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EXTRAVEHICULAR ACTIVITY AND HUMAN SURFACE MOBILITY PROGRAM (EHP) INTEGRATED CONCEPT OF OPERATIONS (CONOPS)

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EXTRAVEHICULAR ACTIVITY AND HUMAN SURFACE MOBILITY PROGRAM (EHP)

INTEGRATED CONCEPT OF OPERATIONS (CONOPS)

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REVISION HISTORY PAGE

Revision No.	Change No.	Description	Effective Date
Baseline	EHP-C0036	Initial Release (N. Mary); approved at the EHPCB on 12/8/2022 as reflected in Directive EHP-D0036	12/8/2022
A	EHP-C0601	Approved at SEICB on 2/14/24 as reflected in Directive EHP-D0601. Summary of changes include: • 24/42 TBXs closed associated with EHACs: EHAC 1.1 Mass, 1.5 Utilization ConOps • Deletion of ISS sections • TBD-EHP-10033-003: Disposal of EVA suits on the surface is not needed • TBD-EHP-10033-005: PR is not operating in a PSR • TBD-EHP-10033-008: Future landing site prep is not baselined • TBD-EHP-10033-010: Gateway needs contamination detection kit for ammonia – remains in ConOps • TBD-EHP-10033-011: Landing site details, science objectives to be documented in Mission Definition Baseline (referenced in ConOps) • TBD-EHP-10033-012: PR will have conditioned sample stowage (EHAC 1.5) • TBD-EHP-10033-013: Some tools/equipment stowed in Starship garage • TBR-EHP-10033-001: Gloves on Orion as example • TBR-EHP-10033-004: Lighting section updated in ConOps • TBR-EHP-10033-006: EVA suits are left on HLS for disposal. • TBR-EHP-10033-010: Artemis Level operations and planning teams will analyze each traverse for thermal and power during long shadow • TBR-EHP-10033-011: Prebreathe protocol generic • TBR-EHP-10033-013: Hard mounting suits being analyzed • TBR-EHP-10033-014: FOD will later determine whether Gateway EVAs get planned before or after the lunar sortie • TBR-EHP-10033-017: ICR will be tested on the ground. • FWD-EHP-10033-002: Aligning/decomposing M2M ConOps with EHP ConOps is standard SEI • FWD-EHP-10033-003: ISS ESOC related • FWD-EHP-10033-004: Landing site details, science objectives to be documented in Mission Definition Baseline (referenced in ConOps) • FWD-EHP-10033-005: ISS stowage related	12/14/2024

Revision No.	Change No.	Description	Effective Date
		• FWD-EHP-10033-006: Gateway EVA tools examples are in logistics masses included in the Artemis Manifest Panel • FWD-EHP-10033-008: Only one of the two airlocks is nominally used for initial surface sorties • FWD-EHP-10033-009: Elevator operations too detailed for EHP level • FWD-EHP-10033-010: Payload ConOps added • FWD-EHP-10033-013: LTV manipulator accuracy too detailed for EHP level • Addition of EHAC 1.3 Autonomy ConOps	
B	EHP-C0695	Approved at EHPCB on6/20/24 as reflected in Directive EHP-D0695. Summary of changes include: • TBXs closed out associated with EHACs: EHAC 1.7 Integrated Contingencies, 1.9 LTV/PR Cooperative Exploration ConOps • Closed TBR-EHP-10033-007, TBR-EHP-10033-016, FWD-EHP-10033-012, FWD-EHP-10033-014, FWD-EHP-10033-015, FWD-EHP-10033-016 • Added Power, Navigation, and MBSE Use Case Appendices • HLS vendor will provide tools/aids for ingress, repress and doffing • The LTV and PR will provide offloading assistance to the healthy crewmember • DRMs to align with M2M-30007 nomenclature • Addressed disposal of the xEVA System at the end of each Artemis mission • Crew specific items taken to PR from HLS; 3 days of consumables remain in PR • Traverse without having to rely on battery recharge to actual distance w/ration 1.3 • Began adding power, lighting, navigation, communication specification use cases • Crew navigation solution can be sent <TBR-EHP-10033-019> to the LTV display • PR may reinitialize its navigation state with the LTV solution • At the end of the mission, the crew stows reusable tools (depending on mission parameters, expected life of tools, and EVA science objectives (i.e. avoiding cross contamination)) • Passive payloads will be loaded/unloaded by crew or by an LTV external robotic manipulation capability if within the operational constraints of the crew or robotic loading • Added MBSE	06/20/2024

Revision No.	Change No.	Description	Effective Date
B, Admin Chg 1	EHP-D0789	Applied “public release” markings per STRIVES.	9/19/24

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1.0 INTRODUCTION

This Extravehicular Activity and Human Surface Mobility Program (EHP) Concept of Operations (ConOps) document captures a high-level definition of the prospective concepts of operations, capabilities, and operational interfaces across the current National Aeronautics and Space Administration (NASA) exploration mission architecture options reflecting stakeholder expectations. The EHP operations includes performing an Extravehicular Activity (EVA) using the Exploration EVA (xEVA) System in both microgravity (cis-lunar on Gateway) and partial gravity (on the lunar surface) and traversing the lunar surface using the unpressurized lunar rover – Lunar Terrain Vehicle (LTV) – and the Pressurized Rover (PR). Science operations physically located on the rovers will be “opportunistic”, meaning that basic capabilities will be provided on them and science will fit within the design scope. Operations with other pre-formulation projects for a second habitable volume, such as the Multi-Purpose Habitat (MPH) or the Surface Habitat (SH), will be included in upcoming revisions of this document as will operations during transit to Mars and Mars surface **<FWD-EHP-10033-001>**.

1.1 PURPOSE

The EHP Integrated ConOps detailed in this document are intended to provide the operational context to inform the development of the xEVA System, LTV, and PR projects. This document describes a bounding set of Design Reference Missions (DRM) to provide scope for interpretation and implementation guidance of the controlled requirements in EHP-10012, *Extravehicular Activity and Human Surface Mobility Program (EHP) System Requirements Document*. The ConOps are informed by the Moon to Mars (M2M) Program Office, a multitude of exploration studies and are also influenced by various integrated field testing and analog missions. This document decomposes higher level concepts of operations and relays further detail focusing on EVA, LTV, and PR for EHP. Results from pertinent integrated operational tests (analogs) were utilized to provide relevant data for informing concepts, fleshing out capabilities, and evolving systems. For spacesuit and lunar surface rover developers, this document provides the basis of what is operationally expected in a given environment. It will also help to provide context for element pre-formulation integration and eventually Mars operations.

1.2 SCOPE

This document describes concepts of operations, assumptions, and preliminary high-level objectives for EVA operations aboard Gateway in cis-lunar space, and for both EVA and mobility operations during Artemis lunar surface operations, and eventually for surface operations on Mars. Mission descriptions, potential vehicles and assets, and several possible EVA tasks are discussed. It is intended that the information presented in this document be provided in sufficient detail to enable high-level design requirements development, interface development, alignment with architecture definition, and to provide context for requirement verification at the Program level as well as guidance for each project level. The ConOps will continue to evolve and mature as information from testing becomes available and the exploration architecture missions evolve.

1.3 CHANGE AUTHORITY AND RESPONSIBILITY

The EHP Board Authority for Approval of this product is the EHP Control Board (EHPCB). Board Authority for future revisions of this product is not delegated. Board Authority for changes is the EHPCB.

The administration of future revisions will be managed by the Office of Primary Responsibility (OPR). Proposed changes to this product shall be submitted via Change Management Workflow (CMW). All such requests will adhere to the EHP-20000, *Extravehicular Activity and Human Surface Mobility Program (EHP) Configuration and Data Management Plan*.

The appropriate NASA OPR identified for this document is the Systems Engineering and Integration (SE&I) Office within EHP.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

TABLE 2-1: APPLICABLE DOCUMENTS

Document Number	Document Revision	Document Title
N/A	April 2023	NASA's Moon to Mars Strategy and Objectives Development
EHP-10012	A	EHP System Requirement Document
ESDMD-001	A	Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Definition Document
M2M-30002	Baseline Draft	Artemis Requirements Document
M2M-30007	Baseline Draft	Artemis Integrated Concept of Operations (ConOps)

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document.

TABLE 2-2: REFERENCE DOCUMENTS

Document Number	Document Revision	Document Title
ACD-50015	Baseline	Artemis Configurations Description Document (ACDD)
ACD-50044	A	Artemis Campaign Development (ACD) Lunar Surface Data Book
AIST010	May 13, 2024	Artemis Internal Science Team (AIST) Adjudication Memo
CAPTEM	1 September 2010	Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) Review of Sample Acquisition and Curation During Lunar Surface Activities report
EHP-10025	Baseline	Extravehicular Vehicle Activity and Human Surface Mobility (HSM) Program (EHP) Planetary Protection Plan
EHP-10028	Baseline	EHP xEVA System Compatibility Standards
EHP-10031	Baseline	EVA/Human Surface Mobility Program Artemis Lunar Exploration Crew Handheld Camera Concept of Operations (ConOps)
EHP-10041	Baseline	Extravehicular Activity and Human Surface Mobility Program (EHP) Pressurized Rover (PR) Concept of Operations (ConOps)
ESDMD-006	A	Exploration Systems Development Mission Directorate (ESDMD) Utilization Plan
ESDMD-411	Version 1	Representative Utilization Instruments for the LTV and PR
EVA-EXP-0042	C	Extravehicular Activity (EVA) Office Exploration EVA Systems Concept of Operations (ConOps)
GP 10027	B	Gateway Concept of Operations (ConOps)
HLS-CONOP-001	C	Human Landing System (HLS) Concept of Operations (ConOps) – Initial Phase Mission (Artemis III)
HLS-CONOP-006	A	Sustained Phase HLS Concept of Operations (ConOps)
HLS-CONOP-007	A	Human-Class Delivery Lander Concept of Operations (ConOps)
HLS-CONOP-008	A	HLS Sustaining Phase RF Communications Concept of Operations (ConOps)
HLS-PAP-034	Baseline	HLS Program Backup Crew Strategy for Sustained Lunar Missions
LTV-CONOP-001	A	Lunar Terrain Vehicle (LTV) Concept of Operations (ConOps)
M2M-32105	B	Moon to Mars Program Medical Operations Requirements Document (MORD)
M2M-51103	A	Mission Definition Baseline (MDB) for Artemis III

TABLE 2-2: REFERENCE DOCUMENTS

Document Number	Document Revision	Document Title
NASA/SP-20205009602	N/A	Artemis Science Definition Team Report
NASA-STD-3001 Vol 1	C	NASA Spaceflight Human-System Standard Volume 1: Crew Health

3.0 NASA CAMPAIGN AND MISSIONS OVERVIEW

EHP provides the capabilities necessary to safely execute missions for the Artemis Campaign in cis-lunar space on Gateway and on the lunar surface for initial and sustained human missions to pave the way for humans to go to Mars. ESDMD-001, *Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Definition Document* describe the goals and objectives, operational requisites for exploration missions, and functions of elements needed for each exploration missions ranging from human lunar return to extended duration Lunar missions and ultimately to the Martian surface. ESDMD-001, *Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Definition Document*, and architecture baseline and exploration strategy will be decomposed here in this ConOps document.

NASA's Moon to Mars Strategy and Objectives document identifies and describes the NASA science and technology utilization goals and objectives that will be enabled by human missions. These goals and objectives have been defined by the NASA Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD), and with the reorganization and split of the Human Exploration and Operations Mission Directorate (HEOMD), now represented by ESDMD and Space Operations Mission Directorate (SOMD). The goals and objectives will be used to identify the manner in which human missions will support the science and technology communities in conducting fundamental research about our universe and solve the scientific and technological challenges for sustaining and expanding human exploration missions. The utilization goals and objectives are implemented through science and technology activities across the ISS, Commercial Low Earth Orbit (LEO) utilization, the Artemis missions to cis-lunar space and the lunar surface, and the first human crewed missions to Mars. EHP capabilities are focused on crew transport and exploration, while supportive of long-term science needs to the greatest extent possible. Prioritizing interoperability and flexibility allows for updated science objectives, instrument exchange, and new technologies throughout the Artemis missions.

3.1 MOON TO MARS OVERVIEW

The M2M-30007, *Artemis Integrated Concept of Operations (ConOps)*, lays out the more tactical missions for Gateway and human lunar return. The Artemis architecture implements the Moon to Mars Strategy and Objectives to "blueprint a sustained human presence and exploration throughout the solar system" by providing enabling capabilities in cis-lunar space and on the lunar surface through Gateway station, Human Lander System (HLS), Lunar surface elements, and Common Exploration Systems Development (CESD) Enterprise comprised of Exploration Ground Systems (EGS), Space Launch System (SLS), and Orion. For Artemis, NASA leads a geographically distributed team of international and commercial partners that provide hardware, software, and operations support. During real-time execution of crewed missions, Mission Control Center – Houston (MCC-H) has mission authority to ensure crew safety and mission success.

The first objective is to leverage the lunar surface and cis-lunar space to conduct experiments to learn more about the universe, our solar system, the Moon, and Earth. The second objective is to demonstrate technologies and space exploration techniques that will ultimately enable a human crewed mission to Mars.

3.2 GATEWAY OVERVIEW

EVA capability out of Gateway will be possible once the Gateway airlock arrives. Gateway EVAs are assumed to be performed while there are four crew on Gateway. Gateway EVAs for activities other than planned maintenance are currently being assessed, as any maintenance items would need to be delivered to Gateway prior to the crew arriving. An exception would be a planned EVA to demonstrate functionality of the systems once the airlock is operational. Gateway will have the capability to perform up to two EVAs per mission, if necessary and maintenance items are available. Currently, xEVA suits are planned to be delivered to Gateway and are dedicated to Gateway (i.e., lunar EVA suits are not used on Gateway). EVA operations in cis-lunar space from an airlock on Gateway will follow a similar approach to those performed from the ISS airlock. EVAs performed at Gateway will not preclude a lunar surface mission, and time may not be available for EVAs on every Artemis mission.

3.3 LUNAR SURFACE OVERVIEW

The EHP Projects supporting operations in partial gravity on the lunar surface will begin with the xEVA System, followed by the LTV, and then the PR. Initially, two crewmembers will descend to the Moon and perform EVAs on the surface from HLS. EVAs will be performed by two crewmembers on each EVA (i.e., "buddy system") at first by walking traverses, and then aided by the LTV to enable longer traverses and provide support to deploy payloads and transport tools, samples and eventually logistics transfer to habitable surface assets. Logistics transfer on the lunar surface **<TBD-EHP-10033-007>** will play a major role once the PR arrives, which provides a habitable mobile platform capability. The PR will have the functional capabilities to allow the two crewmembers to stay for longer durations on the lunar surface. Once a second habitation element arrives on the lunar surface, four crew will descend and live on the surface (two in the PR and two in a habitation element).

The NASA Commercial Lunar Payload Services (CLPS) allows for acquisition of lunar delivery service for payloads that could require crew interaction. International Partners will also contribute to the development of assets which could include the PR and the MPH module which will help extend the range that crewmembers can explore on the lunar surface to increase utilization points of interest. ESDMD Strategy and Architecture Office (SAO) studies are ongoing for MPH, SH, and large lander concepts which include delivery of robotics, habitation, and cargo.

Landing sites and the specific mission objectives are still in work and will be referenced in mission specific Artemis Mission Definition Baseline documentation to guide the development of systems and tools to support utilization in those locations.

4.0 MOON TO MARS TERMINOLOGY AND MISSION DESCRIPTIONS

EHP leverages and is consistent with the M2M-developed terminology associated with Artemis which will be distinct from ISS terminology. ACD-50015, *Artemis Configurations Description Document (ACDD)*, lays out potential configurations which can be applied to the DRMs in the following sections.

4.1 ARTEMIS LUNAR MISSIONS

Many different concepts of operations exist for the lunar surface from DRMs listed in M2M-30007, *Artemis Integrated Concept of Operations (ConOps)*, ACD-50007-ANX01, *Artemis Lunar Surface Concept of Operations (ConOps)*. The Exploration Campaign Segments addressed in the Artemis ConOps document are Human Lunar Return, Foundational Exploration, and Sustained Lunar Evolution. DRMs 1 and 2 are not directly applicable to EHP. DRMs are described in M2M-30007 as:

- DRM 3: Crewed Initial Lunar Surface Landing (Initial Surface Capability)
- DRM 4: Lunar Orbit Sustained Presence (Initial Gateway Capability)
- DRM 5: Expanded Lunar Exploration (Evolved Gateway w/Airlock & Initial Lunar Mobility – LTV)
    - LTV Uncrewed Surface Operations
    - Gateway EVA
- DRM 6: Extended Surface Operations (Enhanced Lunar Surface Mobility Capability – PR
    - PR Uncrewed Operations
- DRM 7: Initial Pressurized Surface Habitat (Habitation Capability includes MPH)
- DRM X: Non-Polar Sortie Mission

Lunar missions will allow for continued scientific research of the Moon, along with providing a critical test bed for concepts of systems bound for Mars. These missions will progress with a phased approach, starting with smaller short missions and expanding to a long duration, sustained human presence on the surface. These missions will initially take place in a south polar region (84 to 90 deg south), with occasional sorties to different non-polar landing sites spread across the surface of the Moon (DRM X). xEVA System cargo will be dependent on the number of EVAs and duration, science objectives/tools, and xEVA suit providers for each mission and each DRM. xEVA system mass can vary from a mission-to-mission basis but is constrained in requirements. No EVAs take place from HLS in Near-Rectilinear Halo Orbit (NRHO).

This ConOps will lay out lunar DRMs with further EHP level detail for crewed Artemis missions as well as uncrewed ConOps for Supporting Mission Excursions. This includes autonomous, semi-autonomous, and remote operations of the LTV and PR.

4.1.1 DRM 3: Crewed Lunar Surface Landing - Initial Lunar Landing Capability

Initial missions to the lunar south polar region will consist of two crewmembers going to the lunar surface for approximately 6 days. The number of EVAs could vary depending on vehicle capability, xEVA suit capability, utilization objectives and crew time; however, the capability to turn around and perform daily EVAs within the given mission parameters will be available. Currently, Artemis III is consistent with the DRM 3 mission profile.

TABLE 4-1: DRM 3 KEY PARAMETERS

Surface System Configuration	HLS, xEVA	
Key Objectives	• Demonstrate Surface Landing Capability • Conduct geological traverses, perform science observations and activities including the collection of a variety of samples to return to Earth for later research	
Key Parameters	Surface Crew	2
	Surface Stay	~6 Days
	Proposed Number of EVAs per Crewmember	Up to 4 Nominal + 1 Additional
	EVA Range (from HLS)	< 2 km **<TBR-EHP-10033-005>**

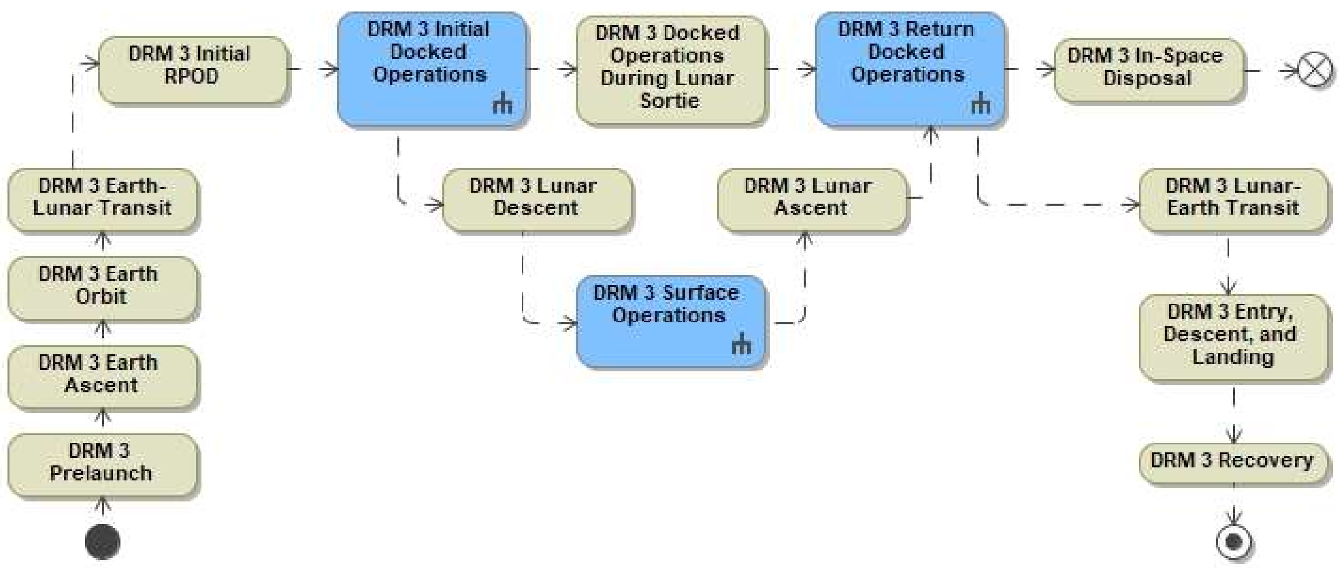

FIGURE 4-1: DRM 3 OVERVIEW

The first DRM 3 mission is a direct dock between Starship and Orion prior to lunar descent. Two crewmembers stay on Orion, while two crewmembers transfer to Starship (SpaceX HLS vehicle) for the lunar surface sortie.

4.1.1.1 DRM 3 Initial Docked Operations

EVA equipment is launched on Starship except the EVA gloves for the two crew that go to the lunar surface. Some equipment (i.e., EVA prime and backup gloves, cameras, map books, cuff checklists, backup crew swap sizing components, etc.) may be sent with the crew on Orion to ensure proper fit. HLS-PAP-034, *HLS Program Backup Crew Strategy for Sustained Lunar Missions*, lays out the HLS Program Backup Crew Strategy for Sustained Lunar Missions. In addition to the primary crew, it is necessary to define a strategy for backup crew members to protect against a pre-launch or post-launch setback that impacts the ability to complete the mission. While a small amount of equipment may be able to launch in Orion, there will be significant mass and volume limitations. Thus, it is expected that only a small amount of EVA equipment will launch on Orion. Backup crewmember items are also sent in Starship and will be swapped out as necessary. As needed, remaining crewmember backup items and launch packaging will be transferred to and left on Orion.

When the crew has completed on-orbit tasks such as xEVA suit assembly and partial xEVA suit checkouts (i.e., power, audio, telemetry) in the lander airlock, the xEVA suits will then be stowed mostly assembled to minimize crew timeline impacts in preparation for lunar descent. Prior to descent, the crew don their HLS-provided Intravehicular Activity (IVA) suits, and wear those during the undock, portions of the descent phase, and lunar landing phase to ensure crew safety.

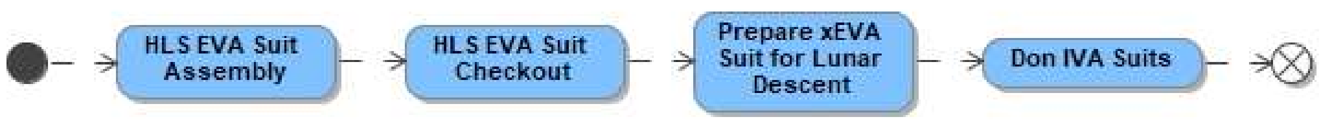

FIGURE 4-2: DRM 3 INITIAL DOCKED OPERATIONS

4.1.1.2 DRM 3 Surface Operations

Immediately following lunar surface touchdown, the HLS and crew, in coordination with MCC, will determine Authority to Proceed (ATP) with the surface mission. Following ATP, the HLS and crew will begin surface stay preparations. This segment includes doffing and stowing their IVA suits, vehicle safing, and cabin reconfiguration. A more complete description of HLS operations can be found in HLS-CONOP-001, *Human Landing System (HLS) Concept of Operations (ConOps) – Initial Phase Mission (Artemis III)*.

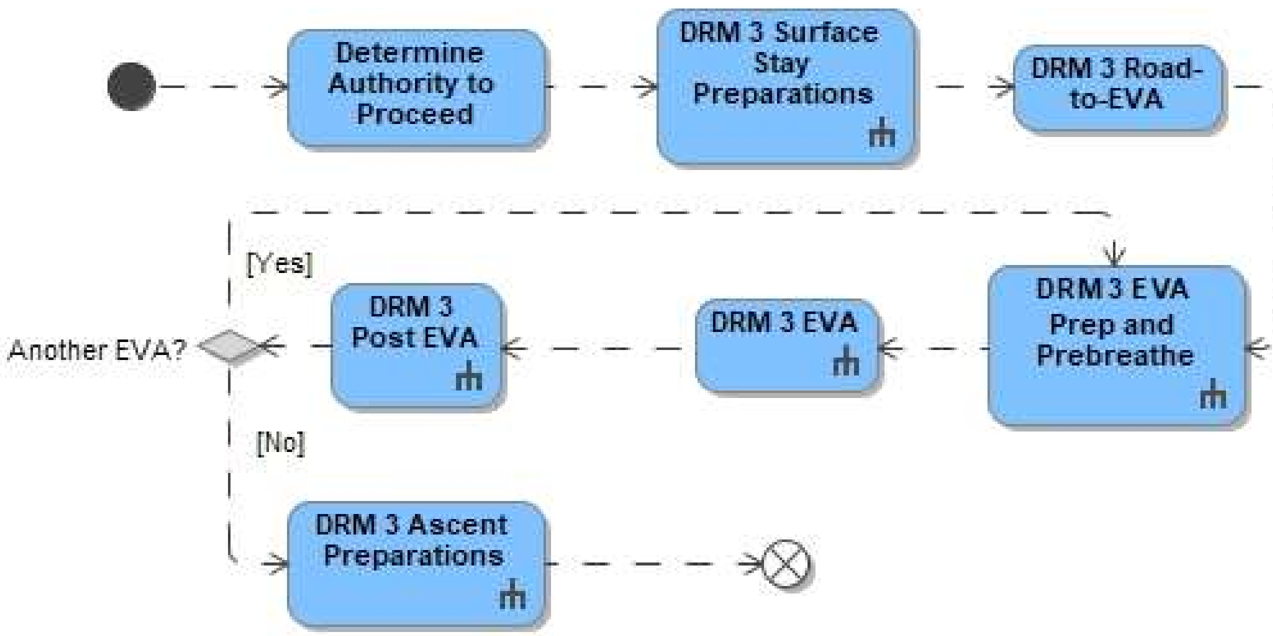

FIGURE 4-3: DRM 3 SURFACE OPERATIONS OVERVIEW

FIGURE 4-4: DRM 3 SURFACE STAY PREPARATIONS

The crew will live in the lander for a surface duration of approximately 6 days during lunar daytime and will perform EVAs from one of two airlocks. Only one of the airlocks will be utilized for initial missions.

The xEVA Suit Consumables Recharge and the EVA System Checkout events may need to take place due to the previous on-orbit xEVA suit fit check/checkout in preparation for the first human lunar return EVA. The number of EVAs performed from HLS will be between two and four EVAs (+one reserved EVA in event of an unplanned or additional EVA need) depending on HLS capabilities and mission science objectives, with each EVA planned to be 4 to 8 hours long (+one hour of reserved consumables in the event of a contingency). The xEVA suit has reserve consumables to support a one-hour contingency return for most suit failures. This one-hour contingency return includes the following activities: recognition of the failure, alerting Extravehicular (EV) buddy, return to the lander, ingressing the airlock, and repressurizing the airlock. Landing site location, science objectives, and the number of EVAs are documented in M2M 51103 *Mission Definition Baseline (MDB) for Artemis III*.

4.1.1.3 EVA Technical Objectives

EVA technical objectives are driven by EHP and EVA Providers and include but are not limited to the following:

- Demonstrate xEVA suit systems performance during IVA and EVA activities
- Demonstrate xEVA suit mobility and outward visibility performance
- Demonstrate Lunar Surface Navigation and Traverse Techniques
- Demonstrate EVA tool and sample containment functionality
- Evaluate lunar dust mitigation activities, including dust transfer, across all vehicle and xEVA suit systems
- Collect EVA metabolic rate data during high met rate activities
- Perform Inspirational Outreach Activities

4.1.1.4 DRM 3 Road-to-EVA

EVA operations on the lunar surface include Road-to-EVA, prep and prebreathe, surface operations, post-EVA, and maintenance. The "Road-to-EVA" is a comprehensive list of all the activities that occur before and up to the day prior to the start of a planned series of EVAs. It includes preparing the xEVA Suit and vehicle interfaces, the lander/airlock, and the tools and equipment, in addition to the crew preparing themselves.

4.1.1.5 DRM 3 EVA Prep and Prebreathe

On the day of the EVA, the crewmembers begin preparation activities and the prebreathe protocol (as applicable). Once the required prebreathe protocol is complete and the crew are ready to egress HLS, the crew initiate cabin/airlock depressurization. The “EVA” phase elapsed time (PET) begins when the spacesuit is switched from the vehicle-provided power source to internal suit power (i.e., batteries).

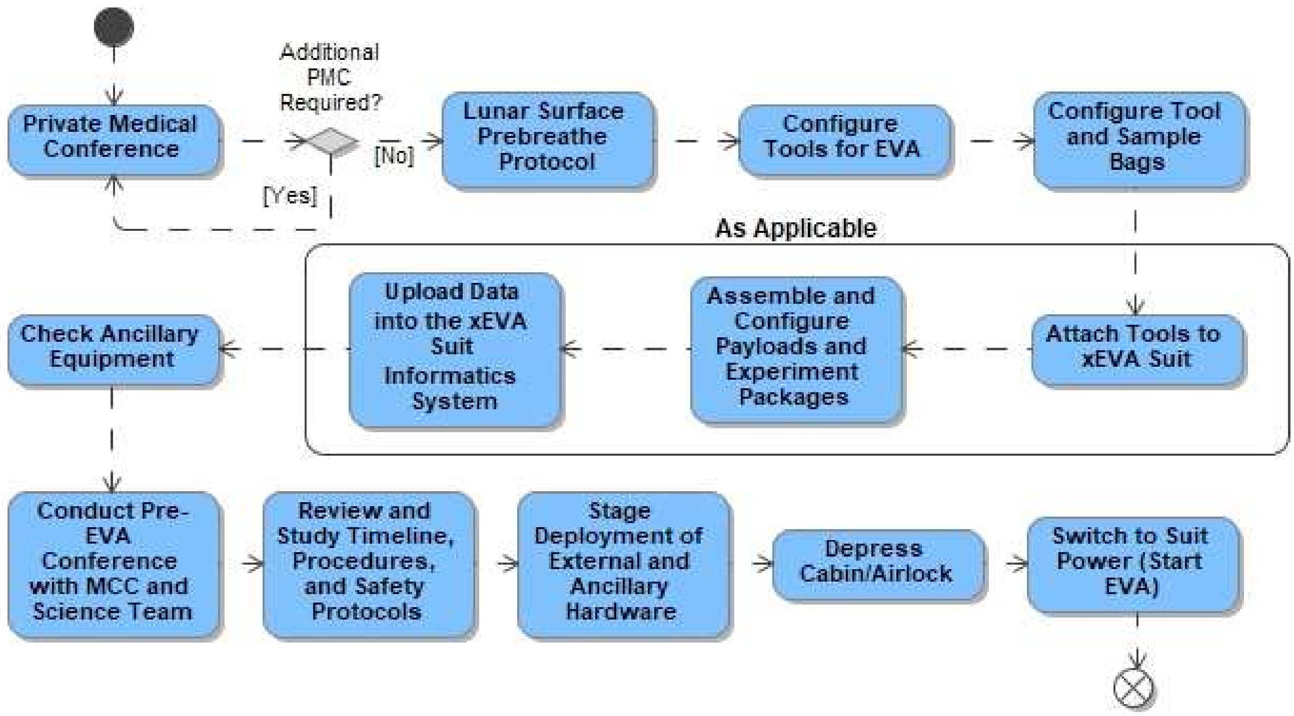

FIGURE 4-5: DRM 3 EVA PREP AND PREBREATHE

4.1.1.6 DRM 3 EVA

The EVA crew open the hatch and gather any equipment they may bring with them from inside the cabin/airlock to the surface. Crew will conduct a final check of tools and equipment on harnesses attached to their xEVA suit and/or in equipment/tool bags. They will destow any tools and equipment from the Starship garage. This may include dust mitigation tools, sample collection tools and instruments, along with equipment to transport tools and samples. They then deploy the elevator and descend down to the surface, utilizing a fall protection system if required. Refer to HLS-CONOP-001 for further information.

Once on the surface, the crew sets up the tools and equipment that are needed for their tasks. The crew will transport smaller tools and equipment to the worksite either directly attached to their xEVA suits or with a harness/carrying system. Larger tools and storage boxes will be transported with an equipment transportation system such as a tools caddy (e.g., a wheeled cart).

In addition to task equipment, the crew will also place the dust mitigation kit where it can be accessed at the end of the EVA. This set of tools will be part of the dust mitigation strategy that the crew will follow during ingress towards the end of the EVA.

One of the first tasks on the first EVA will be collection of an initial sample. This will provide a small science return in the event of any abort. Crew will conduct a multitude of science-focused tasks on the surface. A variety of science-driven tasks will be conducted at any natural environment destination, including observations and imagery, acquisition of data, deployment and retrieval of instruments, and acquiring physical samples for return to Earth. Science tasks will also involve deploying handheld instruments, surface deployed instrument packages, and instruments requiring prolonged crewmember interaction. Imagery using the Handheld Universal Lunar Camera (HULC) during lunar surface EVAs helps to accomplish mission science objectives during traverses and for imaging science targets.

Although unlikely for initial Artemis missions, some tasks will require the EVA crew to scramble up and down steep slopes, possibly using a walking aid to avoid scrambling, traverse across regolith, volcanic terrain, traverse down into craters and back up out of them, and work near or inside Permanently Shadowed Region (PSRs). They will primarily perform geology tasks, characterizing the area and acquiring sample materials.

Nominally, upon completion of an EVA, or having reached predetermined consumables or time limits, the crew will gather their tools, samples, and equipment, and stow them. The crew will pack equipment and science samples into the equipment transportation system and begin traversing back to the lander. Once back at the lander, the crew may then start the dust mitigation procedure to reduce what is brought back into the vehicle. Dust and contamination accumulated on the surface of the xEVA Suit is mitigated prior to ingress of the airlock to limit contamination to the habitable volume and is achieved via both EVA system-provided methods and vehicle-based hardware. These steps will include cleaning the xEVA suits, bags, tools, and hatch in a multi-layer approach. Note that in some contingencies, dust removal may not be possible prior to ingress.

Once this portion of the dust mitigation process is complete, the crew will begin ascent into the lander, utilizing any fall protection that is required. At the hatch, the crew may conduct more dust mitigation steps, and then will work together to move the sample bags inside and stow them according to the science plan. They will restow any tools and equipment in the Starship garage. After ingress, the crew will connect umbilicals to the xEVA Suits and switch to vehicle power and consumables. The crew will then close the hatch and begin repressing the lander/airlock. The EVA PET clock officially ends after repressurization has initiated.

