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Moon to Mars (M2M) Habitation Considerations

A Snap Shot As of January 2022

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I. Background

The following NASA Technical Memorandum (TM) is intended to provide a snapshot in time of NASA's current considerations (ground rules and assumptions, functional allocations, logistics) for habitation systems for the lunar surface (non-roving) and Mars transits. As NASA continues to refine the reference designs to meet the needs of an evolving architecture, it is expected that this information will also be updated as a result. Where appropriate, relevant publicly released documents will be referenced to provide further detail.

NASA's human lunar exploration plan under the Artemis program calls for achieving the goal of sending the first woman and first person of color to the surface of the Moon in the mid-2020s and working toward sustainable exploration by the end of the decade. Working with both commercial and international partners, NASA will establish a permanent human presence on the Moon to uncover new scientific discoveries and lay the foundation for private companies to build a lunar economy. Longer duration missions on the lunar surface and in lunar orbit will also serve as a test bed for technologies to support future Mars exploration campaigns. The agency will use what we learn on the Moon to prepare for humanity's next giant leap – sending astronauts to Mars.

NASA intends to establish a sustained lunar presence with the development of the Artemis Base Camp to prove technologies and capabilities that will one day enable humans to live and work on Mars, beginning with core elements including the Lunar Terrain Vehicle (LTV), the Pressurized Rover (PR), the lunar Surface Habitat (SH), power systems, and in-situ resource utilization (ISRU) systems. For in space operations and eventual transport of humans to Mars, NASA will utilize a Mars Transit Habitat (TH). Following deployment, the TH will complete a series of longer duration missions and shakedown testing while docked at Gateway, leveraging Gateway's habitation redundancy for safety measures. Proposed Gateway-TH missions will far exceed the longest duration cislunar human missions to date. They will be the first operational readiness tests of our long-duration deep space systems, and of the split crew (two crew on the surface, two crew in space) operations that are vital to the approach for the first human Mars mission.

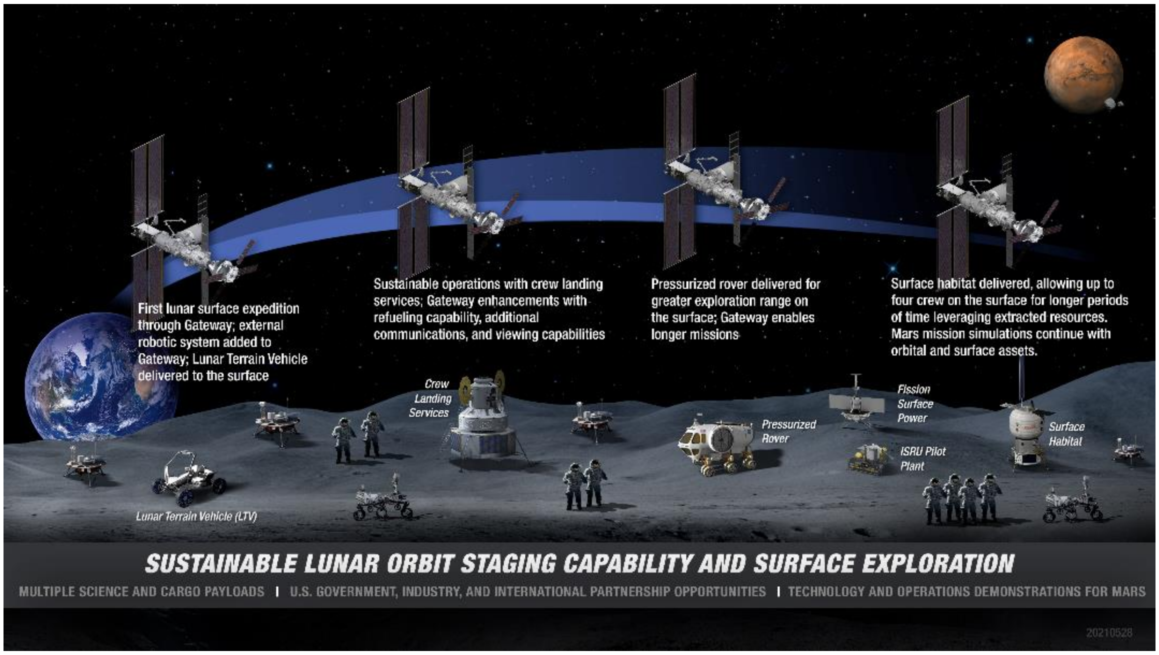

Figure 1: An artist's concept of the missions and activities to build up the Artemis Base Camp

Both the SH and TH are major architectural elements of NASA’s Moon to Mars (M2M) approach, each with very different concepts of operation. The SH is intended for use on the lunar surface as a home for astronauts, surface operations base, science facility, hub for communications, extravehicular activity (EVA) equipment repair site, waste processing facility, and supply hub. It serves as an enabler for a sustained surface presence and preparation for partial gravity operations during Mars missions. The SH will be designed to be self-sufficient for operations on the lunar surface. The SH will independently provide several functions, including its own power generation, energy storage capability, sleep quarters, hygiene areas, work areas, and dining areas. It will be capable of communicating with surface assets, orbital assets, and directly with Earth ground stations. It is planned to operate with two crew in the habitat for ~28-day stays with crew swap-outs in which the PR crew of two trades places with the habitat crew. During the swap-out, the habitat will nominally support four crew for a short period of time. For contingency scenarios, the habitat must also be capable of supporting four crew for up to 7 days.

Figure 2: An artist's concept of the Artemis Base Camp with the three proposed primary mission elements – the Lunar Terrain Vehicle (unpressurized rover), the Pressurized Rover, and the Surface Habitat

The TH will be designed to be capable of up to ~1,200-day Mars missions with the ability to carry all food and supplies needed to support a crew of four for this duration. An assumed Mars mission profile for the TH is to carry crew and supplies for ~850-day roundtrips between Earth and Mars orbit that allows 30-day stays on the Martian surface. To test the systems for this long journey, the TH will be used to extend the duration of missions at Gateway, enabling the orbiting outpost to be used as a Mars analog. These analog missions will be accomplished by attaching the TH to Gateway and conducting lunar surface operations from the TH. The TH may also need to perform free-flying shakedown missions to test out all systems prior to leaving for Mars. The habitat provides many critical functions including: a contingency airlock, crew quarters, galley, hygiene areas, safe haven capability, and science equipment. It can receive docked items from either axial end or on a radial port.

Figure 3: An artist's concept of the Transit Habitat

II. Ground Rules and Assumptions

As the SH and TH are still in the early phases of design, NASA has developed a set of Ground Rules and Assumptions (GR&As). The GR&As, in conjunction with the functional allocations provided in the next section, represent a set of draft requirements which can be applied to concepts. Each GR&A includes accompanying rationale to facilitate further understanding of the current state of the NASA reference architecture. As the development of the architecture and elements matures, ground rules are relatively unlikely to change throughout the development process. Assumptions are generally less rigid than ground rules and either represent constraints that require further assessment or features that are desired. Assumptions are thus more likely to undergo updates as NASA's Moon to Mars architecture is refined. The tables in the following sections summarize the current GR&As for the surface habitat and transit habitat, respectively, at the time of publication. Each ground rule (designated as GR) and assumption (designated as A) is accompanied by a description and rationale.

