National Aeronautics and
Space Administration

EVA-EXP-0042
REVISION B
EFFECTIVE DATE: OCTOBER 19, 2020

EXPLORATION EVA SYSTEM
CONCEPT OF OPERATIONS

Verify that this is the correct version before use

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REVISION AND HISTORY PAGE

Revision No.	Change No.	Description	Release Date
B		Revision B (Reference EVA-CR-00082) New template (change in section numbers) Section 1: Updated with Artemis Program Section 2: Updated references Section 3: Added Artemis Program and phases Section 4: Consolidated information, incorporated information from EVA-EXP-0075, community work on xEVA System, the Artemis Program, Gateway, HLS, and LTV Section 5: Minor cleanup and updates Section 6: Minor cleanup and updates Section 7: Updated per Artemis Program Section 8: Minor cleanup and updates Section 9: Minor cleanup and updates Appendices: New appendices with details and information from revision A, along with architecture information moved to annexes	10/07/2020
A		Revision A (Reference CR EVA-CR-00048 dated 07/03/2019) Section 1: Updates and clarifications Section 2: Clarifications and formatting updates Section 3: Most of section moved to EVA-EXP-0041 Section 4: Content reduced and simplified Section 5: Updates to xEVA System overview Section 6: Minor cleanup Section 7: Minor cleanup Section 8: Updated lunar details per Artemis and EVA-EXP-0075 Section 9: Minor cleanup	07/03/2019
Baseline		Baseline (per EVA-CR-00032) EVA-REF-004 Revision History	12/20/2017
Initial Draft		Preliminary Baseline	05/17/2016
		Pre Baseline	07/07/2014

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1.0 INTRODUCTION

The Exploration Extravehicular Activity (xEVA) System concept of operations (con ops) captures the National Aeronautics and Space Administration's (NASA's) current aims future missions to all potential Exploration destinations. This document captures the mission architectures, stakeholder expectations, and high level definitions of the capabilities and interfaces associated with the xEVA System. This includes missions to Gateway in cislunar space, the lunar surface, a redirected asteroid in cislunar space, Near Earth Asteroids (NEA), Mars' orbit, the moons of Mars (Phobos and Deimos), and the surface of Mars. These missions, which include microgravity, milli-gravity, and partial-gravity surface EVAs, will involve a variety of engineering (maintenance, contingency, pioneering, construction) and science tasks. This document also captures information concerning vehicles and habitats with which the xEVA System will interface. The concepts of operations (con ops) detailed in this document are informed by the Artemis Program and a multitude of Exploration studies, and are also influenced by various integrated operational analog testing.

1.1 PURPOSE

This EVA Office document captures the xEVA concepts of operations for a wide range of destinations. It focuses on the lunar surface in order to support the Artemis Program, including the science goals driving the missions and the xEVA System capabilities needed to successfully complete the operations. The concepts of operations detailed in this document are intended to inform the development of the xEVA System, including the xEVA Suit, the current design solution for which is the Exploration Extravehicular Mobility Unit (xEMU), and the Vehicle Interface to Suit Equipment (VISE).

EVA-EXP-0042 describes the xEVA System operations and the tasks that will be accomplished during missions on the International Space Station (ISS), on Gateway in cislunar orbit, and on the lunar surface as part of the Artemis Phases. It also includes con ops for missions to asteroids and to Mars. This document is intended for Program concept of operations development and Exploration spacesuit suppliers. EVA-EXP-0042 provides the EVA Office standard for conducting EVA in a multitude of environments and locations, and new Programs working with the EVA Office will utilize this con ops as the basis for how EVAs will be conducted, tailored as needed to meet the objectives and goals of that Program. For spacesuit developers, this document provides the basis of what is operationally expected of the spacesuit in a given environment. If there is a conflict between EVA-EXP-0042 and other con ops involving EVA operations, EVA-EXP-0042 takes precedence. An exception is a program specific con ops tailored with support and approval by the EVA Office will take precedence over EVA-EXP-0042.

1.2 SCOPE

It is intended that the content contained in this document is to enable the development of more refined concept of operations for Exploration missions and architecture (e.g., Gateway, the Artemis Program, and the Human Landing System), for the xEVA system (e.g., SSP 51073), and for the subsystems (e.g. xEMU ConOps Ref#) and associated requirements (e.g. xEMU PTRS ref#) and provide the motivating/supporting rational and context for system verification.. The con ops will continue to mature as the Exploration architecture missions evolve, and this document will continuously evolve and be updated accordingly.

This document includes the information contained in EVA-EXP-0075, *Exploration EVA System Concept of Operations Summary for Artemis Phase 1 Lunar Surface Mission*, presented at the EVA Exploration Workshop on 18 February 2020. Results from pertinent integrated operational tests (analogs) were utilized to provide relevant data for informing concepts, flushing out capabilities, and evolving systems. Finally, the xEVA Concepts of Operations Working Group (xEVA Con Ops WG) was utilized to consolidate and finalize the high level definition of the mission architecture, capability needs, and concepts of operations associated with conducting EVA operations.

Specifically for the xEMU project, that suit is intended to have the capability to support missions from the ISS, to the lunar vicinity (on Gateway), and to the lunar surface as a key component of Artemis. The capabilities needed for that suit and associated equipment are described in Section 4.1.2, initial lunar mission parts of Section 4.2 (specifically Section 4.2.1 for the spacesuit), Section 5.1.1, and Section 7.2.

1.3 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted by an EVA Office Change Request (CR) to the EVA Configuration Control Board (EVA CCB) for consideration and disposition.

All such requests will adhere to the EVA Office Configuration Management Change Process (EVA-PLN-012).

The appropriate NASA Office of Primary Responsibility (OPR) identified for this document is EVA.

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 2.1-1: APPLICABLE DOCUMENTS LIST

Document Number	Document Revision/Release Date	Document Title	Applicability	Alternative Documents (allowed/not allowed)
JSC-48538	07/16/2007	ISS EVA Systems Checklist		
SSP 51073 / EVA-RD-001	B 04/10/2020	xEVA Suit Systems Requirements Document		
SSP 51080 / EVA-EXP-0037	Baseline 12/04/2018	xEMU-ISS Interface Requirements Control Document		
EVA-EXP-0031	Baseline 04/04/2018	EVA Airlocks and Alternative Ingress/Egress Methods		
EVA-EXP-0032	Baseline 606/05/2018	EVA-ISS Interface Definition Document (IDD)		
EVA-EXP-0034	B 07/31/2020	Exploration EVA System Technical Standards		
EVA-EXP-0035	Baseline 09/12/2018	Exploration EVA System Compatibility		
EVA-EXP-0039	A 11/29/2017	Exploration EVA System Destination Environments Specifications		
EVA-EXP-0041	Baseline 12/18/2018	Exploration EVA System Architecture Description		
EVA-EXP-0043	Baseline 10/25/2018	NASA Project Management Plan for the Exploration EVA System		
EVA-EXP-0046	TBD-2.1-014	Exploration EVA Suit-Airlock Interfaces, Ops Con and Objectives		

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. Additional reference documents utilized to develop the xEVA con ops are listed in an appendix.

TABLE 2.2-1: REFERENCE DOCUMENT LIST

Document Number	Document Revision	Document Title
EVA-EXP-0075	Baseline 03/17/2020	Exploration EVA System Concept of Operations Summary for Artemis Phase 1 Lunar Surface Mission
EVA-PLN-012	A 10/02/2019	EVA Office Configuration and Data Management Plan
HLS-CONOPS-001	Baseline (draft) 05/21/2020	Human Landing System (HLS) Program Concept of Operations – Initial Phase
Artemis-CONOPS-001	Draft	Artemis Concept of Operations
GP 10027	Baseline 05/07/2020	Gateway Concept of Operations
https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf	04/02/2020	NASA's Plan for Sustained Lunar Exploration and Development
https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf	09/21/2020	Artemis Science Plan
HEOMD-005		Concept of Operations
HEOMD-006		Exploration Utilization Plan
AES-50002	Baseline	Artemis Sustained Lunar Exploration Requirements
AES-50010	Baseline	Advanced Exploration Systems Lunar Terrain Vehicle (LTV) Concept of Operations

3.0 EXPLORATION PROGRAM & ARCHITECTURE GOALS

The United States (U.S.) Executive Branch and the NASA administration have released several policies and documents that outline returning to the moon and eventually landing on Mars. Those documents make up the basis for the xEVA con ops.

3.1 RETURNING TO THE MOON

Through Space Policy Directive – 1 and the 5th Meeting of the National Space Council, the United States set in motion plans to return humans to the surface of the moon.

3.1.1 Space Policy Directive – 1

On 11 December 2017, Space Policy Directive – 1 was updated to redirect the nation's spaceflight efforts to returning humans to the lunar surface. In part, this policy states: "*Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.*"

3.1.2 5th Meeting of the National Space Council

On 26 March 2019, discussions at the National Space Council provided further direction and details on the lunar surface mission plans. In part, it was stated:

- "Fifty years ago, "one small step for man" became "one giant leap for mankind." But now it's come the time for us to make the next "giant leap" and return American astronauts to the Moon, establish a permanent base there, and develop the technologies to take American astronauts to Mars and beyond."
- "…it is the stated policy of this administration and the United States of America to return American astronauts to the Moon within the next five years."
- "*And today, the National Space Council will recommend that when the first American astronauts return to the lunar surface, that they will take their first steps on the Moon's South Pole.*"

3.2 ARTEMIS LUNAR PROGRAM

In response to the new Executive Branch direction, NASA implemented the Artemis Program.

3.2.1 Artemis Phase 1

Per "Forward to the Moon: NASA's Strategic Plan for Human Exploration", 4 Sept 2019, Artemis Phase 1 builds up to the first crewed mission to the lunar surface.

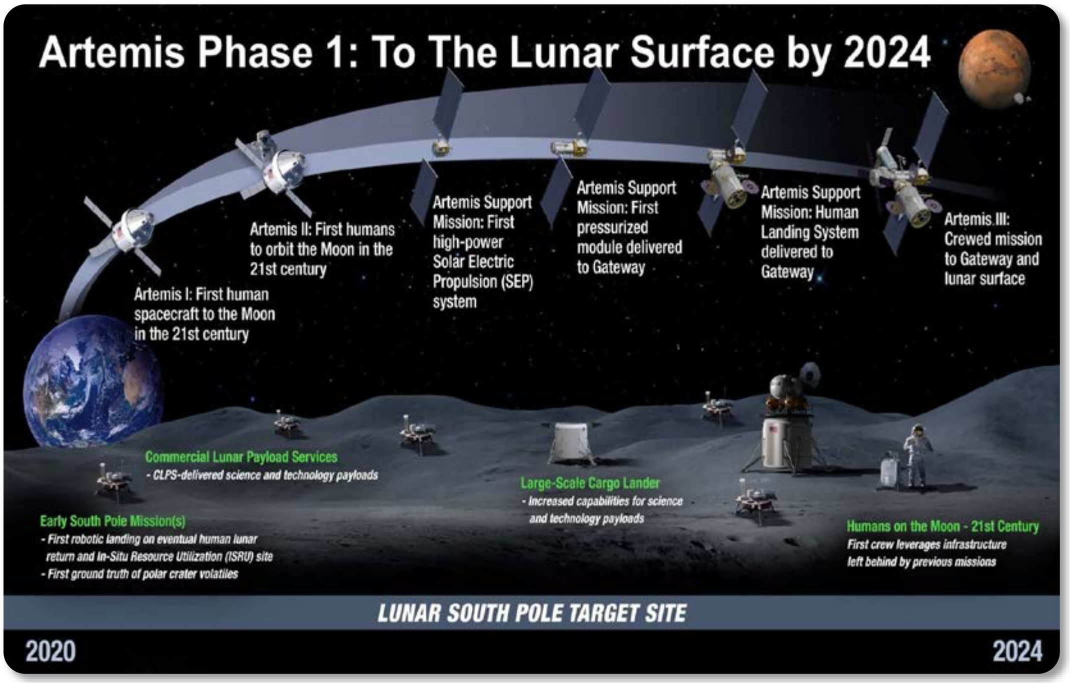


FIGURE 3.2.1-1: ARTEMIS PHASE 1

3.2.2 Artemis Phase 2

Per “Forward to the Moon: NASA’s Strategic Plan for Human Exploration”, 4 Sept 2019, Artemis Phase 2 continues the lunar surface missions into sustainable capabilities and exploration.

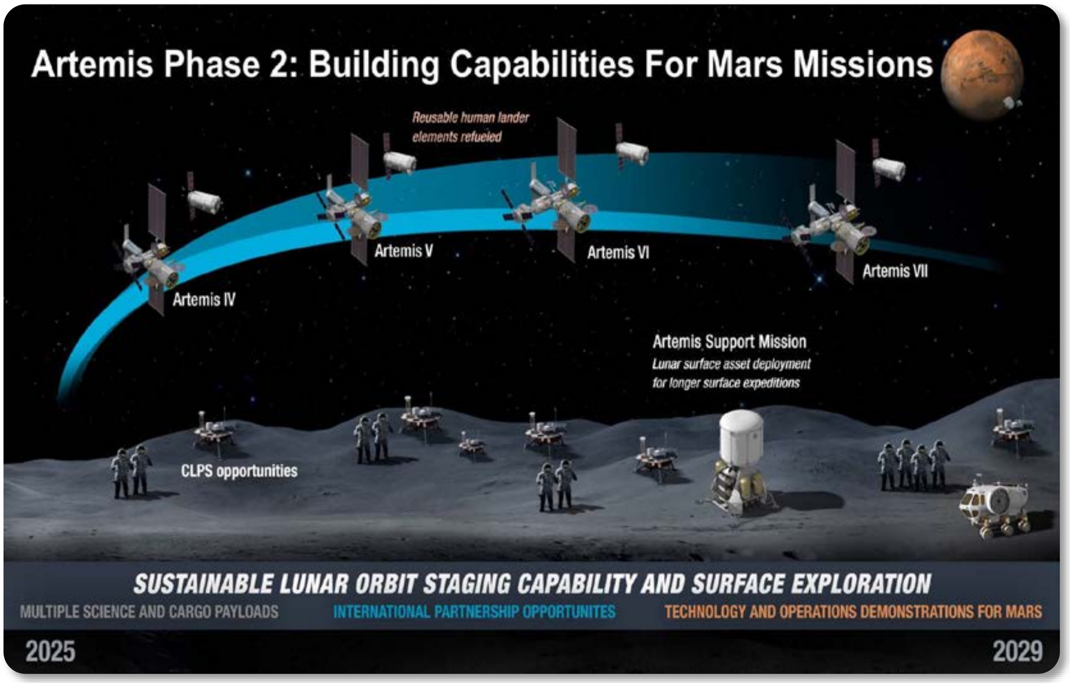


FIGURE 3.3.2-1: ARTEMIS PHASE 2

3.3 INTO THE PROVING GROUND (AND ON TO MARS)

Prior to Artemis, the Human Exploration and Operations Mission Directorate (HEOMD) released several Level 1 documents which lay out objectives, concept of operations, and utilization plans pertaining to EVA through crewed missions to Mars.

Per the paper entitled *ISS, SLS, Orion: Into The Proving Ground* presented by the Human Exploration and Operations (HEO) Associate Administrator at the International Astronautical Congress in Adelaide, Australia in September 2017, the current long term goal for NASA is a crewed mission to the Martian system by 2033 with a human landing later in the decade. This led to the release of HEOMD-001 Human Exploration and Operations Exploration Objectives document, and the high level description of the phases of exploration.

The goal of landing humans on the surface of Mars will be accomplished through five phases. Phase 0, involves continuing to use the ISS for research and as a testbed. Per the IAC 2017 paper, the remaining phases are as follows:

> *In Phase 1, NASA will use the Space Launch System (SLS) and the Orion capsule in the early and mid-2020s to deploy a Deep Space Gateway in cislunar space, comprising a habitation and in-space propulsion capability. In-space power and propulsion, including solar electric propulsion, and deep space habitation are central to future human exploration. Development and deployment of these capabilities will be a focus of the early-to-mid 2020s. The Gateway provides a space infrastructure*

enabling missions—NASA, commercial, and international—to a variety of destinations, including the surface of the Moon. It will be the next step in expanding human presence into the solar system.

Phase 2, in the mid-to-late 2020s, will see NASA using the SLS, Orion, and the Gateway to outfit the Deep Space Transport, which will be used to fly crews to the Martian system in the 2030s. The Deep Space Transport will be launched without fuel and supplies in single SLS launch. The fuel, supplies, and outfitting will occur over a series of SLS and Orion missions. The Deep Space Transport can benefit from the avionics and computer systems being developed for Orion. The Transport represents not only the realization of a robust habitation capability that will keep crews healthy on two-year Mars missions, but also the development of a reliable propulsion system that will be used to fly crews safely across interplanetary distances, and then back to the Earth-Moon system. The Deep Space Transport will be reusable for multiple missions and can be maintained at the Gateway. Phase 2 will culminate in a crewed one-year shakedown cruise or verification mission aboard the Deep Space Transport in cislunar space to validate its readiness to conduct missions beyond the Earth-Moon system. At this point, we will have the knowledge and the infrastructure in place for the voyage to the Martian system.

In Phase 3, NASA will conduct humanity's first missions to another planet, with the initial crewed flight of the Deep Space Transport to the Martian system in 2033, and a potential rendezvous with the Martian moon Phobos. Astronauts will thus gain experience with interplanetary spaceflight and operations, and will fully utilize the cislunar infrastructure that has been developed to support such missions.

During the decade of the 2030s and beyond, in Phase 4 NASA will develop and deploy the systems to land cargo and crews on Mars, sustain crews on the surface, and return them safely to Martian orbit, where they will re-board the Deep Space Transport for the journey back to the Deep Space Gateway, and then home to Earth.

The main Objective Category pertaining to EVA is working in space. Deep space operations focus on providing capabilities in the areas of EVA, staging, logistics, human-robotic integration, and autonomous operations. Objectives for phases 0 and 1 include:

- Phase 0: P0-04 Demonstrate in-space exploration class EVA technologies
- Phase 1: P1-13 Validate ability to conduct EVA in deep space

HEOMD-005, Concept of Operations, includes a description of Gateway (further detailed in a later section of this document) which includes an airlock capability to enable EVAs. Each of the Gateway elements will be designed to not require on-orbit EVA maintenance but will provide EVA translation paths in order to accommodate contingency EVAs or future utilization. The Airlock Module will provide secondary ingress capability to allow EVA crewmembers to safely ingress the stack in the event of a contingency without causing the depressurization of critical stack elements such as a habitat.

HEOMD-006, Exploration Utilization Plan, also includes near term planned EVA technology demonstrations on ISS and xEVA providing for exploration of deep space destinations/environments and contingency EVAs during transit.

4.0 EXPLORATION EVA AND MISSION SYSTEMS OVERVIEW

A multitude of mission systems are required in order to successfully execute Exploration missions and the EVA operations included in those missions.

4.1 EXPLORATION EVA OVERVIEW

The following subsections provide an overview of the xEVA System and other systems/vehicles that will be utilized during Exploration missions.

4.1.1 xEVA System Definition

The xEVA System works in conjunction with the larger mission architecture and systems to conduct EVA operations at Exploration destinations. Figure 4.1.1-1: Systems Utilized to Execute Exploration EVAs shows the constituent elements that comprise the xEVA Mission System. There are elements that exist at the mission destination (and/or leveraged in transit from Earth to that particular mission destination) as well as elements that remain on Earth. While the details of each of these elements will differ between mission types, the fact remains that there will remain a connection to some extent between crew/local elements and Earth.

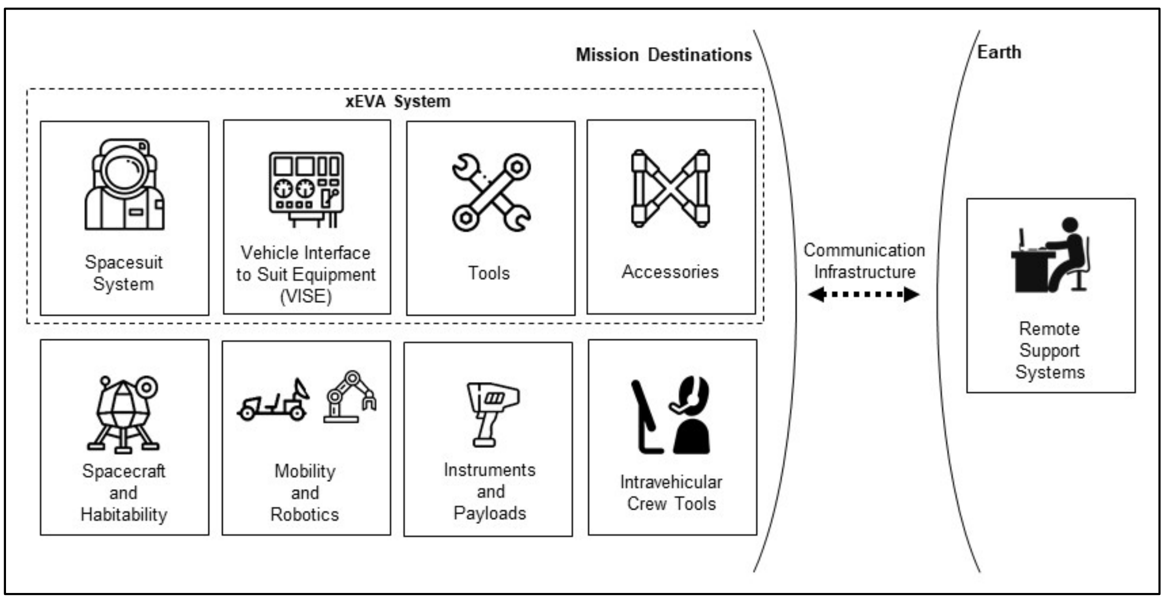


FIGURE 4.1.1-1: SYSTEMS UTILIZED TO EXECUTE EXPLORATION EVAS

As NASA aims to shift from an Earth-reliant mindset to one that is independent of Earth, what will fundamentally drive the success of this shift is how the concepts of operation for a particular mission are established. In other words, who (crew and their local systems or Earth-based personnel) will be responsible for what to satisfy mission objectives. The inclusion of more advanced systems that afford crew the ability to become more self-reliant will become critical for mission success.

The xEVA System allows crewmembers to conduct excursions outside a habitable vehicle in order to perform exploration, science, construction, servicing, and repair operations. The xEVA System includes the following elements:

- Spacesuit (xEVA Suit)
- Vehicle Interface to Suit Equipment (VISE)
- Flight Support Equipment (FSE)
- Tools and equipment necessary to perform EVA tasks

The xEVA Suit (e.g., xEMU) provides life support, environmental protection, and communications capability to the crewmember while allowing sufficient mobility to perform dexterous EVA tasks. The primary functions of the xEVA Suit are to provide a habitable, anthropomorphic, pressurized environment that allows crewmembers to perform work outside of the spacecraft or habitat in hazardous external conditions. The habitable environment is maintained by using suit components such as an outer pressure garment to maintain survivable pressure on the crewmember's body, including boots and gloves, a helmet that allows suitable visibility for tasks, a thermal micrometeoroid garment to protect against thermal extremes and micrometeoroid impacts, a garment to prevent overheating in the suit, and a life support system to provide the necessary consumables (oxygen, water, and power) and remove carbon dioxide and contaminants.

FIGURE 4.1.1-2: XEVA SYSTEM SUIT CONCEPT

The VISE provides the interfaces necessary between the xEVA suit and the host vehicle. These interfaces will enable recharge of consumables and checkout the xEVA equipment. VISE performs that functions that are currently done on ISS by the Exploration Servicing, Performance and Checkout Equipment (SPCE). At a high level, VISE can supply various consumables or resources used by xEMU, but also includes physical structures used to support/restrain the suit. VISE core functions are broken down into the following:

- Power and Data Communication
- Battery Charging
- Suit Loop Ventilation
- Vacuum Access
- High Pressure O2
- Cooling H2O
- xEMU Don/Doff Support
- HLS Descent/Ascent Crew Restraint

The FSE includes the additional equipment and ancillary hardware to support xEVA operations, such as the xEVA suit umbilicals.

The xEVA Tools will interface with a suited crewmember to enable a range of specialized tasks. These include both tools for engineering tasks on vehicles and infrastructure, and tools for science.

The xEVA System will enable and help accomplish the Exploration goals for lunar surface missions, including science.

The remaining elements that support the mission system include:

- Assets could include the addition engineered devices leverage by the mission such as rover vehicles, robotic assistants, and engineering packages
- Additional crewmembers who remain inside spacecraft, known as intravehicular crew, are also another important element of the xEVA Mission System.
- Spacecraft are an obvious component of a mission but must be considered in the context of supporting xEVA which will require interactions with these other identified elements.
- Finally, remote support consists of the entire enterprise of people and technologies that remain on Earth and support the mission objectives remotely. For the entire history of US EVA, ground-based support have play an integral and mission dependent role in successful EVA operations.

4.1.2 Exploration EVA System Strategy

While there is a wide array of possible and feasible variations across the spectrum of conceptual human spaceflight architectures, there exists a limited set of overarching destination classes. For EVA, these destination classes are defined as follows:

- EVA on a Spacecraft (Micro-Gravity on an Engineered Surface)
- EVA on a Small Natural Body (Milli-Gravity on an Asteroid or Moons of Mars)
- EVA on the Moon (Partial-Gravity Planetary Surface in a Vacuum)
- EVA on Mars (Partial-Gravity Planetary Surface in a Partial Atmosphere)

When considered in abstract terms, all human spaceflight EVAs would be conducted within the context of one or a combination of these destination classes. For example: EVA tasks supporting construction of a multi-element spacecraft in Low Earth Orbit (LEO) (such as Mir or ISS) or EVA servicing, maintenance or repair of satellites or launch/entry spacecraft are all particular activities conducted by an EVA System designed to operate in micro-gravity on engineered objects built by humans (spacecraft or habitat), within a vacuum environment. Similarly, the particular details about EVA environments for specific destinations will vary, especially parameters like thermal and radiation, but these too may be enveloped.

Similarly, it is recognizable that although there are large numbers of NEAs and Near Earth Objects (NEO) that may at some point be accessible to human spaceflight missions, in general terms an EVA System designed to conduct activities on or immediately near the surface of a NEA (the “natural” surface) is simply an EVA System capable of performing tasks in milli-gravity within a vacuum environment and withstand intentional or inadvertent contact with material/debris not configured by human hands. Thus, despite the varying chemistries and compositions of the wide array of NEAs, an EVA System compatible with activities on a NEA would consider particular items such as abrasion, sharp edges, dust, and incidental contact temperatures. Instead, EVA activities would utilize varying amounts of engineered crew aids and drive the design of the EVA System, along with operational procedures, to accommodate the reality that the natural surface is a source of potential hazards. This logic is extendable to a NEA and to the Moons of Mars, which may ultimately be shown to be relatively large captured asteroids. Thus, though Phobos and Deimos are massive enough to provide milli-gravity level g-values of concern for spacecraft, the fundamental nature of EVAs done on them is still classifiable as small natural bodies within a vacuum environment with as far as the EVA crewmember is concerned, there is insufficient gravity to provide ground reaction force, though that milli-gravity level may increase the likelihood of contact with the surface such that it is not considered micro-gravity.

The remaining two destination classes must acknowledge a common theme: any other EVA operation must be considered as occurring on a body so massive that it possesses a non-trivial gravitational field, i.e. Earth’s Moon and Mars. Though their specific g-values differ by meaningful amounts when it comes to the resulting on-back mass experienced by the EVA crewmember, they are common in that the nature of EVA activities and tasks are significantly different than in microgravity or milli-gravity. Next, these two destinations each possess their own particular natural surface characteristics which will lead to potentially different concerns for abrasion, sharp edge tolerance, dust mitigation, chemical compatibility, planetary protection, etc. However, many of these concerns are similar between the Earth’s Moon and Mars, and the particular design solutions may be driven just as much by human choices such as EVA frequency, duration, and total quantity of EVA as it is the singular interaction with the natural surface and environment. The difference in gravity levels between the Moon and Mars is significant. Thus, at a destination class level, the biggest differentiator between the two partial-gravity destinations is the g-value, the specific geo-technical properties of the surface, contamination concerns, thermal environment, and the atmosphere or lack thereof.

Details of the xEVA System architecture are in EVA-EXP-0041, xEVA System Architecture Description.

4.1.2.1 xEMU and mEMU

The current design concepts for the xEVA System suit are the xEMU and follow-on Mars Extravehicular Mobility Unit (mEMU). The xEVA System will be capable of operating anywhere in the range from the Venus halo orbit to the asteroid belt, and from microgravity environments to the planetary surface of Mars.

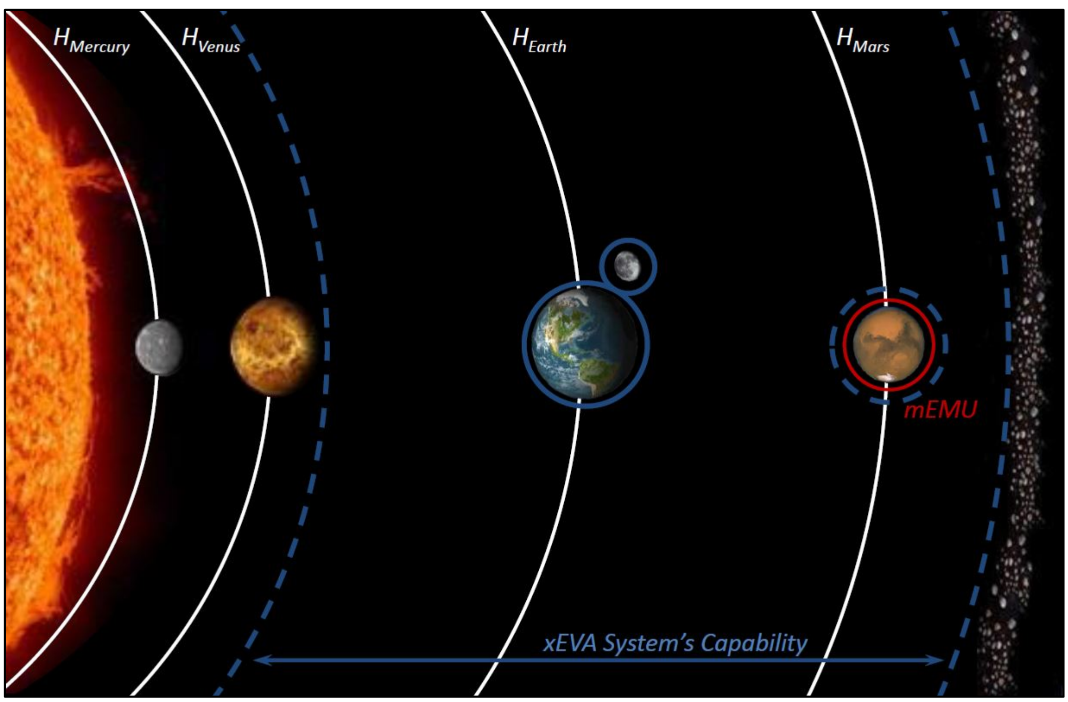


FIGURE 4.1.2.1-1: EXPLORATION XEVA SYSTEM CAPABILITY BOUNDARIES

The xEMU will be a fully outfitted deep space exploration suit that will be utilized in LEO, cislunar space (on Gateway), and possibly Mars orbit, along with transit between the two, in addition to the lunar surface as a key element of Artemis. The xEMU will utilize a lower torso assembly that allows for ambulation on the lunar surface, performance of tasks in a non-neutral posture (e.g., kneeling, squatting, bending, stooping, sitting, lying, crawling, etc.), and recovery from the non-neutral positions. It will include features such as dust tolerance and informatics. The mEMU will incorporate some aspects of the xEMU, but will be modified for operations on the surface of Mars and the different environment encountered there.

The future xEVA Suits will have the capabilities listed in Section 4.2 (specifically Section 4.2.1 for the spacesuit), including (but not limited to) increased mobility & surface ambulation (including kneeling), enhanced consumables capabilities beyond the current EMU, operability at higher and variable suit pressures, advanced integrated informatics, compatibility with a rear-entry airlock (depending on the final mission architecture and programmatic phase), and the ability to attach and transport tools in both microgravity and surface environments.

FIGURE 4.1.2.1-2: XEMU CAPABILITIES

4.1.2.2 Single Suit Architecture

In order to save on mass and conserve volume, the xEVA Program is examining utilizing a single suit system architecture for Human Landing System (HLS) operations during dynamic flight phases on descent, EVA, and dynamic phases during ascent.

The Orion Crew Survival System (OCSS) Earth Launch Entry Abort (LEA) suit will be used during launch from Earth and Earth landing, but will not be used for the lunar portions of the HLS missions. With the single suit architecture concept, the xEMU would be utilized for lunar descent/ascent in Vehicle-Loop Mode (VLM) and on the surface in EVA mode. This means it will have both the capability to be pressurized via the VLM umbilical, without the Exploration Portable Life Support System (xPLSS) backpack during any required dynamic phases, descent, jettison EVA, and ascent, and to operate pre and post EVA with the xPLSS on EVA umbilical.

xEMU suit checkout will be done in the HLS, prior to lunar descent. The HLS will accommodate volume and equipment to stow, assemble the suits, don/doff the suits, and support on-orbit fit checks and xEMU checkout prior to descent. After checking out each xEMU, the crew will then reconfigure the suit for lunar descent by removing the suits rear-entry Hard Upper Torso (HUT) hatch and xPLSS from the Exploration Pressure Garment System (xPGS) and replacing it with a HUT hatch designed for VLM umbilical operations. The xPLSS will be stowed for lunar descent. Upon landing the crew will then reconfigure their suits to EVA mode with the xPLSS attached. If the xPLSS will be left on the lunar surface for mass savings, the xPLSS and HUT hatch will be removed and the xEMU will be reconfigured to VLM mode for lunar ascent.

See Section 4.2.1.3.1 for further details on the single suit configurations.

4.1.3 Phases of Operations for xEVA System

Operations of the xEVA System are separated into the following phases:

1. Preflight Testing, Processing, and Training
   - Ground operations including manufacturing and acceptance testing, fleet and mission-specific sizing
   - Crew training on the xEVA system and the mission
   - Mission planning (including environmental constraints)
2. Earth Launch
   - Launch stowage and logistics prepare the hardware for launch and configuration for transportation to host vehicle
3. Suit Assembly & Checkout
   - On-Orbit Suit Assembly - Operations to assemble the components of the xEVA Suit in preparation for checkout and use
   - Full System Checkout - Operations describing the comprehensive checkout and evaluation of suit systems done prior to first use and after reassembly following a reconfiguration or a period of quiescent stowage
   - On-Orbit Fit Verification - The process of ensuring a good fit for the planned crewmember including necessary adjustments
4. Suited Dynamic Flight Events (traveling to destination)
   - Phases of the mission associated with dynamic vehicle flight and higher risk times
   - Includes planetary descent, planetary ascent, undocking, and certain orbital maneuver burns
   - Prebreathe for initiation of saturation (if required, dependent on lander atmosphere)

- xEMU System is utilized in VLM

5. Prep for Operations (Road-to EVA)
    - 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
    - Typical activities include:
        - Suit assembly or reconfiguration
        - Suit checkout
        - Fit verification
        - Consumables recharge (O2, H2O, etc.)
        - Battery recharging
        - Liquid Cooling Ventilation Garment (LCVG) fill (if required)
        - Airlock configuration
        - Tools and task equipment configuration
        - Filling and installing drink bags in suit
        - Preparation of biomedical and radiation monitoring equipment
        - Configuration of communication system
        - Timeline review
        - Briefings from MCC and the Science Team
        - Uploading of data into the informatics system (as applicable)
6. Pre EVA Operations (Prep & Prebreathe)
    - On the day of the EVA, the crewmembers begin final prep activities and the prebreathe protocol (as applicable)
    - General day-of-EVA activities include, but aren't limited to, the following:
        - EVA prep – activities which occur the day of a planned EVA, just prior to donning the xEVA Suit for EVA
        - Configure vehicle and suit communication
        - Verify the appropriate equipment is in the airlock before isolating the module
        - Activate the Carbon Dioxide (CO2) removal system (if applicable)
        - Prepare for mask prebreathe (if applicable)
        - Power up the xEVA Suits and verify system functionality, and configure for suit donning
        - Verify xEVA Suit communication and data with IV and/or MCC
        - IVA crew performs any remaining airlock configuration tasks (if applicable)
        - Suit Donning - Operations that occur in the xEVA Suit, but prior to disconnecting from the umbilical tied to host vehicle resources
        - xEVA Suit manned checkout
        - Depress to 10.2 psia (if applicable)
        - o Mask prebreathe (if required)
        - Donning of suits
        - In-suit communication and leak checks
        - Prebreathe protocol – Prescribed prebreathe period in order to decrease the risk of Decompression Sickness (DCS)

- o Depress to 10.2 psia (if applicable)
- o Mask prebreathe (if required)
- o Purge nitrogen
- o In-suit prebreathe on umbilical

7. EVA Operations
   - Once the prep and prebreathe procedures are completed, the EVA crew will depress 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 internal suit power (batteries), and officially ends when repressurization has begun after ingress
8. Post EVA Operations
   - Post EVA operations commence with reconnection to umbilical and airlock repress; and include doffing the xEVA Suit, servicing, disassembly, and stowage
   - Consumables are recharged
9. Maintenance
   - Periodic maintenance of the suits may be required, in addition to changing out some of the more consumable aspects, such as the gloves
10. Departure Prep & Quiescent Stowage
    - Quiescent stowage refers to both the period of time EVA hardware is pre-dispositioned at a destination prior to human interaction and the period between crewed presence at the destination
    - Prior to crew departure from the destination, hardware that is to be reused and not returned to Earth for refurbishment will be prepared for quiescent stowage, where the hardware will not be accessed by crewmembers or remotely actuated from the ground for up to three years
    - Suit reconfiguration (if xEMU is needed in VLM for ascent)
11. Suited Dynamic Flight Events (leaving destination)
    - Phases of the mission associated with dynamic vehicle flight and higher risk times
    - Includes planetary ascent, certain orbital maneuver burns, and docking
    - xEMU System is utilized in VLM
12. Post Docking Operations
    - Disassemble xEVA suit for long term stowage in Gateway or leave in lander for disposal
    - Transfer samples and returning xEVA hardware to Gateway and Orion
13. Post Flight
    - Post-flight testing consists of flight hardware returned from orbit for examination of system and component function, health and life
    - Evaluations include failure investigations

- A thorough set of lessons learned, anomaly reports, and failure investigation reports will lead to action plans to improve the xEVA system design, processes, team communication, training, procedures, etc.
- This may include discarding and/or returning the xEVA Suit for ground processing.

4.1.4 Frequency and Duration of EVAs

The xEVA suit will support EVAs of up to 8 hours in duration (6±2 hours). How long EVAs are and at what frequency they are conducted will depend on the destination, phase, mission needs, and vehicle capabilities.