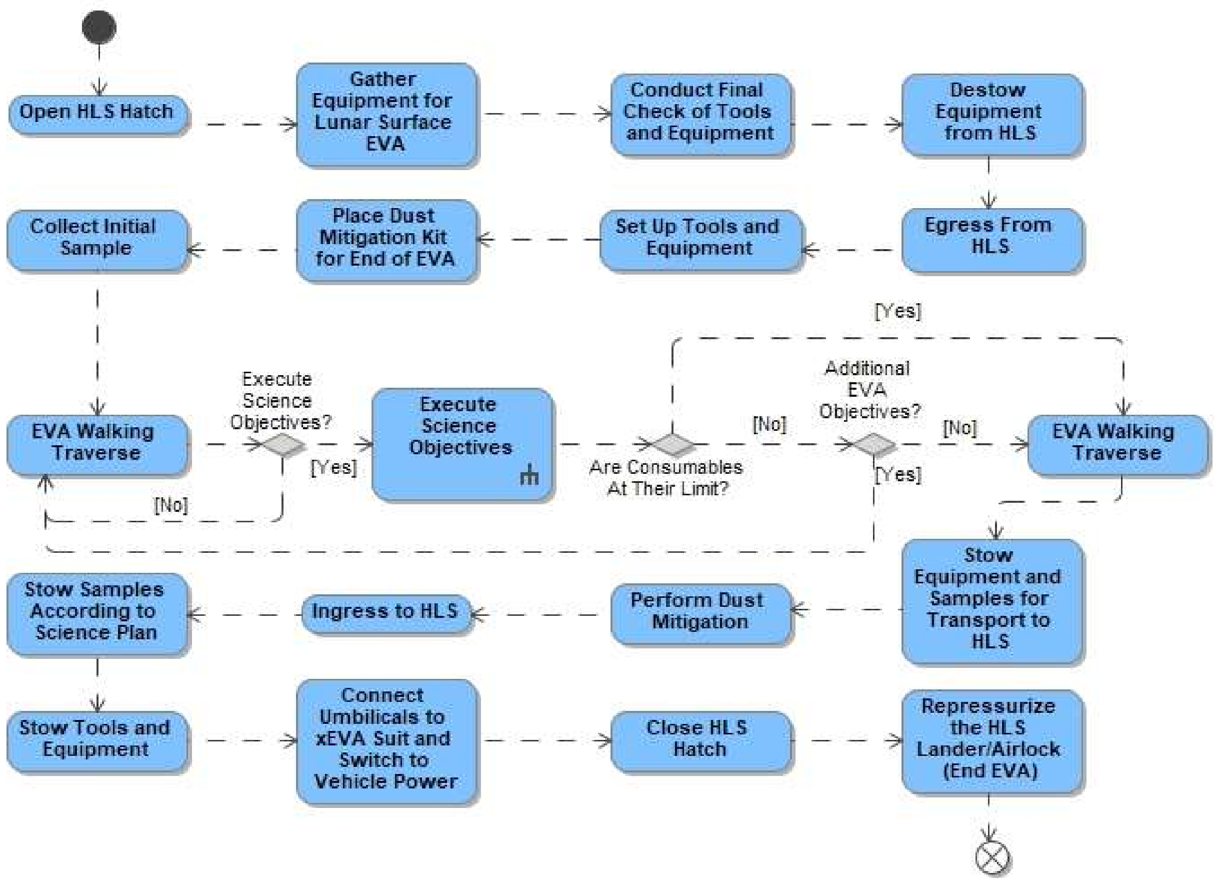

FIGURE 4-6: DRM 3 EVA

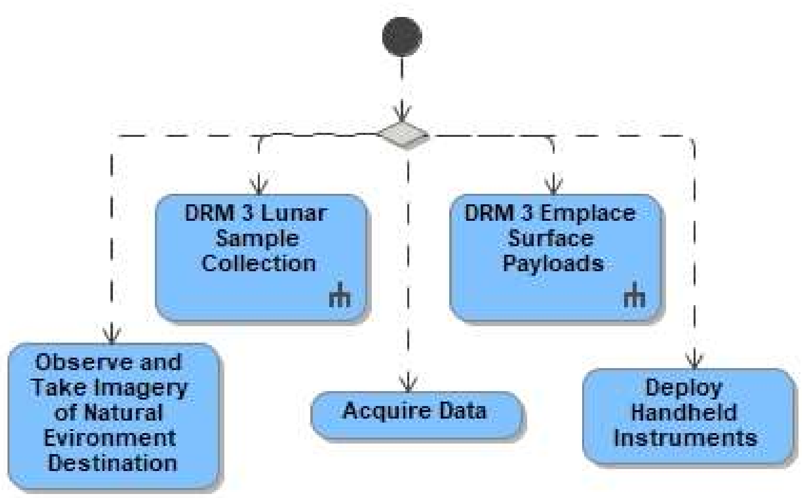

FIGURE 4-7: DRM 3 SCIENCE OBJECTIVES

4.1.1.7 DRM 3 Utilization Operations

Artemis human missions designed to explore new and diverse areas of the lunar surface are necessary to collect critical science data, to address high-priority Artemis science objectives, and to prepare for longer duration Artemis missions in the future. As NASA explores new terrain, the ability of scientifically-trained crewmembers to provide detailed geologic descriptions and document their findings will enable a new view of lunar science. The meticulous collection, curation, and return to terrestrial laboratories of lunar samples will unlock a new era of lunar and planetary science. The in-situ use of both handheld instruments during traverses and deployed science payloads at different locations on the Moon will provide crewmembers and science teams with crucial data, both during an exploration mission and post-crew departure. Activities to characterize and understand the geology of the lunar south polar region are the foundation for a utilization plan for resources (e.g., sunlight, water, and other volatiles) that could be used to establish a long-term human presence on the lunar surface. At Regions of Interest (ROIs), the EVA crew will primarily perform geological tasks, characterize the area, and acquire sample materials. They will move and assemble hardware, take measurements of fields or the environments, and deploy utilization instruments. Reference ESDMD-006, Exploration Systems Development Mission Directorate (ESDMD) Utilization Plan for further details on NASA's science and technology utilization goals and objectives that will be enabled by human missions.

This section will provide potential examples of operational scenarios for the mission. It is not intended to document every possible science/technology objective but to display concepts to drive requirements.

4.1.1.7.1 Lunar Sample Collection

On the lunar surface, EVA crew will conduct a multitude of science-focused tasks that trace to landing site specific objectives within the mission Science Traceability Matrix. Once in ROIs, the crew will apply pre-mission geoscience training to explore and characterize an area, conduct initial inspections of the surroundings, record context documentation, and utilize sample markers to identify target samples.

Science operations will include the EVA crew navigating to new or recurring ROIs with tools necessary for sample collection. The EVA crew may utilize navigation systems to confirm their location, allow MCC to track their progress, allow crew to safety return to the lander, and record position data with the necessary accuracy needed by the science team. Several different types of Regolith samples can be taken on the lunar surface, including bulk (scoop) samples, Core samples taken with a Drive Tube, Surface Samples taken with a Contact Sampler, Volatiles, and Trench samples. Geology sample collection will need to be orchestrated such that samples are collected on the side of the suit opposite to the vacuum access port, to ensure that there are no suit exhaust contaminants in the collected samples. There are several different kinds of rock samples that can be retrieved from the Lunar Surface, including float, chip, or rake samples. Samples are weighed either EVA or IVA before going into an IVA sample return pack.

Reference EVA-EXP-0042, *Extravehicular Activity and Human Surface Mobility Program (EHP) xEVA System Concept of Operations (ConOps)*, for further details on Lunar xEVA Operations and xEVA Tools.

Furthermore, the Artemis Science Definition Team Report (NASA/SP-20205009602) provides a nominal candidate sampling program appropriate for Artemis crewed sortie mission periods to support necessary science investigations. The Lunar Exploration Analysis Group (LEAG) Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) Review of Sample Acquisition and Curation During Lunar Surface Activities report, dated 1 September 2010, provides additional historical data on the Apollo sampling program and lessons learned that can be drawn upon while planning the next lunar sample collection opportunities.

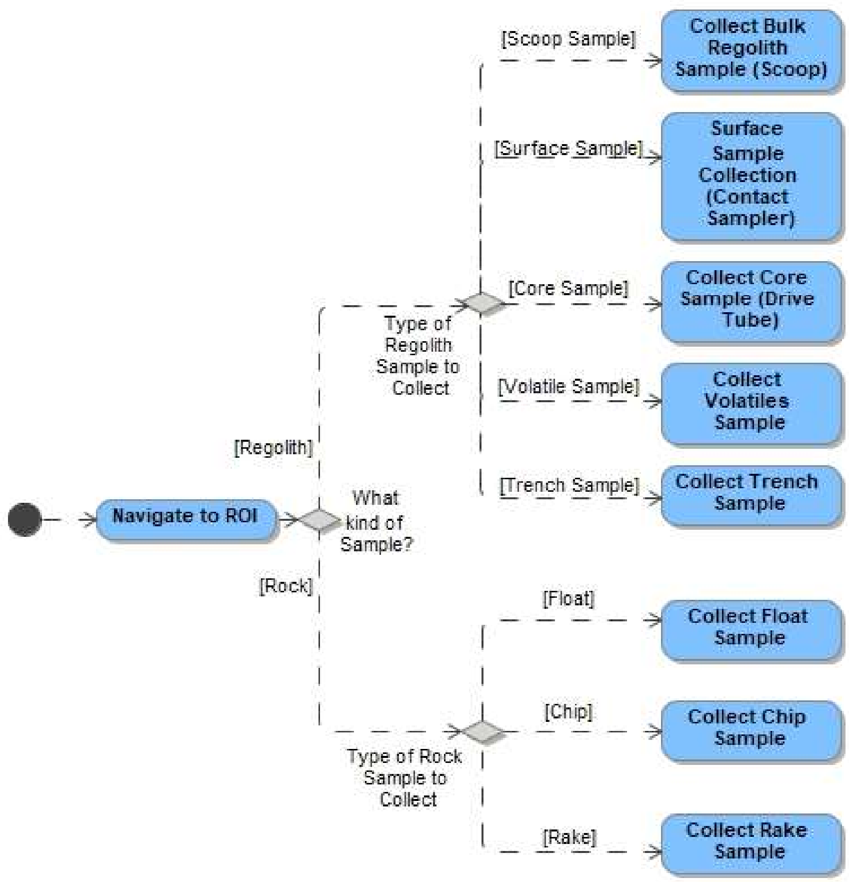

FIGURE 4-8: LUNAR SAMPLE COLLECTION

4.1.1.7.2 Deployed Surface Instruments

Science operations will include deploying science instrumentation packages by the crew on the lunar surface. Instrument examples include geophysical and environmental monitoring, instruments to investigate the effects of long-term exposure of materials to the lunar surface environment, and other surface instruments that will address priority science objectives. Inside HLS prior to the EVA, the crew may assemble, charge batteries, perform a checkout of the science payload hardware, and temporarily stow payloads in a location easily accessible for removal. Payloads may also be accessible from an unpressurized location on HLS and uninstalled from the vehicle for deployment during the EVA.

Once the crew transfers the payload to the lunar surface, the crew then carries, or delivers via cart or carrier, the science instrument to its intended location. The crew will proceed to deploy the payload, which may include orienting antennas or solar panels in the correct position or ground installation. Following deployment, the crew may need to power on the payload, perform calibration steps, and verify the payload is in a nominal operational state with confirmation from the ground team. While the crew traverses along the lunar surface completing other tasks, the payload will continue to collect data. Data path to the ground may include multiple options to route data through the lunar assets or could be self-contained. Once the data is received on the ground it then will be distributed to the Payload Developer who confirms the instrument is operating nominally. Science instrumentation and/or non-geological samples (e.g., hard drives, regolith-derived products, biological specimens, etc.) may be collected by the crew following other task completion and taken back inside the crew lander or may be left behind on the lunar surface to continue science collection during uncrewed periods.

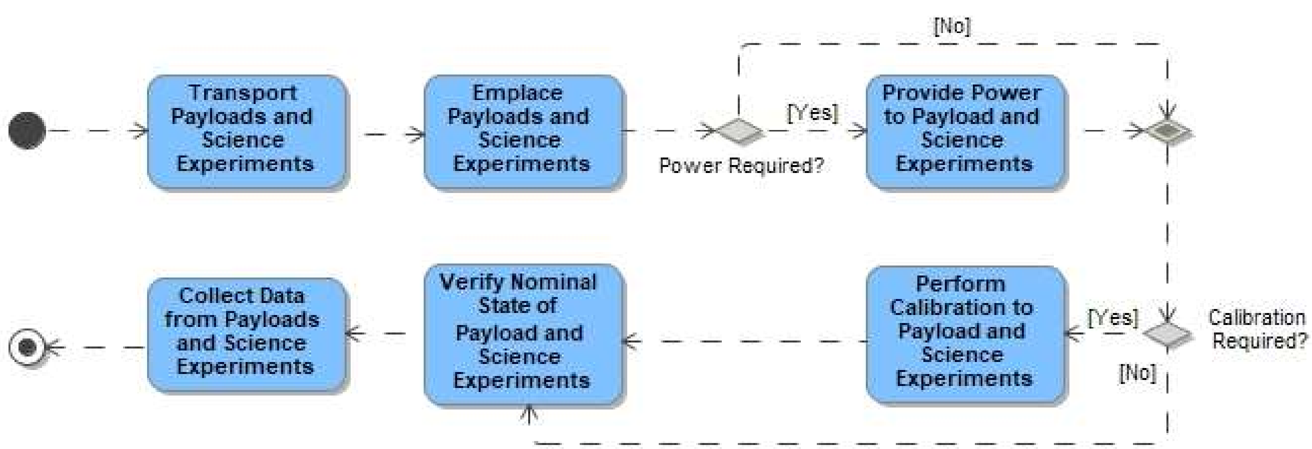

FIGURE 4-9: EMPLACE SURFACE PAYLOAD

4.1.1.7.3 Portable/Handheld Science Instruments

Portable/Handheld science instruments may aid the crew during their geological tasks and can provide valuable insight to the science team's determination of sample collection. For example, an X-ray Fluorescence spectrometer could be used to determine the elemental composition of materials in lunar samples. A temperature sensor may also be utilized to provide additional data of the sample environment within shadowed regions. Pre-EVA, the crew would gather the instrument, verify the instrument battery is fully charged, verify the instrument is operational, and temporarily stowed on the xEVA suit, tool cart, carrier, or bag for use during EVA. Once at the ROI, the crew will utilize the instrument to collect data on candidate samples. The data will be transmitted manually or automatically (by the crew or flight controllers) to the ground team for documentation. and the crew will then receive further direction from the science team on samples to be collected. Once complete with data collection, the device would then be hand-carried or stowed on the xEVA suit or Tool Cart for the traverse back to HLS.

4.1.1.8 DRM 3 Post EVA

Following ingress, the crew will conduct post-EVA activities. Turn-around time is from EVA start of repress and ends at switch to internal xEVA suit power of next EVA. Crew time must be coordinated between EHP systems, host vehicles, and any other systems supporting EVA to enable minimal crew intervention for the system to be turned around within 16 hours. The don/doff aids will provide structure for crew to don/doff the suit unassisted. The HLS Environmental Control and Life Support System (ECLSS) will help to remove any particulates in the atmosphere. Crew may don HLS Personal Protective Equipment (PPE) until dust levels are acceptable. After cleaning, inspection, and xEVA suit recharge is initiated, the required xEVA Suit data is downloaded.

Note: Most of the data download occurs automatically via Wi-Fi interface; however, some data may need to be downloaded manually.

In addition to post-EVA inspections, the xEVA suits may require maintenance, however, no preventative maintenance is foreseen for Artemis III or IV. Maintenance may include replacement of gloves. A post-EVA Private Medical Conference (PMC) is conducted with each EVA crew. Also, a post-EVA conference with MCC and Science Team is conducted to debrief on the EVA.

Note: Post-EVA PMCs may serve as pre-EVA PMCs for subsequent EVAs to assess crew health and readiness.

Reference EVA-EXP-0042, *Extravehicular Activity (EVA) Office Exploration EVA Systems Concept of Operations (ConOps)*, for further details on Road-to-EVA, xEVA Systems Prep, prebreathe, egress and setup, science tasks, cleanup and ingress, maintenance, and post EVA operations.

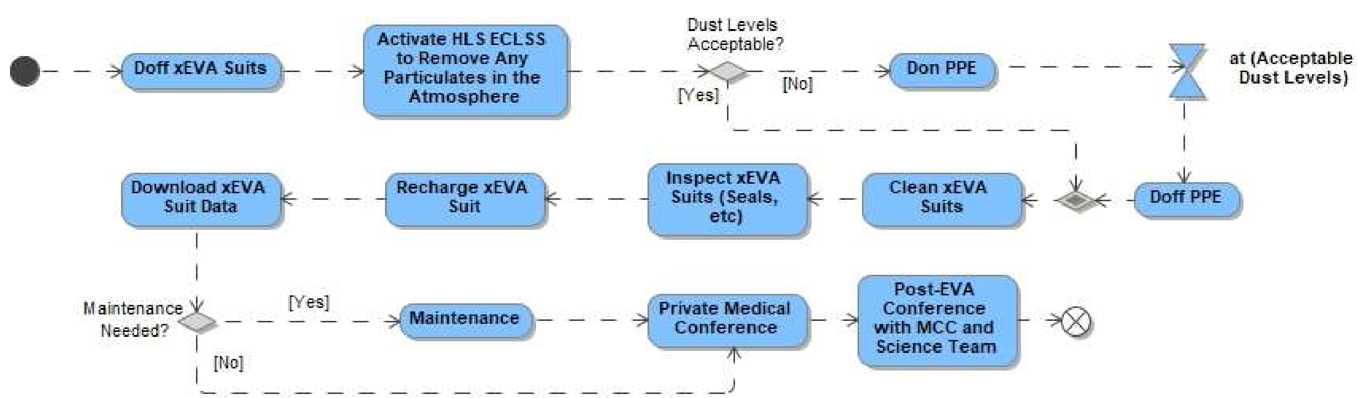

FIGURE 4-10: DRM 3 POST EVA

4.1.1.8.1 DRM 3 Communications, Navigation, and Lighting

DRM 3 xEVA suits provide simultaneous communications between HLS and EVA crewmembers and/or potential lunar surface communication relays by providing video, voice, and suit data communications and crewmember biomedical telemetry. All real-time communication between EVA crewmembers and Earth will be relayed via HLS.

Real-time transmission from xEVA suit is always subject to momentarily loss of data. Since all data recorded during an EVA is likely to be of interest, only having one chance to receive it would be problematic. After an EVA is completed, additional data (that was either not selected broadcast real-time or data that was lost in transmission) may be downloaded from the xEVA Suits and/or EVA equipment/sensors. Once transferred to HLS, the data is subsequently transmitted from HLS to Earth via the same paths listed above.
xEVA suits using Ultra-High Frequency (UHF) (for audio/telemetry) and Wi-Fi (for video/telemetry) may encounter limitations on distance the crew can traverse (<2 km) from HLS **<TBR-EHP-10033-005>**. HLS provides the vehicle side of the EVA wireless radio, antennas, and hardline audio and data connections for the xEVA System umbilicals for two-way communications of EVA voice/data as well as downlink of EVA video.

Time synchronization takes place by using Network Time Protocol Version 4 (NTPv4) compatible format such that all systems can synchronize and agree on a time stamp reference.

The crew will stay in communication with the lander according to Flight Rules. They will walk across regolith and around boulders, up/down slopes of up to 20°, in long shadows, and into PSRs. The crewmembers will likely go into a small, shadowed area (an area smaller than ~5 meters) and collect a sample to be returned in a vacuum sealed container under ambient conditions. These small shadowed areas are sometimes called micro-PSRs or cold traps; within this document, a “small shadowed area” is an area where the surface temperature remains below the nearby surface temperatures. Reference *AIST010 Artemis Internal Science Team (AIST) Adjudication Memo*.

Crew will use coarse navigation systems and navigation aids **<TBD-EHP-10033-006>** to determine their location and their next heading to reach the selected science zones. Both verbal communication and helmet camera feeds will allow the MCC-H to track the crew location and progress improve the chances of a safe return to the lander both nominally and in a contingency. The navigation strategy for EVA from HLS during DRM 3 is currently planned to be primarily orienteering with paper-like navigation aids to support their navigation needs (e.g.; a map book, sun compass, range scale and sighting compass are currently proposed). A standalone navigation system demonstration is also planned (detailed test objective [DTO] for Artemis 3 and certified for Artemis 4) capable of location knowledge of 150-m and heading knowledge of 10-deg.

The crew will experience constant long shadows near the lunar South Pole, while also looking nearly directly at the Sun. In order to traverse safely and effectively through the partially and fully shadowed terrain, across rough terrain and slopes, and into PSRs, crew will need to have access to supplemental lighting options and countermeasures (e.g., sun visors, reflective material, etc.). Supplemental lighting options could include xEVA suit-mounted (lights that move with the crew's change of field of view), portable lamp stands (handsfree) that can be placed around a task area away from a major surface asset, high intensity spot lights for viewing far away targets, and handheld illumination options that allow the crew flexibility to direct light in specific directions. The integrated surface lighting plan will be unique for each task for each lunar lighting condition and that task's position with respect to other major surface assets. Early Artemis missions may have limited lunar surface EVA task capability because of limited lighting countermeasures and surface assets not yet in place to maintain crew safety. The quantity of lamps, the power allocation, the optics, and positioning are all unique to the tasks and surface conditions. These surface assets require planning for the mission and DRM through human in the loop evaluations, integrated lighting and cameras evaluations, and physics-based lighting prediction models and simulations. Traverses and tasks will need to consider the full lighting spectrum, from direct Sun to dark shadows. Thermal ranges in dark shadows will also play into EVA duration in these areas.

Artemis EVA surface operations will experience low angle sunlight that is very slow to change due to the lunar month-long day/night cycle. This low angle sunlight creates extremely long shadows; overhead lighting from the sun is not present. The persistent lack of overhead lighting for general and specific tasks creates a need to provide light at angles that best illuminates the ground and tasks located at “working heights” (waist level). Overhead lighting requires consideration on operational work area, mounting height, glare, power, beam distribution, and quantity of light sources. Lighting systems architectures should be driven by the limitations of the environment and surrounding architectures where the task is located, along with consideration of task performance goals and limitation of the humans and machines required to operate within that environment. The simple assessment of “provide a light and problem is solved” does not take into consideration the challenges associated with human adaptation nor limitations of imaging systems required to operate within that environment. There are many potential tasks the crew could experience, but the following should be accounted for and provisioned accordingly, while considering challenges presented by the lunar lighting environment:

- Inspections of surface support hardware and lander surfaces for damage – Inspections could be direct visual observations by the crew and also include the usage of camera systems for reporting information to the ground. Environmental conditions could be high contrast, so the crew needs to be provisioned with lighting to improve quality of visual inspections of areas that appear to be poorly lit due to shadowing, dark materials, or high contrast due to shadows.
- Translation via walking, jumping, climbing – Visual challenge is recognizing hazards to avoid injury. Hazards could be hidden depending on lighting conditions.
- Performance of maintenance and repair tasks – Maintenance and repair will require more illumination than simple translation because of higher visual acuity needs. High-contrast surface lighting conditions could influence lighting countermeasures and operations plans for maintenance activities. Lighting accommodations need to maintain high-quality light source spectrums to maximize color and color contrast for the observer (crew and camera).
- Performance of science inspection tasks – Science tasks such as rock collection will require lighting considerations similar to maintenance and repair tasks. Lighting accommodations need to maintain high quality light source spectrums to maximize color and color contrast for the observer (crew and camera).

4.1.1.9 Lunar Walk Back Distance (no rovers)

The xEVA Suit will enable EVA crew the ability to ambulate (walk) on the lunar surface. This includes being able to support a walking traverse of up to 2 km radial distance away from the lander on the lunar surface, though distance depends on the local terrain and communication ranges. The EVA crew must have the ability to return safely inside a pressurized vehicle within a one-hour window in the event of specific contingency scenarios, such as a failure of the primary ventilation system, thermal control, or power. Traverse ranges are based on the xEVA contingency systems providing an hour of contingency capability. Actual distances traveled will need to account for several return traverse factors such as terrain, crew metabolic rate, lighting conditions, navigation, vendor design, etc., and take into account time for potential contingency identification, HLS ingress meaning that the crew may need to walk faster than 2 km/hr. See Integrated Contingencies section for further details.

4.1.1.10 DRM 3 Ascent Preparations and Orion Docked Operations

Prior to crew departure from the destination, the crew will prepare/stow the xEVA suits and any other tools for ascent. The crew don their IVA suits for HLS ascent and docking to Orion. Once docked to Orion, the crew transfer to Orion any samples for return to Earth, and any launch packaging/hardware previously left on Orion to HLS for disposal. xEVA suits are left on HLS for disposal.

FIGURE 4-11: DRM 3 ASCENT PREPARATIONS

4.1.2 DRM X: Non-Polar Sortie Mission

Non-polar sortie missions will be very similar to Artemis III and IV missions; however, environments and lighting will be different. The surface stay time will be no longer than 6 days but may be shorter (e.g., 2-day threshold) if the mission calls for a longer time in-transit from NRHO or in Low Lunar Orbit (LLO) loiter.

4.1.3 DRM 4: Initial Gateway Capability

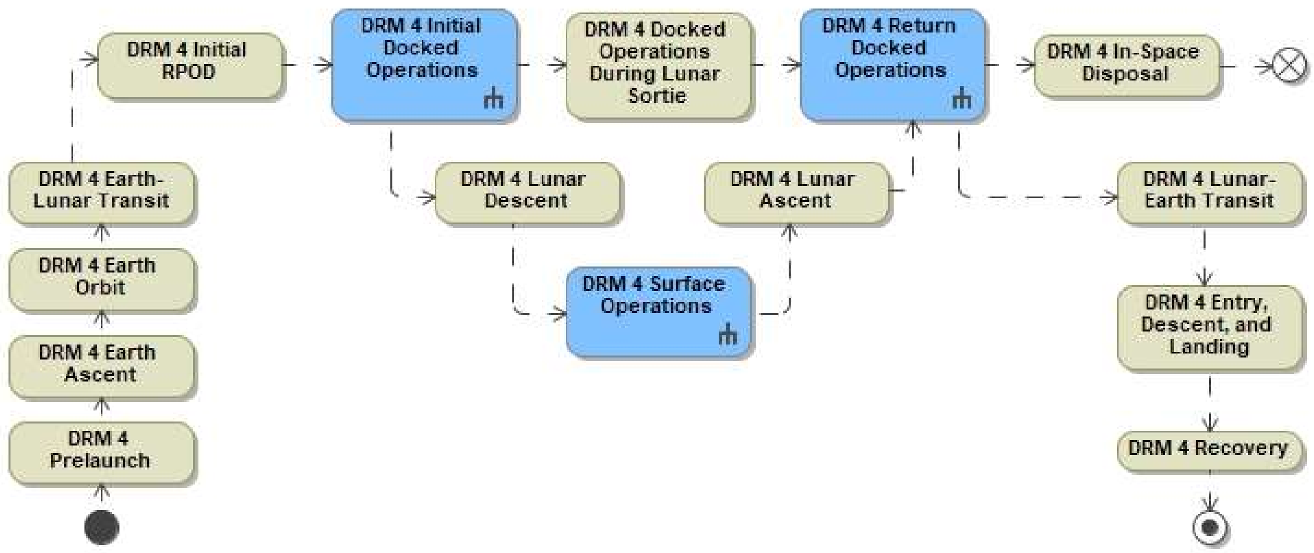

FIGURE 4-12: DRM 4 OVERVIEW

Gateway operations become a part of subsequent Artemis missions involving two crew to stay on Gateway and two crew to descend to the Moon. Gateway provides no capability for Gateway EVA or xEVA suit servicing hardware, such as umbilicals for power, battery recharge stations and other fit check hardware interfaces, prior to arrival of Airlock. xEVA activities requiring the use of vehicle interface equipment will not take place on Gateway until then.

If lunar logistics are sent to Gateway, crewmembers will unpack and transfer to HLS any equipment needed for lunar descent. Additional cargo items are required in NRHO to allow for the contingency substitution of an HLS crewmember prior to the surface mission. The additional cargo allows for resizing of EVA systems and replacement of personal items prior to HLS departure to the surface. Backup crew equipment does not nominally need to be delivered to the lunar surface but rather can be left at or relocated by the crew to Gateway prior to the crewed HLS mission. If backup crew equipment is utilized, it will replace a similar set of HLS equipment of equivalent mass. HLS-PAP-034 lays out the HLS Program Backup Crew Strategy for Sustained Lunar Missions.

The crew will prepare for descent to the lunar surface, including transfer of necessary equipment to HLS, assembly of xEVA suits and partial xEVA suit checkouts inside the designated HLS airlock. Any packaging will be left behind at Gateway in the logistics module for disposal.

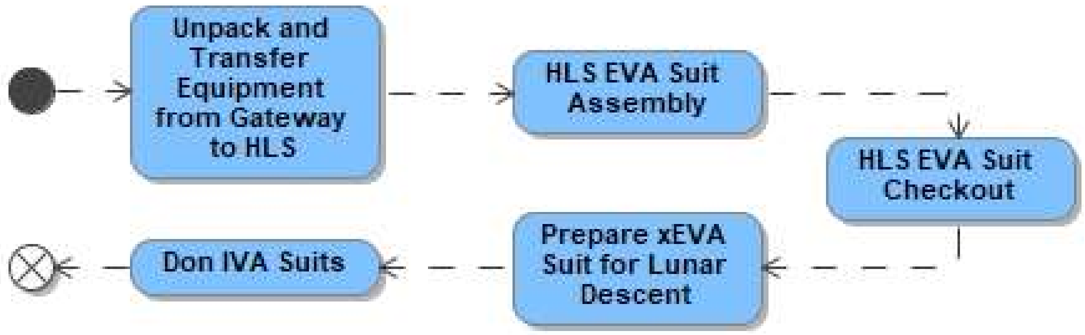

FIGURE 4-13: DRM 4 INITIAL DOCKED OPERATIONS

All real-time communication between EVA crewmembers and Earth will be relayed via HLS, as listed below.

- HLS direct with Earth
- HLS relay via Lunar Communications and Navigation Systems Service (LCRNS)
- HLS relay via HALO module on Gateway
- HLS relay via Power and Propulsion Element (PPE) module on Gateway

The remainder of the mission will look much like Artemis III in the sections above with the exception of specific science objectives and return to Gateway after the surface mission is complete.

4.1.4 DRM 5: Expanded Lunar Exploration - Evolved Gateway & Initial Lunar Mobility with LTV

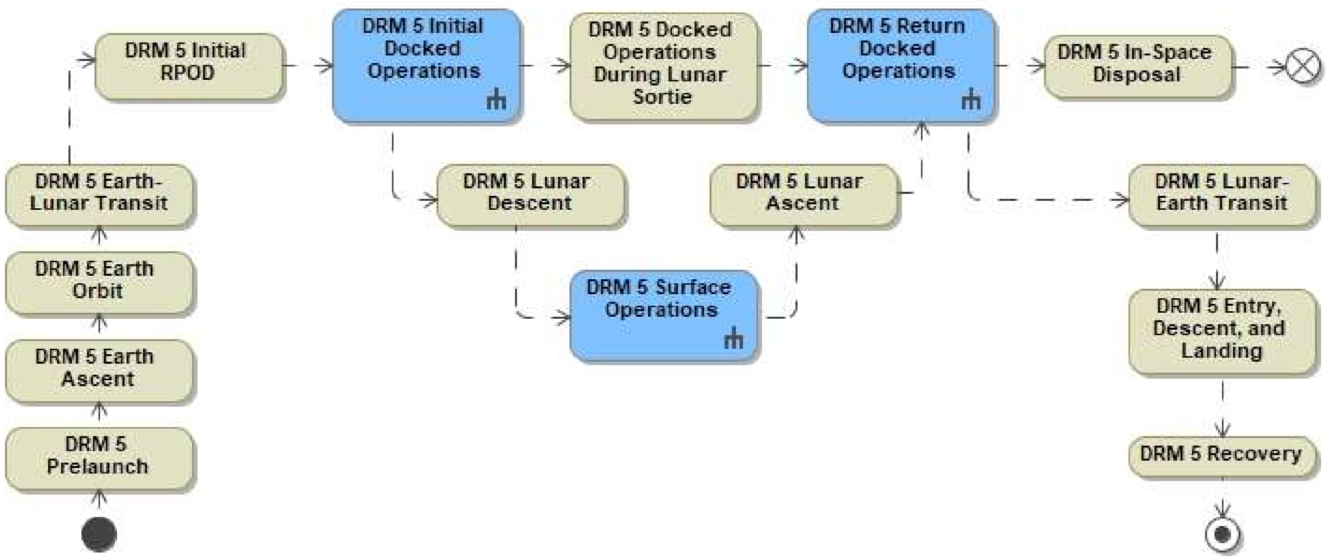

FIGURE 4-14: DRM 5 OVERVIEW

Operations are similar to DRM 3 in duration and will consist of two crewmembers staying on Gateway while two crewmembers descend to the lunar surface. The main difference for lunar surface operations from prior missions will be the availability of the LTV which allows the crew to explore further from the landing site, increasing utilization destinations. The LTV is delivered and deployed by the lander to the lunar surface without assistance from crewmembers. Refer to the LTV-CONOP-001, *Lunar Terrain Vehicle (LTV) Concept of Operations (ConOps)*, for further information on the launch, landing and deployment of the LTV. The LTV will support one crewed mission per year of varying durations, as well as support science activities telerobotically between crewed missions. The LTV may be utilized for surface characterization to help with future landing site selection for both logistics cargo landers and future human landers, as well as utilized in support of addressing key science investigations independent of crewed activities.

The locations of the landing sites are still to be determined. Key parameters for the missions are shown in the table below:

TABLE 4-2: CREWED LUNAR MISSIONS WITH LTV KEY PARAMETERS

Surface System Configuration	HLS Sustained, xEVA, LTV
Key Objectives	• Conduct geological traverses, perform science observations and activities, characterize, and document the regional geology, including small PSRs • Collect a variety of samples to return to Earth for later research • Perform capability demonstration of advanced traverse capabilities with LTV

TABLE 4-2: CREWED LUNAR MISSIONS WITH LTV KEY PARAMETERS

	• Deploy technology demonstration packages and instrumentation	
Key Parameters	Surface Crew	2
	Crewed Surface Stay	~6 Days
	Proposed Number of EVAs per Crewmember	Up to 4 Nominal + 1 Unplanned
	EVA Range with LTV (from HLS)	10 km radial distance
	Uncrewed NASA Surface Operation Duration	4-8 months
	Service Life	10 years

The LTV-CONOP-001 defines the operations on the lunar surface for LTV. The LTV is an unpressurized lunar rover capable of carrying two crewmembers who manually operate it, carrying equipment during crewed lunar surface missions (e.g., payloads, tools caddy, samples and sampling equipment, etc.), and executing uncrewed surface activities via autonomous and teleoperated (or remotely operated) control. The LTV can be used to gather pre-flight data on human landing sites and expected EVA paths, carry equipment, serve as a data gathering tool, serve as a mobility platform for science activities, cargo transport, and/or payload utilization. The LTV is delivered by a commercial lander, deployed without assistance from crew, and checked out prior to the launch of the crewed mission. Use of the LTV occurs year-round, including during seasonal periods when the vehicle may need to follow the Sun for charging and thermal purposes to arrive at designated sites during peak lunar winter seasons. Industry has indicated the desire to use LTV for commercialization purposes which will be weighed with these seasonal periods and NASA utilization. Prior to the next crewed mission, LTV is responsible for getting within range of that HLS landing site.

4.1.4.1 Autonomous, Remote, and Manual Operations on Lunar Surface

Starting with DRM 5 and the arrival of the LTV, and through subsequent DRMs, including the arrival of the PR, EHP will enable autonomous, semi-autonomous, and remote capabilities. Autonomous Operations are those where the vehicle is assigned both the authority and responsibility for the decision to execute a behavior. Semi-autonomous operations occur when an operator agent has the decision responsibility to initiate a behavior and the vehicle has only the authority to execute the behavior. Both Autonomous and semi-autonomous operations may include pre-programmed automated sequences depending on the behavior or task. Autonomous and semi-autonomous functionality will be used, where practical, to enhance vehicle operability and safety.

Remote or teleoperations are those in which control input to the vehicle is initiated by an operator not on board the vehicle. Manual operations are those in which an onboard crew operator is controlling the vehicle.

Depending on the task or mission objective, autonomous, semi-autonomous, remote, and manual operations can be executed in combination, where control of individual system behaviors is shared jointly between the vehicle and an operator. For example, an onboard crew or ground operator could be driving the vehicle between waypoints and the vehicle independently initiates an automated response to a fault or hazard, such as a Warning annunciation.

Time-critical behaviors where the time to effect (TTE) exceeds communication latency expected with remote operations or where the behavior is dependent on local vehicle sensor/imaging system data are those generally initiated autonomously by the vehicle. These behaviors may include automated sequences to achieve:

- Vehicle Safing in the Event of Unexpected Loss of Communications
- Hazard Detection and Response (including Collision Avoidance)
- System/Sub-System Fault Detection
- Communications Signal Acquisition/Re-Acquisition and Relay
- Monitor and Send Vehicle Data, e.g. sufficient to operate vehicle
- Caution, Warning, and Advisory Alerting

Remote operations will be employed for command and control of the LTV and PR during uncrewed mission timeframes and during crewed missions to maximize crew efficiency and safety. Remote operations can also take place while the crewmembers are EVA off of the vehicles. A control hierarchy will be in place to prioritize crew manual operation over autonomous, semi-autonomous, or remote operations.

In order to manage the Earth-to-surface communication latency challenges, with an aim to evolve Mars-forward capabilities, there is a goal for EHP uncrewed rovers to incrementally increase remote and autonomous capabilities over time as confidence is established and more is understood about the landscape in which the rovers will operate. When uncrewed, the vehicle will traverse to a selected waypoint or along a planned closed-loop route. It will navigate in a manner that ensures vehicle safety by avoiding both perceived hazards as well as pre-established keep-out zones (either through operational planning or vehicle capability). If the vehicle cannot find a safe path to the waypoint, or reactive safety checks exceed limits, it will stop and wait for ground or remote operator intervention before continuing.

4.1.4.2 Crewed Lunar Mobility with LTV Surface Operations

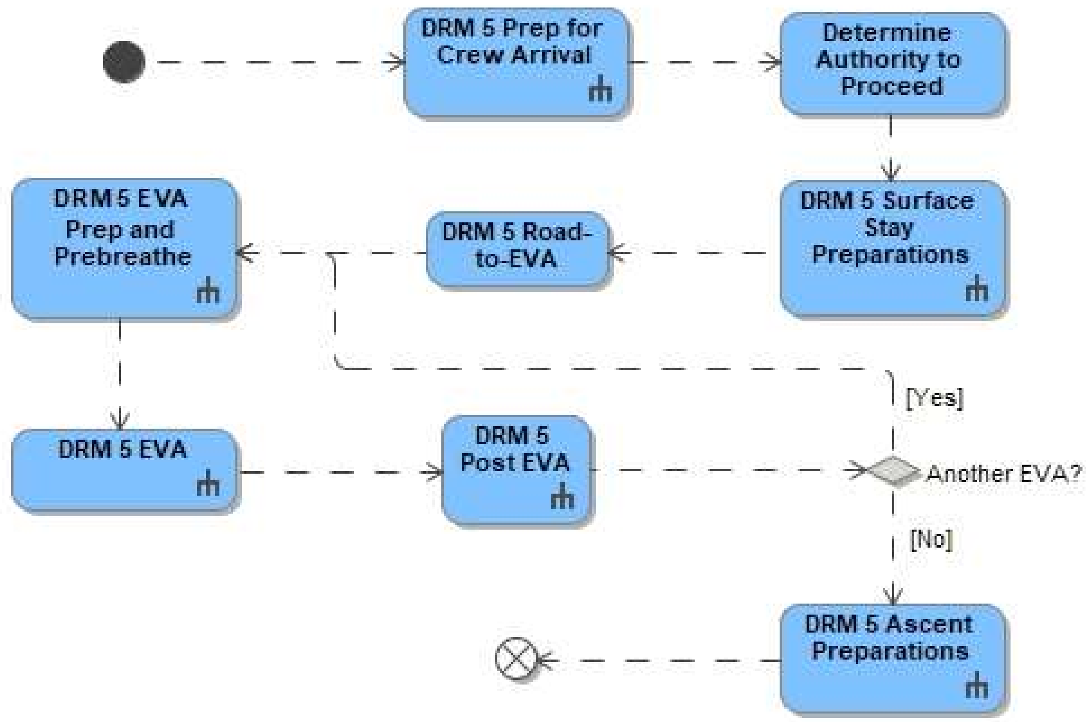

FIGURE 4-15: DRM 5 SURFACE OPERATIONS

4.1.4.3 Prep for Crew Arrival

Prior to each crewed landing during the increment, the LTV is commanded to traverse to a location outside of the landing range accuracy and plume impingement of the HLS, yet still to be within range to video the HLS descent and landing **<FWD-EHP-10033-011>**. The LTV is then nominally teleoperated to a safe distance in order to take video of the EVA crew egressing HLS.

