National Aeronautics and Space Administration

HEOMD Strategic Campaign Operations Plan for Exploration

Date: September 28, 2021
Baseline

CHANGE HISTORY

Rev	Date	Description of Change
Baseline	Aug. 24, 2021	CR HEO-0013, Baseline of document.
	Sep. 28, 2021	Administrative change – moved campaign segments and GR&A to new Sections 6 - 10

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1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of HEOMD-007 Strategic Campaign Operations Plan for Exploration (SCOPE) is to connect NASA's strategic plan and policy with the Human Exploration and Operations Mission Directorate's (HEOMD) activities and implementation at the Divisions and corresponding Programs across the directorate.

The SCOPE will list the goals and objectives for the HEOMD exploration campaign; define operational requisites for exploration missions; define programmatic considerations; and then define operations for each campaign segment, including segment objectives and functions of elements. This document provides rationale for requirements in HEOMD-004 Human Exploration Requirements and supports goals and objectives development in HEOMD-006 Utilization Plan. In addition, this document provides an overview of strategic plans that may eventually become requirements. The document is intended to provide an integrated context for the Divisions and Programs.

1.2 Relationship to NASA's Human Exploration Strategy

The SCOPE serves as the HEO level document to connect the NASA Strategic Plan and policy documents to the Divisions and respective Program level activities/implementation. In conjunction with other HEOMD products, this document provides insight into HEOMD's planning for implementation of the strategy and policy documents and potential engagement points.

It is recognized that changes to national policy, agency goals and objectives, major schedule drivers, annual budget planning assumptions and programmatic factors will affect the campaign content, segment content, and objectives defined in this document. To maintain synchronization between these drivers and this document, HEO-007 will be updated as needed to reflect the latest changes and account for such factors so the SCOPE does not rapidly become out of date or obsolete.

Although this document should reflect current planning as best as possible, the information presented here is a general description of the planning and activities of the campaign at the time this document was developed. This document is not meant to reflect a specific manifest but rather present a generalized sequence and description of one of the ways the campaign may achieve its goals and objectives. Consult the baseline manifest for the current approved launch order and timing.

1.3 Responsibility and Change Authority

Change authority for this document will be the Associate Administrator (AA) of the Human Exploration and Operations Mission Directorate, in accordance with HEOMD-002, HEOMD Configuration Management Process.

2.0 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein.

Document Number	Revision/ Release Date	Document Title
	Apr. 2020	NASA's Plan for Sustained Lunar Exploration and Development
	Sep. 2020	Artemis Plan – NASA's Lunar Exploration Program Overview
HEOMD-004	Rev B Mar. 16, 2021	Human Exploration Requirements
HEOMD-006	In Work (TBD)	HEOMD Utilization Plan
XM-M14282020A	Apr. 28, 2020	M2M Mass Margins for Human Exploration for Strategic Assessments

2.2 Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/ Release Date	Document Title
HEOMD-002	Baseline May 22, 2017	HEOMD Configuration Management Process
HEOMD-003	Mar. 9, 2021	Crewed Deep Space Systems Human Certification Requirements and Standards for NASA Missions
NASA-SP-2009-566	July 2009	Human Exploration of Mars Design Reference Architecture 5.0
ANS/AIAA S-120A-2015(2019)	Jan. 21, 2016	Standard: Mass Properties Control for Space Systems
HLS-RQMT-001	Rev. D Nov. 3, 2020	Human Landing System (HLS) Program Systems Requirements Document
AIAA 2016-5456	Sep. 9, 2016	Evolvable Mars Campaign 2016 – A Campaign Perspective
HEOMD-405	Mar. 19, 2021	HEO Integrated Exploration Capabilities List
HEO-MD-1000	Apr. 20, 2021	Human Exploration and Operations SE&I-HEO Document Flowdown
GP 10000	May 6, 2021	Gateway System Requirements
ESD 10012	Mar. 4, 2020	ESD Concept of Operations

AES 50007	Draft	Advanced Exploration Systems (AES) Concept of Operations
HEO-DM-1004	Jan. 20, 2021	HEO SE&I - Planning Guidance For Artemis Mission Durations As Testbeds To Reduce Risks For Human Missions To Mars
HEO-DM-1006	Feb. 19, 2021	HEO SE&I-Updated Exploration Atmospheres
HEOMD-003-01-08	2019	International Deep Space Interoperability Standards
	Dec. 16, 2020	Space Policy Directive 6: Memorandum on the National Strategy for Space Nuclear Power and Propulsion
HEOMD-406	In Work (TBD)	HEO Strategy & Architecture-Lunar Specific Groundrules and Assumption (GRAs) *(Data Managed)*
HEOMD-407	In Work (TBD)	HEO Strategy & Architecture-Mars Specific Groundrules and Assumption (GRAs) *(Data Managed)*
HEOMD-404	Mar. 30, 2021	HEO Artemis Base Camp Reference Mission - DRAFT

3.0 Strategic Principles

National Space Policy as provided by the White House, Congressional mandates, products from the National Space Council, and other independent sources are inputs to the overarching approach to NASA's Strategic Plan. These policies and inputs, when coupled with directed target dates for human lunar return, followed by initiating a sustained lunar presence, and humans to Mars afterwards, sets the framework for the integrated campaign strategy.

Establishing a sustained human presence on the Moon and conducting the first human mission to the surface of Mars will be among the most challenging technical enterprises in human history. This campaign will require technical approaches and systems that have not yet been demonstrated. It will take well over a decade of heightened effort to realize the necessary capabilities. Between 2019 and 2021, NASA developed a strategy for achieving this campaign. The strategy has four core principles: 1) develop a sustainable presence on the lunar surface to explore, conduct science, and serve as an analog testbed for Mars; 2) prioritize reduced Mars mission duration; 3) pursue the minimum possible Mars mission architecture for humanity's first expedition to the surface of Mars; and 4) scientific discovery and exploration. Each principle is further defined below.

Develop a Sustainable Presence on the Lunar Surface

Previous attempts to architect a Moon-to-Mars exploration program took an approach that resulted in challenges in the areas of complexity and program costs and ignored the strategic value of the Moon and it's resources. Recognizing these program vulnerabilities, NASA is focusing on developing viable solutions for Moon-to-Mars exploration, to include public-private partnerships, to establish a sustainable presence on the Moon's surface, prioritizing the elements and activities that will allow us to complete lunar exploration and utilization objectives and to operationally and scientifically prepare us for the first human mission to Mars. Such an approach provides for a sustainable lunar presence, upon which NASA, international partners, and commercial companies will develop. By choosing this approach on the Moon, NASA can explore the lunar surface and advance our beyond-Low Earth Orbit (LEO) operational experience to ready ourselves for Mars, build confidence in hardware capability, test new capabilities needed for future exploration, and ensure that the cost and complexity of lunar activities are managed appropriately to ensure success both at the Moon and at Mars.

Prioritize Reduced Mars Mission Duration

The ability to send humans into space will always be governed by limits on risk and technology readiness. There are technological and operational choices that NASA can implement to mitigate risks and/or reduce costs. A principle of NASA’s strategy for Mars is an emphasis on mission expediency, with the goal of achieving shorter overall mission durations for crewed Mars missions. Risk factors vary significantly between transit and surface mission phases, and the design and duration of all phases must be assessed when comparing mission design options; however, most risks increase with longer mission duration, and shorter missions can offer significant improvements in risks of crew health impacts, catastrophic system failure, and radiation exposure. Although low-energy, three-year class missions have long been considered the default for crewed Mars missions, shorter two-year class missions are also possible, provided NASA makes significant improvements in deep space propulsion capabilities. Emphasizing mission expediency as a core part of NASA’s strategy translates to a need for advanced propulsion capabilities. As technologies evolve, NASA can make informed decisions on Mars mission duration, balancing risk and evolving risk mitigation strategies. With this knowledge, NASA can align our strategy with Congressional and inter-agency interest in nuclear or other space propulsion systems and begin development of a major enabling capability for future exploration of the solar system.

Pursue the Minimum Possible Mars Surface Mission Architecture

To achieve the first human mission to Mars as soon as realistically feasible, NASA has also evolved its approach to the Mars surface mission. The focus has evolved to a minimum viable architecture over an optimized architecture type that has previously been described in NASA’s Design Reference Architecture (DRA) 5.0. Significant challenges are involved with Mars entry, descent, and landing (EDL) and Mars Ascent Vehicle (MAV) ascent, and the substantial cost and complexity of every additional piece of landed hardware. NASA recognizes the viability of focusing on a small and simple expedition for the first surface mission. This has resulted in a number of significant shifts in strategy relative to DRA 5.0. A short surface stay mission (~30-45 sols on the surface) rather than a long surface stay mission (~350-500 sols on the surface) reduces the total amount of landed mass and the complexity of elements needed. For a short surface stay mission, no long duration habitation and supporting logistics are required, which would necessitate more launches and landings. In addition, implementing a philosophy of build for Mars, test on the Moon provides opportunities for cost savings over the exploration campaign. The systems would be build for dual use, as much as practicable. Furthermore, the shorter stay duration allows for an architecture in which the crew is able to land in and live in only a pressurized rover while on the surface. This accelerates rapid exploration on Mars without the need for a substantial build-up of surface infrastructure, and keeps landed mass significantly lower than trying to build a ‘base’ on the initial mission.

Scientific Discovery and Exploration

For more than half a century, NASA's discoveries have been inspiring the world and transforming the knowledge of life, Earth, our solar system, and the universe. Together, scientific discovery and human exploration open pathways to expand beyond our current bounds. HEOMD-006 Human Exploration and Operations Utilization Plan, coordinated with the Science Mission Directorate (SMD) and the Space Technology Mission Directorate (STMD), outlines the human exploration utilization goals and objectives across the three mission directorates. These utilization goals and objectives emphasize the criticality of continuing synergistic robotic and human exploration of the Moon and Mars to address a variety of high-priority scientific objectives, likely resulting in significant scientific discoveries that advance our understanding of the entire solar system and impact our interpretations of results derived from missions to other destinations. In addition, the Utilization Plan underscores the importance of demonstrating research and technology demonstrations on human missions – in low Earth orbit, in lunar orbit, and on the lunar surface – to enable human exploration to future destinations such as Mars.

4.0 Challenges and Considerations

Establishing a sustainable human presence on the Moon and conducting the first human mission to Mars will require NASA to overcome not only substantial technical challenges, but significant programmatic challenges as well. The exploration campaign (see Section 5) was specifically developed in response to these challenges.

4.1 Sustainability

The planned campaign spans a multi-decade period, establishing permanent foot-holds in cislunar space and the lunar surface, developing and deploying major human-rated transportation systems to the Moon and Mars, and developing and deploying Lunar and Martian surface infrastructure to enable humans to live and explore once they arrive. The term "sustainable" can have different meanings, depending on the context. For the exploration campaign, several definitions apply. Financial sustainability is the ability to execute a program of work within budget levels that are realistic, managed effectively, and likely to be available. Technical sustainability requires that operations are conducted repeatedly at acceptable levels of risk. Proper management of the inherent risks of deep space exploration is the key to making those risks "acceptable." Finally, policy sustainability means that the program's financial and technical factors are supportive of long-term national interests, broadly and consistently, over time. The Artemis program (see Artemis Plan – NASA's Lunar Exploration Program Overview) was structured specifically to improve sustainability, adopting a measured pace to developments and deployments while still meeting high-level schedule objectives. As much as practical, the Artemis program will develop and validate architecture elements that can then be extended to Mars with little modification. For example, the Fission Surface Power lunar demonstrator will incorporate Mars design requirements, eliminating the need for a Mars-specific development effort later. Where it's not practical to extend entire systems to Mars, effort will be made to extend sub-systems. For instance, Gateway's electric thruster experience will directly inform thruster selection for a Mars Nuclear Electric Propulsion vehicle.

4.2 Economically Driven Architecture

Since the 1980s, NASA has been working to increase private-sector involvement in space, laying a foundation for long-term exploration where government agencies are among several customers in a vibrant space economy. Like many examples of historical human expansion, governments must fund and advance the technologies to pave the way, often through public-private partnerships, thereby making it possible, and increasingly economically viable, for private industry and private citizens to join the endeavor as providers or customers. The commercial cargo and commercial crew programs established examples of model frameworks in which NASA is just one of many customers for the space transportation services provided by U.S. companies. NASA is taking the same approach of seeking to take advantage of partnerships in LEO and with Artemis as part of the integrated strategy. With the infusion of up-front government funding, the expectation is that the private sector will soon be able to increasingly incorporate space transportation and exploration services into their portfolios, decreasing the amount of public funding over time. As past endeavors have shown, multi-sector demand drives down cost through volume and innovation.

4.3 Public Engagement

Maintaining public support for the nation's space exploration program is an often-undervalued principle. With an investment of just one-half of 1% of the federal budget, NASA generated more than $64.3 billion in total economic output in FY2019 (see https://www.nasa.gov/press-release/nasa-report-details-how-agency-significantly-benefits-us-economy). Through engaging social media campaigns, in-person presentations and events, crowdsourcing, imagery outreach, and student challenges, Artemis will engage billions of people around the world. Providing opportunities to be a part of NASA's human spaceflight programs are key to maintaining positive public sentiment, inspire and instill science, technology, engineering, and mathematics (STEM) capabilities, and thereby support development of the nation's next generation of space-faring citizenry.

4.4 International Cooperation

Developing a lasting and effective exploration campaign requires the energy, expertise, and innovation of many countries working in partnership. The International Space Station (ISS) has set an enduring legacy of the benefits that international collaboration can bring to a large, complex, and long-duration space program. Because NASA cooperates with its international partners on a no-exchange-of funds basis, the international partners also bring resources to bear in parallel with NASA. International partners can also help generate and sustain support for multi-year and multi-decade missions. The Artemis program is being designed from the ground up in coordination with our international partners, ensuring broad cooperation and cost effectiveness. NASA has strong international partner participation on Gateway and is already in conversations with international partners to contribute to the lunar surface architecture. Leveraging these partnerships will help to ensure the success of the future Mars missions.