4.1.4.1 ISS EVAs

EVAs conducted on ISS will be the same duration and frequency of those that are currently done utilizing the EMU. Typically, EVAs on ISS are planned for 6.5 hours, but have frequently exceeded 7 hours, and on occasion been over 8 hours in duration.

4.1.4.2 Gateway EVAs

EVAs on Gateway will be treated similar to EVAs conducted on ISS in terms of duration.

4.1.4.3 Lunar Surface EVAs

EVAs on the lunar surface will vary according to lander capabilities, surface assets, and program phase. EVAs will be between 4 and 8 hours in length (6±2 hours). The duration will also take into account a number of factors, such as lighting and the time of year.

During the Apollo missions, the crew conducting EVAs ranging from two hours 32 minutes to seven hours 37 minutes. Out of the 14 EVAs conducted on the lunar surface, six of those were over seven hours long.

4.1.4.3.1 Artemis Phase 1 (Artemis III & IV Missions)

EVAs on the lunar surface will vary according to lander capabilities, surface assets, and program phase. EVAs will be between 4 and 8 hours in length (6±2 hours). Artemis III will have between 2 and 5 EVAs. A supplemental EVA may be allocated to dispose of trash and equipment not being brought back up from the surface, and may or may not be executed on umbilical (in VLM).

4.1.4.3.2 Artemis Phase 2 (Sustained Missions)

For Rover and EVA ops during a seven to fourteen-day short stay mission, the crew will have the capability to perform daily 8-hour EVAs in order to take advantage of the short period on the surface. Crewmembers will conduct the EVAs paired together to maximize boots on the ground time and for safety. However, there may be a rest day after three or four days of EVA, depending on the duration of the EVAs.

For Rover and EVA ops during a 42-day mission, operations will differ between lunar day and lunar night. During lunar day, EVAs will be conducted three to four days per week and be two to eight hours in duration (hour for egress/ingress and 1.5 - 7.5 hours of tasks) with one to two per day. EVAs may extend an additional hour for emergency and off-nominal situations.

For days involving two EVA excursions per day, the EVAs will be treated as if a single EVA is conducted in two parts, and therefore the suit consumables won't be required to be recharged between excursions (though some will be recharged simply by plugging in the umbilical, such as O2). The total amount of planned EVA Phased Elapsed Time (PET) time within a crew wake period will stay within the constraints of a single 8-hour EVA. The time between the two EVAs will be considered a 'break' in EVA more than a second EVA. In other words, the crew will be able to take an 8-hour EVA and conduct it in two parts, with the sum of the parts not exceeding what would have been done for a single EVA.

For all rover-based EVA operations on Phase 2 missions with two pressurized rovers, the rover pairs will work together. Both crew in one rover will conduct the EVA together, while the other rover is nearby. Alternately, one crewmember from each rover may conduct the EVA together, still enabling two crewmembers to act as buddies, although this requires the rovers to be parked next to each other and requires two separate and simultaneous airlock operations. The surface teams will have the capability to conduct EVA with all four crewmembers simultaneously, if needed.

4.1.4.4 Mars Surface EVAs

EVAs on Mars are still in work, but will likely have at least the frequency and duration of those for the sustained lunar missions in Artemis Phase 2.

4.1.5 EVA Tasks for Exploration Missions

All future exploration missions include EVA operations that will comprise both engineering-focused tasks for constructing and maintaining infrastructure and assets, as well as science-driven tasks for exploration of the natural environment. Exploration missions will include EVA operations for maintenance, construction (pioneering), science, transfer between vehicles, and contingency. These tasks will largely be planned, but unplanned EVAs may occur for a contingency to repair something that has broken

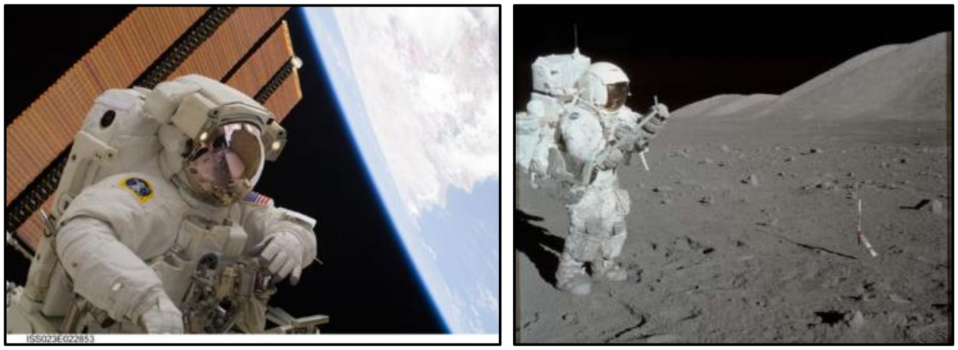


FIGURE 4.1.5-1: EMU MICRO-G EVA ON ISS (L) AND SURFACE EVA DURING APOLLO (R)

4.1.5.1 Engineering EVA Tasks

Engineering-focused EVA operations and tasks can be generally categorized as maintenance, construction/pioneering, or contingency.

4.1.5.1.1 Maintenance

These engineering-focused EVAs are used to conduct proactive maintenance on any vehicle or habitat prior to a failure or the end of life on particular hardware. Maintenance EVAs are used to reduce the likelihood of a vehicle failure that would have driven the need to execute a contingency EVA. Whether in microgravity or partial gravity, these EVAs will be conducted in a similar same way as those on ISS.

4.1.5.1.2 Construction & Pioneering

Construction EVAs are nominal planned events to perform or assist in vehicle or infrastructure assembly. Construction EVAs may be done in a microgravity environment, much like assembly of the ISS, and will be done on any planetary surface mission for sustained operations. Pioneering EVA is the term sometimes used for those specifically that will build up the infrastructure at the partial-g surface destinations. The terms construction and pioneering are essentially interchangeable. Like ISS EVAs, construction and pioneering EVAs will be planned in advance to utilize the maximum available EVA period. Construction tasks may range from connection of lines and driving fasteners in microgravity, to placement of anchoring technology on NEAs, to setting up communication antennas and grading regolith in preparation for habitat construction on a partial gravity planetary surface.

4.1.5.1.3 Contingency

Contingency EVAs include those required to deal with spacecraft, vehicle, and habitat issues and failures, and those needed to rescue crewmembers on planetary surfaces. Vehicle failures can include known possible failures or unexpected and unforeseen events. Contingency EVAs are activated to mitigate the consequence of a vehicle failure. Depending upon the failure, a Contingency EVA may be required and plan-able for an explicitly limited window, such as docking or loss of spacecraft/vehicle power or thermal control. This means that each spacecraft/vehicle must consider its own specific failures to determine if and how EVA will be used. All missions will need to account for Contingency EVAs for those situations such that a next worst failure (i.e., system is now zero-fault tolerant) will result in critical vehicle loss of functionality, an emergency vehicle undocking (crew hazard), or loss of EVA capability to enact repair (loss of vehicle with next worst failure).

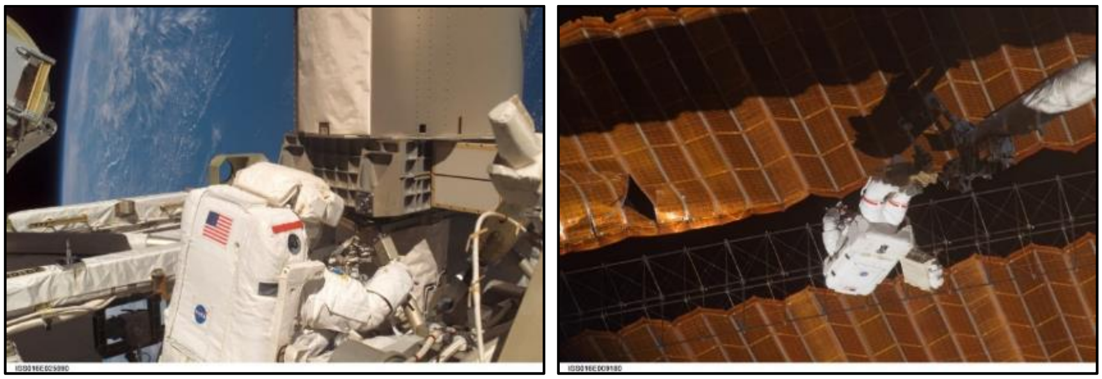


FIGURE 4.1.5.1.3-1: CONTINGENCY BMRRM R&R ON ISS DURING US EVA 14 (L) AND UNFORESEEN SOLAR ARRAY REPAIR DURING STS-120

4.1.5.1.4 General Types of Engineering Tasks

General engineering tasks, especially those on the lunar surface, will be for preparation of equipment for Exploration (such as offloading and loading equipment, maintaining equipment, and maintaining vehicles and transport system), construction of surface infrastructure (transporting tools and equipment, deploying and aligning antennas and comm repeaters, routing and connecting power and communication lines, connecting modular elements, installing/removing fasteners, electrical connectors, and fluid connectors, and preparing surfaces), for assembly and maintenance of equipment (installing/removing fasteners, electrical connectors, and fluid connectors, removing dust and cleaning equipment, and repairing equipment), and preparing ascent vehicles (offloading equipment, transferring equipment and samples from transport system to ascent vehicle, and cleaning equipment and vehicle).

FIGURE 4.1.5.1.4-1: EVA ENGINEERING TASKS FOR SURFACE OPS

4.1.5.2 Science EVA Tasks

A primary focus of the Exploration missions will be science-driven EVAs and tasks. These EVAs will enable the science at each destination and focus on evaluations and characterizations of the natural features of the destination. 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. The science tasks may include the operation of novel EVA hardware and instruments. Sample acquisition will include loosely adhered particles (surface, regolith, float), rock chip samples broken from larger boulders or outcrops, subsurface samples exposed in trenches, samples from permanently shadowed regions (possibly including volatile samples requiring cold curation), and subsurface (core) samples. Science tasks will also involve deploying handheld instruments, larger stationary instrument packages, and instruments requiring prolonged astronaut or rover interaction.

4.1.5.2.1 General Types of Science Tasks

General tasks include making contextual observations at the macro-scale (regional) and micro-scale (local) context, conducting photo and video documentation of the observations, collecting instrument data from handheld instruments and geochemical, geophysical, and geotechnical instruments, deploying science payloads, and acquiring rock, regolith, and specialized samples.

FIGURE 4.1.5.2.1-1: EVA SURFACE SCIENCE OBSERVATION & DATA COLLECTION TASKS

Science sample return is a top priority for missions to natural planetary bodies, including the Moon. Those will include rock, regolith, and specialized (volatile) samples. Rock sample types include float (rocks laying on or loosely adhered to the surface, collected via tongs and rakes), rock chip (fragments forcibly removed from a larger rock/boulder, typically with a hammer and/or chisel), and rock core (cylindrical subsurface sample drilled from a rock). Regolith sample types include bulk (loose surface material collected with a scoop), core (subsurface samples collected with a drive tube and drill), and surface samples (the top ~1mm of undisturbed material). Specialized samples include volatiles and atmospheric samples, both of which require specialized tools and containers.

Rock Sample Acquisition & Curation

- **Float**: rocks that are loosely adhered to the surface
  [Tongs / Rake]
- **Chip**: piece of rock forcibly removed from a larger rock
  [Hammer / Chisel]
- **Core**: cylindrical samples of a rock
  [Core Drill and Bit]

Regolith Samples Acquisition & Curation

- **Bulk**: representative loose surface material
  [Scoop]
- **Core**: cylindrical sample of regolith at depth
  [Drive Tube / Drill]
- **Surface**: undisturbed material from the top ~1mm surface
  [Surface Sampler]

Specialized Sample Acquisition & Curation

- **Volatile Samples**
  [Specialized tools and containers]
- **Atmospheric Samples**
  [Specialized tools and containers]

EVA-EXP-0075

FIGURE 4. 4.1.5.2.1-2: EVA SCIENCE SAMPLE ACQUISITION TASKS

4.1.5.3 Resource Utilization EVA Tasks

In-Situ Resource Utilization (ISRU) is the practice of collection, processing, storing and use of materials found or manufactured on other astronomical objects (the Moon, Mars, asteroids, etc.) that replace materials that would otherwise be brought from Earth. These activities could represent hybrid tasks between the defined Engineering and Science Tasks.

4.2 XEVA SYSTEM KEY CAPABILITIES & FEATURES

The xEVA System includes the xEVA spacesuit, the IVSE, the FSE, and the tools.

The following sections describe some of the high-level key aspects and capabilities of the xEVA System, with a focus on the xEVA lunar surface suit and equipment to needed enable the Artemis missions. The entire system is highly integrated between the spacesuit, ancillary equipment, tools, lander, and other assets, however, these sections attempt to group capabilities in order to assist with comprehension of the overall system. Capabilities and features are separated into Artemis Phase 1 and Gateway (which encompasses ISS) and Artemis Phase 2, where applicable.

4.2.1 xEVA Suit and Ancillary xEVA Equipment

The following are key capabilities and features that are primary encompassed in the xEVA suit. There may be ancillary tools and equipment that are not directly a part of the suit needed in order to enable these capabilities.

4.2.1.1 General xEVA Capabilities

The xEVA System includes, but is not limited to, the following general key capabilities and features for Artemis Phase 1 (including Gateway):

- Perform engineering-focused tasks (contingency, maintenance, and construction/pioneering) in microgravity and partial-gravity surface environments
  [Reference Section 4.1.5.1]
- Perform science tasks in microgravity and partial-gravity surface environments
  [Reference Section 4.1.5.2]
- Support EVAs of up to 8 hours in duration (6±2 hours), with an additional 1 hour of secondary/backup O_2 for off-nominal operations
- Suit pressures range from 0.4 psid to 8.2 psid, with a nominal EVA pressure of 4.3 psid
- Rear-entry spacesuit
- Compatibility with a traditional airlock and/or vehicle cabin as an airlock
- Crew able to “self-don/doff” suit (nominal ops efficiency and contingencies associated with incapacitated crew or failure to repress the vehicle cabin)
- Dust mitigation capability

The xEVA System includes, but is not limited to, the following general key capabilities and features for Artemis Phase 2 (sustained missions):

- Everything from Artemis Phase 1
- Compatibility with a suitlock (rear-entry airlock) (TBD-4.2.1.1-004

FIGURE 4.2.1.1-1: XEVA SYSTEM SUIT CONCEPT

4.2.1.2 Single Suit Configurations

The xEVA System supports two different suit configurations for operations during dynamic flight phases on descent, EVA, and dynamic phases during ascent.

FIGURE 4.2.1.2-1: APOLLO 10 CREW TRAINING FOR LUNAR DESCENT IN SUITS

4.2.1.2.1 Suit VLM (Vehicle Loop Mode)

Key attributes for vehicle loop mode including:

- Use during dynamic flight phases during descent and ascent operations
- Crew removable Exploration Primary Life Support System (xPLSS) and installable VLM umbilical(s) between the Exploration Pressure Garment System (xPGS) and host vehicle for power, data, communication, ventilation, and thermal control
- xPGS will protect astronauts during unexpected depress events (lunar ascent/descent)
- Crew are not expected to be suited for longer than 12 hours at any one time during nominal operations, therefore they may not be suited during the full duration of the descent or ascent

- A Crew Restraint System (CRS) may be used during certain dynamic phases in order to safely stabilize the crew and relieve some loads
- xEMU (including gloves and helmet) will be compatible with the HLS controls, systems, and cabin environment that are required to be actuated during dynamic operations
- Crew will be able to conduct a jettison EVA in VLM mode

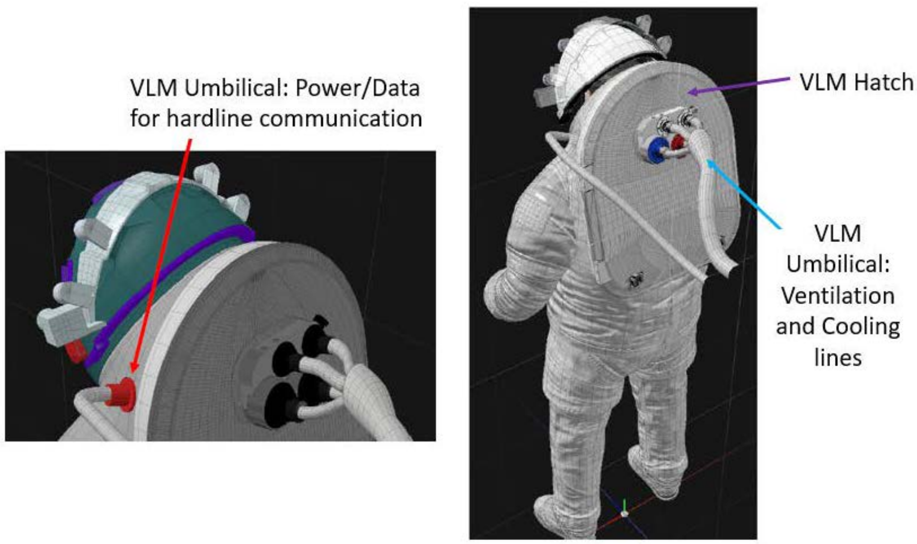


FIGURE 4.2.1.2.1-1: XEMU VEHICLE LOOP MODE CONFIGURATION

4.2.1.2.2 Suit EVA Mode

For the EVA Mode, the suit is configured with the xPLSS attached to the xPGS to provide life support during lunar surface excursions. Umbilicals are provided by the host vehicle for recharge of the xEMU consumables and support during pre- and post-EVA operations.

4.2.1.3 Suit Mobility

The xEVA System includes, but is not limited to, the following key mobility capabilities and features for Artemis Phase 1 (including Gateway):

- Mobility & surface ambulation during partial-gravity surface operations
- Translation via walking, crawling on hands and knees (short distances with slow controlled motions, scrambling (traversing sloped terrain while using one's hands), and climbing steps and ladders
- Walking up/down/across a slope of up to 20°
  [Note: Apollo 15 traversed on slopes of ~17°]

- Ambulating on traverses of up to 2 km away from the lander (depending on terrain)
  [Note: Apollo 14 walked ~1.45 km from the lander]
- Traversing across regolith and scree, down into and out of craters, volcanic terrains (including lava tubes), and shadowed regions (with the appropriate equipment and assets)
- Performing tasks while standing and non-neutral postures (e.g., kneeling)
- Mobility allows crewmembers to stand up unassisted after a fall
- Mobility to egress/ingress a 40 x 40 inch hatch in microgravity
- Mobility to step through (egress/ingress) a 40 x 60 inch hatch in partial-gravity (surface operations)
- Ability to sit on a seat, such as on an unpressurized rover
- Ability to safely carry equipment, including pushing/pulling a carrier (reference 4.2.3 Tools & Task Equipment)

The xEVA System includes, but is not limited to, the following key mobility capabilities and features for Artemis Phase 2 (sustained missions):

- Everything from Artemis Phase 1
- Walking back from a failed rover to a safe haven on ambulating traverses of up to 12 km

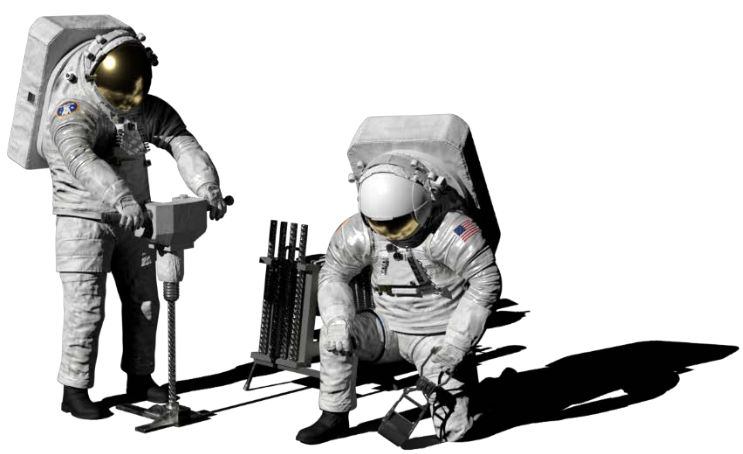


FIGURE 4.2.1.3-1: XEVA SUIT CONDUCTING TASKS STANDING AND KNEELING

4.2.1.3.1 Walk Back for Planetary Surfaces

The xEVA suit will enable EVA crew the ability to ambulate (walk) on planetary surfaces. This includes being able to support a walking traverse of up to 2 km away from the lander on the lunar surface (radial distance) and a total cumulative distance of 16 km during an EVA, though that exact distance depends on the local terrain. Utilizing rovers will extend the ranges that EVA crew will be able to explore the surface. Traverse ranges account for the xEVA suit secondary O_2 system providing an additional hour of gas. These ranges also do not stack any failures, meaning that if the vehicle fails, the suit is presumed to function nominally, and vice-versa. Actual distances traveled will need to account for terrain and time for ingress.

4.2.1.3.1.1 Lunar Surface Excursion Ranges

For lunar surface operations, there will be a goal to maximize the distance possible for science exploration to the greatest extent possible. They will always stay within a range that allows them to get to a safe haven (lander, habitat, or pressurized rover) in the event of a contingency. Depending on the assets on the mission (e.g., rovers), the distance the crew travels from the lander (or habitat) will change. This will be a combination of the EV crew staying within appropriate walk back and/or driving distances. Smart 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 for lunar surface walking: Traverses assume an ~2 km/hr walking pace over relatively level regolith, yielding a walking distance of 2 km away from the lander (safe haven), while factoring in the time to ingress and attach to vehicle consumables. This does not account for slope or obstacles (e.g., boulders), so distances may decrease due to terrain or operational considerations. Note that the Apollo 14 crew walked 1.45 km from their lander.

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 [TBR-EVA-EXP-0042-001]. This protects for a rover failure that drives the EV 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. Giving the rovers the capability of fully recharging the EVA suits before attempting any walk back would help extend this range. During the Apollo missions, the crew got as far away from the Lunar Module as 7.63 km while driving the unpressurized Lunar Rover Vehicle (LRV), which was designed to operate within a 5-mile (~8 km) radius of the Lunar Module.

EVA range with a single pressurized rover range: It is assumed that there is time available for the crew to rest and recharge their suits before they walk back to the lander/habitat, providing a maximum walk-back time of 8 hours (nearly a full EVA). Given a pace of 2 km/hr, a walk of 8 hours could be upwards of 16 km. However, a more conservative approach would be to use a more nominal EVA length of 6 hours, with an associated walk back distance of 12 km. Note, as failures are not stacked, if the suit experiences a failure, the crew simply ingresses the rover, and then drives back to the lander/habitat.

For dual pressurized rover range, the two will be capable or rescuing the other crew. Therefore, the crew essentially have a mobile safe haven, which could extend their excursion range to 100 km or more. The second rescuing rover will stay within less than an 8-hour drive of the EV crew [TBR-EVA-EXP-0042-002]. This protects for the situation in which a rover has been compromised, and they must abandon the vehicle in their EVA suits. Future refinement and testing will determine if this distance should be shortened in order to reduce the amount of time the EV crew may be in their suits, while still striving to provide the greatest range possible for science exploration, especially if a rover failure happens at the end of an EVA.

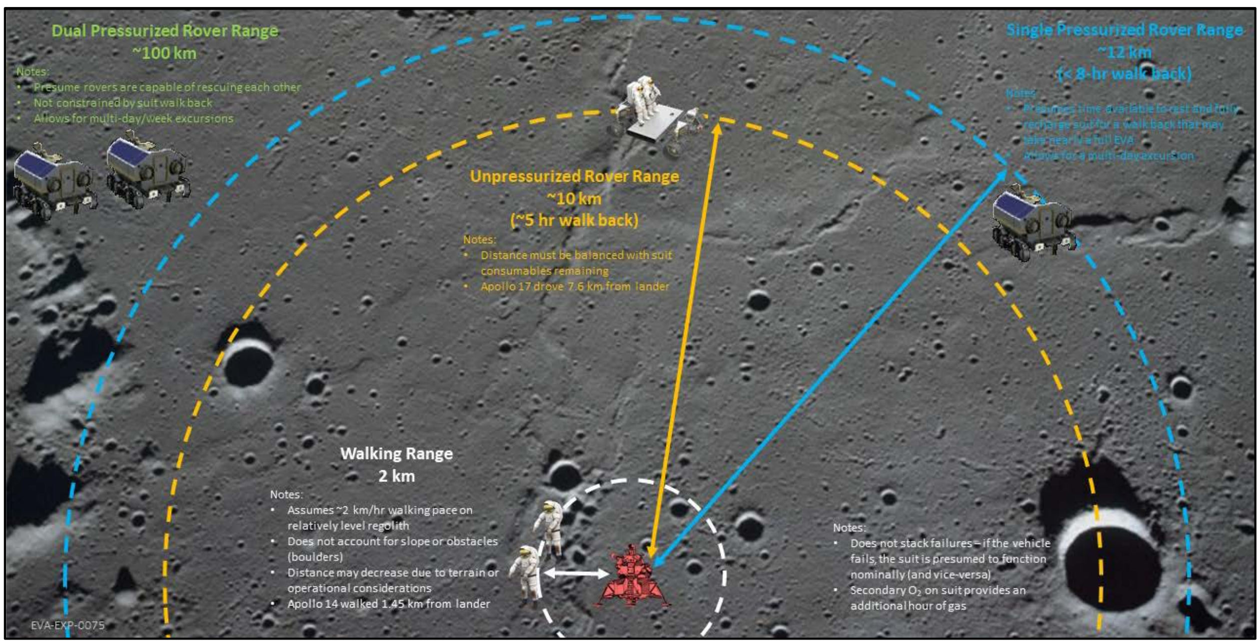


FIGURE 4.2.1.3.1.1-1: LUNAR SURFACE EVA EXCURSION RANGES

4.2.1.3.1.2 Mars' Surface Excursion Ranges

Development of the mEMU and associated walk back ranges are forward work.

4.2.1.4 Environmental

The xEVA System includes, but is not limited to, the following key environmental capabilities and features for Artemis Phase 1 (including Gateway):

- Conduct microgravity operations on the ISS and Gateway (cislunar orbit)

- Conduct partial-gravity operations on the surface of the Moon, including near the south pole
- Operate during lunar day (near continuous light)
- Function for up to 2 hours of contiguous exposure in a shadowed area, including Permanently Shadowed Regions (PSRs)
    - Factors in translating into and out of the shadowed area
    - Crew will return to lit area in order to warm up before going into another shadowed region
- Function within vehicles with the potential following nominal saturation atmosphere set points (note: it is important to recognize that spacecraft design implementation may involve design uncertainty that adds margin to these values and must be considered in requirements for materials compatibilities):
    - 14.7 psia with 21% O_2
    - 10.2 psia with 27% O_2
    - 8.2 psia and 34% O_2

The xEVA System includes, but is not limited to, the following key environmental capabilities and features for Artemis Phase 2 (sustained missions):

- Everything from Artemis Phase 1
- Operate during lunar night (near continuous dark)

For lunar surface missions, the general regions of interest for Exploration include cratered terrain, permanently shadowed regions, and volcanic terrain. The xEVA System will enable exploration into those regions, and return of science samples from them.

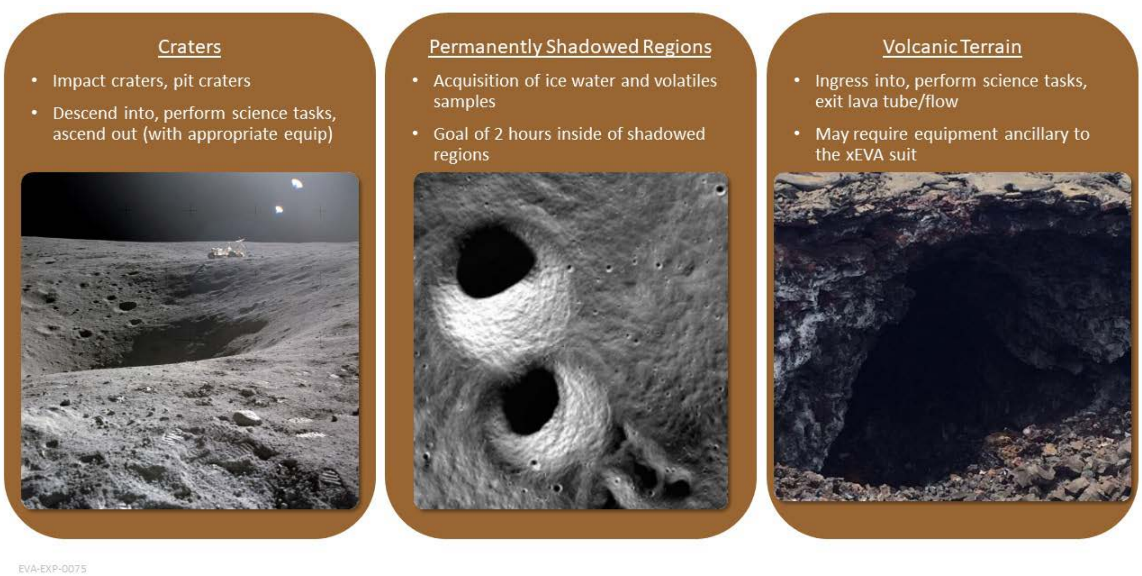


FIGURE 4.2.1.4-1: GENERAL SCIENCE REGIONS OF INTEREST FOR LUNAR SURFACE MISSIONS

Mission to the lunar surface will require xEVA Suits that operate in and survive in the harsh lunar environment. The Pressure Garment System components such as bearings, boots, and gloves must provide a higher level of protection against a dusty environment, higher abrasion resistance, higher cycle life and longer mission durations before refurbishment than the ISS EMU was required to survive. Dust tolerant electrical connectors are also necessary to prevent shorts and mechanical failure of connectors.

The xEVA Suit will enable the crewmembers to ambulate over a variety of terrain. The crew will need to scramble up and down steep slopes, down/up rom and explore craters and lava flows, and possibly down into and back up out of lava tubes and pits (likely involving belaying/rappelling). The EVA Suit must be robust enough to maintain suit pressure and functionality during and after crew falls and impacts with sharp rocks.

Reference the latest version of EVA-EXP-0039, xEVA System Destination Environments Specifications for detailed information on the environments in which the xEVA system will operate.

4.2.1.4.1 Dust Mitigation

The removal of dust from the suits (dust mitigation) is a multi-phase operation to preclude or limit dust introduction into the suit interior, life support system, or into the crew cabin. Dust can damage suit components and can become a crew health hazard if introduced into the crew cabin in sufficient quantities.

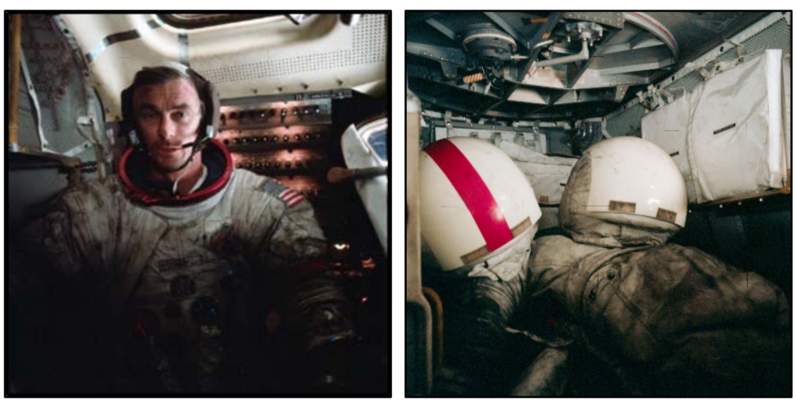


FIGURE 4.2.1.4.1-1: DUST CONTAMINATION DURING APOLLO 17

xEVA surface operations include multiple strategies for reducing the amount of lunar dust that is released into the HLS habitable volume. The theme of the overall strategies can be separated into three processes:

- Prevention (reducing the amount that adheres to the suit)
  - Improved mobility to reduce contact points with regolith during the EVA

    - Reducing dust capture points on the suit based on lessons from Apollo
    - Reducing the amount that adheres to the suit outer layer and surfaces
- Reduction
    - Removing dust that has been captured by the suit
    - Removing dust while minimizing dust that re-adheres to the suit
- Mitigation & Contamination Control
    - Preventing dust from spreading from the suit to the cabin
    - Cleaning up areas that have become contaminated with dust

4.2.1.5 Visibility and Lighting

The xEVA System includes, but is not limited to, the following key visibility and lighting capabilities and features for Artemis Phase 1 (including Gateway):

- Suit-mounted lights will support visual sight of suited astronaut boots, ground ahead including the immediate walking path (and hazards and obstacles therein), EV partner in a PSR, lander, and the EV worksite
- Primary lights are helmet-mounted to illuminate the standard microgravity work envelope
- Crew visibility and lights may need to support color-critical tasks
- Ancillary lights and/or lights on surface assets or other parts of the suit (e.g., hands-free flashlight strapped to the forearm or mounted near the waist) may supplement the helmet lights

The xEVA System includes, but is not limited to, the following key visibility and lighting capabilities and features for Artemis Phase 2 (sustained missions:

- Everything from Artemis Phase 1
- Lighting to support up to a 12,000 m contingency walk-back from a failed pressurized rover

Lighting will be critical for lunar surface missions, especially for those near the lunar South Pole where constant long shadows will be prevalent. Sufficient lighting for walking over rough slopes and conducting science tasks will be required for any incursion into a PSR. Those lights will need to allow the crew to walk hands-free (as much as possible) and perform tasks with tools in both hands.

FIGURE 4.2.1.5-1: XEVA SUIT LIGHT AND VISOR NOTIONAL CONCEPTS

4.2.1.6 Communication and Data

Exploration EVAs require high data rate and high bandwidth communication and data for voice, suit data, scientific data, video, and still imagery, in addition to augmented reality cues. Critical services, such as voice communication and suit telemetry, will be transmitted over UHF. Non-critical services will be transmitted primarily over Wi-Fi.

The xEVA suit will be capable of transferring data and communications through a Radio Frequency (RF) Spectrum Management approved wireless system and a hardline umbilical. For exploration, new protocols will be developed that will be needed for spacecraft proximity (e.g. asteroid mission, Mars moons/orbit) and for surface deployment. Some missions may involve both microgravity and planetary surface EVAs in the same mission. On-orbit updates of software and complex programmable logic devices will allow changes to be made during the mission if necessary. If a hardware change out is required, then the component will have to be an ORU. A special antenna may be required.

Limited or delayed communications coverage may prohibit the Mission Control Center (MCC) from providing guidance to the crew during real-time EVA life support system anomalies. Therefore, the pertinent suit caution and warning alarms, including those sounded, enunciated, and displayed, from one suit will be directly transferred to all other crewmembers on the EVA and in close proximity vehicles, identifying the originating suit, and allowing the crew to immediately respond to a suit failure. For this to be possible, the network coordinator rebroadcasts the warning messages received from one suit to the other suits and users on the network. Alternatively, when generated, the suit Caution and Warning System (CWS) messages may be sent as broadcast or multicast packets. It is envisioned that this type of crew autonomy is eventually provided via an in-suit CWS capable of providing spoken descriptions of the problem, a crew locator system (e.g., transponder system), and an electronic display. The IV crewmember aboard a habitat element or exploration vehicle has communications with the EVA crew as long as the EVA crew is within the line of sight, even when coverage with the MCC is not available, up to a range of 10,000 m on surface missions, which may require relays or other assets.

For lunar surface missions, current plans utilize Ultra-High Frequency (UHF) and Wi-Fi for voice communication and data. This is also a potential to expand to other systems (e.g., LTE or 5G) for lunar surface operations. An Acquisition of Signal (AOS) state from the EVA crew to the HLS is presumed to be the nominal operational condition for EVA, however, there will likely be lower signal strength due to distance or blockage, including up to LOS, which will be addressed by mission rules. Indication of this signal strength to EV crew and MCC will help the team anticipate LOS. During EVAs, the xEVA Suits will have a direct UHF and Wi-Fi communication link to the HLS landed element, enabling the crew to communicate with the Gateway/Orion crew and Earth via KA-band radio. Because HLS will be concurrently communicating with both Gateway/Orion and Earth, it means the xEVA Suits will be able to communicate with both Earth & Gateway.

The xEVA System includes, but is not limited to, the following key audio communication and data capabilities and features for Artemis Phase 1 (including Gateway):

- UHF and Wi-Fi for voice and data
- Ability to record communication and video onboard the suit in case of loss of signal with the MCC
- All audio, video, and integrated xEVA suit still imagery will be recorded with timestamp
- Ability to communicate up to a range of 10,000 m on surface missions
    - Hills, boulders, craters, and other natural obstacles may require the use of EVA-deployable communication repeaters

The xEVA System includes, but is not limited to, the following key audio communication and data capabilities and features for Artemis Phase 2 (sustained missions):

- Everything from Artemis Phase 1
- Ability to communicate up to a range of 12,000 m on surface missions during a contingency walk-back (with appropriate ancillary equipment)

FIGURE 4.2.1.6-1: XEVA SUIT CAMERA NOTIONAL CONCEPT

4.2.1.7 Imagery

Exploration will require high definition video, some amount of transmission and storage on the suit, and enhanced informatics. The imagery aspects of xEVA overlap with the informatics capabilities.

The xEVA System includes, but is not limited to, the following key imagery capabilities and features for Artemis Phase 1 (including Gateway):

- Integrated high-resolution imaging capability in the xEVA suit (i.e., high definition helmet cameras)
- Still photography is required and will be completed by the xEVA suit helmet camera and supplemental equipment as necessary (e.g., a hand-held camera)

4.2.1.8 Informatics

Informatics required for the Artemis III mission include the following for Artemis Phase 1 (including Gateway):

- Cameras (video)
  - o Obtaining and transmitting high-resolution video and still imagery from the suit integrated camera and other hand-held cameras
- Lights
  - o Enables visibility for viewing the ground ahead while walking, the worksites, and tasks
  - o Needed to ensure safe return from shadowed regions and to the lander
  - o May be integrated into the suit or ancillary lights hands-free lights (reference 4.2.1.5 for details on lighting)

For Artemis Phase 2, the xEVA suit will include an integrated informatics system with a heads-up display type of capability that will allow for both increased autonomy and enhanced ability of the flight control and science teams to interact with the EVA crewmembers. The informatics display and processor are anticipated to be a non-critical system and should be distinguished from the Caution & Warning System that monitors safety critical functions of the suit. The xInformatics display system will be used to enhance communication with MCC, along with increasing crew efficiency and autonomy when performing tasks. In the event that data on the xInformatics system does not match information on the Caution and Warning System, the crew will be trained to use the Caution and Warning System information because of its higher reliability.

In addition to lights and cameras, the xEVA suit will have an external power and data interface for ancillary equipment (sensors or devices). This connection could be utilized for integration of data from xEVA tools and instruments, including (but not limited to) hand-held cameras, power tools, and hand-held science instruments.

Informatics systems will need to take into account lighting conditions. Reference the latest version of EVA-EXP-0039, xEVA System Destination Environments Specifications for detailed information on the environments in which the xEVA system will operate.