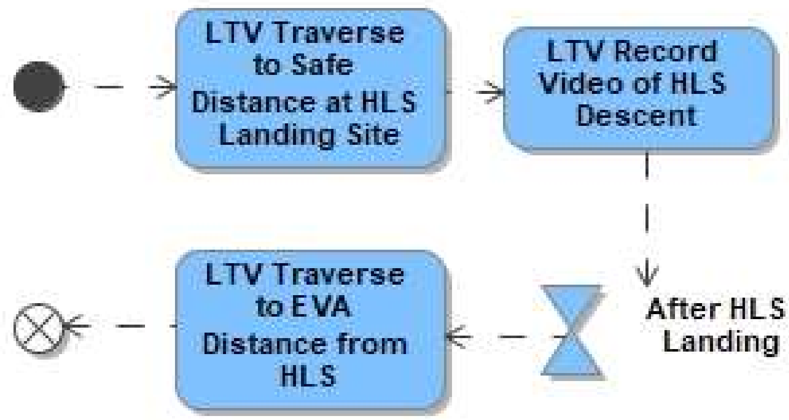

FIGURE 4-16: DRM 5 PREP FOR CREW ARRIVAL

4.1.4.4 DRM 5 EVA

After crew configures and prepares the LTV for traversing, it is then driven by the crew to the first exploration site of the mission. The LTV has allocated stowage locations for NASA payloads which could be science-related or mission systems. Human exploration will be conducted addressing science and exploration goals. The LTV general operations are as follows:

- Continuous driving before needing to stop for recharge to achieve the actual-path-to-radial-distance ratio of 1.3Operate continuously for an 8-hour EVA (when not operating in a PSR)
- Conduct traverses and/or EVA daily according to science and exploration plans with the following conditions:
  - Park during crew sleep periods to recharge
  - Hibernate during lunar night or extended shadowing events (limited or no traversing and limited payload operations)
  - Perform at least two hours inside of a PSR

Mobility assets can survive a certain amount of lunar night, however, must go into hibernation during lunar night. Durations during long shadow events are location and date dependent and can also affect EVA and mobility asset operations. System design, operations, and timelines will need to take into consideration that an entire EVA traverse or vehicle traverse may be performed in shadow.

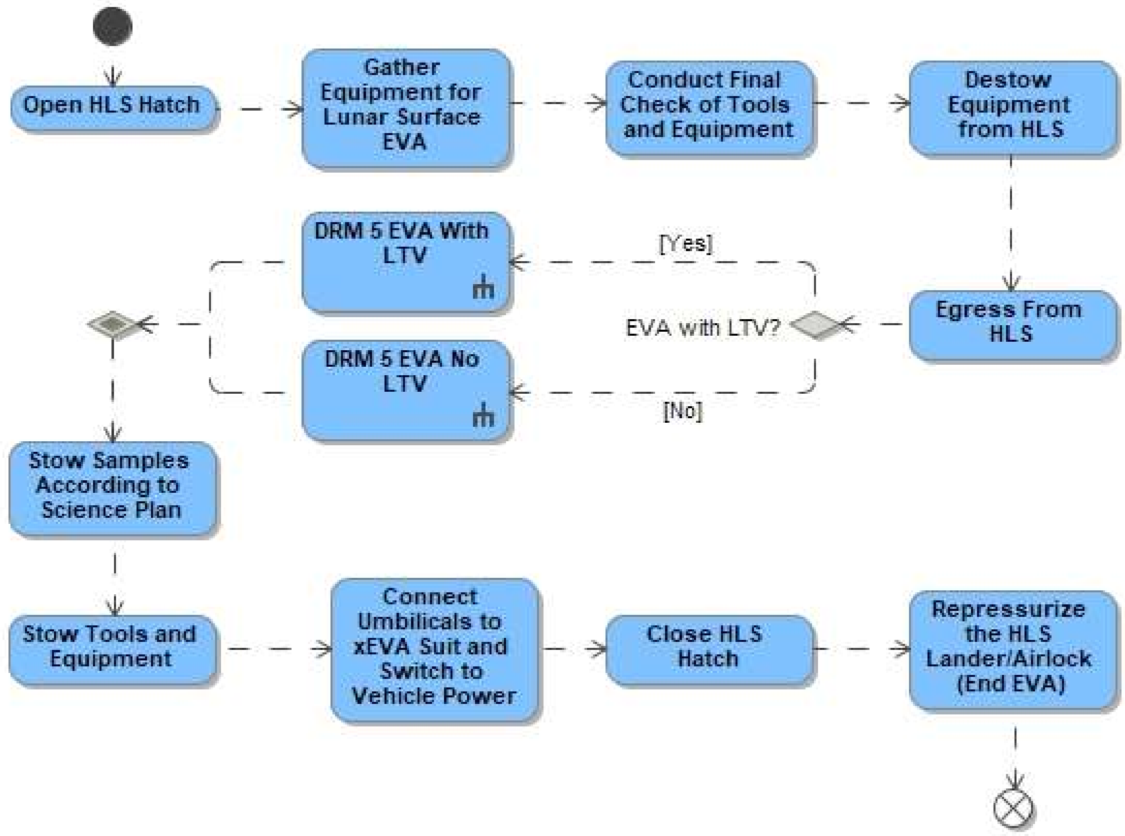

FIGURE 4-17: DRM 5 EVA

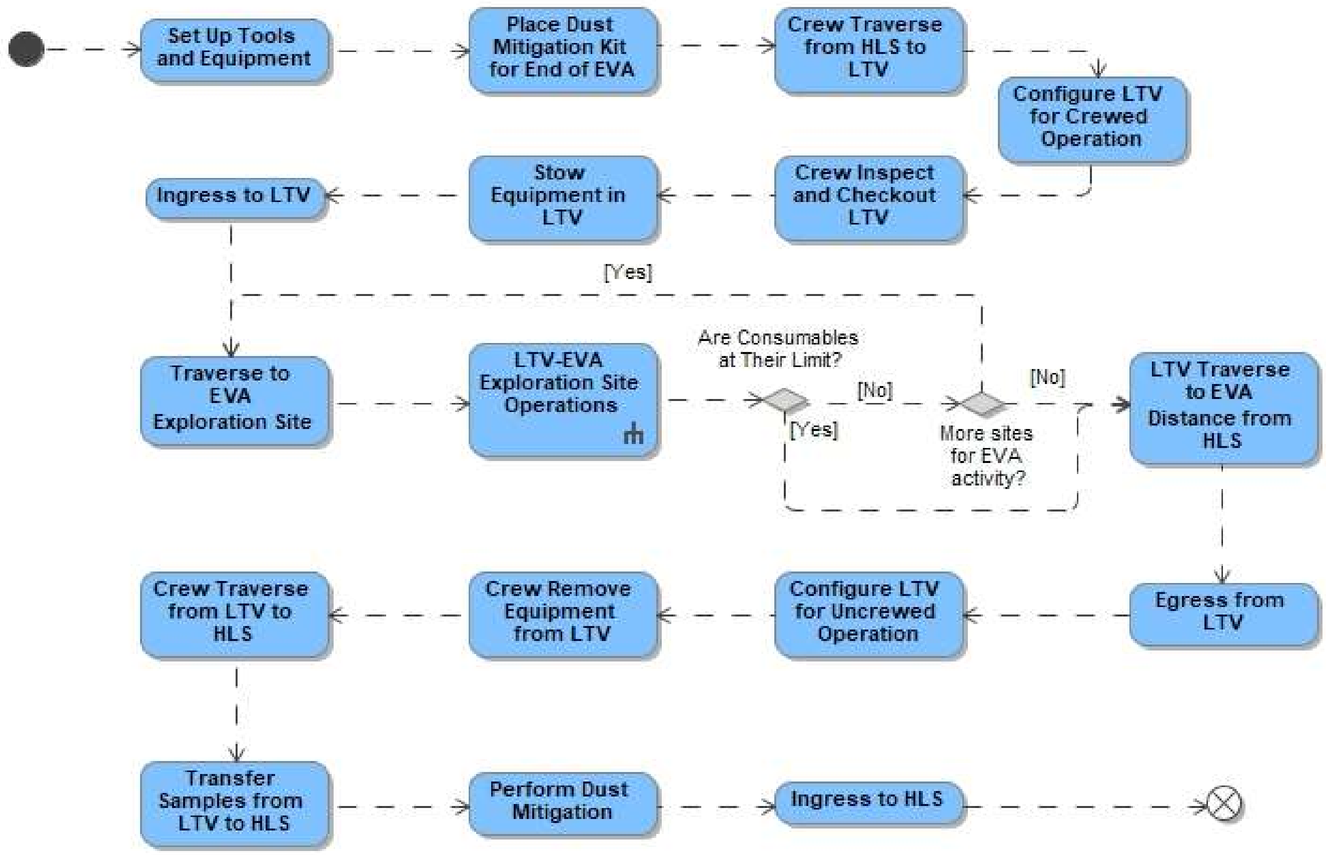

FIGURE 4-18: DRM 5 EVA WITH LTV

If samples requiring cold stowage are taken by the crew, they are placed in a passive container on the LTV as the LTV does not provide the power for cold stowage. While the EVA crewmembers are not on the LTV, they may want the LTV to be remotely commanded in order to support the crew during EVA as a communications relay, camera views, lighting, etc. At the end of each EVA, the crew may stow EVA tools, tools caddy, geology samples, and science payloads back onto the LTV prior to the traverse back to HLS. In general, tools and equipment will be stowed back on the LTV between EVAs and prior to crew departing. This protects the equipment and leaves the tools configured safely in case of an unexpected abort from the surface. At the end of the mission, the crew stows reusable tools (depending on mission parameters, expected life of tools, and EVA science objectives (i.e. avoiding cross contamination)).

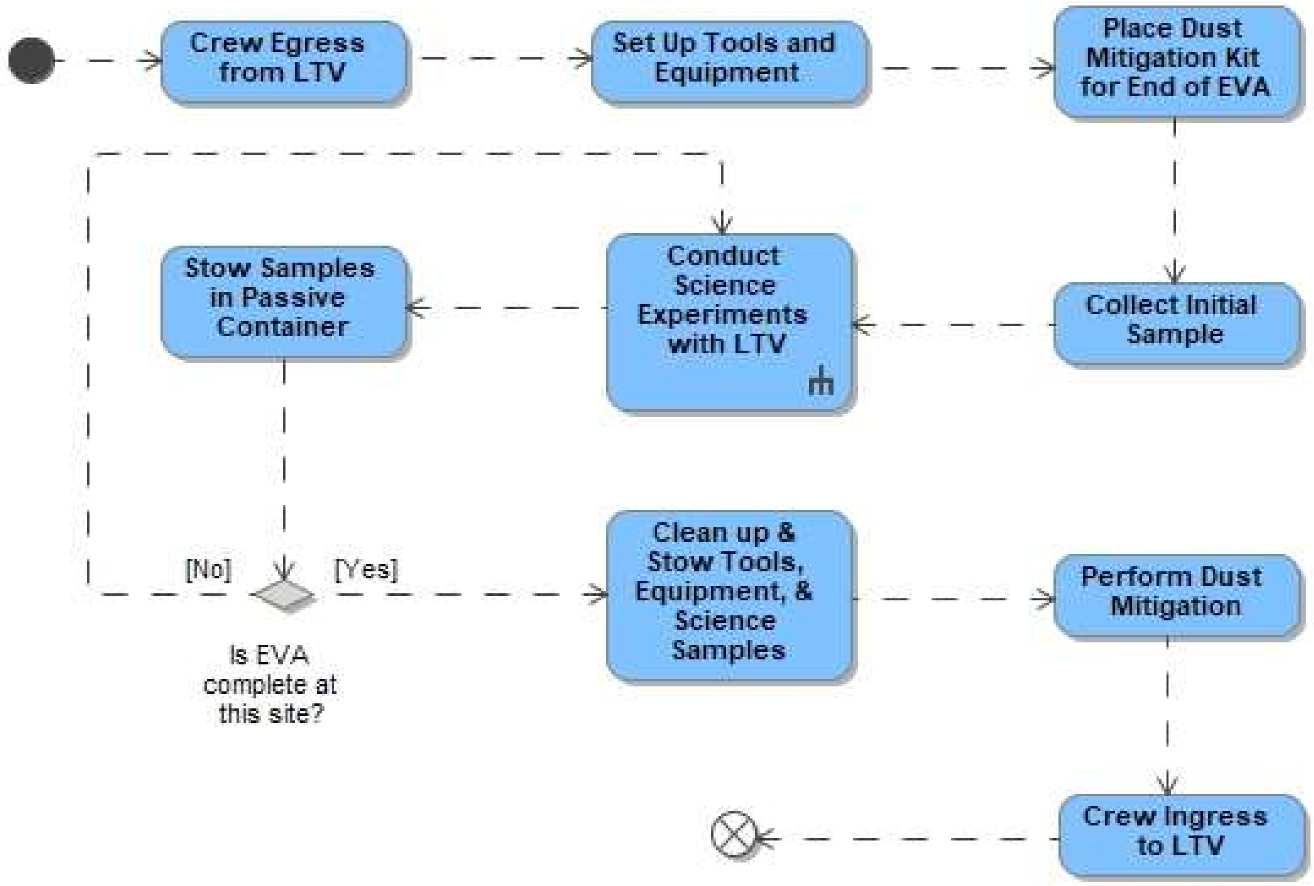

FIGURE 4-19: LTV-EVA EXPLORATION SITE OPERATIONS

4.1.4.5 DRM 5 Post EVA

Once the crew has completed the EVA and ingressed the HLS, the LTV will be remotely driven to a safe distance from HLS to protect for emergency aborts or nominal HLS departure and to take video of descent/ascent.

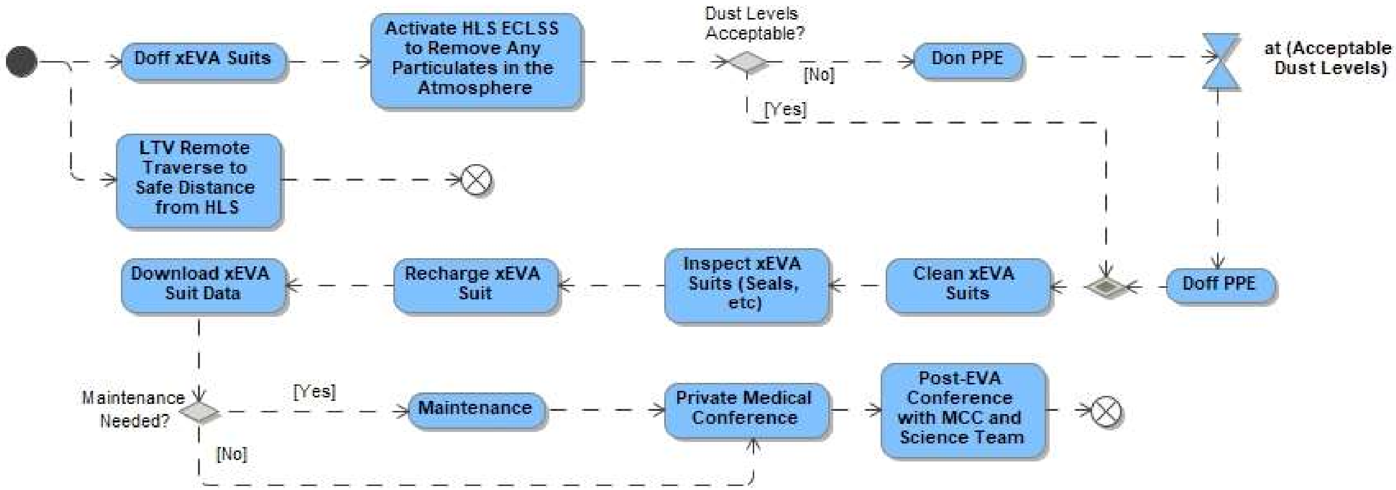

FIGURE 4-20: DRM 5 POST EVA

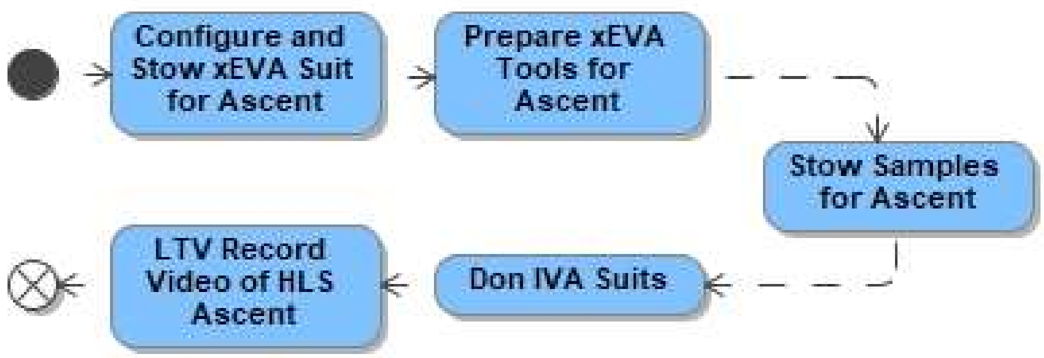

FIGURE 4-21: DRM 5 ASCENT PREP

4.1.4.6 Communications and Navigation

Communications between EVA crewmembers, HLS, Gateway, LTV, and future surface elements is under assessment **<TBD-EHP-10033-002>**. All real-time communication between surface EVA crewmembers and Earth will be relayed via HLS, Gateway, LTV, or other major surface elements. In addition to real-time communication, recorded data, images, video, and audio may be transmitted at a later time after an EVA is completed. LCRNS Satellites will provide positioning services to mobile surface elements and EVA crewmembers **<TBD-EHP-10033-002>**.

A more robust navigation capability for DRM 5 EVA (compared with DRM 3 EVA) is critical due to the distance that the LTV will take the crew away from the HLS (i.e.., up to 10 km radial distance). Under nominal operations, the LTV will have its own navigation capability with 10-m 3-D-RSS absolute position and 4-deg absolute heading accuracies (e.g., using Lunar Augmented Navigation

System (LANS) augmented with optical nav/IMU, pending vendor solutions). See contingency section and Navigation Appendix for further use cases.

4.1.4.7 Power

The following use case categories are scenarios where bi-directional power exchange is required:

Nominally, there could be a use case to include the capability to extend the duration/distance the LTV is able to travel, stay longer at a location, or accommodate science needs for longer. LTV exchanges power with future elements (e.g., PR, MPH, SH, power generating elements and/or charging stations). Power exchange can occur crewed or uncrewed. Power transfer occurs through an interface that is physically compatible (such that it is small enough for crew to handle) with EVA crewmembers and robotics **<TBD-EHP-10033-020>**. This smaller interface is carried by each rover. Larger interfaces (e.g., longer cables) that are robotically manipulated to be used for future elements will not be carried by the LTV.

ConOps and use case details for bidirectional power exchange between the LTV and future elements on the lunar surface are still being understood. See contingency section and Power Appendix for further use cases. Refer to *EHP-10069, EHP Power Specification* **<TBD-EHP-10033-021>** that decomposes this requirement to the projects and missions and includes details on the power interfaces and power quality.

4.1.4.8 Lighting

Lighting will be provided by the LTV to support driving the vehicle (that align with the vehicle's direction of travel) and vehicle-mounted lighting (and provide illumination for area tasks on the LTV, instrumentation, other areas on the vehicle the crew may access, for safely walking around the immediate perimeter of LTV). Other considerations include: Operation of motorized equipment (e.g., robots and rovers) – Whether operating a robot or a rover, the crew will need visuals of sufficient quality and timing to make real-time decisions for control of the robot and rover to both perform the required task and for collision avoidance. Illumination conditions may require additional consideration for illuminating other nearby surfaces rather than just the task surface to increase situational awareness of a moving object.

Contingency operations may require the same or similar task lighting conditions as nominal operations, especially for translation, navigation, and critical inspections. Prior to the mission, evaluations should be performed to determine critical capabilities the crew needs to maintain for their return to a safer point of operation and the duration required for that critical capability. This should establish the minimum contingency power and equipment allocation to maintain the required skill set.

Remote and autonomous operations, particularly those that involve movement (traverse or maneuvering), will require proper surface contrast to maintain optical accuracy of the visual systems involved, to safely achieve the task. Pending on the architecture of the task and surrounding ambient lighting conditions, this may drive the need for supplemental lighting sources or task timing constraints pending on the ability to compensate for the high contrast visual environment.

4.1.4.9 Lunar Walk Back Distance with LTV

For lunar surface operations, there will be a goal to maximize the traverse distance for science exploration to the greatest extent possible. Utilizing rovers will extend the ranges that EVA crew will be able to explore the surface. However, the crew will always stay within a range that allows them to get to a safe haven (lander, habitat, etc.) in the event of a contingency. The distance the crew travels from the lander (or habitat) will change depending on the assets present (e.g., rovers). This will be a combination of the EVA crew staying within appropriate walk back and driving distances. Duration of an EVA on LTV at the maximum traverse distance will be factored into planning and real-time operations in order to preserve consumables for traverse back in order to protect for EVA walk back in case of contingency. If it is determined that capability to increase science objectives is needed to remain at maximum distances for longer, EHP will assess that gap in the architecture **<FWD-EHP-10033-024>**. Traverse planning tools will be utilized to calculate the appropriate distance during any given day. The assumptions for defining EVA ranges are provided below.

- EVA range with lunar surface unpressurized rover – The rover will stay within less than a 5-hour walk back to the lander, which equates to approximately 10 km when walking at a pace of 2 km/hr. This protects for a rover failure that requires the EVA crew to walk back to the lander. This distance must be balanced with suit consumables remaining and does not account for slope or obstacles (e.g., boulders), so distances may decrease due to terrain or operational considerations. This range does not stack system failures. See Integrated Contingencies section for further details.
- During the Apollo missions, the crew traveled 4.74 miles (7.63 km) from the Lunar Module while driving the unpressurized Lunar Rover Vehicle (LRV), which was designed to operate within a 5-mile (~8 km) radius of the Lunar Module.

4.1.4.10 DRM 5 Uncrewed LTV Mission Excursions

Uncrewed LTV mission excursions begin once the LTV has landed on the lunar surface and has been deployed. Uncrewed missions will mainly be focused on utilization; however, there may be opportunities for LTV to be remotely driven to a safe distance from future elements/vehicles to take video of descent/ascent.

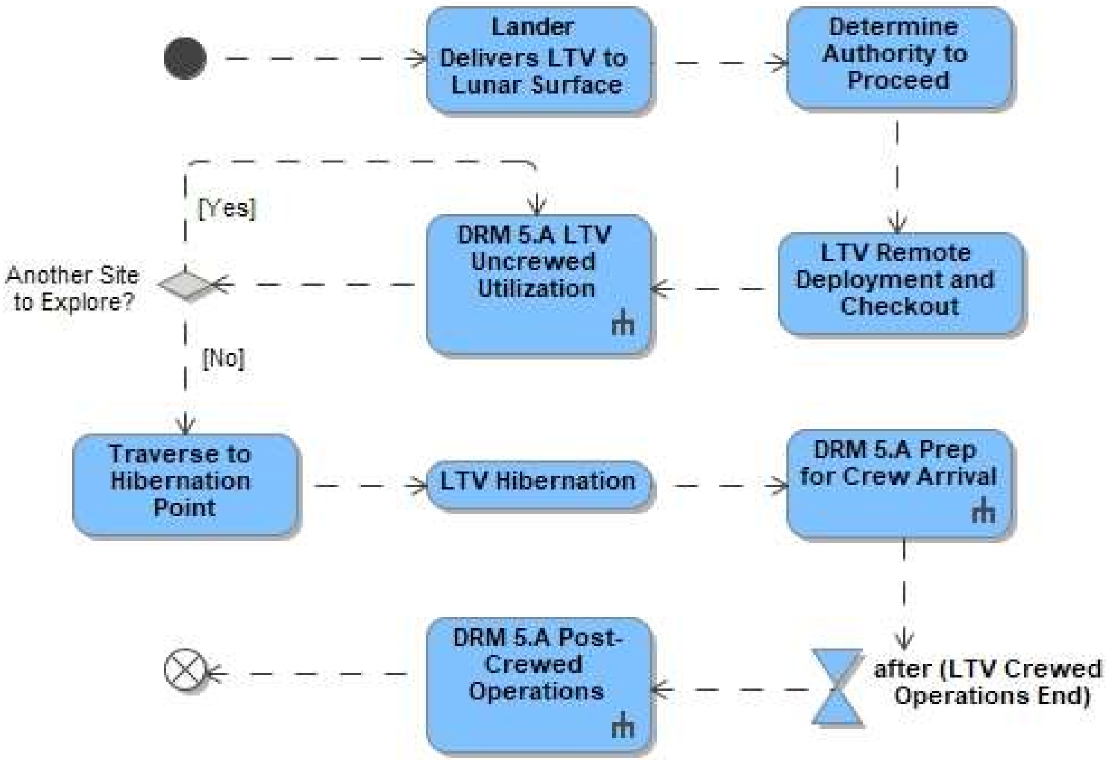

FIGURE 4-22: DRM 5 LTV SURFACE OPERATIONS

4.1.4.11 LTV Uncrewed Utilization Operations

During the uncrewed supporting mission of an increment, the LTV is remotely operated from ground stations. In addition to maintaining and monitoring the vehicle, ground control centers will be capable of further uncrewed science exploration, landing site and future EVA traverse path reconnaissance, payload utilization and deployment, sample collection, and equipment transportation. Ground control centers will work in coordination with LTV vendor(s) to direct the LTV to sites of scientific and/or operational interest to collect measurements and other data, collect and stow samples, and deploy scientific instruments to the lunar surface, as applicable to that mission segment's objectives. The LTV is collecting and transmitting data to help the science team determine future crewed and uncrewed utilization work site locations by providing imagery, video, temperature sensor readings, etc.,. LTV will use an onboard robotic arm to make measurements proximal to the lunar surface, acquire samples, and deploy instruments to the lunar surface. The LTV must also be able to “follow the Sun” to allow for charging prior to periods of extended darkness and lunar night.

The LTV robotic manipulator enables capabilities such as sample gathering, utilization of science tools, and deployment and retrieval of small payloads. The arm is not used in proximity to the crew due to safety considerations.

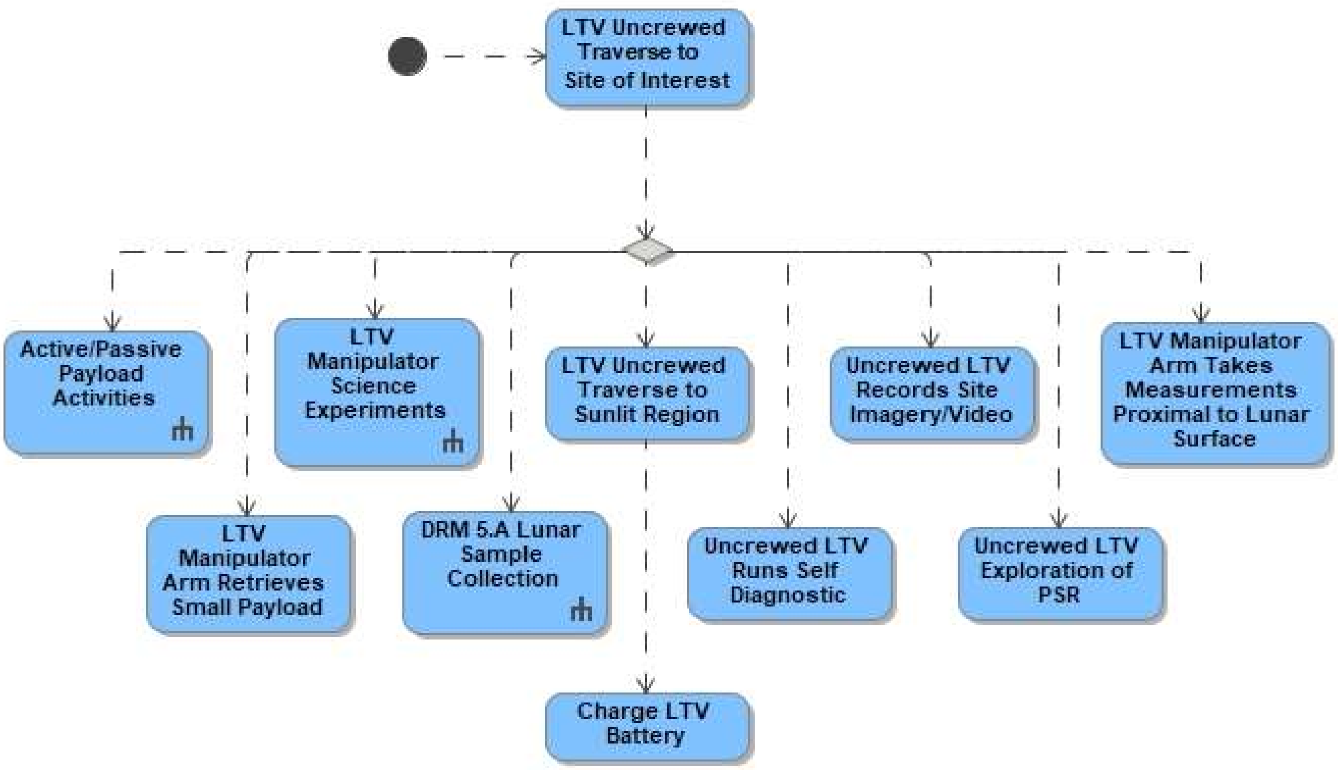

FIGURE 4-23: LTV UNCREWED UTILIZATION OPERATIONS

Prior to each crewed landing during the increment, the LTV is commanded to traverse to a location outside of the landing accuracy range and plume impingement of the HLS, but to be within range to video the HLS descent and landing. Once HLS has landed, the LTV is teleoperated to perform image capture for assessment of the exterior of HLS for the purposes of inspection and hazard identification.

4.1.4.12 DRM 5 Crewed Utilization Operations

With the availability of the LTV as an unpressurized mobility asset in DRM 5, in addition to the utilization capabilities established in DRM 3, the crew has the ability to traverse longer distances, explore new ROIs, and collect samples at new ROIs. The LTV is expected to host active payloads, utilized during crewed and uncrewed operational periods to support mission objectives. The LTV will accommodate at least two payloads for installation prior to launch. Additional payloads delivered on HLS or future cargo landers may be installed by the EVA crew once the LTV is on the lunar surface.

4.1.4.12.1 Lunar Sample Collection

At the start of the crewed missions, crew will retrieve cached samples from manipulator operations during uncrewed periods and transfer them to the lander vehicle for return. LTV will be utilized by the crew to carry and transport utilization tools and collected lunar samples. LTV will also provide a passive cold stowage capability, to maintain sample conditioning of bulk or core collected samples before being transferred to active conditioned stowage location in HLS for return. The cold stowage capability allows for the conditioning of volatile samples, likely from long-duration shadowed or permanently shadowed regions. The end-to-end sampling ConOps will be documented in **<TBD-EHP-10033-018>**.

For further details on sampling operations reference EVA-EXP-0042 xEVA Concept of Operations (ConOps).

4.1.4.12.2 Active Payloads

The LTV provides power, communications/data, and physical interface attachment to active payloads. Payloads will be expected to provide their own thermal control and vibrational dampening as needed, independent of the vehicle and isolated from the LTV interface structure. The LTV will provide a data interface, and data storage/forward, for each active payload as required. LTV will also provide the communication path for payload data through the LTV communications system. ESDMD-411, *Representative Utilization Instruments for the LTV and PR* gives examples of active payloads hosted on the vehicles.

LTV is anticipated to support certain active payload instruments at specified elevation levels above the lunar surface. These mast-mounted payloads will provide a higher vantage point for potential Light Detection and Ranging (LiDAR), stereo multispectral imaging systems, or other instruments. EVA crew will be able to replace or swap instruments for maintenance or repair, and all interfaces will support interoperability of instruments between LTV and PR. Additional details can be found in ESDMD-411, *Representative Utilization Instruments for the LTV and PR*. Payloads may be emplaced on the Lunar surface. Payload communications will flow through the LTV avionics and communications systems to the lunar architecture and distributed to the payload developer by the ground team.

For further information on active payload interfaces, see M2M-30038, Utilization Interface Requirements Document (IRD).

4.1.4.12.3 Passive Payloads

The LTV will be used to transport self-sufficient payloads between locations or may emplace small payloads on the surface. These payloads will be loaded/unloaded by crew or by an LTV external robotic manipulation capability if within the operational constraints of the crew or robotic loading. Logistics carriers will be passive cargo on LTV that may need to be loaded/unloaded with mechanical assistance (such as a remotely operated davit, crane, or other transfer systems).

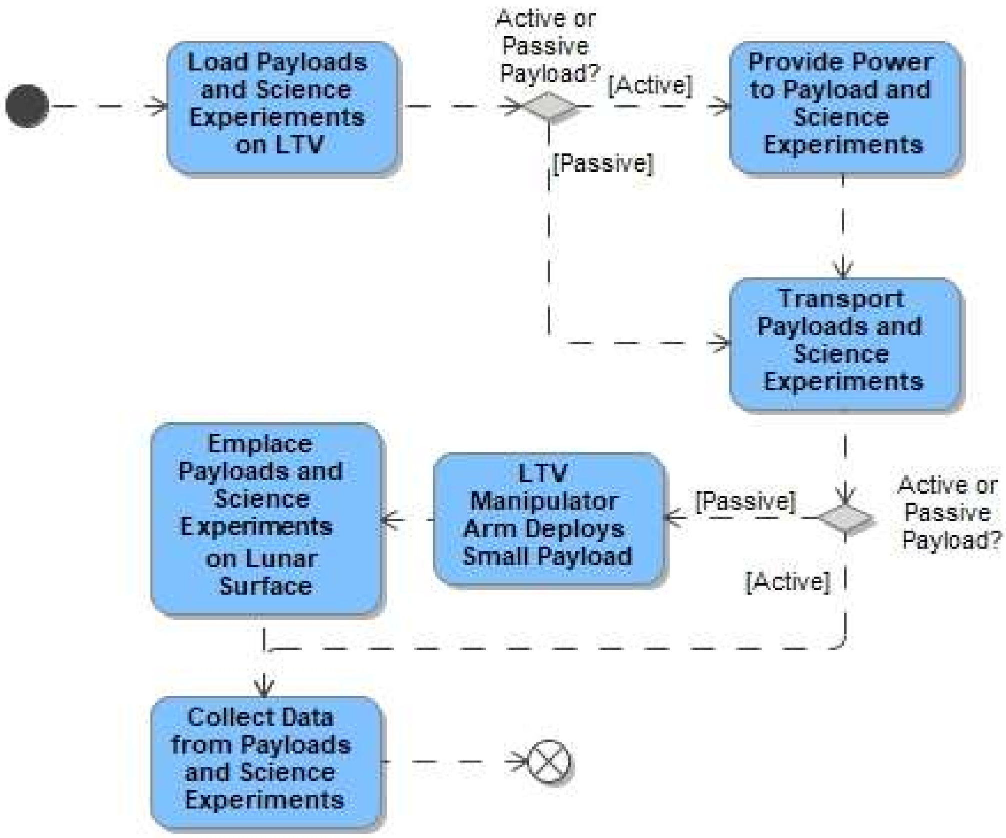

FIGURE 4-24: ACTIVE/PASSIVE PAYLOAD ACTIVITIES

4.1.4.12.4 Manipulation Capability

Robotic manipulation on mobile vehicles for utilization operations will provide an enhanced capability to interact with the lunar surface during uncrewed periods. A limited amount of bulk and rock samples will be collected and stored on the vehicle during uncrewed periods for retrieval by the next Artemis crew. Interchangeable manipulator-connected instruments, also known as end-effectors, will be provided by NASA to conduct NASA science investigations, including sample and data collection. End effectors will also be considered active and passive payloads, requiring common interface to the “wrist” portion of the manipulator. Examples of end effector payloads include remote sensing instruments, contact/collection instruments, and cameras. As mentioned above, the manipulator will also have the capability to load and unload passive payloads for emplacement on the lunar surface.

