and a very high light transmissivity.

Clear Ethylene tetrafluoroethylene (ETFE) – Another Florine based polymer with good properties. All of the polymers tested during the MIHRR study showed that standard heat seal fabrication methods worked well.

Clear Mylar - A proven material used in space environments with high chemical and resistance to UV degradation.

Based on test results Clear Tedlar is currently the leading water cell material candidate. See the MIHRR Test Description for more information on the material testing.

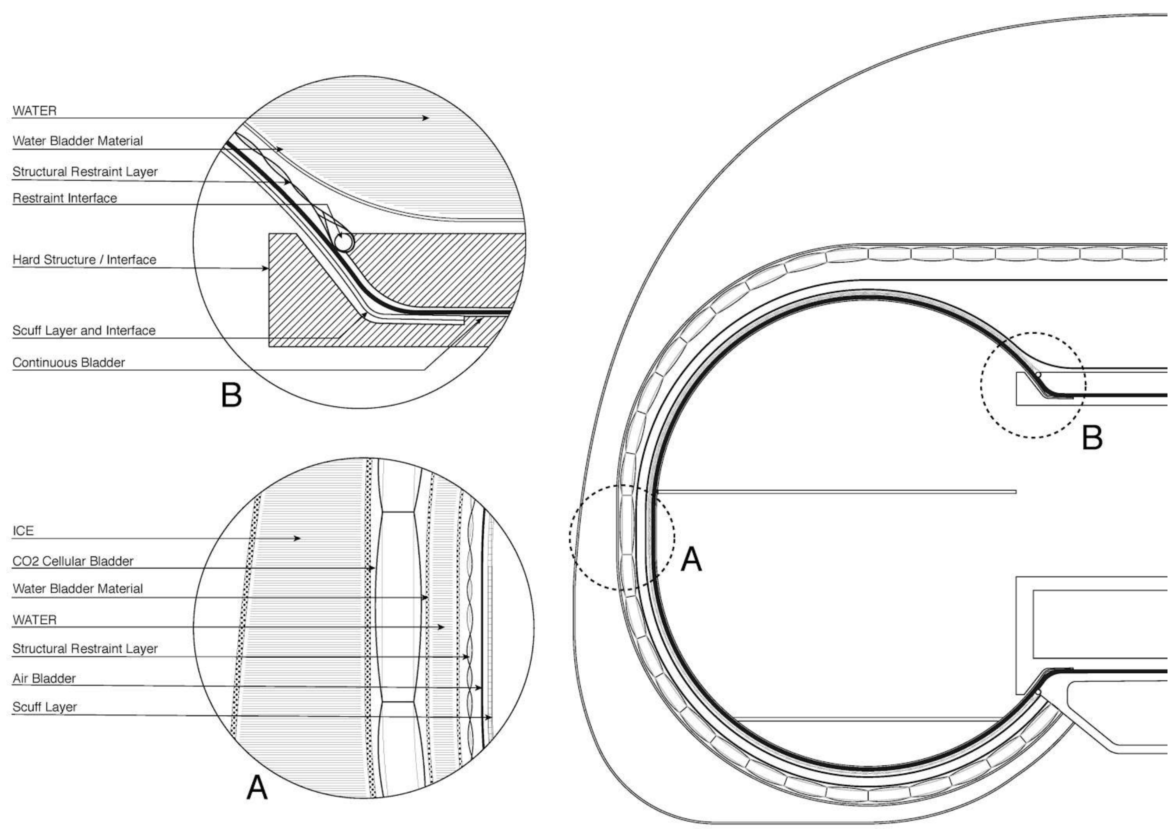


Figure *15*: An early Ice Home Material Layer Drawing without an external insulation layer *(SEArch/ Clouds AO)*

16. **Water Ice Cell Configurations:** Several factors were considered when designing the water Ice Cell configuration. The Mars Ice Home Risk Reduction Test Description provides an extensive listing of potential water ice cell geometries as in the example below:

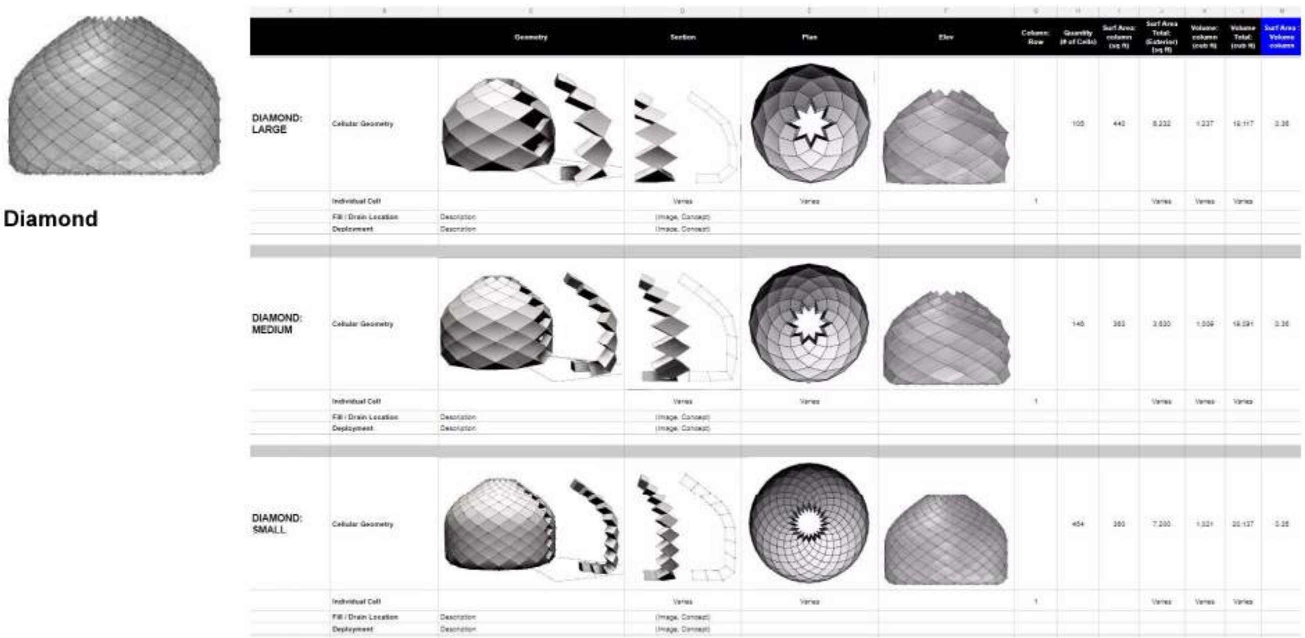


Figure *15*: Example of an Ice Cell Configurations *(SEArch)*

Based on a detailed trade study, the vertical slice design shown below was selected as the baseline water cell configuration.