Beyond the basic informatics capabilities required for Artemis Phase 1, the xEVA System will eventually include, but is not limited to, the following key informatics capabilities and features in Artemis Phase 2 (sustained missions):

<u>Suit System Monitoring</u>

- Suit systems monitoring and consumables displays
    - Enhanced awareness of suit functions for the crew
    - Caution and warning auditory tones and displays will still be controlled by the CWS
- Consumables calculation
    - Allows for real-time timeline adjustments (similar to dive computers)
    - Primary is CWS and MCC monitoring
    - Crew should be trained to check Display and Control Unit (DCU) and/or with MCC before reacting off suit data displayed on any informatics system, which provides situational awareness

<u>Conducting Tasks and Traverses</u>

- Procedure and cue card viewing
    - Down-mode is verbal directions from MCC and/or an IV (as is done today on ISS)
- Viewing of diagrams, photographs, annotated images, and videos
    - Down-mode is verbal direction from MCC/IV
- View timeline status, including time ahead/behind and consumables margin
- Navigation and tracking
    - Safe return to lander (or other safe haven)
    - Transmission of crew and asset positions
    - Marking of science sample locations
    - Down-mode is crew understanding the terrain and manual land navigation with maps
- Augmented reality graphics and cues
    - Includes pre-planned waypoints for navigation and science regions of interest into environment
    - Down-mode is maps, images, or verbal direction from IV/MCC

<u>Capturing data</u>

- Verifying helmet camera video framing and quality
    - Looking at imagery before/during transmission
    - Down-mode is verbal direction from MCC/IV or best effort

- Interface with and transmission of scientific instrument, sensor, and camera data
    - Down-mode is best effort with instruments storing data themselves

Communicating with MCC

- Text communication from both MCC and an IV
    - Down-mode (and nominally primary) is voice comm
- Ability to receive near real-time updates and content from MCC during the EVA

4.2.2 VISE

The VISE consists of equipment required for EVA preparation and post EVA activities. It includes the equipment for recharging consumables on the xEVA suit, providing resources directly from the vehicle, communication systems, the Exploration Don/Doff Assembly (EDDA), and crew restraint system.

The VISE provides for the following:

- Lander descent/ascent vehicle loop mode
    - Breathing gas
    - Suit ventilation
    - Cooling water
    - Communication
- Suit servicing (refill/recharge) and prep/prebreathe activities
    - Oxygen (O_2) recharge
    - Water recharge
    - Battery recharge
- Data/Communication
- Don/doff assembly
- Crew restraint for HLS descent/ascent

Reference the VISE Project for details on the EVA interface equipment planned for use on HLS and Gateway for the Artemis Program.

4.2.2.1 Consumables Recharging

Consumable recharging will nominally be completed prior to the start of the EVA day and will nominally occur while the suit is doffed.

1. Oxygen Recharging – nominally, oxygen tanks will be filled prior to the start of the EVA day. During umbilical operations, the oxygen tanks will remain topped-off prior to disconnection from the vehicle/rover/habitat interface panel.

2. Battery Recharging – the battery can be recharged while installed in the Exploration Portable Life Support System (xPLSS). The power charging equipment also provides a battery discharge capability. The capability to discharge a battery is needed for long-term surface operations (to maintain battery capacity). The suit may be powered while recharging the batteries.

3. Water Recharging – recharging of the water tanks on the xEVA Suit will be provided by host vehicle or habitat. Support equipment will pump feed water into the xEVA Suit water tanks prior to the start of the EVA day.

4.2.3 xEVA Accessories

The accessories include all of the other hardware and equipment not considered part of the xEVA suit, VISE, or Tools.

4.2.4 EVA Task Tools & Equipment

The xEVA System includes a variety of tools and equipment that are critical for accomplishing EVA tasks. Tools will be provided to support exploration science, vehicle assembly and maintenance, inspection, crew safety, and equipment transport. This includes a tool & sample management system, and equipment for rescuing an incapacitated crewmember.

Reference Section 4.1.3 for the tasks that will be done with tools, and reference the Artemis Geology Tools Project for details on the tools planned for the Artemis Program.

4.2.4.1 Tools

The general types of tools include those for:

- Mobility/transportation
- Construction
- Science sampling (e.g., hammer, tongs, scoop, rake, etc.)
- Contingency

Tools utilized during microgravity operations on ISS and Gateway will be similar to, if not the exact same, as the tools currently utilized on ISS during EMU EVAs.

Tools utilized on planetary surfaces will largely focus on construction and science sampling. Construction tools will be modified for use in the partial-g lunar environment. Science tools will be used for achieving scientific objectives and sample acquisition.

TABLE 4.2.4.1-1: TYPES OF GEOLOGY SAMPLING TOOLS

Sampling Tool	Sample Type	Sample Description
Tong	Rock float	Rocks that are loosely adhered to the surface

Rake		
Hammer (with Chisel)	Rock chip	Piece of rock forcibly removed from a larger rock
Core Drill and Bit	Rock core	Cylindrical samples of a rock
Scoop	Regolith bulk	Representative loose surface material
Drive Tube with Drill	Regolith core	Cylindrical sample of regolith at depth
Surface Sampler	Surface	Undisturbed material from the top ~1mm of surface
Specialized Tools and Containers	Volatile	
Specialized Tools and Containers	Atmospheric	

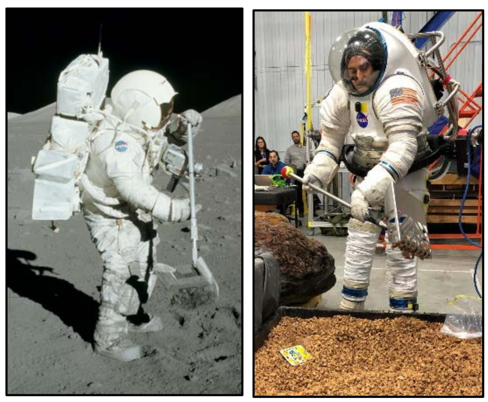


FIGURE 4.2.4.1-1: SCIENCE SAMPLING TOOLS (RAKE)

The tool kit for surface operations will likely include portable lighting.

Powered tools will utilize a common battery architecture that will allow tools to utilize batteries based on the xEVA suit batteries.

4.2.4.2 Tool & Sample Management

The xEVA System includes, but is not limited to, the following key capabilities for tools and sample management:

- Ability to transport tools (microgravity and surface)
- Capacity to carry some tools on the suit (attached directly or via a harness)
- Capability to pull/push an equipment carrier during surface operations
- Capability of interfacing with equipment utilized assist with traversing into and out of challenging terrain (e.g., lava flow) and descending/ascending steep slopes (e.g., craters and lava tubes), such as a belaying device and/or winch

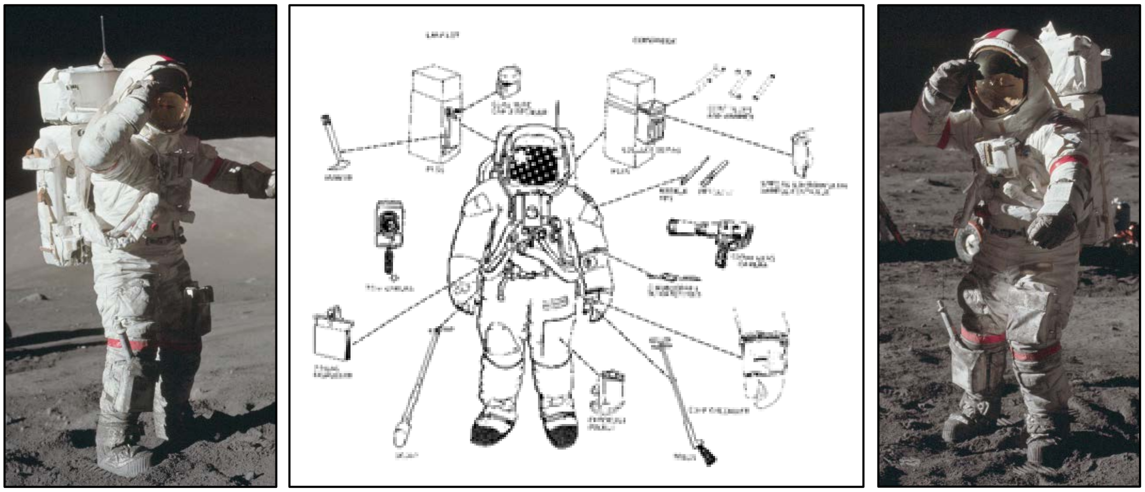


FIGURE 4.2.4.2-1: CARRYING TOOLS ON APOLLO SUITS

As was done during the Apollo missions, some smaller set of tools will be carried on the suit. For Apollo, those included a hammer, sample collection bags, and cameras. For the xEVA suit and the Artemis missions, tools that may be carried on the suit include, but are not limited to the following:

- Hammer
- Chisel
- Scoop
- Handheld Camera
- Documented Sample Bag
- Sample Collection Bag
- Cuff Checklist

4.2.4.3 Incapacitated Crewmember Rescue Equipment

Planetary surface missions will need equipment and interfaces to transport an incapacitated crewmember from a work zone to a safe haven (e.g., lander), and then into the safe haven.

4.3 AUXILIARY SUPPORT SYSTEMS FOR XEVA

The following aspects of missions help enable safe and successful EVA operations.

4.3.1 Navigation & Tracking

The capability to track EVA crew and for the EVA crew to navigate will become critical in future missions for safety, science, and operations. This is especially true for planetary surface missions to the moon and Mars. Any navigation solution will likely involve an integrated and distributed system, with components on the suit, ancillary accessories, the rover (if applicable), and the lander.

4.3.1.1 ISS and Gateway

The xEVA System may include, but is not limited to, the following key navigation capabilities and features for microgravity operations on ISS and Gateway for demonstration and possibly nominal ops:

- Navigation (location) tracking, with real-time data to the Flight Control Team (FCT)
- Orientation tracking on ISS, with real-time data to FCT
- Path to safety tether anchor
- Path to airlock

4.3.1.2 Planetary Surface

In order to support the Artemis mission goals of returning the crew safely and completing the science objectives, there is a need for EVA navigation capabilities on the lunar surface. A navigation system(s) will enable the crew to find and document the science objectives, and will allow them to safely return to their vehicle. Navigation capability for Artemis will likely evolve in a phased approach, with basic capabilities for Artemis III (e.g., something handheld) and more advanced systems coming online in Phase 2.

Early xEVA System navigation solutions are envisioned to be independent of space suit or spacecraft utilities/consumables and operated as a hand-held relative-navigation device available to the EVA crew member. Relative navigation support is intended to provide real time position/heading integration sufficient to return the crewmember to the general vicinity of the lander sufficient for the crew member to obtain visual indication of lander location within expected lighting conditions. From an infrastructure perspective, xEVA will assume the primary responsibility of deriving an adequate navigation capability without use of any other infrastructure. In other words, no assumption is made for supporting capabilities such as range beacons, satellite constellations providing Position/Navigation/Time (PNT) data, or any other form of information. This ensures safe operation/safe return of the crew without interdependence from other assets.

This relative navigation solution may also be used to document approximate locations of surface activities such as science sampling worksites, payload deployments, etc. However, such information will by design be referenced to the starting point (the lander itself) and must be interpreted after the fact to understand/estimate absolute surface location in any broader coordinate system.

As missions and capabilities evolve, these features may be incorporated directly into the suit itself.

4.3.1.2.1 Safety-focused Navigation Capabilities

Safety navigation capabilities for the xEVA System include, but are not limited to, the following for planetary surface operations for Artemis Phase 1 (including Gateway):

- Crew must always be able to safely find the lander, even when out of line-of-sight or in shadows
- Crew will require a system/method for ensured safe return within 2 km of the lander (e.g., a transponder)

Safety navigation capabilities for the xEVA System include, but are not limited to, the following for planetary surface operations for Artemis Phase 2 (sustained missions):

- Crew will have systems to enable navigation when greater than 2 km of the lander that ensures safe return to the lander
- EVA crew must be able to safely return to the lander on their own in the event of a contingency with any rover failure (i.e., not fully dependent on the rover for navigation)

4.3.1.2.2 Science-Focused Navigation Capabilities

Science navigation capabilities for the xEVA System include, but are not limited to, the following for planetary surface operations for Artemis Phase 1 (including Gateway):

- Science objectives will require crew to precisely locate sampling targets within a few meter precision
- Science objectives will require crew/science support to precisely document where samples and data are being collected
- Accuracy required for science:
    - 0.5 m for subsurface instrument emplacement
    - 3-5 m for samples
    - 10 m for general context

4.3.1.2.3 Operations-Focused Navigation Capabilities

Flight operations and flight control navigation capabilities for the xEVA System include, but are not limited to, the following for planetary surface operations for Artemis Phase 1 (including Gateway):

- EVA crew must know their location in order to find worksites, accomplish tasks, rendezvous with pre-deployed assets, and return to the lander
- MCC must know the location of the crew for situational awareness (SA), directing the crew, calculating consumables, and tracking and replanning the timeline
- Traverse path data utilized post-processing for planning the next EVA and understanding sample acquisition locations
- Enables navigation during lunar day and in shadowed areas, including PSRs

Flight operations and flight control navigation capabilities for the xEVA System include, but are not limited to, the following for planetary surface operations for Artemis Phase 2 (sustained missions):

- Everything from Artemis Phase 1
- Navigation tracking on lunar surface, with real-time data to FCT
- Functions both independently of the vehicle when out of line-of-site or range, and also transmits data to the vehicle for relay to MCC for situational awareness (e.g., a transponder system)
- Enables tracking and navigation in lunar daylight, in shadowed areas and PSRs, and during lunar night
- Transmits navigation data to the xEVA suit informatics system Heads-Up Display (HUD) real-time, allowing the EVA crew to navigate independently/autonomously
- Increased visibility of terrain in low-light/shadowed regions, via additional hands-free lighting and/or augmented views that utilize imaging systems (e.g., active infrared night vision system used terrestrially)
- Functions both independently of the vehicle when out of line-of-site or range, and also transmits data to the vehicle for relay to MCC (for situational awareness)
- Resources once identified and characterized will need to be re-located for utilization

4.3.2 EVA Mission Support System

At destinations with long signal latencies and/or blockages (non-continuous links), the IV crewmember directing EVA operations will be more heavily loaded than in current real-time communication operations, and will have the primary responsibility of receiving and addressing EVA suit data along with replanning the timeline during the EVA. Essentially, the IV will perform the roles of a Shuttle-era IV, partial Flight Director, partial EVA Officer, and partial Biomedical Engineer (BME). The IV will utilize an EVA Support System in order to effectively handle the large amount of information and tasking that must be contended with while actively directing an EVA. This system enable the IV to performreal-time timeline tracking and will simplify status monitoring. It will automate relevant analysis tasks wherever possible to offload work from the IV crew member. It will incorporate EVAtask progress, incorporating EVA suit data, consumables usage, and crew location to inform the presentation of high level and low level information about the status of past, current, and future tasks. It will display of actual and planned traverses using geoinformatics systems (GIS) tools. Minimal hardware will be required for operations to reduce space and launch mass, and the system may possibly incorporate augmented reality.

The xEVA System includes, but is not limited to, the following key general capabilities and features:

- Communication with MCC and EVA - both voice and text

- Display of real-time and previously acquired crew video and still images
- Display of procedures and cue cards
- Real-time EVA timeline management and automated analysis
- Monitoring of suit data and telemetry
- Spatially and temporally relevant links to all data products (i.e. pictures, notes on samples, video, locations of interest)
- Real-time update of procedures
- Dynamic prioritization of science candidates
- Image annotation
- Display of crew and asset location
- Display of actual and planned traverses in both distance and time
- Creating and sending augmented reality cues and visuals
- Display of real-time and previously acquired in-situ instrument and sensor data

4.3.2.1 Data Sources

In order to support crew autonomy, data from the following sources must be accessible to the EVA Mission Support System. When applicable, data must be accessible in real-time. All as-executed data must be timestamped and stored in an accessible long-term storage medium as well.

- Task cue cards, descriptions, and supporting imagery
- Planned task durations
- Planned temporal relationships between tasks (ie. the ordering of tasks)
- As-executed task durations, eg. the start and end time for each task
- xEMU suit telemetry, including limiting consumables statuses
- Planned traverse routes
- Crew locations
- Potential scientific sample locations
- Collected scientific sample locations
- Equipment and asset locations
- In-situ sensor and instrument data, including data from scientific instruments
- All EVA-related audio, video, and still imagery sources, including but not limited to:
    - EV, IV, and ground voice
    - EV-handheld still and video imagery
    - xEMU helmet cameras
    - Situational awareness cameras
    - Vehicle cameras
- If possible: the location and heading of still and video imagery sources

4.4 EGRESS/INGRESS METHODS

Many of the possible mission architectures for human exploration depend heavily on EVAs to achieve mission objectives upon arrival at the destination; they include science-focused EVAs that increase EVA frequency and require a paradigm shift from heritage programs. For these heritage programs, NASA has used tightly controlled and highly scripted EVA timelines at a relatively low annual rate (about eight EVAs/year on average in the ISS Program) and relied heavily on interaction between the EVA crew and ground team. Some cislunar and/or transit phases assume an even lower annual rate for contingency only EVAs. For exploration missions, a flexible operational paradigm is needed so that the crew can make changes to their activities in near real-time to satisfy science and maintenance objectives. These include both nominal maintenance and science-based EVAs as well as contingency repair EVAs.

EVA-EXP-0031, EVA Airlocks and Alternative Ingress/Egress Methods discusses the details of multiple ingress/egress methods.

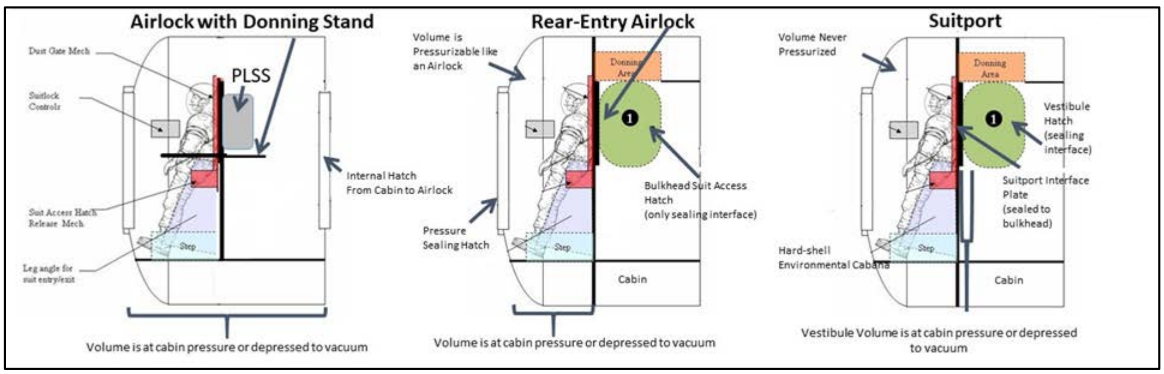


FIGURE 4.4-1: EVA EGRESS/INGRESS METHODS

Currently, traditional dual chamber airlocks and/or suitlocks (rear-entry airlocks) are the prime egress/ingress methods and/or concepts for all microgravity and planetary surface EVA operations. These type of airlocks provide an area for preparation and suit-up, an area for suit maintenance, a reduced volume for depress, and a means for mitigating dust and minimizing forward (planetary protection) and backward (crew health) contamination. A suitlock (rear-entry airlock) provides the best solution for the EVA System on surface habitat and surface rover for dust mitigation, though it does involve some upcoming design challenges for the suit and vehicle. The Artemis Phase 1 missions will utilize a depressed lander cabin or an airlock, and Artemis Phase 2 may include suitlocks or suitports.

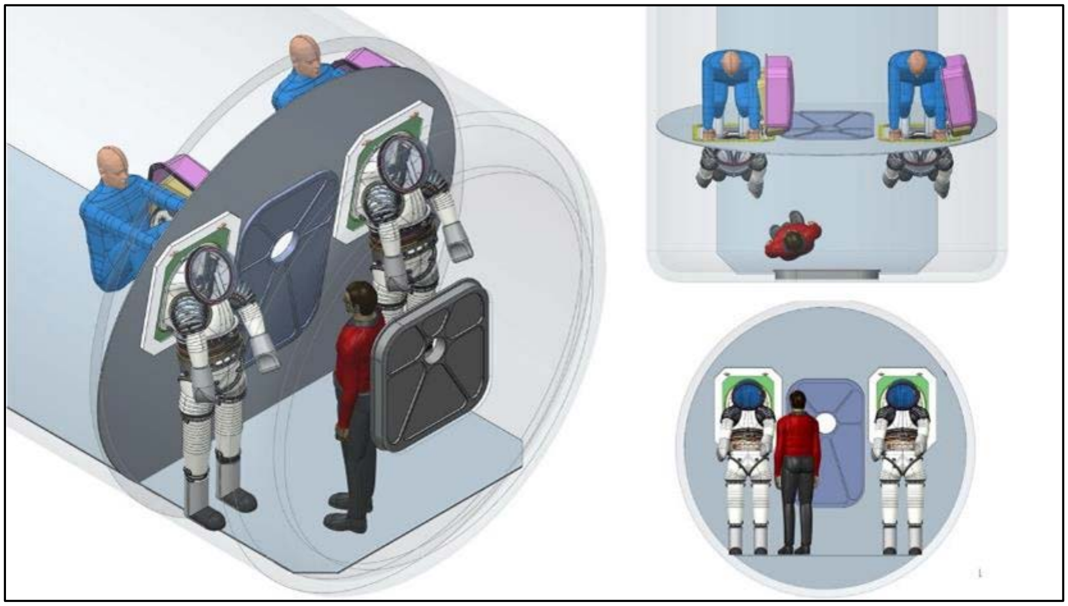


FIGURE 4.4.-2: SUITLOCK (REAR-ENTRY AIRLOCK) CONCEPT

4.5 SPACECRAFT

The following constitute some of the primary vehicles utilized by Exploration crew and for which the xEVA System interfaces in some manner.

4.5.1 Orion

The Orion is a pressurized, crewed element that transports two to six crewmembers from the Earth's surface to destinations beyond LEO and brings them safely back to the Earth's surface at the end of a mission. The Orion provides all services necessary to support the crewmembers while onboard for shorter duration missions (up to 21 days) or until they are transferred to another vehicle. The Orion Multi-Purpose Crew Vehicle (MPCV) consists of a Crew Module (CM), a Service Module (SM), Spacecraft Adaptor (SA) and a Launch Abort System (LAS). The CM provides a habitable pressurized volume to support crewmembers and cargo during all phases of a given mission - from launch operations to Earth Entry, Descent, Landing (EDL) and Recovery. The SM provides services to the CM in the form of propulsion, consumables storage, heat rejection and power generation. The LAS provides an abort capability to safely transport the CM away from the launch vehicle stack in the event of an emergency on the launch pad or during ascent. The crew size and mission duration can be adjusted by changing the vehicle configuration. Reducing the crew complement from four to two provides additional internal stowage and mass capability.

FIGURE 4.5.1-1: ORION

4.5.2 Gateway

A Gateway stack/space station (including an airlock providing EVA capability) will be positioned in a Near Rectilinear Halo Orbit (NRHO). It will allow for crew presence of at least 30 days (possibly up to 45 days). Crew in Gateway will tele-robotically operate surface vehicles, including rovers and landers. The stack will include an airlock for science and utilization to transfer sample containers from the ascent module to the interior of the habitat and Orion while maintaining scientific integrity. It will also include a robotic arm for operations

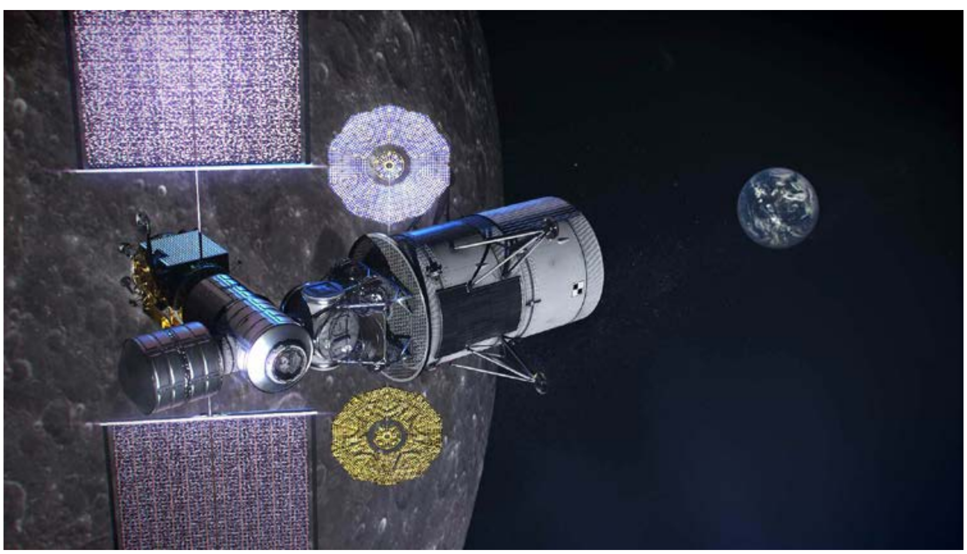


FIGURE 4.5.2-1: GATEWAY

Per "Gateway Program" presented at the 2020 EVA Exploration Workshop, "Gateway will be a sustainable outpost in orbit around the Moon, which will serve as a platform for human space exploration, science, and technology development", including the following:

- The Gateway shall be utilized to enable crewed missions to cislunar space including capabilities that enable surface missions to the lunar South Pole by 2024 (Crewed Missions)
- The Gateway shall provide capabilities to meet scientific requirements for lunar discovery and exploration, as well as other science objectives(Science Requirements)
- The Gateway shall be utilized to enable, demonstrate and prove technologies that are enabling for lunar surface missions that feed forward to Mars as well as other deep space destinations (Proving Ground & Technology Demonstration)
- NASA shall establish industry and international partnerships to develop and operate the Gateway (Partnerships)

As stated in "Gateway Program", the Gateway will not have EVA capability during Artemis Phase 1, but will add that capability for Phase 2.

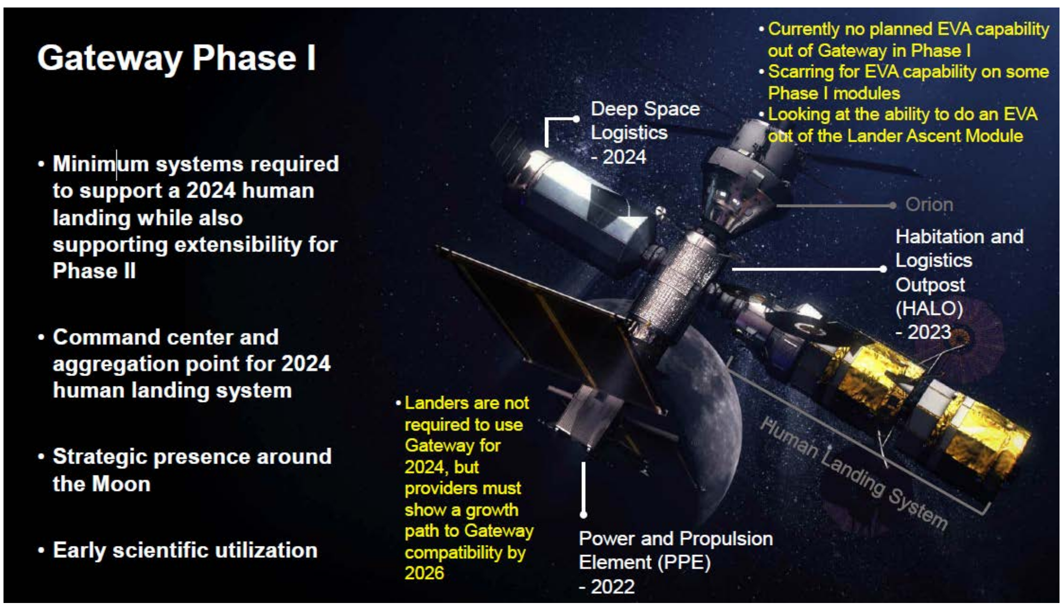


FIGURE 4.5.2-2: GATEWAY PHASE I

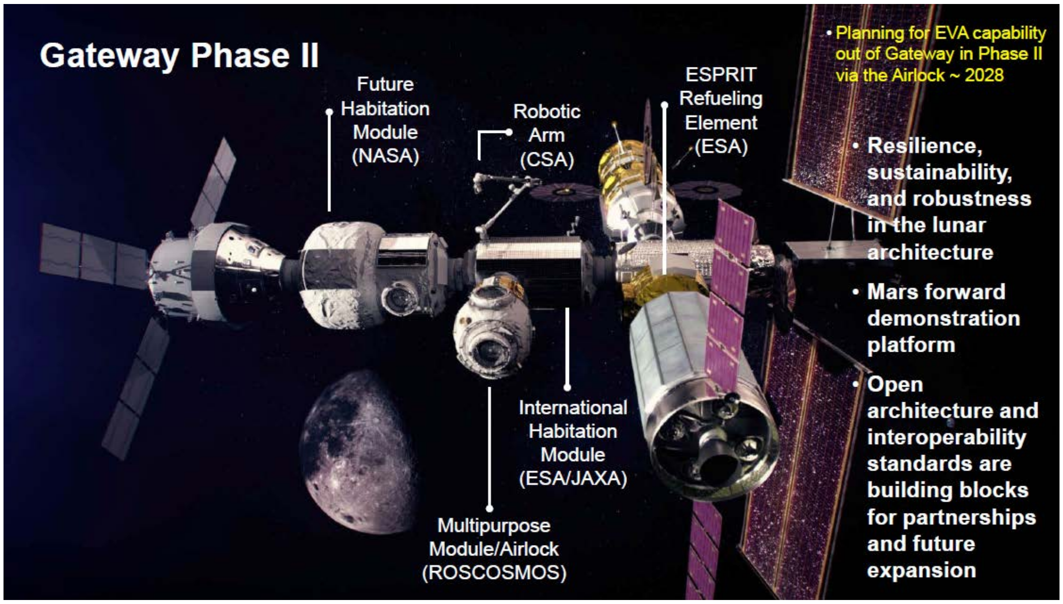


FIGURE 4.5.2-3: GATEWAY PHASE II

4.5.3 HLS (Human Landing System)

The HLS will allow for crewmembers to descend to the lunar surface. It may include a descent stage and a potentially reusable ascent module.

4.5.3.1 Selected Key Attributes for EVA:

- Capability to support up to 5 EVAs during the lunar surface stay
- Capability to support EVAs of up to 8 hours (6±2 hours) in duration each
- Appropriate volume to don, doff, and maintain the suits
- A minimum EVA hatch opening of 1.02 x 1.53 m (40x60 in)
- Allowance for performing incapacitated crewmember operations
- A cabin atmosphere that would allow for the shortest prebreathe and require the least amount of crew time (likely 8.2 psi and 34% O2)
- Layered engineering defense protocols for lunar dust
- Volume and mass launch capacity for returning collected samples
- Margin to bring back as much EVA equipment from the lunar surface (e.g., the entire xEVA suit)
- Total crew time in space, from Orion launch to landing, is expected to fall within 25-34 days, based on vehicle performance and launch opportunities

FIGURE 4.5.3.1-1: HLS REFERENCE CONCEPT

Per Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix H (Human Landing System), the following subsections outline some of the details of HLS that impact EVA:

4.5.3.2 General

- Orion will dock to the Gateway with four crew members
- Some portion of mission logistics (GFE or other) may be launched on a logistics module that would arrive at Gateway before the crew
  - This can include xEMUs, logistics, spares, xEMU tools, etc.
- If in initial missions, HLS bypasses Gateway to dock directly to Orion, all logistics must be launched with HLS
- The total crew time in space, from Orion launch to landing, is expected to fall within 25-34 days, based on vehicle performance and launch opportunities
- Within 1km of Gateway, the HLS may have the option to concurrently utilize dual-band Wi-Fi for non-critical voice, data, and video
- Plan for best-case round trip latencies of slightly under six seconds for voice communications and for low-data rate critical telemetry

4.5.3.3 Assumptions for Initial Mission Capability in 2024

- Crew transfer into the HLS may be achieved either by docking directly to Orion or through the use of the Gateway.
- Two crew members will transfer to the HLS for transport to and from the surface, while two will remain with Gateway/Orion
- Two astronauts land on the Lunar South Pole
- Astronauts live and work out of the HLS during their surface stay

- Pre-deployed surface assets are not required
- Hardware reuse is not required
- xPLSSs may be left on the surface

4.5.3.4 Assumptions for Sustainable Missions

- Four crew land on the Lunar Surface
- Pre-deployed surface assets are available
- The Gateway will be used to facilitate crew and cargo transfers to HLS
- Some or all of the HLS is reusable, depending on sustainability analysis to be performed
- Refueling element enables reuse of elements if required for sustainability and to address disposal of elements for multiple missions.

Reference Appendix E for more details on HLS based on the NextSTEP Appendix H: Human Landing System.

4.6 SURFACE MOBILITY

At some point in the Artemis program, crew will utilize rovers, both unpressurized and pressurized, to extend their range on the planetary surface.

EVA suit can use rovers as a communication relay to other assets. Rovers will take into account visibility issues, such as glare from the sun, lighting in shadowed regions, and dust being kicked up by the wheels. Rovers will aid in navigation to/from the regions of interest, and will incorporate the capability to aid in incapacitated crew rescue.

4.6.1 Lunar Terrain Vehicle (LTV)

For initial missions to the lunar surface, the crew will live in and work out of the lander. In Artemis Phase 2, an unpressurized rover (UPR) allows for longer traverses within an EVA day, as long as the distance is balanced with suit consumables. During these missions, they'll utilize an LTV to extend their traverse range, allowing them to get at least 7.5 km away from their lander.

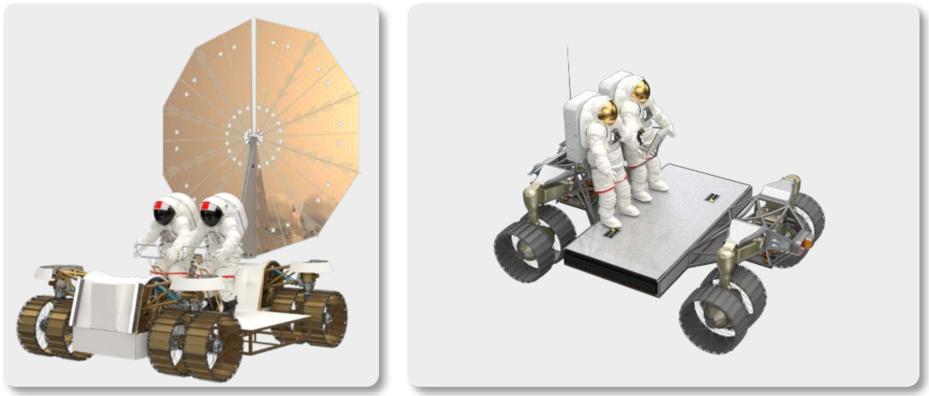


FIGURE 4.6.1-1: UNPRESSURIZED ROVER CONCEPT VEHICLE

Having EVA consumable resupply capability on the rover would ensure that the EV crew has the necessary consumables for a contingency walk back to the lander. Analysis of Apollo Lunar Roving Vehicle (LRV) exploration indicates that approximately 20% of the total EVA time was spent by the crew on the LRV moving from site to site. Thus the EVA team would have sufficient time for recharge of xEVA suit consumables or switching to rover-based support systems to preserve suit consumables. Providing multiple sources of consumables and support systems while on excursions also enhances crew safety by providing contingency options should xEVA suit systems degrade or fail.

A second rover would help mitigate the risk and extend the range.

Reference AES-50010 (LTV Con Ops).

4.6.2 Crewed Pressurized Rovers (CPR)

For living and surface mobility in Artemis Phase 2, crew will have pressurized rovers, also known as the Habitable Mobility Platform (HMP). A single pressurized rover allows for multi-day excursions, with distance limited by a fully recharged suit walk back and the type and number of mobility assets on the surface (e.g., LTV or dual pressurized rovers for drive-back). Dual pressurized rovers allow for multi-day excursions well beyond a suit walk back constraint, presuming one rover can rescue the other.

These will nominally house two crewmembers but will be able to hold four in a contingency situation. They will give the crew an extended range, speed, and payload capability. From an EVA perspective, the vehicle should consist of a habitable crew compartment and one for EVA egress/ingress (e.g., a suitlock or functional equivalent with a minimum of a 40x60 inch external hatch to walk through). The suitlock/airlock portion will be utilized as a suit maintenance area.

However, per the rover team, the vehicle may consist of a habitable crew compartment and suitports for EVA egress/ingress, in addition to a minimum of a 40x40 inch external hatch. The cabin can be depressed in bring suits in for maintenance or in the event of a suitport failure or other contingency. The differences and final concept will be worked out as the rover and xEVA System align.

Note that discrepancies between the xEVA System and the pressurized rover for egress method will need to be worked out.

The rover will be capable of operating at the following nominal cabin atmosphere saturation set points:

- 14.7 psia with 21% O2
- 10.2 psia with 27% O2
- 8.2 psia and 34% O2

The pressurized rovers will have the capability of being controlled autonomously or by the crew and will initially be controlled from the MCC in order to perform sampling and other investigations. Remote control of the rover will be possible from MCC, from a cislunar space station (Gateway), the lander, and while EVA.

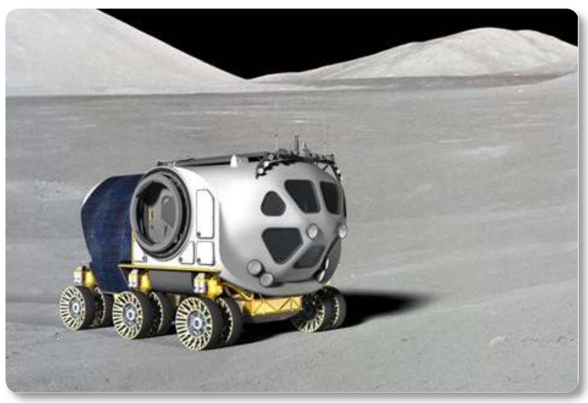


FIGURE 4.6.2-1: PRESSURIZED ROVER CONCEPT

Rovers will be able to navigate slopes of varying soils, and able to handle local slopes of up to 20° and rock sizes of up to 30 cm (per International Space Exploration Coordination Group (ISECG) May 2018 draft con ops). Various equipment will deploy from the rovers, including solar arrays, K-band antennas, panoramic cameras, and robotic arms.

5.0 CONCEPT OF OPERATIONS FOR EVA ON A SPACECRAFT

All future mission vehicles will have the capability for conducting EVAs in a microgravity environment, whether planned or as a contingency. The current concept of operations for an EVA on an engineered surface focuses on the ISS and proving grounds, where systems will be demonstrated, evaluated, and evolve to progress further towards independence from Earth.

These microgravity EVAs may occur in LEO, cislunar space, and during Mars transit. In transit to Mars, there is a possibility for a Venus transit. Any contingency EVA done during transit will need a system/suit that is capable of withstanding the environment near the Venus fly-by.