Surface Habitat Ground Rules and Assumptions

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Crew Size/ Habitable Duration**	Description: At delivery, the SH will support a crew of two for approximately 30 days. Additionally, in a contingency it will be capable of providing a safe haven for four crew for seven days.
		Rationale: The first mission after delivery and activation of the habitat is assumed to be a four-crew mission, with two crew members living in the habitat and two crew members on excursion in the Pressurized Rover (PR). There will be periods in the Concept of Operations (ConOps) where crews will need to swap between the habitat and the pressurized rover. During these swapping periods the habitat will support all four crew. The seven-day safe haven capability does not extend the ~30-day habitation and represents the situation where two crew are unable to remain in the PR and therefore the SH must support all four crew until the next ascent opportunity.
A	**Expanded Habitation Considerations**	Description: NASA is interested in options for expanding SH to support four crew for approximately 30 days and four crew for approximately 60 days.
		Rationale: Showing an evolution after initial deployment to four crew/~30 days and four crew/~60 days is desired. The goal is to evolve to a four crew, ~60-day system, which is currently being traded as either a) within the SH, b) provided by the combination of an SH and a pressurized rover, or c) an SH augmented by additional surface elements.
GR	**Allowable Mass**	Description: The SH allowable landed mass will be 12 metric tons.
		Rationale: Concepts should target habitat landed mass within the capability of anticipated Human Landing System (HLS)-class landers. Should this payload capability be updated, NASA will provide an updated target. Logistics may be delivered separately, but a minimum capability of two crew, ~30 days on the first mission is preferred.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Mass Growth Allowance and Mass Margin**	Description: Mass Growth Allowance (MGA) and Mass Margin will be calculated based upon heritage and design maturity of each component/subsystem per ANSI/AIAA S-120A-2015(2019) Mass Properties Control for Space Systems [1] criteria and definitions. A minimum 15% Mass Margin is needed to account for architectural uncertainties.
		Rationale: This matches the current NASA-internal element assumptions and best practice for conceptual system designs.
GR	**Maximum Dormant Duration**	Description: The SH will have the capability to remain uncrewed and dormant for up to three years. Operations for putting the SH in a dormant state and recovering from dormancy upon return should be considered.
		Rationale: Yearly missions to the SH are currently being planned, but longer dormant periods may be required to protect against launch delays. Dormancy operations are defined by the absence of crew and relative inactivity of a system. Dormant periods could range from several days to months. Dormancy operations will likely be initiated remotely by humans and executed with either automated pre-programmed sequences or autonomously depending on the systems' capabilities and level of automation.
GR	**Lifetime**	Description: The SH will support one crewed mission per year for a minimum of 10 years with a desired lifetime of at least 15 years.
		Rationale: Set by current NASA assumed mission cadence.
A	**Assumed Delivery and Operational Timeline**	Description: The SH will be delivered within the next decade. The SH will be delivered on either a large cargo lander or a cargo variant of a crewed lander. It is assumed that the lander will provide the avionics and propulsion to deliver the habitat to the surface. Habitat offloading to the surface is not required in the current NASA reference ConOps. Optional habitat offloading equipment is not included in the lander mass.
		Rationale: Current NASA studies are assessing a variety of delivery dates for SH. The SH can be considered a payload delivered to the lunar surface, so it will not need independent propulsion and avionics to facilitate the landing. However, the lander as a service does not assume habitat offloading as part of its ConOps or nominal mass. Any desired offloading equipment should be counted against lander payload limits.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Deployment Location and Conditions**	Description: The SH will be deployed to a south polar location during a full sunlit period with sufficient time to conduct all setup prior to prolonged darkness periods.
		Rationale: Sunlight deployment enables the SH to autonomously deploy/connect any needed on-board power, thermal, or communications assets during a period of power availability and have time to prepare for the lunar night by charging on-board energy storage systems.
A	**Crew Operational Periods**	Description: Assume the crew will be present only during mostly illuminated periods.
		Rationale: Operational periods require more power consumption and are assumed to be during sunlit periods to minimize the down mass needed for energy storage.
A	**EVA Capability**	Description: The total EVA time per crew will not exceed 24 hours per week. The SH will support a maximum surge rate of one two-person eight-hour EVA in a 24-hour period. The SH will provide egress/ingress capability to enable EVA. The SH will enable EVA suit maintenance.
		Rationale: These EVA rates are intended to set limits for total EVA hours per week and maximum EVA rate. The minimum EVA numbers required to achieve surface science and exploration objectives are still TBD. NASA is currently assessing options to leverage suitport-compatible suits for benefits in dust protection, reduced EVA overhead time, and reduced consumables resupply. Suitports may be assumed as a means of nominal crew egress/ingress via suitport-compatible suits and logistics and trash transfer via suitport-compatible logistics containers. Consideration should also be given for contingency or off-nominal egress/ingress capability required to perform suit repairs, transfer incapacitated crew, transfer of large logistics, etc.
GR	**Avionics - Communication**	Description: The SH will provide proximity communications on the lunar surface. Ultra High Frequency (UHF) and Wi-Fi should be assumed and are expected to have both omni-directional and directional modes/antenna. The SH will provide direct communications to Gateway. S-band and Ka-band should be assumed. The SH will provide direct communications to Earth. X-band and Ka-band should be assumed.

Ground Rule or Assumption (GR or A)	Title	Overview
		Rationale: NASA is currently trading the lunar communication architecture, including interdependencies between all lunar surface assets. Those trades include the scenario of SH and/or HLS being used to route communication from other lunar surface elements to Earth due to the power-intensive nature of direct to Earth (DTE) links. This scenario should be taken into consideration for the SH communication subsystem. Orbital communication relays are also being traded but should not be assumed as part of the architecture.
GR	**Avionics - C&DH / Autonomy**	Description: C&DH: The SH will contain all avionics necessary to manage its systems, subsystems, and components, report their status, and execute against commands received. The SH may need to be capable of commanding visiting vehicles, orbital assets (ex. Gateway in Mars analog and contingency scenarios), and lunar surface assets. Autonomy: Autonomy should be assumed to the greatest extent possible to enable successful uncrewed, long-duration missions. At a minimum, the SH must be capable of detecting and resolving anomalous conditions autonomously, performing routine maintenance activities necessary to maintain nominal operation, and capable of being remotely commanded by Earth, crew, and Gateway.
		Rationale: Significant autonomy will be required due to extended uncrewed dormant periods.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Habitability Functions**	Description: The SH will provide the following habitability functions as a minimum: dust mitigation, suit and habitat maintenance provisions, solar particle event (SPE) radiation protection, micrometeoroid and orbital debris (MMOD) protection, exercise, medical, galley, private habitation/sleep areas, private hygiene, private waste management, group socialization and recreation, external direct viewing (at least 1-2 windows), logistics/stowage/inventory management, and subsystems monitoring and commanding. The habitat will provide for meaningful IVA crew work including physical and life sciences. The habitat design will enable crew awareness of surroundings and interaction with the environment and others; provide the means for customization and adaptability to changing resources, mission, and environmental dynamics; promote productive and responsible resource utilization; maximize completion of mission objectives; facilitate purposeful, personal, and social actions and activities; and provide for effective transition, flow, and sequencing of actions. Chapter 8 of the Human Integration Design Handbook (NASA/SP-2010-3407) [2] may be consulted for guidance.
		Rationale: The listed habitat functions are considered a minimal set and should be accommodated within the SH volume per best spacecraft design practice.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Habitable Volume and Functional Volume Layout Process**	Description: The SH will be capable of independent spacecraft operation and supporting crew needs with all required spacecraft subsystems, crew support equipment, logistics, and spares appropriate for long-duration missions. A functional volume layout will be performed to verify the volume provided is adequate to accommodate all required equipment, storage, and crew functions.
		Rationale: Rather than specify a habitable volume requirement, all SH concepts must leverage a functional volume layout process to ensure all crew accommodations, subsystems, logistics, spares, and crewed functions can be accommodated as detailed in Reference [5]. Proper accommodation of all functions and hardware are critical to ensure crew physiological, psychological, and psychosocial health and ensure the vehicle can be properly operated and maintained for long duration missions with no resupply or abort. The SH must represent a unified solution for the general size, placement, arrangement, and configuration of spaces in crew stations, compartments, translation corridors, and other habitable volumes where crewmembers live and work. It must demonstrate provision of enough volume for each task while accounting for co-location / separation, dedicated / multipurpose / reconfigurable volumes, gravity influence, and psychosocial issues.
GR	**Power**	Description: Once fully deployed and operational, power will be generated and stored by the SH. Power provided to other elements is TBD. Power storage will be provided to survive ~100 hours darkness periods and maintenance periods.
		Rationale: The current assumption is that a fully deployed SH will be self-sufficient and not rely upon the lander or surface assets for power. However, this is still being traded and may be updated in the future if surface power assets are confirmed. Power resource sharing is being traded for nominal operations, but off-nominal contingency scenarios (where power may need to be shared to or from the habitat) should be considered.
GR	**Thermal**	Description: Once fully deployed and operational, the SH will have the capability to collect, transport, and reject all waste heat it generates.
		Rationale: No other vehicles are assumed to aid in heat transport or rejection throughout SH missions.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Life Support**	Description: The SH will include an Environmental Control and Life Support System (ECLSS) that provides for crew health and safety over the duration of the crewed mission with a nominal operating pressure of 10.2 psia (70.3 kPa) and 26.5% Oxygen concentration and the capability to operate at 8.2 psi (56.5 kPa)and 34% Oxygen.
		Rationale: The SH will provide ECLSS equipment and sparing provisions to enable safe operation of the SH for crewed periods. ECLSS closure assessments are ongoing and more closed systems may be considered in habitat concepts if deemed beneficial. NASA is currently assessing ECLSS options for water processing during uncrewed illuminated periods in order to preserve power during crewed periods.
A	**Life Support Sharing**	Description: The SH should accommodate processing wastewater collected in the Pressurized Rover and provide the Pressurized Rover with potable water and oxygen needed for Rover activities. Commodity exchanges between the SH and the Pressurized Rover should be assumed to correspond with crew rotations between the SH and Pressurized Rover.
		Rationale: It is assumed that the Pressurized Rover will have the capability to collect humidity condensate and urine for processing in the SH.
GR	**Logistics Storage**	Description: The SH will be capable of stowing required Cargo Transfer Bag Equivalents (CTBE) of logistics at the start of a mission. Re-supply logistics will be delivered to the surface of the Moon and must be transferred to the SH.
		Rationale: Logistics amounts are summarized in **Appendix A**, which provides updated details for NASA-assumed rates/totals of logistics, spares, and maintenance for the two-crew 28-day mission. Note that O2 is provided through water leveraging an Oxygen Generation Assembly (OGA) in the NASA assumptions. The initial charges of atmospheric gasses should be included in the habitat systems masses at delivery.
A	**Utilization**	Description: The SH will house a minimum of TBD kg of science and utilization payloads. Volume and resources required by these systems are TBD.
		Rationale: Trades evaluating utilization are ongoing.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Ancillary systems and elements**	Description: Any mass or volume needed for crew access, habitat offloading, and any other ancillary systems or elements needed for the initial crew mission must be manifested with SH delivery.
		Rationale: “Manifested with SH delivery” implies systems and elements would be included in the up to12 metric tons delivered to the lunar surface. Ancillary systems would include any equipment or tool required to support loading, offloading, or crew access to the habitat, including ladders, cranes, etc. New flights may not be added to the manifest to support ancillary systems or elements.
A	**Trash and Waste Disposal**	Description: Surface logistics containers will be used to store trash and waste in a safe state on the lunar surface for TBD years.
		Rationale: Safe storage on the lunar surface is ongoing work and a subject of planetary protection protocol. Waste and trash management touches on site planning and design (e.g. configuration, accessibility, operation, safety, cross-contamination, etc.), and environmental management. Logistics and waste management provisions near habitation areas must not interfere with access to the habitat(s) or impact the environment.
GR	**Supportability**	Description: SH systems must be reliable and maintainable over approximately 30-day mission without resupply from Earth. Systems must have demonstrated a sufficient level of reliability based on flight heritage and ground testing.
		Rationale: All sparing & maintenance items required to keep SH systems functioning must be manifested at the beginning of the mission. In order to accurately manifest spares and maintenance items, the projected failure rates for systems and components must be validated through testing on the ground and in space prior to long duration missions.