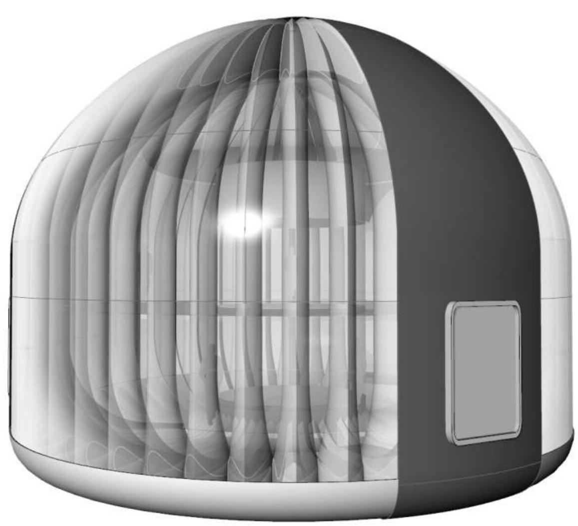
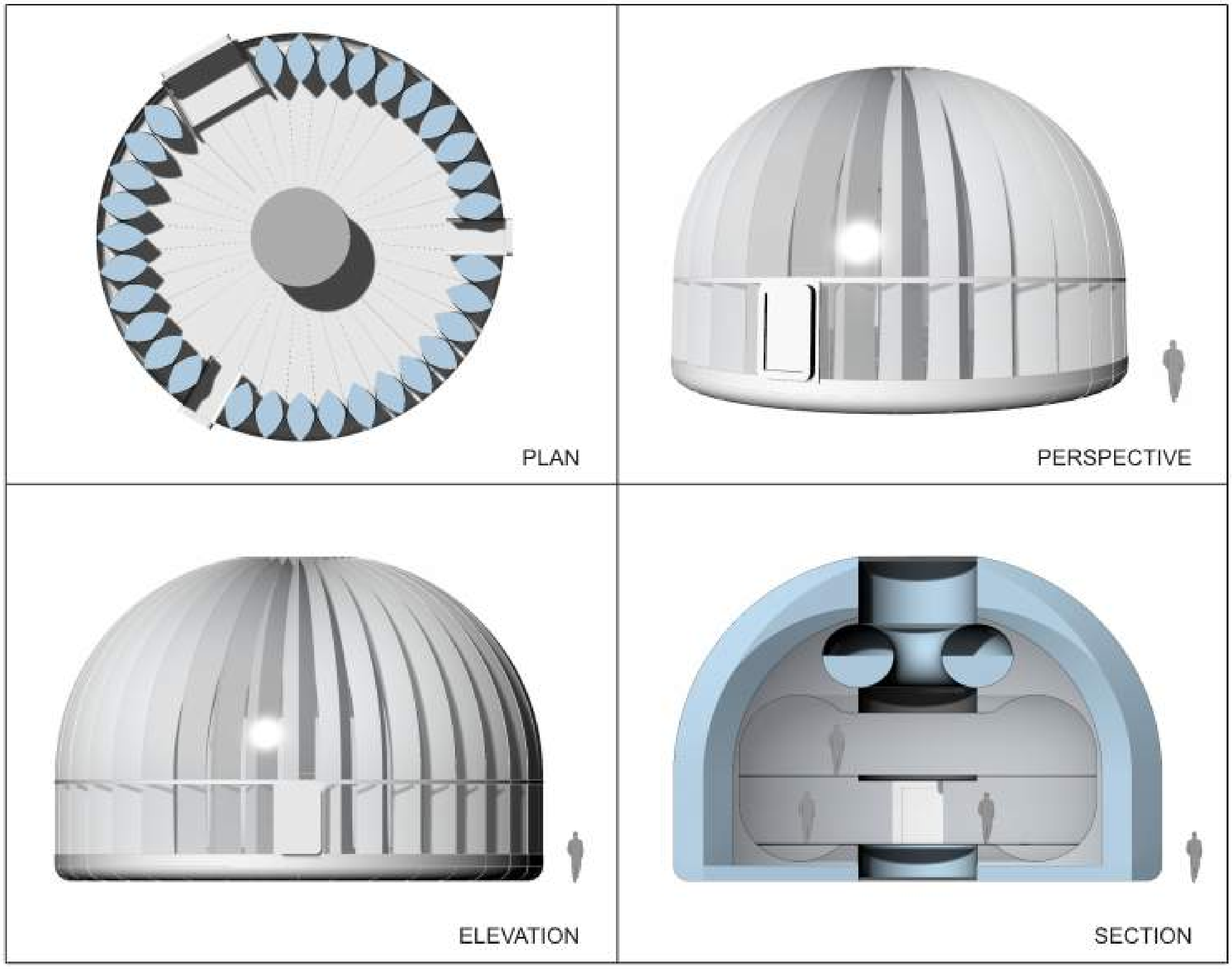


Figure *15a*: Vertical Slice Water Ice Cell Configurations *(Clouds AO)*



A1	PRESSURE VESSEL DIAMETER: 12M	
	ICE RIB THICKNESS:	2.0M
	H_2O VOLUME	**655m^3**

Figure *15*: Ice Home vertical slice water cell configuration *(Clouds AO)*

- Simplifying Fabrication – The construction of the cells must be easily fabricated and reduce complexity as well as the potential for failure in its joints and seams. The vertical slice configuration is similar to commercial air beam structures and proven manufacturing techniques can be utilized.
- Packaging – An accordion like folding method can be used.
- Ease of Deployment – The structure must be capable of being stored during transit and deployed on site. Effective planning for the seaming and packaging as well as ease of deployment is critical to mission success.
- Filling Methods and irrigation system complexity – The Ice Home cells must be realistically filled within the operational timeframe of a mission. Additionally, the capability to fill and freeze an entire cell simultaneously may produce more homogeneous ice properties, with fewer ice-ice

contacts which may serve as failure points. Individual beams could be filled in a sequence. The structure should be self-supporting during the fill operation. Increasing complexity of the water delivery system may lead to increased mass of the inflatable. The vertical slice configuration allows for a drain at the bottom of each beam will simplify tubing complexity. The current vertical slice design has 36 individual cells. Other designs have many more cells and would require a more tubing and a complex distribution manifold.

- Freezing – Having flexible irrigation tubes with spiral heating elements running down the inside edge should provide a good fill configuration that can be folded up with the deployment package. Circulating the water as it freezes has been shown to help produce ice with optimal properties. Carefully maintaining the temperature in the inner and outer gas insulation cells will allow the freeze rates to be controlled. A very slow freezing rate provides better ice properties.
- Structural integrity - The design allows for the failure of one or more water ice cells which can be repaired and fixed when human crews arrive. The vertical water cells can be reinforced with structural webbing or integrated fibers in the areas of highest stress.
- Reducing Mass – Has large cells which reduces boundary layer surface area.
- Maximizing Radiation shielding – Water volume can be maximized where needed. Slices can be thickened as needed. This design can be scaled as needed for radiation protection.
- Providing Diurnal Lighting – The slots near the bottom can be adjusted to trade external lighting for radiation protection. This design reduces the need to light to pass through the water cells which gives more flexibility on the material selections. This allows the water cells to be reinforced with webbing and still retain light penetration into the structure. The design can focus light toward the interior.
- Minimize Material - The design must minimize material mass for launch and EDL considerations.
- Scalability – Can be scaled as needed. Note that the vertical slices can easily be used around an inflatable cylinder for a vault like configuration. This may be optimal for a dedicated greenhouse structure attached to the Ice Home via one of the access ports.

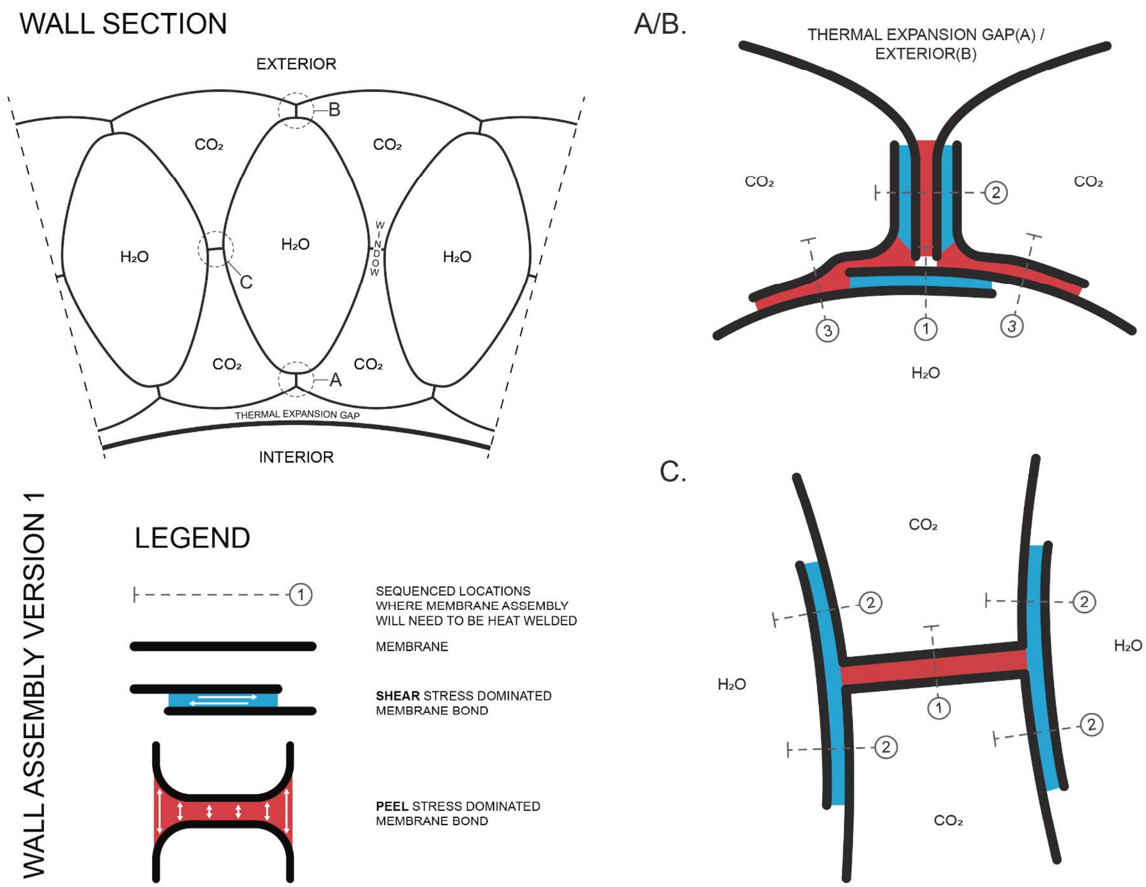


Figure *15*: Ice Cell Construction *(Clouds AO)*

17. **Insulation Options:** Aerogel, Air barriers, etc. – The Ice Home system can incorporate several insulation materials and methods.