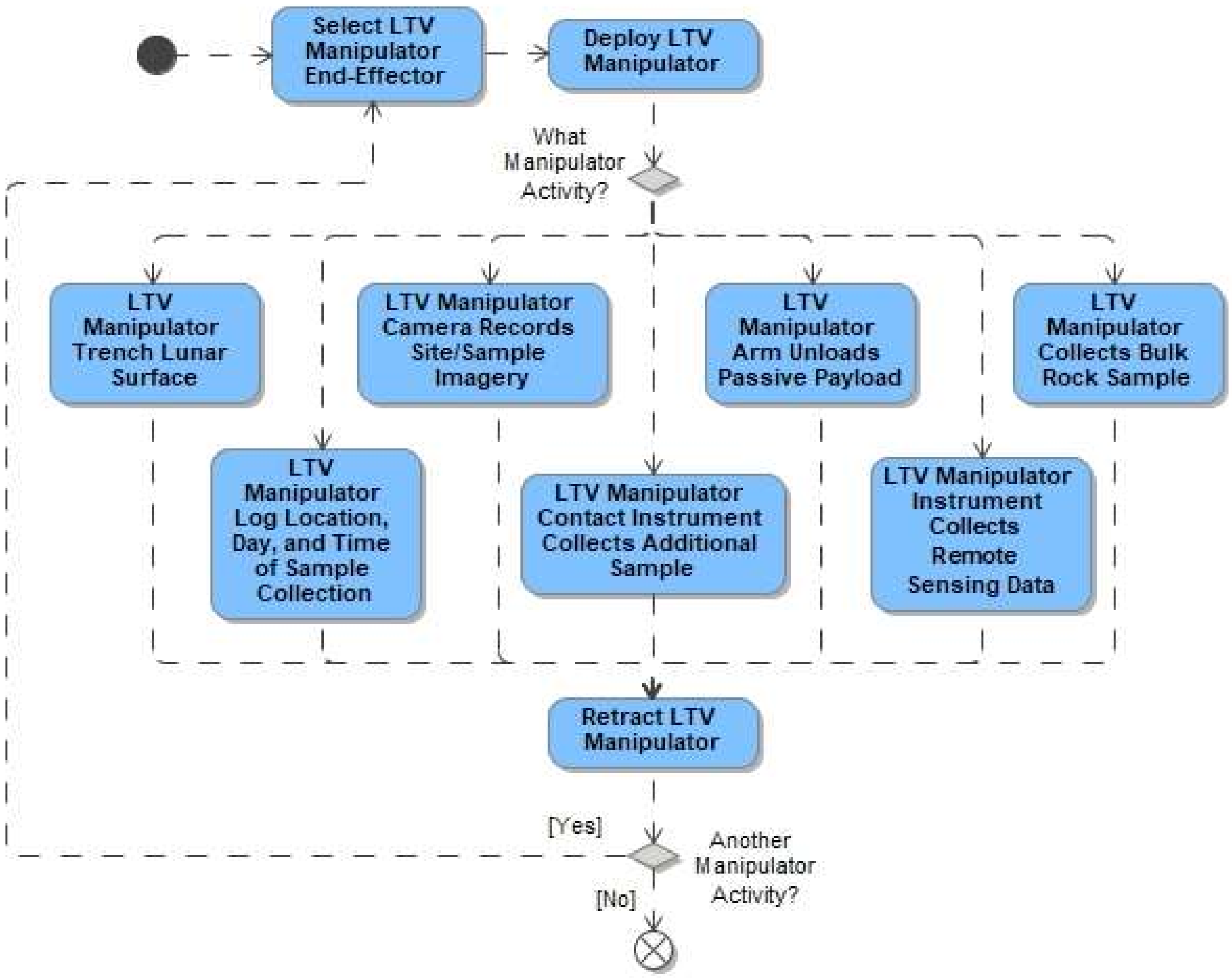

FIGURE 4-25: LTV MANIPULATOR SCIENCE EXPERIMENTS

4.1.4.13 LTV Post-Crewed Operations

During the final EVA, the crew leaves the LTV in a configuration appropriate for the uncrewed mission phase and transfers any tools for disposal and samples to HLS. At the end of each crewed mission, the LTV is commanded to traverse to a location outside of the plume impingement area of HLS to record video of the ascent.

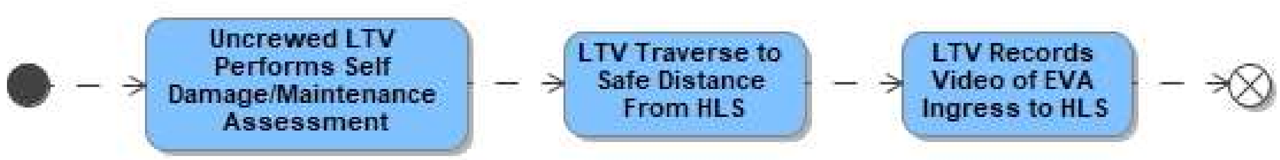

FIGURE 4-26: LTV POST-CREWED OPERATIONS

4.1.4.14 DRM 5 Gateway EVAs

EVA availability on Gateway begins with the activation of a fully functional, dedicated Airlock element with the xEVA System components dedicated to Gateway. To prevent cross-contamination, mix-up, or lack of availability when needed, xEVA System items such as suits and tooling for IVA activities and pre-planned EVA excursions will not be shared between the Lunar surface and Gateway.

EVA operations on a spacecraft in cis-lunar space will share many similarities with those performed on the Space Shuttle and International Space Station (ISS). Egress and ingress will be performed via a dual-chambered airlock, and many of the same or similar tools will be used to perform tasks - including (but not limited to) safety tethers, waist tethers, Body Restraint Tethers (BRT), equipment tethers, a Modular Mini-Workstation (MMWS) equivalent, various bags (crewlock, maintenance items, trash), drivers (powered and manual wrenches) and associated sockets, torque wrenches, pliers, cutters, wire ties, scissors, cameras, and contamination detection kits . Possible maintenance tasks include (but are not limited to) maintenance item Remove and Replace (R&R), preventative maintenance, adding translation paths, and robotics repair.

Gateway EVAs will utilize xEVA Suits which could be from different vendors or include upgrades (utilizing the same vehicle interfaces). Suits and equipment necessary to perform an EVA may be initially launched and delivered in the airlock or sent to Gateway in a logistics module. In the event Gateway Extravehicular Robotics (EVR), the primary means of completing external planned maintenance and contingencies, cannot perform the needed task, EVA may be utilized for planned maintenance and contingencies. EVA will not be utilized as the primary means of Gateway assembly and construction. For consumables and cargo estimates, these missions will allow for up to two 2-crewmember EVAs per mission. Gateway uncrewed periods may be as long as three years; however, reuse of the xEVA suits is still to be determined, as is the method and duration that suits or components of suits may be stowed **<TBD-EHP-10033-001>**. Gateway EVAs are assumed to be performed while there are four crew on Gateway and an IV crewmember is available to operate the Gateway External Robotic System (GERS) as needed and may assist with don/doff as needed. A more complete description of Gateway operations can be found in GP 10027, *Gateway Concept of Operations (ConOps)*.

4.1.4.14.1 Gateway EVA System and Airlock for Microgravity EVA Operations

The Airlock provides EVA capabilities, which include xEVA Suit consumable recharge (e.g., power, oxygen, water), access to vacuum for CO_2 removal, and the ability to reserve suit consumables while connected to the vehicle via umbilical during activities such as prebreathe and suit checkouts. The airlock also provides communication interfaces for voice and data transfer, structural interfaces, and stowage for spare parts and ancillary equipment. Airlock functionality for EVA includes xEVA Suit donning and doffing interfaces, suit servicing and recharge interfaces, communication, prebreathe capability, depressurization and repressurization, egress and ingress, and tools. Initial checkout of the airlock and EVA systems are performed prior to the first EVA.

Servicing and checkout of the suits, performed prior to the first EVA and then between subsequent EVAs, includes consumables recharge (e.g., batteries and thermal system water) using suit servicing vehicle interfaces, and cleaning the suit interior in preparation for the next EVA. Spares and maintenance items will be required for on-orbit suit maintenance (depending on crewed pressurized time). Some spares may be equipment left from previous stages, such as is done on ISS, while others may be launched in logistics modules. General clean-up and stowing of non-EVA equipment are needed to prepare for depressurization and vacuum operations. Any items that cannot withstand vacuum or require special stowage should be moved to other elements of the stack. The equipment lock provides the capability for the EVA crewmembers to ingress in the case of a crew lock contingency **<TBD-EHP-10033-014>**. Airlock equipment in the depressurized portion must be designed to function nominally while exposed to or after exposure to vacuum. Equipment stored within the airlock which is not to be used during depressurization/vacuum operations must be designed to operate after exposure to vacuum.

The dual-chambered airlock provides the volume for two crewmembers to perform on-orbit suit maintenance and the EVA prep and post activities, including suit donning/doffing and prebreathe. It is assumed that EVA suits require two donning/doffing fixtures to allow crewmembers to simultaneously self-don and self-doff their suits if necessary, although an IV crewmember is available to assist.

Gateway EVA wireless radio, antennas, and hardline audio and data for two-way communications of EVA voice/data, as well as downlink of EVA video, are provided by Gateway. This system provides simultaneous communications between Gateway and EVA crewmembers by providing video, voice communications, and EVA suit telemetry and crewmember biomedical telemetry. Wireless communications are available internal to the airlock as well as external. The EVA suit provider furnishes the radio located in or on the suit; Gateway Airlock will provide the radio that is located in the airlock.

4.1.4.14.2 Gateway EVA Operations

The "Road-to-EVA" is a comprehensive list of all the activities that must be completed prior to and following an EVA or series of EVAs. It includes tasks such as suit assembly, sizing, on-orbit fit verification, filling and installing drinks bags, etc. Tools configuration should be internal to the airlock to the extent possible **<TBD-EHP-10033-017>**.

On the day of the EVA, the crewmembers begin final prep activities and the prebreathe protocol. Any necessary inhibits are commanded by MCC-H prior to the EVA. Once the crew performs suit pressure integrity and system checks, they begin their prescribed prebreathe period. Prebreathe protocols decrease the risk of decompression sickness (DCS) and may be different durations depending on suit operational pressure and Nitrogen [N_2] saturation prior to starting an EVA. Gateway is planned to be at 70 kPa (10.2) psia nominally. Gateway may operate at higher pressures up to 101 kPa (14.7 psia) at the start of crewed missions in order to preserve consumables to the extent possible. This may impact DCS prebreathe operations and will need to be considered in Gateway/EHP mission planning.

According to the integrated prebreathe procedures, when the crew are ready to leave the airlock, they initiate cabin/airlock depress; however, prebreathe and airlock depress may occur simultaneously to a lower cabin pressure in support of prebreathe. The EVA crew will depressurize the airlock, switch over to suit systems, egress, and begin their tasks. The “EVA” phase begins when the spacesuit is switched from the vehicle-provided power source to suit batteries, and officially ends after the ingress and initiation of airlock repressurization. See EVA-EXP-0042, *Extravehicular Activity (EVA) Office Exploration EVA Systems Concept of Operations (ConOps)*, for further details on EVAs on Gateway.

4.1.5 DRM 6: Extended Surface Operations (Pressurized Rover)

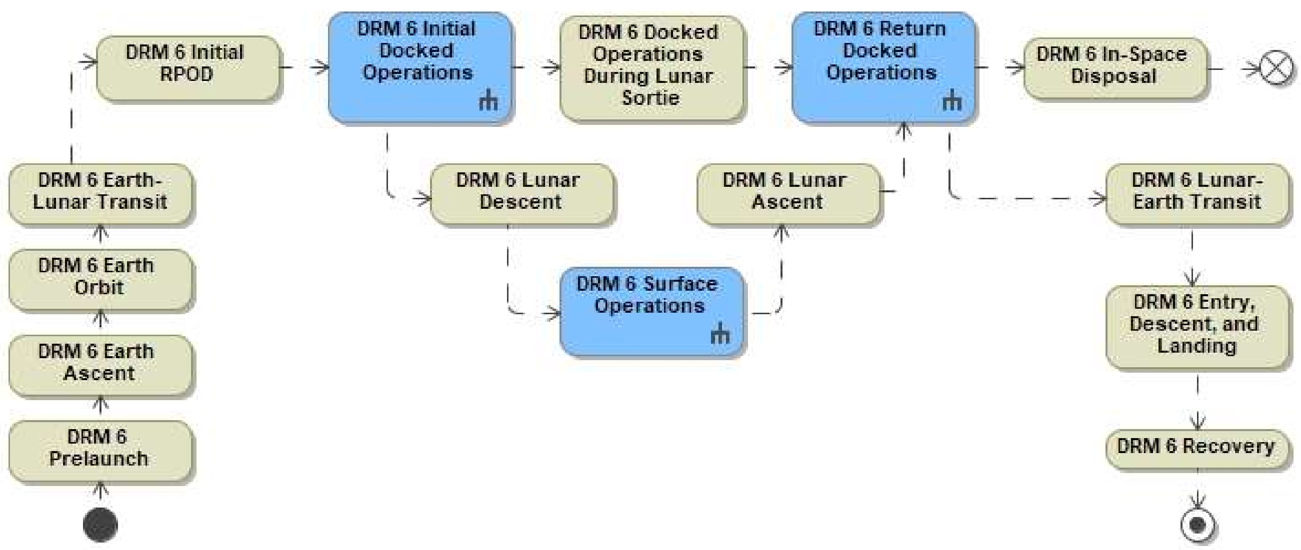

FIGURE 4-27: DRM 6 OVERVIEW

Enhanced lunar surface mobility capability includes the LTV and the PR, as well as lunar logistics delivery. This document will be updated upon formal designations of new programs/projects to include further description of the expected elements and operations associated with them. There is a planned phase of exploration discussed in ESDMD-001, *Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Definition Document*, called the "Foundational Exploration" segment utilizing the LTV and PR to explore regions of the South Pole to include an initial sequence of prioritized landing sites before deciding on the location for habitation. The buildup of Foundational Exploration will provide for expanded lunar surface capability for utilization and demonstration of Mars-forward objectives. The M2M-30007, *Artemis Integrated Concept of Operations (ConOps)*, describes DRM 6 where one pressurized element, the PR, is on the surface for two crew to perform an EVA from HLS to the PR, and live in the PR cabin for up to 28 days with 3 days margin. The PR provides the systems required to maintain crew health. Refer to *EHP-10041, Extravehicular Activity and Human Surface Mobility Program (EHP) Pressurized Rover (PR) Concept of Operations (ConOps)*, for additional details on the PR architecture and operations on the lunar surface. Refer to previous sections in DRM 5 on Autonomous, Remote, and Manual Operations, Active Passive Payloads and Utilization that also apply to DRM 6.

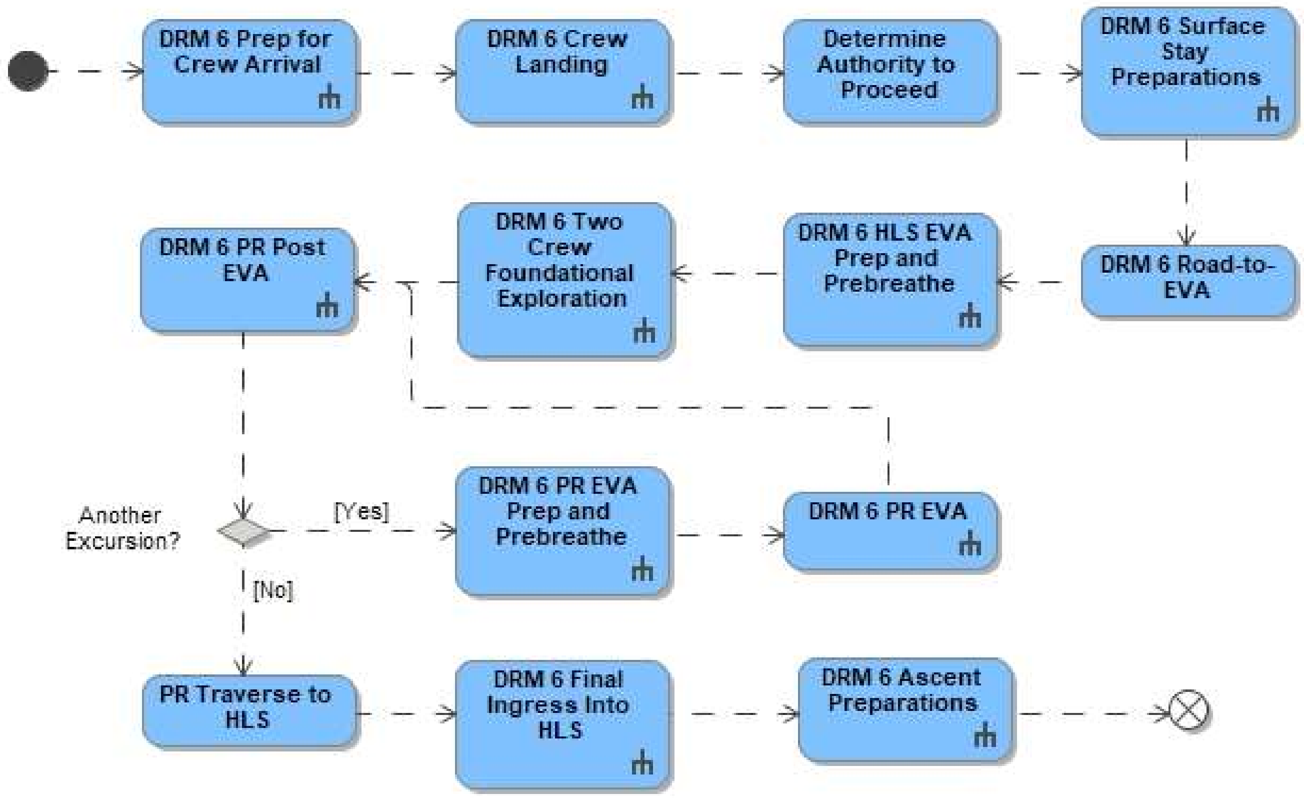

FIGURE 4-28: DRM 6 SURFACE OPERATIONS

From M2M-30007, the overarching goals of the NASA Foundational Exploration are three-fold:
1) to demonstrate elements of a Mars-forward architecture
2) to conduct scientific exploration of the Moon synergistically with crew and robotic explorers
3) to demonstrate the capabilities needed to work and live on the Moon for long durations

TABLE 4--4: CREWED MISSIONS WITH LTV AND PR KEY PARAMETERS

Surface System Configuration	HLS Sustained, xEVA, LTV, PR	
Key Objectives	• Demonstrate extended surface stay • Demonstrate extended NRHO stay • Perform capability demonstration of advanced traverse capabilities with PR • Demonstrate cooperative exploration with multiple mobility assets • Conduct lunar exploration and science on the lunar surface • Deploy technology demonstration packages and instrumentation	
Key Parameters	Surface Crew	2
	Proposed Surface Stay	Up to 33 Days

	Proposed Number of EVAs per Crewmember	Cumulative EVA time per week ≥ 24 hrs
	EVA Range with PR and LTV (from HLS)	20 km radial distance

4.1.5.1 DRM 6 Prep for Crew Arrival

Delivery of the PR helps extend the distance of lunar South Pole exploration and provides a pressurized cabin in which the crew can live shirt-sleeved while on the surface. The PR will have a 10-year lifetime which increases utilization during crewed and uncrewed missions. The PR cabin has the capability to support 2 crewmembers nominally.

The PR is delivered by a lander **<TBR-EHP-10033-008>**, which is expected to provide the PR with services until it is ready to operate. These services are expected to continue for 48 hours after offloading. Disconnecting from these services will be performed remotely. The deployment method of the PR will be determined by the lander provider and the PR provider and will likely be design specific.

Once the PR has been delivered to the surface prior to crew arrival, it is robotically offloaded by the lander onto the surface and performs teleoperated self-checkouts to ensure it is ready for use. After self-checkouts, the PR will be remotely operated to mitigate lander plume impingement and to perform scientific activities such as observations, scouting of potential EVA traverse and HLS landing sites, and possibly sampling and deployment of payloads (although there may be an exception on uncrewed science capabilities post landing/pre-first crewed mission due to landing mass constraints). Shortly before the next crewed Artemis mission, the PR will be positioned near the HLS landing site to record landing, and then reposition closer to the lander for crew access post-landing. At the beginning of each crewed mission, the PR will have 3 days' worth of O2/N2 cabin and EVA consumables until crew subsequently replenishes the O2/N2 tanks. The PR will be teleoperated to perform scientific activities during the traverse to the landing site area.

Prior to the two crewmembers landing in HLS, all surface assets are checked out to be sufficiently operational.

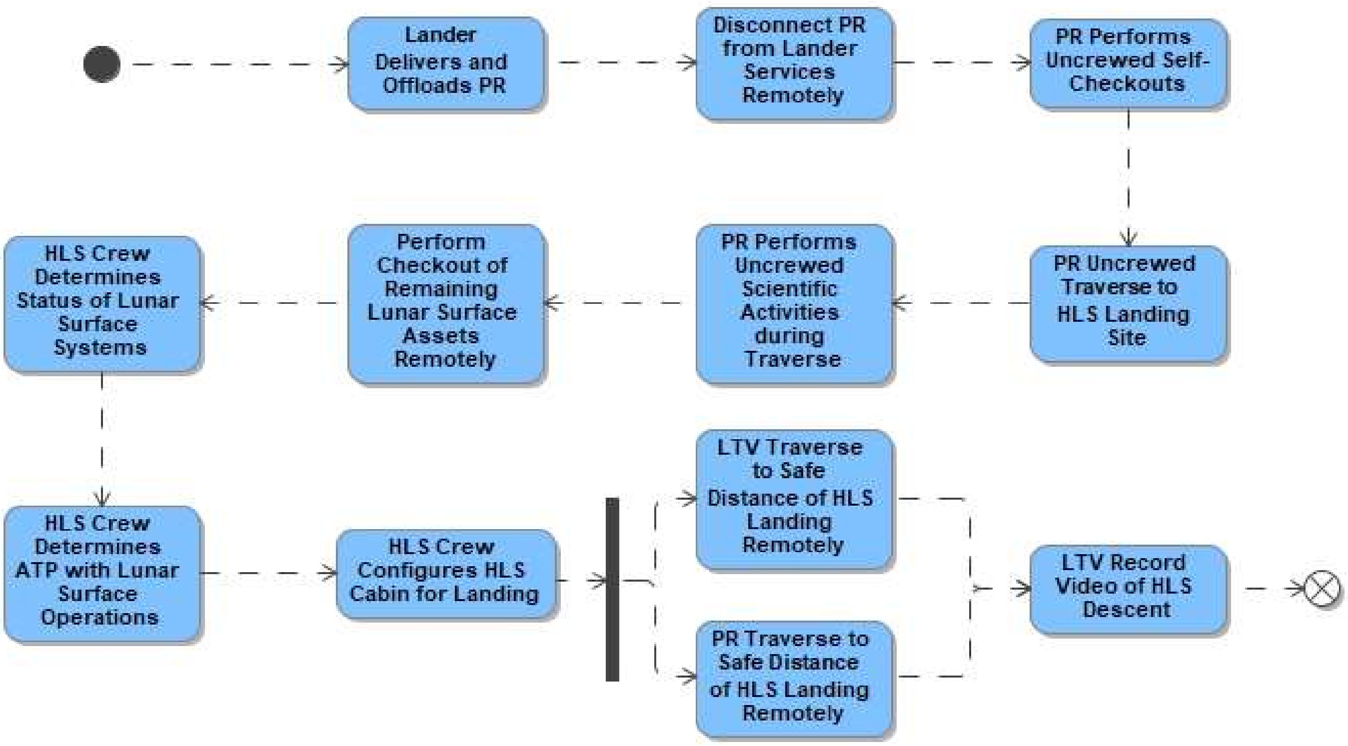

FIGURE 4-29: DRM 6 PREP FOR CREW ARRIVAL

4.1.5.2 DRM 6 Crew Landing Operations

From the HLS-CONOP-006, *Sustained Phase HLS Concept of Operations (ConOps)*, for both sortie and excursion missions, the HLS integrated lander and crew, in coordination with MCC, will determine ATP with the surface operations phase. This includes identifying the health and status of the lunar surface systems and, if necessary, commanding the lunar surface systems transition to operational modes. Following ATP, the HLS integrated lander and crew will begin surface stay preparations. This phase includes vehicle safing and cabin reconfiguration. Both the LTV and the PR are teleoperated to a location outside of the plume impingement and landing accuracy zones to video descent and landing. They will then be commanded closer to the HLS lander to perform remote visual inspections of the lander and landing site, then to traverse to a location within walking distance for the crew to perform an EVA from HLS to the PR, taking with them any limited shelf life/perishable and crew specific items (e.g., EVA spares such as gloves) to the PR.

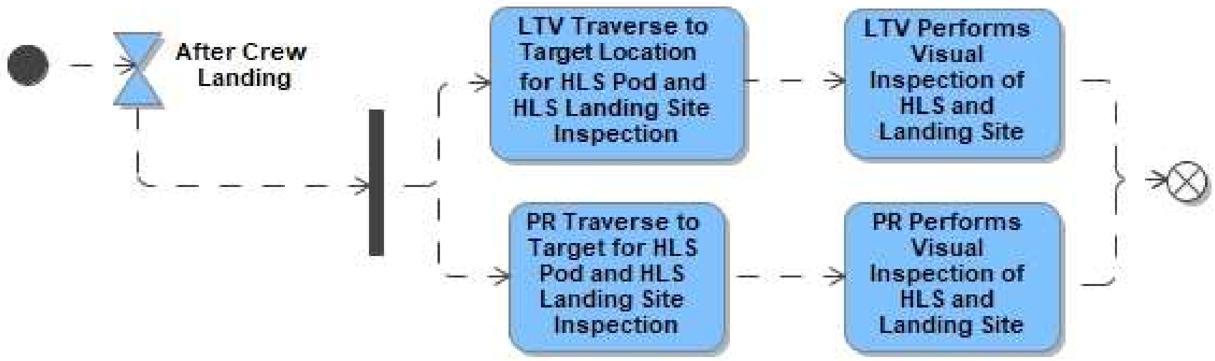

FIGURE 4-30: DRM 6 CREW LANDING

4.1.5.3 DRM 6 EVA

The following figures describe EVAs from PR.

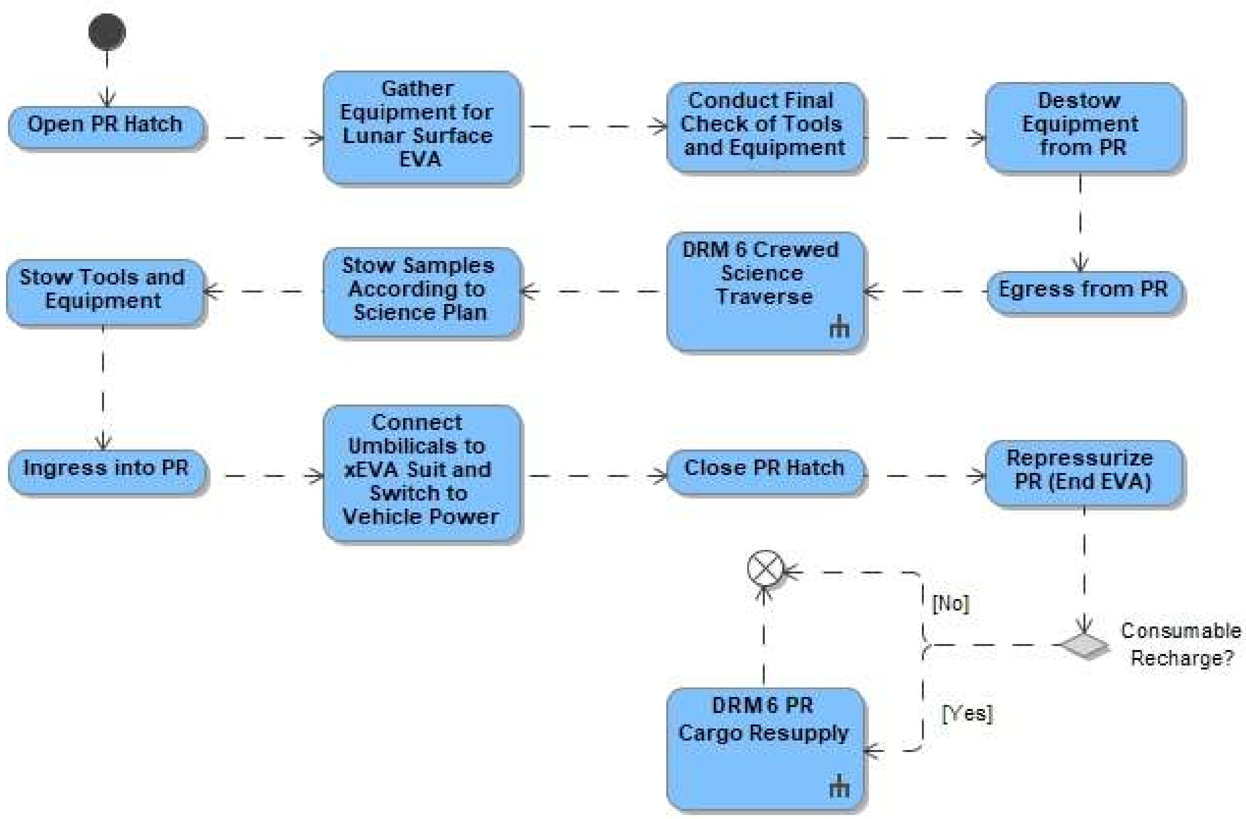

FIGURE 4-31: PR EVA

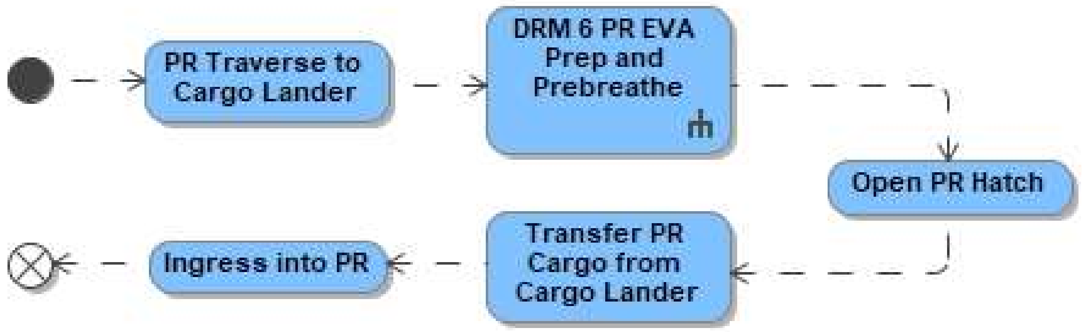

FIGURE 4-32 DRM 6 PR CARGO RESUPPLY

4.1.5.4 DRM 6 Two Crew Foundational Exploration

The amount of cargo that is delivered within the PR may determine the duration that the crew stays on the surface during the first crewed mission utilizing the PR, unless cargo is delivered on another cargo lander. In addition to the operations that are performed prior to any lander-based EVA, the crew will perform activities required to enable the HLS integrated lander to remain uninhabited during the approximately 30-day surface asset-based portion of the mission. When these activities are complete, the two crew members will egress the HLS integrated lander, leaving the hatch in a configuration such that no single failure prevents crew ingress. The crewmembers then transfer from HLS to the PR to conduct the surface mission. The crew will be based from the PR as their habitat for up to 28 days. During the PR portion of the mission, all EVAs will be based out of the PR.

After the ingress volume is depressurized by the crew and/or MCC, the crew ingress the PR hatchway/translation path which is sized to support comfortable ingress and egress for the suited crewmembers (including nominal and contingency, such as fully incapacitated crewmember rescue (ICR) operations) without risking abrasive damage to rover hatch seals and xEVA suits in the process. Currently, PR utilizes the “cabin as an airlock” approach to enabling EVAs. After crew donning of xEVA suits, the entire PR cabin depressurizes. Cabin reconfiguration will need to be conducted pre and post EVAs. The PR and crew are able to maximize utilization capability during EVAs by reducing the amount of crew time it takes to configure the EVA System and cabin reconfiguration. In addition, the PR atmosphere is set to a level that reduces required pre-breathe time.

The PR provides EVA capabilities, which include xEVA Suit consumable recharge (i.e., power, oxygen, and water), access to vacuum for CO_2 removal, and the ability to reserve suit consumables while connected to the vehicle via umbilical during activities such as prebreathe and suit checkouts. The PR also provides interfaces for xEVA System voice and data transfer, structural interfaces, and stowage for spare parts and ancillary equipment. PR functionality for EVA includes xEVA Suit donning and doffing interfaces (allowing parallel don/doff), suit servicing and recharge interfaces allowing suits to be recharged in parallel, communication, prebreathe capability, depressurization and repressurization, egress and ingress, and tools stowage (suit maintenance tools, non-utilization tools, and utilization tools for science). xEVA suit fit check, maintenance, and checkout will occur in PR on the lunar surface. EVA suit fit check will be important for crewmembers to ensure proper fit prior to going EVA, especially if on-orbit for extended periods of time and spinal elongation occurs. Additional configuration change and checkout will be performed on the lunar surface as needed. When there are more than 2 crewmembers on the lunar surface (Artemis-VIII+), not all crewmembers will be doing their fit checks in the PR. There will be one xEVA Suit Fit Verification per crewmember per mission in PR on the Lunar surface.

PR will leverage conditioned stowage carriers, where crew can transfer items that cannot be exposed to vacuum. Some equipment (e.g., food, water, EVA spares (bladder material), medicine, human research items, etc.) may not be able to be exposed to vacuum and must be placed in a pressurized volume during depress. Equipment in the depressurized portion of a pressurized vehicle will be designed to function nominally during or after exposure to vacuum. Equipment which is not to be used during depressurization/vacuum operations must be designed to operate after exposure to vacuum.

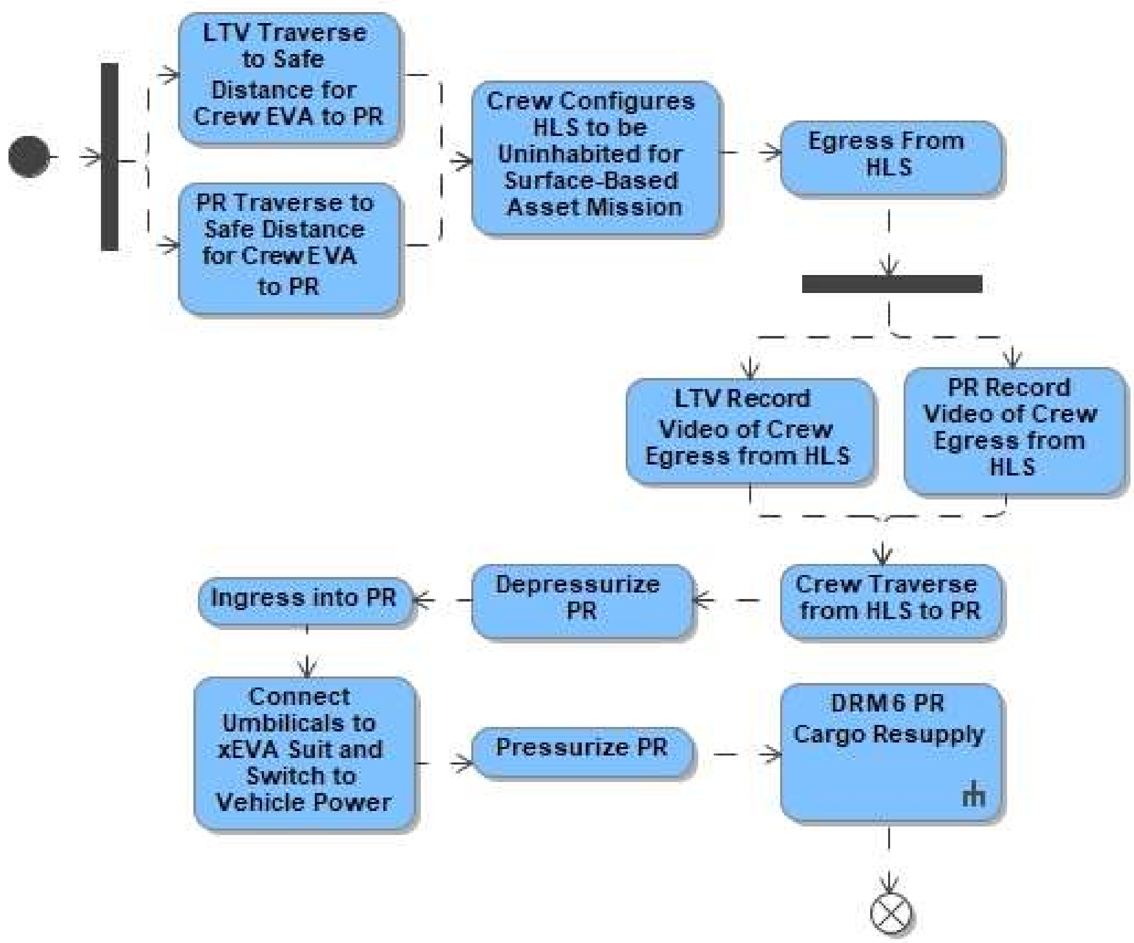

FIGURE 4-33: DRM 6 TWO FOUNDATIONAL EXPLORATION

4.1.5.5 DRM 6 PR Crewed Science Traverse

Once the PR is checked out by the crew, they drive it to the cargo lander and transfer cargo, including consumables, payloads, and other equipment by **<TBD-EHP-10033-007>** methodology.

The PR is then driven by the crew to the LTV at the first exploration site of the mission. Human exploration will be conducted to address science and exploration goals. Daily, the PR will conduct traverses and/or allow crewmembers to perform EVAs according to science and exploration plans, in general:

- Observing crew duty-day and work week requirements per M2M-32105, *Moon to Mars Program Medical Operations Requirements Document (MORD)*
- Crew perform a minimum of 24 hrs/week of EVA operations (from M2M-30002) from the PR; crew time available for EVA operations weekly will be directly affected by the distance PR is driven
- EVAs from PR are conducted only during lunar daytime to avoid thermal constraints

While the EVA crewmembers are not on the PR, they may want the PR to be remotely commanded in order to support the crew during EVA as a communications relay, camera views, lighting, etc. Lighting will be provided by the PR to support driving the vehicle (that align with the vehicle's direction of travel) and vehicle-mounted lighting (and provide illumination for area tasks on the PR, instrumentation, other areas on the vehicle the crew may access, for safely walking around the immediate perimeter of PR). After each EVA, tools are stowed in the appropriate stowage area.

Any cold stowage items (i.e., frozen volatiles or biological samples) are placed into a conditioned sample storage in the PR. At the end of the mission, the crew drives the PR to the landing site and configures it for the upcoming uncrewed period. The PR will be left with three days of non-perishable cargo to be used by the next crew. The crew then performs an EVA to transfer to the HLS, taking with them any samples collected during the surface mission (i.e., biological and/or lunar samples). The PR and LTV will be teleoperated to a safe distance away from the HLS launch area to take video of ascent.