5.1 CON OPS FOR EVA ON ISS (MICROGRAVITY EVA IN LEO)

Microgravity (Micro-g) EVA operations on any future vehicle will be very similar to those done on the Space Shuttle and on ISS.

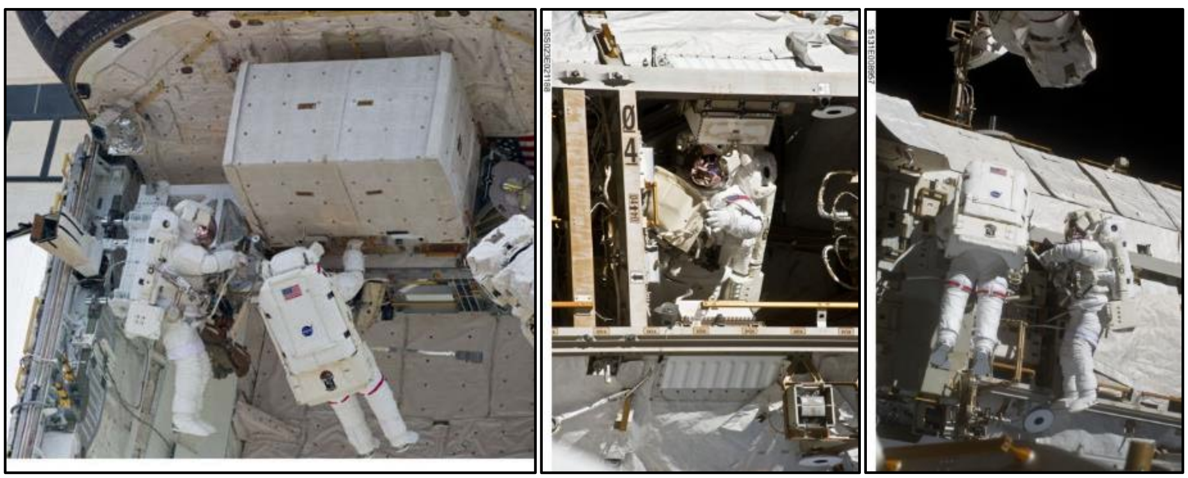


FIGURE 5.1-1: EVA OPERATIONS ON THE SPACE SHUTTLE AND SPACE STATION

The ISS will serve as a test bed for demonstration of the xEVA suit in a microgravity environment. The primary objective is to demonstrate the xEVA suit system and operations in the near term at a known LEO destination. This con ops assumes that all safety-critical functionality has been completed and demonstrated in ground-based testing and that the xEVA Suit will be certified for flight prior to this demonstration test series on ISS.

5.1.1 Demonstration of xEVA Suit (xEMU) on ISS

Initial uses of the next generation xEVA suit (xEMU) will be conducted on the ISS. A demonstration of the xEMU is planned at ISS prior to first use of the suit on the lunar surface to gain experience with the hardware and operations of the suit.

Mission objectives/evaluations:

- Suit prep and post EVA operations, including checkouts of the suit
- Rear entry suit donning and doffing
- Umbilical connection and crew positioning in the crewlock
- Operation of suit systems (Power, Oxygen [O_2], CO2 and contaminant scrubbing, cooling)
- Operation of the variable O2 pressure regulator and prebreathe protocol
- Operation of UIA, Depress Valve, and other airlock switches
- Hatch opening and egress
- Translation
- Use of basic EVA tethers and tools
- Articulating Portable Foot Restraints (APFR) operations
- Reach and access to various ISS worksites including CCE worksites

Mission parameters/capabilities:

- Destination: ISS in LEO
- Mission duration: 2-6 months
- Number of crew: 6
- Number of EVAs: 2-6
- Types of EVAs: Nominal microgravity
- EVA egress method: ISS Joint Airlock (Quest)
- Vehicle systems and configuration:
- ISS O_2 system for recharge
- ISS power system for battery recharge and direct powering of suit
- ISS water system for water bladder recharge
- ISS waste water system and bags for water dump
- ISS hardline system for communication and data
- ISS wireless system for communication, data, and video
- ISS cooling water system (cooling loop and heat exchanger)
- Vacuum access

Reference CTSD-ADV-1639, Exploration Extravehicular Activity Mobility Unit (XEMU) International Space Station (ISS) Flight Demonstration Objectives for specific details on the demonstration EVAs on ISS.

5.1.2 ISS Nominal Operations with xEVA Suit

Once the xEVA Suit is proven to safely and successfully operate on the ISS, it may be certified for EVA system functions so that it may be utilized in a more routine manner in conjunction with or instead of the EMU. As such, the xEVA Suit would perform all of the tasks currently done by the EMU. Potential task operations include Critical Contingency EVAs (CCE) and other maintenance tasks to keep ISS habitable.

Operations on the ISS will follow a similar timeline to that of the EMU for road-to activities, day of EVA preparations and prebreathe activities, timeline execution, and post EVA activities.

The CCEs are a group of hardware failures on ISS which result in a zero-fault-tolerant system for ISS survival, and are recovered by EVA or Extravehicular Robotics (EVR). When needed, the xEVA Suit will complete the CCE tasks as listed in the appendix. The xEVA Suit may conduct maintenance and other EVA tasks that allow ISS to continue operating.

5.2 CON OPS FOR EVA ON GATEWAY (MICROGRAVITY EVA IN CISLUNAR SPACE)

Microgravity EVA operations in cislunar space will take place on small space stations, such as Gateway. EVAs will utilize the xEVA Suit. It is assumed that EVA will not be utilized as the primary means for construction of Gateway, but instead will be available for utilization and mission success, and possibly as a backup for contingencies.

Operations in cislunar space on a small spacecraft stack/space station, such as Gateway, will follow a similar approach to those done on the Space Shuttle and ISS. There will be a series of road-to-EVA activities in order to gather and prepare the appropriate equipment and plans. Within a day or two of the spacewalk, EVA preparation activities will begin, with appropriately configuring the airlock beforehand and some focused on crew suit-up and prebreathe. Following completion of the prebreathe portion of EVA prep, the crew will egress the airlock and conduct the required tasks. Upon completion of the EVA, the crew will ingress, doff their suits, and perform the necessary post EVA activities.

5.2.1 General Aspects of EVA on Gateway

EVA operations on a spacecraft in cislunar space will share many similarities with those done on the Space Shuttle and Space Station. Egress and ingress will be performed via a dual chambered airlock, and many of the same or similar tools will be used to perform any tasks - including (but not limited to) safety tethers, waist tethers, Body Restraint Tethers (BRTs), equipment tethers (Retractable Equipment Tether (RET) and Adjustable Equipment Tethers (AETs)), a Modular Mini Workstation (MMWS) equivalent, various bags (crewlock, ORU, 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) science payload deploy and retrieve, science instrument data acquisition, leak detection and isolation, Orbital Replacement Unit (ORU), Micro Meteoroid Orbital Debris (MMOD) penetration location and repair, solar array repair, and robotics repair.

For consumables and logistics estimates, these missions are assumed to be a minimum of 30 days with four crewmembers and will allow for up to two 2-crewmember EVAs per mission. Gateway uncrewed periods may be as long as three years; however, this is still to be resolved, as well as how and for how long suits are stowed [TBD-6.2.1-001].

EVA availability begins with the launch of a dedicated Airlock element with the EVA System components. For EVAs to occur from the Airlock, permanently mounted hardware and plumbing, such as interfaces to vehicle supplied high pressure O2 (3000 psia), water (iodine or silver impregnated), vacuum (for CO2 removal if utilizing an amine swing bed system), power, data transfer, and communications are in place to enable crew to perform prebreathe and suit checkouts prior to switching to xPLSS services. VISE and a common Umbilical Interface Panel (UIPs) - also known as an Umbilical Interface Assembly (UIA) on ISS – will provide general airlock utility services to the EVA suit. Airlock functionality for US EVA includes xEVA Suit donning and doffing interfaces, suit servicing and recharge interfaces, communication, prebreathe capability, depress and repress, egress and ingress, and tools. While some equipment must be hard-mounted in the Airlock to enable EVA, other equipment may be launched and stowed separately to increase operational flexibility, and the crew would transfer the equipment to the Airlock as needed to support an EVA.

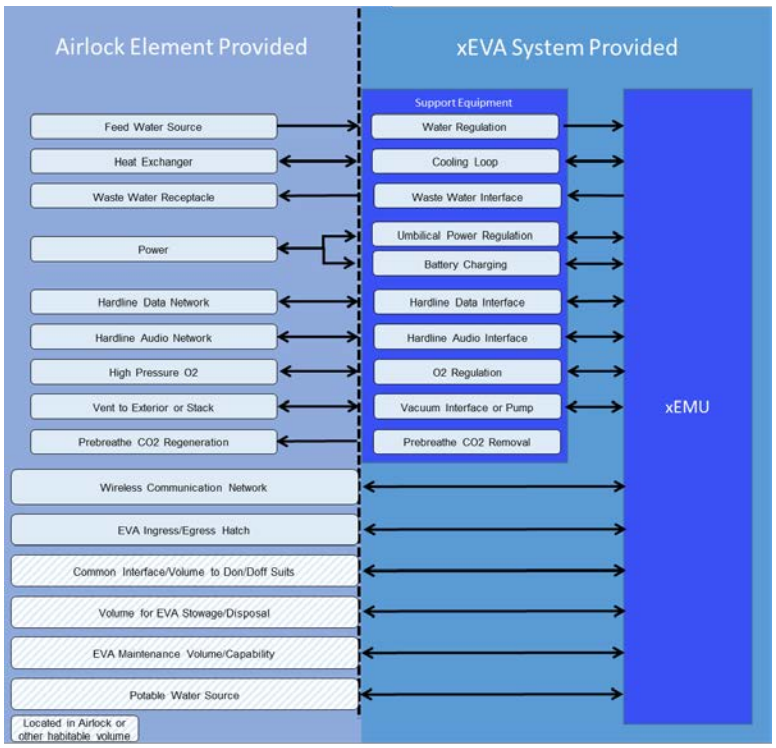


FIGURE 5.2.1-1: EVA INTERFACES SUPPORTING NOMINAL EVA CAPABILITY

The dual chamber airlock provides the volume for two crewmembers to perform on-orbit suit maintenance and all of the EVA prep and post activities, including suit donning/doffing and prebreathe. It is assumed that xEVA rear-entry suits require two donning/doffing fixtures to allow crewmembers to self-don and self-doff their rear-entry suits. Airlock equipment is designed to function nominally while exposed to vacuum or operate after being exposed to vacuum (e.g., battery chargers). This allows airlock equipment to stay in the depressurizable volume.

Servicing and checkout of the suits are performed between EVAs, including recharging consumables (such as batteries and thermal system water) using suit servicing vehicle interfaces, cleaning the suit interior, replacing biomedical sensors, and checkout of xPLSS components in preparation for the next EVA. Vehicle services to the suit are included through an umbilical interface panel and umbilicals in the Airlock. Each suit requires its own dedicated umbilicals (O2 and vacuum).

EVA wireless radio, cabling, and antenna for two-way communications of EVA voice/data as well as downlink of EVA Video are provided by the vehicle.

Spares and logistics will be required for on-orbit suit maintenance (dependent on manned pressurized time). Some spares may be equipment left over from previous flights, such as is done on ISS, while others may be launched in logistics modules.

5.2.2 Road-to EVA (Gateway)

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 the following:

- Suit assembly and sizing
- Pressurized On-Orbit Fit Verification
- Pre-EVA xPLSS consumables charging (e.g., water)
- Battery recharging
- LCVG fill (if required)
- Airlock configuration (items not certified for vacuum are removed)
- Tool and equipment configuration in bags or on suit
- Filling and installing drink bags in suit
- Preparation of biomedical monitoring equipment
- Configuration of communication equipment
- Pre-EVA unmanned automated suit checkouts
- Timeline review

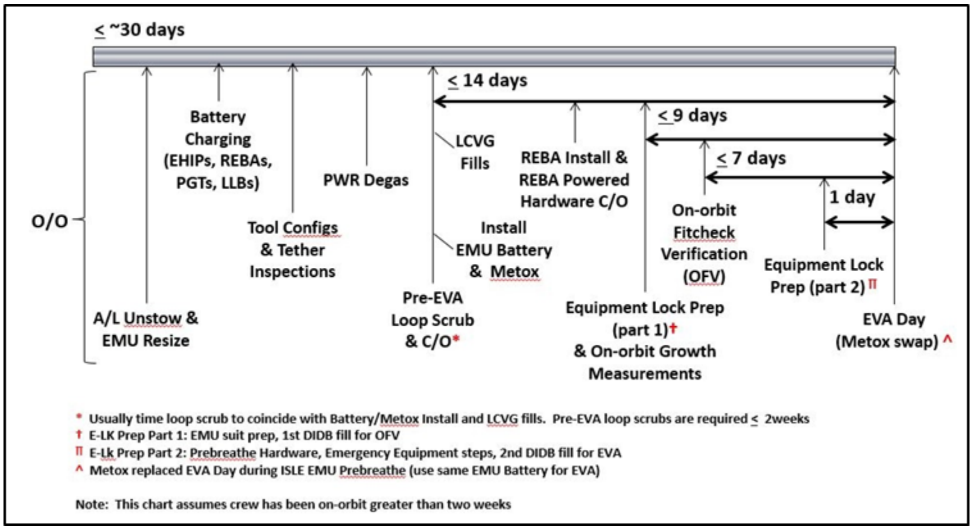


FIGURE 5.2.2-1: ROAD-TO EVA REFERENCE BASED ON ISS EMU EVA

5.2.3 EVA Prep & Prebreathe (Gateway)

On the day of the EVA, the crewmembers begin final prep activities and the prebreathe protocol. These general day-of-EVA activities include, but aren't limited to, the following:

- Non-EVA crew transfer to separate element for duration of EVA activities
- EVA prep
- Mask prebreathe (if required)
- xEVA Suit manned checkout
- Suit donning
- In-suit communication and leak checks
- Prebreathe protocol
- Purge nitrogen
- In-suit prebreathe on umbilical
- IVA crew performs any remaining airlock configuration tasks

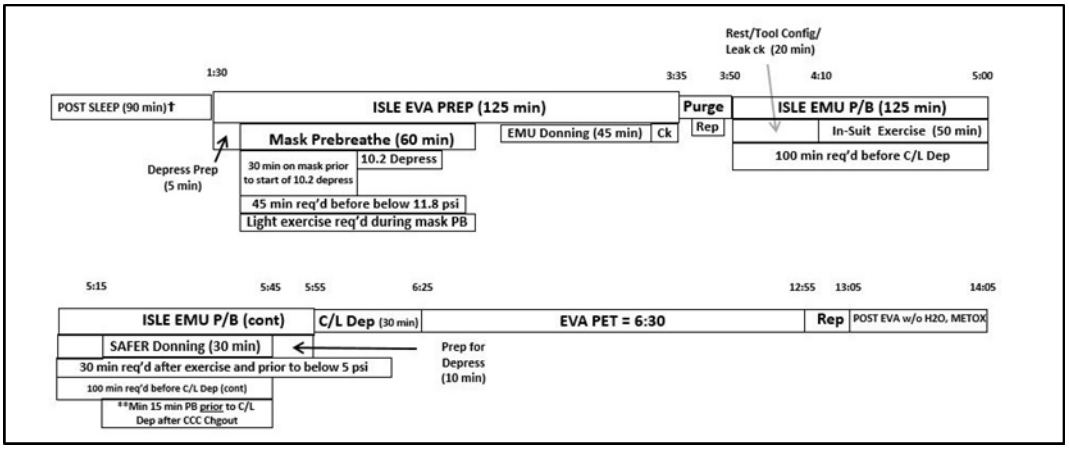


FIGURE 5.2.3-1: DAY OF EVA EXAMPLE TIMELINE BASED ON ISS EMU EVA

5.2.3.1 Prep for EVA (Gateway)

A multitude of activities occur on EVA day in order to prepare the crew and suits. These include, but are not limited to, the following types of activities:

- Configure vehicle and suit communication
- Verify the appropriate equipment is in the airlock before isolating the module
- Activate the CO_2 removal system
- Prepare for mask prebreathe (if applicable)
- Power up the xEVA Suits and verify system functionality, and configure for suit donning
- Verify xEVA Suit communication and data with IV and/or MCC
- Depress to 10.2 psia (if applicable)
- Don suits
- Perform xEVA Suit checkout

General clean-up and stowing of non-EVA equipment is needed to prepare for depress and vacuum operations. Any items that cannot withstand vacuum or require special stowage should be moved to other elements of the stack. Airlock equipment in the depressurized portion must be designed to function nominally while exposed to vacuum. Some exception may include battery chargers, which may not be used during depress/vacuum operations but would be designed to operate after exposure to vacuum. The timing of EVA and cabin preparations will be determined with human-in-the-loop stowage studies.

5.2.3.2 Prebreathe (Gateway)

Once the crew performs suit pressure integrity and system checks, they begin their prescribed prebreathe period. Prebreathe protocols decrease the risk of DCS and may be different durations depending on suit operational pressure and ppO2 saturation prior to starting an EVA. As a starting point, the intent is that future xEVA systems require prebreathe periods no longer in duration than the current ISS EMU In-Suit Light Exercise (ISLE) prebreathe protocol. The current ISLE prebreathe protocol assumes a starting point of 14.7 psia (STP) saturation of the crew, which is consistent with the current FCT architecture and thus a valid comparison. However, alternate prebreathe protocols, such as protocols beginning at 14.7 psia, but beginning the EVA at a higher psid (similar to Russian prebreathe) will also be considered in order to minimize prebreathe time and reduce stack complexity. Additional analysis and protocol testing are required to verify the time required to perform alternate prebreathe protocols.

5.2.3.3 Egress (Gateway)

Once the prep and prebreathe procedures are completed, the EVA crew will depress 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 suit batteries, and officially ends after the airlock hatch is closed upon ingress.

In order to be "GO for EVA" (approved for EVA operations), xEVA Suit will meet the following conditions:

- CO_2 levels are verified nominal
- Pressure integrity verified
- O_2 pressure nominal
- Cooling system is verified operational
- Communications established
- Secondary Oxygen Regulator (SOR) is verified functional
- Telemetry is being received by Vehicle and transmitted to Mission Control Center -Houston (MCC-H)

Once the crew is given the "GO", they perform the following steps:

- EVA crew disconnect from don/doff fixture and translate to crewlock
- IVA closes and secures inner hatch
- Crewlock is depressurized
- EVA crew open the EV hatch (prior to transitioning to xPLSS operations)
- EVA crew transition from umbilical to xPLSS (switching to battery power starts the PET clock)
- EVA crew egress airlock element through a hatch diameter of at least 1000mm
- EVA crew is tethered to the spacecraft for safety

5.2.4 EVA (Gateway)

Once egressed, the crew conducts the planned EVA tasks. Examples of potential tasks include the following:

- External payload installation and removal
- Science payload deploy and retrieve
- Science instrument data acquisition
- Vehicle leak detection and isolation
- Vehicle maintenance and repair
- Fluid ORU Remove and Replace (R&R) (e.g., Pump Module (PM) and Interface Heat Exchanger (IFHX))
- Electrical ORU R&R (e.g., Multiplex/Demultiplexer (MDM) and Remote Power Control Module (RPCM))
- MMOD penetration location and repair
- Solar array repair
- Antenna deploy or repair
- Robotics repair
- Docking contingencies

5.2.5 Post EVA (Gateway)

Crew will conduct post EVA activities immediately after the EVA, and possibly continuing into the next day. The general activities include, but aren't limited to, the following:

- EVA suit are doffed
- Life support units are serviced and recharged
- Suits are soft stowed or stored on the don/doff assembly in the airlock

6.0 CONCEPT OF OPERATIONS FOR EVA ON A SMALL NATURAL BODY

Missions to asteroids currently under consideration vary in duration and location, as well as the assets used and the extent of EVAs involved. There are many challenges associated with traveling to asteroids; such as finding an object with appropriate spin characteristics, mass, and trajectory. Unlike on the ISS, there is no anchoring, translation, and stabilizing EVA hardware built into an asteroid. Due to varying asteroid composition (from loosely held together regolith to solid rock), several types of anchors will need to be available for installation and various methods assessed to discern the most effective technique for anchoring and stabilization. Dust will likely be present on the surface of the asteroid. The presence of regolith on the surface poses potential problems with abrasion, visibility, and transfer of dust into the habitable volume via adhesion to the spacesuit or due to the extended duration that the dust cloud requires to settle in ultra-low gravity environment.

Two basic asteroid missions have been examined to date - one involves manned missions traveling to an asteroid and performing EVAs to collect samples, and the other, in order to mitigate some of the difficulties with traveling to a NEA, involves capturing an asteroid with a robotic vehicle and bringing it to a stable location near the moon, either a Lagrangian/Libration point (L2/EML-2) or a Distant Retrograde Orbit (DRO).

Whether conducting an EVA on a captured asteroid, NEA, or a moon of Mars, the EVA crew will utilize advanced EVA informatics, the xEVA Informatics designed into their xEVA Suit. Utilizing these systems, the EVA crew will navigate themselves to specified worksites and mark their location for MCC awareness and future reference. For science activities, they will call up cue cards, pictures, and imagery that the Science Team has annotated for them. MCC, the Science Team, and IV will also be able to provide the EV crew with augmented reality cues in order to guide them through tasks.

6.1 CON OPS FOR EVA ON A CAPTURED ASTEROID

While there are several concepts for working at an asteroid, the EVA Systems architecture focuses on having two EVA crewmembers work off of a vehicle that has either captured an asteroid or is somehow solidly anchored to one. This maintains the safety of the buddy system, and negates the safety and contamination concerns of a small free-flying spacecraft.

Operations during any likely asteroid mission will take place in a relatively micro-g environment with the crew retrieving geology samples utilizing tools while based on a stabilization boom deployed from a vehicle. If these operations take place in cislunar space, the operations may likely be directed by a Ground or Flight IV.

6.1.1 Road-to EVA (Captured Asteroid)

A crew task during the approximately 10-day transit time will be preparing the cabin and suits for the upcoming EVAs. Shortly after Trans Lunar Injection (TLI), the vehicle cabin will be depressurized to 10.2 psia to facilitate minimal EVA pre-breathe times. The crew will then convert the vehicle interior configuration and their OCSS suits from the launch configuration to one that supports EVA. The crew will mate the helmet mounted lights and cameras (if not integrated), swap gloves, install the xPLSS-to-Hard Upper torso and attach the tool mounting hardware.

FIGURE 6.1.1-1: CONCEPT FOR EVA ON A CAPTURED ASTEROID

6.1.2 Prep & Prebreathe on EVA Day (Captured Asteroid)

On the morning of the first EVA, the crew will complete post-sleep activities and initiate EVA preparations with suit donning. The suit will be purged of cabin air and pressurized with 100% O_2. The crew will then perform suit pressure integrity and system checks followed by a prescribed pre-breathe period that is conducted via umbilical from vehicle Environmental Control and Life Support Subsystem (ECLSS) system. Based on similarity to Shuttle protocols when starting from a saturation pressure of 10.2 psia and corresponding cabin air blends, the in-suit pre-breathe duration will be approximately 40 minutes. Additional analysis is required to verify the time required to perform this task.

When pre-breathe and suit leak checks are complete, the cabin depressurization will be initiated by the crew. The performance of the Orion systems will be evaluated during depress as well as repress operations. Once at vacuum, the crew will open the vehicle hatch and disconnect the umbilicals, marking the formal beginning of the 8-hour EVA time as the point where life support is solely provided by the EVA xPLSS. The sequence of umbilical disconnection and xPLSS activation will be determined through future integrated Orion, xPLSS, & OCSS testing and verification.

6.1.3 EVA (Captured Asteroid)

If not integrated into the vehicle, the crew will set up a translation path/boom to reach the part of the vehicle near the asteroid. There they will retrieve tools and a boom that will allow them to reach various places on the asteroid. After configuring the boom and getting tools, they will take samples from the asteroid.

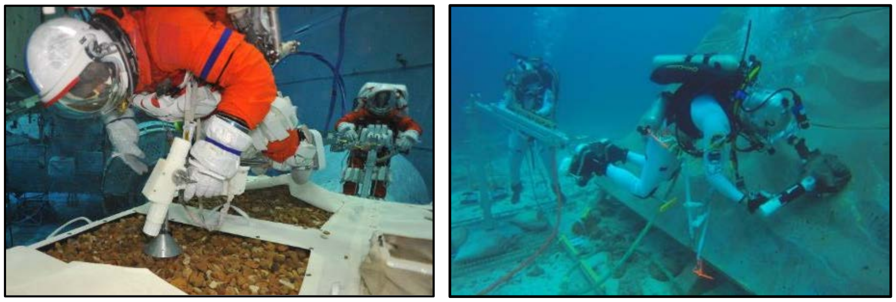


FIGURE 6.1.3-1: EVALUATING ASTEROID EVA BOOM OPERATIONS IN THE NBL AND DURING NEEMO 20

Once positioned over the asteroid, the crew will utilize specialized sample tools to collect and store pieces of the asteroid for return. These tools, currently known as the EVA Integrated Geoscience Sampling System (IGSS), allow for taking pristine samples and putting them into containers that preserve them for study back on Earth. The IGSS will include ways to collect a float sample, surface sample, soil sample, rock chip sample, and a core sample, possibly containing volatiles.

FIGURE 6.1.3-2: ASTEROID SAMPLE COLLECTION CONCEPT (ARCM) AND EVALUATIONS DURING NEEMO 20

The crew will stow the samples in containers for return to Earth. These containers will keep the samples pristine for analysis on Earth.

FIGURE 6.1.3-3: ASTEROID SAMPLE STOWAGE CONCEPT (ARMC) AND EVALUATIONS DURING NEEMO 20

The sample containers will be transferred to the interior of the crewed vehicle at the end of each EVA. The EVA crew stows tools and translation aids on the vehicle for use in future EVAs, and then ingresses the vehicle for cabin repressurization, suit doffing, and preparations for undocking from the Asteroid Retrieval Vehicle (ARV) and return.

FIGURE 6.1.3-4: BRINGING ASTEROID SAMPLE INSIDE VEHICLE

6.1.4 Post EVA (Captured Asteroid)

Servicing and checkout of the suits are performed the day between EVAs, including recharging consumables (such as batteries and thermal system water), cleaning the suit interior, and checkout of the xPLSS components in preparation for the second EVA.

6.2 CON OPS FOR EVA ON A NEAR EARTH ASTEROID (NEA)

A robust NEA mission involves some form of deep space transit habitat and a Space Exploration Vehicle (SEV). The mission is one year in duration with a total of four crewmembers stationed at the NEA for ~28 days. The stack (some combination of transport, habitat, and/or Orion) station-keeps at a safe standoff distance while the SEV free-flies to the NEA surface and provides a stable platform for a crewmember to work from during an EVA. The two crewmembers in the SEV perform microgravity EVAs from a minimal rear-entry airlock, totaling about 192 hours of EVAs over about five or six 3-day long SEV excursions from the stack. Surface activities include sample collection, deployment of probes (radar, acoustic, seismometer, etc.), experiments, and planetary defense devices. The two IV crewmembers in the stack provide support.

Crews will require increased autonomy for NEA missions as compared to current missions, based partly on communication delays of up to four minutes round trip. An xINFO system that enables the crew to capture field notes and contextual observations, and a caution and warning system that provides insight into remaining consumables based on use rate, information on the other crewmember's suit health, and information on the vehicle status is needed. EVA crewmembers can capture High Definition (HD) video for science and public engagement purposes as needed during the EVA. The crew will carry tools and sample stowage bags/containers.

While architecture studies have looked at working off of a small free-flying spacecraft with a single EVA crewmember on the end of a robotic arm on the front of it, there are multiple issues with this sort of con ops, and currently the EVA Office does not have them in the official concept of operations. Until the thruster contamination issues (pluming Phobos), the safety issues of a solo EVA crewmember (all current con ops maintain having an EVA buddy for rescue), and potential problems with having an EVA crewmember on the front of a free-flying spacecraft near the surface (stuck thruster crushing EV crew between Phobos and vehicle, failed thruster resulting in crash, and pilot error resulting in collision) are resolved, the EVA System will focus on working from a non-moving (anchored) platform. Also, while there have been discussions of utilizing some sort of jetpack to extend translation on a NEA, there are numerous safety issues (stuck thruster sending crew to orbit, failed thruster slamming crew into ground, etc.), and the EVA con ops does not include this option.

6.2.1 Road-to EVA (NEA)

Prior to the first EVA, xEVA Suit hardware must be unstowed, and the airlock must be configured with the suit, including all umbilicals and adapters. xEVA Suit consumables are verified to be charged or are charged/swapped out as needed. The crew installs tools and waist tethers on the suit, as required. Depending on the pre-breathe protocol used, tool install may be performed prior to pre-breathe or during pre-breathe. Prior to suit donning, the crew unstows all ancillary equipment and crew preference items, including provisions for biomedical monitoring and crew comfort (e.g. waste collection devices, cooling garments, crew preference items, etc.).

6.2.2 Prep & Prebreathe on EVA Day (NEA)

Following donning of ancillary equipment and crew preference items, the crew connects the umbilical to the xEVA Suit and powers on the xPLSS. In this configuration, the power to the xPLSS and suit electronics, hardline communications, and cooling are provided by the vehicle. Ventilation and CO_2 scrubbing is supplied by the xEVA Suit PLSS, with O_2 and Water (H_2O) resupply from the vehicle via the umbilical and associated adapters. Flow is circulated through the umbilical to the airlock heat exchanger for cooling.

The EVA crew then powers up and dons their suits. The crew connects the biomed and LCVG internally to the suit harness and enables suit ventilation, relying on the xPLSS to provide the ventilation and CO_2 scrubbing as the airlock is not tied to the vehicle ECLSS for this function. If not conducted previously, verification of biomed function is also done.

Once the suits are donned, the crew then performs a communications check with each other and with the vehicle. Upon successful completion of this check, the crewmember in the xEVA Suit closes and locks the suit hatch for subsequent pressurization.

After the suit is pressurized to the IVA prebreathe pressure (~0.9 psid - the equivalent of the IVA mode on the EMU), the crew member verifies the operation of the SOR, and then the crewmember initiates an automated suit leak check followed by a nitrogen purge. The crew performs a leak check at 4.3 psid. Once the suit has passed the leak check, the nitrogen purge is performed as a part of DCS risk mitigation protocols. The nitrogen is purged by opening a purge valve on the suit while using the suit O_2 regulation to maintain a positive pressure in the suit. As the nitrogen is purged, the O_2 concentration increases until the crew is breathing >95 percent O2 from the primary bottle with makeup from the habitat. Duration for the purge will be affected by the flow rate at which gas is purged from the suit and the suit internal gas volume. Purge time will further be constrained by oxygen concentration limits in the airlock.

Following the purge, the crew performs an in-suit denitrogenation prebreathe at 0.9 psid. During this procedure, nitrogen levels in the suit are low enough to cause the crew to release nitrogen from their blood, thereby mitigating the risk of contracting DCS once the crew is subjected to lower total pressures. The xEVA Suit must maintain a positive pressure in the suit to prevent any ambient air (nitrogen) from entering the suit and violating the prebreathe protocol. During prebreathe, the EVA crew performs final checks of the xEVA Suit and rear-entry airlock. The IVA crewmember closes the IVA hatch to prepare for airlock depressurization.

In order to be “GO” for EVA (approved for EVA operations), the xEVA Suit will have to show that it meets the following conditions:

- CO_2 levels are verified nominal
- Pressure integrity verified
- O_2 Pressure nominal
- Cooling system is verified operational
- Communications established
- Secondary Oxygen Regulator (SOR) is verified functional
- Telemetry is being received by stack and MCC-H

6.2.3 EVA (NEA)

EVA operations for the NEA robust mission will involve two crewmembers in an SEV with xEVA Suits. From the SEV, they will perform sampling tasks of the NEA, and eventually return to the stack. EVAs are limited to 24 hours per week. Evaluations of NEA missions at NASA Extreme Environment Mission Operations (NEEMO) and Research and

Technology Studies (RATS) used two 3-hour EVAs each day, with the two pairs of crewmembers alternating days, and that's the EVA frequency assumption that this con ops utilizes.

At the completion of prebreathe, the crew will be ready to depressurize the airlock to vacuum. This process includes a depressurization hold at 5.0 psia to perform a final suit leak check. Following confirmation of suit pressure integrity, the crew enables the contingency O2 system (this should not be enabled for IVA operations), which is the equivalent of going into the 'EVA' mode on the EMU. The airlock is taken to vacuum, and the EV hatch is opened by the EVA crew. The crew then reconfigures the suit to autonomous operations; power is transferred from umbilical power to suit power and the crew switches from hardline communication to wireless communication. The crew performs a wireless communication check, and then disconnects the umbilical from their suits to initiate use of xPLSS consumables. The crewmember verifies that the suit is functioning nominally by viewing their personal suit status list.

Tasks at the NEA will involve both setup and science tasks. The setup tasks may include things such as deploying translation booms. The current ops concepts for science sampling at a NEA have three methods of conducting the EVA:

1. SEV anchored to the asteroid with the EVA crewmember on the end of an Astronaut Positioning System (APS)
2. The EVA crewmember using personal anchors and translation devices to stay attached to the asteroid
3. SEV free-flying with an EVA crewmember conducting sampling tasks from an APS or similar configurable platform
   Note: This option has safety challenges that must be overcome

Several different types of samples will be taken and instruments deployed, including:

- Float samples picked up off the surface with a tool or bag
- Soil sample taken using a scoop
- Rock chip samples taken from a large rock with a rotary percussion drill, powered hammer, or with a manual hammer as a backup
- Core tube sample taken by using a powered driver
- Geophysical array deployed and possibly anchored to the surface

Several types of EVA tools used for different sampling tasks, and they will be stowed on the SEV. Samples will be immediately put in individual sample containers, and then those will be stowed in a large sample container. The sample container will be stowed in a box on the SEV that will eventually be transferred to Orion for return to Earth while maintaining scientific integrity.

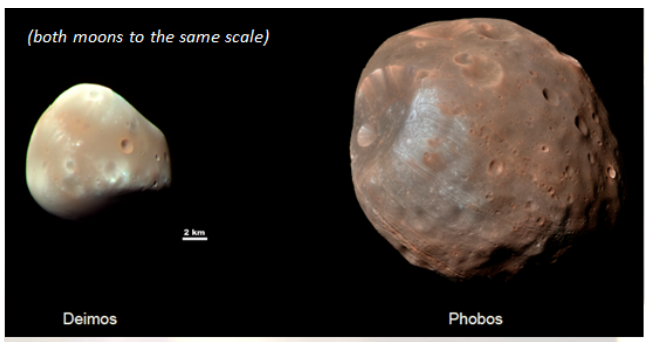
6.2.4 Post EVA (NEA)

Upon return from the EVA, the crewmembers disconnect the recharge umbilicals from the jumper plates and attach them to the suits. Once mated, the crew commands repress of the crewlock volume. Once equalized, the crew opens the hatches and doffs suits.

The suits are cleaned, and maintenance performed as necessary.

6.3 CON OPS FOR EVA ON THE MOONS OF MARS

Both the Capability Driven Framework and Evolvable Mars Campaign studies examined possible missions to the moons of Mars. EVA operations on the moons of Mars, Phobos and Deimos will seem similar to those on a NEA mission, but will differ due to the slight milli-gravity environment. This slight gravity level allows for landing, though vehicles and habitats will only weigh a few pounds. This milli-gravity complicates the EVA operations in that there isn't enough gravity to walk on the surface, but there is enough gravity to cause objects to slowly settle and make contact with the surface. Operations will look close to microgravity EVAs, but plans will need to take into consideration that there may be more contact with the un-engineered surface.



Mass (kg)	1.80×10^{15}
Dimensions (km)	15.6 × 12.0 × 10.2
Albedo	0.068
Equatorial Surface Gravity (μg)	400
Semi-Major Axis (km)	23,459 (Mean)
Inclination (deg.) (to Mars Equator)	0.93
Rotation Period (days)	1.26 (Synchronous)

Mass (kg)	1.08×10^{16}
Dimensions (km)	26.2 × 22.2 × 18.6
Albedo	0.071
Equatorial Surface Gravity (μg)	860–190
Semi-Major Axis (km)	9,378 (Mean)
Inclination (deg.) (to Mars Equator)	1.09
Rotation Period (days)	0.32 (Synchronous)

FIGURE 6.3-1: MOONS OF MARS (PHOBOS AND DEIMOS)

6.3.1 Road-to EVA (Moons of Mars)

The content for this section is TBD. [TBD-7.3.1-008]

6.3.2 Prep & Prebreathe for EVA (Moons of Mars)

The content for this section is TBD. [TBD-7.3.2-009]

6.3.3 EVA (Moons of Mars)

The current con ops focuses on EVA operations on Phobos, the larger of Mars' moons. The crew will land in their habitat in the area where samples need to be taken. They will egress from an airlock in a similar manner to a micro-g EVA. The EVA crew will then deploy a boom from the side of the habitat, which will have multiple ways of articulating it in order to reach the required area. From the boom, they will retrieve geology samples utilizing the EVA IGSS, much like would be done at an asteroid. Missions to Phobos will also deploy science instruments, which the EVA crew will do from the boom.

Due to the several minute communications latency, EVA operations on Phobos will be directed by an IV crewmember in the habitat, with input from the Science Team on Earth.

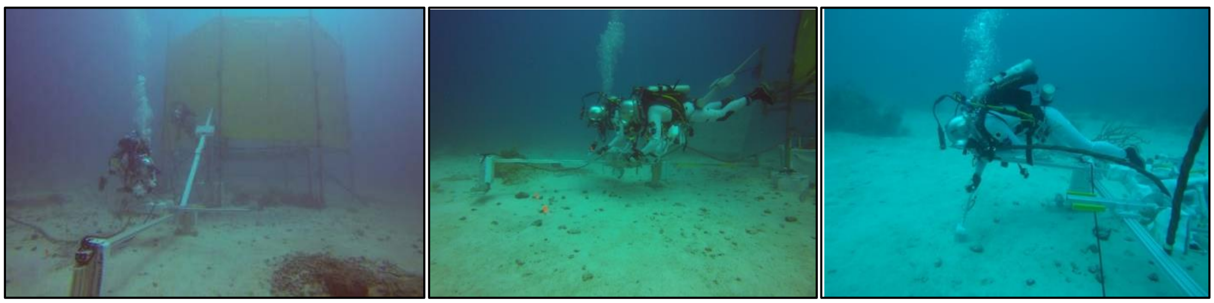


FIGURE 6.3.3-1: EVALUATING SCIENCE EVA TASKS FOR PHOBOS DURING NEEMO 20

As with NEA EVA concepts, one of the architecture studies is looking at working off a small free-flying spacecraft with a single EVA crewmember on the end of a robotic arm on the front of it. There are multiple issues with this sort of con ops, and currently the EVA Office does not include them in the official concept of operations. Until the thruster contamination issues (pluming Phobos), the safety issues of a solo EVA crewmember, and safety issues with having an EVA crewmember on the front of a free-flying spacecraft near the surface are resolved, the EVA System will focus on working from a non-moving platform. Also, while there have been discussions of utilizing some sort of jetpack to extend translation on Phobos, there are numerous safety issues (stuck thruster sending crew to orbit, failed thruster slamming crew into ground, etc.), and the EVA con ops does not include this option.