    Preliminary calculations indicate that a CO_2 insulation layer 13.2 cm thick would require ~5000 Watts of internal energy to keep the internal water cells liquid and the external ice cells frozen. This gas insulation layer also offers several important advantages for the ICE Home design.

    - First it requires no launch mass since it is obtained from the Mars atmosphere.
    - Second, it mitigates the impact of expansion and contraction of the pressurized habitation area on the ice layer when pressure changes occur (due to temperature changes, air lock operation. etc.).
    - Third, the thickness of the gas layer can be adjusted as needed to accommodate differing energy outputs within the habitat so that excess energy is not wasted for heating and cooling.
    - In addition, the gas layer insulation is transparent to maximize light transmission.

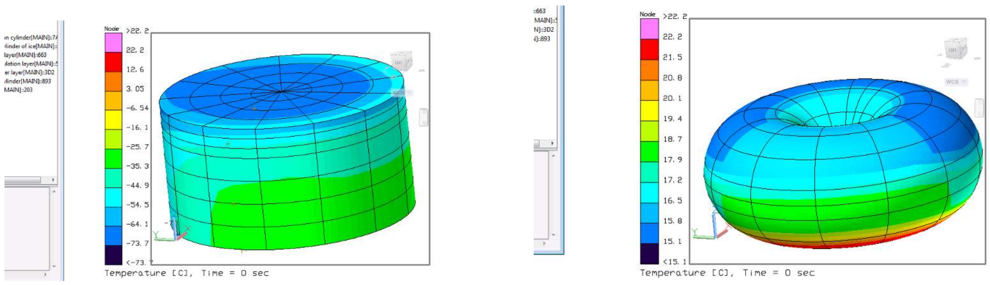


Figure 18: Basic Thermal analysis using a simple geometric models

18. Having an outer layer and an inner layer of CO_2 insulation cells allow greater thermal control which is very important in controlling the freezing rates of the water in the water cells. A slow freezing rate provides ice with better structural and optical characteristics. An external gas insulation layer that can be filled and emptied as needed to allow internal heat to melt the ice layer for filtering, replacement or transfer. By reducing the thickness of internal gas insulation layer and increasing the thickness of the external gas insulation layer operators would be able to control melting for use as fuel for the MAV as well as other potential uses.

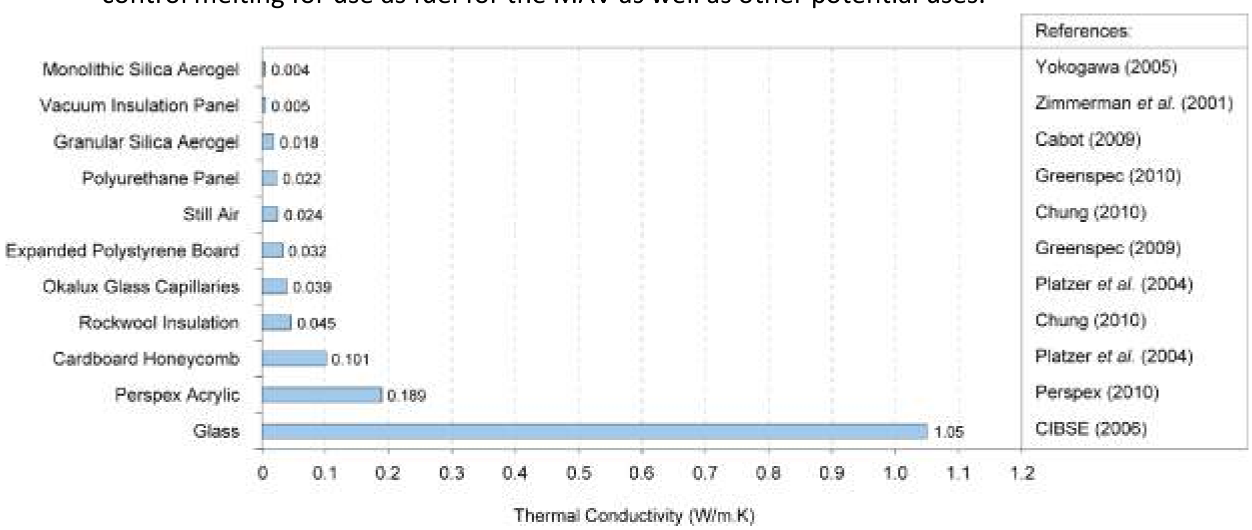


Figure 16: Comparison of Thermal Conductivity for various materials

Figure 17: An Example of an inflatable structure with clear gas cell insulation

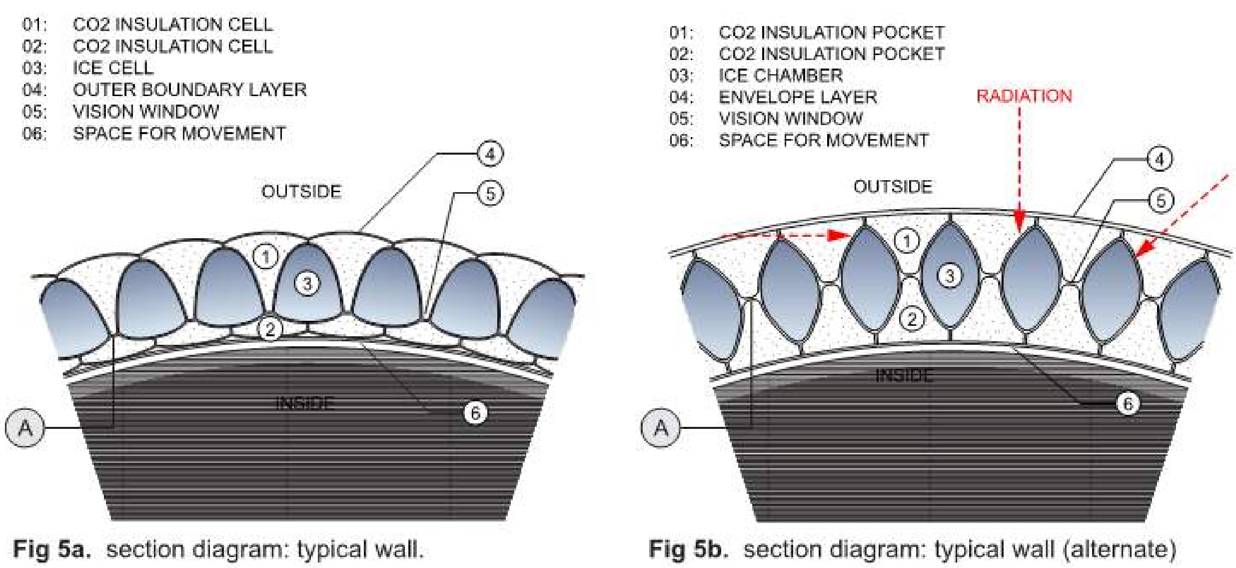


Figure 18: Gas cell configurations

Flexible tubing will be routed to the individual gas insulation cells for filling and circulation and temperature control of the air inside. The temperature of the air in the individual gas cells will be adjustable. This may be done by circulating air at selectable rates from a central manifold where the individual temperatures can be controlled. The designs shown would have 72 individual gas cells.