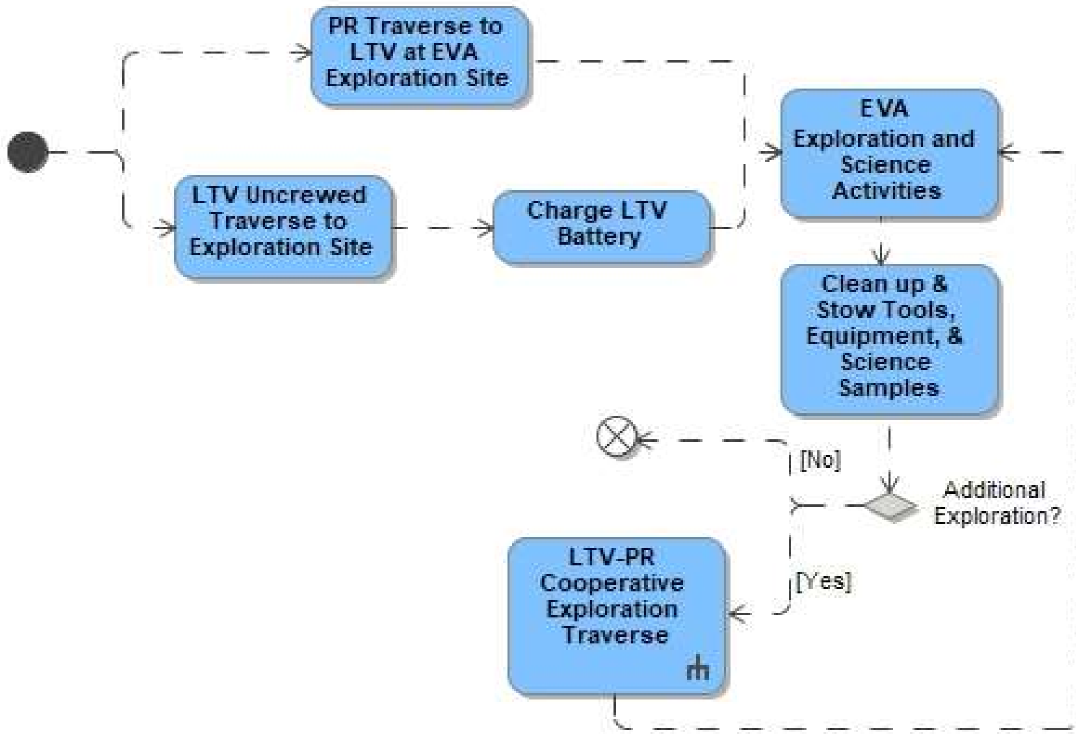

FIGURE 4-34: DRM 6 PR CREWED SCIENCE TRAVERSE

4.1.5.6 LTV-PR Cooperative Exploration Overview

The PR and LTV can be utilized together to perform cooperative exploration to extend and enhance exploration capabilities in the field. Cooperative rover exploration can occur during both DRM 6 two-crew-to-the-surface missions (i.e., two crew living out of the PR with the LTV accompanying) and DRM 7 (see section) four-crew-to-the-surface missions (i.e., two crew living out of the PR and two crew living out of the MPH or SH, with the LTV supporting either the PR crew or the MPH/SH crew). For missions with only two crew on the surface, it is expected that both the LTV and PR will be dedicated to that crew pair for the duration of the mission.

TABLE 4--5: DRM 6 AND 7 COOPERATIVE EXPLORATION WITH LTV AND PR OVERVIEW

Configuration	LTV	PR	MPH
DRM 6	Accompanies PR Crew	2 Crew	N/A
DRM 7	Accompanies PR Crew: 20km radial range Or accompanies the SH/MPH Crew: Both crew Pairs constrained to HLS walk back distance	2 Crew	2 Crew

While dual rover cooperative exploration will certainly enhance scientific exploration (e.g., by providing a second platform for housing camera and science instruments, artificial lighting, communication relay support, etc.), providing a second rover (namely, the LTV) to the PR crew could enable additional contingency support in the event of an unexpected rover mobility failure. If the PR crew have a dedicated LTV supporting them (i.e., DRM 6 mission only, or DRM 7 mission when the LTV is "assigned" to the PR crew and not supporting the SH/MPH crew), exploration range can extend out to 20 km radial distance since, in the event that one rover fails, the other can be used to drive the PR crew back to the HLS. For DRM 7, when 2 crew are living in the PR and 2 crew are living in an alternate surface habitat, the LTV may be nominally dedicated to a specific crew pair, or shared between the crew pairs: e.g., there may be mission phases where the LTV is solely dedicated to the PR crew, solely dedicated to the MPH crew, or shared during a 4-crew cooperative exploration phase (e.g., during a 4-crew EVA), pending mission priorities, the distance between the MPH and HLS, the distance between the SH and exploration worksites, etc. If the LTV is assigned to the MPH/SH crew, the MPH crew would be constrained to operating within 10 km of MPH using the LTV and the PR crew would be constrained to operating within walk back distances of the HLS. If all 4 crew conduct an EVA together, both crew pair would be constrained to operating within walk back distances of either HLS or MPH as the PR would be dedicated to the PR crew and the LTV dedicated to the SH/MPH crew. Ground control and other capabilities needed to support parallel operations (including parallel EVA) for PR and MPH/SH crew will need to be taken into account.

During crewed missions, either the LTV or the PR may be teleoperated at different times to facilitate cooperative exploration. A teleoperated rover will likely traverse slower than a manually operated one due to general remote operator caution, limited fields of view and perspectives (pending rover design details and remote operator capabilities), and Earth-Moon-Earth latency in commanding. This difference in speeds will need to be considered when planning nominal dual rover traverses so that contingency protection can be provided. Contingency protection does not necessarily mean that the cooperative exploration rovers need to be travelling side-by-side or in tandem at all times. This may not be practical due to the environment (e.g., terrain, shadows) or vehicle recharge requirements. However, flight rules will govern separation distances and/or times required to be maintained between cooperatively operating vehicles so that mission objectives are balanced with crew safety, which are then balanced with the overall risk posture acceptance for the mission; different considerations will be made when rovers are operating within walk back range of the HLS verses outside of walk back range, and flight rules will be informed through analyses and testing. Specific integrated contingencies related to DRM 6 missions are described in the Integrated Contingencies Section at the end of this document.

4.1.5.7 DRM 6 LTV-PR Cooperative Exploration and Crew Contingency Protection

The process of deriving how the LTV and PR can be used cooperatively to extend crewed exploration distances includes analysis based on EHP GRAs, analog field data, and rover simulation data. When the LTV is dedicated to the PR crew and the PR crew are within walk back distance of the HLS, there is no constraint on the relative distance between the LTV and PR. In other words, both vehicles can operate as needed to support missions objectives (e.g., cooperative or separate driving to science exploration sites, communication relay support, EVA support, etc.). Once the PR crew travel beyond walk back distance of the HLS, the vehicles will need to perform cooperative exploration and the LTV will remain within ~2-5 km **<TBR-EHP-10033-018>** distance of the PR so that the LTV can respond to a PR crew contingency event within a reasonable amount of time.

TABLE 4--6: DRM 6 COOPERATIVE EXPLORATION WITH LTV AND PR OVERVIEW

Configuration	LTV	PR	HLS	LTV-PR Relative Distance
DRM 6	Accompanies PR Crew	2 Crew	Within walk back distance	No Constraint
	Accompanies PR Crew	2 Crew	Not within walk back distance	~2-5 km <TBR-EHP-10033-018>

In order to support M2M Program objectives that include the ability to explore out to 20 km radial distance from the HLS while still providing contingency protection for the crew, each rover must be capable of actual path continuous driving (e.g., without stopping for recharge). This is to provide full driveback capability in the event of a rover contingency event occurring at max radial exploration distance. A continuous driving distance of > 20 km is needed since it is assumed that the vehicles will likely need to travel longer actual-path distances to reach their destination due to terrain and shadow navigation, communication architecture, onboard artificial lighting capabilities, etc. on the outbound (and inbound) traverse. Based on internal NASA SMD analyses specific to rover operations, an average actual-path-to-radial-distance ratio of 1.3 has been assumed. While this ratio may not cover the exploration within the entire 20-km radius circle surrounding the HLS, it provides sufficient options to extend exploration opportunities beyond single rover operations. Using the 1.3 actual-path-to-radial-distance ratio, both the LTV and the PR need to be able to travel continuously to return crew via driveback to the HLS in the event of a contingency event (e.g., immobilization of one of the rovers) at maximum range as shown in the figure below. If the LTV and PR are able to drive continuously, exploration range may be able to be extended (as bounded by flight rules and any other safety considerations); however, if one of the vehicles is only able to go less distance continuously, cooperative operations will be constrained to the capabilities of the least capable vehicle. Caveat: if either vehicle is driving through excessively cold regions (e.g., LTV driving through a PSR) or extended periods of darkness are encountered, the LTV and PR may travel continuous distances that are less.

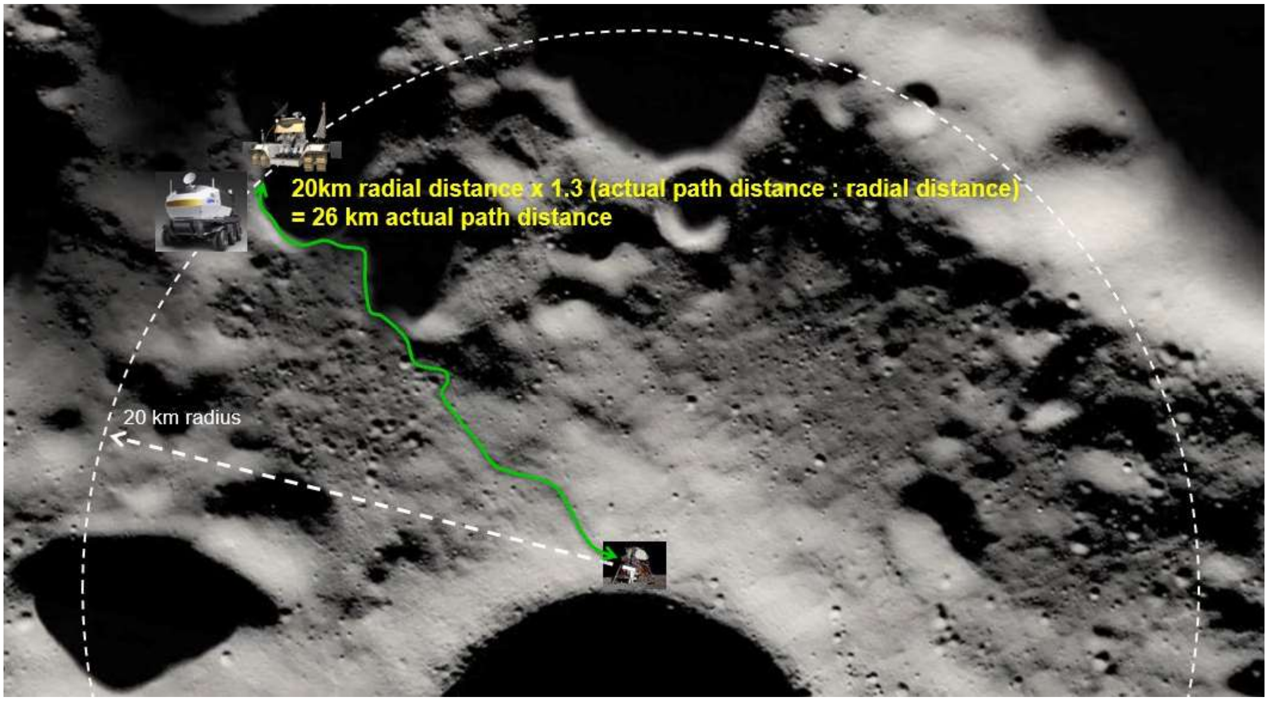

FIGURE 4-35: NOTIONAL LTV-PR COOPERATIVE OPERATIONS

In general, mission objectives will be organized such that the farthest destination is explored first, and then, as consumables are depleted (e.g., rover batteries and/or EVA consumables), the crew work their way closer to safe haven so that they can always reach it in the event of a contingency. To reach a target of interest that is 20 km radial exploration distance from the HLS, the PR crew and accompanying LTV will likely travel in staggered, discrete steps to maintain driveback contingency protection throughout the traverse. Exactly how this process will play out will depend on the differences in manual and teleoperations traverse speeds (e.g., 3-5 kph average manual driving speed vs. 1-2 kph average teleoperations driving speed?) and vehicle recharge needs (e.g., can the vehicles recharge while driving? or do they always need to be stationary to recharge? how fast can they recharge?).

The LTV and PR can travel together or separately, as desired to best support mission objectives, out to the walk back distance constraint from the HLS. Once the PR crew reach this threshold, the vehicles will stagger their outbound traversing (assuming manual and teleoperations speeds between the vehicles differ) so that contingency driveback support is maintained. Once the PR traverses beyond the walk back distance of the HLS, it will remain within walking distance of the LTV. Furthermore, the outbound traverse staggering of the LTV and PR will be set up such that the LTV will have sufficient resources to drive back to the PR to retrieve the crew, if needed, before driving them back to the HLS.

Depending on recharge needs of the vehicle, the LTV (assuming its teleoperations speed is slower than the manual speed of the PR) will start its traverse before the PR so that it can arrive at the next recharge location and begin recharging itself before the PR continues its traverse farther outbound. This will enable the LTV to have sufficient power to support full contingency return of the PR crew to the HLS if the PR experiences an emergency. Once the PR catches up to the LTV recharge location, it will pause to fully recharge, and the LTV will continue its outbound trek. This process will continue until the crew reach their 20 km radial distance destination (or are close enough to be within vehicle exploration and/or walking exploration range). The number of "steps" to reach this distance will depend on all of the factors described above (i.e., manual and teleoperations speeds, vehicle recharge speeds, environmental factors like terrain and natural lighting complexity, etc.). If the manual speed of the PR is comparable to the teleoperations speed of the LTV, it is possible that the vehicles will travel outbound in closer proximity to one another (i.e., less staggering is needed).

An example of this process is shown in the figure below with the assumption that both vehicles can support continuous driving before needing to stop for recharge to achieve the actual-path-to-radial-distance ratio of 1.3. If vehicles are able to support farther distances of continuous driving without stopping for recharge, fewer steps are needed to reach the 20-km radial distance exploration range. If vehicles are only able to support shorter distances of continuous driving, pending terrain complexity, the crew may not be able to reach 20 km radial exploration distances and have full driveback contingency support. Considerations for combined driveback and walk back contingency operations (e.g., driveback as far as you can until you run out of vehicle power, then walk the remaining distance) will depend on risk posture acceptance for contingency support **<FWD-EHP-10033-023>.** Experience, xEVA suit capabilities, and vehicle capabilities including recharge needs will all inform risk posture. Finally, nominal operations will be planned such that neither rover is driven to the point that their batteries are 100% depleted.

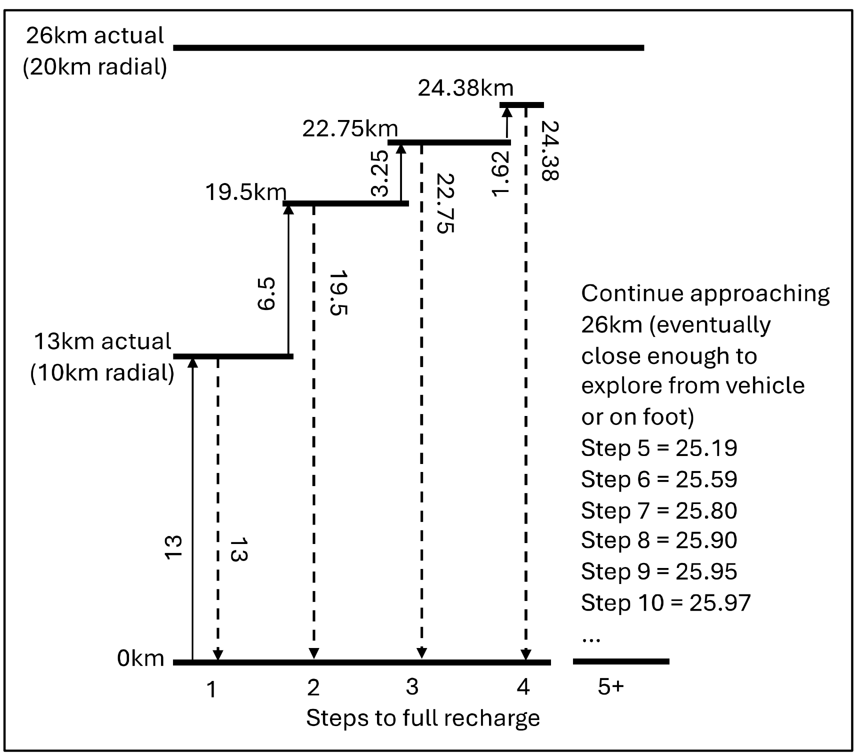

FIGURE 4-36: NOTIONAL LTV-PR DISTANCES

4.1.5.8 DRM 6 Utilization Operations

Artemis utilization operations for DRM 6 missions include capability of both the LTV and PR. The PR provides a crew habitable environment, enables longer range traverses of the lunar surface, which increase scientific study of additional areas of lunar terrain and IVA utilization objectives. PR will have Active and Passive payload capabilities similar to those mentioned in DRM 5, as well as manipulation capability as mentioned in DRM 5. The PR science activities during the crewed rover traverses may include, but are not limited to:

- Stowage of geological samples collected on the lunar surface during EVA. It is assumed that the PR will be equipped to collect and transport samples during all crewed excursions, up to 14 days at a time. To minimize the amount of lunar material brought inside the vehicle, geological samples may mainly be stored externally as long as sample integrity is maintained.
- Handheld instruments may be carried by PR for utilization use. Items such as HULC, a handheld X-ray fluorescence spectroscopy instrument, and a handheld laser-induced breakdown spectroscopy instrument may be used by the EVA crew and located inside the rover for storage and charging. These items will not need to be carried by PR when the vehicle is uncrewed and may be disposed of.
- Deployed payloads may be accommodated by PR, attached externally and deployed by the crew during an EVA once in the designated area for deployment.
- Internal Payloads may include payload bank locations for science instrument use such as an internal freezer for geology, Human Research Program (HRP), Biological and Physical Sciences (BPS), or other samples. IVA investigations are performed by crew inside the PR.
- Cabin deployed payloads to be utilized for IVA research may be deployed from a stowage location and used within the vehicle. This equipment can then be placed on a workbench and utilize wall mounted power and communication resources.
- NASA payloads will be expected to provide their own thermal control and vibrational dampening as needed, independent of the vehicle and isolated from the PR interface structure.
- Geology sample collection will need to be orchestrated such that samples are collected on the side of the PR opposite to the vacuum access port, to ensure that there are no PR exhaust contaminants in the collected samples

4.1.5.9 Communications

Lunar surface communications between EVA crewmembers, HLS, LTV, PR, and future surface elements is **<TBD-EHP-10033-002>**. All real-time communication between EVA crewmembers and Earth will be relayed via HLS, Gateway, LTV, PR, or other major surface elements. In addition to real-time communication, recorded data/images/video may be transmitted at a later time after an EVA is completed. LCRNS Satellites will provide positioning services to mobile surface elements and EVA crewmembers **<TBD-EHP-10033-002>**.

4.1.5.10 Power

The following use case categories are scenarios where bi-directional power exchange is required:

Nominally, use cases include the capability to extend the duration/distance the PR is able to travel, stay longer at a location, or accommodate science needs for longer. PR exchanges power with LTV and future elements (e.g., MPH, SH, power generating elements and/or charging stations). Power exchange can occur crewed or uncrewed. Power transfer occurs through an interface that is physically compatible (such that it is small enough for crew to handle) with EVA crewmembers and robotics **<TBD-EHP-10033-020>**. This smaller interface is carried by each rover to connect to the power source while crewed or uncrewed. Larger interfaces (e.g., longer cables or too large for crew to carry) that are intended for power transfer that are robotically manipulated to be used for future elements will not be carried by the LTV or PR.

ConOps and use case details for bidirectional power exchange between the PR and future elements on the lunar surface are still being understood. See contingency section and Power Appendix for further use cases. Refer to *EHP-10069, EHP Power Specification* **<TBD-EHP-10033-021>** that decomposes this requirement to the projects and missions and includes details on the power interfaces and power quality.

4.1.5.11 Logistics Transfer Operations (LTO)

Lunar Logistics Transfer Operations (LTO) begin when cargo is unloaded from the first logistics lunar lander and transported to other surface elements (e.g., LTV, PR, SH, etc.), and continue through future missions for the duration of the Artemis Lunar Campaign. This cargo is intended to support the crew on the lunar surface by supplying/replenishing elements on the surface. Certain cargo, such as EVA system components, food, medicine, etc., cannot be exposed to vacuum or extreme temperatures and, if it is expected that they would be exposed to these environments, they must be delivered in pressurized, thermally-controlled containers. Science payloads may also be transferred using LTO capabilities. Landers are expected to offload cargo.

LTO will begin after the PR is delivered to the lunar surface. Logistics for all crewed missions prior to the delivery of the PR are delivered within the HLS and do not require LTO; this may also be true for the initial PR mission where supplies are delivered inside of the PR vehicle **<TBR-EHP-10033-002>**. For subsequent missions, a majority of the logistics are pre-delivered to the surface before crew arrive, but some late-stow and short-shelf life items will continue accompany the crew on HLS.

For subsequent missions involving the PR, and later habitation, resupply of cargo will be required. Logistics trade studies and trades are ongoing **<TBD-EHP-10033-007>**. Cargo intended for habitation other than PR are not delivered by the PR, but by the LTV the other two crewmembers are on. If resupply to other surface habitation (MPH or SH) is needed, the crewmembers in that habitat use the LTV to drive to the cargo lander, load the cargo onto the LTV, and transfer it to the habitat they are staying in. Rovers are not required to perform self-loading or offloading.

4.1.5.11.1 Pressurized Logistics and Fluid Transfers

Pressurized logistics are delivered to the surface on logistics landers prior to crew arrival. The lander will provide the necessary payload support (i.e., power and telemetry) until offloading for a limited amount of time. Logistics will be removed from the landers to either a PR or LTV with a **<TBD-EHP-10033-007>** methodology. Cargo resupply and fluid transfer operations can be performed by the crew but would ideally be performed via telerobotic operations to remove the need for EVA and, thereby, increase crew surface time spent on exploration and science rather than logistics operations.

During and at the end of the mission, trash and waste will be transferred from the PR and habitation for long term storage.

4.1.5.11.2 Other Cargo/Payload Logistics Operations

Currently other cargo/payload resupply needs have not been identified; however, it is anticipated that cargo including unpressurized material or equipment (e.g., spare parts) or larger pressurized components will be needed over time to support lunar surface operations. As these items are identified, future revisions of the ConOps will be developed **<TBD-EHP-10033-007>**.

4.1.5.11.3 Logistics Lander Operations (Common Landing Area, Disposal and/or Recycle)

Repeated logistics lander arrivals are anticipated to require landing site preparation such as regolith compacting, berm construction for plume mitigation, and landing site clearing. Additionally, old landers and waste and trash will need to be removed, disposed, processed and/or recycled. All EHP hardware must be safed for disposal at its end of life such that it does not pose a hazard to the crew, or other lunar surface assets; disposal will be performed per EHP-10025, *Extravehicular Vehicle Activity (EVA) and Human Surface Mobility (HSM) Program (EHP) Planetary Protection Plan*. As concepts of operations develop to account for these activities, future revisions will be made to address those.

4.1.5.12 Lunar Walk Back Distance with PR, and Drive Back Distance with PR and LTV

EVA range with a single, PR range: It is assumed that there is time available for the crew to rest and recharge their xEVA suits before they walk back to the lander/habitat, providing a maximum walk-back time of 8 hours (nearly a full EVA). However, a more conservative approach would be to use a more nominal EVA length of 6 hours, with an associated walk-back distance of 10 km.

EVA range with a PR and LTV: With a set of roving capabilities in close proximity, it is assumed that there is time available for the crew to rest and recharge their suits before they drive back to the lander/habitat. If the PR and LTV are within close proximity, the maximum radial distance can be extended to 20 km. If the PR and LTV are not within close proximity, the distance remains 10 km.

See Integrated Contingencies section for further details.

4.1.5.13 DRM 6 Post EVA

The following figure shows the operations associated with post EVA during the mission in PR.

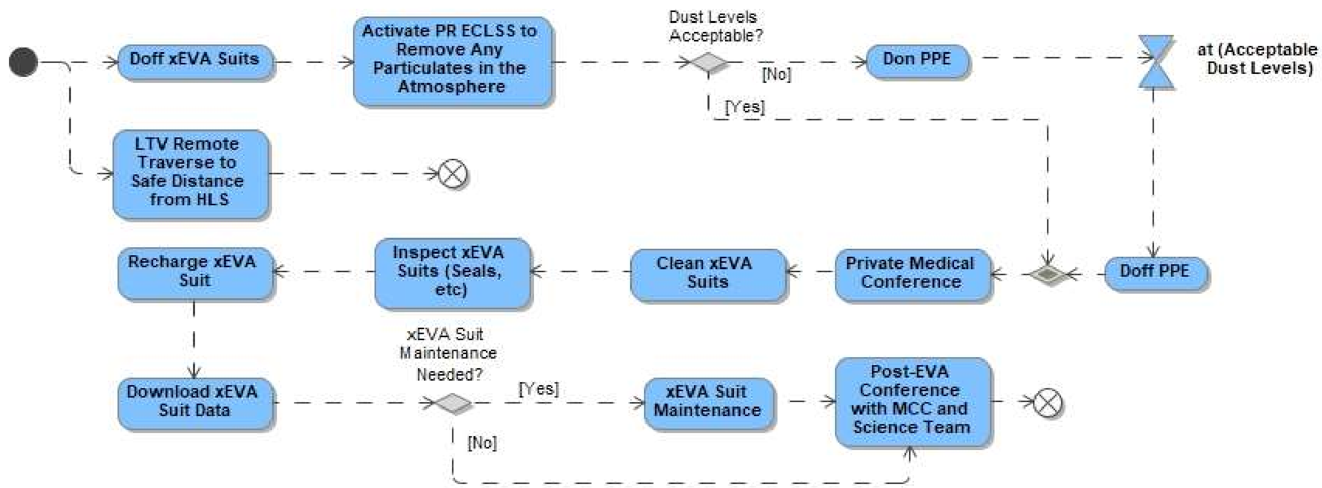

FIGURE 4-37: PR POST EVA DURING THE MISSION

The final EVA of the mission from PR to HLS is shown in the figure below. Once the crew is inside HLS, the PR is remotely driven to a location outside of the plume impingement area of HLS to record video of the ascent.

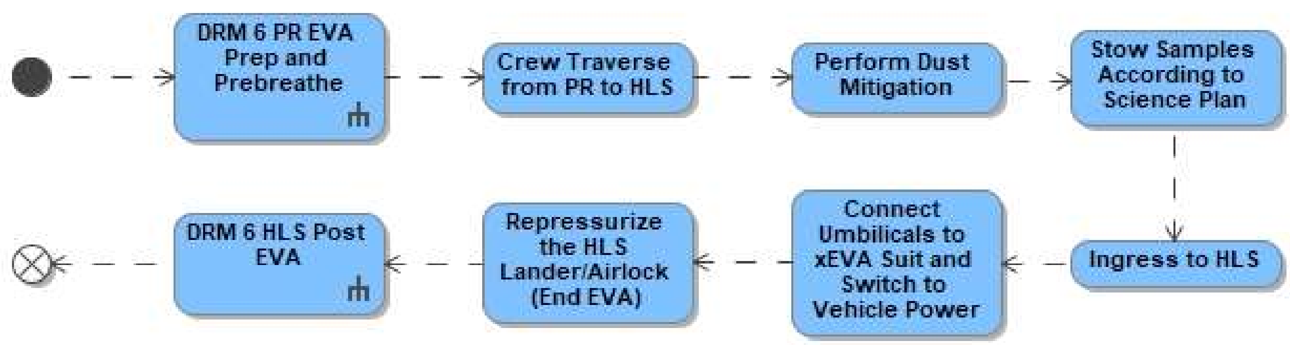

FIGURE 4-38 DRM 6 FINAL INGRESS INTO HLS

4.1.5.14 DRM 6: Uncrewed PR Mission Excursion Objectives

The PR autonomous or teleoperated activities during the uncrewed PR traverses may include, but are not limited to:

- Command and control of vehicle traverse behaviors
- Maintain and monitor vehicle systems
- Cooperation with other uncrewed lunar surface assets, such as the LTV and landers for exploration and logistics
- Scouting the surface for potential traverse paths and scientific sites of interest for future crewed missions (consider details such as terrain, natural lighting, etc.)

- Body mounted payloads surveying the subsurface to understand the geologic layering and presence of frozen volatile ice using payload instruments such as ground penetrating radar or a neutron spectrometer for investigation of polar volatiles in the top meter of regolith
- Elevated external attached payloads to survey lunar environment, such as a laser-induced breakdown spectroscopy instrument, and LiDAR.
- Imagery of potential samples, sampling sites, or other geologic phenomena
- Measuring surface properties or sample characteristics
    - Geotechnical properties as a function of terrain (i.e., bearing capacity, shear strength), geochemical characterization
- Emplace surface assets such as remote science stations:
    - Geophysical station(s), space environmental monitoring, local exosphere and volatile flux, micrometeorite collection, astrophysical payloads

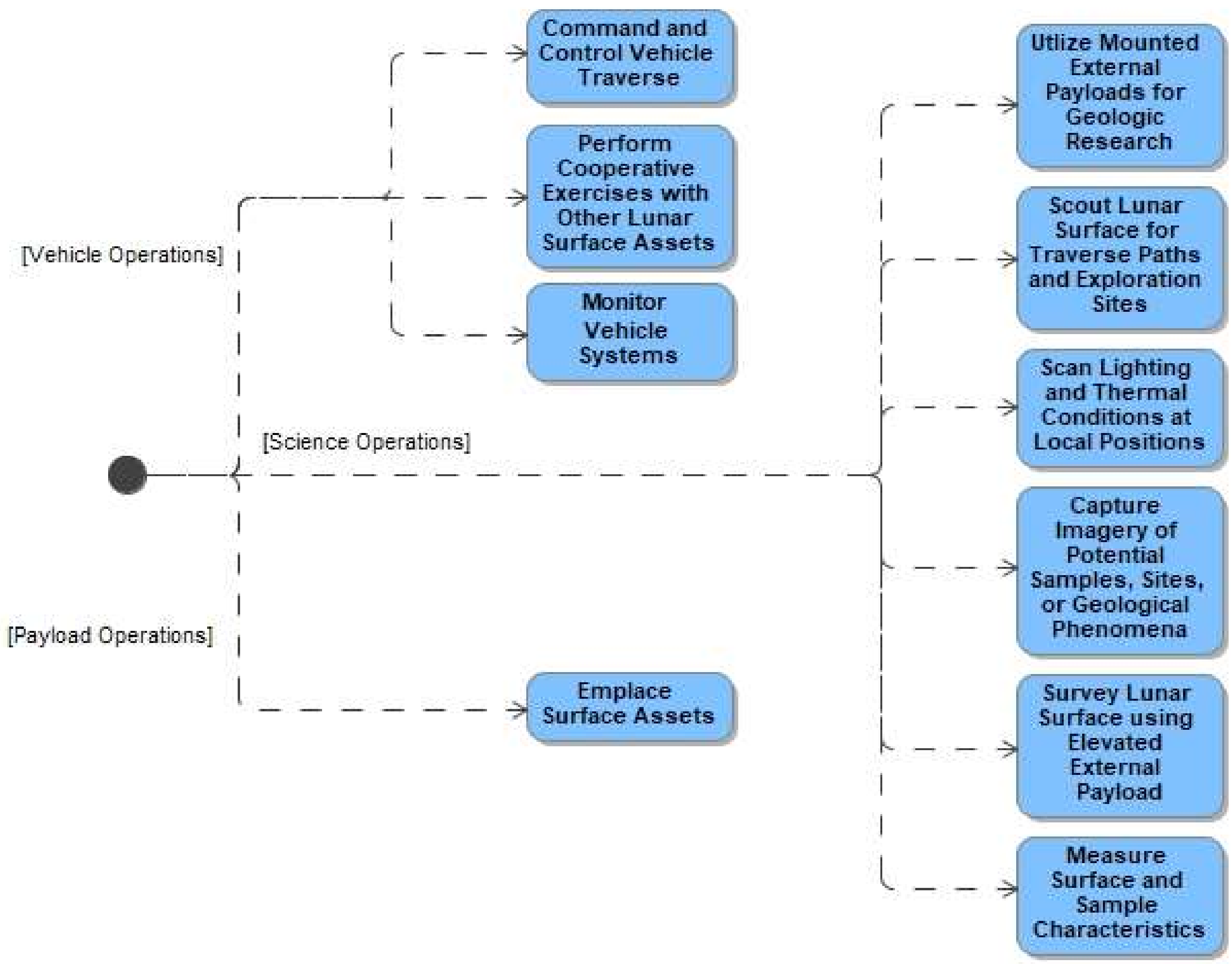

FIGURE 4-39: POTENTIAL UNCREWED MISSION EXCURSION OPERATIONS

Between crewed missions, the LTV, and later also the PR, will traverse the lunar surface in order to satisfy two major objectives: (1) survive the lunar winter by relocating between hibernation points as needed; and (2) accomplish exploration objectives, such as collecting samples, in an opportunistic fashion **<FWD-EHP-10033-027>**. These traverses will be planned in advance, taking lunar terrain and shadow conditions into account, to allow the rovers to survive while still arriving at the next landing site in time to rendezvous with the crew. When both rovers are present, they may coincidentally travel broadly similar paths since they will be traversing between the same start and end points. However, in general, the rovers are not expected to remain in close proximity to each other during uncrewed periods, partly because their exploration objectives may differ and partly because the rovers will be at lower risk of collision, shadowing one another, or obstructing one another's paths (for example, if one rover becomes stuck) if they are not being operated in tandem.

4.1.6 DRM 7: Initial Pressurized Surface Habitation – 4 Crew to Surface for Extended Surface Operations

HLS provides habitability for four crew for at least three Earth days while on the Lunar surface. Delivery of a second surface habitable asset allows the increase of crew to the surface from two to four for longer durations. After HLS descent, all four crew perform an EVA with two crew transferring to the PR and two crew transferring via LTV to the second habitable volume taking with them any perishable and crew specific items (e.g., EVA spares such as gloves) to their respective volume.

TABLE 4-5: CREWED MISSIONS WITH MOBILITY AND SURFACE HABITATION KEY PARAMETERS

Surface System Configuration	HLS Sustained, xEVA, LTV, PR, MPH	
Key Objectives	• Demonstrate prolonged surface stay • Deploy technology demonstration packages and instrumentation	
Key Parameters	Surface Crew	4
	Proposed Surface Stay	Up to 33 Days
	Proposed Number of EVAs per Crewmember	Cumulative EVA time per week ≥ 24 hrs
	EVA Range with PR and LTV (from Habitat)	20 km

4.1.6.1 DRM 7 LTV-PR Cooperative Exploration – 4 Crew to Surface

For missions with four crew on the surface, mission priorities and other factors (e.g., distance of MPH/SH from HLS) will determine when the LTV is co-located with the PR crew versus when it is with the MPH/SH crew. Furthermore, it is possible that over the course of a given mission, the LTV will “switch” support between the PR crew and MPH/SH crew. It is also possible that all 4 crew may conduct cooperative exploration together for a period of time (e.g., during a cooperative 4-crew EVA). When 2 crewmembers are stationed at the second habitable volume (MPH or SH), they may have the LTV with them for both science exploration support and contingency purposes. In this case, the crew in the MPH or SH will be limited to the 10 km walk back radial distance exploration from the SH/MPH during exploration EVA on the LTV, and the crew in the PR will be limited to the 10 km walk back radial distance exploration from the HLS.

Another possibility, depending on relative distances and mission objectives, is that the PR crew and the MPH/SH crew may exchange habitats halfway through the mission. Such an exchange would necessitate exchange of crew-specific cargo, such as hygiene kits and spare gloves.

5.0 INTEGRATED CONTINGENCIES AND APPROACH OPTIONS

All human spaceflight missions entail some level of inherent risk, and hence planning failure mitigations is critical for ensuring as much crew safety and mission success as possible. Artemis elements, including the xEVA System, LTV, and PR, must be ready and able to handle emergencies to preserve crew life and mission objectives. The LTV and PR are required to be at least 1-fault tolerant to catastrophic hazards and all critical hazards must be controlled. The xEVA suit is required to be 2-fault tolerant for catastrophic hazards and 1-fault tolerant for critical hazards. Despite these requirements, contingencies can still occur.

This section outlines a list of integrated contingencies between surface assets specific to include suit failures, crew medical events, environmental events, and loss of capabilities (such as loss of communication or rover mobility failures) that the xEVA suit, LTV, and PR are responsible for supporting. The scope of the list is on EHP element integrated contingencies, does not get into element specific failure details, and is not all encompassing. Contingency scenarios are organized by DRM, (Gateway EVA contingencies are **<FWD-EHP-10033-028>**) and some integrated contingencies can apply to all DRMs. Deltas to each scenario are discussed as opposed to repeating information already encompassed in the ConOps. Program integrated contingencies triggers are organized into three categories: Crew Medical Events, Environmental Events, and System Failure Events.