Transit Habitat Ground Rules and Assumptions

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Crew Size**	Description: The TH will support a nominal crew of four.
		Rationale: Nominal NASA missions are targeting four crew for Mars transit missions.
GR	**Allowable Mass**	Description: The TH allowable mass (dry) at Mars trajectory Earth departure burn will be 26.4 metric tons.
		Rationale: This 26.4 metric ton mass target represents a control mass carried in an internal NASA transportation assessment. Designing to this mass minimizes mass growth on the Mars Propulsion System assumed to perform the Mars trajectory burns. For reference, this dry mass target includes robotics, MGA, and mass margin. It does <u>not</u> include crew, utilization (1000 kg for outfitting is assumed), outfitting (includes logistics, spares, and maintenance items, etc.), or fluids (O2, N2, H2O, Reaction Control System [RCS] propellant, etc.). The Mars propulsion elements are not included in the habitat mass target, but habitat portions of mating/docking hardware and structural attachments to those elements are included. Wet mass targets for various mission options are being leveraged by the NASA transportation assessment. These wet mass targets leverage logistics and technology assumptions described in **Appendix B**. To ensure compatibility with NASA transportation assessments, dry mass reductions should not increase overall wet mass significantly.
GR	**Mass Growth Allowance and Mass Margin**	Description: Mass Growth Allowance (MGA) and Mass Margin will be calculated based upon heritage and design maturity of each component/subsystem per ANSI/AIAA S-120A-2015(2019) Mass Properties Control for Space Systems [1] criteria and definitions. A minimum 15% Mass Margin is assumed to account for architectural uncertainties.
		Rationale: This matches the current NASA-internal element assumptions and best practice for conceptual systems.

Ground Rule or Assumption (GR or A)	Title	Overview
A	**Maximum Habitable Duration**	Description: At completion, the TH should support a total crewed mission duration of up to 1,200-days without logistics resupply. This corresponds to a Mars departure loading of 1,110 days. Rationale: Carrying 1,200 days protects against both conjunction and opposition Mars missions where the surface assets are inaccessible or there is an early surface element abort. The 1,200 day duration represents a 1,100-day nominal mission duration (from Lunar Distant High-Earth Orbit [LDHEO] departure to LDHEO arrival) + 90 days for Space Launch System (SLS) crew launch timing + 10 days for rendezvous, proximity operations, and docking before and after the mission. This 90-day supply of logistics is assumed to be launched with SLS crew and may be stored in a logistics module that can be left in LDHEO prior to departure. NASA is considering a variety of crewed durations, but habitats should be designed to this longest mission duration to ensure the system is capable of executing all possible missions.
GR	**Maximum Dormant Duration**	Description: The TH will be able to operate autonomously in an uncrewed state for a period of up to three years between crewed missions. Rationale: This assumption allows flexibility in launch manifest planning and protects against delays in crewed launches. This assumption does allow for ground situational awareness and control of the vehicle during uncrewed periods.
GR	**Lifetime**	Description: The TH will have a minimum 15-year lifetime and will support multiple missions of increasing duration up to 1,200 days in that lifetime with potential crewed refit/repair/refurbishment opportunities between missions. Rationale: NASA is currently assessing a series of missions including shorter duration shakedowns while attached to Gateway, free-flying shakedowns in cislunar space, and Mars-class missions. This will allow for the development of a highly capable Mars Transit Habitat which envelopes these missions.

Ground Rule or Assumption (GR or A)	Title	Overview
A	**Launch Vehicle**	Description: The TH will be deliverable to Near-Rectilinear Halo Orbit (NRHO) on Commercial Launch Vehicle(s) (CLV). Options for SLS cargo delivery are possible but should feed cost assessments.
		Rationale: At this time, NASA is investigating whether the TH can be launched and delivered to NRHO on two CLVs. It can then be outfitted while at Gateway. The exact timing of TH delivery relative to SLS block upgrades may enable larger launches in the future but maintaining the ability to launch on CLVs if schedule shifts occur enables flexibility in delivery.
A	**Assumed Delivery and Operational Timeline**	Description: TH will support initial delivery to Gateway within the next decade to support sustained lunar and shakedown missions. TH will assume a crewed transfer to Mars vicinity in the following decade.
		Rationale: Current NASA studies are assessing a variety of delivery, shakedown, and Mars mission dates for TH. This initial delivery should be capable of sustained crewed operations while at Gateway. Furthermore, it is suspected that additional outfitting may be required after initial delivery prior to a Mars mission. A notional Mars date drives shakedown missions needed to test the integrated systems. Multiple opportunities are still under consideration.
A	**Rendezvous Operations**	Description: When docking to Gateway and Mars Propulsion System, the TH should be capable of being the chasing vehicle. When docking to Orion/logistics vehicles, Orion/logistics vehicles should be the chasing vehicles.
		Rationale: This assumption helps to inform docking port type considerations. However, landing systems are assumed to be chasing vehicles with passive ports, leveraging the TH active port.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Transit Habitat Operations for Gateway and Shakedown Missions**	Description: The TH will be docked to Gateway through most of its operation leading up to departure from Gateway to rendezvous with the Mars Propulsion System. The TH will have the capability to support crew while attached to Gateway as a habitable volume during TH setup, extended Gateway missions, and lunar surface missions. TH will also be capable of supporting independent, long-duration Shakedown missions while attached to Gateway, nominally only leveraging Gateway for station keeping and attitude control. All other Gateway resources are considered contingency or optional for TH Shakedown missions. The TH will also have the capability to support crew for free-flying shakedown missions separate from Gateway with NASA-provided interim propulsion stages in years prior to arrival of the Mars Propulsion System.
		Rationale: Extended Gateway missions and missions supporting lunar exploration are expected to leverage the TH at Gateway to enhance functionality and extend in-space durations. However, Shakedown missions at Gateway will operate mostly independent from Gateway to prove out integrated operation of the TH similar to expected Mars operation.

Ground Rule or Assumption (GR or A)	Title	Overview
A	**Gateway Resource Sharing and Interfaces**	Description: While at Gateway, TH has the capability to share power, command, and data across the docking interface (similar or common with the Gateway Docking System Standard (GDSS)). Intermodule ventilation may be provided by drag-throughs. Two operational modes are envisioned for the Gateway-TH integrated vehicle: hatch open (setup, refurbishment, outfitting, HLS departure, uncrewed/dormant ops) and hatch closed (Lunar-Mars analogs and Shakedown missions). Hatch Open: TH operates at Gateway nominal operating conditions (assuming 10.2 psia (70.3 kPa), 26.5% O2 atmosphere) with an open hatch. Hatch Closed: TH closes hatch to operate at Mars Transit conditions (14.7 psia (101.4 kPa), reliant on TH subsystems). TH propulsion (or attached propulsive stage) will provide additional delta velocity (DV) to assist Gateway with orbital maintenance and attitude control. TH will be capable of transferring and receiving TBD power and data to Gateway through axial ports.
		Rationale: Power sharing across the Gateway elements protects against any shadowing experienced by the integrated vehicle. Data and command sharing allows for operations from either vehicle. Note that alternate pressure ranges for Shakedown missions and Mars Transit are being investigated, but the assumptions provided represent the latest thinking. Analysis has shown that Gateway may need assistance with integrated vehicle control when TH is docked to the Gateway to achieve required slew rates, particularly during Orion visits. A NASA assessment is currently ongoing to provide assumed maneuver DVs.
GR	**Solar Orbital Operational Range**	Description: The TH will be capable, when mated to the Mars Propulsion System, of operating with a Solar Range from 0.60 AU to 1.6 AU (Astronomical Unit) to support possible conjunction and opposition class trajectories.
		Rationale: This assumption allows flexibility to pursue alternate destinations with the same system, including cislunar, Venus, and Mars.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Docking Ports**	Description: The TH will provide at least two axial Gateway Docking System Standard (GDSS) compatible docking ports (one passive and one active). At least one androgynous/active radial port is required. The two axial ports should be designed to simultaneously be occupied by propulsion elements. It is anticipated that the integrated vehicle bending loads for certain configurations may approach and potentially exceed the GDSS capability to resist bending. Reinforcement to the GDSS ports may be needed.
		Rationale: Various configurations throughout the lifetime of the TH are currently being assessed, and both Gateway-TH and Mars transportation configurations require axial and radial ports. Passive ports are required to accommodate Orion and androgynous ports accept both passive and active vehicles during missions. The two axial ports may both be occupied by propulsion elements in the Mars transit configuration necessitating that the Mars ascent/descent and Orion dock using radial ports. Bending loads are highly dependent on the vehicle configuration and it is possible that future configurations of the integrated Mars transit vehicle may result in loads exceeding GDSS capabilities.
A	**Refurbishment and Outfitting Operations**	Description: Before each Gateway, analog, and Shakedown mission, the TH will be resupplied with logistics and any replacement spares for the next mission while building up spares and non-perishable/long duration outfitting for the upcoming Mars mission. Additionally, the TH RCS should be capable of being refueled through a docking interface or other Gateway refueling interface.
		Rationale: Logistics flights may leverage existing Gateway Logistics Services (GLS) capabilities and small refueling tankers capable of transporting RCS fuel. Transit Habitat should be capable of refueling its RCS leveraging either the Gateway or Propulsion System propellants through available refueling interfaces. It is assumed that multiple launches will build up spares and logistics prior to Mars departure.