It should be noted that the inner gas cells allow the pressurized habitation area to move during pressure changes (i.e. during air lock operations) without applying loads to the water ice cells that could cause cracking of the ice that may damage the boundary layer material.

The primary insulation layer between the water cells and the ice cells will be a CO_2 gas cell layer using Martian atmospheric gas.

19. **Stowed Diameter:** Currently it is expected the stowed system will have a cylindrical shape approximately 6 meters in diameter and 9 meters in height. There are many design options that can be used to reduce the stowed dimensions. Maximum dimensions will be determined by EDL aero shell constraints. This would give a packing ratio of about 2:1. The current design incorporates a telescoping central column of carbon fiber would contain key systems needed for deployment. The column would be surrounded by the folded inflatable structure. An outer protective layer would provide dual use as ground cover.

20. **Shielding Thickness:** The thickness of material is maximized near the center of the structure over crew sleeping areas and is lower in the walls to maximize the shielding effectiveness of the limited water resource. When fully filled, the thicker sections at the center provide over 3 meters of water and water ice. This thickness can easily be increased if new concepts for ISRU water extraction have higher collection rates.

Using the Mars Ice Home design with the vertical slice water cell configuration about 655 m^3 of water was required to provide a shielding value that reduced the effective dose to 50% of an unshielded crew member. It should be noted that a habitat consisting of an aluminum shell will actually increase effective dose through the generation of secondary particles so using an unshielded crewmember is a conservative assumption. 655 m^3 at a production rate of 0.5 m^3/day would take 1310 days to completely fill. At this point in time, given the challenges of water extraction, the shield thickness is believed to be as thick as practical. A primary tenant for radiation protection is to make the effective dose As Low As Reasonably Achievable (ALARA). Given the constraints on water collection and landed mass, the Ice Home team has attempted to do identify a target for water production systems. The Following radiation assessment provides some details:

External Environment:

- Galactic Cosmic Rays (GCR), Badhwar-O'Neill 2014 model, 1977 Solar minimum.
- Mars surface at 0 km elevation.

Response Parameters:

- Whole-body Effective Dose.
- Female Adult voXel 2005 (FAX) body model.
- NASA Q quality factor
- NASA tissue weighting factors for average US population.

Code Version: TARIS 4.0

Comparisons were made to a reference of no shielding since the typical aluminum pressure vessel increases the effective dose inside the vessel. Two targets were analyzed inside the ice home, the first in the center on the second level and the second on the lower level near one of the hatches. Simple spheres of varying thicknesses of water were analyzed to see how much water would be required to get the desired 50% reduction in exposure. The table below summarizes the results.

Shield Geometry	Effective Dose (mSv/year)	Percent different
No Shield	178	baseline
Ice Home Target 1	118	-33
Ice Home Target 2	130	-27
1 meter water sphere	107	-40
2 meter water sphere	75	-58
3 meter water sphere	50	-72
Updated design, target 1	**89**	**-50**
Updated design, target 2	93	-48

Table N: Effective Dose reduction in the vertical slice design

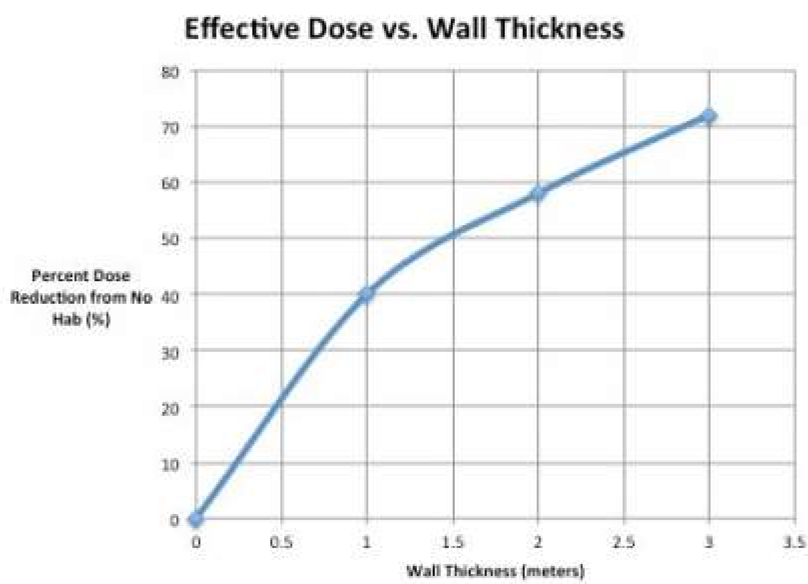


Figure X: Plot of Dose versus Ice Thickness (Hemisherical Shell)

Varies. 2 meters of water ice plus 1 meter of liquid water above key habitation areas such as crew quarters.

21. **Translucency:** Challenged designers to allow > 10% transmission of visible light. A layup of selected materials will be investigated if a follow on effort is performed. Methods of freezing water into very clear solids have been investigated by Ice Home team members.

22. **Airlocks: Number and size –** Currently looking at 2 airlocks for mass calculations. One will be for bringing in cargo for outfitting (2m X 2m) and one will be a crew hatch (1m wide X 2m high) to

connect to an integrated habitat via a softgoods passage. The current deployment concept allows for additional hatches if desired. Masses are extrapolated from existing aluminum hatches. Composite construction may significantly reduce these estimates.

23. **Sensors:** The Ice Home deployment will require multiple sensor types and a data collection system. Below is a preliminary estimate

Measurements:	Channels:	Unit Weight (kg):	Unit Power (W):	Total Weight (kg):	Total Power (W):	Notes:
Inflation Gas Temperature	10	0.84	0	8.4	0	Thermocouples (TC), weight includes 40m of wire, power included in avionics
Water Fill Temperature	10	0.84	0	8.4	0	Thermocouples (TC), weight includes 40m of wire, power included in avionics
Torroid Temperature	60	0.84	0	50.4	0	Thermocouples (TC), weight includes 40m of wire, power included in avionics
Light Meter	10	0.084	0.5	0.84	5	LI-190R broad-spectrum, weight includes 2m cable
Gas Pressure	20	0.3	0	6	0	Strain gauge based, power included in avionics
Strain Gauge	40	0.1	0	4	0	Power included in avionics
Heat Flux	10	0.83	0	8.3	0	Thin film heat flux sensor, power included in avionics
Dosimeters	10	0.03	0.13	0.3	1.3	Microdosimeter
Gas Flow Meter	15	0.018	0.05	0.27	0.75	Mass flow meter for CO2
Water Flow Meter	15	0.1	0.025	1.5	0.375	Low flow gas meter
Deployment Imagery	4	1	6	4	24	Visible CCD, no housing
Total Measurements:	**204**			**92.41**	**31.425**	

Table 2: Ice Home Sensor Information

And the sensor data will need to be collected by the data collection system:

Hardware Readout Example:	Purpose:	Channels Per Unit:	Total Channels Required:	Units Required:	Unit Mass (kg):	Total Mass (kg):	Max Power Use Per Unit(W):	Max Power Use Total (W):
NI PXIe-1085 Chassis System	Chassis	16	1	1	18.9	18.9	900	900
NI PXIe-8880 Controller	Controller		1	1	1.5	1.5	100	100
PXIe-4353	TC Readout	32	160	5	0.139	0.695	2	10
PXIe-4303	Analog Input	32	160	5	0.156	0.78	18	90

Table 3: Ice Home Sensor Data Rates

24. **Other:** Simplicity over complexity was a key design consideration. The Ice Home team minimized technologies currently at a low Technology Readiness Level (TRL).