4.5 Strategic Competition

The strategic advantage of cislunar space and a sustained presence on the Moon have long been recognized. The Biden Administration's Interim National Security Strategic Guidance states, "We will explore and use outer space to the benefit of humanity, and ensure the safety, stability, and security of outer space activities." For more than 60 years, NASA has led the world in the exploration of space for peaceful purposes, and shared the results of our endeavors with humanity.

HEOMD's exploration campaign will continue this civil space leadership role for the U.S. in an increasingly competitive environment. Operating in this remote environment will necessitate a whole-of-govement effort to advance the necessary technologies, as well as develop communications and transportation systems, and other infrastructure. Consequently, NASA will continue to partner with national security space entities, where appropriate, to advance critical technologies for our separate and unique missions, as well as facilitate interoperabitiy of communications, transportation and other infrastructures.

In addition, NASA must remain vigilant to ensure that information and intellectual properties designated as proprietary or governed by International Traffic in Arms Regulations (ITAR) or Export Administration Regulations (EAR) are properly controlled to prevent any unauthorized release or disclosure. Of particular concern is cybersecurity of space and mission systems due to these campaigns' increasing reliance on automated and tele-operated systems. Through these means, the Artemis program and future exploration campaigns will be able to demonstrate secure and reliable transportation and communications while attaining resilience via interoperability with U.S. and cooperative international partners' government, commercial, and privately-operated systems and architectures also present in cislunar space and on the Moon, Mars and other celestial bodies.

4.6 Launch Needs

The total number of launches that will be required to conduct the exploration campaign is large and will involve a combination of SLS and commercial launch vehicles (CLVs). Independent of what costs are assigned to individual launches, it is clear that tens of billions of dollars will be required to support the overall requirements. In addition, exploration campaign needs could exceed the launch cadence capability. Applying more efficient operations, sharing improved manufacturing processes, or leveraging larger capacity/less expensive future launch vehicles are options to reduce costs and improve economic viability.

4.7 Transition to Partners

The exploration campaign will involve operations across numerous locations, including LEO, cislunar space, the lunar surface, and Mars surface. Sustaining operations in all of these theaters simultaneously would be prohibitively expensive. Rather, NASA will strategically formulate its involvement in these activities so that commercial industry and our international partners can share in exploration opportunities that are initiated by NASA, thereby absorbing some of the cost and risk. Strategies for involving commercial or international participants from the beginning needs to be part of the NASA plan to build consensus and to understand where NASA budgets need to be focused. For example, one proposed supplement for ISS involves a follow-on free flying station to maintain a human presence in LEO. The operating model for surface operations will evolve over time to meet the needs of NASA and other surface users. Likely the beginning will be NASA dedicated program evolving to increased international and commercial presence and then evolving to a cooperative usage between NASA, international and commercial partners. The extent of adaptation necessary will depend on how successful NASA is in attracting commercial and international users. The evolution will be user-driven with no specific timeframe defined.

4.8 Technical Risk

HEOMD is engaged in multiple risk reduction activities related to the assessment and mitigation of technical and programmatic risks associated with human spaceflight. The ability to send humans into space will always be governed by limits on operational risk and technology readiness. There are risks that are common to all human missions, such as impacts from space weather/radiation and gravity on humans and their spacecraft. These risks can be somewhat mitigated via better predictive capabilities and the implementation of improved countermeasures, such as exercise. In addition, there are technological and operational choices that NASA can evaluate to trade risks and/or reduce costs. An example of such a choice would be to trade the opposition class Mars trajectory utilized in the current campaign for a conjunction class trajectory that would require much less propellant and less aggressive transportation system technology development. With a conjunction class mission, the mission duration would increase, leading to more risks to crew health, while propulsion system development and propellant launch costs, with their associated risks, would be significantly reduced. Some technologies may offer greater performance, but at the expense of increased complexity which might affect reliability, development risk, and mission risk. In evaluating technologies, there is a trade-off between performance, complexity, and risk. Alternatively, a different approach to technologies and operations, such as those proposed by the commercial sector, could be applied to the Moon-to-Mars campaign, drastically altering the fundamental mission design, trading the potential of reduced cost for potential increases in programmatic uncertainty.

Technology development and readiness when needed are key elements for a successful Exploration architecture. Exploration campaigns will be dependent on successful development of an enabling set of technologies to provide requisite mission performance and acceptable crew and mission risks. The challenge in technology development for Exploration is twofold: to determine the key technologies that can be realistically developed in the available time frame and to obtain sufficient funding to develop those technologies in time for integration into the flight system.

4.9 Operations and Element Integration

The maturation and build-up of the exploration campaign will present challenges to integrate the required hardware and conduct operations to successfully build and use a lunar architecture. To enable compatibility for international and commercial partners across the exploration campaigns (LEO, Cislunar, Lunar, and Mars), the exploration campaign will utilize interfaces and standards to facilitate resource sharing, hardware transfer, logistics resupply, planned and unplanned operations, crew rescue, etc. across programs and elements. As such, careful consideration of standard interfaces and capabilities will be considered cross exploration campaigns. Further definition and development of interoperable standards that support the NASA defined exploration campaign architecture will be led and managed by NASA and will evolve over time.

In addition to flight hardware integration, the mission operations will have to be tightly integrated. This will require consideration for centralized versus distributed operations capabilities. At a high level, operational considerations will have to account for complex and extensive training of crew and flight support, integration of control centers and networks, integration of training systems (mockups, simulators, vehicles, etc), and operational agreements on safety and risk posture. NASA will need to weigh cost and schedule, impacts of pre-flight and real-time mission operations as elements and resources for future missions are identified.

5.0 Introduction to Exploration Campaign and Campaign Segments

The Moon-to-Mars campaign features four primary theaters for exploration. These are not temporal phases, as one may not end as another begins. Therefore, they are referred to in this document as campaign segments. Each campaign segment will have a primary goal that addresses the purpose of exploration, as well as specific objectives that NASA wishes to achieve. In addition, each segment is defined as a series of individual missions that are designed to achieve the segment objectives to the greatest extent possible within the ground rules and assumptions. Figure 1 shows the exploration campaign and campaign segments.

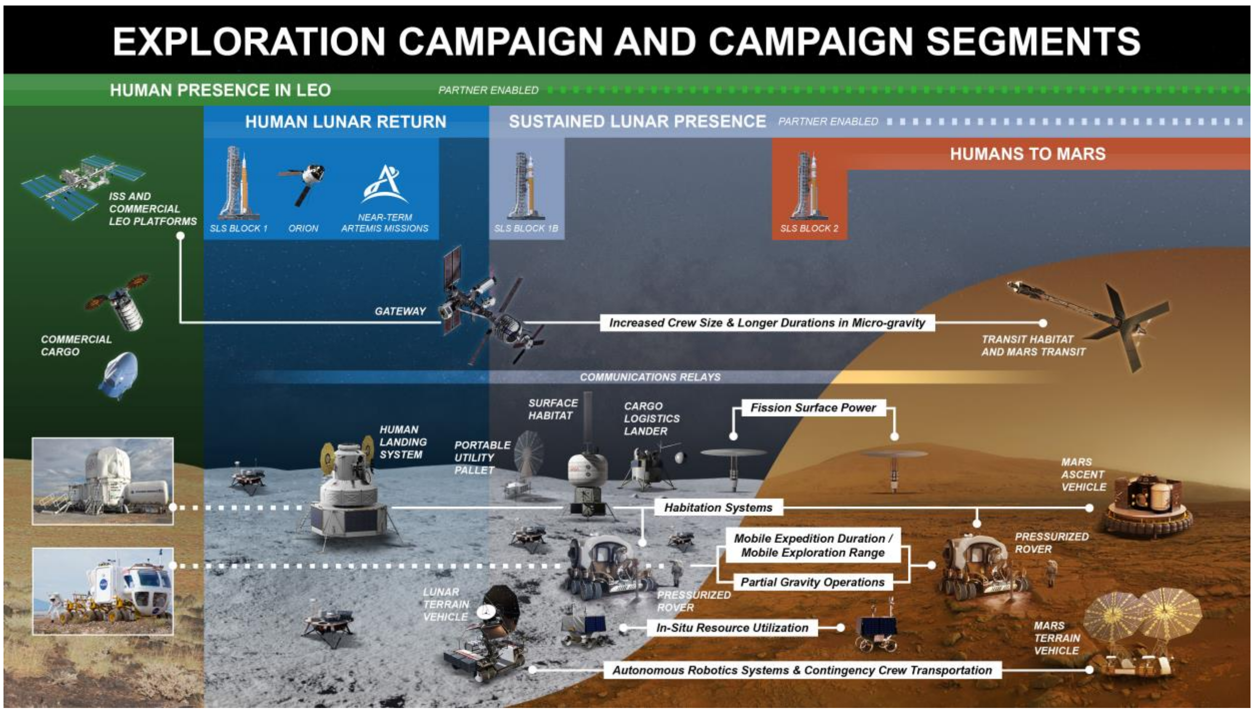

Figure 1 Exploration Campaign Segments

The four segments that make up the exploration campaign are:

Human Presence in LEO Segment: This segment leverages investments in LEO exploration to develop and test systems for long duration spaceflight (ECLSS, logistics, etc.), perform human research with respect to long duration microgravity and space environment exposure, develop commercial crew and cargo delivery systems, complete Mars forward analog missions to assess longer duration effects on crew and equipment, and to pretest operational procedures in the space environment. Operations in this segment will begin on ISS and transition to commercial LEO elements, if available. A description of the Human Presence in LEO Segment is provided in Section 7.

Human Lunar Return Segment: The segment includes the first human return to the Moon in over 50 years and the first woman to set foot on the Moon. These missions will test and exercise the Human Landing System (HLS) and transit systems, bringing two crew to the lunar surface for approximately 6.5 days for each mission. These missions will enable exploration of the Moon and conducting of fundamental science and human research on the lunar surface, including permanently shadowed regions. Deployment of a communications satellite will also occur in this segment. A description of the Human Lunar Return Segment is provided in Section 8.

Sustained Lunar Presence Segment: Initially, in this segment, NASA will have the flexibility to conduct sortie missions in addition to Artemis Base Camp (ABC) missions. ABC missions will include delivery and testing of the foundation elements that are required to enable a sustained human presence on the Moon, such as a pressurized rover (PR) and surface habitation. An unpressurized rover to carry crew and cargo will support some of these missions, significantly enhancing the science return from those missions. Once all elements are delivered, crews of four astronauts will descend to the surface and conduct exploration missions of at least 30 days duration. Activities in this segment will test the capabilities and operations that are required for human missions to Mars and include extended exploration of the lunar surface, deploying experiments and conducting research and support science and utilization. In addition, the Gateway will be deployed in cislunar space. A series of Mars Analogs will be conducted at the Gateway and on the lunar surface to simulate portions of the crewed Mars mission. These analogs will allow NASA to reduce risk in future missions. Additionally, key elements of the Mars transportation system, such as propulsion and habitation systems, will be tested in cislunar space during this segment. A description of the Sustained Lunar Presence Segment is provided in Section 9.

Humans to Mars Segment: The Humans to Mars segment includes all of the capabilities required for a crewed Mars mission, including the launch of the first human mission to Mars. A description of the Human Mars Surface Segment is provided in Section 10. The aforementioned lunar analog missions and other risk reduction activities are leveraged to enable this segment.

6.0 Exploration Campaign Ground Rules & Assumptions

Ground Rules & Assumptions (GR&As) set a common basis for analysis across the Moon-to-Mars (exploration) Campaign and serve as an initial coordination mechanism. GR&As are not requirements, but can eventually be used as the basis of requirements as concepts evolve to projects. Ground Rules are handed down by management and are not traded, and sometimes reflect clarifications to requirements that already have been established. Assumptions represent a common point of departure to be used in the campaign that can be traded, and can be elevated to a Ground Rule by management. The GR&A in this section are for future element concepts (up through Program/Project formulation) to support the exploration campaign (see Section 5). Current Divisions and associated Programs/Projects will adhere to their set of requirements and standards. Requirements that are published in HEOMD-004 Human Exploration Requirements are not repeated in this section.

GR&As also assume sufficient budget appropriations are allocated to support the capabilities in the timeframes noted. They will be reviewed as needed, to ensure alignment with current agency goals and objectives, major schedules and budget planning.

For the exploration campaign, there are three classes of GR&A that are defined in the following sections:

- Overarching GR&A, denoted with an O.G.x or O.A.x
- Overarching Lunar GR&A, denoted with an OL.G.x or OL.A.x
- Overarching Mars GR&A, denoted with an OM.G.x or OM.A.x

6.1 Overarching GR&A

Item	Ground Rule / Assumption	Rationale
O.G.1	Any Commercial Lunar Payload Services (CLPS) delivery services required by HEO will be in addition to the 2 Science Mission Directorate (SMD) delivery services per year, and HEO will have to account for the costs.	Drives budget and launch manifest
O.G.2	Nuclear-enabled Mars transportation system is preferred.	Aligns with NASA and national space nuclear policy goals. See Space Policy Directive 6.
O.G.3	Mars surface elements operate at cabin atmospheres consistent with the operational experience gained in the Lunar Campaign.	HEOMD-004 defines cabin atmosphere for cislunar and lunar surface habitable volumes. Need to leverage operational experience for Mars surface. This ground rule is intended to align Mars surface architectures to a common design and operability standard.