6.3.4 Post EVA (Moons of Mars)

The content for this section is TBD. [TBD-7.3.4-010].

7.0 CONCEPT OF OPERATIONS FOR EVA ON THE MOON

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 at the South Pole, and then at multiple different landing sites spread across the surface of the Moon. EVA operations will involve a variety of engineering-focused and science-focused tasks.

FIGURE 7.0-1: LUNAR EVA DURING APOLLO 16

Exploration of the lunar surface will involve a variety of architectural scenarios. Assets will range from Gateway (with its orbit as a mission length driver), human landers, unpressurized rovers, pressurized rovers, habitats, and Exploration spacesuits. Missions may range from a few days, to 42 days, to six months or more. They will involve landing two to four crewmembers to the surface. Lunar surface missions will build on the heritage of Apollo and demonstrate planetary partial-gravity surface exploration, near-term capability development, and operations to support the goal of human exploration of the inner solar system, including Mars.

The lunar surface con ops will be driven by fulfillment of key lunar science and Mars preparation objectives. Mission activities of human lunar return will include addressing the high priority objectives of the science community which benefit from human surface presence. They will also characterize human health and performance, long distance mobility concepts (such as rovers), dust mitigation practices, crew autonomy, concepts for human-robotic partnership, utilizing precision landing technologies, and in-situ resource utilization.

The Artemis missions will take place in two general phases, with the following approximate years for the crewed missions:

- Artemis Phase 1
  - Artemis III (~2024)
  - Artemis IV (~2025/2026)
- Artemis Phase 2
  - Artemis V (~2027)
  - Artemis VI (~2028)
  - Artemis VII (~2029)

7.1 SCIENCE OBJECTIVES & REGIONS OF INTEREST

One of the primary purposes for landing on the surface of the Moon will be for science. The science community identified a set of primary objectives for lunar missions, and regions of interest to achieve those objectives. On Thursday, May 28th, 2020, NASA HQ released the high level science objectives (explained in more depth in section 8.1.1) as including the Study of Planetary Processes, Understanding Volatile Cycles, Impact History of Earth-Moon System, Record of the Ancient Sun, Fundamental Lunar Science, and a Platform to Study the Universe.

7.1.1 Science Objectives for the Lunar Surface

In June 2020 NASA outlined the Artemis Science Plan that includes using the Lunar surface as a place to study planetary processes, to understand volatile cycles, study the impact history of the Earth-Moon system, study the record of the ancient Sun, and serve as a platform to study the Universe. In addition, the 2007 National Research Council's (NRC) Scientific Context for the Exploration of the Moon (SCEM) laid out a series of science concepts to study during missions to the moon. The 2017 Lunar Exploration Analysis Group (LEAG) Advancing Science of the Moon (ASM) Specific Action Team (SAT) Report assessed progress made in achieving the science goals laid out in the 2007 NRC Report, and added additional concepts/objectives.

The NRC-SCEM study identified eight areas of scientific research that should be addressed by future lunar exploration. Within each concept was a list of 35 prioritized science goals. The eight science concepts were defined and ranked as follows:

- S.1: The bombardment history of the inner Solar System is uniquely revealed on the Moon.
- S.2: The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body.
- S.3: Key planetary processes are manifested in the diversity of lunar crustal rocks.
- S.4: The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.

- S.5: Lunar volcanism provides a window into the thermal and compositional evolution of the Moon.
- S.6: The Moon is an accessible laboratory for studying the impact process on planetary scales.
- S.7: The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
- S.8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.

The ASM-SAT added three new concepts as follows:

- A.1: The Lunar Water Cycle: while the SCEM report included polar volatiles, work over the last decade has pointed to a water cycle with three principle components: primordial (interior) water, surficial water (linked to solar wind), and polar (sequestered) water.
- A.2: The Origin of the Moon: clues to lunar origin and geologic processes that operated during planetary accretion are recorded in the lunar rock record. Focused sample studies and sample return could be used to unlock these mysteries and test long-standing origin hypotheses.
- A.3: Lunar Tectonism and Seismicity: over the last decade, high-resolution imagery has led to a dramatic increase in the number of tectonic landforms present on the lunar surface, including wrinkle ridges, rilles, and lobate scarps. The interior structure, thermal history, and mechanism(s) of heat loss of a planet are all related to the resulting distribution of surface tectonism.

In addition to the Artemis Science Plan, the NRC-SCEM and ASM-SAT reports, the NRC Vision and Voyages for Planetary Science, or the Planetary Decadal Survey, identifies key planetary science questions and provides a list of prioritized robotic missions to be undertaken in the decade 2013-2022. For the Moon specifically, the Decadal Survey specifies two high priority missions: 1) South Pole-Aitken Basin sample return, and 2) establishing a long-lived global Lunar Geophysical Network.

The NASA HQ-released Artemis Science Strategy document highlights four advantages of Artemis astronauts accomplishing science objectives including an increase in mobility, the ability to widely sample the geologic diversity of the Moon, the ability to deploy delicate instrumentation, and access to regions with cold temperatures.

Per the 2020 Lunar Surface Science Workshop, the Artemis program has several high-level objectives for lunar surface missions, and corresponding science requirements. The high-level objectives include the following:

- Study of Planetary Processes
- Understanding Volatile Cycles
- Interpreting the Impact History of the Earth-Moon System

- Revealing the Record of the Ancient Sun
- Observing the Universe from a Unique Location
- Conducting Experimental Science in the Lunar Environment
- Investigating and Mitigating Exploration Risks to Humans

The corresponding science requirements include the following:

- Mobility to visit geologically different features
- EVA traverses & suits designed for sample collection
- Access to persistently shadowed terrain
- Sealed collection canisters designed for cold sample curation
- Collection of several walnut-sized rocks for chronological analyses
- Identification of and collections of rocks from outcrops and boulders
- Collection of core tube samples to capture ancient solar wind trapped in regolith layers
- Understanding regolith stratigraphy
- Dexterity to deploy delicate instrumentation
- Characterization of the local environment (dust, RF, plasma)

7.1.2 General Regions of Interest

To accomplish the scientific goals and objectives outlined in the NRC-SCEM, ASM-SAT, and NRC-Decadal reports, site selection for lunar surface operations is critical. Prioritized scientific goals and objectives will have to be carefully weighed against engineering constraints of exploration regions. A number of reference documents and community workshops have explored and selected lunar regions of high scientific interest:

- The January 2018 Global Exploration Roadmap (GER) and the May 2017 draft of the ISECG Human Lunar Exploration Surface Campaign Concept of Operations discussed potential lunar landing sites and areas to explore.
- A study entitled A Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon takes the first 7 NRC-SCEM concepts and looks at the best lunar regions to accomplish the specified science goals.
- The Lunar Science for Landed Missions Workshop convened at the NASA Ames Research Center in January 2018 with the goal to produce a set of high-priority landing site targets for near-term lunar missions generated by the lunar science community. The workshop defined a set of targets that near-term landed missions could visit for scientific exploration and commercial exploration companies with interest in pursuing ventures on the surface of the Moon.

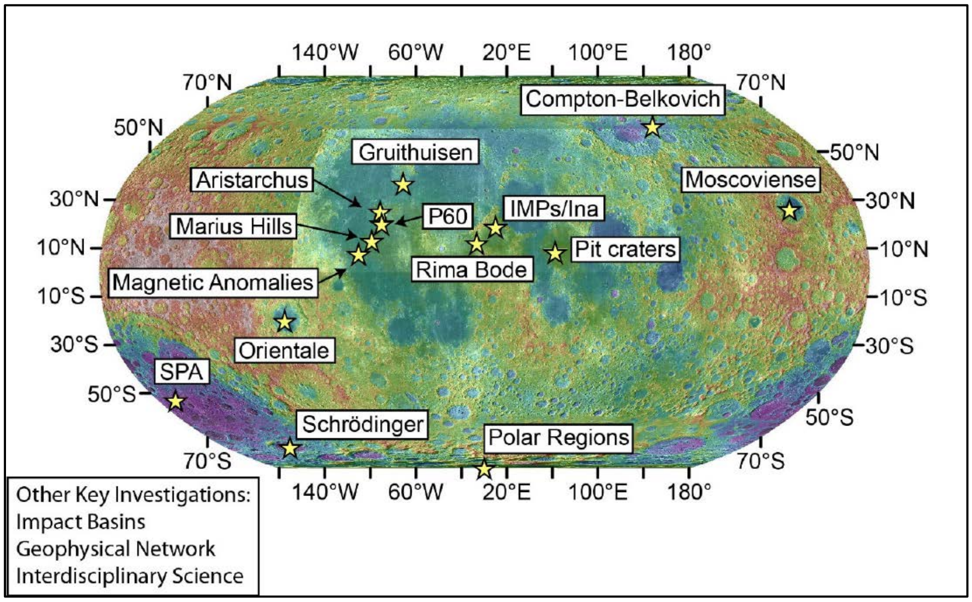


FIGURE 7.1.2-1: POTENTIAL LUNAR SCIENCE LANDING SITES

This includes the following potential exploration regions and landing sites:

- Volcanic deposits
- Compton-Belkovich Volcanic Deposit
- Marius Hills
- Lunar polar regions (north and south)
- Plateau near Shackleton Crater at 88.8°S and 125.5°E
- Schrodinger Basin at 75.40°S and 138.77°E
- South Pole - Aitken Basin Interior at 60.0°S and 159.9°W
- Impact craters and basins
- Lava tubes or pits

7.1.3 Lunar South Pole Region

The Artemis Program has directed efforts towards the south pole of the Moon. Near that area are three general types of regions of interest for scientific exploration. Those include craters, permanently shadowed regions, and volcanic terrain.

Efforts to plan for the Artemis III mission have identified several notional landing sites. One of these sites is on Connecting Ridge, between Shackleton Crater and de Gerlach Crater. This ridge is ~540 meters wide with slopes that are generally less than 20°.

7.2 CON OPS FOR EVA ON LUNAR SURFACE (ARTEMIS PHASE 1)

Artemis Phase 1 is the initial crewed missions returning to the moon. This initial mission will focus on demonstrated human operations on the lunar surface, in addition to providing science sample return and deployment of long-lived experiment packages.

Aspects of the first two mission, Artemis III and Artemis IV, include the following aspects and parameters:

- Artemis III initial crewed mission in ~2024
- Artemis IV mission in ~2025/2026
- Mission takes place in lunar daylight (i.e., constant light)
- Four crew fly to cislunar orbit, with two crewmembers staying in Orion for Artemis III and in Gateway for Artemis IV, and two crewmembers landing on the surface
- Surface stay duration: 6.5 days
- Crew on surface live in and conduct EVAs out of lander
- Total number of surface EVAs: 2 – 5
- Crew on EVA: 2
- EVA duration (PET): 4-8 hour excursions (6±2 hours)
- Egress method: Lander cabin depress, severable airlock, or airlock(s)
- Excursions distances: up to a 2 km radius away from the lander walking
  - Based on walking at 2 km/hr over fairly level and clear terrain
  - Slopes and other natural features will affect any range

Reference Section 3.2.1 for high-level architecture information for Artemis Phase 1.

Lunar surface missions generally have the following phases with respect to the xEVA system.

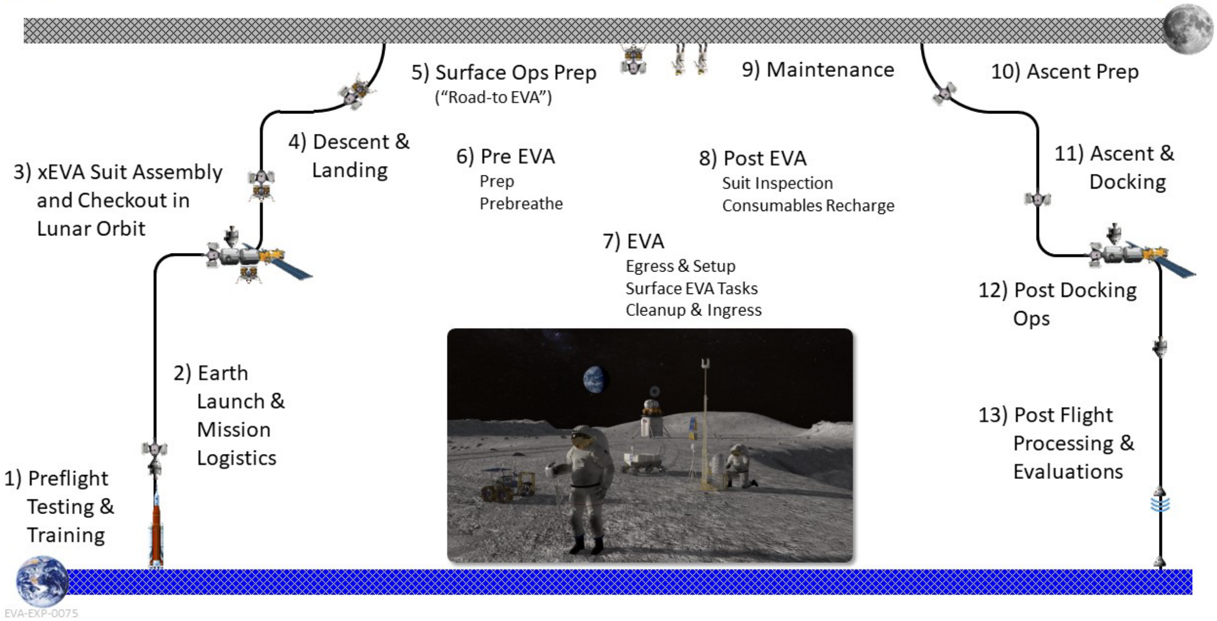


FIGURE 7.2-1: PHASE OF XEVA OPERATIONS FOR LUNAR SURFACE MISSIONS

FIGURE 7.2-2: LUNAR SCIENCE EVA OPERATIONS DURING APOLLO 17

7.2.1 Preflight and Earth Launch

7.2.1.1 Preflight Testing, Processing, and Training

A multitude of events occur surrounding the xEVA System before it or the crew are launched on a lunar surface mission. The actions before flight include, but are not limited to, the following:

- Technique and task development
- Timeline and procedure development

- Suit sizing
- Flight-specific training
- Assigned astronaut training
- Flight control team training
- Procedure verification testing
- Pre-acceptance testing
- Bench reviews and functional checks
- Readiness reviews

7.2.1.2 Earth Launch & Mission Logistics

Mass allocation and stowage for all spaceflight missions are a challenge. As such, the xEVA System will be launched in a distributed manner, with the majority of the hardware planned to be launched on the unmanned HLS or in a Gateway logistics module, depending on the mission. The xEMU will be launched in a soft stowed configuration. This includes, but is not limited to, the xEVA suits, the VISE, tools, and spares. The crew may bring some astronaut specific items (i.e., gloves) and any required suit modification kits with them in Orion.

If Artemis IV goes to Gateway (TBD-7.2.1.2-005), logistics may be prepositioned there. The xEVA Suit may launch on a cargo mission (no crew) in a quiescent stowage configuration. In the quiescent stowage configuration, the xEVA Suit will not require any periodic maintenance, and will remain in this configuration until a contingency or planned EVA event is imminent.

7.2.2 On-Orbit Operations (Crew Arrival)

Once crew arrives at Gateway or docks with HLS, the crew will prepare for descent to the lunar surface, including stowing their EVA suits in the ascent vehicle of the Human Lunar Lander.

7.2.2.1 Suit Assembly & Checkout

In the current single suit architecture, suit configuration and checkout is broken into two distinct phases. The first is the initial assembly and checkout into the full EVA mode configuration. That involves the following general steps:

- Unpack xEVA equipment from launch stowage containers and assembly in HLS
- Checkout xEMU and VISE (e.g., O_2, battery, cooling, comm, umbilical power, etc.) in HLS
- Gross on-orbit fitcheck verification and sizing adjustments of the xEMUs

7.2.2.2 Stand-up EVA

Once the suits are successfully checked-out, a "stand-up EVA" may potentially be performed (TBD-7.2.2.2-006). This short EVA would allow for an operational verification that the HLS system and particular serial number suits are fully functional before landing on the lunar surface. This EVA would test the processes for prebreathe, cabin depress, hatch opening, suit ops in vacuum, and repress. As the EVA could be conducted from the HLS, it is transparent to which vehicle the HLS is docked (Gateway or Orion).

7.2.2.3 Suit Configuration for Descent

The second phase has the crew reconfigure the suits for vehicle loop mode in preparation for lunar descent and landing. That involves the following general steps:

- Configure the xEVA suit into vehicle-loop mode for descent to lunar surface
- Checkout the xEMU xPGS in vehicle-loop mode
- Complete any stowage tasks or other xEVA hardware activities required prior to undock and descent

7.2.3 Descent to Lunar Surface

The suited dynamic flight events include the phases of the mission with the crew traveling in the lander from orbit down to the lunar surface. The xEVA suit may be utilized in VLM.

Prior to departure from Gateway/Orion and descent to the lunar surface, the crew begin their saturation to a lower pressure environment with higher O_2 concentrations. This saturation will reduce (or possibly eliminate) any prebreathe required on the lunar surface.

Considerations for suited dynamic flight phases include the following:

- Some descent profiles last ≥ 24 hours
- Astronauts must be able to sleep during the descent and ascent portions
- xEMU certified for 12 continuous hrs in VLM (dependent on host vehicle)
- Gloves and helmet should be removed when not needed
- Crew will be saturating to vehicle atmosphere during descent

Notional (TBD-7.2.3-007) suited times during lunar descent include the following:

- Fully suited and pressurized for undocking
- Remove suits for/during Descent Orbit Insertion (DOI) burn
- Unsuited for Powered Descent Initiation (PDI) burn
- Get suited again (no helmets or gloves) during Braking phase
- Partially suited (no helmets or gloves) for Approach Phase
- Fully suited and pressurized for Terminal Descent
- Fully suited and pressurized for Touchdown Phase

For Artemis III and IV, the crew will land in the area targeted for science characterization.

7.2.4 Lunar Surface EVA Operations

EVA operations on the lunar surface include road-to EVA, prep and prebreathe, surface ops, post EVA, and maintenance.

7.2.5 Road-to EVA (Lunar)

Upon touchdown on the lunar surface, crew doff their suits and prepare the HLS cabin and xEVA hardware for surface operations, including converting the xEMU from VLM to to EVA configuration. 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 VISE, the lander/airlock, and the tools and equipment, in addition to the crew preparing themselves.

7.2.5.1 xEVA System Prep

Preparation of the xEVA suit and VISE includes those tasks necessary to convert the suit from VLM (descent/ascent configuration) to the EVA mode configuration:

- Configure xEMU with xPLSS (convert from VLM to EVA mode)
- Install the suits on the don/doff assembly
- Configure the umbilicals and connect the suits to the VISE via the umbilicals
- Perform pre-EVA inspection and checkout
- Conduct fit verification in lunar gravity
- Recharge consumables (O_2, H_2O, battery power)
- Fill and install drink bags
- Prepare biomedical monitoring equipment (as applicable)

7.2.5.2 Lander/Airlock Prep

Once the suits are checked out, the crew prepares the lander and/or airlock for EVA operations. This includes:

- Securing equipment used for descent
- Configuring communication systems
- Activating O_2 monitoring systems

7.2.5.3 EVA Tools and Tasks Prep

Preparing the tools, ancillary equipment, and the crew includes:

- Complete EVA tool configuration
    - Configure tool and sample bags
    - Attach tools to suit

    - Assemble and configure payloads and experiment packages
- Upload data into the informatics system (as applicable)
- Check all ancillary equipment, especially powered devices such as lights
- Conduct pre-EVA conference with MCC and Science Team
- Review and study timeline, procedures, and safety protocols
- Stage ancillary hardware and external hardware to deploy

Once the suits are initially prepped and the crew begins surface exploration, the equipment remains at a relative state of being prepared for EVA. This reduces the amount of road-to activities that need to be conducted, but there will still be several things that must be done before each EVA. This will include finalizing the tasks and timeline, reviewing the approved timeline, briefings from MCC and the Science Team, an xEVA Suit checkout, tool configuration, uploading of data into the xEVA informatics system (as applicable), and housekeeping duties to prepare the lander cabin for unmanned operations.

7.2.6 Prep & Prebreathe for EVA (Lunar)

On the day of the EVA, the crewmembers begin final prep activities and the prebreathe protocol (as applicable).

EVA prep includes the following:

- Suit initialization and power up on vehicle power to verify system functionality
- Donning of suits
- Checkout of primary and backup systems
    - In-suit communication checks
    - Suit leak checks
    - Verification of caution & warning system
- Final suit fitcheck

EVA prebreathe actions include the following:

- Purge to remove N2 from the suits
- Prebreathe
    - Prebreathe requirements will depend on the saturation atmosphere
    - Surface EVA protocols are in development, and may be different from microgravity due to higher metabolic rates, ground reaction forces, and musculoskeletal forces
    - Protocols may make use of vehicle saturation atmosphere, prebreathe time and/or exercise, and the ability of the suit to operate for periods at higher delta pressures

During the surface crew prep operations, the crew in Orion (Artemis III) or Gateway (Artemis IV) will prepare for monitoring and guiding the EVA operations as the IV when needed, along with conducting tasks unrelated to the EVA.

7.2.7 Egress and Setup

Once any required prebreathe is complete and the crew are ready to leave the lander, they initiate cabin/airlock depress. This will involve a hold, likely around 5 psia, to verify the suits are holding pressure with a final leak check. Once that leak check is passed, the crew proceed with taking the volume down to vacuum.

Once the cabin/airlock is at vacuum, the crew switch over to their suit systems and disconnect the vehicle umbilicals. The “EVA” phase elapsed time (PET) begins when the spacesuit is switched from the vehicle provided power source to internal suit power (batteries).

The EV crew open the hatch, and gather any equipment they may bring with them from inside the cabin to the surface. This may include some geology tools, such as the contingency sampler. Crew will conduct a final check of tools and equipment on harnesses attached to their suit and/or in equipment/tool bags. They then egress the hatch and descend down to the surface, which may involve a ladder, sled, or elevator, utilizing a fall protection system as required.

Once on the surface, the crew set up the tools and equipment they’ll need for their tasks. They will destow any tools and equipment transported on the exterior of the vehicle. This will include sample collection tools and instruments, along with equipment to transport tools and samples. The EV crew will transport smaller tools and equipment to the worksite either directly attached to their suits or with a harness/carrying system. Larger tools and storage boxes will be transported with an equipment transportation system (e.g., a wheeled cart).

In addition to task equipment, the crew will set up the dust mitigation kit. 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.

7.2.8 EVA Surface Operations

Once on the surface, the crew will conduct a multitude of engineering and science tasks, with a primary focus on successful science return.

7.2.8.1 EVA Traversing – Navigation and Lighting

During Artemis III, the crew will stay within a walking range of approximately a 2 km radius of the lander. Within this 2 km radius, they will walk across regolith and around boulders, up/down slopes of up to 20°, and in long shadows, and into PSRs. Over the course of an 8-hour EVA, it is possible that crew may walk a total distance of 16 km on level terrain at 2 km/hr, but for more challenging terrain, crew may walk or scramble much less at significantly slower speeds, though exact total distances are still being determined.

They will utilize local and accessory navigation systems and/or methods for locating the target science zones, allowing MCC to track their location and progress, and always maintaining a safe return to the lander both nominally and in a contingency.

The crew will experience constant long shadows near the lunar South Pole, while also looking nearly directly at the sun. In order to safely and effectively traverse through the dark shadows and across rough terrain and slopes, in addition to incursions into PSRs, they will utilize hands-free lighting (such as lights strapped to their arms or mounted at the waist). While in shadows and/or PSRs, the crew will utilize tools to perform the science tasks, and will utilize hands-free lighting for visibility. Traverses and tasks will need to take into account the full lighting spectrum, from direct sun to dark shadows.

7.2.8.2 Engineering EVA Tasks

At the landing site, crew will conduct pioneering construction tasks for surface architecture and maintenance of the surface assets. This will include, but is not limited to, tasks such as:

- Deploy and construct antennas
- Align antennas
- Grade regolith
- Route and connect power and communication lines
- Remove dust
- Clean equipment
- Repair equipment

7.2.8.3 Science EVA Tasks

The first task on the first EVA will be collection of a contingency 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. Once in the general region of interest, EV crew will utilize geoscience training to explore and characterize an area. Guidance and navigation systems/methods will aid crew in autonomously getting to destinations and back without IV or MCC support, and guide them to targets specifically designated by the Science Team. Reference Section 4.1.5.2 for additional information on surface navigation and tracking.

Some tasks will require the EV crew to scramble up and down steep slopes, traverse down into craters and back up out of them, and work near or inside PSRs. Later missions in Phase 2 may have the crew also get into and out of lava tubes and pits..

Science operations will include the EV crew navigating to Regions of Interest (ROIs) with tools and instruments. They will utilize navigation systems and/or methods that allow for them to know they are at the right region, allow MCC to track their progress, allow them to safety return to the lander, and allow for the necessary accuracy for the science team to have the appropriate data on where samples were collected.

Along the way and once there, they will conduct initial inspections of the surroundings, perform context documentation, and potentially place markers to identify target samples. At the work zone, the EV crew will perform a variety of tasks. They will move and assemble hardware, make measurements of fields or the environments, set up science experiments, and deploy scientific instruments. They will primarily perform geology tasks, characterizing the area and acquiring sample materials. These generic tasks include, but are not limited to, the following:

- Observations and Documentation (Imagery)
  - Regional macro-scale context
  - Local micro-scale context
- Sample acquisition
  - Rock float samples
  - Rock chip samples
  - Rock core samples
  - Regolith bulk samples
  - Regolith core samples
  - Regolith surface samples
  - Volatile samples
- Data collection
  - Geotechnical and subsurface instrument measurements
  - Handheld instrument measurements
- Science payload deployment

Sampling may be achieved in several ways. Collecting regolith may include sampling via a scoop, rake, core tube, surface contact tool, and/or trench. Rock samples include float, chips, and samples from a core drill. Volatiles may be part of a regolith sample or contained in a drill tube. In each case, detailed imagery of the sample site before and after sample collections is required.

Generic regolith sampling process:

- Surface contact – EV begins with the surface contact tool, stamping the ground from a standing position before disturbing the area with other sample types. EV closes the door on the end effector, detaches it, and then stows it in the sample container bag.
- Scoop – EV attaches the scoop end effector to the tool handle, crouches down to collect a sample of regolith, and then stows it in a sealable bag to keep it pristine. EV weighs the sample, holds the bag up to the helmet camera for recording by the Science Team, and then stows that bag in the temporary collection bag.

- Rake – EV switches the end effector on the tool handle for the rake and proceeds to scrape the ground to collect small rocks, which get put into a sealable container and stowed in the larger sample bag after being weighed.
- Trenching – EV then uses the trenching tool to expose a lower level of regolith, scraping from a standing position and kneeling when necessary. EV records context descriptions of the trench, takes imagery, and holds stationary to allow the Science Team in MCC to get a good view of the trench. The Science Team directs EV towards a sample, which EV then acquires with the appropriate tool.
- Drive tube – EV completes the sampling suite at the worksite with a drive tube sample. EV retrieves the drive tube, manually drives it into the ground from a standing position, kneels and pulls the tube out, caps the end, weighs the tube with the sample inside, holds the tube up in the field of view of the helmet camera, and then stows the tube in the vacuum-sealed container.

Generic rock sampling process:

- Float – EV picks out a couple of float (loose rock) samples that appear as if they would satisfy the science requirements. EV holds the helmet camera steady for the Science Team to review the selection. From a standing position, EV uses the float end effector attached to the end of the tool handle to collect the float sample. EV holds the sample up to the helmet camera, detaches the end effector, weighs the end effector with sample inside, and then seals it inside the sample collection bag.
- Chip – EV retrieves the hammer and chisel. The Science Team directs EV towards an outcrop. EV proceeds to the desired rock, kneels down, and uses the hammer to break a chip off the rock. EV collects the rock chip with a tool (as rocks may be sharp and so as not to contaminate the sample), puts it in a sealable bag, weighs the bag, holds it up to the helmet cam while reading off the bag number, and then stows that bag in the sample collection bag.
- Core drill – EV retrieves the hammer drill and a core bit. EV2 assembles the two together, then walks to the outcrop. Using a combination of helmet camera video, pointing, and cues from the Science Team, EV determines the best location for a core sample. EV kneels down, presses the bit against the rock, leans into it to provide reaction force, and then proceeds using both hands to hammer drill the core bit into the rock. After reaching the desired depth, EV extracts the tool. EV deploys a core sample container tube, activates the break off feature of the bit, and slides the core sample into the tube. EV carries the sample and drill bag to the tool carrier, kneels down, disassembles the core bit from the hammer drill, and then stows them both.

7.2.8.4 MCC/IV Tasks

During EVA ops, both MCC and the IV in Orion (Artemis III) or Gateway (Artemis IV) will monitor and direct the EV crew. When the EV crew are conducting science-driven tasks, the Science Team in MCC will provide communications with the crew via the CAPCOM or SCICOM (Science Communicator).

Reference Section 4.1.3 for additional information on tasks performed by the suited crewmembers.

7.2.9 Cleanup and Ingress

Upon completion of tasks at a work zone, reaching a consumables bingo (limit), or running out of time, the crew will clean up (gather and stow) their tools and equipment. They'll pack equipment and science samples into the equipment transportation system and begin traversing back to the lander.

Back at the lander, the EV crew will stow equipment and samples. In general, tools and equipment launched in exterior tool boxes will be stowed back in those boxes between EVAs. This protects the equipment, and leaves the lander configured safely in case of an unexpected abort from the surface.

Samples and sample bags will be unstowed from the transportation system and positioned near the lander for bring them inside.

The crew will 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 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 the ground portion of the dust mitigation process is complete, the crew will begin ascending into the lander, utilizing any fall protection that is required. For lander designs with a ladder or sled, the crew will work together to get the sample bags up into the hatch. For larger landers with an elevator, the crew will carry the sample bags onto the elevator and ride up with them.

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. After the 2nd crewmember is inside, 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 the lander/airlock hatch is closed and repress has initiated.

7.2.10 Post EVA Operations

Following ingress, the crew will conduct post-EVA activities. The don/doff aids will provide structure for crew to pull themselves up out of the rear entry hatch unassisted. Post EVA operations commence with reconnection to umbilical and includes the following:

- Utilize HLS ECLSS to remove any particulates in the atmosphere
- Doff/egress the suits
- Doff ancillary equipment (such as a Liquid Cooling & Ventilation Garment)
- Clean the suits
- Perform detailed inspection of the suits
- Bag the suits as required to minimize dust migration
- Recharge consumables (O_2, H_2O, battery power)
- Download required xEVA suit data

7.2.11 Maintenance

A thorough inspection, with video and photo documentation, of the suit is performed between each EVA, with particular attention paid to the gloves, boots, and any suit surface that came in contact with the lunar surface. The crewmembers visually inspect the bearings and interfaces. While areas covered in dust are wiped and cleaned, it is not expected that all dust that has adhered to the suit is removed. However, it is expected that a sufficient amount of dust is removed from the suit to allow inspection of damage.

In addition to post-EVA inspections, the EVA suits may require periodic maintenance, though no preventative maintenance is foreseen for Artemis III or IV. This may include replacement of gloves and boots.

7.2.12 Ascent from Lunar Surface

7.2.12.1 Departure Prep & Quiescent Stowage

Prior to crew departure from the destination, the crew will reconfigure xEMU into VLM for dynamic operations during lander ascent and docking. This may necessitate a suit checkout once the xPLSS has been removed. Depending on the specific mission plan, the crew may perform an umbilical EVA as required to discard xPLSS, waste, and other disposables not required for return.

7.2.12.2 Suited Dynamic Flight Events (lunar ascent)

During ascent from the surface, the crew will be suited for parts of the profile. This will be in the xEMU in VLM for missions utilizing the single suit architecture.

Considerations for suited dynamic flight phases include the following:

- Astronauts must be able to sleep during the ascent portions

- xEMU certified for 12 continuous hrs in VLM
- Gloves and helmet should be removed when not needed

Notional suited times during lunar ascent include the following:

- Fully suited and pressurized during powered ascent/liftoff
- Remove suits during and for phasing orbit for return to Gateway in NRHO
- Unsuited during cruise from phasing orbit to NRHO
- Partially suited (no helmets or gloves) during rendezvous with Gateway
- Fully suited and pressurized during docking phase to Gateway

7.2.13 On-Orbit Operations (Crew Return)

7.2.13.1 Post Docking Operations

Whether docked to Orion or Gateway, the crew will perform the following post-docking tasks:

- Disassemble xEVA suit for long term stowage in Gateway or leave in lander for disposal
- Transfer samples and returning xEVA hardware to Gateway and/or Orion, per science plan
- If the lander is to be disposed of, EVA will advocate for salvage of any possible xEVA System hardware Gateway can accommodate

7.2.13.2 Return and Post Flight Processing

The majority of the xEVA system equipment will not return to Earth with the crew. Any hardware returned will be examined for system and component function, health, and life. A thorough set of lessons learned, anomaly reports, and failure investigation reports will lead to action plans to improve the xEVA system design, processes, team communication, training, procedures, etc.

7.2.14 Design Reference EVA for Artemis III

This section outlines a notional design reference series of EVAs, and a notional design reference EVA for development of the xEVA system. It contains a variety of potential example tasks, and is an example of a snapshot of one particular mission scenario. The landing zone for this reference is presumed to be near the South Pole Aitken Basin, on an area between Shackleton crater and de Gerlach crater known as Connecting Ridge. This section outlines a notional series of EVAs for a mission at Connecting Ridge, which includes traverses to PSRs that are within 2km of the landing site.

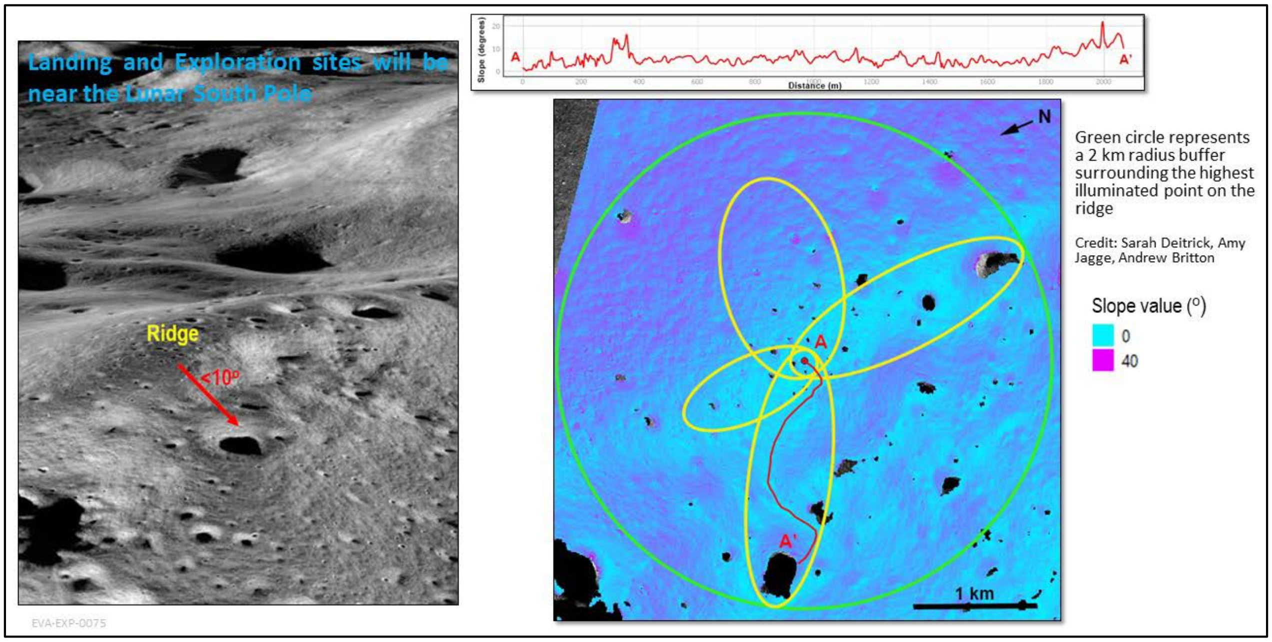


FIGURE 7.2.14-1: NOTIONAL LUNAR LANDING SITE AT CONNECTING RIDGE

7.2.14.1 Design Reference EVA Series for Artemis III

Per the current plan for Artemis III, this design reference mission outlines a series of five EVAs over the course of a 6.5 day mission on the surface.

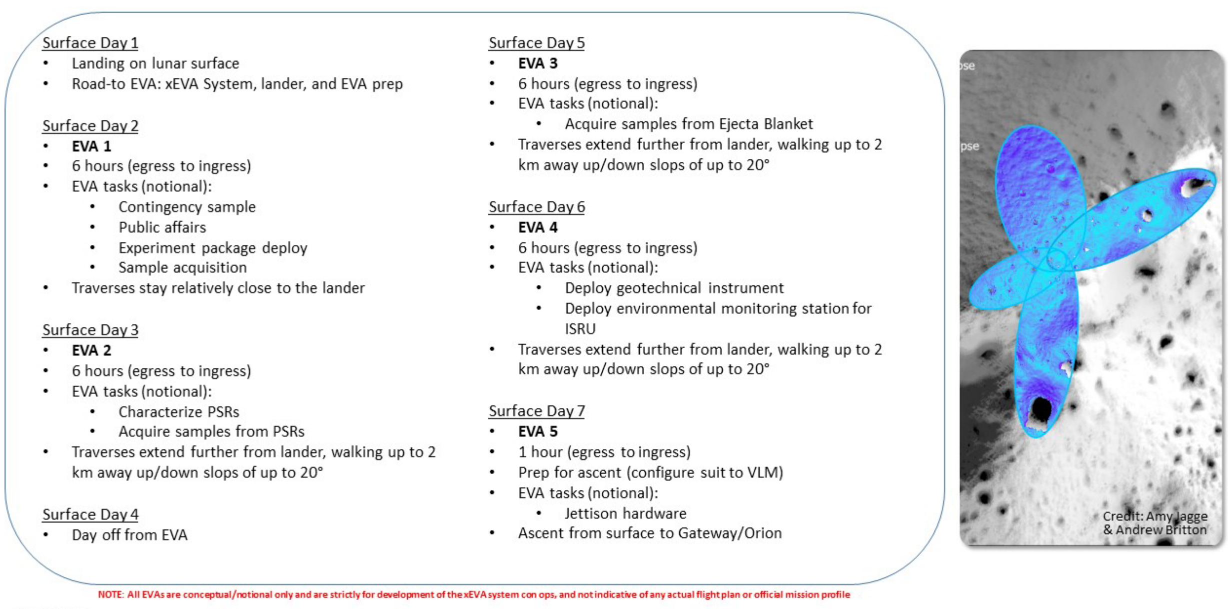


FIGURE 7.2.14.1-1: NOTIONAL DESIGN REFERENCE EVA SERIES FROM EVA-EXP-0075

After landing on the surface, the crew immediately get to work on the road-to EVA activities. By the end of the first day on the surface, all of the xEVA and lander systems are prepped for the first EVA the next day.