Technical Resource Estimates

The Ice Home system was decomposed as shown below:

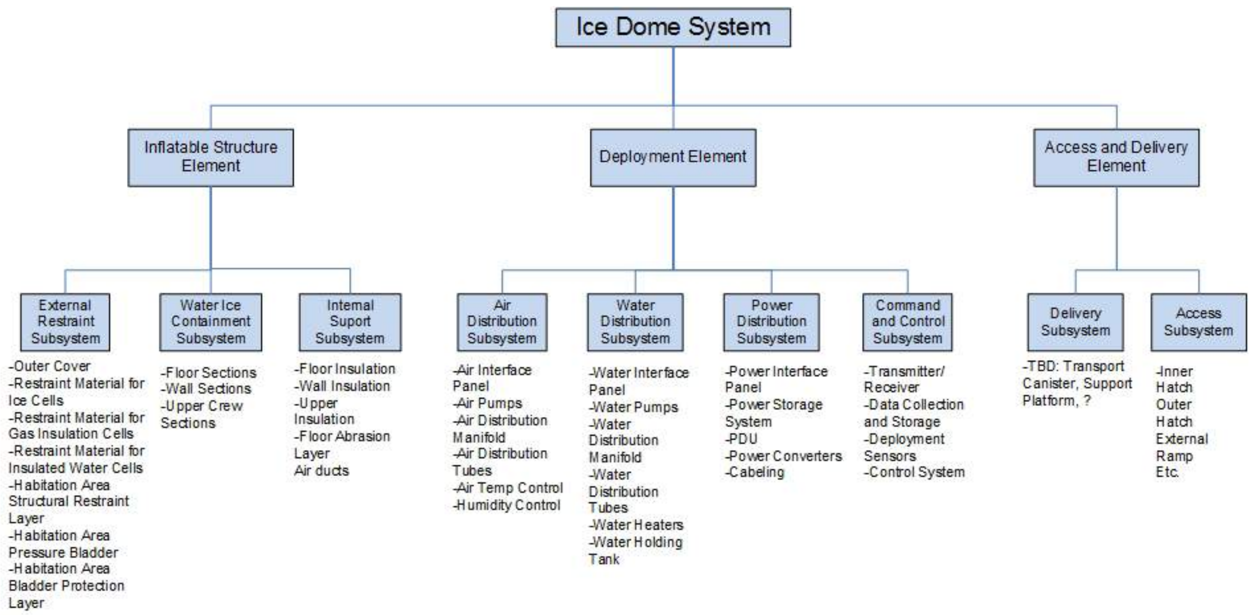


Figure 19: Basic Ice Home System Decomposition

Mass: The mass of the External Restraint Subsystem (i.e. Inflatable structure) is not believed to be a key driver for overall system mass. Potentially less than a metric ton it will be a minor player in the overall system mass although high factors of safety may drive it up. The key mass driver will be how much habitat functionality will be pre-integrated into the Ice Home. The largest Mass items will be the upper and lower hubs that restrain the torus hoop loads and also contain pumps, blowers, manifolds, and key avionics systems. The second largest mass item is expected to be the hatches used to connect to the airlocks. These structural items can be made from composite materials for significant mass reductions over current aluminum structures.

External Restraint Subsystem:

Material	Thickness [cm m in]			Unit Weight			Density		Layer Surface Area*	Mass	
	cm	m	in	g/m2	kg/m2	lbs/yd2	g/cm3	kg/m3	m2	kg	
Outer Cover											
Beta Cloth	0.020	0.0002032	0.008	237	0.237	0.44			453	107.4	
COR (Clear Oxygen Resistant)									453		<---------- still need matl props
Ice Bag											
Mylar	0.013	0.000127	0.005				1.39	1390	799	141.0	
Insulation Bag (CO2 inside)											
Mylar	0.013	0.000127	0.005				1.39	1390	680	120.0	
Water Bag											
Mylar	0.013	0.000127	0.005				1.39	1390	659	116.3	
Structural Layer											
S-2 Fiber Glass Fabric	0.023	0.00023	0.009	303	0.303	0.56			-		needs to be one layer >.030" thick but only have info for .009" thick
4 Layers	0.092	0.00092	0.036	1212	1.212	2.24			325	393.9	so layering only for mass calculations
Redundant Bladders											
HDPE (3 layers)		7.62195E-05	0.003				0.94	940	325	69.9	
Scuff Layer											
White Nomex Cloth		0.000178	0.007		0.122	0.225			325	39.7	
Totals										988.3	
									*Values from CAD model		

Table 4: Ice Home Inflation Element Mass Estimates

The Ice Home power consumption is primarily for heating, pumps, and transmission of sensor data. Prior to habitation, the largest power use will be to keep the water holding tanks from freezing. The water tanks will be inside the air insulation cells and will also have additional insulation to minimize heater power requirements. Since Ice Home is a dual use system for water storage it will provide a power efficiency in this dual role. Another pre-habitation power use will be to collect and transmit status updates. It is expected that the ISRU water extraction system will drive the capacity of the power generation system prior to habitation. During habitation it is expected that the internal waste heat generated by the crew and equipment will be adequate to meet the heating requirements.

Deployment Elements:						
	Quantity:	Unit Weight (kg):	Unit Power (W):	Total Weight (kg):	Total Power (W):	Notes:
Power Distribution:						
Power Conditioning	1	20	500	20	500	Assuming 10kW input to hab with 95% efficiency conversion
Air Distrubution:						
Air Pumps	4	10	75	40	300	Power and mass estimates based on ISS values
Air Temp Control	1	80	360	80	360	Power and mass estimates based on ISS values
Humidity Control	1	80	360	80	360	Power and mass estimates based on ISS values
Water Distribution:						
Water Pumps	4	10	20	40	80	Low flow, centrifugal COTS pump
Water Heaters	4	10	200	40	800	Just a guess of power, thermal would be better able to answer this question
Command and Control:						
Transmit/Receiver	1	20	100	20	100	TX/RX to orbit, based on S/X Band, dish, cabling, electronics
Data Collection and Storage	2	28.4	412	56.8	824	Assume 24 SSD in rack mount enclosure, CPU acting as a controller
Deployment Sensors	1	92.41	31.425	92.41	31.425	See above table
Control System	2	60	700	120	1400	Two primary computers, backup power, misc avionics + margin. Based on COTS hardware.

Table 5: Power Estimates for Key Ice Home Systems Based on Current Flight Systems

Design Reference Material

Radiation Considerations

The Cosmic Ray Environment

Data from the Mars rover Curiosity has allowed experts to calculate an average dose over the 180-day transit to Mars. It was approximately 300 mSv (where "m" stands for milli, "Sv" stands for Sieverts). That's ~600 mSv/year, the equivalent of 24 CAT scans. So in just getting to Mars, an explorer would be exposed to more than 15 times an annual radiation limit for a worker in a nuclear power plant.

The Mars atmosphere (low-density COSPAR model; Smith and West, 198359) provides 16 g/cm2 of CO_2 as protection in the zenith direction with protection increasing to over 50 g/cm2 at large off zenith angles (toward the horizon) at 0-km altitude (Simonsen 1990 60). Previous estimates of Mars surface exposures concluded that the atmosphere significantly reduces the exposure from Solar Particle Events (SPEs) and less for GCRs (Simonsen et al., 1990; Simonsen and Nealy, 1993 61; Simonsen et al., 2000 62);

Cosmic Ray Shielding

Mars surface radiation exposure limits: *Current limits are in NASA Standard 3001 vol. 1, with additional information in vol. 2. The limiting requirement for GCR exposure is that planned astronaut exposure shall not exceed a 3% Risk of Exposure Induced Death (REID) due to cancer and this shall be ensured at a 95% confidence (Refer to the standard for the exact wording). With our current capability for modeling astronaut risk, the trips to and from Mars will exceed this, so there really isn't a good way to decide how much exposure you would allow an astronaut to get on the surface stay part of the mission. Another important requirement is that space radiation exposures be maintained As Low As Reasonably Achievable (ALARA). While we let the Human Research Program continue to work on reducing uncertainties in modeling astronaut radiation risk, vehicle and habitat designers (like this study) should focus on the ALARA requirement. We want to show what we can "reasonably" do with ice shielding to reduce astronaut risk. This means trading the difficulties associated with getting the water (and all of the other challenges associated with the Ice Home) with the reduction in astronaut exposure we can get from the water. There is no simple answer.*

Table 7—Example Effective Dose Limits in Units of Sievert (Sv) for 1-Year Missions resulting in 3-percent REID Point Value, Assuming an Ideal Case of Equal Organ Dose Equivalents for All Tissues and No Prior Occupational Radiation Exposures*

	Females		Males	
Age (yr)	**Avg. US Adult Population**	**Never-Smokers**	**Avg. US Adult Population**	**Never-Smokers**
30	0.44 Sv	0.6 Sv	0.63 Sv	0.78 Sv
40	0.48	0.70	0.70	0.88
50	0.54	0.82	0.77	1.00
60	0.64	0.98	0.90	1.17