Item	Ground Rule / Assumption	Rationale
O.G.4	Mass growth allowances (MGAs) for future elements are applied in accordance with the M2M Mass Margins for Human Exploration policy.	To ensure consistency across element mass estimates, a common process was developed in accordance with “Mass Properties Control for Space Systems,” per American Institute of Aeronautics and Astronautics, ANSI/AIAA S-120A-2015 (2019).
O.A.1	Exploration systems will be operable when crew is not present.	A mix of autonomy and telerobotics maximizes Return on Investment (ROI) to continue uncrewed exploration and utilization as well as protect the integrity of the system. It also keeps stakeholders engaged between crewed missions.
O.A.2	During uncrewed periods, all habitable elements will be single failure tolerant to catastrophic events during periods without sunlight.	To preclude architecture decisions that could allow a loss of major assets (fixed or mobile) during an uncrewed period without sunlight due to lack of keep-alive power. This drives operations, base camp architecture, and element sizing. Failure tolerance can be achieved via redundancy or, where possible, operationally (such as, mobility following the sun or defaulting to survival mode if caught in shadow without primary power).
O.A.3	Gateway Interaction: • Gateway logistics deliveries provided by international partners and/or commercial services support Human Landing System (HLS) and Mars mission logistics and outfitting; • Reusable HLS elements will be stationed at Gateway during the HLS Services (Sustainable) phase; • Transit Habitat (TH) is docked to Gateway and supports crew missions longer than 60 days in cislunar orbit and missions beyond cislunar space; • TH returns to Gateway after each mission beyond cislunar space is completed;	Informs Gateway operations and future Mars transportation system design

Item	Ground Rule / Assumption	Rationale
	• TH departs and arrives at Gateway autonomously; • Augmentation of Gateway orbit maintenance and attitude control while TH is docked to Gateway will be provided by TH (TBR-HEOR-001).	
O.A.4	SLS schedule and launch assumptions: • SLS Block 2 utilizes an 8.4 m (27.6 ft) fairing; • SLS Block 2 is planned to be available after 8 Booster flight sets (RSRMV - five segment reusable solid rocket motor) are expended.	Informs budget and launch manifest
O.A.5	Commercial Launch Vehicle (CLV) availability and launch assumptions: • Design reference: minimum 15 metric ton performance to TLI; • ~5.1m & 7m fairings available; • Number of CLVs per year commensurate with need to support launch campaign.	Informs budget and launch manifest

6.2 Lunar GR&A

Item	Ground Rule / Assumption	Rationale
OL.G.1	Artemis Base Camp will be located at the lunar South Pole region.	Consistent with Space Policy Directive (SPD)-1, "…the United States will seek to land Americans on the Moon's South Pole by 2024, establish a sustainable human presence on the Moon by 2028, and chart a future path for human Mars exploration. NASA's lunar presence will focus on science, resource utilization, and risk reduction for future missions to Mars." Artemis Base Camp location will be chosen in consideration of scientific requirements.
OL.G.2	Artemis Base Camp missions are long duration missions (~32 days) that are enabled by the operation of prepositioned habitable assets (e.g. a	Guidance provided by HEOMD to define ABC missions for desired duration, surface infrastructure, and when ABC missions begin.

Item	Ground Rule / Assumption	Rationale
	surface habitat or a pressurized rover) on the lunar surface. Crewed Artemis Base Camp operations can begin with the delivery of the first prepositioned habitable asset.	
OL.G.3	To support sustained surface operations, HLS will need to transport 4 crew and provide habitation on the lunar surface for 6 (TBR-HEOR-002) days.	Lunar surface missions to ABC are expected to be at least 30 days in duration. HLS is not expected to provide habitation for that duration. However, HLS will need to provide habitation for transport to and from the Moon and post-descent and pre-ascent while the crew prepares for the transition. In the case that anytime abort is not realized and the surface assets are uninhabitable, 6 days is commensurate with the next ascent opportunity.
OL.A.1	The Surface Habitat with sufficient logistics can support a minimum of 2 crew for a minimum of 30 days and 4 crew for (TBD-HEOR-001) days.	Emphasizes the nature of the surface habitat being a foundation element and not a habitat intended for continuous habitation, such as ISS, however will be occupied periodically during it's lifetime. SH must have the capability to support a minimum of 4 crew for the duration of crew handover and contingency periods.
OL.A.2	The Pressurized Rover can support 2 crew for a minimum of 30 days (with sufficient logistics, as well as trash and waste removal) and 4 crew for (TBD-HEOR-002) days, and is capable of remote science and payload operations during uncrewed periods.	Pressurized Rover is a primary element for ABC. Pressurized Rover will need to perform operations during crewed and uncrewed periods. PR must have the capability to support a minimum of 4 crew for the duration of crew handover and contingency periods.
OL.A.3	Crewed HLS missions requiring either more than 2 crew or more than 6.5 days (TBR-HEOR-003) on the surface will utilize pre-deployed surface assets.	The initial crewed lunar missions will be limited by unknown performance margins and communications coverage. The primary purpose of the first mission is to test the transportation systems. Longer duration missions or missions that require more than 2 crew require infrastructure previously deployed on the lunar surface.
OL.A.4	For planning purposes, once Artemis Base Camp (ABC) is established, all	The Artemis Base Camp site will be selected with inputs from the science

Item	Ground Rule / Assumption	Rationale
	crewed missions are assumed to go to ABC.	community as well as other considerations, including transportation requirements. Logistics planning will be sized by this assumption.
OL.A.5	Artemis Base Camp initial location for analysis purpose will be Connecting Ridge. The alternate ABC location to be analyzed (TBD-HEOR-003).	This is not a selection, but an effort to coordinate HLS landing performance, lighting, and communications in the context of an Artemis Base Camp site plan.
OL.A.6	Mars analog missions on the Moon will accommodate at a minimum 2 crew exposed to long duration microgravity (45-105 days) immediately prior to lunar surface stays. These missions will include operations with increased crew autonomy and under simulated Mars communication, navigation, and resupply (e.g. food system) constraints.	Mars forward conops requirement that needs long duration microgravity effects to be factored in to the lunar based Mars mission analogs. See HEO-DM-1004 Planning Guidance For Artemis Mission Durations as Testbeds to Reduce Risks for Human Missions to Mars. Additionally, long duration stays at Gateway exceeding (TBR-HEOR-007) days will require either additional logistics modules or availability of a Transit Habitat at Gateway to simulate Mars transit operations.
OL.A.7	The Artemis Base Camp surface architecture includes crew, HLS sustained, EVA, LTV, Pressurized Rover, Surface Habitat, power architecture, Portable Utility Pallet (PUP), communications and navigation, logistics, and science and technology utilization. Mobile and deployable assets (rovers, surface payloads, EVA suits, operations) should be extensible to the Mars surface architecture.	Current stategy aligns utilization of the Moon for Mars analogs to demonstrate both hardware and operations in addition to lunar exploration. The ABC surface architecture is reflective of both themes with the recognition that Mars surface assets will likely be mobile especially for the initial missions.

6.3 Mars GR&A

Item	Ground Rule / Assumption	Rationale
OM.G.1	First crewed Mars mission will depart Earth before 2040.	Given the orbital mechanics, a transportation system designed for a particular Earth departure year may not be optimized—or even feasible—for other departure years. For the purpose

Item	Ground Rule / Assumption	Rationale
		of current studies, a 2039 departure year is assumed as this would encompass a significant number of subsequent opportunities.
OM.G.2	First crewed Mars mission will consist of 4 crew; 2 crew to remain in Mars orbit, 2 crew to the Mars surface, exploring on the surface while living in a small pressurized rover.	This is considered to be near the lower practical limits for a mission of this complexity and length. 2 crew to the surface is intended to minimize surface infrastructure and ascent mass. The approach of 2 crew for a surface stay is risky, but not as risky as only sending 2 crew for the entire 2 year mission. Therefore, the transit portion of the mission includes 4 crew, of which 2 stay on the TH while the other 2 crew go to the surface. Note that this ground rule is under review by NASA Engineering and Safety Center (NESC) to determine what the “right size” crew is for a Mars mission. In addition, the four crew per mission aligns the Mars architecture with current Artemis element sizing.
OM.G.3	Surface mission will be accomplished with no more than three 25 t payload landers.	Without ISRU, it would be difficult to close the architecture to a 5 sol parking orbit without creeping up above 20 t. Per the Entry, Descent, and Landing team, up to 25 t is a comfortable "red line" with the Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technology.
OM.G.4	A primary objective of the first human Mars mission is to land humans on Mars and safely return them to Earth.	The mission will not be considered successful unless the humans are returned safely.
OM.G.5	First Mars mission crew will explore the surface for ~30 sols (TBR-HEOR-004) stay duration.	Provides substantial exploration time, while preserving the short-stay (~2 year) mission profile.
OM.G.6	Mars surface crew will land and live in a Pressurized Rover.	Given the minimal viable architecture approach and short 30 sol surface stay, the Pressurized Rover volume should be sufficient for the first human mission along with allowing for expanded exploration range from the ascent element.

Item	Ground Rule / Assumption	Rationale
OM.A.1	The campaign will include follow-on Mars missions that may or may not leverage initial surface infrastructure and/or be to the same site.	Design life can affect mass and development time. The cost of some Mars mission elements, such as the Nuclear Electric Propulsion (NEP) stage, may not make sense for only a single mission use. However, it is likely the initial mission to Mars will not be at the same location as the follow-on missions to Mars. Given the cost difference of a pressurized rover compared to a NEP, it might be more palatable to assume the pressurized rover is not reused for follow-on missions.
OM.A.2	The Mars transportation system will be sized to enable four mission opportunities within a 10-year span to the assumed site(s).	Assures from a campaign cadence perspective the Mars architecture is not optimized for a single date, therefore robust to schedule/budget changes.
OM.A.3	First crewed Mars mission will be a short-stay class mission.	Trajectories analyzed represent opposition class and may or may not include a Venus flyby. This is an assumption so other mission modes can be traded.
OM.A.4	The reference landing site, currently assumed to be 35 north latitude (TBR-HEOR-005) and (TBD-HEOR-004) MOLA, is used to size the transportation system and MAV. If multiple candidate landing sites are eventually selected, the mission can select a site from the candidates, depending on the mission opportunity, that minimizes propellant and system requirements for that mission.	To better coordinate Mars transportation system performance analyses and surface operations development, a specific reference site will be identified to anchor the analyses. Note that the reference landing site is under review (recommendation from Mars Architecture lead, coordinated with SMD).
OM.A.5	The first human Mars surface mission will be a "minimum viable" mission.	At this stage of conceptual design the goal is to identify an existence proof for minimal cost within the schedule constraints while meeting campaign and mission goals and objectives.
OM.A.6	The Orion spacecraft can be launched without crew onboard to be used for crew return.	The initial Orion that the crew launches in will have far exceeded its lifetime when the crew returns from Mars, so a new Orion will be required to be launched to retrieve the crew. It is assumed that Orion is launched up to

Item	Ground Rule / Assumption	Rationale
		90 days prior to the crew returning to the lunar distance high Earth parking orbit, and that the autonomous rendezvous of the Orion with the in-space habitat will occur within 10 days of the crew returning to Earth orbit.
OM.A.7	A single 10 kilowatt electric (kWe) Fission Surface Power (FSP), and a single duplicate spare unit, will provide all surface power for the first crewed Mars mission.	In multiple previous studies, fission power consistently traded better than solar power for mass. An updated analysis based on new Mars dust storm data from 2018 concluded that solar power would be nearly 3x the mass of fission power and improve mission risk posture.

7.0 Exploration Campaign Segment – Human Presence in LEO

The Human Presence in LEO segment includes all activities in low Earth orbit that allow NASA to prepare for exploration of the Moon and Mars and foster economic expansion.

7.1 Segment Goals and Objectives

The specific objectives of the Human Presence in LEO segment include:

- Achieve a continuous U.S. presence in LEO – both with government astronauts and with private citizens – in order to support the utilization of space by U.S. citizens, companies, academia, and international partners and to maintain a permanent American foothold on the nearest part of the space frontier;
- Foster an environment in LEO that enables American commercial activities to thrive;
- Conduct human spaceflight research in LEO that will advance the technology and systems required for long-duration spaceflight systems, including those necessary for interplanetary travel and permanent space habitation;
- Expand and extend commercial opportunity though international partnerships and engagement; and
- Continue to inspire and provide opportunities for citizenry engagement and STEM skill development.

The International Space Station (ISS) has been a test bed for long duration spaceflight since its inception. Living in space for long durations with resupply from Earth is a fundamental capability that is being matured through day-to-day operations on the ISS. However, as NASA focuses on missions beyond LEO with the Artemis program and exploration of Mars, there are still additional capabilities and operational procedures that will need to be developed. The ISS provides a proving ground for the advanced technologies, human research, life support systems, space suit testing, and crew health and performance that require the microgravity environment and/or integrated environment to improve and validate metrics required for lunar exploration. Any demonstration or development that can be done on the ground should be done in integrated ground tests or ground analogs (e.g. does not require microgravity and/or integrated environment), demonstrations in low Earth orbit will be done on ISS or on future LEO commercial platforms, due to their robust capabilities and accessibility in terms of both location and frequency of resupply. Activities that require the specific environment of the Gateway or the lunar surface will be conducted at those locations. Because of the limited access for utilization in lunar orbit, the testing of hardware on ISS as a precursor is encouraged, as well as the leveraging of ISS for cross-platform testing where appropriate.

Technology demonstrations on ISS and future LEO commercial platforms, including 3-D printing, new recycling techniques, free-flying robotics, automated docking systems, ECLSS, and innovative designs like roll-out solar arrays, will contribute to the maturation of designs for future exploration. The continuously crewed ISS has provided critical insights into the integrated effects that microgravity, radiation, and a closed environment have on human health and performance. Additional one-year crew missions on ISS will provide more data on the health effects of long-duration space travel and effectiveness of countermeasures. Over the span of ISS mission operations duration, NASA gains experimential knowledge and insight of ISS life support system operations including failure occurrences, how best to enable recovery after the failures occur, and what additional ground and flight operational testing would benefit our capability of using this life support system during long-duration space travel. Continued one-year crew and multi-year technology (ISS and augmented by ground test) demonstrations are required to validate robust/reliability exploration capabilities).