On the second day on the surface, the crew conducts their first EVA. This full length EVA focuses on gathering the contingency sample, giving them at least one sample in case the rest of the EVAs or even surface mission is aborted. They will conduct some public affairs activities, deploy science packages, and proceed with nominal traverse activities and sample acquisition for the remainder of the EVA. During this excursion, the crew will stay relatively close to the lander.

On the third surface day, the crew conducts EVA 2. As the volatiles are a high priority for science return, the crew traverses ~2km towards a PSR, walking down and up slopes of up to 20°, collecting traverse data and samples, including samples that could contain volatiles.

On the fourth surface day, the crew take a day off from EVA activities. They focus on lander housekeeping and IVA experiments.

On the fifth surface day, the crew conduct EVA 3. They execute the science plan, acquiring samples of the local ejecta blanket. This traverse is also up to 2 km from the lander, walking up and down slopes of up to 20°.

On the sixth surface day, the crew heads out on EVA 4. This is their last full length surface EVA for this notional design reference series. They will focus on deploying geotechnical instruments, experiment packages, and an environmental monitoring station for ISRU.

The seventh surface day is the last day on the surface. The crew may perform a short one-hour EVA in VLM in order to jettison trash and hardware that won’t be returning to lunar orbit. They configure their suits for ascent, and take off from the surface on their way to meet Orion.

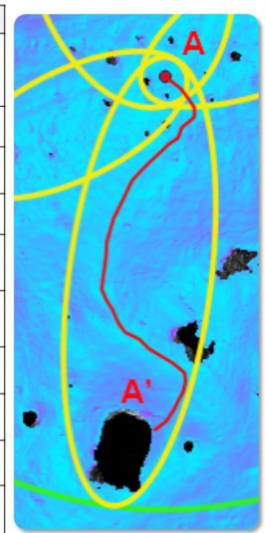
7.2.14.2 Design Reference EVA for Artemis III

The notional design reference EVA included is likely oversubscribed for any single EVA, however it will give the reader an idea of what will need to be performed on the lunar surface via EVA. This section does not timeline an actual EVA, but only provides a potential example of tasks performed by EVA on the lunar surface, with the goal to help the designers and users understand the various movements and interfaces for the xEVA suit. The design reference EVA begins with egress and ends with ingress, following the path of an EVA crew from the lander at point A to a PSR at point A’ and back. It walks through the EVA tasks at a high level in order to provide information without being prescriptive. This example will be updated in future revisions as the lunar surface mission architecture develops and evolves.

	EV1	EV2
Egress & Setup	• Switch from vehicle power to suit battery power • Open hatch and egress • Descend to surface • Configure equipment transport system and tools on suit	• Switch from vehicle power to suit battery power • Open hatch and egress • Transfer any tools brought inside HLS to the surface • Descend to surface
Traverse to EB	• Walk downslope towards PSR at located A' • Radial traverse distance is ~1 km, slopes range up to ~16°	• Walk downslope towards PSR at located A' • Radial traverse distance is ~1 km, slopes range up to ~16°
Sampling from EB Deploy Instrument	• Conduct context observations, with imagery and verbal descriptions • Acquire sample as directed by MCC Science Team	• Set up sampling tools from transport system • Deploy geophysics instrument
Traverse to Crater	• Walk downslope towards PSR at located A', begin descent into crater • Radial traverse distance is ~1.5 km, slopes range up to ~12°	• Walk downslope towards PSR at located A', begin descent into crater • Radial traverse distance is ~1.5 km, slopes range up to ~12°
Sampling in Crater Deploy Station	• Conduct context observations and plan route into PSR • Deploy environment monitoring station	• Conduct context observations, with imagery and verbal descriptions • Acquire sample as directed by MCC Science Team • Ready tools for sampling in PSR [e.g., core drill]
Traverse into PSR	• Walk down into PSR at located A' • Radial traverse distance is ~2 km, slopes range up to ~20° • Starts 2-hour thermal clock	• Walk down into PSR at located A' • Radial traverse distance is ~2 km, slopes range up to ~20° • Starts 2-hour thermal clock
Sampling from PSR	• Conduct context observations, with imagery and verbal descriptions • Acquire sample as directed by MCC Science Team [e.g., core]	• Conduct context observations, with imagery and verbal descriptions • Acquire sample as directed by MCC Science Team [e.g., core]
Traverse to HLS	• Walk back upslope towards the HLS at located A • Radial traverse distance is ~2 km, slopes range up to ~20°	• Walk back upslope towards the HLS at located A • Radial traverse distance is ~2 km, slopes range up to ~20°
Maintenance	• Deploy comm antenna • Align antenna	• Route and mate power cables to comm antenna
Cleanup & Ingress	• Stow tools and equipment • Transfer science samples up to lander hatch • Conduct dust mitigation • Ascend to lander hatch and ingress • Attach servicing umbilcals • Close hatch and repress	• Stow tools and equipment • Conduct dust mitigation • Ascend to lander hatch • Transfer science samples up to lander hatch • Ingress lander and attach servicing umbilcals

NOTE: All EVAs are conceptual/notional only and are strictly for development of the xEVA system con ops, and not indicative of any actual flight plan or official mission profile

EVA-EXP-0075



Note: Details on EVA Timelines can be found in the "Preparation for Lunar Training and Execution"

FIGURE 7.2.14.2-1: DESIGN REFERENCE EVA OUTLINE FROM EVA-EXP-0075

7.2.14.2.1 Egress & Setup

Once depress is complete, the two EVA crewmembers perform post depress actions. They will switch from vehicle to battery power, officially starting the PET clock. They release themselves from the don/doff assembly, walk to the EV hatch, and open it. The EV crew detaches their umbilicals and stows them in the airlock/cabin on dummy connectors that protect the interface from dust and debris. Before egressing, the crew conduct a final check of tools and equipment attached to their suit on harnesses and in bags they'll hand carry. For the first EVA, this includes the contingency sample tool, which will ensure that the mission returns some science in the event of an abort.

The crew step through the hatch (minimum of 40x60 inches) and attach to any fall protection system that's required. Once safely configured, EV1 descends the ladder to the surface. With boots firmly on the ground, EV1 detaches from the fall protection system. EV2 begins lowering tools and equipment bags down to EV1, who places them on the surface. Once all equipment has been transferred to the surface, EV2 descends to the surface and detaches from the fall protection system.

The crew set up the dust mitigation kit that they'll use before ingressing.

Before beginning their traverse, the crew collects the contingency sample, documents the collection and communicates with the ST. The crew then unstow the remaining required equipment from tool boxes on the outside of the lander. Most of the basic geology sampling tools will be stored in the external tool boxes. The EV crew transports some smaller tools and equipment to the worksite either directly attached to their suits or with a harness/carrying system. Larger tools and bags are taken to the worksites in an equipment transport system (e.g., carrier or wheeled cart).

7.2.14.2.2 Science on Ejecta Blanket

From the lander at point A, the crew begin walking towards the PSR at A' across an ejecta blanket. The PSR is slightly downhill, with an average slope of ~10° and peaks of up to ~16°, and approximately 2 km away from the lander.

Approximately a kilometer into their walking traverse, the crew pause on the ejecta blanket in their first region of interest. There they conduct contextual observations, with in-depth verbal descriptions that are transmitted to scientists in MCC and are recorded by the xEVA suit. The crew utilize their helmet cameras to give overview video imagery, and take pictures with handheld cameras.

Using the crew's verbal descriptions, video imagery, and training opinions, the Science Team in MCC directs the crew to acquire samples of the ejecta blanket. They deploy the required tool for their tool management system, whether attached to the suit or on a carrier, kneel down, and take the sample. They put each sample in individual sample bag, and put those bags in temporary collection bags.

The Science Team in MCC notes the location of the samples, utilizing the tracking and navigation system incorporated into the architecture (e.g., transponder).

At the end of sampling tasks on the ejecta blanket, the crew work together to stow the temporary collection bags in the larger sample collection bags. Those are attached to the carrier or possibly to the xEVA suit PLSS. They clean up their tools, and perform checks before proceeding to the next region of interest.

7.2.14.2.3 Science in Crater

At the rim of the crater, the EV crew begin initial regional context observations. This includes visual inspection of the crater and surrounding areas, complete with imagery and verbal descriptions. EV1 stands on the rim and locates the specific zone inside the crater from which sampling will take place.

After verifying they are good to proceed and receiving a GO from MCC, the crew continue their walking translation towards the PSR at A'. They continue downslope until they reach the rim of the crater with the PSR. Once there, they check with each other, and then proceed with descending the ~12° slope.

Before they reach the PSR, the crew stops to conduct local contextual observations of the crater, and perform some sample acquisition. At the primary sampling area, the crew set down their bags and retrieve photo equipment and context/sampling markers. They both conduct detailed visual inspection and examination of the surroundings, recording detailed observations, context descriptions, and taking imagery with handheld cameras to fully characterize the area. EV1 takes panoramic photos of the area, while EV2 retrieves the context/sampling markers. They both scout the local area, approach and access vertical exposures, look for good target samples, and deploy the markers near them. For each marker, they stop and provide a verbal description provide helmet cam video for the Science Team. During the area context process, the Science Team in MCC listens to the verbal descriptions and watches the helmet cam video. They note any marker that is near a sample that is worth taking.

With the verbal descriptions and context imagery completed, the EV crew retrieve the handheld instruments from the carrier. Back at the vertical exposures (e.g., cliff face), they both proceed with operating their respective handheld instruments. They take measurements as high above their heads as they can reach, near chest level, and kneel down to take readings at the contact interface between the wall and the crater floor. When all instrument readings are completed, the crew stows the handheld instruments back in the carrier.

Both EV crew proceed with acquiring the geological samples. They deploy sampling tools from their equipment bags, assembling the ones their going to use first. For the targets identified and documented (context description and imagery), they collect various sample types. The crew collect regolith samples – including sampling via a scoop, rake, core tube, surface contact tool, and trench – and rock samples – including float, chip, and core drill.

While there, they deploy an environmental monitoring station for long duration study of the crater region. They deploy the instrument and get confirmation from MCC that it's operating.

They also plan their excursion into the PSR in order to minimize their exposure to the shadowed region. Before proceeding, both crew check the timeline and their consumables and trends, and ensure that they have enough for continuing the planned mission.

7.2.14.2.4 Science in PSR

With their plan detailed out and reviewed, the crew progress into the shadowed area. At this point , they are nearly 2 km away from the lander. This starts their 2 hour thermal clock for being in a shadow, and requires the use of helmet lights and possibly ancillary lights in order to see their path. As they near their target spot, the slopes increase to nearly 20°.

At their stopping point in the PSR, they conduct contextual observations and take imagery as best as possible. If required per the plan, the crew operate their handheld instruments, accessing as much of any vertical exposure as possible. This involves reaching above their head, near chest level, and at the interface of the wall and surface.

Being as efficient as possible with time, the crew set out to acquire a core sample that contains volatiles. They drill the drive tube into the ground, extract it, cap the segment in order to keep the stratification, and stow it in a vacuum-sealed container. They also acquire float and regolith samples as directed by the MCC Science Team, stowing them in the appropriate bags.

With the container stowed, the crew make their way back upslope out of the PSR. Exiting the shadowed area ends the thermal clock. They then proceed ascending out of the craters, walking when able and scrambling when needed in order to get out.

7.2.14.2.5 Traverse back to HLS

The crew make their way back towards the lander, following their tracks as best as possible. This 2 km trek is upslope, with slopes hitting near 20° but typically closer to 10°. Along the way, they continue to make contextual observations and taking imagery. They also stop to take samples of opportunity, based on their own training or something the Science Team caught in a helmet camera view.

Back at the lander, the crew stow their sample collection bags, which hold all of the individual sample bags, into a temporary return bag. This bag will be brought inside the lander upon ingress.

7.2.14.2.6 Engineering Construction Task

With their science samples temporarily stowed, the crew conduct a construction task before ingress. They retrieve equipment for a communication antenna from a storage compartment on the lander. They also retrieve their construction tools from the external toolboxes.

The crew work together to carry all of the equipment and tools far enough away from the lander to be out of the ascent engine blast zone. There, they put together and deploy the antenna. They run cables to the power source, and give MCC the GO to activate the antenna.

7.2.14.2.7 Cleanup & Ingress

With their science tasks and engineering tasks complete, the crew begin cleaning up. They stow all of the tools and equipment that they had retrieved from the external toolboxes.

The crew initiate the dust mitigation procedures, using the kit they deployed after egress. The remove the bulk of the dust from their suits and the temporary return bags.

For ingress to the lander, the crew essentially reverse the actions they performed during egress. EV2 ingresses the hatch with the last return bag, and EV1 follows behind. While EV2 stows the bags out of the way, EV1 secures the hatch.

Both crew lock themselves in their respective EDDAs, and attach their umbilicals and switch over to vehicle consumables. The crew follows the AIRLOCK DEPRESS/REPRESS CUE CARD for repress. EV1 then actuates the pressure equalization valve, beginning repress. Part way through, he stops repress to verify the airlock is holding pressure. Once a good hatch seal is confirmed, the cabin/airlock is fully repressed.

7.3 CON OPS FOR EVA ON LUNAR SURFACE (ARTEMIS PHASE 2)

Artemis Phase 2 establishes longer and sustained mission to the lunar surface, include the following:

- Longer excursion ranges:
  - Up to ~10 km radius away from the lander in an LTV
    (note that the distance will depend on EVA walk-back limitations)
  - Up to ~12-15 km radius away from the lander in a single pressurized rover
    (note that the distance will depend on EVA walk-back limitations)
  - ~200+ km away from the habitat with dual pressurized rovers
- Both longer lunar daylight missions and mission extending through lunar night, with four (or more) crew landing on the surface
- Longer extended missions during lunar daylight (~14 Earth days)
- Sustainable long duration missions during lunar day & night (~42 Earth days to 6+ months)
- Exploration excursion distances from lander/habitat increased with use of unpressurized rovers and eventually pressurized rovers

Reference Section 3.2.2 for the architecture overview of Artemis Phase 2.

7.3.1 Sustained Mission – Short Stay

For Rover and EVA ops during a seven to fourteen-day short stay mission, the crew will have the capability to perform daily 8-hour EVAs in order to take advantage of the short period on the surface. Crewmembers will conduct the EVAs paired together to maximize boots on the ground time and for safety. However, there may be a rest day after three or four days of EVA, depending on the duration of the EVAs. The crew will utilize a conventional airlock or dual chamber rear-entry airlock (e.g., suitlock) for egress and for suit repair/maintenance.

During Artemis V, with an LTV available, the crew will stay within approximately a 10 km contingency walk back radius. The EVA crew may utilize navigation systems on the rover, however, will always need to be able to return to the lander safely on their own in case of a failure of the rover.

7.3.2 Sustained Missions – Extended Stay

For Rover and EVA ops during a 42-day extended stay (campaign) mission, operations will differ between lunar day and lunar night. During lunar day, the two rovers stay in close proximity, operating as a pair in case of an emergency. Rovers will notionally travel at max speed of 10 kph with crew inside and 1.5 kph when operated remotely without crew inside. The rovers will notionally never travel farther than 100 km from the ascent vehicle in case of an emergency abort from the surface situation. During lunar day, EVAs will be conducted three to four days per week and be two to eight hours in duration (hour for egress/ingress and 1.5 - 7.5 hours of tasks) with one to two per day. EVAs may extend an additional hour for emergency and off-nominal situations. Nominally two crew will be out on an excursion from the rover, however there is a potential for more or less to go out EVA.

For days involving two EVA excursions per day, the EVAs will be treated as if a single EVA is conducted in two parts, and therefore the suit consumables won't be required to be recharged between excursions (though some will be recharged simply by plugging in the umbilical, such as O2). The total amount of planned EVA PET time within a crew wake period will stay within the constraints of a single 8-hour EVA. The time between the two EVAs will be considered a 'break' in EVA more than a second EVA. In other words, the crew will be able to take an 8-hour EVA and conduct it in two parts, with the sum of the parts not exceeding what would have been done for a single EVA.

Enabling this EVA frequency may involve logistics to replace suit components or even entire suits. Some consumable items, such as gloves and boots, will need to be replaced more often than long life components (such as the xPLSS).

For Rover and EVA ops during an extended stay mission in lunar night, there will be limited traverse operations. Crew will primarily stay in rovers and minimize energy consumption, using the time during lunar night to analyze the samples they collected, perform IVA experiments, and complete maintenance and repairs on the rovers. The primary challenges for EVA at lunar night will be thermal, lighting, and navigation. EVAs operations during lunar night (eclipse) will be similar to EVA operations in shadowed regions, including Permanently Shadowed Regions (PSR). The xEVA System will be able to function in the PSRs and therefore should be able to operate during lunar night, with certain constraints (such as time). .

For all rover-based EVA operations on extended stay missions (42 days), the rover pairs will work together. Both crew in one rover will conduct the EVA together, while the other rover is nearby. The crew in the non-EVA rover will act as the local IV to help direct the EVA operations, and will conduct any rover duties and maintenance, along with performing experiments. Crew will don suits in the airlock instead of the cabin in order to mitigate lunar dust exposure into the habitable volume. Alternately, one crewmember from each rover may conduct the EVA together, still enabling two crewmembers to act as buddies, although this requires the rovers to be parked next to each other and requires two separate and simultaneous airlock operations. The surface teams will have the capability to conduct EVA with all four crewmembers simultaneously, if needed. Aside from egress/ingress of the ascent stage, all EVAs will be conducted out of a conjoined dual chamber airlock (or functional equivalent) in order to reduce exposure of the crew cabin to dust and provide space for suit maintenance.

Lunar surface EVAs will also require a support system for the IV crewmember helping direct the EVA.

7.3.3 Design Reference EVA for Artemis Phase 2

This subsection details an example "design reference EVA" narrative that contains a variety of potential example tasks and concepts for the sustained lunar mission phase. It is an example of a snapshot of one particular mission scenario. The landing zone for this reference is presumed to be near the South Pole Aitken Basin, close to an area known as Connecting Ridge. While this reference EVA is likely oversubscribed for any single EVA, it will give the reader an idea of what will need to be performed on the lunar surface via EVA. This reference EVA calls out some "simulated" specific example tasks, though not necessarily actual tasks since those haven't been developed or planned yet, however these are not the full list of things that will be done over the course of missions to the moon. This subsection does not timeline an actual flight EVA, but only provides a potential example of tasks performed by EVA on the lunar surface, with the goal to help the designers understand the various movements and interfaces for the xEVA suit. This example will be updated in future revisions as the lunar surface mission architecture develops and evolves. This design reference EVA also incorporates a pressurized rover, which includes a suitlock for egress. As this reference EVA is notional and the suitlock (and suitport) concept have not been fully matured, a more conventional airlock or cabin depress may end up being used.

7.3.3.1 Post Depress and Egress

Once prebreathe and depress are complete, the two EVA crewmembers perform post depress actions. They will switch from vehicle to battery power, officially starting the PET clock. They release themselves from the suitlock port (if included in pressurized rover design) and open the EV hatch. The EV crew detaches their umbilicals and stows them in the suitlock on dummy connectors that protect the interface from dust and debris. Before egressing, the crew will conduct a final check of tools and equipment attached to their suit on harnesses and in bags they'll hand carry.

The crew step through the 40x60 inch hatch and attach to the fall protection system to their suits. Once safely configured, EV1 descends the ladder to the surface. With boots firmly on the ground, EV1 detaches from the fall protection system. EV2 begins lowering tools and equipment bags down to EV1, who places them on the surface. Once all equipment has been transferred to the surface, EV2 descends the ladder and detaches from the fall protection system.

7.3.3.2 Setup

The EV crew transports smaller tools and equipment to the worksite either directly attached to their suits or with a harness/carrying system. Larger tools and storage boxes are transported in a wheeled cart (or functional equivalent) and a pressurized rover. Once both EV crew are on the surface, they unstow the modular equipment transport system (cart) for short traverses to nearby worksites, and configure the pressurized rover for the longer traverses.

EV1 displays the equipment checklist on his HUD and checks through each item as both crew load the cart with maintenance equipment and stow the science tools and payloads on the rover. They load the pressurized rover with science equipment, including sampling tools, handheld instruments, and instrument payloads.

To minimize their risk posture, the crew start the EVA tasks at the location furthest from the lander and work their way back towards their safe haven. As such, they mount up on the rover and sit in their seats for their first science task, planning on ending the EVA with the maintenance task that's within close proximity to the lander.

7.3.3.3 Science Task - Crater

With the pressurized rover loaded with the needed science equipment, the EV crew begin driving to a crater in their first Region of Interest (ROI) of the day. This crater is 12 km from the lander, which extends the Apollo 17 record of 7.6 km for distance traveled away from a lunar lander.

At the rim of the crater, the EV crew egress from the rover and begin initial context observations. This includes visual inspection of the crater and surrounding areas, complete with imagery and verbal descriptions. EV1 stands on the rim and locates the specific zone inside the crater from which sampling will take place. The Science Team views EV1's helmet cam video and makes a real-time confirmation of the target area. Using the suit display (e.g., augmented reality capability of the suit projected through the HUD) and the navigation data, the Science Team indicates the target area (e.g., draws an augmented cue circle around the target area) and suggests a path based on precursor information (e.g., Lunar Reconnaissance Orbiter (LRO) data).

While EV1 is conducting the visual inspection and receiving instructions from the Science Team in MCC, EV2 offloads the rover with the tools and instruments that will be needed on the floor of the crater. EV2 also deploys and sets up the belaying equipment that will be used to help them descend into the crater.

The EV crew both hook into the belaying system based on the rover, which will provide them assistance as they climb down into the crater by providing constant tension to help hold them upright on the incline. They both grab bags holding the science equipment, then begin their descent. Once on flatter ground, they detach from the belay system and continue walking towards their sampling area.

At the primary sampling area, the crew set down their bags and retrieve photo equipment and context/sampling markers. They both conduct detailed visual inspection and examination of the surroundings, recording detailed observations, context descriptions, and taking imagery with handheld cameras to fully characterize the area. EV1 takes panoramic photos of the area, while EV2 retrieves the context/sampling markers. They both scout the local area, approach and access vertical exposures, look for good target samples, and deploy the markers near them. For each marker, they stop and provide a verbal description provide helmet cam video for the Science Team.

During the area context process, the Science Team in MCC listens to the verbal descriptions and watches the helmet cam video. They note any marker that is near a sample that is worth taking. They screen capture images, annotate them, and then transmit them to the crew. The EV crew access those images on their HUD and use them to confirm what sample to take. If needed for clarification, the EV crew approaches the sampling site, and the Science Team uses the suit display to indicate a target location (e.g., draws augmented cues on the EV crew's HUDs) and guides them to a specific sample of interest.

With the verbal descriptions and context imagery completed, the EV crew retrieve the handheld instruments from the bags they carried down into the crater. EV1 kneels down at EV1's bag and pulls out the contact spectrometer, while EV2 kneels down next to EV2's bag and gets out an imaging spectrometer. Back at the vertical exposures (e.g., cliff face), they both proceed with operating their respective handheld instruments. They take measurements as high above their heads as they can reach, near chest level, and kneel down to take readings at the contact interface between the wall and the crater floor. When all instrument readings are completed, the crew stows the handheld instruments back in the bags.

Both EV crew proceed with acquiring the geological samples. They deploy sampling tools from their equipment bags, assembling the ones required for the first samples. For the targets identified and documented (context description and imagery), they collect various sample types.

EV1 focuses on collecting the regolith samples. These include sampling via a scoop, rake, core tube, surface contact tool, and trench. All samples are documented, and post-collection imagery is acquired at each sampling site.

- Surface contact: EV1 begins with the surface contact tool, stamping the ground from a standing position before disturbing the area with other sample types. EV1 closes the door on the end effector, detaches it, and then stows it in the sample container bag.
- Scoop: EV1 attaches the scoop end effector to the tool handle, crouches down to collect a sample of regolith, and then stows it in a sealable bag to keep it pristine. EV1 weighs the sample, holds the bag up to the helmet camera for recording by the Science Team, and then stows that bag in the sample container bag.
- Rake: EV1 switches the end effector on the tool handle for the rake and proceeds to scrape the ground to collect small rocks, which get put into a sealable container and stowed in the larger sample bag after being weighed.

- Trenching: EV1 then uses the trenching tool to expose a lower level of regolith, scraping from a standing position and kneeling when necessary. EV1 records context descriptions of the trench, takes imagery, and holds stationary to allow the Science Team in MCC to get a good view of the trench. The Science Team uses the suit display to point EV1 towards a sample (e.g., augmented cues displayed on the HUD), which EV1 then acquires with the appropriate tool.
- Core tube: EV1 completes the sampling suite at this worksite with a core tube sample. EV1 retrieves the core tube, manually drives it into the ground from a standing position, kneels and pulls the tube out, caps the end, weighs the tube with the sample inside, holds the tube up in the field of view of EV1's helmet camera, and then stows the tube in the sample container bag.

EVA 2 focuses on the rock samples. These include float, chip, and core drill. All samples are documented, and post-collection imagery is acquired at each sampling site.

- Float: EV2 picks out a couple of float (loose rock) samples that appear as if they would satisfy the science requirements. EV2 holds the helmet camera steady for the Science Team to review the selection. The Science Team picks the final rock and draws a virtual cue in EV2's field of view to circle the rock they want collected. From a standing position, EV2 uses the float end effector attached to the end of the tool handle to collect the float sample. EV2 holds the sample up to the helmet camera, detaches the end effector, weighs the end effector with sample inside, and then seals it inside the sample collection bag.
- Chip: EV2 then retrieves the hammer drill and chip end effector, assembling the two. The Science Team projects cues to EV2's informatics HUD, directing EV2 towards one of the outcrops that was measured with the spectrometer. EV2 proceeds to the desired rock, kneels down, presses the chisel end of the tool to the surface of the rock, and actuates the hammer drill. The rock chip breaks off and is contained within the end effector. EV2 takes the hammer drill back to the equipment bags, detaches the end effector, temp stows the hammer drill, weighs the end effector, holds it up to the helmet cam, and then stows the end effector and sample in the appropriate slot within the larger sample bag. For good measure, EV2 walks back to another outcrop, deploys the manual hammer from EV2's tool harness, breaks off another rock chip, collects it and puts it in a sealable bag, weighs the bag, holds it up to her helmet cam while reading off the bag number, and then stows that bag in the sample bag.
- Core drill: EV2 retrieves the hammer drill and a core bit. EV2 assembles the two together, then walks back to the outcrop where she took instrument measurements. Using a combination of helmet camera video, pointing, and augmented cues from the Science Team, EV2 determines the best location for a core sample. EV2 kneels down, presses the bit against the rock, leans into it to provide reaction force, and then proceeds using both hands to

hammer drill the core bit into the rock. After reaching the desired depth, EV2 extracts the tool. EV2 deploys a core sample container tube from her tool harness, activates the break off feature of the bit, and slides the core sample into the tube. EV2 carries the sample and drill bag to the equipment bags. EV2 kneels down at the bags, stows the sample in the appropriate slot, disassembles the core bit from the hammer drill, and then stows both of them in the equipment bag.

With the sampling complete, the EV crew collect their equipment and sample bags, and proceed to ascend the rocky slope out of the crater. They walk when able, and scramble when they need to in order to get out. Back at the rim, then stow their bags on the rover.

They then retrieve the surface instrument payload from the rover and work together to carry it down to the floor of the crater. There they deploy the instrument and get confirmation from MCC that it's operating.

With all of the science tasks at this location complete, they scramble out of the crater again, and lock into the rover. Before leaving the area, both crew check the timeline and their consumables and trends, and ensure that they have enough for continuing the planned mission.

7.3.3.4 Science Task - Lava Tube

The crew drive the rover to ROI at lava tube, which is closer to the lander. Navigation cues projected on their HUDs help them get to the right location.

At the edge of the lava tube, the EV crew dismount from the rover and begin initial context observations. As at the crater, this includes visual inspection of the lava tube and surrounding areas, complete with imagery and verbal descriptions. The Science Team views EV1's helmet cam video and makes a real-time confirmation of the target area. Using the suit-mounted display (e.g., augmented reality cues projected via a HUD), the Science Team indicates a suggested entrance point.

While EV1 is conducting the visual inspection and receiving instructions from the Science Team in MCC, EV2 offloads the rover with the tools, instruments, and lights that will be needed inside the tube. EV2 also deploys and sets up the belaying equipment that will be used to help them descend into the crater.

The EV crew both attach the rappelling equipment and descend the steep slope into lava tube. Once on relatively flat terrain, they proceed with their penetration of the tube. Before entering, they set up a small communication relay to ensure that they don't lose communication with their rover or MCC. They traverse as far as their comfortable, likely staying within visual sight of the entrance point.

The crew work together to deploy and set up freestanding illumination devices. These supplement the helmet lights and help illuminate the general area.

EV2 conducts observations and characterizes the area, recording context descriptions and imagery, while EV1 retrieves the handheld instruments from the equipment bags.

Both crew operate their handheld instruments, taking measurements throughout the tube. This involves accessing above their head, near chest level, and on the floor of the tube.

With instrument readings completed, both crew set about acquiring geology samples. For the lava tube, they focus on float, surface, and a shallow core. As they did in the crater, they document sample locations, collect the samples, seal them in containers, weigh them, show them to their helmet cameras, and then stow the samples in the larger sample bag.

Before departing, the crew work together to deploy the seismic instrument payload. They kneel down next to it, open it up, deploy arrays, and then activate the instrument.

With the science tasks complete, the crew clean up all of their equipment and lights, and traverse to the tub entrance. They then ascend the slope out of lava tube with assistance from a remotely operated winch on the unpressurized rover.

Back at the rover, they stow samples, instruments, and bags on pressurized rover, and lock in.

7.3.3.5 Science Task - PSR

The crew drive the rover to ROI near the targeted PSR, which is on the way towards the lander, getting them closer to their safe haven. Navigation cues projected on their HUDs help them get to the right location.

At the edge of the permanently shadowed region, the EV crew dismount from the rover and begin initial context observations. As at the crater and lava tube, this includes visual inspection of the PSR and surrounding areas, complete with imagery and verbal descriptions. The Science Team views EV1's helmet cam video and makes a real-time confirmation of the target area. Using the suit display (e.g., augmented reality cues projected via a HUD), the Science Team indicates a suggested shadowed area from which the crew should acquire a sample.

While EV1 is conducting the visual inspection and receiving instructions from the Science Team in MCC, EV2 offloads the rover with the tools and instruments that will be needed. These include the instrument bags and the wheeled deep core drill.

When ready, the EV crew will preconfigure their suit thermal setting and begin walking into the PSR, approaching a vertical exposure. EV1 pulls the deep core drill along, while EV2 manages the instrument bags. Due to the colder temperatures, the crew work quickly but safely.

Both crew operate their handheld instruments, taking accessing as much of the vertical exposure as possible. This involves reaching above their head, near chest level, and at the interface of the wall and surface.

The crew work together to document the sampling location, set up the deep core drill in order to acquire volatiles 2-3 meters below the surface on the edge of the PSR. EV1 kneels down to set the outriggers and feet, while EV2 deploys the drill head to its maximum height over her head. Once the drill is configured, they activate the drill process.

While the deep core drill penetrates the ground, the crew work together to deploy the ISRU and environmental instrument payloads.

When the drilling has reached its target depth, the crew retract the core bit. They break apart the drill stem, compressing and capping each segment in order to keep the stratification. The segments are then put into the insulated and sealed volatiles container. With the samples safely secured, the crew break down and stow the drill, and document the drilling location after sample acquisition.

The EV crew gather their bags and samples and walk out of the colder PSR area. They stow the samples and instruments on unpressurized rover.

With all of the science tasks complete, the crew navigate back to lander on their rover.

7.3.3.6 Maintenance Tasks

Back at the lander area, the EV crew park the rover. The unload the rover, stowing the equipment bags with non-powered science tools back in the external toolboxes, the instrument bag near the ladder, and the samples near the ladder. They stow the deep core drill on the decent element, ensuring that it's receiving recharge power. The crew configures the drill with the appropriate socket and load the tool bag in the cart.

As an example to a potential maintenance task and task details, EV1 and EV2 walk to the maintenance worksite, a small pump module and remote power control module on a surface communication & power station, with EV2 pulling the cart. The Ground IV in MCC powers down the station, confirming all inhibits are in place, which EV1 verifies via the overlay on the informatics display.

At the worksite, EV1 begins removing and replacing the pump module.

- Demating power connectors: EV1 begins demating the power cables for the pump module. EV1 kneels down to reach the low power connectors. For each one, he cleans the exterior, removes the MLI sleeve, demates the connector, checks the pins and for FOD, mates the connector to a dummy location, then recovers the connector. When done with the lower power connectors, EV1 stands and begins the process of demating the connections that are overhead. EV1 uses pliers (or pin straightener) from the suit-mounted equipment carrying system (harness) to fix any bent pins on the connectors.

- Demating fluid connectors: EV1 demates the fluid connectors linking the pump module to the communication station's radiator. The process is similar to the electrical connectors, working both on the kneeling level and overhead, with the female connectors ending up safely covered on male dummy connectors.
- Removing fasteners: EV1 retrieves the power tool (hammer drill) and begins backing out the fasteners on the pump module. When the fasteners are fully released, EV1 stows the power tool.
- Removing/installing module: EV1 removes the failed pump module, carries it to the METS, and temp stows it. He then removes the spare module from its packaging, takes it to the communication station, and soft docks it in place.
- Installing fasteners: EV1 uses the power tool to drive all of the bolts to full engagement, verifying torque and turns.
- Mating fluid connectors: EV1 reverses the demating process, moving each fluid connector from the male dummy to the new pump module.
- Mating power connectors: EV1 reversed the demating process, moving each power connector from the dummy panel to the new pump module.
- With the R&R complete, EV1 notifies MCC and powers up the system.
- While EV1 works on the pump module, EV2 begins connecting the power cable from the communication & power station and the lander. This will provide extra power to the lander.
- EV2 begins with digging a trench between the lander and the station in order to bury the power cable. She uses a shovel/trenching tool from the lander external tool box. EV2 digs the trench deep enough to cover the cable and have the rover drive over it without damaging the cable.
- EV2 retrieves the power cable and carries it to the interface panel on the lander. She dusts off the lid on the panel with a brush from her harness, then opens it up. She inspects the lander side connector, and mates it to the panel.
- With the lander end secured, EV2 then begins walking towards the communication & power station, laying the power cable in the trench.
- At the power station, EV2 cleans off the interface with her brush, inspects the connector and jack, and then mates the cable to the station panel.
- EV2 cleans the solar arrays with the brush from her suit-mounted equipment carrying system.
- EV2 contacts the Ground IV in MCC (or IV in Gateway) to remove inhibits and verify that the lander is receiving power from the station.
- EV2 walks along the trench, filling it in and covering the power cable with her trenching tool.

7.3.3.7 Cleanup

When the pump module R&R and power cable installation tasks are complete, the EV crew clean up their tools and stow them on the cart. They take the cart back to the lander. Tools that don't have any electronics are stowed in the external tool boxes on the decent element. They secure the cart in its temporary stowage area, making sure it's in a safe configuration for any abort ascent scenario.

They take the tools needing conditioning and recharge to the base of the lander ladder.

7.3.3.8 Ingress

With all objectives complete and cleanup done, the crew begin the ingress process. EV2 attaches to fall protection and climbs ladder to the platform on the ascent element. She kneels down on the platform and ensures she's stable and secure to receive bags. EV1 begins handing bags (powered tools, instruments, and sample containers) up to EV2. When all of the bags are up on the platform, EV2 moves each one in the airlock.

EV1 attaches to fall protection and climbs ladder. On the platform, both crew perform dust mitigation tasks.

EV2 ingresses the hatch with the last bag, and EV1 follows behind. While EV2 stows the bags out of the way, EV1 secures the hatch.

Both crew back into the xPLSS hatches in suitlock wall, and lock themselves in place. They attach their umbilicals and switch over to vehicle consumables.

The crew follows the SUITLOCK DEPRESS/REPRESS CUE CARD for repress. EV1 then actuates the pressure equalization valve, beginning repress. Part way through, he stops repress to verify the airlock is holding pressure. Once a good hatch seal is confirmed, the suitlock is fully repressed.

Once the suitlock is equalized with the lander cabin, the crew commands the suitlock hatches open. They then open their xPLSS hatches and egress their suits.

8.0 CONCEPT OF OPERATIONS FOR EVA ON MARS

One of the primary goals of the human spaceflight program is to land on and explore Mars. Current architecture holds that during the decade of the 2030s and beyond, NASA will develop and deploy the systems to land cargo and crews on Mars, sustain crews on the surface, and return them safely back to the Gateway, and then home to Earth.

Mars provides a unique environment for EVA operations with its partial gravity level (3/8 that on Earth), partial atmosphere dominated by CO_2, issues with dust, and both forward (planetary protection) and backward (crew health) contamination concerns. The distance between Mars and Earth also means that the communication latency between MCC and the crew will range between ~4 and 20 minutes. Given the current development of a xEVA System that's focused on the lunar surface, missions to the surface of Mars will involve a modified suit that is capable of operating in the higher gravity gradient and partial atmosphere. This Mars xEVA Suit will have different methods for thermal protection and scrubbing CO_2 (among other modifications).

8.1 GENERAL CONSIDERATIONS FOR MARS

Once on the surface and acclimated to the gravity environment, the crew will conduct EVA operations in three general categories.

- Pioneering tasks to assemble the base infrastructure
- Maintenance tasks to keep the infrastructure operating
- Science tasks for geoscience and astrobiology sampling, along with instrumentation

With such a long signal latency and blockage, EVA operations will be directed by an IV crewmember in-situ on Mars, with input from the Science Team both during and between EVAs. The crew will also likely utilize their in-situ knowledge to plan some of the EVAs, with MCC concurring and putting together the detailed timelines. Many of the science operations tasks will likely be far from the habitat, so the EVA crew will rely on a navigation system to find the correct sampling area and find their way back to the habitat or rover.

During missions to the surface of Mars, there will need to be an emphasis on the informatics system and mission support systems. The EVA crew will utilize xEVA Informatics designed into their Mars xEVA Suit. These informatics will grant the EVA crew more autonomy with both tasks and suit monitoring. An in-helmet HUD and on-suit electronic display system will provide the crew access to digital data/information and augmented reality cues. Utilizing these systems, the EVA crew will navigate themselves and mark their location for MCC awareness and future reference. The xEVA Informatics capability will allow them to pull up procedures, schematics, and videos to assist with pioneering, construction, and maintenance activities. For science activities, they will be able to call up cue cards, pictures, and imagery that the Science Team has annotated for them. MCC, the Science Team, and IV will also be able to provide the EV crew with augmented reality cues in order to guide them through tasks.