Ground Rule or Assumption (GR or A)	Title	Overview
A	**EVA, Contingency Airlock Capability, and EVR**	Description: The TH will provide a contingency airlock capability that allows the crew to perform external and/or internal repair EVAs using xEVA suits. If subsystem repair without an EVA is assumed, assessments must show subsystems will not require an EVA to repair or replace them during the mission. For EVA-required repair locations, TH must support EVA translation and access to those worksites (via handhold, extravehicular robotics [EVR], etc.). EVR is considered supplemental, and does not replace EVA if external operations are required. Any chosen use of EVR should be compatible with Gateway EVR interfaces.
		Rationale: Planned nominal operations do not include EVA for repairs or replacements while on missions away from Gateway. As EVAs are inherently risky, the EVA capability provided should be sized for infrequent, non-nominal operations as a last resort. NASA is assuming use of hardwired/cross-strapped spares to eliminate the need for nominal external ORU replacement where practical. If an EVA is required for repair contingencies, a mass trade of hardwired/cross-strapped spares vs. EVA suit functionality should be leveraged.
GR	**Safe Haven**	Description: The TH should provide the capability to temporarily shelter the crew during catastrophic loss of habitable volume (e.g. fire, depressurization, or similar event) and enable recovery and return to operational state.
		Rationale: This assumption protects the crew from some urgent and emergent events which may compromise the habitable volume. An isolatable volume to allow for recovery of an unsafe environmental condition is anticipated to greatly reduce risk of many likely contingency events. NASA is currently assessing the required time and capability of this safe haven to affect repairs and reduce crew risk while satisfying mass constraints.
GR	**SPE Shelter**	Description: The TH should provide a space for the crew to shelter during a solar proton event (SPE) that minimizes crew dose within TH mass constraints. This shelter should also allow for ease of ingress/egress from the shelter to the rest of the vehicle.
		Rationale: This assumption ensures radiation exposure from SPEs can be minimized throughout the long duration mission following best practice.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Logistics Storage**	Description: The TH should be capable of stowing required Cargo Transfer Bag Equivalents (CTBE) of logistics at the start of a mission. Logistics should be accessible, particularly those required for contingency scenarios. For additional assumptions for logistics, please refer to **Appendix B**.
		Rationale: Logistics amounts are summarized in **Appendix B**, which provides details for NASA-assumed rates/totals of logistics, spares, and maintenance for the roughly 1,110-day mission from Earth orbit departure to Earth orbit return. Furthermore, this logistics storage requirement reflects the assumption that logistics are not pre-deployed to Mars but carried with crew, avoiding the risk of docking to a logistics module in Mars orbit. Fluids are assumed to be stored in integral tanks sized within the TH.
A	**Trash and Waste Disposal**	Description: The TH should have a capability for trash and waste removal prior to departure/arrival burns. However, more frequent trash removal capability should be considered to optimize propellant on low-thrust trajectories at an average rate of 11.6 kg/day (mix of vented gases, liquids, and solid goods).
		Rationale: Trash disposal is deemed necessary to achieve propulsive performance enabling Mars mission trajectories. For high specific impulse systems being investigated, these dumps may occur as often as every day. Habitats should include the capability to dump on average 11.6 kg of gases, liquids, and solid goods per day, with trash dumps occurring at a TBD frequency. The minimum viable case is with trash dumps only occurring right before each major trajectory burn. Note that options to offload unneeded spares are being considered by NASA, but this system mass is not captured in this trash removal rate. For more details on the breakdown of the trash and waste streams, please consult the **Appendix B**.
GR	**Avionics**	Description: The TH will provide primary Communication, Navigation, Command and Control, and Data Handling for the Mars Propulsion System and TH.
		Rationale: The TH will contain all avionics and propulsion to free-fly for periods between Gateway departure and rendezvous with the Mars Propulsion System. The TH will provide communications, guidance and navigation, command and control, and data handling equipment to allow for crew operation and maintenance of those systems. It is assumed that similar systems may be available on the Mars Propulsion System, but these will be considered backup after integration.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Avionics - C&DH / Autonomy**	Description: C&DH: The TH will contain all avionics necessary to manage its systems, subsystems, and components, report their status, and execute against commands received. The TH will be capable of commanding visiting vehicles, orbital assets (ex. Gateway in Mars Analog and contingency scenarios), and lunar/Mars surface assets. Autonomy: Autonomy should be assumed to the greatest extent possible to enable successful uncrewed, long-duration missions. At a minimum, the TH must be capable of detecting and resolving anomalous conditions autonomously, performing routine maintenance activities necessary to maintain nominal operation, and capable of being remotely commanded by Earth, crew, and Gateway.
		Rationale: The Mars Propulsion System may carry similar avionics that would operate as backup while attached to the TH.
A	**Power**	Description: The TH should supply primary power to operate itself but can receive up to 20 kWe of power from the Mars Propulsion System for use within the habitat for redundancy purposes and supplementation at orbits beyond 1 AU. TH should provide power storage to survive at minimum1.5-hour eclipse periods and power maintenance periods. The TH should be capable of supplying and receiving power to/from Gateway through high power and low power interfaces.
		Rationale: The TH should at minimum be able to power itself from 0.60 AU to 1 AU without any assistance. Beyond 1 AU, some amount of primary power support can be assumed to be provided by the Mars Propulsion System.
GR	**Thermal**	Description: The TH should have the capability to collect, transport, and reject waste heat it generates.
		Rationale: No other vehicles are assumed to aid in heat transport or rejection throughout TH missions.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Life Support**	Description: The TH will include an Environmental Control and Life Support System (ECLSS) that provides for crew health and safety and which recycles waste products to a degree that the balance of available water and oxygen is maintained, assuming water is only added to the balance through metabolism and food ingestion. The TH will support operational pressures at 10.2 psia and 14.7 psia while at Gateway. The TH will support long duration transits at 14.7 psia. Hardware and consumables for pressure transitions will be provided by the TH. The number of repressurization/transition events is TBD.
		Rationale: The TH will require an ECLSS capable of supporting 1,200-day missions without resupply. Regenerative ECLSS technologies should be used to minimize the logistics that must be manifested.
GR	**Supportability**	Description: TH systems must be reliable and maintainable over the 1,200-day mission without resupply from Earth. Systems must have a demonstrated level of reliability based on flight heritage and/or ground testing.
		Rationale: All sparing & maintenance items required to keep TH systems functioning must be manifested at the beginning of each Mars mission and potential long-duration shakedown missions. To accurately manifest spares and maintenance items, the projected failure rates for systems and components must be validated through testing on the ground and in space prior to long duration missions.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Crew Support Equipment**	Description: The TH will provide crew support equipment (e.g., food preparation, exercise, crew quarters, hygiene, medical) and spares for 1,200-day missions without resupply. Maintenance and refurbishment will be available between crewed missions. Crew support equipment and spares will be provided to enable safe operation of the TH for crewed periods. Required functions include: Private Habitation, Private Hygiene, Private Waste Collection, Meal Preparation, Meal Consumption, Group Socialization and Recreation, Exercise, Medical Operations, Radiation Protection, Scientific Research, Robotics/Teleoperations, Spacecraft Monitoring and Commanding, Mission Planning, Maintenance, Logistics Operations (including long-term food storage/refrigeration), and EVA Operations.
		Rationale: The TH will require crew support equipment capable of supporting 1,200-day missions without resupply. These functions are largely derived from NASA Space Flight Human-System Standard (NASA-STD-3001) [3, 4] and the Human Integration Design Handbook (NASA/SP-2010-3407) [2]. Cold food storage is assumed to be required for the long duration mission with long logistics deployment but may be traded in the future with other approaches.

Ground Rule or Assumption (GR or A)	Title	Overview
GR	**Habitable Volume and Functional Volume Layout Process**	Description: TH will be capable of independent spacecraft operation and supporting crew needs with all required spacecraft subsystems, crew support equipment, logistics, and spares appropriate for long-duration missions. A functional volume layout will be performed to verify the volume provided is adequate to accommodate all required equipment, storage, and crew functions.
		Rationale: Rather than specify a habitable volume requirement, all TH concepts will leverage a functional volume layout process to ensure all crew accommodations, subsystems, logistics, spares, and crewed functions can be accommodated as described in Reference [5]. Proper accommodation of all functions and hardware are critical to ensure crew physiological, psychological, and psychosocial health and ensure the vehicle can be properly operated and maintained for long duration missions with no resupply or abort. The TH must represent a unified solution for the general size, placement, arrangement, and configuration of spaces in crew stations, compartments, translation corridors, and other habitable volumes where crewmembers live and work. It must demonstrate provision of enough volume for each task while accounting for co-location / separation, dedicated / multipurpose / reconfigurable volumes, gravity influence, and psychosocial issues.
A	**Propulsion**	Description: TH propulsion (or attached propulsive stage) will support a minimum of 180 m/s total DV to protect against four docking/undocking and rendezvous maneuvers in cislunar space (3 nominal, 1 contingency). These TH propulsion capabilities will be refuelable from the Mars Propulsion System and/or while at Gateway.
		Rationale: Current ConOps have TH docking with Gateway, undocking, and rendezvousing with Mars propulsion elements to complete a Mars mission (3 nominal burns). After each Mars mission the TH will detach from Mars Propulsion System in NRHO prior to rendezvous and docking to Gateway. Analysis of propulsion maneuver requirements is ongoing, but current minimum assumptions for propellant sizing between refuelings is 180 m/s.

Ground Rule or Assumption (GR or A)	Title	Overview
A	**Multiple Units for Additional Mars Missions**	Description: It is assumed that new TH units will be required for missions beyond the first crewed Mars mission. These TH units will be able to leverage limited capability advancements to reduce mass, improve functionality, and decrease risk to crew.
		Rationale: The 15-year lifetime will necessitate a new or upgraded TH unit for future Mars missions. The current assumption is that a new unit will be needed possibly earlier than 15 years from the delivery of the first TH, due to the need to not exceed the element lifetime during a Mars mission.
A	**Utilization**	Description: The TH should accommodate a minimum of 1,000 kg of science and utilization payloads. Volume and resources required by these systems are TBD.
		Rationale: A notional, minimum TH utilization mass allocation is provided for current studies. Additional utilization is preferred if it can be accommodated within mass limits.