7.2 Segment Description

This segment consists of a series of exploration activities taking place at the ISS or at future LEO commercial platforms. Initially, these activities will take the form of technology and capability demonstrations at ISS. Many of the technologies and systems that will eventually enable sustained lunar missions and human exploration of Mars will first be delivered to and tested on-board ISS. Building on the ISS research and development framework over the past several years, there will be an increased focus over the next several years on exploration-driven systems that can be deployed and tested at ISS. The full list of capabilities can be found in HEOMD-405 Integrated Exploration Capability Gaps List. An abbreviated list is provided here and includes, but is not limited to:

- The Exploration Mobility Unit (xEMU) advanced EVA system, which will eventually be deployed to Gateway and to the lunar surface;
- Next generation regenerative ECLSS systems, which will be deployed on the Transit Habitat to Mars, have components modified to support sustained lunar campaigns;
- An advanced exercise system, which will reduce mass and improve maintainability while optimizing capabilities for maintaining crew health and performance for future exploration missions; and
- Advanced medical capabilities, which will allow astronauts to safely live longer in space and operate more autonomously from Earth.

In addition, NASA and its partners will continue to expand testing of human health and performance during long duration stays in space. Crew members will spend increasingly long periods of time aboard ISS, contributing to the scientific knowledge of how their bodies respond and how space environment exposure affects operability of equipment and operational procedure conduct.

Simultaneously, Mars analog activities will begin on ISS. Crews will begin to simulate components of the crewed Mars mission, refining operations and reducing risks. Specifically, crews will simulate communication delays, autonomous operations, remote training, and in situ system repair and maintenance.

In the longer term, many of these activities will transition from ISS to LEO commercial platforms.

8.0 Exploration Campaign Segment – Human Lunar Return

The Human Lunar Return segment includes all activities on or around the Moon that contribute to the return of humans to the lunar surface and allow for lunar exploration. This segment encompasses Artemis I through the first Artemis crewed lunar landing, including both crewed and uncrewed missions.

8.1 Segment Goals and Objectives

The goal for the entire human lunar return segment is to land the first woman and next man at the lunar South Pole and safely return them to Earth.

Major objectives during the segment will include:

- Validate a deep space transportation system, including the Space Launch System (SLS) and Orion crew vehicle;
- Validate the Human Landing System (HLS) in end-to-end operations;
- Validate Exploration Extravehicular Systems capabilities and operations on the lunar surface; and
- Perform science and technology demonstrations in cislunar space and on the Moon, including the innovative use of human and robotic exploration, measurements from the lunar surface, and sample return, in accordance with HEOMD-006 Utilization Plan.

8.2 Segment Description

The Human Lunar Return segment includes the first human missions to the lunar surface since Apollo. The focus of Artemis I and II will be the demonstration of both the SLS and the Orion crew vehicle to meet test and demonstration objectives. The next set of Artemis missions, starting with Artemis III, include limited lunar infrastructure to meet segment objectives. These missions, along with associated activities in cislunar space make up the Human Lunar Return campaign segment. The integrated architecture for landing humans on the lunar surface and returning them safely to Earth will serve as a vital demonstration of key elements of the Mars architecture, in addition to the SLS, Orion, Gateway, and terminal landing dynamics, as well as EVA systems for surface exploration. Because many of these will be used on Mars as designed, or will serve as prototypes for Martian designs, understanding the performance and operability of the lunar designs will be vital for future human missions to Mars.

Starting with Artemis III, each Artemis increment begins after the return to Earth of the previous crew including the uncrewed activities and operations that commence during this defined timeframe. This culminates in a crewed mission that utilizes and leverages uncrewed mission content and results. The envisioned mission sequence for the Human Lunar Return segment is shown in Figure 2. A communications relay is also expected to be deployed during this segment. It is recognized that the cadence and sequence of missions will be driven by changes in budget, implementation activities, and balancing competing Agency and HEOMD goals and objectives. Artemis I and II are reflected in the respective Exploration System Development (ESD) Mission Definition Baseline (MDB). For Artemis III and beyond, detailed mission objectives to be worked through development of the mission-specific MDBs.

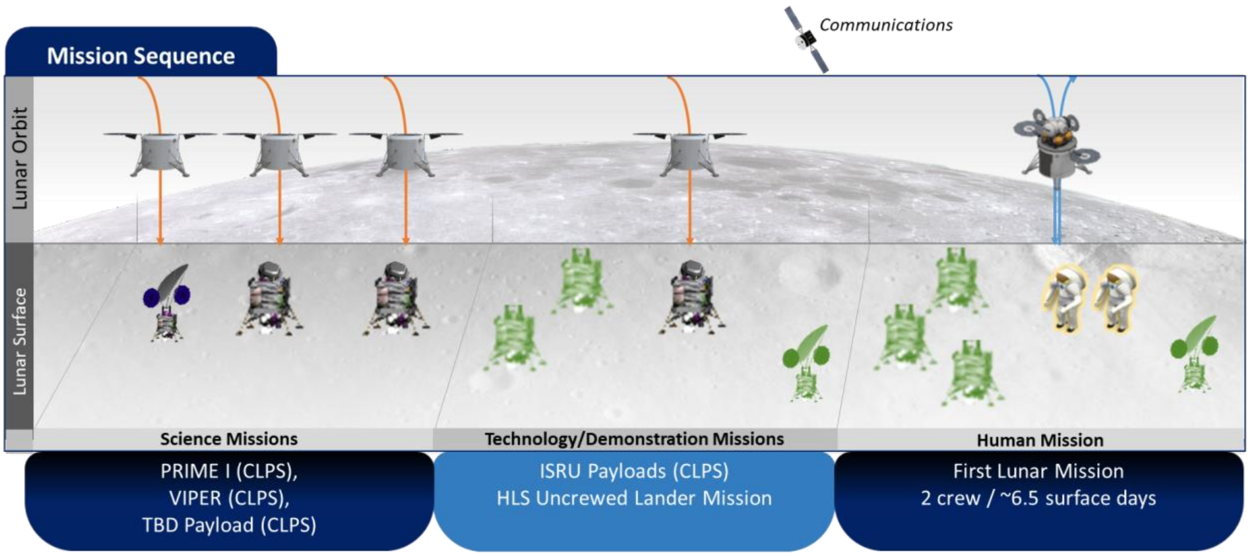

Figure 2 – Human Lunar Return Representative Sequence

The first human lunar landing will be a crewed demonstration of an "initial HLS" configuration and refers to a lander design that prizes rapid innovation and speed over more sustainable attributes. The next human lunar landing may also be a demonstration mission from a different provider. Alternatively, NASA could elect to fly the next human lander under the requirements of a "sustained HLS" configuration.

First Human Landing Increment

During the uncrewed portion of the First Human Landing increment, several important science and technology demonstration payloads will be delivered to the surface. Payloads that are planned to interface with the crew will be delivered within (TBD-HEOR-005) km of all proposed crew landing sites but outside the area where plume ejecta could damage the payloads. These payloads will begin to operate on the surface and may later interface with the crew. The first crewed lunar surface mission begins with the launch, assembly, and checkout completion of the HLS in a cislunar orbit. The goal would be to launch the first crew of four, in Orion on a Space Launch System (SLS) launch vehicle. Their initial destination may be Gateway, or it may be directly into a South Polar Near-Rectilinear Halo Orbit (NRHO). Two crewmembers will descend to the lunar South Pole landing site in a Human Landing System (HLS) vehicle. For this mission, no pressurized infrastructure will have been emplaced on the surface, so the crew will live up to 6.5 days in the HLS. The two crewmembers will perform up to 5 EVAs. There will likely be no mobility assets deployed yet, so they will be limited to distances they can safely reach on foot. Gateway and an initial lunar communications relay satellite(s) will provide high bandwidth communications relay capabilities to enable both cislunar and surface communication to/from the crew and Mission Control.

Following their surface stay, the crew, having met all their mission goals, including collection and stowage of samples for return and deployment of any necessary utilization instrumentation, will use the HLS to ascend and rendezvous with the other two crewmembers (either directly to Orion, or to the Gateway). All crewmembers will return to Earth in the Orion capsule.

9.0 Exploration Campaign Segment – Sustained Lunar Presence

The Sustained Lunar Presence segment includes all activities on or around the Moon that contribute to both the establishment of a sustained human lunar presence and to risk reduction for human Mars exploration. It begins with the splashdown of the crew after a successful demonstration of the intial HLS landing on the Moon and all the follow-on crewed and uncrewed missions to cislunar space and the lunar surface.

9.1 Segment Goals and Objectives

NASA's "Plan for Sustained Lunar Exploration and Development," released in April 2020, states that "Over the next decade, the Artemis program will lay the foundation for a sustained long-term presence on the lunar surface and use the Moon to validate deep space systems and operations before embarking on the much farther voyage to Mars. Over the coming decades and generations, our presence will grow to use and develop the extensive resources of the Moon, including its water and metal deposits." It further states that "A core focus of Artemis is to extend the nation's geo-strategic and economic sphere to encompass the Moon with international partners and private industry."

The Moon has long been viewed as a potential proving ground for technologies, equipment, and operations, and a venue upon which to learn the art of surface exploration. Many of the activities and systems required to enable human Mars exploration are similar and can share development activities. The Gateway, surface mobility, enhanced habitation, power, and portions of the human lunar access system have common applications for both long-term cislunar presence and human Mars exploration. Though the lunar environment and gravity differs from Mars, and will thereby not provide a perfectly analogous environment, the remoteness, limited logistics, and harsh conditions on the Moon provide an environment that can be used to stress many systems that will be used or will be extensible to hardware and operations on Mars.

The current Sustained Lunar Presence segment includes both the flexibility to conduct sortie missions around the Moon to high priority scientific sites along with delivery of the minimal set of surface infrastructure elements to provide the foundational knowledge and technology demonstrations necessary to evaluate the difficulty of sustainable, long-term operations on the Moon. This set of surface infrastructure elements will be located at the lunar South Pole and will be called Artemis Base Camp. Other stressors that Mars will bring, e.g., delayed telecommunications/teleoperations, can be procedurally imposed in lunar operations to create analogous conditions.

The overarching goals of NASA's Sustained Lunar Presence are three-fold: 1) to demonstrate elements of a Mars-forward architecture, 2) conduct scientific exploration of the Moon synergistically with crew and robotic explorers, and 3) to demonstrate the capabilities needed to work and live on the Moon for long durations. Detailed objectives are listed below:

- Establish the Artemis Base Camp at the South Pole of the Moon;
- Execute at least 30 day lunar surface missions;
- Develop the Gateway in lunar orbit to provide a permanent command center at the Moon, provide for logistics aggregation, and leverage its capabilities to advance deep space science and technology development;

  - Deploy the Gateway Power and Propulsion Element (PPE) / Habitation and Logistics Outpost (HALO) as a communications relay and an initial crew habitation element;
  - Establish Gateway Logistics Services to provide logistics to cislunar space;
  - Deploy the International Habitat (I-Hab) to provide expanded life support for the crew to perform science/utilization, conduct crew health and performance, and maintain pressurized cargo/stowage;
- Upgrade SLS to Block 1B/EUS capability, including the ability to launch co-manifested cargo and crewed Orion;
- Deploy and demonstrate the Lunar Terrain Vehicle (LTV) capabilities and operations on the lunar surface;
- Conduct Mars mission analogs using both the Gateway and lunar infrastructure, including integrated missions with increasing durations of crew time in lunar orbit combined with surface activities in partial gravity;
- Enable opportunities for international partners to contribute to Artemis in orbit or on the surface of the Moon;
- Encourage academic and private-sector demand for lunar access, driving down costs with more frequent access that will balance the lunar public-private marketplace;
- Demonstrate the capabilities required for human missions to Mars and other destinations, both on and near the Moon, to include living and working safely on another planet with greater independence from Earth;
- Continue performing science and technology demonstrations in cislunar space and on the Moon, including the innovative use of human and robotic exploration, measurements from the lunar surface, and sample return, in accordance with HEOMD-006 Utilization Plan, leveraging sortie missions as needed; and
- Demonstrate xEVA Sustained Phase Systems capabilities and operations.

9.2 Segment Description

During the Sustained Lunar Presence segment of exploration, NASA and its partners will expand their presence on the Moon, increasing the number of astronauts visiting the surface, the duration that crews remain on the surface, and the range of exploration away from the Artemis Base Camp. The addition of a surface habitat and PR will allow a crew of four to live on the surface for at least 30 days. In addition, sortie missions will provide the flexibility to address high priority scientifically interesting sites around the lunar surface.

Sustained Lunar Presence activities assume a single crewed HLS mission flown to the Moon annually, along with activities in cislunar space and robotic activities at Artemis Base Camp when the crew is not present. It is expected that each of these missions will make great strides in the study of the Moon and its origin, as well as other scientific endeavors and resource utilization. An important aspect of Sustained Lunar Presence is conducting Mars analog missions. These analogs are intended to simulate parts of a Mars crewed mission, leveraging both Gateway and the lunar surface infrastructure, allowing NASA to gain knowledge of how Mars systems may operate during exploration and how crew react to different types of conditions and experiences. A representative surface mission sequence for the Sustained Lunar Surface segment is shown in Figure 3. It is recognized that the cadence of missions will be driven by changes in budget, implementation activities, and balancing competing Agency and HEOMD goals and objectives, including when sortie missions are executed.