*Reference table 6.2, Cucinotta, et al., 2013

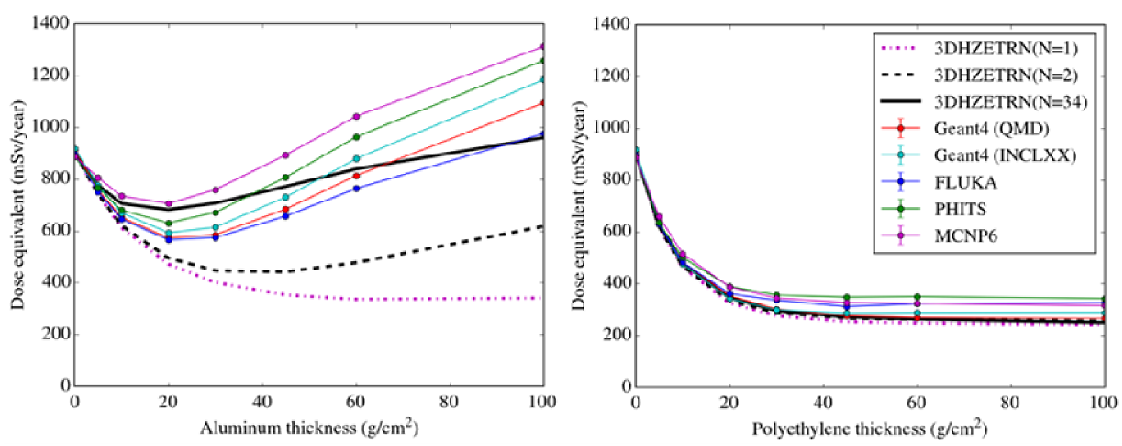
It appears that ~700 - 800 mSv would be a reasonable goal for a full mission but that is likely unattainable since the space segments will greatly exceed this. Dose limits for men are about 180 mSv higher than for women. At a 95% confidence level, such exposures are predicted not to increase the risk of exposure-related fatal cancers by more than 3%. For the surface stay mission architects would want the lowest reasonable value per year (i.e. ALARA) to minimize overall risk.

During their stay, the Mars Surface Environment will be considered as the place where the astronauts are able to at least partially recover from the effects of radiation and the zero-g transit environment.

Shielding Calculations

Shielding information from the Advanced Radiation Protection Project: In year one of the project, the team identified an optimal range of aluminum shield thicknesses near 20 g/cm^2 (corresponding to ~7.4 cm of aluminum). In year two of the project, these simulations were re-evaluated for polyethylene shielding where the shielding properties are characteristically different due to significant hydrogen content (It is believed that polyethylene is a reasonable analog for water due to the high Hydrogen content which is effective in reducing secondary particles).

As shown in the figure below, there is a substantial difference in the shielding properties of aluminum and polyethylene beyond ~20 g/cm^2.



Total dose equivalent (mSv year) versus shield thickness exposed to a solar minimum GCR radiation environment

Figure 20: Aluminum and Polyethylene Shielding of GCRs in a Space Environment

Note the Effectiveness of Materials containing Hydrogen versus those without. Also note the slope after the first ~20g/cm^2 of polyethylene indicating that a large amount of material is needed to bring down the dose equivalent further. There is a great deal of uncertainty on the shielding affect after >1 meter of Hydrogen bearing material is added and the curve may start falling off at some point.

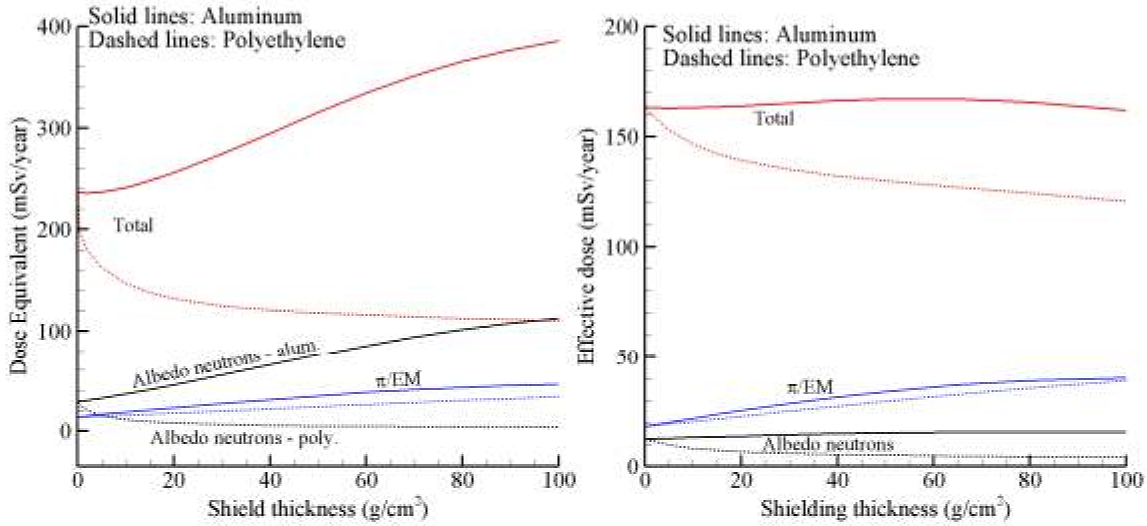


Figure 3. Dose equivalent (left pane) and effective dose (right pane) as a function of shield thickness on the Martian surface.

Figure 21: Aluminum and Polyethylene Shielding of GCRs on the Martian Surface
From 2013 NASA white paper: Radiation Shielding Optimization on Mars (Tony C. Slaba, Christopher J. Mertens, and Steve R. Blattnig - Langley Research Center, Hampton, Virginia)

The graph above shows that the reduction in dose for Hydrogen bearing materials flattens out after the first 20 g/cm^2 on the Martian surface. It appears that dose is reduced ~ 20mSv per meter of water after 20 g/cm^2. Based purely on this curve and assuming Polyethylene has equivalent shielding properties as water, ~3 meters of water shielding would reduce the dose to ~70 mSv/year.

ALARA will be an important guideline in the Ice Home design and must be traded against ISRU capacity and structural considerations.

Estimates for a shield thickness are based on a study that Tony Slaba did in 2013. The study was based on using a spherical shield sitting on the Martian surface surrounding the astronaut. He then calculated the astronaut effective dose for various thicknesses of the spherical shield. He did this for an all-aluminum spherical shield and repeated the process for various thicknesses of polyethylene (which has similar properties to water due to the large fractions of hydrogen in the material and is within the uncertainty of the transport calculation). The results are shown above. The plot on the left shows dose equivalent at a point, but the focus should be on the plot on the right which includes the astronaut's body in the effective dose calculation. On the Mars surface, you can see that for polyethylene, there is a significant reduction in effective dose for the first 10 or 15 g/cm^2 and then the curve becomes somewhat flatter. The 10 to 15 cm of water would get to the point in the curve where increasing the thickness of material provides a small but steady increase in protection. Due to the flattening of the curve, a lot of material must be added to get a significantly larger reductions in astronaut exposure. For example, looking at Tony's Figure 3, you would need about a meter of water to reduce the astronaut exposure by another 40 mSv. The shielding provided by the Mars atmosphere means that we are already *near the flatter part of the effective dose versus shield thickness curve. Realistically, given the small return on the shielding value for large amounts of water, the Ice Home concept may not be effective if the water resource is too difficult or costly to acquire. Also, if revolutionary methods for excavation and burial of habitats on Mars are developed using water as shielding may not be as cost effective.*

Structural Considerations

- What is the minimum practical pressure needed between the layers to let water flow into the structure and freeze? The outer layers will be pressurized at a much lower pressure than the habitation area. There are many different varieties of water ice that are dependent on environmental conditions when freezing. Determining the optimal pressures to use to achieve the ice properties desired can be investigated as part of a follow on effort.
- Current assumption is to use 14.7 PSI (~100 kPa) for the habitation area as is used on the ISS. This is very conservative. 11.5 PSI would be very reasonable as it is higher than the atmospheric pressure in Santa Fe NM at 7000 ft. The Mars Architecture discusses 8.0 PSI for habitat pressure based on a lunar habitat study (LAT2).
- Design factors from NASA-STD-5001B for soft goods structures. Note BEAM was tested to 8X maximum predicted pressure and weighs 1360 kg and is only 10.5 ft. in diameter and 13 feet long.