III. Functional Allocation

Similar to the Ground Rules & Assumptions (GR&As), functional allocations are provided for both Surface Habitat (SH) and Transit Habitat (TH). These allocations represent NASA's guidance, at the time of this publication, on the functionality to be accounted for by the SH and TH. Functional allocations, in conjunction with the GR&As provided in the previous section, represent a first-level set of draft requirements which can be applied to concepts.

Surface Habitat Functional Allocations

Functions	SH Applicability	Notes
Structures The primary structure of the SH will require the strength to support the anticipated loads experienced in the launch environment, natural and induced environments, and gravity forces. A structural health monitoring system will measure responses of the SH to actual dynamic loads in order to assess structural life consumption and perform damage detection, location, and assessment.		
Human-Rated Pressurized Volume	Yes	
Micrometeoroid Protection	Yes	
External Viewing Window(s)	Yes	Class C window or larger as per JSC 63320
Internal Mounting Structure for Support of Internal Subsystems and Logistics	Yes	
Unobstructed Emergency Response Equipment Stowage & Access	Yes	
Monitor Structural Health	Yes	
Mechanisms If not integrated to the lander for launch, the SH will include unpressurized mating systems for aggregation in space. The SH shall be capable of sending or receiving power and data through mated interfaces.		
Hatch(es) for Crew/Cargo	Yes	
Support Docking	TBR	Dependent upon launch/transfer configuration
Support Mating with Lander	Yes	SH will be responsible for any structural attachments needed

Functions	SH Applicability	Notes
Power The electrical power system of the SH will include solar arrays for power generation, distributed energy storage, and power distribution converters and switchgear to condition and distribute the power throughout the SH. Internal to the SH, power interfaces will be provided to support science, portable devices, and crew systems.		
Generate Power	Yes	
Store Energy	Yes	
Receive Power	Yes	From surface power assets as a contingency scenario
Distribute Power	Yes	Rover may need additional power to support extended duration on the lunar surface
Condition & Convert Power (sub to Distribute Power)	Yes	
Internal Portable Equipment Power	Yes	
Thermal The SH Thermal Control System (TCS) must maintain components and subsystems (both internal and external) within their specified temperature limits through active thermal control systems (ATCS) and passive thermal controls systems (PTCS). Any heat generated by the SH must be rejected without the aid of other surface assets. The SH TCS will need to minimize thermal dissipation during Survive the Night conditions.		
Passive Thermal Control	Yes	
External Component Active Thermal Control	Yes	
Internal Component Active Thermal Control	Yes	Cold plates, cabin cooled-to IATCS, other heat exchangers (science payloads)
Heat Rejection Capability	Yes	External radiators, coldplates

Functions	SH Applicability	Notes
Avionics The SH will require all necessary avionics to successfully manage its systems, subsystems, and components, report their status, and execute against commands received. As the SH may be uncrewed for long durations, the SH architecture should be designed to accommodate autonomy to the greatest extent possible. Part of this is being able to detect and resolve anomalous conditions autonomously and perform routine maintenance activities necessary to maintain nominal operation. SH systems, subsystems, and components must be capable of being remotely controlled from Earth and by crew at Gateway. The SH may also need capabilities for controlling visiting vehicles, orbital assets (ex. Gateway in contingency scenarios), and lunar surface assets. Data storage and retrieval functionality will be used during limited communications contact periods to backup transmitted data and to accommodate low data transmission rates.		
Command and Telemetry	Yes	
Data Processing & Storage	Yes	
Fault Management	Yes	Fault detection, response, and notification
Annunciate Caution and Warning Data	Yes	Visual and auditory
Crew Displays and Controls (hardware)	Yes	Computer human interface
Autonomous Commanding Capable	Yes	
Video Imagery Imagery systems on the SH will include still imagery, motion imagery and associated synchronized audio, metadata, and support capabilities that span SH internal and external environments. Real-time/live streaming will be required for monitoring of active operations (ex. EVA, Robotics, etc.). Other cases may require long-term monitoring of vehicle condition, and therefore video or periodic still images will need to be collected for onboard storage and subsequent downlink. The development of these imagery systems will consider trades of options, including the number and locations of cameras, camera resolution versus task image detail needs, and bandwidth usage versus image quality for display to the crew.		
Imagery from Internal Cameras	Yes	
Imagery from Hand-Held Cameras (EVA or IVA)	Yes	
Imagery from External Cameras	Yes	
Imagery from EVA Helmet Cameras	Yes	

Functions	SH Applicability	Notes
Communication & Tracking (C&T) To support surface missions, the SH will require a communication system to handle data exchange and radiometric tracking with other communication systems. SH communication systems will include: an SH to Earth system that supports low and high rate data transfer for communications and radiometric tracking; an SH to lunar lander and lunar rover link that provides communications between the SH and other assets on the lunar surface, orbiting the Moon or in the vicinity of the Moon (direct link or via a relay); a proximity communication system to provide core communications between extravehicular activity (EVA) and SH; and SH wireless communications to support high rate communications between EVA, cameras, wireless sensors, laptops, etc. The SH communication systems may be used as a backup.		
Communication w/ Earth	Yes	Uplink and downlink
Communication w/ Lunar Assets	Yes	Includes orbiting (ex. Gateway) and surface assets (ex. rover, lander)
Communication w/ EVA	Yes	
Communication Security	Yes	Encrypt and decrypt data
Wireless Communications Access Points	Yes	External and internal
Guidance Navigation & Control (GN&C)		
Determine Absolute Navigation State	Yes	
Navigation Docking Capability	Yes	Including sensors, targets, and external lighting to support lander docking position and location
EVA SH extravehicular activities (EVAs) will include rover transfer, science activities, maintenance, and contingency operations to address issues and failures. EVA support includes the capability to prepare the EVA suits, ingress and egress the SH while minimizing the loss of cabin atmosphere, translation, and post-EVA suit maintenance and stowage. Stabilization aids, such as EVA handrails, aid EVA crew and allow them to ingress/egress in a stable, safe manner.		
EVA Ingress/Egress of SH	Yes	
EVA Suit Donning/Doffing Space	Yes	
Pre-Breathe Capability	Yes	
EVA Translation Path & Worksite Interfaces	Yes	
EVA Suits and Tools Stowage	Yes	
EVA Suit Servicing	Yes	Servicing/maintenance, recharging, repairs
Robotics Internal robotics will provide the SH the capability to perform inspection, maintenance and repairs, logistics management, and emergency management during all mission phases (crewed/uncrewed). Provisioning for robotics will require mechanisms (i.e. Translation Aids), power, and data. As the SH may be uncrewed for long durations, robotics are essential for enabling autonomy and continuity in operations		

Functions	**SH Applicability**	**Notes**
Intravehicular Robotics (IVR)	No	IVR will be launched via logistics services
IVR Interfaces	Yes	IVR compatible interfaces are not required to be installed as part of the initial deployment
Crew Systems The SH must provide sufficient habitable volume and provisions for the crew to successfully accomplish all intravehicular activities (IVA).		
Accommodate Crew Living and Working Tasks	Yes	
Crew Medical Care	Yes	
Crew Physiological Health	Yes	Crew exercise space and equipment
Private Crew Quarters	Yes	
Private Crew Hygiene Compartment	Yes	Facial, oral, hand, full body, grooming, etc.
Private Waste Management Compartment	Yes	Toilet and associated supplies and stowage
Food Preparation	Yes	
Internal Vehicle Lighting	Yes	
Cold Food Stowage	Yes	
Housekeeping Activities	Yes	Including point-of-use stowage
Maintenance Workstation	Yes	Separate from the EVA workstation
Manage Stowage Inventory	Yes	
Stowage Volume	Yes	Not for EMUs/suits or EVA tools
Manage Trash and Waste	Yes	Stowage and disposal
In-situ Space Radiation Absorbed Dose/Dose Rate Measurements	Yes	
Protect Crew from Acoustic, and Radiation Hazards	Yes	

Functions	SH Applicability	Notes
Utilization Payloads The SH will need to accommodate both internal and external utilization payloads, including science and technology demonstrations. Accommodations include volume, power, data, environmental controls, and robotic interfaces. Utilization payloads will be allocated mass and volume through the logistics services task.		
Internal Utilization Accommodations	Yes	
External Utilization Accommodations	Yes	
Gas Venting for Payloads	Yes	
Interface Access for alternate or complimentary life support technologies	Yes	
Science Ingress, Egress, and Interfaces	Yes	
ECLSS The SH ECLSS must establish and maintain a habitable volume for a crew of four and internal payloads on missions of approximately 30 days. When the SH is uncrewed, the ECLSS will maintain a threshold atmosphere to protect itself and other SH systems. This includes maintaining a minimum pressure and temperature to protect against freezing and removing cabin air humidity to protect against condensation. The ECLSS will provide a habitable atmosphere prior to crew return by re-establishing an acceptable total pressure, oxygen partial pressure, trace gaseous contaminant levels, and temperature. During ramp-up for crew arrival, full recovery and verification of ECLSS functionality should be achieved to support the next crewed mission phase.		
Control Cabin Pressure	Yes	Maintain a habitable total pressure and oxygen concentration by controlling venting and relief, storage, and distribution of the O2 / N2 gases, as well as monitor cabin total pressure and partial pressure oxygen to manage the atmosphere in the SH.
Remove Air Contaminates	Yes	Ensures habitable atmosphere is free of pollutants that might harm the crew by managing removal of metabolic waste, trash, and equipment-generated contaminants in gaseous and particulate (solid) phases within the pressurized volume and controlling them to concentrations below prescribed physiological limits.