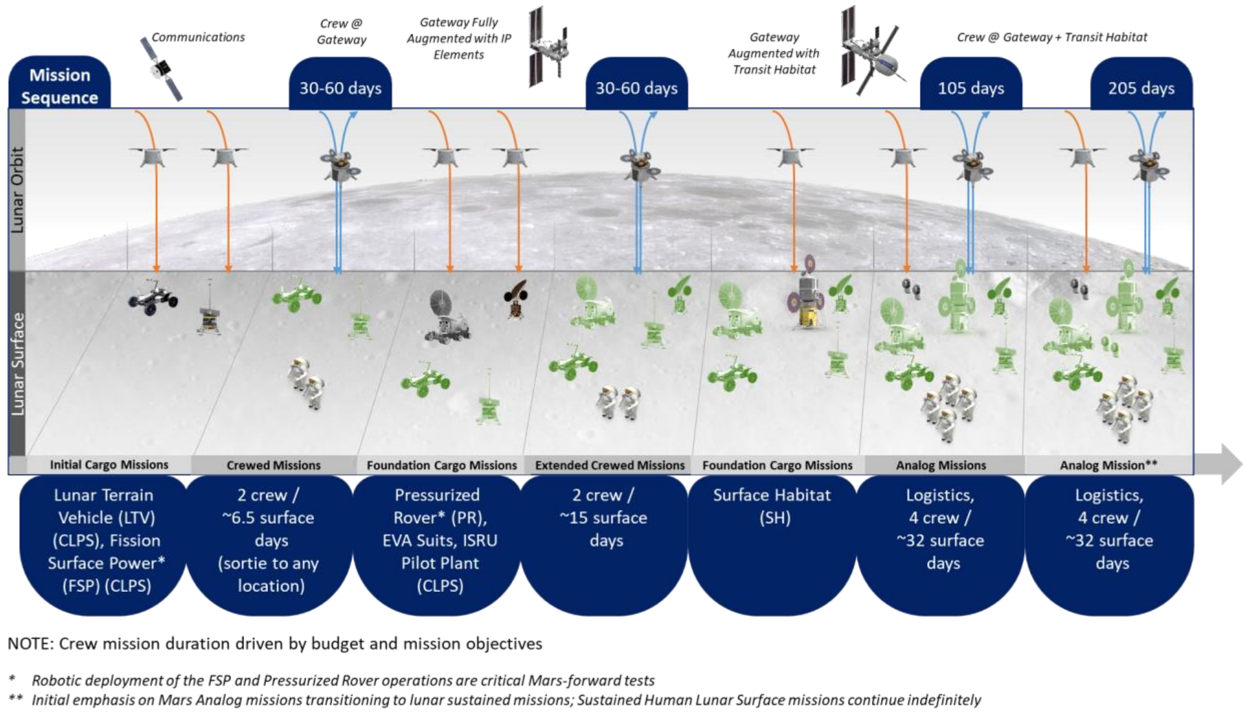

Figure 3 – Sustained Lunar Presence Mission Representative Sequence

Lunar Surface Cargo Deployment

Prior to the next crewed mission, an unpressurized Lunar Terrain Vehicle (LTV) and two ISRU demo plants will be delivered. The ISRU demo plant is a proof of concept demonstration of propellant production from lunar surface resources. The first step in the goal of one day harvesting lunar material for larger scale production, the ISRU demo plant will inform the agency with key information necessary for disruptive technology maturation. The demontsration may also pave the way for a pilot plant that could produce propellant to be used by future landers or systems. Once the LTV has been offloaded to the surface it will be utilized to perform telerobotic operations such as site survey, science investigations, navigation aid emplacement, and instrumentation/hardware asset emplacement. Extended duration operations of the LTV will demonstrate autonomous and latency operations that are vital for future Mars missions. When the crew arrive, the LTV will enhance EVA capabilities, allowing traverses several kilometers from the landing site, balancing science needs and operational (crew safety) constraints (actual traverse distances will depend on terrain, environmental conditions, available communication, navigation and lighting capabilities, available rover and suit consumables indlucing recharge capabilities and crew-specific individual factors). LTV will allow the crew to meet the Artemis program goals of utilization and further demonstration of systems to be used for human lunar exploration.

After landing but prior to the arrival of the next crew, the LTV will perform checkout activities, scout the crew landing site, and perform low-risk science activities. As it is desired to obtain imagery of the crewed landing, LTV may take video if able to do so from a safe position outside of plume ejecta or another method will be needed to document the landing. Once safe, the LTV will approach the crew lander (autonomously or teleoperated) and position itself near the lander for crew use on EVA.

Two large dedicated lunar cargo missions, likely launched on CLVs, are needed to deliver the Pressurized Rover (PR) and the Surface Habitat (SH) to the Artemis Base Camp site in preparation for longer term exploration of the lunar surface. A Fission Surface Power (FSP) system is also delivered on a cargo lander to demonstrate this capability, and as possibility serve as a dissimilar backup power supply to support base camp operations.

The PR is designed to support two crew members for at least 30 days. The PR will use suitports, which allow rear entry suits to be donned through a bulkhead hatch in the rover, eliminating the need for an airlock on the PR and reducing the gas losses associated with extravehicular activities (EVAs). In combination with the cabin operating at an exploration atmosphere of 8.2psi/34% O_2 (HEOMD-004), reduced pre-breathe times enable more rapid EVA egress times. This approach enables multiple short duration EVAs throughout the day and allows the crew to be inside the rover for surface transportation and selection of sampling sites, all while in a shirtsleeve environment. Use of the PR allows the crew to go on extended excursions away from the lander or other habitation elements for up to 14 days, without the overhead of having to return to another pressurized surface element each day.

Once landed, the PR will establish communication with Earth and perform activation and checkout before being teleoperated for offloading to the surface. Following offload, the PR will be teleoperated to perform a checkout/validation of all capabilities and perform an uncrewed “shakedown” cruise near the cargo lander. After this initial checkout, it will be teleoperated to the crewed mission landing site, performing low risk scientific activities along the route.

The SH is a lunar surface habitat that forms the core of the Artemis Base Camp. It provides nominal habitation for two crew for periods of at least 30 days. It can also provide habitation for two additional crew during periods of rover crew handover and contingency periods. It will also be outfitted with utilization facilities to conduct science of the lunar surface in accordance to HEO-006 Utilization Plan goals and objectives. The SH includes regenerative ECLSS capabilities, (validated with multi-year LEO and ground operations) which allow for processing of the four crew’s waste into clean water and oxygen. These capabilities significantly reduce the amount of logistics that must be delivered to the lunar surface to enable the sustained crew missions. The SH also includes an airlock, which allows crew to enter the habitat without depressurizing the entire volume. The airlock provides protection from lunar dust and allows EVA suits to be brought inside for maintenance.

FSP is a compact fission electric power system with a common design approach for both the Moon and Mars surfaces and for deep space science applications. The concept envisioned for the lunar analog shall be a self-regulating design capable of distributing power to other surface assets at a (TBD-HEOR-006) power level up to a minimum of one kilometer via a cable and provide radiation shield protection to the crew and other assets to mission dependent (TBR-HEOR-006) as low as reasonably achievable (ALARA) levels. The FPS operations shall also be controllable via commands from Earth. The system is designed to be activated within 24 hours after landing via commands from the lander or from Earth. After boom and radiator deployments, a simple mechanism is commanded to retract the control rod in the reactor core, allowing fission to begin. Once the reactor reaches operating subsystem temperature and a commissioning phase is complete, continuous power is available. There is no radiation hazard prior to activation on the lunar surface, and the system includes a dedicated radiation shield to protect the crew and surface assets following activation. To maintain ALARA human radiation dosages, the FSP must be landed to maximize the use of natural terrain shielding from the SH. The reactor is self-regulating, and power management and distribution, along with 1 km of power cable, are provided to demonstrate and, if necessary and as able, provide recharging capabilities for other lunar assets such as the Pressurized Rover. Surface assets, such as the unpressurized rover, will deploy the 1 km power cable from the FSP.

Periodic delivery of logistics will be required to support crewed and uncrewed operations on the lunar surface. These logistics deliveries may be provided by international partners and/or commercial services. NASA will assess logistical delivery performance after the early delivery missions to determine appropriateness for commercial provider deliveries to be on the critical path for Artemis.

Cislunar Deployment
The Gateway is deployed in this segment starting with the launch of Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO) as a communications relay and an initial crew habitation element. Additional habitation, refueling, logistics resupply with Gateway Logistics Services, external robotics and the capability of an airlock further expand Gateway's capabilities and supports further operations in cislunar space and on the lunar surface including teleoperations of assets on the surface. The International Habitat (I-Hab) will be launched on an SLS as a co-manifested payload with a crewed Orion and delivered to the Gateway in lunar orbit. The additional ECLSS system on I-Hab will increase the crew duration capability on Gateway from 17.5 days to ~60 days, with logistics resupply. This element will also add key capabilities to improve self-sufficiency and to prepare for Mars, including reliable ECLSS, validated with multi-year LEO operation, and high bandwidth communications. In addition, the ESPRIT module, provided by ESA, will be launched on an SLS as a CPL. The ESPRIT will be delivered and docked to Gateway using Orion as the tug. This module will provide the ability to refuel Gateway, extending its operational life. The module will include an observation port, allowing for unobstructed views of the Moon and Earth. Also, Gateway Logistics Services (GLS) will deliver logistics modules capable of autonomous docking and supply the Gateway with supplies, cargo, and science as manifested per mission.

Delivery of the Mars transit habitation system, known as the Transit Habitat (TH), occurs during this segment. The TH is assumed to be delivered to the Gateway in the NRHO by CLVs. The TH is designed to extend stays on Gateway beyond 60 days (TBR-HEOR-007), up to 2-3 years commensurate with Mars mission durations, and to operate independently away from Gateway. Additional logistics will be needed to supply Gateway and TH to support longer duration stays. Extended duration missions will also include the need to extend the certification life for systems on Orion. The TH will function as a point of logistics aggregation and center of subsystem management tasks in preparing for future missions. The TH will have multiple docking ports to accommodate and augment the Gateway capability. Ultimately, the TH will serve as the in-space crew habitat for the human Mars mission.

Crew Missions

Artemis Base Camp missions to the South Pole are enabled by the operation of prepositioned habitable assets (e.g. a surface habitat or a pressurized rover) on the lunar surface. Crewed ABC operations can begin with the delivery of the first prepositioned habitation asset. Sortie missions, however, are short-duration missions (<7 days on surface) that require only the HLS as a habitable asset. It is likely the the mission after the initial HLS landing will comprise of a sortie mission, either to the South Pole or other high value scientifically interesting surface sites. For each of these missions described below, the crew will use the HLS to ascend and rendezvous with the other two crewmembers likely at the Gateway, but may also rendezvous with Orion.

Sortie Mission

For the sortie mission, the crew will live out of the HLS, leveraging the utilization equipment carried with them on the lander to complete utilization and exploration objectives. Following their surface stay, the crew will use the HLS to ascend and rendezvous with the other two crewmembers and all crewmembers will return to Earth in the Orion capsule.

Sortie Mission – South Pole

If the crew lands at the South Pole, they can utilize the LTV to begin testing its capabilities and will begin to expand the range of exploration on the lunar surface. The crew can visit and inspect the two ISRU demo plants and other science packages that have been deployed prior to their arrival. The crew will spend approximately 6.5 days on the surface in the HLS before returning to Orion and then to Earth.

It is anticipated that successive crew missions to the South Pole are similar in operations until the arrival of the first habitable asset. The crew will continue to expand the area of exploration, using the LTV to further investigate areas around the HLS landing site. The crew will also conduct activities to prepare for deployment of the Artemis Base Camp, including detailed surveys of potential sites for the habitat and power systems, identification of sites of scientific interest, and identification of resource areas. The landing zone as envisioned at the current reference ABC location can accommodate about eight missions where a lander is left on the surface. At the completion of those missions, an alternative landing zone would have to be defined or the spent stages would have to be relocated. Of course, if the HLS configuration does not leave behind a spent lander stage, the current landing zone as envisioned can be used for repeated missions well into the future.

ABC Mission – PR Only

The delivery of the PR enables longer duration stays, a minimum of 30 days for 2 crew, at the South Pole. Likely the first mission of this type will be of shorter duration, as represented in Figure 3 with 15 days. A crew of two will land in the HLS and transfer to the PR to conduct a surface mission. Prior to operating the PR, the crew will perform final activation and check out the PR. This final checkout includes operations that could not be performed remotely by either the crew or ground controllers prior to landing. With the LTV, the crew in the PR will be able to expand out to farther distances, up to 20 km, away from the HLS. Exploration traverses in the PR could include up to four short-duration EVAs on each EVA day, limited to a total of 24 hours of EVA per crew per week. PR-based EVAs will primarily be focused on exploration, science, and research at designated sites on the surface.

After conclusion of the surface mission, the crew will prepare the PR for a long-duration uncrewed state (a minimum of ~330 Earth days), and will prepare robotic assets, such as the PR and LTV, for teleoperations from Earth. Samples selected for return to Earth will be packaged in sample containers (both pressurized and unpressurized, and both cold and ambient), and prepared for transfer to the HLS lander. Studies are ongoing to address options for cold stowage return. After launch in the HLS, the crew will rendezvous and dock to the Gateway, where they will then spend some time before their return to Earth via the Orion spacecraft, with their cargo of returned samples.

ABC Mission – PR and SH

Once both habitable assets are on the lunar surface, the crew will initiate sustained human operation at Artemis Base Camp. A crew of four will land in the HLS and prepare to transition from HLS to the PR and LTV then traverse to the SH. Prior to operating PR, LTV, and SH, the crew will perform final activation and check out of the PR, LTV, and SH. This final checkout includes operations that could not be performed remotely by either the crew or ground controllers prior to landing. The surface mission duration will be about ~32 days. These missions with four crew to the surface will be the first time in NASA history where all crewmembers vacate the Earth return vehicle and then have to return to that vehicle. This risk must be balanced with the benefits of the exploration goals and objectives.

The general nature and sequence of operations at Artemis Base Camp will follow a typical pattern. The surface operations begin with the arrival of 4 crew in an HLS lander at a designated location within the launch/landing zone. Once a steady-state mode has been achieved for the lander, the crew and any cargo that accompanied them will be transferred to the LTV and/or PR and driven to the habitation zone of Artemis Base Camp. For the majority of the mission, two crew will live out of the PR while the other two live out of the SH. The crew members may swap elements during their stay on the surface, and all four may stay together in the SH for a limited stay of up to (TBD-HEOR-007) days or the PR for limited stay times of up to (TBD-HEOR-008) days during resupply, for public affairs activities, or in contingency situations.

Exploration with the PR will be much like previously stated, a combination of traverses and EVAs to achieve utilization and exploration objectives. However, maintenance and repair EVAs will be needed as well. Up to two EVAs per crew per week are planned from the SH, however the rate will be dictated by mission priorities.