Table 6—Minimum Design and Test Factors for Structural Softgoods

Hardware Criticality Classification	Ultimate Design Factor	Prototype Test Factor	Proof Test Factor
Loss of Life or Vehicle	4.0	4.0	1.2
All Others	2.0	2.0	1.2

Prototype testing is required for softgoods to demonstrate qualification. Each flight article has to be proof tested, unless the requirements of section 4.6 are met.

- Changes in internal pressure could affect the dome structure and must be managed (Gas cell insulation, minimize material creep, Expansion features in the design, relief valves, buffers, etc.).
- The restraint layer may benefit from a system of restraint webbing to reduce loads on the material

Figure 22: MASH Test Article
Note the Vectran restraint system to take most of the loads off the skin material.

Environmental Considerations

Even on worst annual hot case (for melting at ~25 degrees south latitude in the Martian summer) there is only a ~5 hour duration of above freezing temperatures which, given the large amount of energy needed to melt water ice, can be mitigated with a minimal insulation barrier. The more significant issue is insulating the ice from internal heat generated in the habitation area. A detailed thermal analysis needs to be done at some point however to verify assumtions

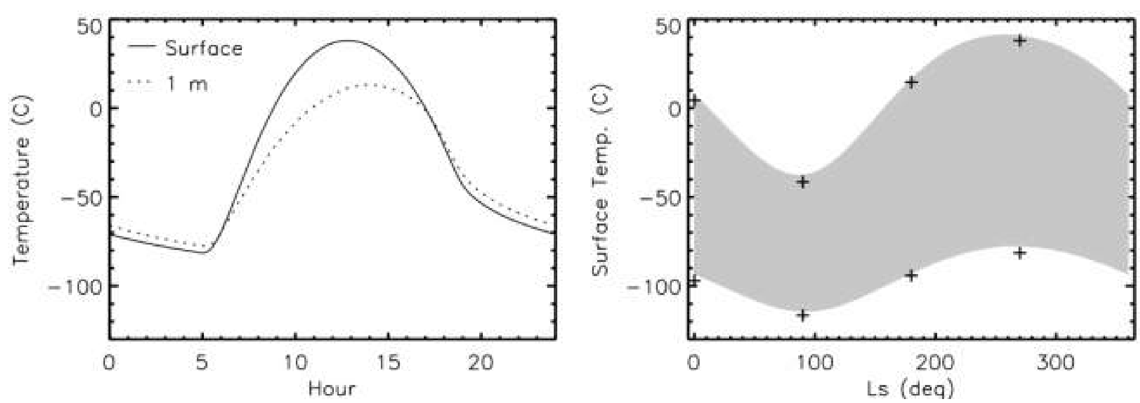


Figure 23: Worst Case Annual High Temperatures (From MSL Environmental requirements Document)

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Worst Cold Case: The issue here is getting liquid water distributed without freezing prior to emplacement. Significant thermal work to understand heating system requirements will be needed. The ISRU system will have significant challenges during the Martian winter at these temperatures and may have to be suspended during this time. Since the Ice Home can provide a heated interior it may be advantageous to tightly integrate Ice Home with the ISRU water collection system to store the water as it is collected from the regolith instead of having a separate storage system.

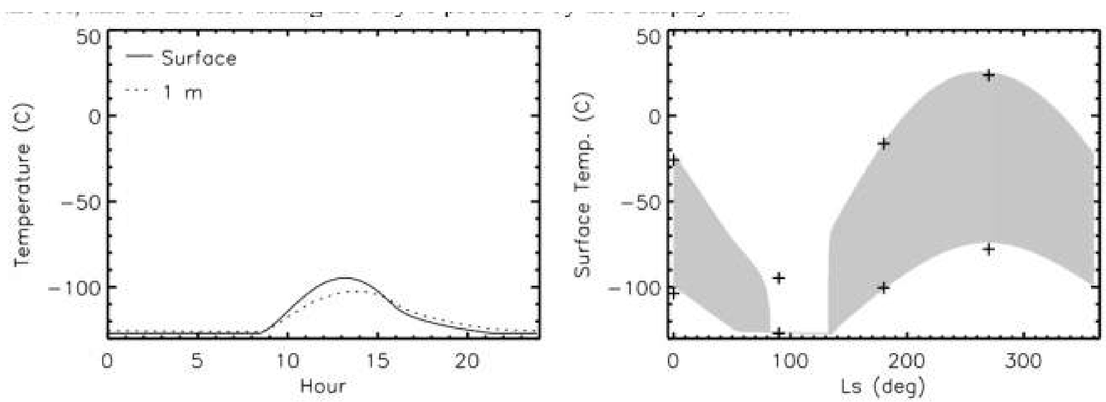

Figure 24: Worst Case Annual Low Temperatures (From MSL Environmental requirements Document)

Note the high diurnal temperature range. Ice Home may be used as a storge area during the predeployment phase of a human mission to Mars to help protect equipment from the extreme thermal changes until the crew arrives.

Sustained wind speeds measured by the Viking landers rarely exceeded 15 m/s, and were often less than 10 m/s. Momentary wind speeds may reach 95 m/s due to events such as dust devels. Since the atmosphere is very thin, wind loading is not believed to be structural issue however it will deposit a significant amount of Martian dust on any exposed surface.

The very fine Mars dust will be a significant challenge and filters on any intake air pumps must have fiters that are maintainable (likely maintained by robotics). Airlocks to the external environment will require clean air blowers such as used in clean rooms to help remove dust prior to entry into the main work area if the Ice Home. Dust on external surfaces will also increase opacity and reduce any diurnal lighting that may be achieved.

Missions have measured Mars soil and it is believed to be generally basic with a pH of ~8.3

Mars Gravity averages 3.72 m/s on the surface.

On Mars UV light is much higher than on Earth. Exposed materials for the Ice Home must be UV resistant or coatings must be aplied that will last for the duration of the mission.

Due to the low temperatures and low pressures there were several technical risks related to inflation, filling, freezing and the interaction of different materials with water and water ice in Martian environments. Low pressure freezing was tested as part of the MIHRR study and showed promising results down to 1.0 psi. The results can be found in the MIHRR Test Description. A subscale demonstration system has been proposed that would allow some testing to be performed in thermal vacuum chambers.

Figure 25: Section parallel to the ice-vapor interface in the bag frozen at <1 psi ambient pressure, cut from near the surface.

Planetary Protection Considerations

"To minimize the potential for harmful exposure events, operations for human missions shall include isolation of humans from direct contact with planetary materials until initial testing can provide verification that exposure to the material is safe for humans. Exploration, sampling, and base activities shall be performed in a manner that will limit inadvertent exposure of humans to material(s) from untested areas. For the initial landing site, testing will probably have been performed as a part of precursor mission activities; but a means for allowing controlled access to untested areas, or areas that are considered unsafe, must be provided during human missions. Sterilized and cleanable robots, which are under appropriate operational constraints, are one suitable approach for ensuring appropriate access."
"Human EVAs shall be planned and executed to ensure that mission-associated microbial or organic contamination shall have a low probability of entering Mars Special Regions. Tools that are capable of attaining and retaining the required cleanliness shall be used to explore and sample these regions. Appropriate equipment shall be provided to enable transfer of materials from collection devices to study facilities while maintaining the required levels of cleanliness and containment."

From the Mars Science Laboratory Planetary Protection Plan (JPL D-27176/MSL 216-0210 - June 2006)

Dry heat microbial reduction at a relative humidity less than 25% (referenced to 0°C and 1 atmosphere) for spores has a D value at 125°C (254°F) (i.e., the time for a reduction by 10 at that temperature) of 0.5 hour for free surfaces, 1 hour for mated surfaces, and 5 hours for encapsulated non-metallic material, and a Z value of 21°C (i.e., the change in temperature for a factor of 10 change in the D value), on the temperature interval 104°C to 125°C.

Approach	Applicability	Requirement	Typical Method
I	Instruments that: • will not make direct contact with a surface to be sampled, and • are not packaged with instruments or tools that are part of the sampling chain. • have encapsulated volume* such that Approach III is not applicable. Example: mast-mounted wind sensing instrument.	• Cleaned to an average bioburden on the exposed and internal surfaces prior to launch of less than 300 viable spores/m^2. • Cleaned to Particulate Cleanliness Level 100 per IEST-STD-CC1246D.	Wipe with a mixture of isopropyl alcohol and water, plus assay verification.