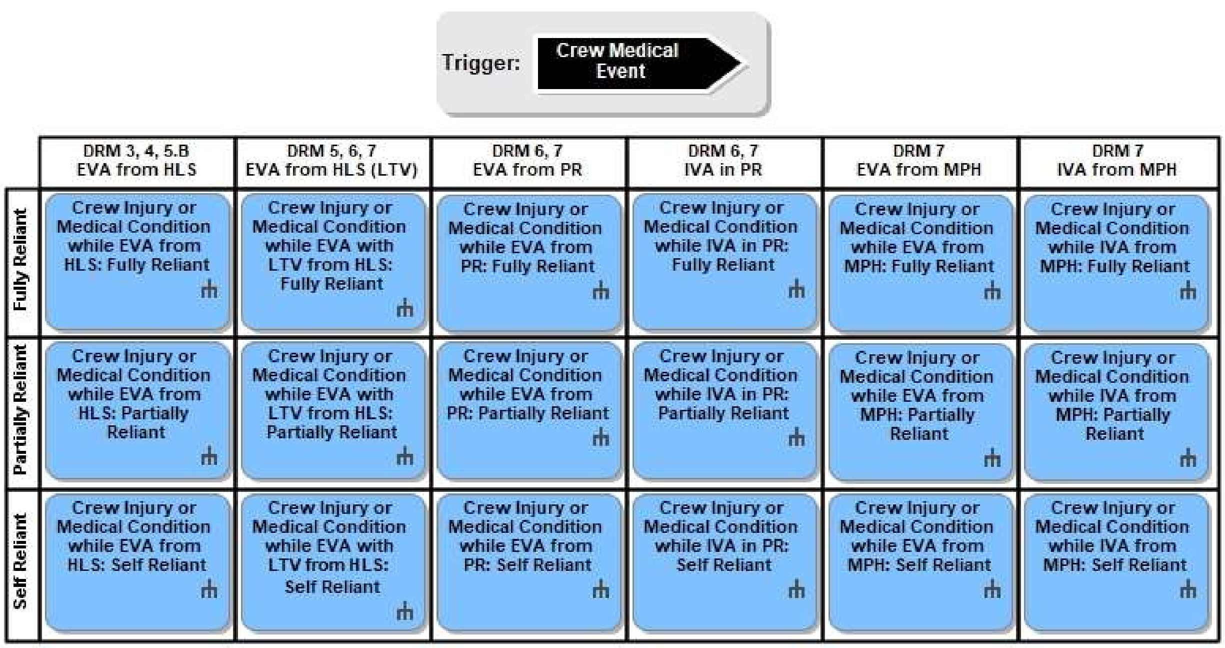

FIGURE 5-1: CREW MEDICAL EVENT INTEGRATED CONTIGENCIES

Crew Injuries: There exists a wide variety of crew injuries or medical conditions that could occur during Artemis surface mission phases. The point of injury or condition onset could occur at any time and in any location where the crew is present. The corresponding physical and/or cognitive impairment could result in the injured crewmember being fully or partially reliant on their buddy crew for survival. Alternatively, the injury might be minor enough such that the crewmember is able to transfer him or herself back to a safe location without assistance (i.e., a self-reliant). Depending on the nature of the injury/condition and medical aid capabilities available, treatment could range from facilitating a full recovery on the surface (e.g., in the event of DCS) to otherwise stabilizing the crewmember as best as possible and returning the injured crewmember back to Earth as soon as possible for definitive care (e.g., broken bone). For injuries that require return to Earth, continuity of care should be transferred as the crew transitions from one element to the next (e.g., xEVA suit → rover → HLS → Gateway → Orion). Importantly, medical care of the injured crewmember must not incur additional risk to the uninjured crewmember. Note that in terms of failure classifications, crew injuries and medical events are not in and of themselves considered failures.

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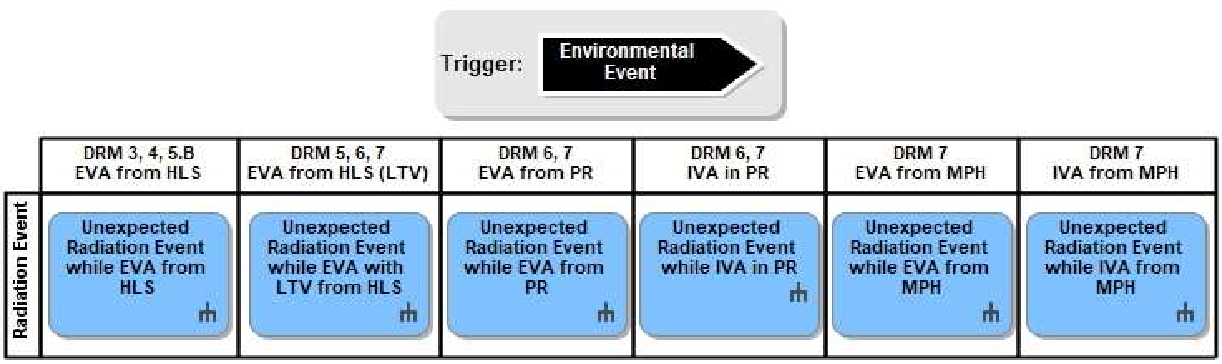

FIGURE 5-2: ENVIRONMENTAL EVENT INTEGRATED CONTIGENCIES

Environmental Events: Unexpected radiation events are covered in each section. Other environmental events such as micrometeoroid debris or contingencies due to terrain can cause both injury and a feed the leak scenario or system failure.

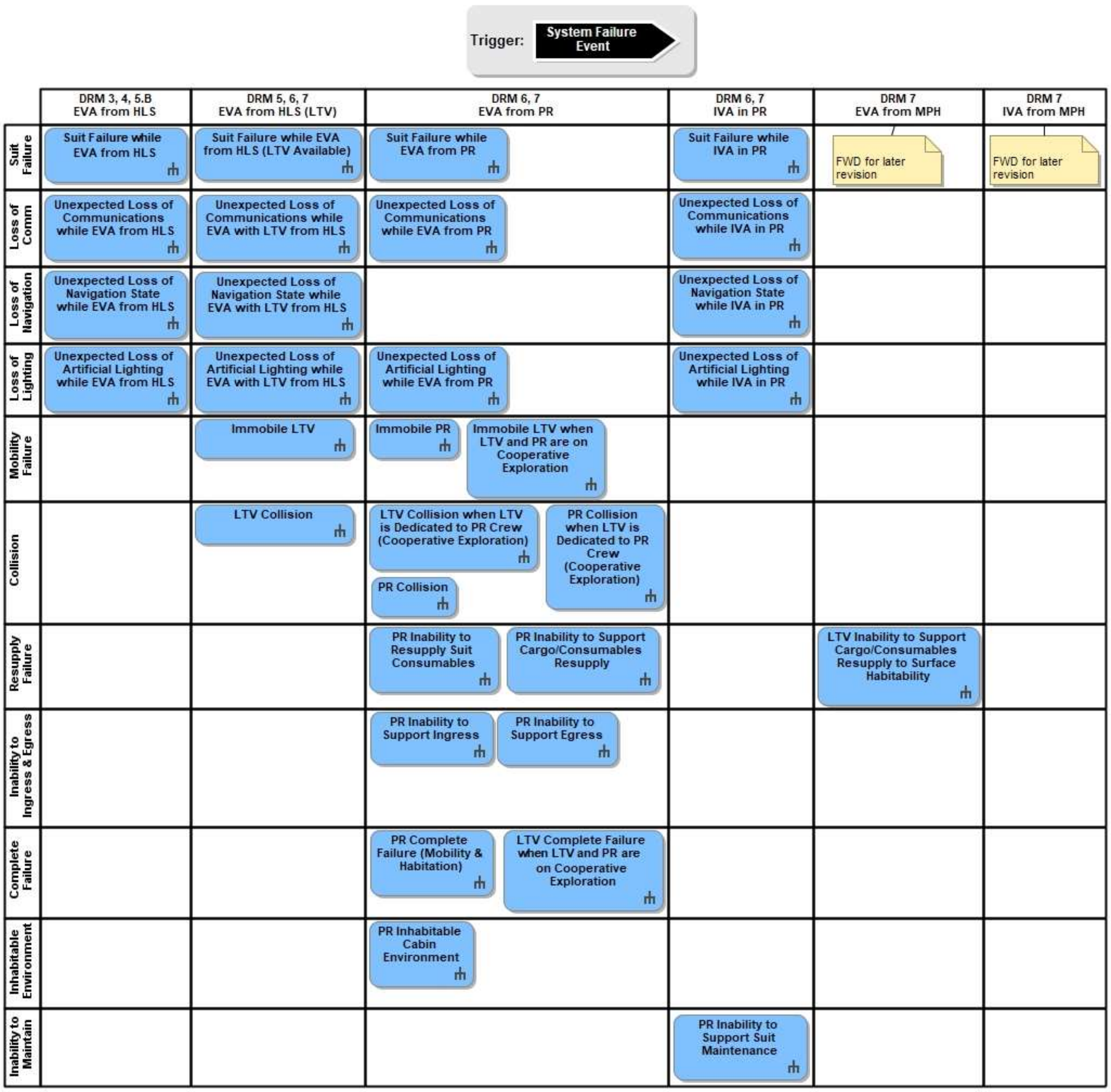

FIGURE 5-3: SYSTEM FAILURE EVENT INTEGRATED CONTINGENCIES

Suit Failures: Suit failures can result from mechanical, power, pressure, or thermal anomalies. A single failure event can cause other loss of capability on the xEVA suit (e.g., power failure → loss of artificial lighting) and can range in severity from catastrophic in nature, to critical, to minor. This document will not identify every potential suit failure that could result in an integrated contingency, as that is the role of the safety review panel process that continues throughout the life of the project including certification for flight. Instead, the focus will be on high-level integrated responses to suit failures.

Lunar Replaceable Units (LRU) or replacement parts will need to be either onboard the vehicle or able to be delivered to the lunar surface on a later mission. LRUs would need to have the capability and compatibility to be removed and replaced by a suited crewmember. Adequate lighting will need to be provided to support the maintenance. All maintenance will need to occur within the nominal bounds of EVA consumables and without requiring excess physical exertion by the crew.

5.1 DRM 3: POLAR SORTIE SUITS ONLY AND DRM X: NON-POLAR SORTIE SUITS ONLY

DRM 3 and DRM X integrated contingencies, located at a polar site and non-polar site, respectively, are categorized into four topics: xEVA suit failures, crew medical events, environmental events, and loss of capability. These DRMs assume EVA capability only and no rovers or other surface assets outside of the HLS. This section outlines integrated contingencies that occur while the crew are EVA from the HLS, including suit failure, crew injury or medical condition (responses separated by fully reliant, partially reliant, and self-reliant injuries), environmental events including unexpected radiation event, and loss of capabilities including loss of communication, loss of navigation state, and loss of artificial lighting.

TABLE 5-4: DRM 3 AND DRM X INTEGRATED CONTINGENCIES

DRM	IC Category	Hazard/Integrated Contingency
3 (polar sortie), X (non-polar sortie): Suits only	Suit Failures	Suit failure on EVA from HLS
	Crew Medical Events	Crew injury or medical condition while EVA from HLS: fully reliant
		Crew injury or medical condition while EVA from HLS: partially reliant
		Crew injury or medical condition while EVA from HLS: self reliant
	Environmental Events	Unexpected radiation event while EVA from HLS
	Loss of Capability	Unexpected loss of communication while EVA from HLS
		Unexpected loss of navigation state while EVA from HLS
		Unexpected loss of artificial lighting while EVA from HLS (i.e., loss of suit helmet lights)

5.1.1 Suit Failure on EVA from HLS

In the event of a xEVA suit failure while EVA from HLS, mission flight rules will determine (based off of hazard reports) which failures require immediate EVA termination and return to HLS versus which failures may allow an EVA to continue, possibly with some in-field troubleshooting and/or altered mission objectives. If the nature of the suit failure requires EVA termination, the affected crewmember will, if needed, switch to emergency Secondary Oxygen Pack (SOP), and then both crewmembers will walk back to HLS together as safely and efficiently as possible. It is possible that the unaffected crewmember will have to guide the affected crewmember depending on which suit capabilities are functioning in an off nominal state; furthermore, mission planning will need to account for additional time needed to return to HLS in an emergency (e.g., to initially communicate the issue between crewmembers and to the ground, navigate and traverse back to HLS in an off nominally functioning suit which might reduce pace and/or require a different traverse path, etc.). Once the crew reach HLS, they will ingress and repress, during which the HLS will provide power, cooling, comm/telemetry, and O2 to both suited crew.

In the event that the suit failure can be either troubleshooted and fixed in the field or the EVA can progress because the contingency does not pose undue risk (as bounded by flight rules, e.g., an isolated, failed helmet camera), it is possible that the EVA can continue, though potentially under reduced capabilities or with altered objectives (e.g., due to lost time to attend to the contingency initially). Throughout a suit failure contingency, the MCC team will assist the crew in following their contingency procedures, and navigating, troubleshooting, etc. as needed.

5.1.2 Crew Medical Events

For all injuries and medical conditions occurring during an EVA, the first step towards resolution is for the healthy crewmember to recognize that an injury or medical event has occurred with his or her buddy. That might include the healthy crewmember first locating the injured crewmember not within immediate line-of-sight; the ground may assist with location support. The healthy crewmember will then assess the situation and determine, in consultation with the injured crewmember (if he or she is able) and the MCC, the level of care needed and subsequent steps to take.

Medical conditions could include, e.g., DCS, which, depending on severity and how quickly it is detected, could render that crewmember anywhere from self-reliant to fully reliant on the EVA buddy. In the event of DCS while EVA from HLS, the injured crewmember and buddy will first return to HLS, repress the cabin/airlock, and connect to vehicle consumables (power and O2). It is then expected that the xEVA suit will provide elevated pressure above atmospheric and increased O2 concentration at the appropriate levels and for sufficient duration to fully treat the DCS.

5.1.2.1 Crew injury or medical condition while EVA from HLS: Fully Reliant

In the event of an injury or condition that results in a fully reliant crewmember, he or she will return to HLS utilizing EVA vendor provided tools that safely, securely, and efficiently support transport to the base of lander with the support of their healthy crew buddy. It is expected that the xEVA suits will be able to support at least some dragging along the lunar surface, the amount of which will depend on design of the xEVA vendor-provided tools for aiding in the transport a fully reliant crewmember. Once the fully reliant crewmember reaches the base of HLS, HLS vendor-provided tools and aids will provide ingress, repress, and suit doffing accommodations for a fully reliant suited crewmember.

5.1.2.2 Crew injury or medical condition while EVA from HLS: Partially Reliant

In the event of an injury or medical condition that results in a partially reliant crewmember, he or she will return to HLS utilizing vendor provided tools to the base of lander with the support of their healthy crew buddy, as needed based on the nature of the injury or condition. HLS vendor will provide tools and aids for ingress, repress, and xEVA suit doffing accommodations for a partially reliant suited crewmember.

5.1.2.3 Crew injury or medical condition while EVA from HLS: Self Reliant

An injured crewmember who is considered "self-reliant" can return to HLS under his or her own power. However, the injured crewmember may opt to use vendor provided tools and/or their healthy buddy for support to reach base of lander as an added safety precaution and to reduce risk of further injury, as long as those tools are used in an acceptable manner that is consistent with their design and intent. A self-reliant injured crewmember is not expected to use HLS-provided ingress assistance or alternate doffing accommodations.

5.1.3 Environmental Event: Unexpected Radiation Event while EVA from HLS

An unexpected radiation event (e.g., solar particle event [SPE]) could occur at any time and result in a dangerous environment for the crew and lunar surface assets. Each system in the Artemis architecture will offer an innate level of protection from Galactic Cosmic Radiation (GCR) and SPEs in line with As Low As Reasonably Achievable (ALARA) principles; innate protection levels will drive operational planning and flight rule development for minimizing the risk to crew and mission systems. Space weather forecasting will guide EVA go/no-go decisions, as risk to the crew is highest during an EVA due to exposure levels (including duration of exposure). The xEVA suits will provide active radiation monitoring and alerting to the crew. Mission flight rules will define go/no-go decisions for continuing the EVA based on the current radiation detection level. A low level event may enable the EVA to continue when in line with ALARA principles. A major event, which could last for multiple hours, will require EVA termination and the crew returning to HLS as quickly as possible.

5.1.4 Loss of Capability

There are multiple causes that could lead to loss of capabilities such as communications, navigation, lighting, etc.; furthermore, a single event could result in loss of multiple capabilities simultaneously (e.g., something that knocks out a power system).

5.1.4.1 Unexpected Loss of Communications while EVA from HLS

During DRM 3 EVAs, the xEVA suits will have UHF SSCS (space-to-space communication system) to communicate with one another and a direct UHF SSCS and Wi-Fi communication links to HLS, enabling the crew to communicate with MCC. There are multiple events that could lead to an unexpected loss of communication between crewmembers on EVA or between EVA crew and ground, such as communication network failures (including connections between HLS and ground) or EVA suit communication system failures. In the event of an unexpected loss of communication while EVA, mission flight rules will include (1) getting crew to a safe and stable state, if needed (e.g., did the loss of communication result from some other anomaly that needs to be addressed more immediately?); this could include terminating the EVA, and the (2) if/when time and resources allow, attempting to understand the cause of the loss of communication (e.g., communication blockage, suit radio failure, ground relay failure, etc. - this could be achieved by returning to the last known location of communication, swapping to an alternate radio or radio frequency, swapping to an alternate antenna or antenna station, recycling ground communication hardware, etc.) so that it can be recovered. In the event of an HLS or network failure resulting in reduced bandwidth, the data streams between HLS and Earth will be prioritized (e.g., drop to crew voice only, or crew voice and a single helmet camera).

5.1.4.2 Unexpected Loss of Navigation State while EVA from HLS

The navigation strategy for EVA from HLS during DRM 3 is currently planned to be a standalone navigation system DTO for Artemis III and certified for Artemis IV) capable of 150-m/10-deg accuracy performance. In the event that the navigation system is not ready or breaks down during the mission and no navigation state is provided to the crew, the crew will use orienteering and paper-like products to support their navigation needs: e.g., a map book, sun compass, range scale, and sighting compass are currently proposed. A sun compass can be used in combination with traverse maps to show bearing to a target and position using triangulation. A range scale provides a means for measuring the range back to the lander using the lander height (or other feature of the lander). A sighting compass can use a fixed spot on the horizon (e.g., the Earth) and while maintaining the fixed spot as base reference, helps with orienteering toward a specific heading.

In the event that the crew becomes lost during an EVA, they will pause to re-establish their current location relative to HLS, their path back to HLS, and/or their worksite (e.g., looking for key local terrain features, following boot prints until regaining line of sight with their target, etc.). Once the crew is able to re-establish navigation, they may continue their EVA, pending resources remaining. Flight rules will ensure that sufficient time for crew to safely walk back to HLS at the end of their EVA tasks.

Additional safety navigational aids such as lighting beacons (on HLS or deployed during traverse) are under investigation as a means to reduce cognitive load/time to determine direction back to safety.

5.1.4.3 Unexpected Loss of Artificial Lighting while EVA from HLS

In the event of an unexpected loss of artificial lighting while crew are EVA from HLS (i.e., xEVA suit helmet light failure which could be caused by a more general power or thermal failure in the suit, as described more generically above), the crew will follow pre-defined procedures (memorized response, relayed from the ground, their crew buddy, and/or a cuff checklist) that prioritize their safety, followed by troubleshooting and completing objectives, as time and resources allow. The affected crewmember will first complete necessary suit systems checks to determine any other problems that could impact safety (e.g., loss of artificial lighting as the result of a larger failure, such as loss of primary power, malfunction of the thermal management system, or overheating due to dust accumulation, etc., that needs to be addressed with high priority). A decision will then be made regarding which (if any) of the planned tasks can continue without artificial lighting and/or upstream failure mode that caused the lights to fail. The EVA may be continued, potentially with altered objectives to account for loss of lighting or other impacted system, or it may be terminated, in which case both crewmembers will return to HLS. It is possible that the affected crewmember may need to be assisted by the non-affected crewmember: for example in the more extreme case if the affected crewmember loses artificial lighting when operating in a fully shadowed region they might need to first be located by the unaffected crewmember and then guided out of or through the shadows. Return time may be longer than under nominal circumstances (e.g., due to needing to walk slower or change course if line-of-sight is limited). If alternate artificial lighting, that is designed to provide required light levels for the EVA task, is available (e.g., via vendor provided tools), they may be used as a substitute for suit helmet lights, which might enable more of the EVA tasks to be completed.

5.2 DRM 5: POLAR SORTIE WITH SUITS + LTV

DRM 5 integrated contingencies located at a polar site with EVA capability and LTV capability are categorized into topics similar to those outlined in DRM 3: xEVA suit failures, crew medical events, environmental events, loss of capability, with DRM 5 including vehicle collision. Only deltas from DRM 3 descriptions, i.e., due to the availability of the LTV, are included below. This section outlines additional LTV loss of capabilities while on EVA from HLS (communication, navigation, lighting, immobile LTV, and complete LTV failure) as well as a vehicle collision scenario.

TABLE 5-5: DRM 5 INTEGRATED CONTINGENCIES

DRM	IC Category	Hazard/Integrated Contingency
5: Suits + LTV	Suit Failures	Suit failure on EVA from HLS (LTV available)
	Crew Medical Events	Crew injury or medical condition while EVA from HLS: fully reliant (LTV available)
		Crew injury or medical condition while EVA from HLS: partially reliant (LTV available)
		Crew injury or medical condition while EVA from HLS: self reliant (LTV available)
	Environmental Events	Unexpected radiation event while EVA from HLS (LTV available)
	Loss of Capability	Unexpected loss of LTV communication while EVA from HLS
		Unexpected loss of LTV navigation state while EVA from HLS
		Unexpected loss of LTV artificial lighting from LTV while EVA from HLS
		Immobile LTV
		LTV - complete failure
	Vehicle Collision	LTV collision

5.2.1 Suit Failure on EVA from HLS (LTV Available)

If a xEVA suit failure occurs while EVA from HLS with the LTV that requires EVA termination, the affected crewmember will, if needed, switch to emergency SOP, and then both crew will ingress the LTV and drive back to HLS as safely and quickly as possible **<FWD-EHP-10033-024>**. The crew will ingress, connect their umbilicals to HLS consumables, and repress the HLS. In the event that the suit failure can be either troubleshooted and fixed in the field (e.g., if LTV has additional resources onboard that can support the crew) or the EVA can progress because the contingency does not pose undue additional risk, it is possible that the EVA can continue, though potentially under reduced capabilities or with altered objectives (i.e., loss of helmet lights → use LTV for lighting support).

5.2.2 Crew Medical Events

In the event of an injury or medical condition during an EVA with the LTV that requires the crewmember to return to HLS, vendor provided capabilities (EVA and LTV) will support the return of the two crew to the base of the lander. Forward work will determine medical stabilization positions for ICR transport on LTV **<FWD-EHP-10033-025>**. If the injury or medical condition requires the crew to return to the HLS for departure to Earth, vehicle safing and prep for uncrewed operations may need to be conducted by the onboard crew and/or ground, as determined by vendor design specifications.

5.2.2.1 Crew injury or medical condition while EVA with LTV from HLS: Fully Reliant

In the event of an injury or medical condition during an EVA with the LTV that renders a crewmember fully reliant on their buddy for safe haven return, vendor provided capability (EVA and LTV) will aid the healthy crewmember in returning his or her injured crewmate back to the base of lander. First, the LTV will be driven as close as practical (pending terrain) to the injured crewmember and oriented to best support crew loading and ingress; EVA vendor tools might be used to support the crew in reaching the LTV from the location of the incident. The LTV will then provide assistance to the healthy crewmember with onloading/offloading the fully incapacitated crewmember into the vehicle. It is expected that the xEVA suits will be able to support at least some dragging along the lunar surface and portions of the LTV (pending design) during the transition from the point of injury to the LTV and during the LTV ingress process. Once the fully reliant crewmember has ingressed the LTV, the vehicle will provide restraints to protect the injured crewmember during the drive back to HLS. Once the LTV reaches the base of HLS, the rover will be positioned relative to HLS to best support egress of the fully incapacitated crewmember. Depending on vendor designs, EVA tools may be used to help the injured crewmember transition from the base of the LTV to the base of HLS. Once the crew reach the base of HLS, HLS vendor provided tools and aids will provide ingress, repress, and xEVA suit doffing accommodations appropriate for a fully reliant suited crewmember. After crewmembers have ingressed HLS and prior to HLS ascent, LTV will be commanded to traverse to a location outside the HLS plume field.

5.2.2.2 Crew injury or medical condition while EVA with LTV from HLS: Partially Reliant

A similar process will be followed if the injury or medical condition leads to partially reliant incapacitation of an EVA crewmember: The LTV will provide ingress and loading assistance, restraint during the return drive, and egress and offloading assistance. EVA tools will support the transition of the partially incapacitated crewmember from the incident location to the base of the LTV, and from the base of the LTV to the base of the HLS, as needed. HLS will provide ingress assistance and alternate suit doffing accommodations appropriate for a partially reliant suited crewmember.

5.2.2.3 Crew injury or medical condition while EVA with LTV from HLS: Self Reliant

In the event of a self-reliant injury or condition that results in EVA termination, the crew will return to the lander via the LTV. In a self-reliant injury or condition, the crew are not expected to need the EVA tools, LTV ingress/egress assistance accommodations, or HLS ingress assistance and alternate suit doffing accommodations, but the crew and ground may use their discretion and utilize these features as desired to prioritize crew safety and reduce the risk of further injury, provided they are used in their intended manner.

5.2.3 Environmental Event: Unexpected Radiation Event while EVA with LTV from HLS

An unexpected radiation event while EVA from the HLS with the LTV will follow similar protocols to those defined for DRM 3 (i.e., EVA from the HLS without the LTV): flight rules will define go/no-go decisions for continuing the EVA based on the current radiation detection level. A low-level event may enable the EVA to continue when in line with ALARA principles, while a major event will require EVA termination and the crew returning to HLS via the LTV as quickly as practical.

LTV Power System Failure resulting from Radiation. **<TBD-EHP-10033-019>**

5.2.4 Loss of LTV Capability

In the event of a loss of capability of the LTV (worst case being 10 km radial distance from HLS or a habitable environment), the crew walks back to HLS **<FWD-EHP-10033-024>**. Unless there is supplemental communication extending the distance of communication between the EVA System and HLS, the crewmembers must use either a pre-planned traverse back (if no LTV communications at all) or coordinate a traverse back with ground control before departing the LTV vicinity. Loss of communication with the crew occurs once the crew leave the vicinity of the LTV and is acquired once they are within vicinity of HLS.

5.2.4.1 Unexpected Loss of LTV Communications while EVA with LTV from HLS

Similar to DRM 3, various events or circumstances could lead to unexpected loss of communication between crewmembers or between the crew and ground while EVA from HLS with the LTV. In DRM 5, the LTV could serve as a communication host: communication from xEVA suits can be relayed by the LTV to Earth, or relayed by HLS to Earth. Communication paths between LTV and HLS other than Wi-Fi are forward work **<FWD-EHP-10033-020>**. Options include relay links through Gateway or LCRNS, or dedicated direct link that is not yet defined. If the LTV loses communication with Earth, it is required to execute all critical functions without communication with Earth. Similar to the discussion above for DRM 3, in the event of an unexpected loss of communication with the LTV present, crew will prioritize getting to a safe and stable state followed by gathering an understanding of and troubleshooting the cause of the loss of comm, as time and resources allow. In the event of a communication failure resulting in reduced bandwidth, data streams between crew and ground (via the LTV or HLS) will be prioritized. If the EVA needs to be terminated, the crew will return to HLS on the LTV. The full definition of the order of operations in an unexpected loss of communication situation will be determined with input from LTV vendor details.

5.2.4.2 Unexpected Loss of LTV Navigation State while EVA with LTV from HLS

A more robust navigation capability for DRM 5 EVA (compared with DRM 3 EVA) is critical due to the distance that the LTV will take the crew away from the HLS (e.g., up to 10 km radial distance). Under nominal operations, the LTV will have its own navigation capability with 10-m 3-D-RSS absolute position and 4-deg absolute heading accuracies (e.g., using LANS augmented with optical nav/IMU, pending vendor solutions).

In the event that the LTV loses its navigation state, the EVA crew will, at a minimum, have capabilities similar to DRM 3 EVAs (150-m / 10-deg). The challenge will be the distance with which the crew are from HLS when the failure occurs, which can be compounded by the specific terrain surrounding the traverse path, natural lighting condition, available features to use as orienteering references (the Earth or other celestial objects, terrain), etc. If by DRM 5 the crew has the same navigation capability as the LTV (e.g., via the suits or a separate handheld device), then this will provide full redundancy. The crew navigation solution can be sent **<TBR-EHP-10033-019>** to the LTV display and the crew can drive based on that information.

In the event that the LTV breaks down at distance from the HLS and the crew needs to return to the HLS on foot, at a minimum, the crew will have capabilities similar to DRM 3 EVAs (150-m/10-deg accuracy). The challenge will once again be the distance with which the crew are from HLS when the failure occurs and how much extra time/resources it will take to walk-back due to coarse navigation. If by DRM 5 the crew has the same navigation capability as the LTV, the crew should be able to navigate back to the lander provided that there are enough resources remaining for a walk-back with bounded-metabolic rates.

5.2.4.3 Unexpected Loss of LTV Artificial Lighting from LTV while EVA from HLS

Pending vendor designs, artificial lighting onboard the LTV may be an important asset to EVA operations, including LTV surface traverse, EVA tasks performed off of LTV, off LTV vehicle service activities, off LTV payload operations, and off LTV science operations. If artificial lighting is lost due to a LTV contingency event (e.g., power or thermal failure, terrain impact), the crew will need appropriate capabilities to off vehicle support tasks and return safely to HLS within sufficient time to complete their return within their remaining consumables. These capabilities may come in the form of redundant or additional power systems, artificial lights, reflective materials, etc. Since DRM 5 EVAs may require the crew to travel up to 10-km radial distance away from HLS to achieve science and exploration objectives, if the lighting failure occurs at significant distance from HLS, the crew may need to take an alternate (longer) traverse path home to take advantage of more favorable natural light and/or may need to drive slower. It is not expected that EVA System lights will be sufficient for supporting LTV driving. However, it is possible that if the lighting failure occurs while the rover is in a shadowed area, one crewmember may need to walk alongside the rover and use their helmet lights to scan the terrain immediately in front of the rover to visualize obstacles and determine navigable pathways. If the lighting failure is part of a larger LTV system failure (e.g., complete power outage), the crew will need to return to HLS on foot within their remaining consumables.

5.2.4.4 Immobile LTV

In the event of an immobile LTV, e.g. due to getting stuck in terrain or following a system failure rendering the vehicle immobile, the crew will need to get themselves into a safe and stable state (if necessary) and acknowledge their remaining EVA consumables. As time and resources allow, they will work with the ground to identify and troubleshoot the failure. Troubleshooting might need to occur over multiple EVAs, pending the exact nature of the failure, vehicle design and onboard capabilities, resources needed and where they are located, and where the incident occurs in relation to the HLS.

If the LTV is stuck in terrain and requires crew involvement to become unstuck, the vehicle will need to be freed without requiring excess physical exertion by the suited crewmembers. The crew will also need to be able to access and transport (if needed) the necessary resources (e.g., tools, lights) to assist with vehicle freeing. All of this must be done within the bounds of nominal EVA consumables, accounting for time to walk out to the LTV (if multiple EVAs are needed) and walk back to the HLS at the end of the EVA. Alternatively, it is possible that vendors may provide completely autonomous or teleoperable solutions for freeing a stuck vehicle (e.g., to meet the multi-year life requirement during which uncrewed traversing will occur with the potential for getting stuck) that can also be applied during crewed mission phases.

If an LTV system failure renders the LTV immobile, then the crew will work with the ground to identify the cause and resolve so that the vehicle remains viable for future missions.

The inability of LTV to remain mobile, will preclude the ability to charge its batteries. This will result in the loss of energy storage capability. This risk can be mitigated by having a vehicle with the ability to receive power, resulting in recharging batteries via an external source **<TBD-EHP-10033-019>**.

5.2.4.5 Complete LTV Failure

In the event of a complete LTV failure (i.e., all systems inoperable including mobility, power, thermal control, communication and navigation systems, lighting, etc.), the crew will need to intervene to be part of the solution, as in this instance the vehicle will not be able to send or receive telemetry and data with the ground or conduct autonomous operations. The crew will need to have access to the necessary resources to do the preliminary diagnostics and troubleshooting so that vehicle capability can be restored. Depending on the severity of the failures and nature of the required corrective maintenance, multiple EVAs as well as support from the ground will need to be prioritized to ensure sufficient vehicle function can be restored, if possible.

5.2.4.6 LTV Collision

An LTV collision event, either with the lunar terrain or with another surface asset, could render damage to the vehicle. The severity of damage would depend on a number of factors including, but not limited to, speed on impact and location on the vehicle where the impact occurred. In general, the likelihood of such an occurrence will be reduced by operator training in realistic environments (for both manual and remote operators), flight rules outlining acceptable operating limits, smart vehicle design (e.g., appropriate Center of Gravity (CG) to minimize chances of rollover events, sufficient tread to minimize ground slippage, mechanical speed limits like governors), terrain limits (e.g., driven only over shallower slopes, limitations on rocky terrain), etc. Furthermore, current analysis and testing in analog environments has indicated that the vehicle will likely travel relatively slowly due to the challenging natural environment inherent to the lunar south pole region, as well as the desire to conduct scientific exploration while traversing (which might require starts/stops and/or slower speeds to use cameras, instruments, and conduct contextual surveys).

Nevertheless, if a collision event does occur, the crew will first need to be assessed for their own safety, and any crew injuries or xEVA suit failures will need to be evaluated and resolved. Once the crew are confirmed in a stable condition, pending remaining suit consumables and other resource needs, the vehicle will need to be assessed for damage. LTV health and status diagnostic information should be accessible by the ground without crew involvement to save on EVA time (e.g., autonomously or via teleoperations); however, pending vehicle damage, the crew may need to intervene to conduct a thorough damage assessment. The crew will then work with the ground to conceive a corrective maintenance plan, which depending on severity might extend over multiple EVAs. Replacement parts will need to be either onboard the vehicle or able to be delivered to the LTV if the LTV is unable to drive to the location due to damage. Lighting (natural and/or artificial) will need to be provided to support the maintenance. All maintenance will need to occur within the nominal bounds of EVA consumables and without requiring excess physical exertion by the crew. In case of a minor collision, yet the LTV is drivable, ground stations will confer for a go/no-go decision for continuing the EVA objectives and/or determining if the crew drive back to HLS. If the vehicle is not operable, the EVA may be terminated and the crew will need to return to HLS on foot within their remaining consumables.

If collision occurs with a crewmember, they will first need to be assessed for their own safety, and any crew injuries or xEVA suit failures will need to be evaluated. Refer to Crew Injury sections for further detail.

5.3 DRM 6: POLAR SORTIE WITH SUITS + LTV + PR

DRM 6 integrated contingencies located at a south polar site with xEVA suits, LTV, and PR capabilities include discussions relevant to DRM 6 (2 crew to the surface) and DRM 7 (4 crew to the surface). For DRM 6, the 2 crew have access to both the LTV and PR, as needed, to support science exploration and protection during contingencies. For DRM 7, the LTV may be nominally dedicated to a specific crew pair or shared between the crew pairs pending mission priorities. Using the LTV to support PR contingencies will be determined by availability of the LTV to the PR crew (e.g., is it already dedicated to the MPH or SH crew?) and proximity to the PR to render aid in time. For this reason, operating constraints are presumed so that in the event of a PR failure without the LTV available, the PR crew will always remain within walk back range of the HLS. Whether or not the LTV is available to the crew in the PR is defined in each section.

Unique to Artemis PR missions is the fact that under the current PR architecture, the crewmembers living out of the PR must perform an EVA from the PR to return to HLS (and hence return home). Contingencies during PR missions that require abort to HLS will require:

(1) If crew are EVA from the PR when the contingency occurs: EVA ingress into PR, followed by an additional PR-HLS transfer EVA

(2) If crew are IVA inside the PR when the contingency occurs: PR-HLS transfer EVA.

Prior to the PR-HLS transfer EVA, crew injuries, xEVA suit failures, and any other off-nominal circumstances will need to be considered so that the crew can safely complete their PR-HLS transfer EVA. Without the ability to complete the PR-HLS transfer, Loss of Crew is at risk. Forward work will consider alternate PR-HLS transfer capabilities **<FWD-EHP-10033-017>**.

Integrated contingency categories for DRM 6 are the same as above, but with additional loss of capabilities related to PR-specific integrated contingencies (e.g., due to PR providing IVA habitation as well as an EVA exploration platform) and callouts for dependencies on LTV availability. There are multiple integrated contingencies (e.g., suit failure, crew injury, loss of habitation, etc.), that require the ability for crew to remain suited while all of their suit consumables (power, water, O2) are supplied from the PR to the suit.