EVA science operations on the surface of Mars will involve different ways of communicating information between the EV crew and the Science Team (ST) on Earth. The ST will provide input to the crew both during the EVA and between EVAs. With such a long communication delay, the IV will be prime for directing the EVA. The ST will provide the IV input, and the IV will filter and pass it along to the EV crew. This input will likely be largely done via text and file transfer to the IV, as opposed to audio communication. The IV will talk to the EV crew and possibly send files to electronic displays on their suits. The ST may also directly provide files and text to the electronic displays.

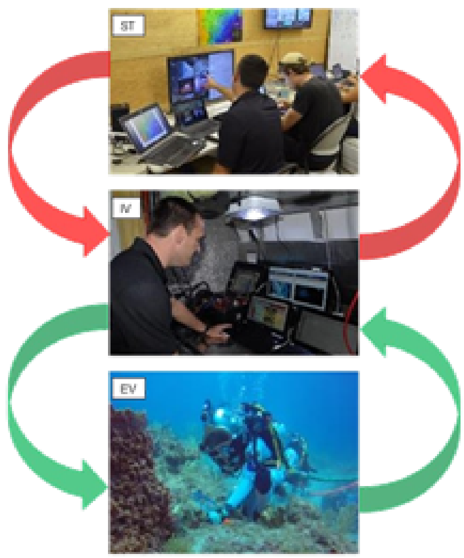


FIGURE 8.1-1: EVALUATING SCIENCE TEAM INTERACTION WITH MARS EVA DURING NEEMO 20

The crew will be very well trained, such that they can operate mostly autonomously to get science samples. However, science ops can be constructed such that a Science Team on Earth can provide relevant, timely feedback to influence the plan and sampling tasks during an EVA, provided that the EVA is timelined such as to allow the transmission of data back and forth (i.e., having multiple sites to move between and having some tasks that don't require MCC input).

The Science Team will be a focal point of the primary MCC team and be fully integrated with all other operations taking place.

An EVA mission support system will be utilized due to the amount of information and tasking the IV crewmember must contend with (essentially performs the roles of IV, Flight Director, partial EVA Officer, and partial BME).

Timelines and tasks will be dependent on precursor data and the ability of the crew to collect new data. Interactions with the MCC ST will need to be planned carefully in order to allow feedback from the MCC ST.

Robotic assets will likely assist EVA crewmembers, including the following:

- Area reconnaissance
- IV and ST situational awareness
- EVA tool management
- Sample stowage and transportation

The robotic vehicle will be driven by a 2nd IV crewmember in the habitat for dynamic operations and will be controlled by the ST in MCC for things such as camera views and photographing an area.

Due to the expense of launching hardware to Mars, and the possibility that more things will break than expected or certain things weren't anticipated ahead of time, a Three-Dimensional (3D) printer will be useful for things such as:

- Designing and printing broken hardware, such as the IGSS end effectors
- Printing missing parts
- Rapid delivery of parts whose need hadn't been anticipated pre-mission

With long duration missions at destinations with a long communication latency, the crew will likely be more involved in planning their EVAs than as is currently done on ISS. Multi-day EVA planning will incorporate crew input, ground based planners, and automated planning tools. Crew autonomy and planning techniques on Mars should be informed by lessons learned from prior Lunar operations.

FIGURE 8.1-2: EVALUATING MULTI-DAY CREW SELF-SCHEDULING OF EVAS

8.2 CON OPS FOR EVA ON MARS

8.2.1 Road-to EVA (Mars)

The content for this section is forward work. [TBD-9.2.1-011]

8.2.2 Prep & Prebreathe for EVA (Mars)

The content for this section is forward work. [TBD-9.2.2-012]

8.2.3 EVA (Mars)

EVAs on the surface of Mars will involve pioneering (construction and maintenance) and science tasks.

8.2.3.1 Pioneering Tasks

EVA will conduct pioneering tasks to assemble the base infrastructure. The number and types of tasks involved are still in work.

8.2.3.2 Science Tasks

The primary goal for a mission to Mars is the collection of various science samples, including both geoscience and astrobiology. These samples, along with verbal descriptions and imagery, will characterize areas on Mars. Specialized EVA tools will allow for the collection and storage of pristine samples.

The EVA Integrated Geology Sampling System will house tools for collecting float, surface, soil, rock chip, and core samples. It will allow for a strict contamination protocol that is designed for sample management, ease of operation, and consistency across sampling activities. The IGSS "briefcase" houses various End Effectors (float, soil, surface, chip, and core) with two different types of drivers to secure samples manually or with a powered device.

Three types of samples will be taken with manual tools, including surface samples, float samples, and soil samples. The surface sample captures the very top layer of dust on the surface and will likely be the first one taken before it is disturbed. During Apollo, this type of tool used a metallic mesh, but missions to Mars may make use of more advanced materials, such as aerogels. One of the primary sampling tools will be the float tool. This will enable the crew to capture whole small rocks and store them in end effectors to prevent contamination. Another tool, that may very well resemble the float tool, is one to collect soil samples. It will enable the crew to scoop up a small quantity of the regolith.

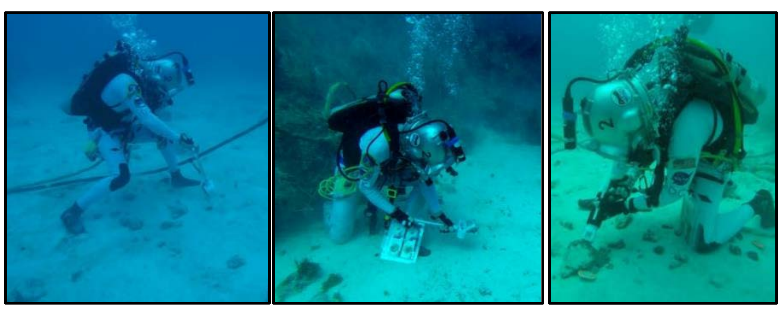


FIGURE 8.2.3.2-1: EVALUATING SCIENCE SAMPLE ACQUISITION ON MARS DURING NEEMO 20

Two different types of samples will likely be taken with powered tools: a rock chip sample and a core sample. To aid in chipping off a piece of a large rock for sample return, a power tool with a rock chip end effector may be used to chisel off and then contain a small piece of the rock. A power tool and core tube may aid in taking a small core sample at the location where the EVA crew are walking.

Concepts such as the IGSS may prove feasible for EVA collection of geology and astrobiology samples. It provides a viable method for minimizing sample contamination, though its size and mass are rather large compared to the actual samples obtained. Further work should be done on methods or modifications to keep the EV crew from contaminating areas as they arrive to take samples.

A number of handheld and deployable science instruments will also be utilized on a mission to Mars. The handheld tools will enable the EVA crew to conduct scientific measurements on samples that they collect to provide initial data and will be used to take measurements on samples that won't be collected.

While surveying an area and making contextual comments, the EVA crew will utilize temporary sample markers to both record data in imagery and for communicating sample data with IV and ST/MCC.

Since the goal of a planetary science Exploration mission is to characterize an area, not simply pick up a specific rock, a navigation system needs to guide the crew close to a landmark that indicates an area of interest rather than just locate a specific sample. Electronic navigation will be critical in areas where the terrain looks similar, especially when marking new locations and returning to a site. Early missions will likely utilize a relative navigation system, such as radar. This system, when coupled with a heads-up display, will allow EVA crew to navigate themselves to the desired regions.

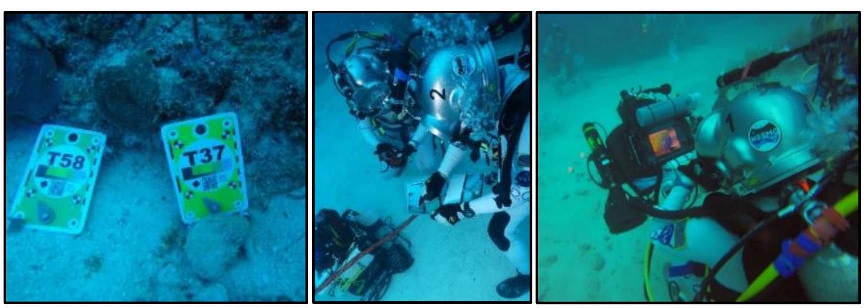


FIGURE 8.2.3.2-2: EVALUATING SAMPLE MARKERS NAVIGATION METHODS TO IDENTIFY ZONES

8.2.4 Post EVA (Mars)

The content for this section is forward work. [TBD-9.2.4-013]

9.0 CONTINGENCIES & CREW RESCUE

All spaceflight missions entail some risk, and that risk increases when the crew leave the relatively safe confines of their vehicle and venture out EVA. The EVA crew and system must be ready and capable of handling various contingency scenarios which include, but are not limited to an incapacitated crewmember, DCS, loss of communication, loss of transportation, and contamination.

9.1 SELF-RESCUE

The xEVA spacesuit will incorporate a secondary life support system that can sustain a leak of a specified size (the exact size is still in work). This system will provide an EV crewmember with the capability to reach a safe haven (airlock) within a defined minimum amount of time.

9.1.1 Microgravity Self-Rescue

In the event of a suit leak during a microgravity EVA, the crewmember will terminate or abort the EVA, and translate back to the airlock. At the airlock, the EV crew will perform either a nominal, expedited, or emergency repress based on the severity of the situation.

9.1.2 Lunar Surface Self-Rescue and Rover Rescue

For lunar surface operations, the EVA crew is expected to stay within a range that allows them to reach a safe haven in the event of a contingency. The EVA suits will provide a minimal capacity of eight hours' worth of primary consumables, plus one hour of contingency consumables. The additional hour allows the EVA crewmember to be approximately within an hour's walk from their safe haven (rover). The calculation of this distance could be further augmented with implementation of smart traverse planning tools.

For short stay sortie missions, rover-based excursions will stay within less than an 8-hour walk back to the lander [TBR-EVA-EXP-0042-001]. In the event of a rover failure, the crew would prepare, and don fully charged suits. This gives them the capacity to walk for up to 8 hours on primary consumables.

For extended stay campaign missions, a second rover will stay within an 8-hour drive of the EV crew to maintain rescue capability [TBR-EVA-EXP-0042-002]. If the EV crew experiences a suit emergency, they will return to their primary rover. If the EV crew's primary rover suffers a failure, the EV crew will utilize rover consumables until the rescuing rover arrives.

9.2 INCAPACITATED CREWMEMBER RESCUE

Each EVA crewmember will be capable of and responsible for rescuing the other in the event that one becomes incapacitated for any reason. The xEVA Suit will contain a secondary oxygen tank that will allow for an hour of emergency gas.

9.2.1 Microgravity EVA Rescue

If a crewmember becomes incapacitated during a microgravity EVA, the other EV crewmember will initiate and perform a rescue. The rescuing crewmember translates along the surface of the vehicle to the location of the incapacitated crewmember (ICM), and verifies the incapacitated crewmember is securely tethered to the vehicle. The rescuing crewmember secures any equipment not necessary for survival or that might interfere with the ability to translate to the airlock, and then tethers the incapacitated crewmember to himself/herself. Once the crew are tethered together, the rescuer translates to the airlock towing the ICM, and once there tethers and inserts the affected crewmember into the airlock. The rescuer then ingresses the airlock, releases external safety tethers, and closes and locks the hatch. Umbilicals may be mated as the specific emergency and timing permits. Once the hatch is closed, the rescuer initiates an emergency airlock repress.

The time between identification of the incapacitated crewmember and connection to the umbilical and/or repressurization of the airlock shall not exceed 30 minutes. The airlock can be re-pressurized in an expedited manner as required by the situation (which bypasses the two-minute airlock leak check) or perform an emergency repress (which can repress in ~90 seconds). The affected crewmember is then removed from the airlock first by the IV crew who will perform expedited suit doffing and provide any required medical assistance.

9.2.2 Partial-Gravity Surface Rescue

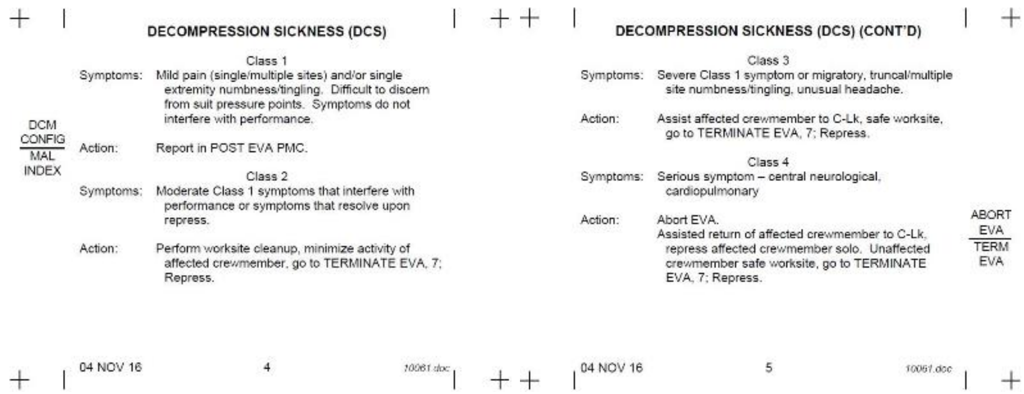
Future planetary surface missions will factor in the complexity associated with the possibility of having an EVA crewmember become incapacitated in a partial-gravity environment, where it will not be as easy to maneuver that crewmember back to an airlock. Some type of rescue assist device will be developed that can interface to the EVA suit to enable a rescue. The systems and methods for the rescue of an incapacitated crewmember during surface operations must consider that there may be times where only one crewmember is available to perform the rescue. Current microgravity operations protect for one crewmember (of an EVA pair) to save another. However, surface operations may also reserve the capability for IV crewmembers (not currently out on EVA) to perform rescue operations of the primary EVA crew. The rescuer will need to be capable of getting the ICM into a safe haven (rover or habitat) within 60 minutes in an average thermally neutral environment.

With two crewmembers out EVA away from the sanctuary of the habitat or pressurized rover, the EV crew will need hardware and techniques for rescuing each other in the event of a catastrophic incident. On the lunar surface, these techniques will differ from microgravity, where the incapacitated crewmember is usually towed behind the rescuer. This is also a driver for a winch to be available on surface elements like rovers and airlocks. The gravity field and terrain on the moon will require specialized hardware and suit interfaces in order to perform a successful rescue with a single crewmember. The EVA System will enable rescue of an incapacitated crewmember and get him/her back to a pressurized safe haven, and the suit will have interfaces for rescue equipment and points to lift the suit. In addition to getting to a pressurized vehicle, the rescue system will need to enable getting the incapacitated crewmember inside.

Any surface rescue entails multiple phases, including stabilization, loading onto transport equipment, transport to a safe haven, and ingress to a habitable volume. Methods and equipment for stabilization of the incapacitated crewmember depend on the reason for incapacitation. Suit malfunctions or ruptures may result in decompression injuries/illness that could entail the need for increased suit pressure while still out EVA, and musculoskeletal injuries may require limb stabilization to prevent worsening the injury. Once stabilization is established, the incapacitated crewmember is loaded onto a transport mechanism. Depending on the mission and Artemis phase, transport mechanisms (such as a deployable litter) are retrieved from a nearby rover or deployed from accompanying storage, and brought to the crewmember. Hard points and soft-goods handles available on the exterior of the suit provide attachment and aids for the rescuer crewmember to move and position the incapacitated crewmember on the litter. Once in the litter, straps secure the crewmember in place for transport. Transport entails dragging or rolling (on attached wheels) the deployable litter by the rescuer crewmember to the closest habitable volume. Once at the habitable volume, the incapacitated crewmember ingresses the airlock. Ingress of the incapacitated crewmember is assisted by haul/winch systems designed to lift and translate the crewmember into the habitable volume, and then onto a donning stand or rear-entry airlock interface. At any time during the stabilization, transport, and ingress, the rescuer crewmember may obtain, control, and monitor suit and life support parameters for the incapacitated crewmember via DCU displays.

9.3 EMERGENCY RECOMPRESSION

Decompression sickness/illness is a potential hazard during EVA operations due to changes in the pressure environment and operating the suit at relatively low pressures (~4.3 psid). The response to DCS symptoms is a function of the severity (cuff class) and the treatment protocol varies as a function of how quickly symptoms resolve. In order to prevent progression of DCS symptoms or the development of DCS-induced deficits or permanent injury during EVA, it is necessary to provide prompt increased pressure to the crewmember. Upon detection of Class one or four symptoms as described in Figure 9.3-1, the suit pressure is elevated as high as possible while EVA (~8 psid) while the crewmembers translate and ingress the airlock. Classification of DCS symptoms will determine if action is EVA TERMINATE or EVA ABORT. Once the airlock is repressed, the suit's internal pressure is increased above the starting vehicular atmospheric pressure without compromising suit integrity. The pressure profile and duration is determined based on crewmember symptom resolution and monitored by the Flight Surgeon and/or Crew Medical Officer (CMO). The suit consumables sustain the elevated suit pressures for up to one hour prior to reattachment of vehicle umbilicals. The one-hour duration provides sufficient time for the EVA crewmember to return to the vehicle, connect the umbilical, and switch over to the vehicle gas supply. This capability does not assume that the crewmember is on the Secondary Oxygen system. Rapid and appropriate intervention is required to optimize the outcome for the affected crewmembers.


DECOMPRESSION SICKNESS (DCS)

Class 1

Symptoms: Mild pain (single/multiple sites) and/or single extremity numbness/tingling. Difficult to discern from suit pressure points. Symptoms do not interfere with performance.

DCM CONFIG / MAL INDEX

Action: Report in POST EVA PMC.

Class 2

Symptoms: Moderate Class 1 symptoms that interfere with performance or symptoms that resolve upon repress.

Action: Perform worksite cleanup, minimize activity of affected crewmember, go to TERMINATE EVA, 7; Repress.

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DECOMPRESSION SICKNESS (DCS) (CONT'D)

Class 3

Symptoms: Severe Class 1 symptom or migratory, truncal/multiple site numbness/tingling, unusual headache.

Action: Assist affected crewmember to C-Lk, safe worksite, go to TERMINATE EVA, 7; Repress.

Class 4

Symptoms: Serious symptom – central neurological, cardiopulmonary

Action: Abort EVA.
Assisted return of affected crewmember to C-Lk, repress affected crewmember solo. Unaffected crewmember safe worksite, go to TERMINATE EVA, 7; Repress.

ABORT EVA / TERM EVA

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FIGURE 9.3-1: ISS EMU CHECKLIST DCS CUFF CLASSES

9.4 CONTAMINATION

Scenarios exist during EVAs on spacecraft that present the possibility of crewmembers coming into contact with contaminants, such as ammonia from the thermal loops, thruster residue (i.e., hydrazine), paint flakes, or grease. If EVA crew are confirmed or even suspected of becoming contaminated, measures are taken prior to ingress of the airlock, such as brushing or wiping away the contaminant, or 'baking' it out. The second suited crewmember will assist with brushing and wiping to properly clean the suit.

Contaminants such as ammonia are not easily removed with wipes or brushes, necessitating a 'bake-out' of the suit. This involves exposing the suit to the sun or putting it in a 'warm' area in order to allow the ammonia to sublimate off. Operational planning minimizes the impact of ammonia bake-outs by planning activities where possible ammonia contact can occur earlier in the timeline, allowing a bulk of the bake-out to occur during the remainder of the EVA. However, this does not preclude that situations occur where contamination occurs later in the EVA and a bake-out must occur prior to fully repressing the airlock.

9.5 LOSS OF COMMUNICATION

For loss of communication (LOC) between the vehicle and EV crew, the crewmembers will initiate the process of attempting to restore communications. The EVA crew will initially attempt recovery by changing position to regain line of sight with the vehicle communication antennas, then switch over to alternate radios (or functional equivalent) if unsuccessful. If communication is still not restored between the EV crew and the vehicle, they attempt to notify the IV crewmember of the situation via hand signals (and possibly signs from a cuff checklist page) at a vehicle window or external vehicle camera. After notifying the IV crewmember, the IV crewmember and EVA crew coordinate switching over to an alternate frequency. If swapping frequencies does not restore communications, the crewmembers are expected to terminate the EVA and return to the airlock. If communication is also lost between the EVA crewmembers, the EVA crewmembers communicate with each other via hand signals.

On the lunar surface, there are situations where either an IV crewmember is not present or the EV crewmember is beyond the field of view of the IV crewmember. In this situation, if there is a loss of communication or signal between EVA crewmembers, the EVA crewmembers notify each other via hand signals and follow a checklist in the xEVA Informatics subsystem or via a hardcopy for restoring communication. If the communication loss persists, the crewmembers return to the rover (or habitat).

9.6 LOSS OF TRANSPORTATION

Crewmembers are expected to traverse away from their vehicle or habitat to conduct EVA operations on the lunar surface. This creates the possibility of a system failure that can strand the rover and crewmembers from other habitable safe havens.

During short stay sortie missions, where there is not a second crew available for recovery, the exploring rover won't exceed a distance from the ascent vehicle that would preclude the EV crew from returning on foot using real-time navigational tools within the limiting consumables of the excursion crew.

During extended stay campaign missions, two rovers will be positioned within rescue distance of each other, and all excursions from the rovers are performed with at least two crewmembers. The maximum time it takes for a second rover to respond to the loss of another rover and bring the EV crew inside will not exceed the limiting consumables of the excursion crew. EVA crewmembers will stay within a one hour walk back to their rover in case of any contingency or emergency.

9.7 RADIATION

Crew will respond to Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs) as appropriate. This includes potential uses of an Active Radiation Dosimeter (ARD).

9.8 VEHICLE CONTINGENCIES

This section is in work with the HLS Program.

9.8.1 Orion

9.8.2 Gateway

9.8.3 HLS

9.8.4 Pressurized Rover

APPENDIX A
ACRONYMS AND ABBREVIATIONS
AND GLOSSARY OF TERMS

A1.0 ACRONYMS AND ABBREVIATIONS

AET	Adjustable Equipment Tether
AOS	Acquisition of Signal
APFR	Articulating Portable Foot Restraint
APS	Astronaut Positioning System
ARCM	Asteroid Redirect Crewed Mission
ARD	Active Radiation Dosimeter
ARV	Asteroid Retrieval Vehicle
ASM	Advancing Science of the Moon
ATSC	Advanced Television Standards Committee
BME	Biomedical Engineer
BMRRM	Bearing Motor Roll Ring Module
BRT	Body Restraint Tether
CCB	Configuration Control Board
CCE	Critical Contingency EVA
CM	Crew Module
CMO	Chief Medical Officer
CO_2	Carbon Dioxide
CR	Change Request
CRS	Crew Restraint System
CWS	Caution Warning System
DCS	Decompression Sickness
DCU	Display and Control Unit
DOI	Descent Orbit Insertion
DRO	Distant Retrograde Orbit
DSG&T	Deep Space Gateway & Transport
DTE	Direct to Earth
ECLSS	Environmental Control and Life Support System (Subsystem)
EDDA	EMU Don/Doff Assembly
EDL	Entry, Descent, Landing
EMU	Extravehicular Mobility Unit
EV	Extravehicular
EVA	Extravehicular Activity
EVR	Extravehicular Robotics

FCT	Flight Control Team
FOM	Figure of Merit
FSE	Flight Support Equipment
GCR	Galactic Cosmic Ray
GER	Global Exploration Roadmap
HALO	Habitation and Logistics Outpost
HD	High Definition
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HLS	Human Landing System
HUD	Heads-Up Display
HUT	Hard Upper Torso
H_2O	Water
ICM	Incapacitated Crewmember
IDD	Interface Definition Document
IGSS	Integrated Geoscience Sampling System
ISECG	International Space Exploration Coordination Group
ISLE	In-Suit Light Exercise
ISRU	In Situ Resource Utilization
ISS	International Space Station
IV	Intravehicular
IVA	Intravehicular Activity
JSC	Johnson Space Center
LCVG	Liquid Cooling Ventilation Garment
LEA	Launch Entry Abort
LEAG	Lunar Exploration Analysis Group
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
LOC	Loss of Communication
LOI	Lunar Orbit Insertion
LOS	Line of Sight
LRU	Line Replaceable Unit
LRV	Lunar Rover Vehicle
LSS	Life Support Subsystem
LTV	Lunar Terrain Vehicle
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston

MDM	Multiplex/Demultiplexer
mEMU	Mars Extravehicular Mobility Unit
MMOD	Micro Meteoroid Orbital Debris
MPCV	Multi-Purpose Crew Vehicle
MMWS	Modular Mini-Workstation
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NEA	Near Earth Asteroid
NEEMO	NASA Extreme Environment Mission Operations
NEO	Near Earth Object
NHRO	Near Rectilinear Halo Orbit
NRC	National Research Council
O_2	Oxygen
OCSS	Orion Crew Survival System
OPR	Office of Primary Responsibility
ORU	Orbital Replacement Unit
PDI	Powered Descent Initiation
PET	Phased Elapsed Time
PGS	Pressure Garment System
PLSS	Portable Life Support Subsystem
PM	Pump Module
psia	pound per square inch absolute
psi	pound per square inch
psid	pound per square inch delta
PSR	Permanently Shadowed Region
RATS	Research and Technology Studies
RET	Retractable Equipment Tether
RF	Radio Frequency
RPCM	Remote Power Control Module
R&R	Remove and Replace
SA	Situational Awareness
SA	Spacecraft Adapter
SAT	Specific Action Team
SCEM	Scientific Context for the Exploration of the Moon
SEV	Space Exploration Vehicle
SLS	Space Launch System
SM	Service Module

SPCE	Servicing, Performance, and Checkout Equipment
SPE	Solar Particle Events
ST	Science Team
STP	Starting Point
TBD	To Be Determined
TBR	To Be Resolved
TLI	Trans Lunar Injection
UHF	Ultra-High Frequency
UIA	Umbilical Interface Assembly
UIP	Umbilical Interface Panel
UPR	Unpressurized Rover
VISE	Vehicle Interface to Suit Equipment
VLM	Vehicle Loop Mode
xEMU	Exploration Extravehicular Mobility Unit
xEVA	Exploration Extravehicular Activity
xINFO	Exploration Informatics System
xPLSS	Exploration Portable Life Support Subsystem

A2.0 GLOSSARY OF TERMS

Term	Description
Ancillary Hardware	Ancillary hardware consists of the following items: recharge umbilical, tools, SAFER, and FSE.
Consumables	Resource that is consumed in the course of conducting a given mission. Examples include propellant, power, habitability items (e.g. gaseous oxygen), and crew supplies.
Crew	Human onboard the spacecraft or space system during a mission
Dry mass	Uncharged unit, without water or oxygen, as well as without any tools or other ancillary hardware.
Flight	This is the sequence of events that takes place between liftoff and landing of a transportation vehicle.
Flight Support Equipment	All equipment (in-flight check-out hardware, launch carriers and enclosures, in-flight stowage containers, etc.) required post launch to support in-flight operations and logistics.

Term	Description
Heads-Up Display	An electronic display of data from instruments or other sources projected at eye level so that an EVA crewmember (or driver or pilot) sees it without looking away from the task (or road or course)
Microgravity	An environment where gravity has little or no measurable effect, commonly referred to as "weightlessness" or "zero-g”.
Mobility	The sum of weight, range of motion, and center of mass that affects the performance of a human.
Motion Imagery	Transient imagery and sound captured via electronic sensors and converted to data for retention and observation. Motion imagery may utilize portions of what is currently referred to as traditional video or television architectures and systems. Future television or motion imagery distribution will be required to be in a digital format that is compliant with the Advanced Television Standards Committee (ATSC) standard.
ORU	A piece of equipment which can be removed and replaced with a working spare by a user or operator during the mission. This is a subclass of Line Replaceable Unit (LRU).
Prep and Post	The activities required preparation for and transition from an EVA including configuration and checkout of EVA hardware, suit donning and doffing, and all other procedures required before or after an EVA.
Spacecraft	A spacecraft is considered to be any host vehicle such as habitats, rovers, landers, as well as orbiting and transit vehicles.
Suitlock (Rear-Entry Airlock)	An airlock designed for a rear-entry spacesuit, where the suit back extends through the bulkhead of the airlock into the habitable volume such that the crewmember directly ingresses the suit from the habitable volume.
Suitport	Similar to a suitlock, but the vestibule through which the back of the suit penetrates into the habitable volume acts as a pressure seal, such that the area around the front of the suit can be depressed with the suit hatch still open.
Suitport Airlock	A suitport inside of a full airlock.

Term	Description
Umbilicals	Umbilicals include service umbilicals used for recharge before, after, and during EVAs. Vehicle services include O2, water, hardline communication, power, data, vacuum, and suit to vehicle vent loop pressure equalization. The services may be supplied through multiple umbilicals as determined by the operational need.
Vehicle	Often synonymous with the term spacecraft.

APPENDIX B
OPEN WORK

B1.0 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 (i.e., **<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.

TABLE B1.0-1: TO BE DETERMINED ITEMS

TBD	Section	Description
TBD-2.1-014		
TBD-4.2.1-004	4.2.1	Compatibility with a suitlock (rear-entry airlock)
TBD-6.2.1-001	6.2.1	How and for how long suits are stowed is still TBD
TBD-7.2.1.2-005	7.2.1.2	If Artemis IV goes to Gateway
TBD-7.2.2.2-006	7.2.2.2	Stand-up EVA
TBD-7.2.3-007	7.2.3	Suited times during lunar descent
TBD-7.3.1-008	7.3.1	Road to EVA for Moons of Mars
TBD-7.3.2-009	7.3.2	Prep & Prebreathe for Moons of Mars
TBD-7.3.4-010	7.3.4	Post EVA for Moons of Mars
TBD-9.2.1-011	9.2.1	Road to EVA for Mars
TBD-9.2.2-012	9.2.2	Prep & Prebreathe for Mars
TBD-9.2.4-013	9.2.4	Post EVA for Mars
TBD-Apx D-002	Appendix D	
TBD-Apx D-003	Appendix D	Number of EVAs during transit to Mars

B2.0 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 (i.e., **<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.

TABLE B2.0-1: TO BE RESOLVED ISSUES

TBR	Section	Description
TBR-10.1.2-001	10.1.2	8-hour walk back to lander from a lander or disabled rover
TBR-10.1.2-002	10.1.2	8-hour drive for rescuing rover to reach disabled rover

B3.0 FORWARD WORK

The table Forward Work lists the known issues in the document that are being worked. The identifier CR-XXXXX-XXX refers to the CR that the comments was received on and the comment number for that review. For example, comment 63 on CR-00032 would be CR-00032-063.

TABLE B3.0-1 FORWARD WORK

Forward Work	Section	Comment
CR-00030-C107	7.4.1	Update ARCM with last ARCM Con Ops information.
CR-00030-C130	Appendix D	Entire Appendix as related to ARCM in 7.4.1 -ARCM was a Project within Exploration Integration and Science Directorate (EISD) (was considered to be a Proving Ground Phase 1: Cis-Lunar Flight Testing of Exploration Systems in the 2025 timeframe per Exploration Systems Directorate (ESD) 00012 Rev E. Suggest update Appendix D 7.4.1 to align with information contained in the Baseline JSC-66954 document and state that the Project was retired.
CR-00030-C211		The document doesn't provide a lot of detail on what limits are needed for an EVA crew to work with robotics. Are there standard load limits from robot to crew? Acceleration limits if crew is on the end of an arm? These would likely be nominal human factors aspects taken from a 'typical' human physiology. Are there any other aspects that would define or focus the development of the robotic assistants or vehicles mentioned throughout to make them more useful to EVA?
CR-00030-C216		b. mention is made of a self-rescue jetpack or Simplified Aid For EVA Rescue (SAFER) device is TBD-EVA-EXP-0042-004 for NEA missions, however no mention is made of true EVA mobility aids (e.g. an MMU-like capability) which may be enabling for EVA productivity (e.g. avoid time to transit from airlock to worksite).
CR-00030-C217		c. mention is made of "robotic assets" for various EVAs, but no mention is made of dedicated EVA robotic free-flyer assistance equipment, e.g. for in-space EVAs a robotic inspector could go out before the EVA for inspection (better planning and/or substitute for the EVA), during the EVA for monitoring (better safety during the

Forward Work	Section	Comment
		EVA), and after the EVA for closeout documentation (better use of EVA time).
CR-00048-42	5.5.2	Suggest investigating robo-carts, and mentioning that as a possibility here.
CR-00048-86	6.2.1.1	Add why an OCSS suit is being used for asteroid missions.
CR-00048-156	6.3.2	I suggest the following text be added to the end of the bullet: "The study found that (i) a majority of the objectives could be addressed within the Schrodinger impact basin, which is within the South Pole-Aitken impact basin, on the lunar farside; that (ii) Amundsen basin is a useful target for examining the potential of lunar volatile deposits; and (iii) while the highest-priority landing site may be the Schrodinger basin, global access to the lunar surface is required to address all science and exploration objectives. The landing sites in this report are suitable for both robotic and human EVA missions.
CR-00048-160	6.3.2	ISECG published a DRM with five landing sites, based on input from HEOMD Chief Exploration Scientist Ben Bussey. Thus, one might add at the end of the section the following text: "An ISECG-defined DRM published in 2015 contains five landing sites: Malapert Massif, South Pole/Shackleton Crater, Schrodinger Basin, Antoniadi Crater, and the center of the South Pole-Aitken Basin. Crew/rover traverses around each of those landing sites have been studied by team managed by LPI and ARES, as well as traverses for tele-operated rovers between those landing sites."
CR-00048-161	6.3.5.10	The text indicates EV crew may "rappel into and out of lava tubes and pits." That is an issue I would like to discuss. I do not anticipate a need to do that for near-term science purposes. On the other hand, it may be useful to carry that capability so that it is a future option.
CR-00048-163	5.5.1	Do we want to have self-rescue (SAFER) tools added to this list of EVA tools and equipment?
CR-00048-169	6.2.3	Better define "numerous safety issues" as they are understood
CR-00048-171	6.3.5.1.2	Paragraph three, better define the 8 hour EVA and how it will be conducted in two parts
CR-00048-172	6.3.5.12	"Crew may need to wear PPE to prevent dust inhalation, but that is still to be determined" List PPE that has been discussed for dust inhalation
CR-00048-175	6.5.1.1	Add words that a device for self-rescue (i.e. SAFER) will be used should the microgravity EVA crewmember become separated from the vehicle (ISS/Gateway, etc.)
CR-00048-183	H	Mars Surface Mission - Uncrewed Cargo Better define suit sizing concerns
CR-00048-256	Overall	the document should include references for sources of information in-line within the text as well as in image/table captions.
CR-00048-260	6.3.5.10	consider changes to this section accounting for more approriate methods than rappeling for accessing steep, sloped terrain as well

Forward Work	Section	Comment
		as areas such as lava tubes; lowering/raising winches should be considered along with associated auxiliary surface hardware
CR-00048-261	6.4.1.1	should include a deeper explanation of designing EVA timelines and tasks to allow for interactions with Earth-based scientists; should acknowledge that all science tasks and EVA timeline designs are dependent on the level of precursor information, specific science objectives/tasks, and the communication latency; since there are no DRMs that document this, reference the historical origin of this approach following from DRATS, to PLRP, to NEEMO, to BASALT and the associated publications
CR-00048-262	6.5.2.2	multiple areas cover incapacitated crew rescue on a partial gravity surface and this section is more complete; possibly merge this section w/ 6.4.1.4.5
CR-00048-264	6.4.1.2	acknowledge that different science objectives may require different specialized tools; acknowledge there may be an ability to take more samples on EVA than will be taken back to Earth and the desire/capability to analyze some samples in between EVAs and provide additional data to MSC for considerations; should talk about how IV, EV, and MSC coordinate activities and interact; include other capabilities such as feature pointers, cameras, etc., as ancillary EVA equipment
CR-00048-278	3.2	With future lunar landings using powered landing and larger payloads, vertical distance to surface of moon is large (Altair/LSAM ~ 30ft). There may need to be a capability for a contingency vertical translation on engineered surface.
CR-00048-296	5.6.3	For planetary surface operations, EVA umbilical charging stations providing oxygen, water, and power may be available outside multiple pressurized elements. These could potentially allow crew to optimize suit mass for shorter duration EVAs, but still have the ability to recharge or extend an EVA without having to come back into a pressure cabin.
CR-00048-298	6.4.1.6	Not sure how to word it but we should say something about discarded suits on Mars likely being reused to repair later suits.
CR-00048-301		You can make it forward work, but you should at least have a section on planetary protection for the Mars missions. Note that there may also be planetary protection restrictions near permanently shadowed craters on the moon.
CR-00048-302	2.2	Add Apollo reference materials
CR-00048-307	5.4.1	Update informatics for more possible design solutions
CR-00048-316	2.2	Add Special Issue Papers on D-RATS 2010
CR-00048-317	2.2	Add published paper on field portable instruments ("The Incorporation of Field Portable Instruments in Planetary Surface Exploration")
CR-00048-352	2.2	References should be applied directly within the manuscript. I find it difficult to see which information is pulled from which references. This is particularly important for all figures and tables and 'raw' data

Forward Work	Section	Comment
CR-00048-383	5.1.1	Need to figure out how to reference a public list. Section 5.1.4 does list contingency EVAs, most of which are also maintenance. There is no current consolidated list for just maintenance EVAs, though internal FOD EVA dashboards do contain them.
CR-00048-388	5.1.4	"For this Con Ops, EVA will assume that no contingency events will require the use of the EVA system with less than 24 hour notice." This is a major requirement/assumption. Needs to be made much more explicit. Consider bolding or making a bullet point. There should also be a massive list of assumptions somewhere in this document that helps 'define' the Con Ops scenarios
CR-00048-391	5.2	Add language that includes Science traceability matrix that links these discrete tasks to more abstract Science Objectives
CR-00048-439	5.5.3	This may be another place to include instruments that could be integrated into the suit
CR-00048-440	6.3	Create a science traceability document (XI) and reference that document somewhere in this section.
CR-00048-586	6.3.5.12	Recommend explicitly stating in various Rescue scenarios what kinds of faults you are and are not protecting for. Include in this assumptions about the fault tolerance of the systems. For example, when you speak of Rover failures driving the need for walk-back capability, it seems you are talking simply of a failure of Rover drive/steering systems, not a failure of Rover Life support systems. Is the fault tolerance of the life-support systems higher than that of the drive systems? Is there a need for crew to be able to recharge suits even if life support system fails to begin 8-hr walk back to lander? Also in failure scenarios it seems to be assumed only protecting one failure deep - no tolerance for second failure after first occurs (ie, in 8 hr walkback we don't have normal failure tolerance to xEMU failure). These types of assumptions should be explicitly stated.
CR-00048-600	6.3.5.10	Careful to distinguish what critical information can and should be displayed depending on the environment and task. It may not "always" need to be displayed depending on the criticality of the caution or warning. Priority should be easily understood information at readable resolution. Information needs to be simple and not cluttered.
CR-00082-001	3.3.3	Is Artemis IV part of Phase 1 or 2
CR-00082-002	6 & 7	these two sections need to be reconciled with content in xEMU ConOps Chapter 7 in particula
CR-00082-003	5.2.2	Chart shows things like Metox install, EMU Battery Install, REBA Install
CR-00082-004	9	Add EVA responses to program level contingencies, such as the following: (1) failure of HLS to repress at the end of an EVA; (2) unexpected HLS depress event while in VLM; (3) HLS failure to dock to Gateway or Orio
CR-00082-005	4.2.2.1	"Geochemical, geophysical, and geotechnical measurements

Forward Work	Section	Comment
CR-00082-006	4.2.1.4	"Cratered Terrain"
CR-00082-007	4.2.1.4	"Circumnavigate, descend into, perform science tasks"
CR-00082-008	4	Current figure does not match the xEMU ConOps figures which show a different suit. The verbiage associated with Figure 4.0-1 mentions the lunar surface and but the picture does not match current xEMU documentation. Specifically (and also throughout the document) the picture shows current EMU arms and legs but these do not match the pictures in the xEMU document for Lunar EVAs.
CR-00082-009	6	These concepts seem to be for tasks that are slated far out in time. However, there are some long range con-ops development goals that need to be considered. External lighting will need to be in larger supply and smarter (automated and variable light fields) to adapt to changing and unknown environments. Interior lighting will need to be able to duplicate earthlike lighting environments, not just adding a spectrum shift for circadian countermeasures but actually increasing the levels significantly (daylighting) to significantly stimulate their circadian system and provide subjective worker productivity countermeasures that are similar to impacts skylights and windows bring to the business environment.
CR-00082-010	7	These concepts seem to be for tasks that are slated far out in time. However, there are some long range con-ops development goals that need to be considered. External lighting will need to be in larger supply and smarter (automated and variable light fields) to adapt to changing and unknown environments. Autonomous and robotic centered tasks, which require camera systems for the crew to "drive" or control the remote mechanical system, will also need smart lighting systems that improve visibility for video feeds. Because of the Martian soil and sky color, lighting may need to have modified spectrums to provide a white point that is more compatible for humans and RGB camera color systems. Interior lighting will need to be able to duplicate earthlike lighting environments, not just adding a spectrum shift for circadian countermeasures but actually increasing the levels significantly (daylighting) to significantly stimulate their circadian system and provide subjective worker productivity countermeasures that are similar to impacts skylights and windows bring to the business environment.
CR-00082-011	4.2.1.3.1	If the crew member traverses to the outer 2 km radius of the lander, not including walking around completing EVA tasks, they will have done a minimum of 4 km in one day. This already will cause significant fatigue. Other considerations such as standing and kneeling as well as mental workload will contribute to fatigue.
CR-00082-012	3.2	Clarification with regard to the role of Gateway in Artemis Phase I would be helpful to those supporting multiple Exploration programs. Will the role of Gateway be determine by the HLS provider(s) selected?