….

III	Instruments that have encapsulated volume* such that sterilization contributes to keeping landed spacecraft within the bioburden budget: • more than 40 cm^3 of encapsulated bulk non-metallic volume* if electronics are present, or • more than 150 cm^3 of encapsulated bulk non-metallic volume* if no electronics are present.	Penetrating sterilization method must be applied prior to instrument delivery. Cleaned to Particulate Cleanliness Level 100 per IEST-STD-CC1246D.	DHMR at a specified humidity, duration and temperature profile, 50 hours at 111°C or 5 hours at 125°C after surface wipe as described in Approaches I and II ** (Note: Actual required DHMR profile is configuration specific and may result in significantly longer durations (100 to 250 hours).

NOTES: * Encapsulated volume is defined as volume of non-metallic hardware only (e.g., printed circuit boards and chips, plastic packaging, insulation and blankets, polymerics and adhesives, etc.), excluding empty space inside the instrument chassis.

**Alternative methods to achieve required sterilization may be proposed but must be approved by the NASA PP Officer prior to project acceptance.

In addition, in order to meet a potential subsystem level PP sterilization requirement, DHMR may be performed at higher levels of assembly. To accommodate this possibility, each instrument should be designed to tolerate a subsystem-level DHMR environment. Where a unique science capability drives usage of materials not tolerant of the DHMR environments (50 hours at >111°C), an instrument-unique, heat-rejection interface to a cold sink accommodation may be provided. Proposers must identify any potential instrument-unique requirement for heat-rejection during a rover system-level DHMR, but are not required to include cost for a special heat-rejection interface in this proposal. For Approach III hardware, an instrument requirement to mitigate the effects of subsystem-level DHMR does not imply an exemption from any Planetary Protection requirement.

What this means for Ice Home components

The components of highest concern are those with encapsulated volume containing electronic and photonic parts that would be damaged by the DHMR (i.e. sensors). Another concern is that material will stick together after exposure to these high temperatures and not inflate properly.

Applicable Notes from Latest Mars Architectures

Per latest Mars Architecture Reference Mission:
https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf

"Each of the three missions would use the conjunction class (long-stay) trajectory option. A portion of each mission's assets would be sent to Mars one opportunity prior to the crew. This, the so-called "pre-deploy" or "split mission" option, would allow a lower energy trajectory to be used for these pre-deployed assets, which allows more useful payload mass to be delivered to Mars for the propellant available. The decision to pre-position some of the mission assets also better accommodates the decision to make part of the ascent propellant at Mars, using the Martian atmosphere as the raw material source for this ascent propellant. This use of in-situ resources and the equipment to process these resources into useful commodities results in a net decrease in the total mass that is needed to complete a mission as well as a significant reduction in the size of the landers. A surface nuclear power source, as compared to an equivalent solar power system, was found to be better suited for producing this ascent propellant. This choice was further supported by the fact that this power system would be more than adequate to meet the needs of the human 3 crew members when they arrive, which occurs after all of the necessary propellants have been produced.

A key feature of the long-stay mission architectures is the autonomous deployment of a portion of the surface infrastructure before the crew arrives such as the surface power system. This strategy includes the capability for these infrastructure elements to be unloaded, moved significant distances, and operated for significant periods of time without humans present. In fact, the successful completion of these various activities would be part of the decision criteria for launch of the first crew from Earth.

The primary habitat would have space and resources allocated for on-board science experiments.
In-situ resource utilization trade study results"

Table 4-5. Mass summary for surface systems and the Distribution

Manifested Item	Quantity	Hab Lander CBE MASS (kg)	DAV Lander CBE Mass (kg)
Crew Consumables		1,500	4500
Science		0	1,000
Robotic Rovers	2	0	500
Drill	1	0	1,000
Unpressurized Rover	2	500	0
Pressurized Rover	2	8,000	0
Pressurized Rover spares		(included above)	0
Pressurized Rover growth		1,600	0
Pressurized Rover power	2	0	1,000
Traverse Cache		0	1,000
Habitat	1	16,500	0
Habitat growth		5,000	0
Habitat spares		(included above)	0
Stationary Power System	2	7,300	7,300
ISRU Plant	1	0	1,305
Ascent stage 1 (no LO_2)		0	12,156
Ascent stage 2 (no LO_2)		0	9,330
30-day temporary habitat		0	0
Descent Stage (wet)		23,300	23,300
Aeroshell		437,000	437,000
Total IMLEO Mass		107,400	106,100

"The duration of the Mars mission makes crew and equipment reliability of all systems a large risk contributor, particularly in terms of the criticality and time on the power, thermal, and environmental control life support systems. An important question arises: namely, at what level do you introduce repair or replacement of the elements of a system? These levels range from raw materials on the low end"

Ground Rule Assumption	Notes
Power required for continuous thermal control en route, before habitation and during crew occupancy (~4 years)	Maintain seals, equipment, and consumables within thermal specifications; coolant in-place for transit and surface operations
One airlock (A/L) per Mars habitat (MH), 2 A/Ls for commuter (C) and telecommuter (TC)	Crew safety, dual ingress/egress
75% of habitat crew H_2O and O_2 provided by ISRU	Orbiting habitat has 100% H_2O, closed-loop ECLSS
100% of SPE radiation protection H_2O provided by ISRU	H_2O for shelter available on crew arrival (no additional H_2O from Earth)
Habitat internal pressure same as LAT2	8 psi
Structural loads same as LAT2	Mars entry/landing no greater than Ares launch loads

	base
No EVA cooling water provided from Earth for surface operations	Assumes new technology for cooling (CO_2), ISRU provided H_2O, or tethered operations
Provide habitat subsystem health prior to Earth departure	Assumes Earth control and monitoring of habitat
SPE radiation protection same as LAT2 habitat	Mars environment more benign than moon, but crew stay is longer and lunar approach accommodates worst-case site selection; additional mass for six crew members
Dust management same as moon	Will be different, but not enough to affect mass or volume for this assessment
Redundant habitable volumes; each accommodates all crew members in emergency situation	Infrequency return opportunities require survival until launch opportunity
Food and clothing brought from Earth; 10% food margin for emergency	Accommodates distribution due to separate pressure volumes
250 EVAs per crew member (C and TC)	EVA every other day for 500 days
Fixed-base power provided lander	Mass for power is not book-kept by the habitat
Subsystems designed for maintenance	500-day stay requires a design for continued operation while inspecting, servicing, or repairing subsystems

Evolvable Mars Campaign (EMC) Notes

EMC assumes multiple crewed mission to the same location, and reuses surface assets for at least 3 crewed missions (~15 years). Surface systems will be dormant, but can be robotically tended, when crew are absent.

Typical mission cycles pre-deploy payloads to Mars surface one opportunity prior to the crew departure.

Long-duration crew missions range from 300-500 days on the surface. EMC hab assumes at least 25 m3/person. Missions consist of 4 crew members.

Two fairing diameters are under consideration: 8.4m and 10m. Payloads for the 8.4m fairing must fit within a 7.5m dynamic envelop. Payloads in the 10m fairing must fit within a 9.1m dynamic envelop.

Each lander can land up to 20t to the surface of Mars. Both monolithic and modular habitat concepts are valid trade options. Outfitting for the habitat can be delivered in a separate logistics module and installed on the surface.

A hoist-type system (currently assuming LSMS) is available for offloading cargo from the landers. A surface transport system will be available to relocate the module if necessary. Currently the Mars surface team is looking at a maximum payload mass of 10-12 t for the surface transporter.

Habitat should have 3 docking ports to support operations. Elements connecting to the habitat include pressurized rovers and logistics modules. Logistics modules can remain connected to the habitat as a logistics 'closet'/trash stowage. The habitat should also support EVA access to the surface.

The habitat should minimize dust intrusion into the habitable area.

EMC assumes a habitat atmosphere of 14.7 psia at 21% O2. Atmosphere trades include 10.2 psia and 26.5% O2, SEV at 8.2 psi and 34% O2.

Surface power is available for systems. Total power available should be determined by the needs of the habitat and associated ISRU system to fit the needs of the architecture. EMC options currently run from 40-50 kW power generation on the surface.

High-rate surface-to-orbit communications route through the habitat.