Work inside the SH will include scientific research, inclusive of space biology, human research, physics, and geology. IVA work in both the PR and SH may include teleoperation of surface systems and subsystem maitenance. IVA in the SH may also include support of the EVA crewmembers.

Rest days will be scheduled for crews whether in the SH or the PR approximately each week while on the surface. These days for both the PR and SH crews will focus on the crews' needs for living on the Moon, such as eating, sleeping, hygiene, entertainment, and communications with family. For nominal lunar exploration missions, the crew may trade places between the SH and PR during the surface mission when needed as dictated by mission objectives.

As the surface mission comes to an end, the crew will prepare the surface infrastructure for a long-duration quiescent state (~330 Earth days), and will prepare robotic assets, such as the PR and LTV, for teleoperations from Earth. Samples selected for return to Earth will be packaged in sample containers (both pressurized and unpressurized, and both cold and ambient), and prepared for transfer to the HLS lander. Again, studies are ongoing to address options for cold stowage return. After launch in the HLS, the crew will rendezvous and dock to the Gateway, where they will then spend some time before their return to Earth via the Orion spacecraft, with their cargo of returned samples.

Mars Analogs

Although every mission to the lunar surface will contribute to Mars risk reduction, after the first few crewed missions, they will become increasingly Mars-focused. With its location a few days from Earth and a partial gravity environment, the Moon provides unique test bed opportunities for refining exploration concepts to be used on a human Mars mission, Although the Mars mission will be years in duration with very limited Earth return opportunities, surface operations for the Mars mission can be demonstrated during the lunar surface missions.

Additionally, the Gateway, along with other elements delivered to cislunar space, will be used in conjunction with the lunar surface assets to perform a series of crewed Mars analog tests, in which the crew will spend extended periods in space prior to descending to the lunar surface. These missions will help NASA better understand human health and performance, crew autonomy, and other issues involved in deep space missions.

These Mars analog tests will begin to demonstrate some of the operational concepts necessary for future Mars missions, including both in-space and surface capabilities. In-space demonstrations include but are not limited to: aggregation and assembly of vehicle systems in deep-space; highly-autonomous and remotely-controlled operations; system dormancy; elliptical orbit rendezvous; and zero-g cryogenic fluid management. Surface demonstrations include but are not limited to: dust mitigation strategies; planetary protection protocols; sample containment and return; plume ejecta analysis; precision landing / hazard avoidance; surface exploration strategies; surface crew mobility, EVA science protocols, tool use and crew egress/ingress techniques.

Subsequent sustained crew missions to the lunar surface continue lunar research and utilization as well as the series of Mars analog tests on and near the Moon. Each mission extends the time spent in cislunar space, starting at 45 days and increasing to 180 or 210 days, to provide greater fidelity in simulating the zero-g transits to Mars. Each Artemis crew mission will then include a 30 day crewed mission to the lunar surface following the duration in cislunar space.

The extended durations at the Gateway will provide valuable research data for long durations in an integrated set of deep space hazards. While in cislunar space, the crew will perform scientific investigations, collect key human health data, and perform system checkout, maintenance, and repair of the Gateway as well as the TH for subsequent Mars mission execution. Demonstration of the environmental control and life support systems will be completed to enable sustaining the Mars crew for the approximate two-year round trip to Mars and return to Earth.

Once the crew has experienced adequate time in cislunar space to simulate the human health effect of zero-g transits to Mars, the crew will land on the surface utilizing the HLS system. Since the crew will be adapted to zero-gravity, several enhanced capabilities will be required beyond HLS initial requirements, potentially including highly-autonomous operations and support of gravity transitions.

The surface analog phase, while not the same as what would be conducted on Mars, serves as an operational "dress rehearsal" of many aspects of the Mars surface mission segment. During the surface Mars analogs two crew will operate out of the PR for the entire 30-day mission, simulating Mars surface operations, while the other two crew live in the SH conducting other lunar exploration activities. An overview comparison of both the lunar and Mars surface concept of operations timelines is graphically depicted in Figure 4 below.

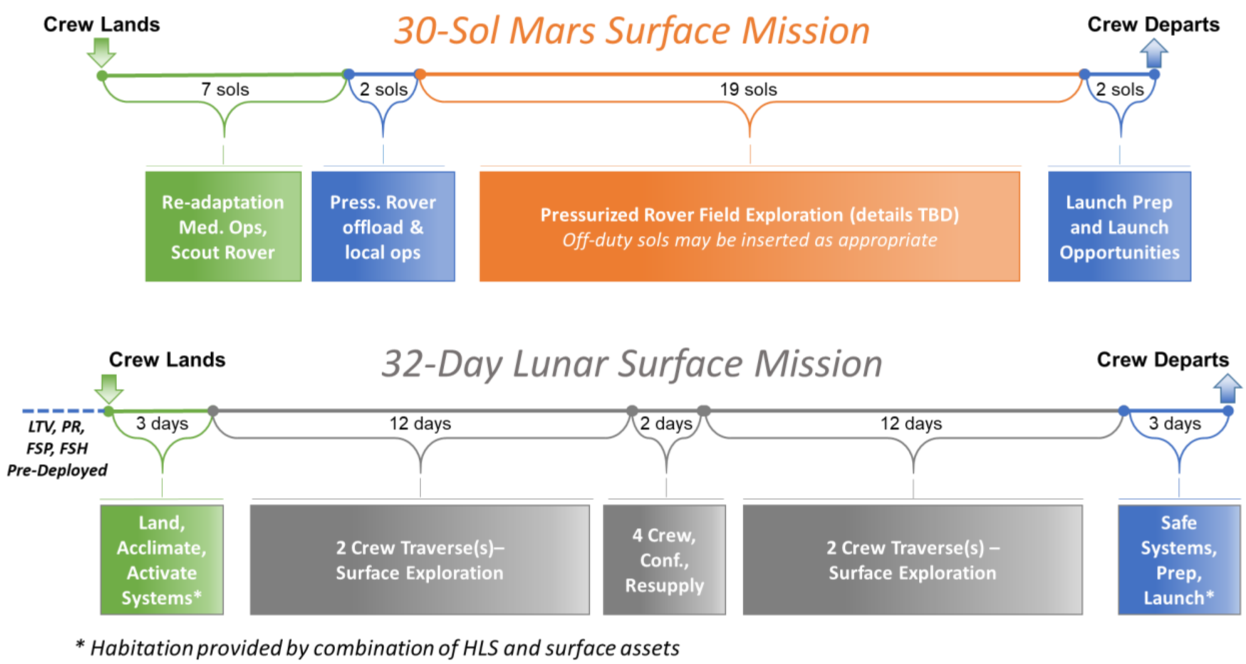

Figure 4 – Example lunar analog for Mars operational surface timelines

Key operations or risk mitigations during the Mars analog include:

- Automated landing of the HLS crewed vehicle, which is also needed for Mars due to the crew adaptation to zero-g during the long-transits to Mars;
- Acclimation of crew to partial gravity operations;
- Traverse of the surface to simulate a Mars mission profile with mobility, EVA and sample collection operations;
- Logistics resupply of the PR with pre-deployed logistics carriers every 7 to 14 days;
- Demonstration of elements and tools by aclimated crew, e.g., PR operations, science tools, Mars mission exploration medical capability; and

- Extension of two-crew habitation in the PR to 30 days.

Uncrewed Lunar Surface Operations and Support

Apart from Artemis Base Camp crew missions, surface assets will be controlled from Earth, Gateway, or will be operated autonomously. Uncrewed surface operations are those designed to operate independently of surface crew timeline activities. With relatively short and infrequent crew stays at the ABC, the envisioned surface architecture aims to provide effective and efficient utilization during periods of availability and apply capabilities that enhance mission objectives and enables the crew to focus on higher priority tasks. In addition, utilization of uncrewed surface assets will occur aligning with objectives in HEOMD-006 Utilization Plan.

Certain operations and sustaining tasks may be performed prior to crew arrival, or after their departure, to reduce the burden on valuable crew time. Uncrewed surface operations include: surface and site preparation; system deployment; surface cargo, logistics handling and transfer; lunar surface science and technology demonstrations; resource utilization activities; landing and departure support; and public outreach events. Sustaining tasks include: cleaning and dust mitigation; inspection, maintenance and repair; instrumentation calibration; waste management on the surface; mobile asset upkeep; post-departure tasks such as safing, damage asessments and site restoration; and uncrewed tasks associated with adding new capabilities.

Lunar surface systems may be capable of operating in several different modes, or a mix of operational modes. These modes are determined by various factors including system cost, functional criticality, reliability, and operational requirements. Other important aspects include task complexity, communications latency and bandwidth, availability of sensory information, anticipated *remote operator* workload, and demonstrated operational trust. Uncrewed lunar surface modes of operation may consist of teleoperations, automated operations, supervised and/or fully autonomous operations, and contingency modes (e.g., surviving periods of darkness).

Night-survival operations may be initiated remotely by teleoperation, automated, or by supervised autonomous operation. Surface systems may hibernate (operate at a predetermined low-power energy-saving mode) through periods of darkness and then awaken to continue nominal operations. Other surface assets, such as critical systems that support the crew, may need to maintain full operations throughout these day/night cycles. Mobile assets may use a more adaptive approach optimizing their power and operations.

Uncrewed ABC operations are a key Mars-forward capability that can identify, develop, and simulate critical operational methods and techniques vital to reduce Mars mission risks. For example, such lunar-based uncrewed analogs could incorporate time delays to inject communication blackouts and latencies and to verify critical capabilities that build confidence in achieving human exploration missions to Mars.

10.0 Exploration Campaign Segment – Humans to Mars

The Humans to Mars segment includes all of the capabilities required for a crewed Mars mission, including the launch of the first human mission to Mars, landing the first humans on the surface of Mars, and returning them safely to Earth.

10.1 Segment Objectives

The first human mission to Mars will mark a transformative moment for human civilization. Establishing a sustained lunar presence and taking the initial steps toward the first human mission to Mars will be the greatest feat of engineering, and the greatest voyage of exploration and discovery, in human history. These missions will drive technology and innovation using the country's unparalleled scientific capabilities, dynamic economy, and robust industrial base. These missions will inspire generations of STEM professionals and countless other disciplines, while offering opportunities to partners in government, industry, and academia.

Balancing risk and achievement, using the best combination of robots and humans, and using advanced technologies such as nuclear propulsion, NASA will conduct a Mars campaign that visits new ground, yields new discoveries, and answers questions fundamental to our existence. The campaign will culminate with a short duration human mission to the surface that utilizes the human in situ ability to the maximum benefit possible. The discoveries and knowledge obtained on this mission will determine the path for future human activity on Mars.

Primary objectives for the Humans to Mars segment are to:

- Successfully land human crews on Mars and safely return them to Earth;
- Autonomously deploy and validate the systems that are required to support the crewed mission phase, including delivery and fueling of an Mars Ascent Vehicle (MAV) prior to the crew arriving in Mars orbit; and
- Conduct science and technology demonstrations on the Martian surface, in accordance with HEOMD-006 Utilization Plan.

10.2 Segment Description

The Human Mars Surface segment consists of two phases, a deployment phase, in which all of the required elements are pre-deployed to Mars or to cislunar space, and a crewed phase, in which the crew is sent to the Martian surface and returned to Earth. This segment assumes a Mars crew departure date of 2039. Most of the Mars mission architecture is not set at this time and various open trades are being assessed for the best approach for exploring Mars. Primary trades include propulsion systems, mission duration, lander design, and surface architecture. The Point of Departure (POD) architecture description provided in this section is one solution given various constraints.

Deployment Phase

All in-space and surface elements required to complete the crewed Mars mission must be launched and deployed prior to the crew departure. The Mars deployment phase of the Human to Mars segment therefore encompasses the launch and delivery of all Mars systems in advance of the crewed Mars surface mission.

All Mars elements, propulsion stages, and required refueling and logistics elements aggregate in a cislunar orbit prior to departing for transit to Mars. Every element is required to operate autonomously during the deployment segment. All of the system checkouts, element fuel transfers and vehicle integration will be completed in the aggregation orbit. The aggregation phase of the Mars element occurs within the Earth's sphere of influence.

To meet a Mars crew departure in 2039, beginning in 2032, the SLS launch rate increases (see HEOMD-004, ESD-R-15, Launch Rate). This launch rate sets the cadence for the element deliveries during the deployment segment. With a TLI performance of 45 t, the SLS Block 2 cargo variant is utilized to maximize launch mass and minimize the number of launches. Given the assumed launch rate for SLS, which is based on forecasted funding, elements may loiter at the aggregation orbit for an extended period of time prior to departure.

The launch and delivery of Mars surface landers and related propulsion elements would also need to begin in 2032. The baseline strategy for the surface architecture is to deploy no more than three landers to deliver the surface systems for the Mars short stay crew mission. The three Mars Descent Stage (MDS) landers will deliver the Fission Surface Power (FSP) and support systems, the Mars Ascent Vehicle (MAV) and the PR, respectively. For each lander, the MDS lander itself would require a heavy lift capability, such as an SLS Block 2 Cargo. In addition, a cryogenic chemical propulsion stage would require a heavy lift capability, such as an SLS Block 2 Cargo. Each lander then performs a rendezvous and docks with the propulsion stage in cislunar space. If any propellant is needed by the elements for the transfer to Mars, the propellant would be provided by CLVs and all propellant is transferred autonomously in the aggregation orbit. Logistics for the mission can be launched during this time to be offloaded by the crew prior to departure to Mars. The final lander element would be launched in 2037 to meet a crew departure of 2039.

At the first Mars departure opportunity following the assembly and fueling of each lander, the chemical propulsion stage performs a Trans Mars Injection (TMI) to fly a low energy conjunction class trajectory to Mars vicinity, and then performs a Mars Orbit Insertion (MOI) to capture in a 5-sol Mars parking orbit. In the current POD, it is assumed that the MDS consists of a Hypersonic Inflatable Aerodynamic Decelerator (HIAD) paired with a Supersonic Retro Propulsion (SRP) module. The concept utilizes a single 14.8 meter inflated HIAD to perform initial deceleration in Mars' atmosphere. LOX/LCH_4 engines are utilized to perform supersonic retro propulsion and landing. Each MDS payload is limited to 25 t delivered capacity to the surface. The MDS will leverage entry, descent, and landing technologies to safely place human-class landers on the Martian surface—at 20 times the payload mass that has successfully been landed to date.