Functions	SH Applicability	Notes
Conditioning Cabin Air	Yes	Provide a habitable and comfortable environment by managing the atmospheric temperature and removal of humidity, including circulation of air for proper thermal distribution and a uniform breathable atmosphere, as well as the control of air conditioning systems, including monitoring of atmospheric temperature and relative humidity, plus any further heat (crew metabolic, basic subsystems, computers/displays, refrigerators/incubators, science payloads) added to the cabin air.
Provide Water (Systems, Payloads, Crew)	Yes	Crew consumption, medical, hygiene, and water for payloads and Extravehicular Activity (EVA). Includes storage, distribution, dispensation, and quality control, as well as the control of water management system(s), including monitoring system performance.
Protect Crew and Vehicle from Hazardous Conditions	Yes	Protecting the crew and vehicle from a hazardous environment consists of providing Personal Protective Equipment (PPE) for the crew and returning the cabin atmosphere to a habitable environment.
Manage Crew Metabolic Waste	Yes	Collection and isolation of crew body waste from the crew. If body waste is not transferred to a resource recovery system (such as a Water Recovery System) or immediately discarded via venting, then waste will be stabilized and transferred to long-term storage and disposal.
Remove Lunar Dust	Yes	Protect against lunar dust from visiting rovers, EVAs, receiving lunar cargo, etc. Includes mitigating dust ingress to cabin and dust removal.
Emergency Response		
Provide Fire Safety	Yes	Detect, suppress, and recover
Provide Personal Protective Equipment (PPE) Stowage	Yes	
Operate Critical Systems following a Decompression Event	Yes	
Re-establish Cabin Atmosphere after a Depression Event	Yes	
Maintain Emergency Cabin Pressure Under a Leak Event	Yes	
Provide a Safe Haven to Protect Crew during Catastrophic Loss of Habitable Volume	Yes	

Functions	SH Applicability	Notes
Provide a Solar Proton Radiation (SPR) Shelter to Protect Crew during a Solar Proton Event	Yes	

Transit Habitat Functional Allocations

<table>
<tr><th>Functions</th><th>TH Applicability</th><th>Notes</th></tr>
<tr><td colspan="3">**Structures**
The primary structure of the TH will require the strength to support the anticipated loads experienced in the launch environment, as well as on-orbit loads from docking, natural and induced environments. A structural health monitoring system will measure responses of the TH to actual dynamic loads in order to assess structural life consumption and perform damage detection, location, and assessment.</td></tr>
<tr><td>Human-Rated Pressurized Volume</td><td>Yes</td><td></td></tr>
<tr><td>Micrometeoroid Protection</td><td>Yes</td><td></td></tr>
<tr><td>External Viewing Window(s)</td><td>Yes</td><td>Class C window or larger as per JSC 63320</td></tr>
<tr><td>Internal Mounting Structure for Support of Internal Subsystems and Logistics</td><td>Yes</td><td></td></tr>
<tr><td>Unobstructed Emergency Response Equipment Stowage & Access</td><td>Yes</td><td></td></tr>
<tr><td>Monitor Structural Health</td><td>Yes</td><td></td></tr>
<tr><td colspan="3">**Mechanisms**
The TH will include 2 axial GDS compatible docking ports (1 active, 1 passive) and at least one radial (1 androgynous/1 passive) GDS port to support active and passive docking events with Gateway, Mars Propulsion System, landers, and visiting vehicles. NASA trades are currently assessing if the removal of the passive radial port is a viable configuration. When attached to the Mars Propulsion System, the docking system will enable the transfer of power and data and augment structural mating points to handle off-axial loads.</td></tr>
<tr><td>Hatches for Crew/Cargo</td><td>Yes</td><td></td></tr>
<tr><td>Support Docking</td><td>Yes</td><td></td></tr>
<tr><td>Support Mating to the Mars Propulsion System</td><td>Yes</td><td></td></tr>
</table>

Functions	TH Applicability	Notes
Power The electrical power system of the TH will include solar arrays for power generation, distributed batteries for energy storage, and power distribution converters and switchgear to condition and distribute the power throughout the TH and to other potential elements. Internal to the TH, power interfaces will be provided to support science, IVR, and crew systems. When attached to the Mars Propulsion System, the TH may receive power as backup or supplementation at certain orbits, but it may also distribute power to the Mars Propulsion System as backup. When docked at Gateway, the TH may receive power as backup but it may also distribute power to the Gateway as backup.		
Generate Power	Yes	
Store Energy	Yes	
Distribute Power	Yes	To Gateway and visiting vehicles
Receive Power	Yes	From Gateway and Mars Propulsion System
Condition & Convert Power (sub to Distribute Power)	Yes	
Internal Portable Equipment Power	Yes	
Thermal The TH Thermal Control System (TCS) must maintain components and subsystems (both internal and external) within their specified temperature limits through active thermal control systems (ATCS) and passive thermal controls systems (PTCS). Any heat generated by the TH must be rejected without the aid of other vehicles. To maximize the flexibility to support visiting vehicles, maintain sufficient communication coverage and minimize propellant demand, the TH TCS will need to be attitude independent.		
Passive Thermal Control	Yes	
External Component Active Thermal Control	Yes	
Internal Component Active Thermal Control	Yes	Cold plates, cabin cooled-to IATCS, other heat exchangers (science payloads)
Heat Rejection Capability	Yes	External radiators, coldplates
Heating to Hatches	Yes	To prevent condensation

Functions	TH Applicability	Notes
Avionics To support free-flying missions, the TH will require all necessary avionics to successfully manage its systems, subsystems, and components, report their status, and execute against commands received. As the TH may be uncrewed for long durations, the TH architecture should be designed to accommodate autonomy to the greatest extent possible. Part of this is being able to detect and resolve anomalous conditions autonomously and perform routine maintenance activities necessary to maintain nominal operations. The TH should be capable of being remotely controlled from Earth or by crew at Gateway. The TH should also be capable of controlling visiting vehicles, orbital assets (ex. Gateway in contingency scenarios), and lunar/Mars surface assets. Data storage and retrieval functionality will be used during limited communications contact periods to backup transmitted data and to accommodate low data transmission rates. The Mars Propulsion System may carry similar avionics that would operate as backup while attached to the TH.		
Command and Telemetry	Yes	
Data Processing & Storage	Yes	
Fault Management	Yes	Fault detection, response, and notification
Annunciate Caution and Warning Data	Yes	Visual and auditory
Crew Displays and Controls (hardware)	Yes	Computer human interface
Autonomous Commanding Capable	Yes	
Commanding of Visiting Vehicles, orbital assets, and surface assets	Yes	
Module to Module Communication	Yes	Internal communication

Functions	TH Applicability	Notes
Video Imagery Imagery systems on the TH will include still imagery, motion imagery and associated synchronized audio, metadata, and support capabilities that span TH internal and external environments. Real-time/live streaming will be required for monitoring of active operations (ex. EVA, Robotics, etc.). Other cases may require long-term monitoring of vehicle condition and therefore systems must be able to collect and store video or periodic still images which can be subsequently downlinked. The development of these imagery systems is expected to consider trades on several options including the number and locations of cameras, camera resolution versus task image detail needs, and bandwidth usage versus image quality for display to the crew.		
Imagery from Internal Cameras	Yes	
Imagery from Hand-Held Cameras (EVA or IVA)	Yes	
Imagery from External Cameras	Yes	
Imagery from EVA Helmet Cameras	Yes	

Functions	TH Applicability	Notes
Communication & Tracking (C&T) To support free-flying and surface missions, the TH will require a communication system to handle data exchange and radiometric tracking with other communication systems. TH communication systems will include: a TH to Earth System that supports low and high rate data transfer; a TH to visiting vehicle system that supports communications and radiometric tracking during rendezvous and proximity operations; a TH to lunar system that provides communications between the TH and assets on the lunar surface, orbiting the Moon or in the vicinity of the Moon (direct link or via a relay); a TH to Mars System that provides communications between the TH and assets on the Mars surface, orbiting the planet or in the vicinity of the planet (direct link or via a relay); a Proximity communication system to provide core communications between extravehicular activity (EVA) and TH; and TH Wireless communications to support high rate communications between Gateway modules (when docked), EVA, cameras, wireless sensors, free flyers, laptops, etc. While docked at Gateway, the TH communication systems will operate as backup. The Mars Propulsion System may carry similar communication systems that would operate as backup while attached to the TH.		
Communication w/ Earth	Yes	Uplink and downlink
Communication w/ Visiting Vehicle	Yes	Attached or orbiting
Communication w/ Lunar Assets	Yes	
Communication w/ Mars Assets	Yes	
Communication w/ EVA	Yes	
Crew-to-Crew Communication	Yes	Video, voice, data
Communication Security	Yes	Encrypt and decrypt data
Wireless Communications Access Points	Yes	External and internal
Guidance Navigation & Control (GN&C) To support free-flying missions, the TH will require a GN&C system to ensure proper flight dynamics meet mission objectives. While docked at Gateway, the TH GN&C system will operate as backup. The Mars Propulsion System may carry a similar GN&C system that would operate as backup while attached to the TH.		
Absolute Navigation State	Yes	
Absolute Attitude	Yes	
Rendezvous & Nav Docking Capability (sensors, targets, external lighting)	Yes	
Momentum Management	Yes	