TABLE 5-6: DRM 6 AND 7 INTEGRATED CONTINGENCIES

DRM	IC Category	Hazard/Integrated Contingency
6 (2 Crew to Surface), 7 (4 Crew to Surface): Suits + LTV + PR (2 crew missions, 4-crew missions)	Suit Failures	Suit failure while EVA from or IVA in PR (LTV not available; LTV available)
	Crew Injuries	Crew injury while EVA from PR: fully reliant (LTV not available; LTV available)
		Crew injury while EVA from PR: partially reliant (LTV not available; LTV available)
		Crew injury while EVA from PR: self reliant (LTV not available; LTV available)
		Crew injury while IVA in PR: fully reliant (LTV not available; LTV available)
		Crew injury while IVA in PR: partially reliant (LTV not available; LTV available)
		Crew injury while IVA in PR: self reliant (LTV not available; LTV available)
	Environmental Events	Unexpected radiation event while EVA from PR (LTV not available; LTV available)
		Unexpected radiation event while IVA in PR (LTV not available; LTV available)
	Loss of Capability	Unexpected loss of PR communication while EVA from PR (LTV not available; LTV available)
		Unexpected loss of PR communication while IVA in PR (LTV not available; LTV available)
		Unexpected loss of PR navigation state while IVA in PR (LTV not available; LTV available)
		Unexpected loss of PR artificial lighting while EVA from PR (LTV not available; LTV available)
		Unexpected loss of PR artificial lighting while IVA in PR (LTV not available; LTV available)
		LTV inability to support cargo/consumables resupply of pressurized surface habitat
		PR inability to support cargo and consumables resupply
		PR inability to resupply suit consumables
		PR inability to support suit maintenance
		PR inhabitable cabin environment
		PR inability to support egress (LTV not available; LTV available)
		Immobile LTV when LTV is dedicated to PR crew
		Immobile PR (with and without LTV available)
		LTV complete failure when LTV is dedicated to PR crew
		PR complete failure (mobility & habitation failure) (with and without LTV available)
	Vehicle Collision	LTV collision when LTV is dedicated to PR crew
		PR collision when LTV is dedicated to PR crew
		LTV collision when LTV is dedicated to MPH crew

5.3.1 Suit Failure on EVA from PR

In the event of a xEVA suit failure while EVA from the PR, flight rules will determine (based off of hazard reports) which failures require EVA termination vs. which failures allow the EVA to continue, possibly with some in-field troubleshooting and/or altered mission objectives. If the suit failure can be either troubleshooted and fixed in the field or if the EVA can progress because the contingency does not pose undue risk (as bounded by flight rules, e.g., an isolated, failed helmet camera), it is possible that the EVA can continue, though potentially under reduced capabilities or with altered objectives (e.g., due to lost time to attend to the contingency initially). If the nature of the suit failure requires EVA termination, the affected crewmember will, if needed, switch to emergency SOP, and then both crew will walk back to the safe haven (in this case PR) together as safely and efficiently as possible (or drive back on the LTV if the LTV is available to the crew and deemed more expeditious). It is possible that the unaffected crewmember will have to guide the affected crewmember back to the PR and support them through ingress, repress, and suit doffing, depending on which suit capabilities are malfunctioning. Once the crew are safely inside the PR and have doffed their suits, they will complete suit inspections and perform necessary maintenance; repair tools and spare parts must be inside the PR for the crew to access. Suits will need to be resupplied (power, water, O2) prior to the next EVA.

If the suit remains in an off-nominal state (e.g., due to inability to return it to the nominal state with the existing supplies inside the rover, inability to resupply, etc.), or if the suit is found in a failed state while the crew are IVA inside the rover (e.g., potentially independent from the last EVA), considerations will need to be made with ground input regarding how to return the crew from the PR to the HLS to prevent against Loss of Crew **<FWD-EHP-10033-017>**. Forward work will consider what level of suit functionality following a suit failure is required so that crew can perform the PR-HLS transfer EVA <**FWD-EHP-10033-018>**. . Examples include getting the suit "as good as possible", feeding the leak, etc.

5.3.2 Crew Medical Events

If the injury or medical condition requires the crew to return to the HLS for departure to Earth, vehicle safing and preparations for uncrewed operations may need to be conducted by the onboard crew and/or ground, as determined by vendor design specifications. This would include the PR, e.g., prior to final egress, and LTV if available to the PR crew. In emergency medical situations, it is ideal if vehicle safing and preparation for uncrewed mission phases can be conducted via autonomous operations and/or teleoperations so that the healthy crewmember can prioritize support to their injured crewmate.

5.3.2.1 Crew injury or medical condition while EVA from PR: Fully Reliant

In the event of an injury or medical condition during an EVA from the PR that renders a crewmember fully reliant on their buddy for safe haven return, vendor provided tools (i.e., from EVA and PR, and possibly LTV if it is available to the PR crew and in close proximity) will aid the healthy crewmember in returning his or her injured crewmate from the location of injury or incident back to the base of lander.

If the LTV is available and the injured PR crewmember must return to HLS for treatment and/or transport back to Earth, it is possible that the LTV may be used to transport the fully reliant crewmember back to the HLS, pending available suit consumables and other resources **<FWD-EHP-10033-024>**. This decision might be made to expedite the transport and/or reduce stress on the injury/condition, pending LTV vs. PR design solutions for supporting a fully reliant individual. In this case, the healthy crewmember will need to get their injured buddy to the base of the LTV, load him/her onto the LTV, restrain him/her, drive the LTV back to HLS, unload him/her, and ingress into the HLS.

If the fully reliant crewmember needs to be transported to the HLS via the PR, the healthy crewmember must first transfer the fully reliant crewmember into the PR cabin. It is expected that the suits will be able to support at least some dragging along the lunar surface and portions of the

PR (pending design) during the transition from the point of injury to the PR and during the PR ingress process. If the EVA crewmembers are at distance from the PR with the LTV nearby, the healthy crewmember may use the LTV, similar to operations described in DRM 5, to get the fully reliant crewmember to the PR. The PR will then provide assistance to the healthy crewmember with onloading/offloading the fully incapacitated crewmember into the vehicle. Once the fully reliant crewmember is inside, he or she will be positioned according to the injury, and vehicle-provided supports and/or restraints will be used to protect the injured crewmember during the drive back to the HLS. Upon reaching the HLS, the PR will be positioned relative to the HLS to best support PR egress and final transport for HLS ingress.

If the fully reliant crewmember needs a more detailed medical assessment and/or treatment inside the PR that requires them to be unsuited, the healthy crewmember will need to conduct suit doffing of both himself/herself as well as the injured buddy. If return to HLS is still necessary following stabilization/treatment inside the PR, the PR will either be driven by the healthy crewmember or teleoperated by the ground (e.g., if the healthy crewmember must tend to the injured crewmember), and then the healthy crewmember will need to re-don the suit of the injured buddy in preparation for PR egress and HLS ingress. With the exception of DCS treatment, forward work will define which other injuries and/or medical conditions will need be treated inside the PR **<FWD-EHP-10033-019>** verses those require stabilization and transport to HLS. Forward work will consider alternate pressurized transfer methods from the PR to the HLS **<FWD-EHP-10033-017>**.

If a crewmember experiences DCS while EVA from the PR, he or she will return to the PR and ingress the cabin, either on their own or aided by their EVA buddy depending on severity of the hit. The PR cabin atmosphere will be repressed to 8.2 psi, and the suited crewmember will be connected to vehicle consumables (power and O2). The xEVA suit will provide elevated pressure and increased O2 concentration at the appropriate levels and for sufficient duration to fully treat the DCS.

5.3.2.2 Crew injury or medical condition while EVA from PR: Partially Reliant

The process for supporting a partially reliant crewmember is similar to that described above; however, in this instance, the injured crewmember may be able to assist in their own rescue, thereby partially reducing the burden on their healthy buddy. It is expected that EVA tools, and/or LTV tools pending their availability to the PR crew and proximity, will support the transition of the partially reliant crewmember from the incident location to the base of the PR, and from the base of the PR to the base of the HLS, as needed. The PR will provide any necessary PR ingress, suit doffing, restraint, suit donning, and egress assistance for the partially reliant crewmember. HLS vendor will provide tools and aids for HLS ingress, repress, and suit doffing accommodations for a partially reliant suited crewmember.

5.3.2.3 Crew injury or medical condition while EVA from PR: Self Reliant

In the event of a self-reliant injury or condition that results in EVA termination, the crew will return to the PR on foot or via the LTV. In this case, the crew are not expected to need the EVA tools or PR ingress/egress assistance accommodations. However, the crew and ground may use their discretion and choose to utilize these features to prioritize crew safety and reduce the risk of further injury, provided they are used in their intended manner. A determination will be made regarding treatment in the PR and/or return to HLS. If return to HLS is needed, the self reliant crewmember will be able to conduct suit donning, PR egress, and HLS ingress on their own without the use of ICR tools provided by the vendors or the assistance of their healthy crewmate.

5.3.2.4 Crew injury or medical condition while IVA in PR: Fully Reliant

The following integrated contingency is a subset of the above Crew Injuries while EVA from the PR. In the event of an injury or medical condition while IVA in the PR that renders a crewmember fully reliant, the healthy crewmember and ground control medical officers will assess whether or not the fully reliant crewmate can be treated inside the PR **<FWD-EHP-10033-019>** or needs to be returned to the HLS. If the crew must return to the HLS, the PR will either be driven by the healthy crewmember or teleoperated by the ground (e.g., if the healthy crewmember must tend to the injured crewmember). The PR will be positioned relative to HLS to best support egress of the fully reliant crewmember and ingress into the HLS. Then the healthy crewmember will need to don the suit of their fully reliant buddy **<FWD-EHP-10033-030>** and support them through PR egress and HLS ingress. Once the fully reliant crewmember is transported to the base of HLS, HLS vendor-provided tools and aids will provide ingress, repress, and suit doffing accommodations for a fully reliant suited crewmember. Forward work will consider alternative pressurized transfer capability between the PR and HLS **<FWD-EHP-10033-017>**. After crewmembers have ingressed HLS and prior to HLS ascent, PR will be commanded to traverse to a location outside the HLS plume field.

5.3.2.5 Crew injury or medical condition while IVA in PR: Partially Reliant

The following integrated contingency is a subset of the above Crew Injuries while EVA from the PR. A partially reliant crew injury while IVA in the PR will follow a similar process to that described for a fully reliant injury with the exception that the injured crewmember will be able to assist their healthy buddy in their own rescue (including treatment, suit donning, PR egress, and HLS ingress as needed).

5.3.2.6 Crew injury or medical condition while IVA in PR: Self Reliant

The following integrated contingency is a subset of the above Crew Injuries while EVA from the PR. A self reliant crew injury will IVA in the PR will follow a similar process to that described above for a self reliant injury while EVA from PR: A determination will be made regarding treatment in the PR and/or return to HLS. If return to HLS is needed, the self reliant crewmember will be able to conduct suit donning, PR egress, and HLS ingress on their own without the use of ICR tools provided by the vendors or the assistance of their healthy crewmate.

5.3.3 Environmental Events

PR Power System Failure resulting from Radiation. **<TBD-EHP-10033-019>**

5.3.3.1 Environmental Events: Unexpected Radiation Event while EVA from PR

An unexpected radiation event while EVA from the PR will follow similar protocols to those defined for DRM 3 and 5: flight rules will inform go/no-go decisions for continuing the EVA based on the current radiation detection level. A low level event may enable the EVA to continue when in line with ALARA principles, while a major event will require EVA termination and the crew returning to the PR. If the LTV is available, it might be used to the return the crew to the PR more expeditiously than walking.

5.3.3.2 Environmental Events: Unexpected Radiation Event while IVA in PR

The PR will be designed to limit radiation exposure to crewmembers inside the PR cabin per NASA STD 3001 Volume 1: Crew Health. Furthermore, the PR will monitor and report radiation levels produced by galactic cosmic rays and solar energetic particles to the crew and the ground. If an unexpected radiation event occurs while the crew are IVA, they will shelter inside the cabin. Depending on the design of the PR, the crew may need to conduct some cabin reconfiguration to set up a temporary radiation shelter. If the strength and anticipated duration of the radiation event exceeds the sheltering support of the PR, considerations may be made for return the crew to HLS (though the decision will need to be balanced with the need to go EVA to ingress HLS).

5.3.4 Loss of Capability

5.3.4.1 Unexpected Loss of PR Communications while EVA from PR

Similar to DRMs 3 and 5, various events or circumstances could lead to unexpected loss of communication between crewmembers or between the crew and ground while EVA from the PR, with or without the LTV. For example, communication failures could result from vehicle system or communication network (including Earth station) failures or occur due to terrain blockage. In DRM 6, the PR could serve as a communication host: i.e., communication from EVA crew can be relayed from the PR to Earth, in addition relay from the LTV or HLS to Earth. Direct surface links or relay links between the PR and LTV and HLS are forward work **<FWD-EHP-10033-020>**). If the PR loses communication with Earth, it is required to execute all critical functions without communication with Earth.

If an unexpected loss of communication occurs while the crew are EVA from PR, the crew will first get to a safe and stable state (e.g., was the communication failure due to a larger suit failure that needs to be attended to?) and then work with the ground (if accessible) to diagnose and troubleshoot the failure, as time and resources allow. Flight rules will designate when communication losses are acceptable for continuing the EVA vs. when EVA termination is necessary. In the event of a communication failure resulting in reduced bandwidth, data streams between crew and ground (via the PR or LTV or HLS) will be prioritized. If the EVA needs to be terminated, the crew will return to the PR by foot or via the LTV if it is available. The full definition of the order of operations in an unexpected loss of communication situation will be determined with input from PR vendor details.

5.3.4.2 Unexpected Loss of PR Communications while IVA in PR

If the crew lose communication with the ground while they are IVA in the PR, flight rules will bound which circumstances allow for continuation of mission objectives vs. those that require an immediate pause for diagnosing and troubleshooting the failure. E.g., if the crew were traversing through an area of terrain with a high likelihood of communication dropouts, flight rules may allow for continuation of the traverse under a degraded communication state, including LOS (loss of signal), for a specific period of time. Similar to the contingency description above, crew safety will be prioritized, followed by failure diagnostics and re-establishment of the communication.

5.3.4.3 Unexpected Loss of PR Navigation State while IVA in PR

Similar to the LTV, the PR will have its own navigation capability via a partner solution with 10-m 3-D RSS absolute position and 5-deg absolute heading accuracies. Furthermore, for DRM 6 missions, the crew navigation capability will be accurate to 10-m position/5-deg heading.

In the event that the PR loses its navigation state and the LTV is available to support the PR crew (i.e., not dedicated to another surface element crew) and is in close proximity to the PR:

1.) If the PR navigation hardware is unaffected, the PR may reinitialize its navigation state with the LTV solution and the relative state between the two vehicles **<TBR-EHP-10033-019>** as the LTV will have the same absolute navigation capability as the PR and is in close enough proximity to estimate the relative state between the vehicles.

2.) If the PR navigation hardware has failed but the vehicle remains operational, the PR crew will either (a) follow a teleoperated LTV to the desired destination, or (b) don their suits and have one crewmember transfer to the LTV for manual driving while the other crewmember drives the PR (with cabin depressed in his or her EVA suit and assuming this does not violate the buddy rule) by following the LTV (i.e., the LTV navigation system will be used to return the crew to the desired traverse path and destination).

3.) If the PR is rendered inoperable, both crewmembers will don their suits and transfer to the LTV to return to safe haven. The maximum exploration range of the PR is limited to be no greater than the driveback distance of the LTV, with time remaining to egress the LTV and ingress HLS. In this case, considerations will need to be made for PR troubleshooting so that the vehicle is not lost.

In the event that the PR loses its navigation state and the LTV is available to support the PR crew (i.e., not dedicated to another surface element crew) but not in immediate proximity of the PR:

1.) If the PR navigation hardware is unaffected, the LTV can be remotely driven to the last known PR location and transfer its navigation state to reinitialize the PR navigation system.

2.) If the PR navigation hardware has failed but the vehicle remains operational, the LTV will be teleoperated to the PR for navigation support and the PR crew will either (a) follow a teleoperated LTV to the desired destination, or (b) don their suits and have one crewmember transfer to the LTV for manual driving while the other crewmember drives the PR (with cabin depressed in his or her EVA suit) by following the LTV to the desired destination.

3.) If the PR is rendered inoperable, the LTV will be teleoperated to the PR and then both crew members will don their suits and transfer to LTV to return to safe haven. Considerations will need to be made for PR troubleshooting so that the vehicle is not lost.

In the event PR loses its navigation state and the LTV is not available to support the PR crew:

1.) Similar to DRM 5, the crew will use the EVA navigation solution (this may require the crew to be EVA so that one crew member can walk and use his or her crew navigation capability while the other crewmember follows by manually piloting the PR in his or her xEVA suit unless this violates the single crewmember EVA rule). The walking crewmember can transfer their navigation state to the PR **<TBR-EHP-10033-019>** for path planning and other functions, depending on navigation state information.

5.3.4.4 Unexpected Loss of PR Artificial Lighting while EVA from PR

Pending vendor designs, artificial lighting onboard the PR may be an important asset for both IVA and EVA operations, including but not limited to habitation, utilization, traversing, and maintenance tasks. It is possible that vehicle exterior lighting will be used as the primary light source to support nominal EVA tasks onboard the PR or in close proximity of the PR, including egress/ingress operations, tool setup and stowage, sample organization and stowage, dust mitigation, and vehicle maintenance activities. If exterior vehicle lights fail due to a PR contingency event during an EVA (e.g., power or thermal failure), the crew will need other resources on hand to be able to complete their priority tasks (which may include EVA vehicle contingency diagnostics and troubleshooting) and safely ingress the vehicle. These capabilities may come in the form of redundant or additional power systems and alternate emergency lighting systems. If the LTV is available to the PR crew, it may be driven close to the PR so that its lights can be used to support the contingency operations. In this type of contingency maneuver, the system illumination designs provided by both the LTV and suit systems need to provide a light field that meets the illumination requirements of the continency task, or otherwise its utilization cannot be used as a control to cover the loss of the lighting system on the other vehicle. Once the crew is safely inside the vehicle, they will work with the ground to identify the failure(s) and plan for corrective maintenance, if needed. If PR interior lights are also failed, the PR cabin will need additional IVA illumination capabilities so that the crew can see to be able to complete basic IVA habitation and necessary maintenance tasks. If lighting cannot be restored and the vehicle needs to be relocated (e.g., to a cargo logistics lander carrying necessary maintenance supplies or back to the base of the HLS), the crew may need to take an alternate (longer) traverse path to their destination to take advantage of more favorable natural light and/or may need to drive slower. If the vehicle is in a completely shadowed area when the incident occurs, the LTV (if available to the PR crew) and/or the suit helmet lights will need to be used to scan the terrain immediately in front of the PR to visualize obstacles and determine navigable pathways. If the lighting failure is part of a larger PR system failure (e.g., complete power outage), the crew will need to return to the HLS via the LTV (if available to the PR crew), or on foot within their remaining consumables.

If suit helmet lights fail during an EVA, the first line of defense will be for the unaffected crew buddy to be notified and regroup with his affected buddy and ensure crew safety and suit functionality. It is not expected that the PR or LTV be designed to support task lighting for all EVA utilization activities, especially those occurring at distance from the vehicles (some utilization activities may occur away from the rovers to minimizing worksite contamination, e.g., due to the vehicles otherwise thermally heating potential sampling areas). However, in an emergency and based on nominal vendor lighting designs, the extent that the vehicles can be positioned and oriented to provide emergency task lighting will be considered as part of the contingency mitigation strategy.

If the LTV is supporting the PR crew during an EVA and its lights fail, a similar procedure to that described for DRM 5 will be employed. However, to the extent that the PR nominal lights can support the contingency, they will be considered.

5.3.4.5 Unexpected Loss of PR Artificial Lighting while IVA in PR

If PR artificial lighting fails while the crew are IVA, the crew will need to first determine the scope of the failure (lighting hardware failure only? larger power or thermal systems failure? etc.) and ensure their own safety. The crew will need sufficient resources inside the PR to support this contingency (e., emergency lighting). If the vehicle needs to drive without lights, it is likely that the traverse path will need to be longer to employ favorable natural lighting conditions and the rover may need to traverse slower. If the LTV is available to the PR crew, its nominal lights may be used to support the contingency driving and PR crew egress. If the LTV is not available to the PR crew or is available but it's nominal lights are unable to illuminate the traverse path in front of the PR, it is possible that the PR crew will need to don suits and go EVA so that one crewmember can use suit helmet lights to scan the terrain immediately in front of the rover to visualize obstacles and determine navigable pathways. If the lighting failure is part of a larger PR system failure (e.g., complete power outage), the crew will need to return to the HLS via the LTV (if available to the PR crew), or on foot within their remaining consumables.

5.3.4.6 Inability to Support Cargo/Consumables Resupply

5.3.4.6.1 LTV Inability to Support Cargo/Consumables Resupply to Surface Habitability

Under nominal operations, the LTV will support cargo transfer for MPH/SH crew. Nominally, the crew would not be committed to the surface without cargo logistics landers in place and the LTV available to support cargo transfer. In the event that the LTV cannot be used to transfer cargo (e.g., mid-mission due to a contingency) and no other mobility assets are available, the mission will be aborted with an early return to the HLS **<FWD-EHP-10033-026>**.

5.3.4.6.2 PR Inability to Support Cargo/Consumables Resupply

The PR will need to support resupply of cargo and consumables to meet its ten year requirement for supporting annual crewed missions. Cargo and consumables are needed to meet crew health and habitation objectives (food, water, O2, IVA science and utilization equipment), as well as enable EVA activities (suit tools and supporting equipment, EVA science and utilization equipment). For nominal PR missions that are supplied by cargo logistics landers, the crew will not be committed to the surface until (1) the cargo logistics lander(s) and associated contents are confirmed healthy and ready to support the crewed mission, and (2) the PR is confirmed able to receive these items; this will be conducted via autonomous and/or teleoperations checkouts by ground operators. (Details regarding which specific cargo and consumables are delivered to the lunar surface via uncrewed cargo logistics landers (e.g., non-crew specific items, items with long shelf lives) vs. which come down with the crew on HLS (e.g., crew-specific items, perishables/items with low shelf life) are in work **<FWD-EHP-10033-021>**.)

Nonetheless, there are two integrated contingency scenarios that could result in an inability to resupply the PR in support of a crewed PR mission:

(1) If the HLS lands outside of the range of the cargo lander (i.e., off-nominal HLS landing location), or

(2) If the PR has a failure that results in an inability to receive logistics (e.g., mechanism for tank swap fails)

If the HLS lands outside of the range of the cargo logistics lander (i.e., outside of the nominal traversing range of the PR or PR + LTV if LTV is available to support the PR crew), mission objectives will need to be re-worked to consider the new landing location. Considerations for conducting a mission from HLS will need to be worked between EHP and HLS and will need to consider HLS surface capacities and consumables needed to support exploration operations vs. those for mission termination and abort scenarios HLS-PR contingency support).

If the PR is unable to receive logistics, e.g., the crew finds damage/contamination to the cargo once it is brought into the PR, or the crew finds an issue with the PR mechanisms necessary for supporting cargo and consumables resupply (e.g., inoperable or incorrect connectors for gas tank swaps), an assessment of the severity of the issue will need to be determined. Pending the diagnosis, a decision will need to be made for mission continuation, potentially of reduced scope or different priorities, vs. mission termination.

5.3.4.6.3 PR Inability to Resupply Suit Consumables

To enable EVA from the PR, including the ability of the crew to return to the HLS at the end of a mission, xEVA suits will need to be resupplied with power, water and O2 between all EVAs. If the PR crew return from an EVA and cannot doff their suits (e.g., due to an inability to repress, an uninhabitable cabin atmosphere, etc.), the PR will need to support suit consumable resupply while the crew remain suited while that failure is being addressed. If crew are injured or supporting a medical condition that requires them to drive suited (e.g., injury on EVA that requires return to the HLS), the suits will need to be resupplied while the crew drive to their destination to minimize delay in injury/medical condition resolution (e.g., while waiting for consumables resupply/recharge).

If the PR is unable to resupply suit consumables, the crew will not be able to conduct a nominal EVA, including a nominal PR-HLS transfer EVA (link to inability to transfer risk + **<FWD-EHP-10033-017>** with regard to alternate transfer methods + **<FWD-EHP-10033-018>** with regard to how nominal do you need to be to do PR-HLS transfer EVA). If the LTV is available to the PR crew and it has a payload to support xEVA suit emergency resupply, that can be employed to support the PR crew.

5.3.4.6.4 PR Inability to Support Suit Maintenance

The PR will need to be designed to support preventative suit maintenance, including patching or swapping of suit parts due to anticipated wear and tear (e.g., glove changeouts). This will include sufficient interior cabin space to support the maintenance and associated suit sizing and fit checks, as well as volume to store the necessary suit tools and spares. Forward work will define what level of contingency suit maintenance is needed to be supported within the PR cabin (**<FWD-EHP-10033-022>**).

5.3.4.7 PR Uninhabitable Cabin Environment

Prevention against an uninhabitable atmosphere and IVA cabin environment begins with design: for example, controlling sources for fire and toxin release, providing early detection capabilities for smoke and leaks, and supplying PPE and suppression equipment for the crew in the event that the cabin environment does inadvertently become uninhabitable. Pending vendor design, a variety of causes could lead to failure to support habitation such as fire, toxic atmosphere (e.g., elevated CO2 levels, elevated dust levels, biohazard contamination) or loss of atmosphere (e.g., pressure failure, thermal control system failure). Vendor hazard reports will identify potential sources of an uninhabitable cabin environment, and controls and crew survival methods will be considered for mitigation of such events.

If the crew are driving when a cabin atmosphere or IVA environment warning is detected, the crew will quickly park the vehicle in stable terrain and don safety equipment (e.g., PPE, portable breathing apparatus [PBA], as needed). Automatic detection systems, to the extent that vendors can incorporate them, will save crew valuable time searching for the source of the failure, likely reducing overall damage and facilitating a faster suppression response by the crew and/or ground. Once the failure source is identified, the failure will need to be mitigated (e.g., fire - extinguish the fire) and the habitable environment will need to be recovered by removing the toxins and cleaning contaminated surfaces.

In the event that the habitable atmosphere cannot be restored, the crew may need to use their suits as a safe haven and don suits as quickly as possible to egress the PR; note however that escape via suits may not be a viable resolution as, pending the exact emergency situation and PR design, the TTE might be less than time to don suits. It is also possible that depending on the timing of the emergency, e.g., immediately following an EVA, the suits may not be fully recharged to support a full EVA, pending suit recharge and resupply capabilities. If the crew do need to conduct a rapid suit don and egress from the PR, any equipment not designed to go to vacuum that is not able to be moved into conditioned stowage would end up damaged or destroyed.

For cabin loss of pressure scenarios, the PR will be designed to "feed the leak" up to a certain hole size and/or leakage rate. In this case, the crew may need to don their suits while the failure is mitigated. If cabin pressure cannot be restored (e.g., through pressure system repair, patching, replacement parts, etc.), the crew will need to drive the PR back to the HLS while suited. In the event that this scenario happens at the end of an EVA (e.g., failed cabin repress), the suits will need to be recharged (power, water, O2) while they are worn (e.g., via umbilicals, battery swap, etc., pending xEVA suit and PR vendor design details).

For all scenarios identified above, if the cabin atmosphere and IVA environment cannot be fully recovered, the crew and ground controllers will consider an alternate mission where the PR crew transfer into the HLS for continuation of exploration surface operations (likely of reduced scope with alternate priorities) and/or consider mission termination and abort scenarios.

5.3.4.8 PR Inability to Support Egress

EHP-10028 xEVA System Compatibility Standards includes a best practice EVABP-29 EVA Secondary Ingress Method in the event that the primary method of ingress/egress should fail due to a mechanical failure (hatch or power issue) or blocked exit, etc.

5.3.4.9 Immobile LTV when LTV and PR are on Cooperative Exploration

If the LTV is dedicated to the PR crew for exploration operations, the PR crew will be able to explore beyond the nominal 10-km walk back distance and out to 20-km radial distance due to the added driveback redundancy provided by the LTV in the event of a PR failure. If, however, the LTV becomes immobile during an excursion (i.e., stuck in terrain or system failure rendering the vehicle immobile), the PR crew will fall back to within walk back range of the HLS. If the LTV failure occurs within walk back range of the HLS, then the crew will work with the ground to identify and troubleshoot the LTV failure and complete LTV corrective maintenance as needed so that vehicle function can be fully restored. If LTV maintenance is required, tools and parts will need to be either onboard the LTV or reachable by the crew and brought back to the incident location (e.g., the crew may need to drive the PR to a cargo lander to retrieve the necessary supplies). If the LTV failure occurs outside of walk back range, the crew and ground will need to consider plans for LTV troubleshooting and maintenance within flight rules for contingency support **<FWD-EHP-10033-023>**. The extent by which the LTV can support failure identification and maintenance without crew hands-on engagement will support crew safety if failures occur outside of the walk back range.

5.3.4.10 Immobile PR (with and without LTV available)

In the event that the PR becomes immobile, i.e., stuck in terrain and/or system failure that leads to PR immobility such as a flat tire or broken chassis, but PR habitation and EVA support are operating nominally, the crew will first get themselves into a safe and stable state (if necessary). If the crew are EVA when the event happens, they may work with the ground to alter their EVA objectives to support diagnosing the failure and troubleshooting, pending remaining EVA consumables and EVA priorities. Once the failure has been identified, how PR mobility is re-established will depend on the exact nature of the failure, vehicle design and onboard capabilities, resources needed and where they are located (e.g., maintenance tools and parts onboard the PR? or in a cargo lander at some distance away?), and whether or not the LTV is available to the PR crew for support. If the resolution requires crew engagement (e.g., for failure diagnosing and/or corrective maintenance), the crew may need to conduct an EVA (or multiple EVAs). If the failure happens outside of walk back range (e.g., because the LTV was dedicated to the PR crew and the PR was farther than 10 km from the HLS when the incident occurred), the crew and ground will need to consider plans for PR troubleshooting and maintenance within the flight rules for contingency support when only a single rover (i.e., the LTV) is operating nominally **<FWD-EHP-10033-023>**.

If the PR is stuck in terrain and requires crew involvement to become unstuck, the vehicle will need to be freed without requiring excess physical exertion by the crew; this is also true if crew are needed for conducting corrective maintenance on system failures that render the PR immobile. The crew will also need to be able to access and transport (if needed) the necessary resources (e.g., tools, lights) to assist with vehicle freeing. If EVA is required, corrective maintenance must be conducted within the bounds of nominal EVA consumables. Alternatively, it is possible that the PR vendor may provide completely autonomous or teleoperable solutions for freeing a stuck vehicle (e.g., to meet the multi-year life requirement during which uncrewed traversing will occur with the potential for getting stuck) that can also be applied during crewed mission phases.

The inability of PR to remain mobile, will preclude the ability to charge its batteries. This will result in the loss of energy storage capability. This risk can be mitigated by having a vehicle with the ability to receive power, resulting in recharging batteries via an external source <TBD-EHP-10033-019>.

5.3.4.11 Complete Failure when LTV and PR are on Cooperative Exploration

If the LTV experiences a catastrophic failure such that none of its systems are working while it is dedicated to supporting the PR crew, the PR crew will need to intervene to be part of the diagnostics and resolution. This can include bi-direction power transfer from the PR to the LTV to diagnose the LTV failure. If the failure occurs within walk back distance of the HLS, troubleshooting and corrective maintenance can proceed as described in DRM 5. If the failure occurs outside of walk back distance, the crew and ground will need to consider plans for LTV troubleshooting and maintenance within flight rules for contingency support with a single rover (i.e., the PR) operating nominally **<FWD-EHP-10033-023>**.

5.3.4.12 PR Complete Failure (Mobility & Habitation), (with and without LTV available)

The PR will be designed to be 1-fault tolerant for catastrophic failures. Nevertheless, if the PR experiences a failure such that its habitation systems fail and the vehicle is simultaneously immobile (e.g., significant micrometeoroid hit), the PR crew will need to first get themselves into a safe and stable state, if possible. Pending vendor designs, the crew will most likely need to don suits, or stay suited if the incident occurs while the crew are EVA. Pending remaining suit consumables, if the LTV is available to the PR crew, the crew will use it to drive back to HLS; if the LTV is not available, the crew will need to walk back to the HLS. Once PR crew safety is established, the crew will work with ground controllers to establish the forward plan for failure diagnosis, troubleshooting, and corrective maintenance. Similar to the above descriptions, if crew engagement is required to mitigate the failure, it will need to be conducted within the bounds of nominal EVA consumables and without excess physical exertion by the crew. Furthermore, the crew will need to be able to access and transport (if needed) the necessary resources to assist with the corrective maintenance.

5.3.4.13 LTV Collision when LTV is Dedicated to PR Crew (Cooperative Exploration)

Similar to the discussion in DRM 5, an LTV collision event, either with the lunar terrain or with another surface asset such as the PR, when the LTV is dedicated to the PR crew could render injury to the crew and damage to the LTV and/or other asset involved in the collision. Flight rules will govern dual rover manual operations (e.g., in the event that one crewmember needs to drive the LTV while the other drives the PR), as well as rover teleoperations when the PR crew are in the vicinity of the teleoperated rover (either onboard the other rover or EVA). Both the LTV and PR will have automatic hazard detection and annunciation systems (to the crew and to the ground) to identify hazardous terrain and other objects on the surface, including the crew and other rovers.

If an LTV collision event does occur (e.g., due to operator error or onboard system failure), the crew will be assessed for their own safety, and any crew injuries or suit failures will be evaluated and resolved first. If the collision is with the terrain and the crew are inside the PR when the event occurs, the PR crew may drive the PR close to the LTV to better assess the damage and project recovery needs, and/or work with the ground to plan an investigative EVA; considerations will need to be made if the LTV is immobile (or presumed immobile) and the incident occurs outside of walk back distances. If the crew are EVA when the collision occurs, EVA task priorities may shift to LTV damage assessment, pending remaining consumables and projected stability of the rover for the crew to approach it. Crew assessments will be augmented by detailed health and status reports automatically sent to the ground for additional analyses.

If the LTV collides with the PR while the crew are EVA, both vehicles will need to be evaluated for damage, likely through a combination of crew inspections and detailed automatic health and status reports sent to the crew and ground. If the LTV collides with the PR while the crew are inside, crew health and safety will need to be established first, and then the vehicles will be assessed for system damage.

In all cases, following a thorough damage assessment, the crew and ground will plan for corrective maintenance, as needed. Any necessary replacement spares or tools will need to be either immediately available (e.g., onboard one or both of the vehicles) or able to be retrieved by the crew (e.g., might require driving one of the vehicles to a cargo lander and returning to the incident); risk posture will need to consider a collision event that renders both vehicles immobile, outside of crew walk back distance, and without onboard supplies to fix either rover. Lighting (natural and/or artificial) will need to be provided to support the maintenance. All EVA maintenance will need to occur within the nominal bounds of EVA consumables and without requiring excess physical exertion by the crew.

5.3.4.14 PR Collision when LTV is Dedicated to PR Crew (Cooperative Exploration)

Similar to the integrated contingency description above, a PR collision event (either with the lunar terrain or with another surface asset such as the LTV) could injure the crew and damage the vehicles. If such an event occurs with the terrain or another asset, crew safety and injury resolution will be prioritized, followed by vehicle damage assessment and maintenance as needed.

If collision occurs with a crewmember, they will first need to be assessed for their own safety, and any crew injuries or xEVA suit failures will need to be evaluated. Refer to Crew Injury sections for further detail.

PR Collision with another object resulting in the need for power. **<TBD-EHP-10033-019>**

5.3.4.15 LTV Collision when LTV is Dedicated to MPH Crew

Similar to the integrated contingencies description above, the LTV crew will be assessed for their own safety, and any crew injuries or suit failures will be evaluated and resolved first. The PR crew will drive the PR close to the LTV/MPH crew to better assess the damage and project recovery needs, and/or work with the ground to plan an investigative EVA. If the crew in not injured, they will walk back to the MPH while the PR crew investigate. If a crewmember is injured, he/she would be swapped with a PR crewmember for assessment.

5.4 HLS CONTINGENCY SCENARIOS <FWD-EHP-10033-020>

5.4.1 HLS Ingress Failure <FWD-EHP-10033-020>

5.5 CONTINGENCY TRANSFER TO ORION/GATEWAY

In the event that a contingency transfer inside HLS and/or to Orion or Gateway, the xEVA suit will not be used as a mitigation due to inability to fit through internal hatches. HLS and Orion do not have the capability to support EVA transfer on the vehicles in microgravity.

6.0 RECORDS

Records associated with this document that require retention are held by the EHP Configuration Management Office.

7.0 RISKS

EHP risks are tracked in the M2M Active Risk Manager (ARM) database. To facilitate integration in the risk management process, and to provide a consistent understanding of risk management information, M2M uses a common database across the division organizations and programs. ARM is the tool used by M2M for risk documentation and communication.