Following Mars orbit insertion and separation from the in-space chemical propulsion module, the MDS will enter a phase of check out operations and loiter for one orbit. Assuming clear weather at the landing site, the MDS will perform a descent orbit insertion burn. Transit in the descent orbit apoapsis to periapsis will take about 2.5 days. Before reaching 125 km altitude, the HIAD is inflated for entry. The HIAD slows the MDS from hypersonic speeds to supersonic speeds. Following HIAD operation, the SRP module performs the final 30 seconds of terminal descent and landing.

To perform a precise and safe landing, the MDS will employ terrain relative navigation along with autonomous hazard detection and avoidance during descent to identify a safe landing site within the predetermined landing ellipse. The vehicle will undergo a period of checkouts after landing and main engine cut off to ensure proper operation post landing.

The initial two landers, carrying the MAV, FSP, Mars Terrain Vehicle (MTV), and MAV propellant, descend to the surface after arriving in the Mars parking orbit and begin autonomous surface operations. The third lander, with the crew habitation and mobility lander, remains in orbit around Mars until the crew arrives. After all three landers touch down in close proximity at the designated mission landing site, the crew surface operations can begin. This lander sequence for the Mars mission deployment is shown in Figure 5.

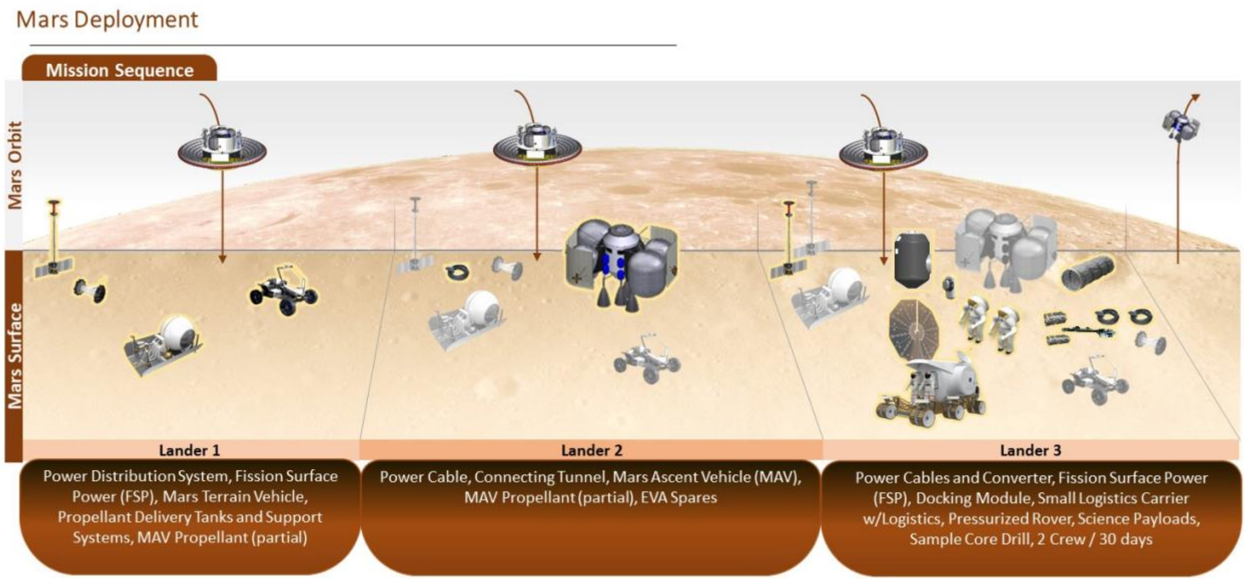

Figure 5 – Mars Deployment Description

Deep Space Transport Aggregation and Outfitting

The launch and delivery of the Nuclear Electric Propulsion (NEP)-Chemical hybrid propulsion transportation stages for the crewed Deep Space Transport (DST) would begin in 2036 to support crew departure in 2039. For the current POD, NEP-Chemical hybrid propulsion transportation was the assumed approach, leveraging high-energy nuclear propulsion technologies to reduce the round-trip time for crew transit to Mars and back. The NEP stages provide the efficient interplanetary thrust to get the crew stack to Mars. Prior to integration with the TH, the NEP stages must fulfill all deployment, commissioning and shakedown checks. Key to the success of the aggregation and integration of the NEP stages is the proper checkout of the nuclear and thermal systems on the NEP stage.

The Chemical Propulsion stage for the crew transportation stack is next to be delivered. Prior to any propellant delivery to the Chemical stage, the stage must demonstrate its thermal control and power systems are functioning properly and are able to handle the zero boiloff (ZBO) requirements necessary to complete the Mars transit, including consideration of the conditions of the Venus gravity assist flyby and closest approach to the sun of (TBD-HEOR-009) AU, if applicable.

After completion of the Mars analog missions in the Lunar Sustained Presence segment, the TH departs Gateway to be integrated with the NEP and crew Chemical Propulsion stages. The TH docks with the Chemical Propulsion stage and the dual NEP stages.

Prior to the full stack integration, commercial tankers are delivered by CLV to provide propellant to the crew transportation stack. The mission propellant must be fully loaded into the Chemical and NEP stages prior to final crew checkout and before the crew stack departs NRHO. The tankers will loiter in NRHO space awaiting the arrival of the transportation stages. The tanker elements must be able to remain viable in a dormant state until needed and consistently deliver Xenon and cryogenic propellants. The successful transfer of propellant to the crew transport vehicle is critical to preparing the crew transport for the round-trip transit to Mars.

The DST is assembled in NRHO from the Chemical stage, dual NEP stages, and the TH. All four main elements must autonomously dock to integrate into the full crew stack, with the TH in the center of the vehicle. After the crew vehicle has been assembled, the final checkout and outfitting of the habitation element can be completed. An checkout crew of four visits the integrated stack prior to the Mars crew. This crew will spend up to 180 days checking out the vehicle and ensuring that the crew transport is ready to depart NRHO to begin the transit to Mars. The checkout crew refits the habitat and loads final mission logistics. After the checkout crew departs, the integrated crew transport begins a 120-day transfer from NRHO to Lunar Distance High Earth Orbit (LDHEO), ending the aggregation and outfitting segment of the POD campaign.

The current concept is that there would not be a crewed post-integration shakedown cruise. There would be the uncrewed transfer from NRHO to LDHEO that may currently suffice as a "shakedown" prior to departure to Mars, to look for potential integrated transport system caused issues with respect to human safety and performance (e.g., possibly vibration/loads, communications integration, integrated alerting and commonality in operability).

Uncrewed Mars Surface Operations and Support
Prior to crew arrival in Mars orbit, uncrewed surface predeployments occur over a couple of Mars mission opportunities. These include: autonomous emplacements of needed equipment, supplies, and services; systems verification and validation in the Mars environment; as well as the operations and sustainment of these surface assets until the crew arrives. In addition, utilization of uncrewed surface assets will occur aligning with objectives in HEOMD-006 Utilization Plan.

Uncrewed surface propellant acquisition, liquefaction, storage, and transfer ahead of crew arrival (or between crew arrivals) may be required and can be supported by surface assets such as the MTV. Such a capability would need to be maintained and operated remotely. Thermal control systems will be required regardless of propellant type. Whether pre-deployment of propellant or on-site production is selected, maintenance of storage and transfer systems will be necessary. Maintenance activities likely involve the replacement of soft seals, periodic verification of valve settings, calibration of instruments, contamination control of sensitive parts, etc. Mars propellant loading operations will involve: a method of verifying propellant quality; leak detection and resolution; and limit exposure of equipment and crew to propellant related hazards. Post mate/de-mate methods to verify the integrity of seals and fidelity of communication and power systems will also be needed. Propellant fluid transfers are extremely dynamic and complex processes that require careful timing of valve cycles, in-depth system instrumentation for verification of system performance, troubleshooting of system faults, and corrective action procedures.

Operating and sustaining these surface assets over a period encompassing several landings will require significant electrical power. Predeployment of FSP and distribution cabling can be performed and verified ahead of crew arrival. Initialization of FSP to support uncrewed and crewed operations will need to be completed.

Automation and autonomy capabilities play an important role in performing uncrewed surface operations and maintenance. Communications delays and blackout periods necessitate increased human independence. Direct communication delays between the Earth and Mars are nearly 30 minutes and communication blackout periods occur and are about two weeks long during solar conjunction. Due to these constraints, surface operations need to be automated. These activities include not only propellant operations, but also deployment of surface assets, inspection, routine maintenance and repair as needed, checkout and verification testing, and continued science data collection.

Crewed Mission Phase

The crewed mission phase involves all operations to transport the crew to Mars vicinity on the DST, descend two crew members to the surface, return those crew members to the DST, and to safely return the crew to Earth. Crew operations (transfer methods and associated devices) to be used at Mars will be tested in Lunar analog studies.

The mission begins with launch of the crew on SLS and Orion to rendezvous with the DST in LDHEO. The crew will begin launch attempts 90 days prior to the Mars departure date to allow for launch delays and multiple launch opportunities. After the crew rendezvous with the DST, they transfer time-critical logistics and perform the final checkout in LDHEO. The DST then performs a chemical burn to depart LDHEO.

During the outbound transit to Mars, nominal crew operations will include routine vehicle system health monitoring, maintenance, and repair, and vehicle course monitoring and corrections. Housekeeping activities will include TH cleaning and periodic trash disposal. Live interface education and public outreach activities will become increasingly more difficult as the crew transit farther from Earth and roundtrip communications time lags, but recorded question and answer sessions or lessons will be possible. In deep space, crew will have opportunities for solar system astronomical observations, to conduct research on the effects of the deep space environment on humans and vehicle systems, and to conduct other planned microgravity science research. To maintain fitness for landing, crew will exercise daily, undergo health and performance monitoring and testing, and utilize on-board training systems to maintain proficiency for critical entry, descent, and landing operations. The landing crew will use on-board training systems to virtually practice surface mission transits and science operations in collaboration with scientists and mission controllers on Earth.

After the crew and the transportation stack arrive at Mars, the vehicle performs a three-burn arrival maneuver to capture into the 5-sol Mars parking orbit. The final parking orbit will have its perigee directly over the +35 degree latitude landing site. The crew lander will have previously maneuvered itself into the same parking orbit that the crew transportation stack inserts into, and the crew has 7.5 sols (or one and a half orbits) to dock with, check-out, and transfer to the lander, then depart the transportation system in preparation for the deorbit burn and descent to the surface.

Because of the relatively brief amount of time that the crew will spend on the surface of Mars, the crew lander carries just two elements: the PR, assumed to be a block upgrade of the pressurized rover used on the lunar surface, and a Docking Adapter (DA). The PR will be configured for crew entry and landing (e.g., recumbent couches, crew in Launch, Entry, Abort (LEA) suits) and later reconfigured for traverses on the surface. EVA suits which have been checked out to the extent possible on orbit are stowed for descent. The DA is a proposed element for the crew to transition to the PR from the TH in a shirt-sleeve environment. Functional allocations between the PR and the DA will be revisited to determine the correct balance of allocation between the two elements.

The crew lander, with the crew in the PR, descends and lands in close proximity to, but at least 1000 meters straight line distance away from, Landers #1 and #2, to minimize the potential for debris from engine plume interaction with the surface damaging assets already in place. The orbital crew can aid the surface crew by handling remote tasks, such as telerobotic operation or monitoring of surface assets, or data analysis to support next-day planning and coordination with subject matter experts on Earth. The orbital crew may also use their vantage point for Mars surface or Phobos/Deimos observations.

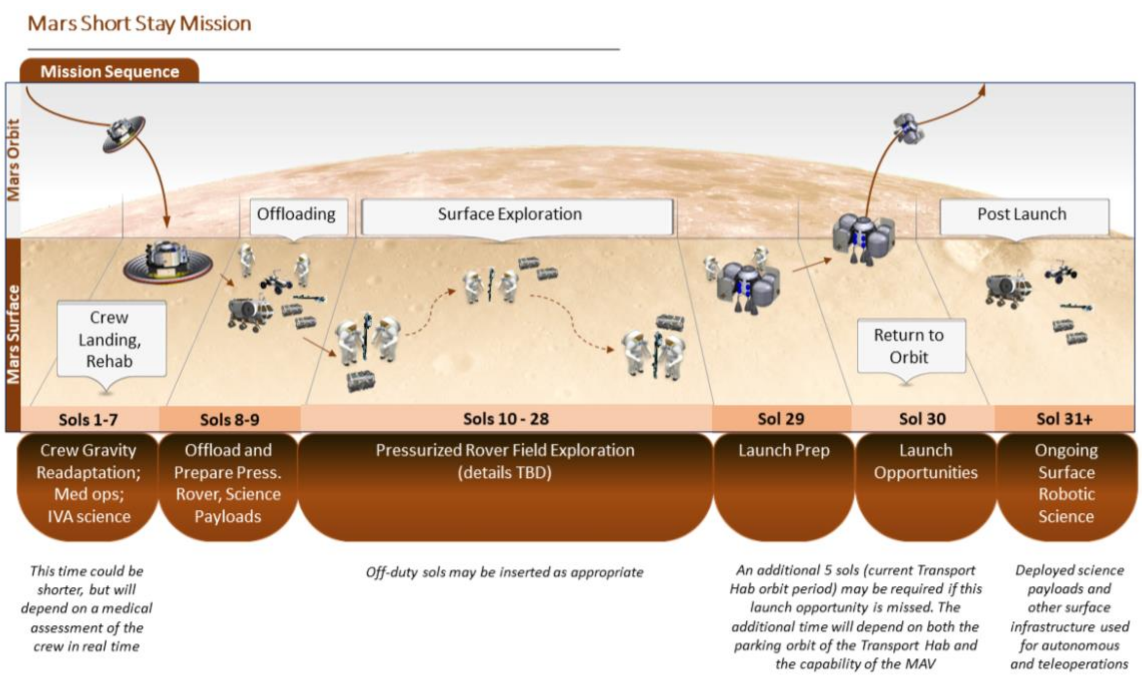

Figure 6 – Example of a Mars Short Stay Mission

Once on the surface, the crew of two will undertake a series of activities to establish operations and to conduct science activities. They will begin surface operations with an acclimatization period, allowing them to readapt to a gravity environment and to remotely check out surface systems. Once readaptation has been confirmed, the crew will begin EVA activities and will remotely offload the PR from the lander. The crew will also unload required logistics and science packages and will conduct short excursions to test the operations of the PR. A likely destination for a test excursion will be the MAV, enabling a visual inspection of this vehicle. The crew will leverage both the PR and the MTV to support crew operations, enabling excursion distances beyond the EVA walkback limitations.