Functions	TH Applicability	Notes
Propulsion Independent of the Mars Propulsion System, the TH propulsion (or attached propulsive stage) will support free-flying shakedown missions, docking/undocking with Gateway, and docking/undocking with the Mars Propulsion System. When docked at Gateway, the TH propulsion (or attached propulsive stage) may augment Gateway Stack Control to achieve required slew rates. To be capable of supporting multiple missions, TH propulsion capabilities will need to be refuelable from the Mars Propulsion System and while docked at Gateway.		
Docking, Undocking and Rendezvous Maneuvers	Yes	Via chemical propulsion system
Orbit Transfer and Maintenance	Yes	
Augment Gateway Stack Control while docked	TBR	
Propellant Resupply Capability	Yes	Including propellant transfer for TH propulsion only
Propulsion System Management	Yes	
EVA TH extravehicular activities (EVAs) will be reserved for contingency operations to address spacecraft issues and failures. EVA support includes the capability to prepare the EVA suits, ingress and egress the TH while minimizing the loss of cabin atmosphere, translation, and post-EVA suit maintenance and stowage. Translation and stabilization aids, such as EVA Handrails and EVA Worksite Interfaces, provide a method to restrain EVA crew and allow them to work in a stable, safe manner. Nominal external maintenance and utilization operations will be performed by EVR.		
Airlock for Ingress/Egress of TH	Yes	
EVA Suit Donning/Doffing Space	Yes	
EVA Suit Servicing	Yes	Servicing, maintenance, recharging, repairs
Pre-Breathe Capability	Yes	
EVA Translation Path & Worksite Interfaces	Yes	
EVA Suits and Tools Stowage	Yes	
EVA Umbilical Transfer	TBR	

Functions	TH Applicability	Notes
Robotics Robotics will provide the TH the capability to perform inspection, maintenance and repairs, payload and logistics management, emergency management, and berthing/unberthing support of visiting vehicles during all mission phases (crewed/uncrewed). Provisioning for robotics will require mechanisms (i.e. Low Profile Grapple Fixtures (LPGF), Translation Aids), power, and data. As the TH may be uncrewed for long durations while at Gateway, robotics are essential systems for enabling autonomy. No dedicated IVR system is planned for the TH, but while docked at Gateway, the TH may interface with a future Gateway IVR system.		
Extravehicular Robotics (EVR)	Yes	
EVR Interfaces	Yes	Gateway EVR and TH EVR
Orbital Replacement Unit (ORU) External Stowage	Yes	Large and small ORUs Assume via EVR services
Intravehicular Robotics (IVR)	No	No TH IVR planned
IVR Interfaces	No	
Crew Systems The TH must provide sufficient habitable volume and provisions for the crew to successfully accomplish all intravehicular activities (IVA).		
Crew Living and Work Tasks	Yes	
Crew Medical Care	Yes	
Crew Physiological Health	Yes	Crew exercise space and equipment
Crew Medical Workstation	Yes	Medical lighting, medical oxygen access, medical equipment, pharmaceuticals, etc. needed for patient treatment
Private Crew Quarters	Yes	
Private Crew Hygiene Compartment	Yes	Facial, oral, hand, full body, grooming, etc.
Private Waste Management Compartment	Yes	Toilet and associated supplies/stowage
Food Preparation	Yes	
Group Meal Consumption	Yes	
Group Socialization and Recreation	Yes	
Internal Vehicle Lighting	Yes	
Cold Food Stowage	Yes	
Housekeeping Activities	Yes	Including point-of-use stowage
Maintenance Workstation	Yes	Separate from the EVA workstation
IVR/IVA Restraint and Mobility Aids (R&MA)	Yes	
Manage Stowage Inventory	Yes	
Stowage Volume	Yes	Not for EMUs/suits or EVA tools

<table>
<tr><th>Functions</th><th>TH Applicability</th><th>Notes</th></tr>
<tr><td>Trash and Waste Temporary Stowage</td><td>Yes</td><td>Volume at points of trash/waste generation</td></tr>
<tr><td>Manage Trash and Waste</td><td>Yes</td><td>Stowage and disposal</td></tr>
<tr><td>In-situ Space Radiation Absorbed Dose/Dose Rate Measurements</td><td>Yes</td><td></td></tr>
<tr><td>Mitigate Dust Ingress to Cabin</td><td>Yes</td><td>Protect against Mars dust from visiting vehicles, receiving Mars cargo, etc.</td></tr>
<tr><td>Protect Crew from Acoustic, and Radiation Hazards</td><td>Yes</td><td></td></tr>
<tr><td colspan="3">Utilization Payloads
The TH will need to accommodate both internal and external utilization payloads, including science and technology demonstrations. Accommodations include volume, power, data, environmental controls, and robotic interfaces.</td></tr>
<tr><td>Internal Utilization Accommodations</td><td>Yes</td><td>Life and physical sciences, technology, etc.</td></tr>
<tr><td>External Utilization Accommodations</td><td>Yes</td><td>Assume deployment and servicing via EVR services.</td></tr>
<tr><td>Gas Venting for Payloads</td><td>Yes</td><td></td></tr>
<tr><td>Interface Access for alternate or complimentary life support technologies</td><td>Yes</td><td></td></tr>
<tr><td>Science Ingress, Egress, and Interfaces</td><td>No</td><td></td></tr>
<tr><td colspan="3">ECLSS
The TH should utilize a closed-loop ECLSS that establishes and maintains a habitable volume for a crew of four and internal payloads on missions up to 1,100 days without resupply. When the TH is uncrewed, the ECLSS will maintain a threshold atmosphere to protect itself and other TH systems. This includes maintaining a minimum pressure and temperature to protect against freezing and removing cabin air humidity to protect against condensation. The ECLSS will provide a habitable atmosphere prior to crew return by re-establishing an acceptable total pressure, oxygen partial pressure, trace gaseous contaminant levels, and temperature. During ramp-up for crew arrival, full recovery and verification of ECLSS functionality should be achieved to support the next crewed mission phase. While docked at Gateway, the TH ECLSS will continue to maintain its own habitable volume and should be capable of exchanging pressurized gases between modules in the stack.</td></tr>
<tr><td>Control Total Cabin Pressure</td><td>Yes</td><td></td></tr>
</table>

Functions	TH Applicability	Notes
Control Cabin Pressure	Yes	Maintain a habitable total pressure and oxygen concentration by controlling venting and relief, storage, and distribution of the O2 and N2 gases, as well as monitoring of cabin total pressure and partial pressure oxygen to manage the atmosphere in the TH.
Remove Air Contaminates	Yes	Ensures habitable atmosphere is free of pollutants that might harm the crew by managing removal of metabolic waste, trash, and equipment-generated contaminants in gaseous and particulate (solid) phases within the pressurized volume and controlling them to concentrations below prescribed physiological limits.
Conditioning Cabin Air	Yes	Provide a habitable and comfortable environment by managing the atmospheric temperature and removal of humidity, including circulation of air for proper thermal distribution and a uniform breathable atmosphere, as well as the control of air conditioning systems, including monitoring of atmospheric temperature and relative humidity, plus any further heat (crew metabolic, basic subsystems, computers/displays, refrigerators/incubators, science payloads) added to the cabin air.
Provide Water (Systems, Payloads, Crew)	Yes	Crew consumption, medical, hygiene, and water for payloads and EVA. Includes storage, distribution, dispensation, and quality control, as well as the control of water management system(s), including monitoring system performance.
Protect Crew and Vehicle from Hazardous Conditions	Yes	Protecting the crew and vehicle from a hazardous environment consists of providing Personal Protective Equipment (PPE) for the crew and returning the cabin atmosphere to a habitable environment.

Functions	TH Applicability	Notes
Manage Crew Metabolic Waste	Yes	Collection and isolation of crew body waste from the crew. If body waste is not transferred to a resource recovery system (such as a Water Recovery System) or immediately discarded via venting, then waste will be stabilized and transferred to long-term storage and disposal.
Emergency Response		
Fire Safety	Yes	Detect, suppress, and recover from fire
Personal Protective Equipment Stowage	Yes	
Provide Suited IVA to Recover from a Contingency Pressurization Event	Yes	
Operate Critical Systems following a Decompression Event	Yes	
Re-establish Cabin Atmosphere after a Depression Event	Yes	
Maintain Emergency Cabin Pressure Under a Leak Event	Yes	
Temporary Safe Haven to Protect Crew during Catastrophic Loss of Habitable Volume	Yes	
Solar Proton Radiation (SPR) Shelter to Protect Crew during a Solar Proton Event	Yes	

IV. Conclusion

NASA is continually refining its mission concepts, habitation assumptions, and habitation functional allocations as the agency pursues optimal solutions to achieve exploration objectives, reduce cost, and enable sustainability. The GR&As and functional allocations documented in this paper correspond to the current 2021 concepts for habitation architecture. Assumptions in this document are subject to change as the architecture continues to evolve.

Appendix A: Surface Habitat Logistics Assumptions

Surface Habitat 28-day Sustained Mission Logistics Storage Assumptions

The Surface Habitat (SH) should support a crew of two for a duration of ~28 days from transfer from the Human Landing System (HLS) to return to the HLS. In addition, the SH should support a contingency scenario where four crew shelter in the habitat for a period of up to seven days, using the habitat as a safe haven.

There are several assumptions associated with the maximum crewed duration:

- EVA crew access in the SH is provided through an integrated airlock.
- Logistics resupply of solid goods and water to the SH is provided through the transport of small logistics carriers through the airlock.
- All solid goods logistics are stored in the SH in Cargo Transfer Bags.
- Makeup water is delivered in containers derived from ISS Contingency Water Containers -Iodine (CWC-Is), delivered in the small logistics carriers.
- If required, oxygen and nitrogen are supplied to the SH using high pressure gas tanks.
- The SH supports a total of eight EVAs from the habitat for crew exploration. In addition, the SH supports initial crew transfer from the HLS and crew return to the HLS via EVA, as well as a mid-mission swap of crew between the SH and the Pressurized Rover (PR).
- The SH supports repair of EVA systems for four crew though the airlock.
- The logistics estimates provided in this appendix are based on a regenerative ECLSS system that include an Oxygen Generation System, a Urine Processor, a Water Processor, a Brine Recovery System, and a Sabatier-based Carbon Dioxide Recovery System.
- The SH has an oxygen compressor that is capable of pressurizing oxygen to at least 4,000 psia to allow for recharge of Portable Life Support System (PLSS).
- The SH will process wastewater transferred from the PR and will supply fresh potable water and high-pressure oxygen to the PR.
- Sufficient contingency water and oxygen are manifested on the SH to support a continuous period of up to 7 days where the regenerative ECLSS might be inoperable. Waste products could be stored during this period for reprocessing and to replenish the contingency store.
- The logistics storage assumption outlined herein do not include an allocation for storage of surface transfer containers, utilization (science) equipment, or system consumables.