APPENDIX A: ACRONYMS AND ABBREVIATIONS AND GLOSSARY OF TERMS

A.1 ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ACD	Artemis Campaign Development
ACDD	Artemis Configurations Description Document
AEGIS	Artemis EVA Geographic Information System
AIST	Artemis Internal Science Team
ALARA	As Low As Reasonably Achievable
ARM	Active Risk Manager
ATP	Authority to Proceed
BPS	Biological and Physical Sciences
BRT	Body Restraint Tether
CAPTEM	Curation and Analysis Planning Team for Extraterrestrial Materials
CB	Control Board
CESD	Common Exploration Systems Development
CG	Center of Gravity
CLPS	Commercial Lunar Payload Services
CO_2	Carbon Dioxide
ConOps	Concept of Operations
DCS	Decompression Sickness
DRM	Design Reference Mission
DTO	Detailed Test Objective
ECLSS	Environmental Control and Life Support System
EGS	Exploration Ground Systems
EHP	Extravehicular Activity and Human Surface Mobility Program
EHPCB	Extravehicular Activity and Human Surface Mobility Program Control Board
EMSS	EVA Mission Systems Software
ESDMD	Exploration Systems Development Mission Directorate
EV	Extravehicular
EVA	Extravehicular Activity

Acronym	Definition
EVR	Extravehicular Robotics
FOD	Flight Operations Directorate
FSP	Fission Surface Power
GCR	Galactic Cosmic Radiation
GERS	Gateway External Robotic System
GRA	Ground Rules and Assumptions
HEOMD	Human Exploration and Operations Mission Directorate
HLS	Human Lander System
HRP	Human Research Program
HULC	Handheld Universal Lunar Camera
ICR	Incapacitated Crewmember Rescue
IDRD	Increment Definition and Requirements Document
IRD	Interface Requirements Document
ISS	International Space Station
IV	Intravehicular or Roman Numeral 4
IVA	Intravehicular Activity
Km	Kilometer
LANS	Lunar Augmented Navigation System
LCD	Launch Countdown
LCRNS	Lunar Communications and Navigation Systems Service
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
LLO	Low Lunar Orbit
LRO	Lunar Reconnaissance Orbiter
LRU	Lunar Replaceable Unit
LRV	Lunar Rover Vehicle
LTO	Logistics Transfer Operations
LTV	Lunar Terrain Vehicle
M2M	Moon To Mars

Acronym	Definition
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MDB	Mission Definition Baseline
MGRS	Military Grid Reference System
MMWS	Modular Mini-Workstation
MORD	Medical Operations Requirements Document
MPH	Multi-Purpose Habitat
N2	Nitrogen
NASA	National Aeronautics and Space Administration
NRHO	Near-Rectilinear Halo Orbit
NTPv4	Network Time Protocol Version 4
O2	Oxygen
OPR	Office of Primary Responsibility
PBA	Portable Breathing Apparatus
PET	Phase Elapsed Time
PMC	Private Medical Conference
PNT	Position, Navigation, Timing
PPE	Personal Protective Equipment/Power and Propulsion Element
PR	Pressurized Rover
psia	Pounds per Square Inch Absolute
PSR	Permanently Shadowed Region
R&R	Remove and Replace
SAO	Strategy and Architecture Office
SE&I	Systems Engineering and Integration
SH	Surface Habitat
SLS	Space Launch System
SMD	Science Mission Directorate
SOMD	Space Operations Mission Directorate
SOP	Secondary Oxygen Pack

Acronym	Definition
SPE	Solar Particle Event
SSCS	Space-to-Space Communication System
STMD	Space Technology Mission Directorate
TBD	To Be Determined
TBR	To Be Resolved
TDRS	Tracking and Data Relay Satellite
TTE	Time To Effect
UHF	Ultra-High Frequency
xEVA	Exploration Extravehicular Activity

A.2 GLOSSARY OF TERMS

Term	Description
Actor or Agent	Any human or system within the work system attempting to achieve work goals.
Artemis Mission	Begins at Launch Countdown (LCD) call to stations and ends with crew extraction to a stable platform with access to medical support and the Crew Module safely secured in the well deck in the recovery ship.
Authority	In an Autonomous system, describes which actor/agent is assigned the execution of a function or behavior in an operational sense.
Automation	A pre-programmed sequence of related functions performed by a system that is initiated by vehicle or operator command.
Autonomy	The ability of a system to achieve goals in a dynamic environment while operating independently of external control and includes the deliberate allocation of authority and responsibility for specific functions or behaviors to an Actor or Agent, such as a vehicle or a crew/ground operator. Note: during crewed phases, the crew on board the system is considered a part of the system for autonomy.
Campaign	A series of interrelated mission that together achieve Agency goals and objectives
Cargo	Cargo typically refers to all removable supplies and equipment (either provided by the vehicle or manifested as logistics or science) that are transported from one location to another for intended use beyond the system providing the transportation. Scientific and exploration-enabling cargo is needed to support mission goals at DRM destinations. A certain quantity of scientific and sample cargo can be returned to Earth in the pressurized volume with the crewmembers.
Excursion	While on an expedition, a journey from a fixed location or mobile habitable asset in the pursuit of exploration objectives, sample collection, or setting up science experiments or technology demonstrations.
Expedition	A dedicated activity within a mission (e.g., two crewmembers will descend to the lunar surface for a ~6-day expedition).
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.
Logistics	Represents all hardware manifested through the manifesting process and are necessary to be delivered during missions.
Near Rectilinear Halo Orbit (NRHO)	Used to refer to the specific stable orbit used for Artemis missions of the NRHO family of orbits with a 9:2 lunar synodic resonance characterized by a period of 6.5 days, a perilune radius of about 3,200 km, and an apolune radius of approximately 71,000 km.

Term	Description
Responsibility	In an Autonomous System, describes an Agent that will be held accountable in an organizational and operational sense for a decision outcome.
Safe Haven	A functional association of capabilities and environments (e.g., lander, habitat, pressurized rover, or EVA suit) that is initiated and activated in the event of a potentially life-threatening anomaly and allows human survival until rescue, the event ends, or repair can be affected. A lunar-surface safe haven is a temporary state that provides an opportunity for re-planning, may or may not provide an immediate path to a return vehicle, and may be limited by remaining consumables.
Scramble	A walk up steep terrain involving the use of one's hands.
Segment	Each segment will have a primary goal that addresses the purpose of exploration, as well as specific objectives that NASA wishes to achieve. These are not temporal phases, as one may not end as another begins. Includes: Human Presence in LEO, Human Lunar Return, Sustained Lunar Presence, Humans to Mars.
Semi-Autonomous	Describes a system with multiple automated sequences that can be performed without human input that result in an objective being completed. Supervised autonomy is shared control between operator and Vehicle and assumes that the operator performs some tasks and supervises the automated sequences.
Sortie	A single crewed mission to a lunar surface location for a period of days supported solely by the lunar crewed lander. The main characteristics of the sortie mission are that crew habitation is provided by the crewed lander and the crew can perform all lunar surface activities using self-contained resources – although, pre-deployment of resources is not necessarily precluded during a sortie mission.
Stage	The major events occurring on Gateway and timing of crew presence onboard Gateway. The Stage number (X) is incremented according to a major milestone in the Gateway Program, synchronized with the Artemis mission numbering. Stages are typically broken up by visiting vehicles. Gateway Stage X.0 identifies the preparation or buildup of the Gateway to be ready for crew arrival. Gateway Stage X.A identifies the presence of crew on the Gateway and an Artemis mission. Gateway Stage X.1 identifies the post-Artemis (Orion) departure Gateway reconfiguration or cleanup activities. Gateway multi-stage strategic plans will be developed with the international partnerships and incorporate high-level Artemis enterprise requirements to account for crew and lunar lander launch schedules.

Term	Description
Teleoperate	Refers to the operation of a system or machine at a distance. To control a device or machine remotely.
Uncrewed	Uncrewed mission portions refer to the duration that crew is not on the lunar surface.
Utilization	Utilization is the use of the 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).

APPENDIX B: OPEN WORK

B.1 TO BE DETERMINED

The table *To Be Determined Items* lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBD item is numbered based on the document number, including the annex, volume, and book number, as applicable (e.g., **<TBD-XXXXX-001>** is the first undetermined item assigned in the document). 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.

APPENDIX TABLE B-1: TO BE DETERMINED ITEMS

TBD	Description
TBD-EHP-10033-001	Reuse of xEVA suits/components on Gateway is not baselined. Suits not planned to need loop scrub; however, TBD if needed on Gateway Airlock side.
TBD-EHP-10033-002	Communications between EVA crewmembers, HLS, LTV, and future surface elements has not been baselined. Communication trade studies are currently in work.
TBD-EHP-10033-006	Navigation aids are currently being traded; operations are unknown. Trade studies are currently in work.
TBD-EHP-10033-007	Logistics transfer trade studies are currently in work (need to confirm what/how the cargo is packaged on the lander (eg hand carry? robotic transfer? large docking/berthing carrier?).
TBD-EHP-10033-014	Gateway Airlock providing an equipment lock and crew lock is in work.
TBD-EHP-10033-017	There is an external toolbox currently on the reference model, but no definite plans identified for one yet. It is worst case for the external config, and in the mass with caveat that it would only be used if there is not enough stowage internally. Operations preference is to have their tools inside for timeline efficiency.
TBD-EHP-10033-018	Add reference to the M2M end to end sampling document once available.
TBD-EHP-10033-019	LTV and PR Power Use Case Definition for contingencies
TBD-EHP-10033-020	Awaiting definition of compatible robotic interface
TBD-EHP-10033-021	Awaiting power specification approval

B.2 TO BE RESOLVED

The table *To Be Resolved Issues* lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBR issue is numbered based on the document number, including the annex, volume, and book number, as applicable (e.g., **<TBR-XXXXX-001>** is the first unresolved issue assigned in the document). 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.

APPENDIX TABLE B-2: TO BE RESOLVED ISSUES

TBR	Description
TBR-EHP-10033-002	Analysis will be performed to see how many days of logistics in the PR is feasible.
TBR-EHP-10033-005	Communications between EVA crewmembers, HLS, and Earth has not been baselined. Communication trade studies are currently in work.
TBR-EHP-10033-008	The acquisition strategy for the PR lander has not yet been formally decided.
TBR-EHP-10033-018	Determine if LTV is to remain within ~2-5 km distance from the PR so that the LTV can respond to a PR crew contingency event within a reasonable time.
TBR-EHP-10033-019	Determine if/how crew navigation solution and data can be sent to/from the navigation aid, EVA, LTV or PR and displays.

B.3 FORWARD WORK

APPENDIX TABLE B-3: FORWARD WORK

FWD	Description
FWD-EHP-10033-001	Forward work to include pre-formulation elements, Mars forward demonstrations on the Moon, and placeholder population for Mars operations.
FWD-EHP-10033-007	Follow lunar coordinate system decisions and reference documentation.
FWD-EHP-10033-011	Positioning the LTV in such a way that it will be out of range of plume impingement but also able to image ascent/descent may be difficult. Follow plume impingement work.
FWD-EHP-10033-017	Forward work to address inability to perform suited transfer from lunar surface assets to HLS. Update ConOps with outcome of Risk 14167.
FWD-EHP-10033-018	Consider what level of suit functionality following a suit failure is required so that crew can perform the PR-HLS transfer EVA. Update ConOps with outcome of analysis.
FWD-EHP-10033-019	Define which injuries and/or medical conditions will need be treated inside the PR verses those require stabilization and transport to HLS. Update ConOps with outcome of analysis.
FWD-EHP-10033-020	Determine direct surface links or relay links between the PR and LTV and HLS. Update ConOps with outcome of communications studies.
FWD-EHP-10033-021	Determine the details regarding which specific cargo and consumables are delivered to the lunar surface via uncrewed cargo logistics landers (e.g., non-crew specific items, items with long shelf lives) vs. which come down with the crew on HLS (e.g., crew-specific items, perishables/items with low shelf life)
FWD-EHP-10033-022	Determine what level of contingency suit maintenance is needed to be supported within the PR cabin.
FWD-EHP-10033-023	If the LTV or PR failure occurs outside of walk back range, the crew and ground will need to consider plans for troubleshooting and maintenance within flight rules for contingency support when only a single rover is operating nominally.
FWD-EHP-10033-024	Further investigate options to close 10 km radial path walk back capability (consumables, communications, objectives, etc.). Related to DI Risk 14391 - Lack of LTVS to xEVAS Integrated Hazard Mitigations at Maximum Traverse Distance.
FWD-EHP-10033-025	Forward work will determine medical stabilization positions for ICR transport on LTV
FWD-EHP-10033-026	Determine if a loss of cargo transfer by the LTV (mid-mission) would result in an abort in HLS

FWD	Description
FWD-EHP-10033-027	LTV and PR will not necessarily go to the same location. Divide and concur operations for certain uncrewed capabilities like science can be looked at during EHAC 2.9. Use cases and objectives need to be added for uncrewed portion which will drive out capability needs.
FWD-EHP-10033-028	Add Gateway EVA Contingencies to table and DRMS 5+.
FWD-EHP-10033-029	Add further to HLS EVA Contingencies: ingress failure, A/L or HLS repress failure, feed the leak to don IVA suits
FWD-EHP-10033-030	Donning a suit of a fully reliant crewmember does not currently exist in requirements and will be worked through ICR decomposition.
FWD-EHP-10033-031	Update MBSE: diagram color keys, labels, Use Case and Capabilities grouping, combining EHP-U-0008 and 0010, EHP-F-0036 definition, coordinate review of Use Cases and Capabilities.

APPENDIX C: NAVIGATION

There are two navigation configurations for DRM-3. For the first configuration Nav-1, the crew is using orienteering with paper-like navigation aids to support their navigation needs (e.g.; a map book, sun compass, range scale and sighting compass are currently proposed). The second configuration Nav-2, the crew will be able to use a handheld navigation system with an accuracy of 150 m for location and 10 deg for heading. Nav-1 configuration will be a backup for Nav-2 configuration.

The following ground rules and assumptions (GRAs) apply for the Nav-1 and Nav-2 configuration:

- Crew will stay within voice range with MCC
- Crew will stay within eyesight and/or voice range of each other
- At least one crewmember will stay within eyesight of HLS for awareness of HLS location
- Crew will send real-time helmet video feed when within Wi-Fi range
- Crew will capture a HULC panoramic when instructed by MCC (location estimation post-processing)

HULC bracketed JPG images will be transferred via Wi-Fi when Wi-Fi is available. High-resolution imagery and video will be stored in HULC memory cards for return to earth and optionally download when back at the lander. Crew will be provided with a display including digital maps.

Additional GRAs apply for Nav-2 configuration only:

- Each crew is provided a handheld navigation system
- Navigation system is compliant with 150 m/10 deg performance requirement
- Navigation system estimate can be displayed on the suit display
- Navigation system data can be sent to MCC when within Wi-Fi range

EVA Walking Traverse within Wi-Fi range

In the case where the crew traverse to a location within Wi-Fi range, crew will be able to send images and real-time video feed to MCC. The crew will communicate their position over voice based on grid nomenclature to MCC. This estimate will either be derived based on orienteering (Nav-1) or based on the handheld navigation system (Nav-2). MCC will track the crew position using Artemis EVA Geographic Information System (AEGIS) functionality. The AEGIS software tool built by the EVA Mission Systems Software (EMSS) Team enables EVA Flight Operations Directorate (FOD) to compose and execute lunar surface operations by seamlessly integrating map data into the EVA product development process to plan, train, fly, explore for Artemis. Note that the navigation system location and heading data is expected to be sent back to MCC as well.

In addition, MCC may be able to process real-time video feed and camera images to improve the crew position estimate. MCC may communicate better estimates to the crew verbally. When in Nav-1 configuration, MCC may also send the crew position best estimates to the EVA suit display so that the crew can visually see the actual traverse path as recorded along with planned path/return path information **<TBR-EHP-10033-019>.** Otherwise, Crew will be able to track their position on the EVA display maps.

EVA Walking Traverse within UHF range

In the case where the crew traverse to a location within UHF range only, the crew can exchange navigation information verbally. The crew may choose to indicate the last known location within Wi-Fi range with a visual indicator <**TBD-EHP-10033-006>**. MCC will not receive any real-time image or video and will rely on the crew verbal information to determine the crew location. However, the video and image information and any handheld navigation system information will be saved and stored and time-stamped for later post-processing.

EVA Walking Traverse: Return to Lander (Nominal)

MCC will monitor crew location and progress during the traverse along with overall health, safety and remaining EVA resources. Based on operational criteria (e.g. required EVA resources for the return, actual traverse progress versus expected progress, EVA science sampling success, overall supporting hardware status, etc.), MCC will instruct the crew to return to the lander. Crew will head in the general direction of the lander if not visible. This may be facilitated by visual indicator(s) deployed during the traverse, a lander visual indicator or using the handheld navigation system information. They will head directly toward the lander unless a terrain obstacle requires a temporary detour. If EVA visual indicators were deployed, crew may retrieve them on their return. Location estimates and range to lander estimates will be exchanged between crew and MCC to evaluate estimated time of return to the lander as well as remaining resources on return.

EVA Walking Traverse: Return to Lander (Suit Contingency)

In case of a suit anomaly, the crew will spend about 5 min troubleshooting and identifying the anomaly and will then proceed with a return to the Lander based on instructions from MCC. No other activities are expected besides walk back with a large portion of the walk-back with the lander visible to the crew. If communication with MCC is lost, crew will rely on awareness of a general direction where lander becomes visible and then follow lander's direction when visible. This lander direction awareness may be facilitated by traverse visual indicators, a lander visual indicator or the handheld navigation system. Since time is critical in this scenario, paper like navigation aids may be used sparingly when in Nav-1 configuration by any unaffected crew member to confirm general heading direction if needed.

Lunar Standards and Data Exchange Across Architecture <FWD-EHP-10033-007>

Multiple coordinate systems and reference frames are in use across the Artemis Campaign. Users must seek means to integrate across the community to provide Artemis missions a common language for referencing position and orientation of lunar surface assets at the lunar South Pole.

Apollo mission analysis and recent field testing has shown that a grid coordinate system (similar to the Military Grid Reference System (MGRS)) provides an efficient and intuitive method for crew members on the surface to describe their position and orientation effectively to ground teams, at scales bounded by human performance. By contrast, a latitude/longitude (lat-long) system can be disorienting in practice on the surface, due to longitude convergence and cardinal direction ambiguity near the poles.

Many remote sensing platforms, such as the Lunar Reconnaissance Orbiter (LRO), employ lat-long systems to describe locations on the lunar surface. Users analyzing data received from such platforms must be able to easily translate to and from operational reference frames, such as a grid coordinate system, to enable mission planning and integration, and scientific analysis.

Current studies are investigating the deployment of Position, Navigation, Timing (PNT)-enabled services for the Artemis Campaign. Any coordinate system and/or reference frame in use across the community should also integrate with PNT-enabled services, especially if those PNT-enabled services provide navigation data to crew members on the surface.

ACD-50044, *Artemis Campaign Development (ACD) Lunar Surface Data Book*, can be used as a reference for a common set of data sources and assumptions provides examples of traverses. Once landing sites and objectives are known, detailed traverses will be planned by the operations community.

APPENDIX D: POWER

Power exchange on the lunar surface is crucial for a variety of reasons. As we venture beyond Earth, establishing a sustainable presence on the Lunar surface and preparing for future Mars missions, reliable electrical power becomes a lifeline. Here's why:

1. Artemis Program and Beyond: NASA's Artemis program aims to return humans to the Moon and demonstrate technologies essential for Mars missions. A permanent habitat on the lunar surface requires continuous power for life support systems, communication, and scientific research.
2. In-Situ Resource Utilization (ISRU): To reduce reliance on Earth, we must extract resources from the Moon. ISRU processes like mining water ice and producing oxygen depend on energy sources. Power exchange enables these critical activities.
3. Fission Surface Power (FSP): Nuclear reactors can provide abundant, reliable energy. Establishing a shared power system with long distance power transfer allows us to integrate fission-based systems, ensuring a steady supply of electricity.
4. Commercial Lunar Economy: As private companies explore lunar resources, long distance power transmission facilitates their operations. In-space manufacturing, mining, and tourism all require electricity. A shared power system via long distance power transfer enhances efficiency and cost-effectiveness.
5. Reliability and Evolvability: A lunar power grid offers flexibility. It allows seamless integration of various sources—solar arrays, batteries, regenerative fuel cells, and even nuclear power. As power demands grow, the grid adapts, ensuring uninterrupted energy supply.

Nominally, there exists a potential use case for extending the operational duration and travel distance of the LTV. This extension could allow the LTV to remain at a specific location for an extended period or accommodate longer scientific missions. The LTV engages in power exchange with other elements, including the PR and future components (such as MPH), SH, power generators, and charging stations). This power exchange can occur either with crewed or uncrewed operations through an interface compatible with both crew-operated mating connectors and robotically operated mating connectors. Each rover will carry crew-operated power exchange hardware, while hardware requiring robotic manipulation (such as long cables) will be reserved for future elements and not carried by the LTV or PR.

The ability to utilize the power exchange interface for external recharging of power storage devices is crucial for success of lunar exploration and habitation. Let's explore why:

1. Sustainability and Longevity
    1. Lunar missions, especially those involving long term habitation, require a reliable and sustainable power supply
    2. Rechargeable batteries serve as an essential energy reservoir, allowing continuous operation during periods of low or no sunlight (such as lunar nights)
2. Mitigating Power Source Failure
    1. Primary power sources, like solar arrays, can face unforeseen issues (e.g. dust accumulation, damage, or malfunction)

    2. Backup batteries act as a safety net, providing power when primary sources fail. They ensure uninterrupted operations for critical systems.
3. Flexibility and Adaptability
    1. External rechargeable batteries allow flexible energy management. They can be charged during peak sunlight hours and discharged during Lunar nights.
    2. Robotic explorers, habitats, and scientific instruments can rely on these batteries, adapting to varying power demands
4. Emergency Situations
    1. In emergencies (e.g. equipment malfunction, unexpected events), battery power becomes crucial, not limited to:
        1. **Full Loss of Power Generation**: This situation may arise due to damage to power generation devices, inability to fully retract them, arcing, or other reasons. In such cases, the vehicle loses its power generation capability, rendering it unable to charge batteries or provide power to the vehicle. Power exchange and external recharge become essential for vehicle startup and power transmission.
        2. **Partial Loss of Power Generation**: Partial loss of power generation can occur due to array damage, inability to partially retract solar arrays, shadowing, or other factors. When power generation becomes insufficient, external recharge via the power exchange interface allows successful battery charging.
        3. **Inability to Recharge from the Vehicle**: If the vehicle cannot recharge its batteries using its own power generation devices, external power recharge via the power exchange interface becomes a critical solution. Vehicle to vehicle power exchange can support diagnostics in the case of a system failure.
5. In-Situ Resource Utilization
    1. Rechargeable batteries facilitate ISRU activities (e.g. mining water ice, producing oxygen) by providing power during resource extraction and processing
6. Lunar Dust and Charging Hazards
    1. Lunar regolith dust particles accumulate charge due to electrostatic interactions
    2. Battery powered equipment avoids direct contact with charged surfaces, reducing risks associated with Lunar dust

In summary, external battery recharge capability via the power exchange interface ensures reliable, adaptable, sustainable power for lunar missions, supporting scientific research, exploration, and future human presence on the moon.

APPENDIX E: EHP USE CASES AND CAPABILITIES

E.1 EHP USE CASES

EHP Use Cases are a high-level dataset that categorizes all EHP behavioral responsibilities that are independent of EHP system solutions. The EHP Use Case dataset is currently allocated to the ESDMD Use Case and Functions dataset. In the teamwork cloud version of the EHP CONOPS, a user can select any of these Use Cases and be navigated to a table automatically filtered by the selected EHP Use Case to show all EHP Functions associated to that Use Case. This supports a traceability analysis which shows how EHP is meeting its required behavior.

FIGURE E-7-1: EHP USE CASES

The following table details the allocation of the EHP Use Cases to the ESDMD Use Cases. This allocation facilitates a parent-child traceability analysis to report and ensure that EHP satisfies the behavioral needs of the agency. This table is also accessible via the teamwork cloud version of the EHP ConOps

TABLE E-1: EHP USE CASE TO ESDMD USE CASE ALLOCATION

EHP Use Case	ESDMD Use Case
EHP-U-0001 Collect Lunar Samples	• UC-025-L Crew extravehicular explorations and identification of surface samples • UC-030-L Collect surface samples from PSRs • UC-111-L Collect sub-surface samples from PSRs • UC-117-L Provide tools, including EVA tools, to collect, recover, and package sub-surface samples • UC-034-L Collect sub-surface samples from non-PSRs and sunlit regions • UC-026-L Collect surface samples from non-PSRs and sunlit regions • UC-107-L Document sample details prior to collection on the lunar surface • UC-019-L Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
EHP-U-0002 Command & Handle Data	• UC-174-L Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received • UC-176-L Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
EHP-U-0003 Communicate with Earth	• UC-047-L Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities • UC-175-L Communications and data exchange between assets in cislunar space and Earth • UC-066-L Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth • UC-158-L Transmit data from in-space and surface asset(s) to medical personnel on Earth
EHP-U-0004 Communicate with Lunar & Cislunar Assets	• UC-173-L Communications and data exchange between assets in cislunar space and the lunar surface • UC-067-L Communications and data exchange between assets at a variety of exploration locations on the lunar surface
EHP-U-0005 Conduct Science Activities	• UC-043-L Conduct intravehicular science and utilization activities on the lunar surface • UC-077-L Demonstrate operational techniques to recover water from the lunar regolith in the polar regions • UC-040-L Crew conduct fundamental physics experiments while in habitable volume on the lunar surface • UC-076-L Demonstrate operational techniques to recover oxygen from lunar regolith • UC-036-L Crew conduct biological science and human research activities on the lunar surface • UC-046-L Provide in-situ training to crewmembers for science tasks during mission(s) • UC-150-L Demonstrate operational techniques to recover and refine metals from the lunar regolith

TABLE E-1: EHP USE CASE TO ESDMD USE CASE ALLOCATION

EHP Use Case	ESDMD Use Case
EHP-U-0006 Deploy Assets & Payloads	• UC-063-L Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation • UC-031-L Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation • UC-142-L Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation • UC-033-L Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation • UC-062-L Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation • UC-171-L Deploy and set up assets to monitor induced environment on the lunar surface • UC-042-L Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation • UC-039-L Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation • UC-053-L Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation • UC-169-L Deploy and set up assets to monitor natural environments on the lunar surface • UC-057-L Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation • UC-041-L Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation • UC-159-L Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation • UC-124-L Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation • UC-144-L Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation • UC-134-L Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation • UC-007-L Unload large exploration assets on the lunar surface • UC-165-L Deploy assets to monitor natural environments in cislunar space • UC-014-L Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
EHP-U-0007 Determine PNT	• UC-126-L Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface • UC-127-L Position, navigation, and timing for accurate sample tracking • UC-068-L Position, navigation, and timing for crew and robotic assets in cislunar space
EHP-U-0008 Dispose Trash, Waste, & Assets	• UC-136-L Manage disposal of hardware and waste products

TABLE E-1: EHP USE CASE TO ESDMD USE CASE ALLOCATION

EHP Use Case	ESDMD Use Case
EHP-U-0009 Ensure Crew Health & Performance	• UC-161-L Nutrition monitoring for crew during mission • UC-138-L Ensure safe and effective interaction between crew and autonomous asset(s) • UC-163-L Crew health maintenance with countermeasure activities in partial gravity environment • UC-160-L Crew survival during off-nominal situations • UC-154-L Crew emergency health care, diagnosis, and treatment on the lunar surface • UC-152-L Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface • UC-018-L Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface • UC-104-L In-situ diagnosis and treatment of crew on the lunar surface
EHP-U-0010 Ensure System Health & Performance	• UC-191-L Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
EHP-U-0011 Habitate Surface	• UC-147-L Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface • UC-092-L Reuse habitation system(s) on the lunar surface • UC-146-L Habitation capabilities for short-duration (days to weeks) missions on the lunar surface
EHP-U-0012 Maintain Systems	• UC-122-L Robotic system(s) support of maintenance and repair operations as appropriate • UC-183-L Crew repair and/or replacement of failed or off-nominal systems
EHP-U-0013 Return Samples & Artifacts to Earth	• UC-118-L Package sub-surface samples for return • UC-097-L Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers • UC-116-L Return physical artifacts from experiments to Earth
EHP-U-0014 Supply Power	• UC-189-L Provide continuous power availability in off-nominal conditions

TABLE E-1: EHP USE CASE TO ESDMD USE CASE ALLOCATION

EHP Use Case	ESDMD Use Case
EHP-U-0015 Support Mars Forward Architecture	• UC-130-L Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions • UC-139-L Demonstrate maintenance, modification, and/or upgrades of asset(s) • UC-143-L Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction • UC-145-L Demonstrate regolith based additive/subtractive manufacturing techniques • UC-075-L Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region • UC-093-L Demonstrate in-situ crew command and control of robotic system(s) • UC-108-L Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
EHP-U-0016 Transport Crew & Systems	• UC-056-L Land exploration missions at sites removed from sites of historic significance • UC-004-L Transport crew and supporting system(s) between cislunar space and the lunar surface • UC-119-L Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface • UC-133-L Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface

TABLE E-1: EHP USE CASE TO ESDMD USE CASE ALLOCATION

EHP Use Case	ESDMD Use Case
EHP-U-0017 Traverse, Explore, & Operate	• UC-010-L Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface • UC-083-L Conduct autonomous/semi-autonomous mission operations on the lunar surface • UC-024-L Crew excursions to locations distributed around landing site • UC-011-L Support crew extravehicular operations on the lunar surface • UC-035-L Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth. • UC-128-L Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface • UC-048-L Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest • UC-089-L Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning • UC-005-L Operate transportation assets(s) from Earth during crew surface missions • UC-094-L Remotely manage robotic system(s) during surface operation as required • UC-022-L Crewed mission(s) to distributed landing sites on the lunar surface • UC-102-L Operate habitation system(s) on the lunar surface while uncrewed • UC-184-L Remotely manage robotic system(s) during in space operation as required • UC-105-L Perform lunar surface activities with surface robotic system(s) assistance • UC-121-L Robotic system(s) support of logistic operations on the lunar surface as required • UC-023-L Robotically survey potential crewed landing and exploration sites to identify locations of interest
EHP-U-0018 Withstand the Environment	• UC-125-L Limit spread of dust raised by lunar surface operations • UC-172-L Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics • UC-170-L Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges • UC-115-L Reduce path erosion, dust lofting, and sample contamination
EHP-U-0019 Ensure Task Visibility & Visual Monitoring	• UC-011-L Support crew extravehicular operations on the lunar surface

E.2 EHP CAPABILITIES

An EHP Capability identifies the categorization of EHP Functions. Where EHP Use Cases describe the problem domain (the behaviors levied onto EHP), the EHP Capabilities outline the solution domain (the Function categorization we need to meet the Use Cases). An EHP Function can be allocated to one or more EHP Capability. Additionally, the EHP Capability dataset is allocated to the M2M Capability dataset to facilitate cross-project collaboration and consistency. In the teamwork cloud version of the EHP ConOps, a user can select any of these capabilities and be navigated to a table automatically filtered by the selected EHP Capability to show all Functions of that Capability. Please see the below table for descriptions of each capability.

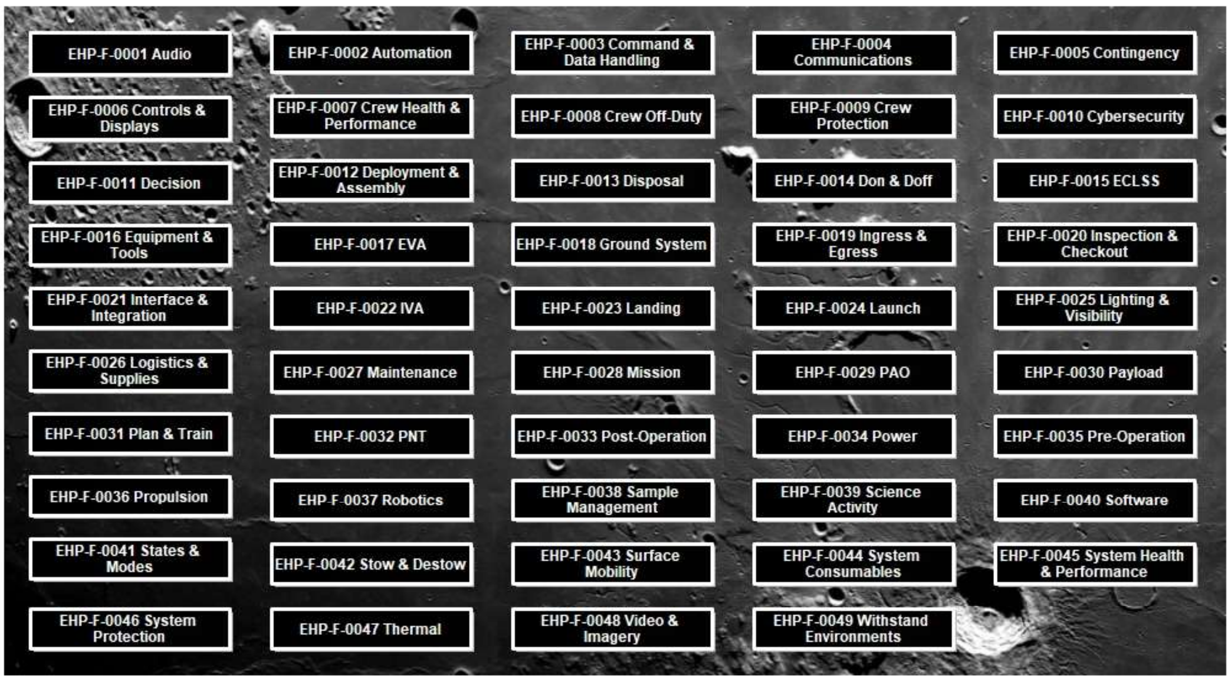

FIGURE E-2: EHP CAPABILITIES

TABLE E-2: EHP CAPABILITIES DEFINITION TABLE

Name	**Description**
EHP-F-0001 Audio	The capability to capture, playback, send, and receive audio.
EHP-F-0002 Automation	The capability to provide automated and autonomous functionality. Autonomous: The ability of a system to achieve goals in a

TABLE E-2: EHP CAPABILITIES DEFINITION TABLE

Name	Description
	dynamic environment while operating independently of external control and includes the deliberate allocation of authority and responsibility for specific functions or behaviors to an Actor or Agent, such as a vehicle or a crew/ground operator. Note: during crewed phases, the crew on board the system is considered a part of the system for autonomy.
EHP-F-0003 Command & Data Handling	The capability to store, process, and execute commands & data.
EHP-F-0004 Communications	The capability to send and receive data to and from an external system.
EHP-F-0005 Contingency	The capability to support off-nominal events, including: a crew medical event, environmental event, system failure event, crew abort, termination of an operation, self-rescue, incapacitated crew rescue, and walk back scenarios.
EHP-F-0006 Controls & Displays	The capability to provide user input and receive visual information needed to operate a system.
EHP-F-0007 Crew Health & Performance	The capability to monitor and support crew health, including: health management, crew routine, monitor crew vitals, and health treatments.
EHP-F-0008 Crew Off-Duty	The capability to enable crew personal time.
EHP-F-0009 Crew Protection	The capability of the system or equipment to safeguard the crew.
EHP-F-0010 Cybersecurity	The capability of the system to protect information systems from unauthorized access and usage.
EHP-F-0011 Decision	The capability to enable decision making activities such as "go or no-go".
EHP-F-0012 Deployment & Assembly	The capability to deploy or assemble a system, equipment, or supplies.
EHP-F-0013 Disposal	The capability to support the disposal of the system, equipment, supplies, trash, or waste.

TABLE E-2: EHP CAPABILITIES DEFINITION TABLE

Name	**Description**
EHP-F-0014 Don & Doff	The capability to support the don & doff of xEVA or IVA suits.
EHP-F-0015 ECLSS	The capability to provide or control atmospheric parameters (pressure, temperature, humidity, oxygen levels, etc.), fire detection and suppression, waste management and water supply.
EHP-F-0016 Equipment & Tools	The capability to utilize crew equipment & tools for EVA, logistics, maintenance, and supplies.
EHP-F-0017 EVA	The capability to perform activities by a pressure-suited crewmember in an unpressurized or space environment.
EHP-F-0018 Ground System	The capability to provide terrestrial support of lunar and cis-lunar assets using ground stations, mission control, remote terminals, and ground networks.
EHP-F-0019 Ingress & Egress	The capability to provide suited crew access to enter or exit the system.
EHP-F-0020 Inspection & Checkout	The capability to support a system's initial deployment, nominal inspection, and checkout activities. Note: Inspection may include visual checks from crew and/or instrumentation. Checkout may include verifying system functionality and operability.
EHP-F-0021 Interface & Integration	The capability to provide exchange (data, material, energy) between hardware, software, and/or environmental elements.
EHP-F-0022 IVA	The capability to perform activities by a crewmember in a pressurized environment.
EHP-F-0023 Landing	The capability to support operations related to the landing of a system on the lunar surface or returned to earth.
EHP-F-0024 Launch	The capability to support operations related to the launching of a system from earth and the lunar surface.
EHP-F-0025 Lighting & Visibility	The capability to illuminate the lunar surface for the crew, exploration, maintenance, and science activities.

TABLE E-2: EHP CAPABILITIES DEFINITION TABLE

Name	Description
EHP-F-0026 Logistics & Supplies	The capability to support equipment inventory, flight crew resources, and resupply.
EHP-F-0027 Maintenance	The capability to maintain systems and equipment.
EHP-F-0028 Mission	The capability to support mission level activities on the lunar surface.
EHP-F-0029 PAO	The capability to support activities of the PAO.
EHP-F-0030 Payload	The capability to support payload operation, deployment, transport, and storage.
EHP-F-0031 Plan & Train	The capability to support the planning and training of operations and procedures.
EHP-F-0032 PNT	The capability for systems and crew to determine their position, navigation, and timing.
EHP-F-0033 Post-Operation	The capability to support turnaround activities immediately after the end of an operation.
EHP-F-0034 Power	The capability to generate, store, exchange, and manage power.
EHP-F-0035 Pre-Operation	The capability to support activities immediately before the start of an operation.
EHP-F-0036 Propulsion	The capability to support activities related to a system's movement.
EHP-F-0037 Robotics	The capability to robotically perform activities including: manipulate the environment, equipment, and payloads, take measurements, and scout traverse paths.
EHP-F-0038 Sample Management	The capability to collect, store, and manage lunar samples.
EHP-F-0039 Science Activity	The capability to perform science activities.
EHP-F-0040 Software	The capability to perform functions via system software.

TABLE E-2: EHP CAPABILITIES DEFINITION TABLE

Name	**Description**
EHP-F-0041 States & Modes	The capability to change a system's configuration (such as changing from On to Off state).
EHP-F-0042 Stow & Destow	The capability to store, unpack, load, unload.
EHP-F-0043 Surface Mobility	The capability to traverse the lunar surface in a vehicle.
EHP-F-0044 System Consumables	The capability to utilize and resupply a system's consumable materials (O2, H2O, propellant, etc.).
EHP-F-0045 System Health & Performance	The capability to monitor system health, status, and performance; and alert and assist local or remote operators in troubleshooting.
EHP-F-0046 System Protection	The capability of the system to safeguard itself.
EHP-F-0047 Thermal	The capability of the system to manage thermal loads.
EHP-F-0048 Video & Imagery	The capability to capture, store, and communicate video and imagery.
EHP-F-0049 Withstand Environments	The capability to withstand natural and induced environments of space.