Any crew logistics needed for the surface mission beyond that which can be carried in the PR or DA during entry and landing will be carried in environmentally controlled modules and brought to the surface as deck cargo. When additional logistics are needed, the crew offloads one of these modules from the deck and connects it to one of the suitports. One of the crew then enters the PR through the remaining suitport, empties the logistics, and loads trash into the module. While this is a fundamental change in the way EVAs are currently performed using the “buddy system”, single person EVAs enable logistics transfer and efficient use of crew time. The logistics module is then placed in a location where it will not interfere with surface operations.

Scientific activities supported by the crew on the surface may include collection of surface samples or operation of scientific experiments to meet mission objectives. The PR will provide flexibility for the crew to explore areas away from the landing site, since the crew will be able to drive the pressurized rover to sites of interest, surveying along the way, and then conduct EVAs to explore a site in detail and collect samples.

EVAs from the PR are assumed to be carried out via suitports; no separate airlock is anticipated, but the PR is expected to be capable of depressurization. The depressurization capability will be used to install the EVA equipment on the suitports for the first time, or to bring EVA suits into the cabin for maintenance.

Once all exploration activities have been completed and the crew has returned to the landing site for the final time, preparations for launch will get under way. The MAV will have been remotely monitored and checked by Earth-based support teams since its arrival, well before the crew starts their surface mission. The orbiting crew will also be available to support launch preparations in near-real time.

The surface crew will position the PR next to the MAV and connect to it via a pressurized tunnel. The tunnel is a proposed method to move the crew and returning payloads into the MAV in a shirt-sleeve environment, without the need to expose the MAV cabin to the Martian surface environment. The LEA suits are transferred to the MAV for ascent. The EVA suits are left behind on the surface for several reasons, including reduced ascent cargo mass and to minimize ascent of uncontained Mars material in deference to planetary protection. A subset of surface samples, designated by the science support team, will be transferred to the MAV, and the crew will then enter the MAV and disconnect it from the tunnel to the PR. Return cargo and equipment that has been exposed to the Martian surface environment will be prepared in accordance with applicable planetary protection requirements and guidelines developed under purview of NASA's Planetary Protection Officer.

When the launch window opens, the MAV and crew will ascend from the surface for rendezvous with the orbiting DST. Once in orbit, the MAV will rendezvous with the orbiting transit vehicle and the crew will transfer the core samples and other science samples, and move to the DST. The MAV is then undocked from the transit vehicle and is placed in an appropriate, safe quarantine orbit.

The DST with the crew will depart Mars. During the return transit, the vehicle will perform a flyby of Venus. The crew and the transportation stack return to Earth vicinity. For this architecture, the transportation system does not perform a high thrust chemical Earth orbit insertion burn. Instead, during the return leg, the spacecraft's electric propulsion system will provide the necessary thrust to target a lunar flyby encounter when it reaches cislunar space. This lunar flyby maneuver will loosely capture the vehicle into orbit around the Earth-Moon system. The vehicle will then perform a roughly 30-day transit maneuver to align itself for a second lunar gravity assist maneuver, capturing into the final high Earth parking orbit. During this 30-day transit, the electric propulsion system is utilized to perform small maneuvers to align and phase the orbit for the second lunar encounter.

The second lunar gravity assist maneuver will capture the vehicle into a lunar distance high Earth orbit (notional 400 x 400,000 km), where it will rendezvous with an uncrewed Orion vehicle and return the four crew to Earth. This architecture assumes that the Orion vehicle is already in orbit when the vehicle enters the high Earth orbit, and that the rendezvous, docking, and transfer of crew supportability to the Orion takes no more than 10 days. Although this architecture is for a single mission to Mars, after the crew returns to Earth in the Orion module, the in-space transportation system, with the habitation module, performs a weak stability boundary transfer, using very minimal electric propulsion thrusting to return to its original aggregation orbit in cislunar space, allowing potential reuse of the element.

APPENDIX A – ACRONYMS AND ABBREVIATIONS

AA	Associate Administrator
ABC	Artemis Base Camp
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
CLPS	Commercial Lunar Payload Services
CLV	Commercial Launch Vehicle
DA	Docking Adapter
DRA	Design Reference Architecture
DST	Deep Space Transport
ECLSS	Environmental Control and Life Support Systems
EDL	Entry Descent and Landing
EMU	Extravehicular Mobility Unit
ESPRIT	European System Providing Refueling Infrastructure and Telecommunications
ESD	Exploration Systems Development
EVA	Extravehicular Activity
FSP	Fission Surface Power
GLS	Gateway Logistics Services
GR&A	Ground Rules and Assumptions
HALO	Habitation and Logistics Outpost
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HIAD	Hypersonic Inflatable Aerodynamic Decelerator
HLS	Human Landing System
I-HAB	International Habitat
ISRU	In Situ Resource Utilization

ISS	International Space Station
IVA	Intravehicular Activity
LDHEO	Lunar Distance High Earth Orbit
LEO	Low Earth Orbit
LEU	Low Enriched Uranium
LOX/LCH_4	Liquid Oxygen / Liquid Methane
LTV	Lunar Terrain Vehicle
M2M	Moon-to-Mars
MAV	Mars Ascent Vehicle
MDB	Mission Definition Baseline
MDS	Mars Descent Stage
MGA	Mass Growth Allowance
MOI	Mars Orbit Insertion
MOLA	Mars Orbiter Laser Altimeter
MTV	Mars Terrain Vehicle
NEP	Nuclear Electric Propulsion
NESC	NASA Engineering and Safety Center
NRHO	Near Rectilinear Halo Orbit
PAF	Payload Attach Fitting
POD	Point of Departure
PPE	Power and Propulsion Element
PR	Pressurized Rover
PRIME 1	Polar Resources Ice Mining Experiment-1
ROI	Return on Investment
SCOPE	Strategic Campaign Operations Plan for Exploration
SE&I	Systems Engineering & Integration
SH	Surface Habitat

SLS	Space Launch System
SMD	Science Mission Directorate
SPD	Space Policy Directive
SRP	Supersonic Retro Propulsion
STEM	Science, Technology, Engineering, and Mathematics
STMD	Space Technology Mission Directorate
TBD	To Be Determined
TBR	To Be Resolved
TH	Transit Habitat
TLI	Trans-Lunar Injection
TMI	Trans-Mars Injection
VIPER	Volatiles Investigating Polar Exploration Rover
xEMU	Exploration Extravehicular Mobility Unit
ZBO	Zero Boiloff

APPENDIX B – DEFINITION OF TERMS

Architecture – A set of functional capabilities, their translation into elements, their interrelations and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

Autonomy – The ability of a system to achieve goals while operating independently of external control.

Campaign – A series of interrelated missions that together achieve Agency goals and objectives.

Capability – The ability to complete a task or meet an exploration objective through Architecture, Engineering, Development, Technology, or Operations or Research for a given set of constraints and level of risk.

Co-manifested Payload – Cargo on a transportation element utilizing excess volume and mass, e.g., cargo located inside the PAF adapter ring.

Conjunction-class Trajectory: Alternately referred to as "Long-Stay Missions", Conjunction-class missions are a class of low energy round-trip Mars missions where total mission duration and the time at Mars, from arrival to departure, are allowed to vary. Conjunction-class missions minimize the required change in velocity (delta-v) and therefore energy, and are typically longer than opposition class missions with a long stay time at Mars (in orbit or on the surface) to await for optimal Earth return timing. Conjunction-class trajectories require the Earth and Mars to be in proper relative alignment, thus opportunities occur roughly 26 months apart, with small variation in energies across mission opportunities.

Element – A notional exploration spacecraft/development or surface system providing functions required to support missions and/or exploration infrastructure, e.g., crew transport, habitation, logistics delivery, etc.

Expedition – a dedicated activity within a mission, (e.g., two astronauts will descend to the lunar surface for a 6.5 day expedition).

Excursion – While on an expedition, a journey from a fixed location in the pursuit of exploration objectives, sample collection, or setting up science experiments or technology demonstrations.

Habitable Environment – The environment that is necessary to sustain the life of the crew and to allow the crew to perform their functions in an efficient manner.

Increment – The period of time between the end of one crew mission (i.e., crew splashdown) and the end of a second crew mission, including the uncrewed activities and operations that commence during this defined timeframe. The first increment starts with the splashdown of Artemis II.

Minimum Viable – Least amount of infrastructure required to keep the crew healthy and safe over the duration of the mission with an emphasis on minimal cost within the schedule constraints, while meeting the priority mission objectives.

Mission – A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution. (Definition from NPR 7120.5).

MOLA - refers to terrain elevation on Mars. Mars Orbiter Laser Altimeter (MOLA) topography is measured with respect to a zero elevation surface level known as the MOLA areoid, which is defined as the gravitational equipotential whose average value at the equator is equal to the mean radius determined by MOLA.

Opposition-class Trajectory - Alternately referred to as "Short-Stay Missions", Opposition-class missions are a class of high energy, fast round-trip Mars missions where the overall mission duration and time at Mars are constrained to be short. Opposition-class missions require large change in velocity (delta-v) and therefore energy, are typically constrained to a short stay time at Mars (30-60 days), and require a flyby of Venus either on the outbound or the return leg to help keep the roundtrip change in velocity to a reasonable level. Opposition-class trajectories exist essentially every year, but the energy required to complete the roundtrip mission can vary significantly across different mission opportunities.

Sustainable/Sustained - For the exploration campaign, several defintions apply: Financial sustainability is the ability to execute a program of work within budget levels that are realistic, managed effectively, and likely to be available. Technical sustainability requires that operations are conducted repeatedly at acceptable levels of risk. Proper management of the inherent risks of deep space exploration is the key to making those risks "acceptable." Finally, policy sustainability means that the program's financial and technical factors are supportive of long-term national interests, broadly and consistently, over time.

To Be Determined (TBD) – Used when it is not known what value to be placed and there is open work to determine what it should be.

To be Resolved (TBR) – Used when a value is presented but it is to be resolved or refined as to whether it is the right number.

Utilization – The use of a platform and/or mission to conduct science, research, development, test and evaluation, public outreach, education, and commercialization. Utilization is distinct from the carriers designed to sustain the mission and health of the crew (which include launch vehicles, transportation vehicles, orbital modules, and space suits) [Carrier and payload definitions per NPR 8705.4].

APPENDIX C – OPEN WORK

C.1 To Be Determined (TBD)

Table C.1-1 lists the specific To Be Determined items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed. The TBD item is numbered based on the document number, including the annex, volume, and book number, as applicable (i.e., TBD-HEOR-xxx). As each TBD is resolved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

Table C.1-1 To Be Determined Items

TBD	Section	Description
TBD-HEOR-001	OL.A.1	Number of days Surface Habitat (SH) can support 4 crew.
TBD-HEOR-002	OL.A.2	Minimum number of days for Pressurized Rover to support 4 crew.
TBD-HEOR-003	OL.A.5	Alternate location of Artemis Base Camp (ABC) to be analyzed.
TBD-HEOR-004	OM.A.4	Mars reference landing site assumption.
TBD-HEOR-005	8.2	Delivery distance of payloads planned to interface with the crew.
TBD-HEOR-006	9.2	Power distribution level from FSP concept to other surface assets.
TBD-HEOR-007	9.2	Four crew limited number of days in Surface Habitat.
TBD-HEOR-008	9.2	Four crew limited number of days in Pressurized Rover.
TBD-HEOR-009	10.2	Chemical Propulsion Stage closest approach to sun in AU after Venus gravity assist flyby during Mars transit.

C.2 To Be Resolved (TBR)

Table C.2-1 lists the specific To Be Resolved issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed. The TBR issue is numbered based on the document number, including the annex, volume, and book number, as applicable (i.e., TBR-HEOR-xxx). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

Table C.2-1 To Be Resolved Issues

TBR	Section	Description
TBR-HEOR-001	O.A.3	Transit Hab's (TH) augmentation of Gateway orbit maintenance and attitude control while TH is docked to Gateway.
TBR-HEOR-002	OL.G.3	Number of days needed by HLS to support 4 crew in transport and habitation for sustained surface operations.
TBR-HEOR-003	OL.A.3	Determine whether HLS missions with more than 2 crew or longer than 6.5 days need pre-deployed surface assets.
TBR-HEOR-004	OM.G.5	First Mars mission crew surface duration stay (in sols).
TBR-HEOR-005	OM.A.4	Mars reference landing site assumption.
TBR-HEOR-006	9.2	Determine as low as reasonably achievable (ALARA) radiation levels.
TBR-HEOR-007	OL.A.6 9.2	Determine how far beyond 60 days Transit Hab (TH) can extend stays on Gateway.

APPENDIX D – FORWARD WORK

The following items in Table D-1 have been identified as forward work for the HEOMD-007 document.

TABLE D-1 Forward Work

Section	Description
6	Addition of a GR&A for Mars Terrain Vehicle (MTV)
All	Need to factor in long-term strategy, including potential for resource development and industrialization.