Solid Goods:

The consumables goods that must be stored within the SH to support the mission are detailed in Table 1.

Table 1: Consumables Required for 28-day Mission

	Mass (kg)	CTBEs
Food	147	7.5
Wipes and Gloves	11	1.5
Health Care Consumables	5	1.0
Trash Bags	2	0.5
Waste Collection – Fecal Canisters	13	1.5
Waste Collection – Urine Prefilter	2	0.5
Operational Supplies	10	1.0
Recreation & Personal Stowage	20	2.0
Hygiene Kits	2	0.5
Clothing	24	3.0
Towels	5	1.0
Fecal/Urine Collection Bags (Contingency)	5	0.5
LiOH Cannisters (Contingency)	49	2.5
EVA	22	2.5

The volume of the consumables is indicated in units of CTBE (Cargo Transfer Bag Equivalents). One CTBE has an equivalent exterior volume of 0.053 m^3. Volumes for required consumables are determined using historical average “as-packed” densities for ISS resupply. These densities capture real-world packing in cargo transfer bags and are expected to be similar for exploration missions.

Spare parts and maintenance items that must be stored within the SH to support the maximum mission duration are detailed in Table 2. Maintenance items are those sub-system components that have a set replacement schedule. Spare parts are sub-system components that are manifested in case they are required to repair a random failure of a sub-system.

Table 2: Spare Parts and Maintenance Items Required for 28-day Mission

	Mass (kg)	CTBEs
Sub-System Spares	903	34.0
Sub-System Maintenance Items	58	2.0

Water and Gasses:

Table 3 details the total amount of water that should be stored on the SH for the 28-day mission.

Table 3: Water Required for 28-day Mission

WATER	Mass (kg)
Make-up water	243
Flush (Contingency)	4
Hygiene (Contingency)	6
Drink (Contingency)	28
Food Rehydration (Contingency)	7
TOTAL WATER	**288**

Table 4 details the total amount of contingency oxygen that should be stored on the SH for the 28-day mission.

Table 4: Oxygen Required for 28-day Mission

OXYGEN	Mass (kg)
Crew Respiration (Contingency)	12
Cabin Repress (Contingency)	18
TOTAL OXYGEN	**30**

Table 5 details the total amount of nitrogen that should be stored on the SH for the 28-day mission.

Table 5: Nitrogen Required for 28-day Mission

NITROGEN	Mass (kg)
Pres Vol Leakage	1
EVA Airlock Loss	11
Cabin Repress (Contingency)	30
TOTAL NITROGEN	**42**

Appendix B: Transit Habitat Logistics Assumptions

The Transit Habitat (TH) should support a crewed, in-transit mission duration of up to 1,100 days from Earth orbit departure to Earth orbit return. In addition, the TH should support a period of an additional 10 days post-Earth arrival to support rendezvous and docking with an Earth return vehicle. Therefore, the TH should support the storage of logistics sufficient to cover a period of up to 1,110 days.

There are several assumptions associated with the maximum crewed duration:

- Any logistics required for the operational period prior to Earth orbit departure can be stored in an external vehicle and/or logistics module and do not need to be stored within the TH. All logistics and waste for the pre-departure period are discarded prior to departure.
- The TH has the ability to accommodate logistics for the full crew for the entire Mars mission duration. Although the nominal plan is to have some or all of the crew descend to the Mars surface for part of the mission, there could be contingencies that would prevent descent to the surface. In that case the entire crew would remain on the TH for the full mission duration.
- The TH is intended to support only contingency Extravehicular Activities (EVAs) during the mission. Logistics are loaded to support no more than 12, 2-crew EVAs over the duration of the mission.
- All solid goods logistics are moved into and stored in the TH in lightweight "in-space" cargo bags. These bags are significantly lighter than those required for launch.
- Water and gases are transferred into integral tanks in the TH. No additional water and gas carriers are loaded into the TH.
- 50% of the food by mass will be stored in the TH in a frozen state. Food will be delivered to the TH in a frozen state. Freezers may be permanently installed in the TH, with frozen food transferred from temperature-controlled launch/delivery carriers or freezers. Carriers or freezers used to support launch and delivery of food may be moved into the TH and used for the Mars mission.
- The logistics provided in this appendix are based on a total food hydration rate of 30%.
- The logistics estimates provided in this appendix are based on a regenerative ECLSS system that include an Oxygen Generation System, a Urine Processor, a Water Processor, a Brine Recovery System, and a Sabatier-based Carbon Dioxide Recovery System.
- The TH has an oxygen compressor that is capable of pressurizing oxygen to at least 4,000 psia to allow for recharge of Portable Life Support System (PLSS).
- The TH has a trash airlock, or some similar trash disposal system, that allows for trash to be periodically offloaded.
- Sufficient contingency water and oxygen are manifested on the TH to support a continuous period of up to 10 days where the regenerative ECLSS might be inoperable. Waste products could be stored during this period for reprocessing and to replenish the contingency store.
- The logistics storage assumption outlines herein do not include and allocation for storage of utilization (science) equipment or consumables.

Solid Goods:

The consumables goods that must be stored within the TH to support the maximum mission duration are detailed in Table 6.

Table 6: Consumables Required for 1,110-day Mission

	Mass (kg)	CTBEs
Food	8,129	216.0
Wipes and Gloves	888	98.5
Health Care Consumables	400	44.5
Trash Bags	133	15.5
Waste Collection – Fecal Canisters	1,021	113.5
Waste Collection – Urine Prefilter	178	20.0
Operational Supplies	100	9.0
Recreation & Personal Stowage	200	18.0
Hygiene Kits	163	18.5
Clothing	779	94.5
Towels	561	62.5
Fecal/Urine Collection Bags (Contingency)	7	1.0
LiOH Cannisters (Contingency)	70	3.0
EVA MAGs (Contingency)	4	0.5

The volume of the consumables is indicated in units of CTBE (Cargo Transfer Bag Equivalents). One CTBE has an equivalent exterior volume of 0.053 m^3. Volumes for required consumables are determined using historical average “as-packed” densities for ISS resupply. These densities capture real-world packing in cargo transfer bags and are expected to be similar for exploration missions.

Spare parts and maintenance items that must be stored within the TH to support the maximum mission duration are detailed in Table 7. Maintenance items are those sub-system components that have a set replacement schedule. Spare parts are sub-system components that are manifested in case they are required to repair a random failure of a sub-system.

Table 2: Spare Parts and Maintenance Items Required for 1,110-day Mission

	Mass (kg)	CTBEs
Sub-System Spares	6,621	186.5
Sub-System Maintenance Items	391	30.5

Water and Gases:

Table 8 details the total amount of contingency water that should be stored on the TH for the 1,110-day mission. It is assumed that the water is stored in integral tanks on the TH.

Table 8: Water Required for 1,110-day Mission

WATER	Mass (kg)
Hygiene (Contingency)	16
Flush (Contingency)	12
Drink (Contingency)	112
Food Rehydration (Contingency)	42
TOTAL WATER	**182**

Table 9 details the total amount of contingency oxygen that should be stored on the TH for the 1,110-day mission. It is assumed that the oxygen is stored in integral tanks on the TH.

Table 9: Oxygen Required for 1,110-day Mission

OXYGEN	Mass (kg)
Crew Respiration (Contingency)	36
Cabin Repress (Contingency)	87
TOTAL OXYGEN	**123**

Table 10 details the total amount of nitrogen that should be stored on the TH for the 1,110-day mission. It is assumed that the oxygen is stored in integral tanks on the TH.

Table 10: Nitrogen Required for 1,110-day Mission

NITROGEN	Mass (kg)
Pres Vol Leakage	4
EVA Airlock Loss	11
Trash Airlock Loss	50
Docking Pressurization	8
Cabin Repress (Contingency)	289
TOTAL NITROGEN	**362**

Appendix C: Nomenclature

ATCS	Active thermal control system
ATP	Authority to Proceed
C&DH	Command and data handling
C&T	Communication and tracking
CLV	Commercial launch vehicle
ConOps	Concept of operations
CTBE	Cargo transfer bag equivalent
CWC-I	Contingency Water Containers - Iodine
DTE	Direct to Earth
DV	Delta velocity
ECLSS	Environmental control and life support system
EVA	Extravehicular activity
EVR	Extravehicular robotics
GDSS	Gateway Docking System Standard
GLS	Gateway Logistics Services
GR	Ground rule
GR&A	Ground rule and assumption
HLS	Human Landing System
ISRU	In-situ resource utilization
ISS	International Space Station
IVA	Intravehicular activity
IVR	Intravehicular robotics
LDHEO	Lunar distant high-Earth orbit
LEA	Launch Entry and Abort
LPGF	Low Profile Grapple Fixtures
LTV	Lunar Terrain Vehicle
MAG	Maximum Absorbency Garment
MGA	Mass growth allowance
M2M	Moon to Mars
MMOD	Micrometeoroid and orbital debris
NASA	National Aeronautics and Space Administration
NRHO	Near-rectilinear halo orbit
OGA	Oxygen generation assembly
ORU	Orbital replacement unit
PLSS	Portable life support system
PPE	Personal protective equipment
PR	Pressurized Rover
PTCS	Passive thermal controls system
R&MA	Restraint and mobility aids
RCS	Reaction control system
SH	Surface Habitat
SLS	Space Launch System
SPE	Solar particle event
SPR	Solar proton radiation
TBD	To be determined
TBR	To be refined
TCS	Thermal control system
TH	Transit Habitat
TM	Technical Memorandum
UHF	Ultra High Frequency

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