APPENDIX C
ADDITIONAL REFERENCES

The following documents contain supplemental information to guide the user in the application of this document and were utilized to assist in developing the various EVA Concepts of Operations.

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APPENDIX D
KEY FIGURES OF MERIT (FOM)

This appendix contains the key FOM tables for each Exploration destination.

TABLE D-1: KEY FOMS FOR A MICROGRAVITY EVA ON ISS

Mission Parameters	
Mission Duration	2 - 6 months
Total Crew	6
Vehicle	ISS
EVA Parameters	
EVA Category	Microgravity EVA on an Engineered Spacecraft
Type of Suit	xEVA Suit
Type of Life Support Subsystem (LSS) (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Informatics	xINFO
Egress Method	ISS Joint Airlock
Purpose of Typical EVA	Demonstration Maintenance and Contingency
Number of EVAs	Up to 13 per year
Avg Duration of EVA (PET)	6.5 hours
Max Duration of EVA (PET)	8.0 hours
Number of Crew EVA	2
Quiescent Period	1-6 months

TABLE D-2: KEY FOMS FOR EVA ON GATEWAY (MICROGRAVITY IN CISLUNAR SPACE)

Mission Parameters		EVA Parameters	
Mission Duration	26-42 days	EVA Category	Microgravity EVA on an Engineered Spacecraft
Number of Mission	7+	Type of Suit	xEVA Suit
Quiescent Periods (between missions)	Up to 2 years (~1 year & 339 days per Deep Space Gateway & Transport (DSG&T))	Type of LSS (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Total Crew	4	Egress Method	Dual chamber airlock
Vehicle	Cislunar habitat (Gateway)	Purpose of Typical EVA	Demonstration Contingency

Mission Parameters		EVA Parameters	
		Number of EVAs	2 per mission
		Duration of EVA (PET)	Up to 8 hours
		Number of Crew EVA	2

TABLE D-3: KEY FOMS FOR EVA FROM DEEP SPACE TRANSIT (DST) VEHICLE IN CISLUNAR SPACE

Mission Parameters		EVA Parameters	
Mission Duration	191-221 days in transit vehicle docked to hab 300-400 days in transit vehicle free-flying	EVA Category	Microgravity EVA on an Engineered Spacecraft
Number of Mission	3+	Type of Suit	xEVA Suit
Quiescent Periods (between missions)	Up to 1 year (~330 days per DSG&T)	Type of LSS (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Total Crew	4	Egress Method	Dual chamber airlock
Vehicle	Cislunar habitat (Gateway) Mars transit vehicle (DST)	Purpose of Typical EVA	Maintenance Contingency
		Number of EVAs	~1 for each month of mission
		Duration of EVA (PET)	Up to 8 hours
		Number of Crew EVA	2

TABLE D-4: KEY FOMS FOR EVA FROM DST VEHICLE IN TRANSIT TO/FROM MARS

Mission Parameters		EVA Parameters	
Mission Duration	TBD for days in Mars transit vehicle [TBD-Apx D-002]	EVA Category	Microgravity EVA on an Engineered Spacecraft
Number of Mission	TBD for number of mission [TBD-EVA-Apx D-003]	Type of Suit	xEVA Suit
Quiescent Periods (between missions)	Up to 1 year (~330 days per DSG&T)	Type of LSS (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Total Crew	4	Egress Method	Dual chamber airlock
Vehicle	Mars transit vehicle (DST)	Purpose of Typical EVA	Contingency

Mission Parameters		EVA Parameters	
		Number of EVAs	~1 for each month of mission length
		Duration of EVA (PET)	Up to 8 hours
		Number of Crew EVA	2

TABLE D-5: KEY FOMS FOR EVA ON A CAPTURED ASTEROID

Mission Parameters			
Mission Duration	25-30 days		
Time at Destination	~6 days		
Total Crew	2		
Crew Vehicle	Orion		
Habitation	Orion		
Excursion Vehicle	N/A		
EVA Parameters			
EVA Category	Microgravity EVA on Small Natural Body		
Type of Suit	OCSS		
Type of LSS (PLSS/Umbilical)	xPLSS		
Egress Method	Depressed cabin		
Purpose of Typical EVA	Science		
Number of EVAs	2		
Duration of EVA (PET)	Up to 8 hours		
Number of Crew EVA	2		

TABLE D-6: KEY FOMS FOR EVA ON A NEA

Mission Parameters		EVA Parameters	
Mission Duration	~1 year	EVA Category	Microgravity on Small Natural Surface
Time at Destination	~28 days	Type of Suit	Microgravity xEVA Suit
Total Crew	4	Type of LSS (PLSS/Umbilical)	xPLSS
Crew Vehicle	Orion	Egress Method	Rear-entry dual chamber airlock
Habitation	DST	Purpose of Typical EVA	Science
Excursion Vehicle	SEV	Number of EVAs	10 per mission
		Duration of EVA (PET)	Up to 8 hours

Mission Parameters		EVA Parameters	
		Number of Crew EVA	2

TABLE D-7: KEY FOMS FOR EVA ON THE MOONS OF MARS

Mission Parameters		EVA Parameters	
Mission Duration	~600 days	EVA Category	Microgravity (milli-g) EVA on Small Natural Body
Time at Destination	~30-90 days	Type of Suit	xEVA Suit
Total Crew	4	Type of LSS (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Crew Vehicle	Orion	Egress Method	Dual chamber airlock
Habitation	Phobos Habitat	Purpose of Typical EVA	Science Vehicle Maintenance
Excursion Vehicle	N/A	Number of EVAs	10 per excursion
		Duration of EVA (PET)	Up to 8 hours
		Number of Crew EVA	2

TABLE D-8: KEY FOMS FOR EVA ON THE LUNAR SURFACE

Mission Parameters		EVA Parameters	
Mission Duration	Minimal Stay: <1 day Initial Short Stay: 6.5 days Short Stay: 7-14 days Extended Stay: 42 days Long Duration: 6 months	EVA Category	Partial-Gravity EVA on Lunar Surface in a Vacuum
Number of Missions	4+	Type of Suit	Surface xEVA Suit
Quiescent Periods (between missions)	Minimun Stay: N/A Initial Short Stay: N/A Short Stay: In work Extended Stay: Up to 2 years (~1 year 339 days per DSG&T) Long Duration: Up to 2 years	Type of LSS (PLSS/Umbilical)	xPLSS (part of xEVA Suit)
Total Crew	Minimal Stay: 2 Initial Short Stay: 4 (2 on surface, 2 in Gateway) Short Stay: 4 (all on surface) Extended Stay: 4 (all on surface)	Number of Crew EVA	2-4 for nominal/planned 4 for transfer from/to lander 4 for contingency

	Long Duration: 4 (all on surface)		
Transport Vehicles	Orion (to NRHO) Human Lander (to surface)	Purpose of EVA	Science Maintenance Construction/Pioneering
Habitation	Gateway (in NRHO) Lander (surface) Pressurized Rover (surface) Habitat (surface)	Number of EVAs (per mission)	Sortie: 7-24 Extended Stay: 4-48 Long Duration: 104-208
Excursion Vehicle	Unpressurized Rover Pressurized Rover	EVA Frequency (nominal/scheduled)	Minimum Stay: 1 Initial Short Stay: Daily for 5 days Short Stay: Daily, with rest days after 3-4 EVAs Extended Stay: 4 days per week Long Duration: 4 days per week
		Duration of EVA (PET)	2-8 hours
		Egress Method	Cabin depress from Lander (min hatch of 40”x60”) Airlock/suitlock (min hatch of 40”x60”) from pressurized rover Dual chamber rear-entry airlock (suitlock) (min hatch of 40”x60”) from habitat

TABLE D-9: KEY FOMS FOR EVA ON MARS

Mission Parameters		EVA Parameters	
Mission Duration	~1000 days	EVA Category	Partial-Gravity EVA in Partial-Atmosphere on Mars’ Surface
Time at Destination	~7-540 days	Type of Suit	Mars Surface xEVA Suit
Total Crew	3-6	Type of LSS (PLSS/Umbilical)	xPLSS (part of Mars xEVA Suit)
Crew Vehicle	Orion	Egress Method	Dual Chamber Rear-Entry Airlock (min hatch of 40”x60”) from Lander Dual Chamber Rear-Entry Airlock (min hatch of 40”x60”) from Habitat Rear-Entry Airlock (min hatch of 40”x60”) from Pressurized Rover

Mission Parameters		EVA Parameters	
Habitation	Trans Hab, Lander	Purpose of Typical EVA	Pioneering Science Vehicle/habitat maintenance
Excursion Vehicle	Pressurized Rover	Number of EVAs	Up to 27 hours/week
		Average Duration of EVA (PET)	8 hours
		Number of Crew EVA	2

APPENDIX E
NEXTSTEP APPENDIX H: HLS

Per Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix H (Human Landing System), the following subsections outline some of the details of HLS that impact EVA:

Communication

- On the surface, the crew will need to talk from inside the HLS landed element to the ground, and to the crew on the Gateway.
- For EVA crew on the surface, they can communicate to Gateway and/or Earth through the HLS landed element.
- There is no direct communication link from an EVA crew member to the Gateway or Earth.
- Crew members inside the HLS will need to communicate with the Gateway and Earth both suited and in shirt sleeves.
- During sustainable operations, if there are two crewmembers in the HLS while the other two conduct an EVA, the EVA crew will need to talk to their two surface companions in the HLS.
- EVA crew members may talk directly to each other in their xEMU's.
- During Lunar Surface Operations, the HLS landed elements will support EVA operations via Wi-Fi and UHF Space-Suit communications.
    - Other options may be possible in the sustainable mission phase, such as 5G or LTE.
- Crew communications during EVA will have Wi-Fi as well as UHF for EVA astronaut voice and data.
- An acquisition of signal (AOS) state from the EVA crew to the HLS is presumed to be the operational state for EVA, however, mission rules will have to determine if any LOS time during EVA, caused by distance or blockage, is allowable.
- During EVAs, the HLS will have a direct UHF and Wi-Fi comm link from the suits to the HLS landed element to enable the crew to communicate with the HLS, and by extension, with the Gateway crew and Earth.
- Because HLS will be concurrently communicating with both Gateway and Earth, it means the HLS EVA Suits will be able to communicate with both Earth & Gateway.
- Direct to Earth (DTE) communications from lunar polar locations are subject to multi-path issues and blockages, due to the low angle of Earth over the horizon.
    - DTE communications requires line of site from the HLS landed element to Earth.
    - This condition is highly variable at the lunar poles, with DTE LOS periods being a dynamic condition.

- Communications coverage from Gateway will therefore be crucial for providing adequate AOS communication time for the EVA crew.
- It is possible that lunar communications assets may be available to mitigate these conditions but those are TBD as of now.

EVA Checkout, Prep, and Prebreathe

- In the initial capability phase the Gateway configuration will not have suit servicing hardware, so suit checkout will be done in the HLS, while still docked to Gateway, thus providing access to Gateway suit spares and tooling if needed.
- HLS will have to provide volume to assemble the suits and support pre-form fit and pressure checks prior to descent.
- In the sustainable phase, suit fitting and checks may be done on the Gateway.

Configuration for Lunar Descent

- The crew must begin their pre-breathe operations prior to departing for the lunar surface, with a total of 36 hours of [saturation] required prior to the first EVA.
- Prior to crew ingress of the HLS for descent to the surface, the integrated inhabited space's pressure is reduced to 10.2 psi for a predetermined period of time.
- Once the hatch is closed, the HLS cabin pressure will be reduced to 8.2 psi. After a successful checkout, HLS cabin saturation operations will begin as part of the prebreathe.
- For the initial missions, two crew will descend to the surface, and two will remain at Gateway/Orion. For sustainable phase missions, we expect up to four crew members on the surface. The HLS must support the crew during surface operations, including life support, consumables, power and communications and must enable surface access and EVA.
- The initial mission(s) should not exceed 6.5 days of surface stay. Sustained missions may be of longer surface stay duration.

Departure from Gateway

- Based on current operational planning, the period between final crew ingress and touchdown on the surface is expected to be more than a day.
- As such, the crew will require sleep, and other activities such as meals and biological waste elimination.
- Go/no-go calls and vehicle checkout(s) from the ground and/or performed by the crew will be determined in mission planning.

NRHO to Phasing Orbit

- A loiter in low lunar orbit (LLO), up to three revolutions, will likely be needed either for crew preparation for descent and/or navigation state updates to
- reduce error after the Lunar Orbit Insertion (LOI) burn.
- A nominal transit of 12 hours from NRHO to a 100 km circular LLO is anticipated, but trip time can vary based on final mission designs.

Decent to Surface

- For descent, the crew will wear the xEMU (on umbilicals, without the PLSS).
- The descent from the phasing orbit to the lunar surface will typically consist of four distinct phases.
- A DOI burn will place the HLS in an orbit with a perilune sufficiently low to perform Powered Descent Initiation (PDI).
- The Powered Descent Initiation (PDI) and Braking phase will slow the HLS into a surface-intercepting trajectory and arrest the HLS to a sufficiently low altitude to begin the approach phase.
-
- The Approach Phase typically consists of a pitch maneuver to allow for crew viewing of the landing site.
- The Terminal Descent and Touchdown Phase consists of the final vertical descent to the surface achieving the desired velocity/attitude state for touchdown.
- The duration and profile of these phases will vary with descent trajectory design.

EVA Checkout & Prep on Lunar Surface

- Donning the EVA suit is currently anticipated to take approximately one-hour.
- Based on current analysis, once the crew has donned their suits, the half-hour EVA pre-breathe begins, followed by the cabin or airlock depressurization process.

Airlock & Depress

- Initial EVA ingress/egress capability can only be achieved through an airlock-style option (could be main cabin or separate isolated volume).
- Lander Systems with an isolated EVA ingress/egress volume will not require entire cabin depress for each EVA cycle.
- However, Lander Systems without an isolated EVA ingress/egress volume will require complete cabin depress for each EVA cycle.

Surface Operations

- The surface mission operational intent is to perform EVA's.
- Preparation for EVA's begins before the crew opens the hatch to egress the HLS landed element. EVA preparation time is driven by vehicle atmospheres, oxygen saturation levels, and pre-breath protocols.
- Science EVA plans are in formulation and will grow with capability.
- They are expected to include general scouting, surveying, sampling including rocks, volatiles, and subsurface drilling.
- Other possible science objectives include identification and marking of the highest local terrain.

Dust Mitigation

- The EVA System and Lander System will share responsibility for maintaining dust exposure within the permissible exposure limits.
- Operationally, the crew will perform post-EVA dust mitigation activities external and internal to the lander.
- The exact activities are still being developed but likely include coarse cleaning with EVA System-provided tools prior to ingress and then stowing the suit in a container inside the lander when not in use to minimize loose dust in the vehicle.

Post EVA

- Between EVA's, the suits will have access to HLS resources for maintenance and recharge, including power for batteries, O2, water for cooling, waste water removal and vacuum.

Ascent Prep

- For ascent, the crew will wear the xEMU (on umbilicals, without the PLSS).
- If possible the PLSS will be returned to the Gateway. If necessary the PLSS may be left on the surface.
- These, and any other items that are to be left behind, must be moved to their disposal locations.
- The crew will perform any required vehicle reconfiguration and the vehicle systems will be checked out prior to ascent. Vehicle checkout may be initiated onboard or from the ground, depending on vehicle design, mission planning and flight rules.

Ascent

- Upon completion of the surface mission, the crew will use the HLS to ascend to the Gateway.

- This phase will include a powered ascent phase, similar to a launch to orbit on Earth, a loiter period in a phasing orbit to target a return to Gateway in NRHO, a cruise phase from phasing orbit to NRHO, and a rendezvous and docking phase to connect to Gateway.

Abort

- [For] an aborted landing, the HLS will safely return the crew to the Gateway
- A surface abort may require the crew to shelter in place until the Gateway is in the correct orbital position for an ascent.

APPENDIX F
EVA TASKS FOR EXPLORATION MISSIONS

A variety of both engineering (maintenance and construction) and science tasks will be completed by EVA crewmembers during Exploration missions with the appropriate equipment. These generic tasks include, but are not limited to, the following sections.

TABLE F-1: ENGINEERING TASKS

ET#	ENGINEERING TASKS (ET)
1.0	**Microgravity Translating**
1.1	Egress Airlock
1.2	Attach and Remove/Swap Tethers
1.3	Transporting Tools
1.4	Transporting ORUs
2.0	**Microgravity Maintenance**
2.1	Removing/Installing Fasteners
2.2	Removing/Installing Electrical Connectors
2.3	Removing/Installing Fluid Connectors
2.4	Unforeseen Repair
3.0	**Prepare Rovers for Exploration**
3.1	Offload Equipment from Landers
3.2	Load Equipment onto Rovers
3.3	Clean Equipment
3.4	Checkout Rover Systems
3.5	Maintain Rover
4.0	**Construct Surface Habitat and Infrastructure**
4.1	Transport Tools
4.2	Deploy and Construct Antennas
4.3	Align Antennas
4.4	Grade Regolith
4.5	Route and Connect Power and Communication Lines

ET#	ENGINEERING TASKS (ET)
4.6	Install/Remove Fasteners
4.7	Install/Remove Electrical Connectors
4.8	Install/Remove Fluid Connectors
4.9	Align and Connect Modular Elements
5.0	**Assemble and Maintain Equipment**
5.1	Install/Remove Fasteners
5.2	Install/Remove Electrical Connectors
5.3	Install/Remove Fluid Connectors
5.4	Remove Dust
5.5	Clean Equipment
5.6	Repair Equipment
6.0	**Prepare Ascent Vehicle**
6.1	Offload Equipment from Rovers
6.2	Transfer Equipment and Samples from Rover to Ascent Vehicle
6.3	Clean Equipment

TABLE F-2: SCIENTIFIC TASKS

ST#	SCIENTIFIC TASKS (ST)
1.0	**Conduct Documentation / Perform Context Descriptions**
1.1	Conduct Visual Inspection / Examine Surroundings
1.2	Conduct Photo Documentation
1.3	Conduct Video Documentation
1.4	Place Context/Sampling Markers
2.0	**Sampling**
2.1	Retrieve Sampling Tools and Equipment
2.2	Transport Sampling Tools and Equipment

ST#	SCIENTIFIC TASKS (ST)
2.3	Collect Regolith Samples
2.4	Collect Rock Samples
2.5	Collect Regolith Core Samples
2.6	Collect Rock Core Samples
2.7	Collect Atmospheric Samples
2.8	Collect Surface Samples
2.9	Conduct Trenching for Sub-surface and Wall Sampling
2.10	Collect Volatile and Cryogenic Samples
2.11	Seal/Store Samples
2.12	Transport Samples
3.0	**Instrumentation (Smaller - Hand Operated)**
3.1	Retrieve Instrumentation
3.2	Transport Instrumentation
3.3	Deploy Instrumentation
3.4	Operate Instrumentation
3.5	Perform Instrument Maintenance
3.6	Re-stow Instrumentation
4.0	**Experimental Packages (Larger - Field Deployed)**
4.1	Retrieve Experimental Package
4.2	Transport Experimental Package
4.3	Deploy Experimental Package
4.4	Operate Experimental Package
4.5	Perform Experimental Package Maintenance
4.6	Re-stow Experimental Package
5.0	**Traversing**
5.1	Conduct Navigation / Geo-Locate
5.2	Descend Rocky and Scree Slopes

ST#	SCIENTIFIC TASKS (ST)
5.3	Ascend Rocky and Scree Slopes
5.4	Approach and Access Vertical Exposures (ex. Large Boulders / Vertical Outcrops)
5.5	Access and Traverse Void Spaces (ex. Lava Tubes)
5.6	Access Permanently Shadowed Regions
5.7	Install Milli-Gravity Anchoring System

Examples of microgravity critical contingency (and maintenance) tasks based on the ISS include:

- NH3 Leak Detection and Isolation
- Pump Module (PM) R&R
- Flex Hose Rotary Coupler (FHRC) R&R
- Interface Heat Exchanger (IFHX) R&R
- Electronic Control Unit (ECU) R&R
- Solar Array Wing Manual Positioning
- Bearing Motor Roll Ring Module (BMRRM) R&R
- Ammonia Tank Assembly (ATA) R&R Overview
- Nitrogen Tank Assembly (NTA) R&R
- Main Bus Switching Unit (MBSU) R&R
- External Multiplex/Demultiplexer (EXT MDM) R&R
- DC to DC Converter Unit (DDCU) R&R
- RPCM R&R
- Pressurized Module Micro Meteoroid Orbital Debris (MMOD) Penetration

APPENDIX G
EVA TOOLS & EQUIPMENT

The xEVA System provides a set of tools which are critical to accomplishing the tasks envisioned on an exploration mission. Tools will be provided to support exploration science, vehicle assembly and maintenance, inspection, crew safety, and equipment transport. Common tools, fasteners and vehicle interfaces should be pursued to limit the number of tools required to support all operations. The full tool set will be defined for specific tasks as vehicle designs and exploration concepts of operations mature.

MICRO/MILLI-GRAVITY EVA TOOLS AND EQUIPMENT

In the event of a microgravity EVA, a variety of tools and equipment will be needed to perform EVAs, including, but not limited to:

- Safety Tether (including crew hooks)
- Retractable Equipment Tethers (RET)
- Adjustable Equipment Tether (AET)
- Waist Tethers
- Body Restraint Tether (BRT)
- Modular Mini Workstation (MMWS) or equivalent
- Crewlock bags
- ORU bags
- Trash bags
- Wire ties
- Scissors
- Camera
- Contamination detection kit
- Power driver - such as the Pistol Grip Tool (PGT)
- Ratchet wrench
- Torque wrench
- Socket kit
- Compound cutter
- Needle nose pliers
- Foot restraints
- Small natural body anchoring system

FIGURE G-1: UTILIZING THE PISTOL GRIP TOOL (PGT) DURING AN ISS EVA

SURFACE EVA EQUIPMENT AND TRANSPORT

Tools and equipment utilized during surface EVAs will differ from those used for microgravity operations. Large, heavy tools, such as the PGT, will need to be lighter when used in a partial-g environment. Additionally, science tools will have special cleanliness and material requirements to meet science objectives. Furthermore, dust will be a factor that needs to be accounted for in tool design and maintenance. There will also be a significant difference with how equipment will be transported during surface EVA operations as opposed to in microgravity. In microgravity, tools and bags are restrained on the crewmember via the MMWS, BRT, and various soft tethers. Equipment on surface EVAs will not be able to be carried in that manner due to the effect of the partial-g environment. Surface operations will require EVA crew to transport equipment, especially larger items, to and from a worksite via a caddy/cart that is either manually pulled or robotically driven. Larger equipment needed for EVA tasks can be grouped and stowed together in smaller, detachable transport modules to make operations more efficient. For example, a Drilling Module could include the Power Drill, drill bits, core bits, drill guides and sample containers. A crew member who needs to perform drilling would be able to carry this smaller module to their drilling location and they would have everything they needed to accomplish that task. This architecture could provide added efficiency to the EVA timelines, as opposed to having to continually go back and forth to the larger caddy/cart for each individual tool.

Smaller tools will need to be carried on the EVA suit in a manner that keeps the tools tightly restrained, as opposed to flopping around on a tether. Potential options include a harness to latch tools onto a module attached to the thigh and a module attached to the forearm of the suit. Small tool stowage on the suit would provide fast and easy access to the crew member. Examples of potential small tools carried on the suit include, but aren't limited to the following:

- Forceps
- Snips
- Brushes

- Tongs
- Chisels
- Sample markers
- Zip ties
- Drill bits
- Sockets
- Lights

Longer term exploration of a planetary surface will likely include examination of lava tubes due to their potential use as a radiation shelter and geologic interest. This would present unique challenges of providing equipment capable of lowering suited crew members down into these tubes and safely getting them out. The suit might need to accommodate features like mounting points, face shields, and harnessing locations to safely enable such an endeavor.

SCIENCE TASK EVA TOOLS AND EQUIPMENT

Various tools and equipment will be needed for scientific sampling in both microgravity and partial-g environments.

FIGURE G-2: POWERED AND MANUAL EVA SAMPLE ACQUISITION TOOL CONCEPTS (CORE, CHIP, SOIL, SURFACE)

TABLE G-1: GEOLOGY SAMPLE TYPES

Surface Samples	The fine, top layer (~1mm) of a surface.
Regolith Samples	Loose conglomerate of fine particulate that can usually be retrieved by a scooping action.
Float Samples	Rocks that are loosely adhered to the surface
Chip Samples	Small pieces of rock liberated forcibly from a parent body.
Core Samples	Cylindrical masses of rock drilled out of a parent body.
Trench Samples	Regolith from walls of a trench.

In addition to retrieving and stowing samples, field portable instruments will play a key role in helping to provide in-situ scientific data and high grade samples real-time. The future tool kit will consist of a multitude of tools and equipment including but not limited to:

- Geologic hammering tool (will require impact containment for micro-g)
- Rotary-percussive drill
- Subsurface sampling tool (core tube)
- Surface sampling device
- Soil sampling tool (scoop)
- Float sampling tool (tongs/clamshell)
- Shovel
- Rake
- Sample collection bags
- Sample storage and handling device
- Sealable volatiles and cryogenic container
- Handheld X-ray Fluorescence (hXRF) Analyzer
- Handheld Laser Induced Breakdown Spectroscopy (hLIBS)
- Spectrometer
- X-Ray Diffractometer (XRD)
- Visible Near-Infrared Spectrometer (NVIR)
- Magnetometer (Magnetometry/Magnetic Susceptibility)
- Light Detection and Ranging (LiDAR)
- Multi-View Stereo Photogrammetry (MVSP)
- Visible Near-IR Spectrometer
- Ground Penetrating Radar (GPR)
- Seismometers
- Gravity Meter

COMMON TOOLS AND EQUIPMENT

It is envisioned that each vehicle (spacecraft, rover, or habitat) will carry a small set of IVA and EVA tools that would be able to service each system. This drives each system to design their components with similar fasteners and interfaces to prevent the need to fly unique tools that can only be used on one component. Not only does this concept create efficiencies in hardware preparation and maintenance but limited mass and volume makes this common tool architecture necessary. Each part of the EVA System will adhere to this architecture in which integration will be key. Reference EVA-EXP-0035, Exploration EVA System Compatibility, for a list of common tools.

APPENDIX H
INFORMATICS

Current EVA operations on the ISS depend on near constant and instantaneous communication between MCC and the EV crew. At destinations with signal outages and/or long latencies, Exploration crew will need informatics capabilities and support systems in order to effectively handle the large amounts of information and tasking while conducting efficient EVA operations. The xEVA System will incorporate advanced informatics for Exploration missions beyond low Earth orbit. The informatics will take the form of systems on the xEVA Suit, and on systems within the spacecraft.

An informatics system with heads-up display and fixed electronic display capabilities will ultimately grant the EVA crew more autonomy with both tasks and suit monitoring, and will provide astronauts access to digital data/information, including, but not limited to, the following:

- Procedures
- Location and navigation
- Text communications with both IV and Mission Control Center (MCC)
- Auditory cues
- Diagrams
- Photographs and annotated images
- Videos
- Augmented reality cues, including pre-planned waypoints for navigation and science regions of interest into environment
- Verifying Extravehicular (EV) video framing and looking at EV imagery before/during transmission
- Display of calculated consumables levels to inform the crewmember
- Candidate sample locations for navigation
- Science instrument, sensor, and camera data

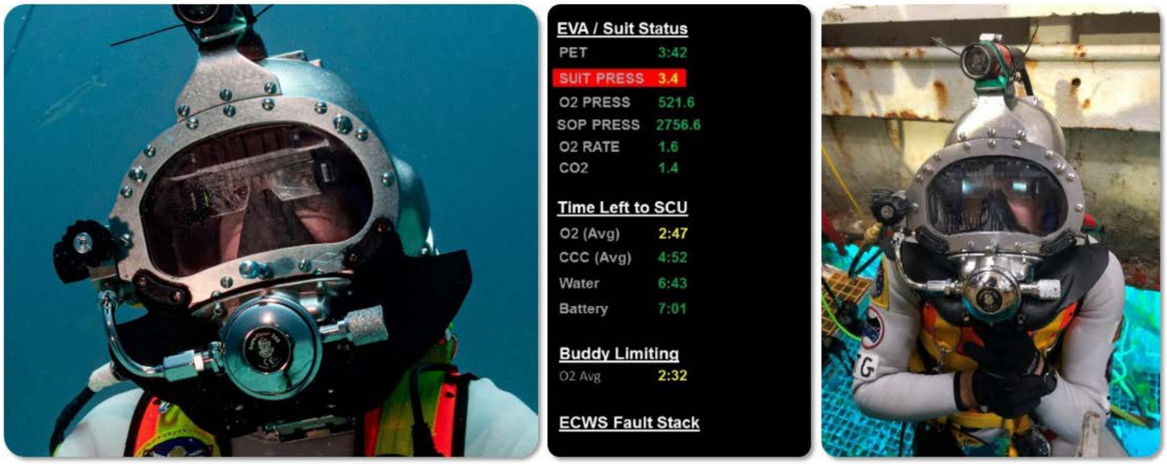

FIGURE H-1: CAPABILITY CONCEPT FOR AN AUGMENTED HEADS-UP DISPLAY SYSTEM

Having real-time operational data enables greater situational awareness allowing for increased efficiency and safety. The xEVA hands-free advanced informatics system (xEVA Informatics) may take on a combination of several potential forms, including things such as a heads-up display, a heads-in display, and/or an electronic cuff display mounted on the arm of the suit. Utilizing these systems, the EVA crew will be able to navigate themselves to specified worksites and mark their location for MCC awareness and future reference. The xEVA Informatics (INFO) capability will allow them to access procedures, schematics, and videos to assist with pioneering, construction, and maintenance activities, in addition to providing the necessary lighting. For science activities, they will be able to reference cue cards, pictures, and imagery that the Science Team has annotated for them. MCC, the Science Team, and IV will also be able to provide the EV crew with augmented reality cues in order to guide them through tasks and point out specific things in the EV crew's field of view. Any informatics system will have to take into account the lighting conditions.

FIGURE H-2: TESTING AN EVA ELECTRONIC CUFF DURING STS-69

APPENDIX I
PRE-ARTEMIS LUNAR MISSION SCENARIOS

The following appendix contains the lunar missions scenarios from revision A of this document.

MINIMAL STAY MISSION ("FLAGS & FOOTPRINTS")

The initial lunar mission will return humans to the surface of the Moon and bring them back safely. This mission will only be a few hours on the surface (much like early Apollo missions) in order to re-rendezvous with Gateway on its current orbit. During this mission, all four crew will descend to the surface and live out of the lander.

Mission parameters and capabilities:

- Surface stay duration: ~12 hours
- Crew to surface: 4
- Egress method: Lander cabin depress
- Crew on EVA: 4
- EVA duration (PET): 2-8 hr
- EVA frequency: 1
- Total number of EVAs: 1
- Rover: None
- Traverse distance from lander: ~1.5 km (< 1 hr walk during ICM rescue) (Note: Apollo 14 walked 1.45 km from lander)
- LEA (OCSS) Suits down/up: 0/0
- xEVA Suits down/up: 4/4
- Science return:
- Limited sampling
- Some handheld instrument measurements
- Emplace single simple long-lived surface experiment

INITIAL SHORT STAY MISSION (LUNAR DAYLIGHT, TWO CREW)

These initial missions to the lunar surface of 6.5 (~7) days in lunar daylight (i.e., constant light) will land humans at high latitude for the first time, explore local features, acquire science samples, set up experiments, and inspire future missions. This initial ~156-hour mission will focus on demonstrated human operations on the lunar surface, in addition to providing science sample return and deployment of long-lived experiment packages. This architecture involves having four crewmembers fly to lunar orbit and dock to Gateway. Two crewmembers will remain in the Gateway cis-lunar facility, while two crew will descend to the surface in the human lander wearing xEVA suits. They will test out surface systems, perform EVAs, and address strategic science and engineering objectives, allowing for exploration of high-interest science sites and demonstration of technology development objectives.The crew on the surface will live in the lander, use the cabin or a severable airlock for egress, and utilize xEVA suits to conduct EVAs of up to 8 hours in duration during local excursions. The crew will have the capability to perform daily EVAs. On any given day, two crewmembers conduct an EVA, with rest days anticipated after three or four days of EVAs, depending on the durations of the EVAs. They will utilize the lander cabin as an egress or a severable airlock on the lander for egress. The EVA crew will traverse on foot nominally up to ~1.5 to 2 km (< 1 hr walk during ICM rescue) from the lander (safe haven), which is similar to the 1.45 km distance that the Apollo 14 walked from their lander.

This initial short stay two-crew con ops does not presume any pre-positioned assets or equipment.

Mission parameters and capabilities:

- Surface stay duration: ~6.5 days (~156 hr during lunar daylight)
- Crew in Gateway: 2
- Crew to surface: 2 to the surface (2 stay on Gateway)
- Egress method: Lander cabin depress or severable airlock
- Crew on EVA: 2
- EVA duration (PET): 4-8 hour excursions (2-crew/EVA)
- EVA frequency: Daily EVAs for 5 days
- Possibility of a rest day
- Possibility of 2 excursions per day (a day's EVA may be split into 2 parts)
- Total number of EVAs: Up to 5 per mission
- Possibility of 10 excursions out of the vehicle if an EVA is split into two parts on a day (10 cycles on suit and airlock)
- Rover: Unpressurized (initial missions)
- Traverse distance from lander: ~7.5-10 km with unpressurized rover (5 hr walk from failed rover) (Note: Apollo 17 traveled 7.6 km from lander)
- xEVA suits down/up: 2/2
- Science return:
- Diverse sample set
- In-situ instrument deployment
- Multiple long-lived experiment packages deployed
- In Situ Resource Utilization (ISRU) demonstration

<u>SHORT STAY MISSIONS (LUNAR DAYLIGHT, FOUR CREW)</u>

This architecture involves having four crewmembers fly to Gateway in lunar orbit, with two then landing on the lunar surface. These ~156-336-hour missions will focus on demonstrating operations on the lunar surface, in addition to providing science sample return and deployment of long-lived experiment packages. Two crewmembers will descend wearing the xEVA suits in the human lander to the surface. On the surface, the crew will utilize xEVA suits to conduct EVAs of up to 8 hours in duration. The crew will live in the lander, utilizing an airlock (likely suitlock) for egress, an unpressurized rover for longer distance excursions from the lander, and a pressurized rover for two crewmember to perform even longer multiday excursions.

The crew on the surface will live in the lander and utilize an unpressurized rover for local excursions, and a prepositioned pressurized rover to live in and conduct EVAs during longer excursions. They will test out surface systems, perform EVAs, and address strategic science and engineering objectives, allowing for exploration of high-interest science sites and demonstration of technology development objectives.

During a lunar daylight sortie, the crew will have the capability to perform daily EVAs. They will utilize a suitlock on the lander or a suitlock on a pressurized rover for egress. Unpressurized roving capability may be available for use on any given sortie. The EVA crew will traverse on foot nominally up to ~1.5 to 2 km (< 1 hr walk during ICM rescue) from the lander (safe haven), which is similar to the 1.45 km distance that the Apollo 14 walked from their lander. When riding on an unpressurized rover, the crew will travel ~7.5-10 km from the lander (~5 hr walk from failed rover), which is similar to the 7.6 km that the Apollo 17 crew traveled from their lander. During operations with a single pressurized rover, two crew will traverse up to ~12 km from the lander (< 8 hr walk back on full suit consumables).

Mission parameters and capabilities:

- Surface stay duration: 14 days (336 hours during lunar daylight)
- Crew in Gateway: 0
- Crew to surface: 4
- EVA frequency: Daily, alternating crew
- EVA duration: 6-8 hours (2-crew/EVA)
- EVA egress:
  - Suitlock/airlock on lander
  - Suitlock/airlock on pressurized rover
- Rover:
  - Unpressurized (local daily excursions)
  - Pressurized (extended multi-day excursions)
- Crew on EVA: 2-4
- 2 EV crew from lander
- 2 EV crew from pressurized rover
- Possibility of conducting EVAs simultaneously from both the land and pressurized rover
- EVA duration (PET): 2-8-hour excursions
- EVA frequency: Daily EVAs during full days on surface
- Possibility of a rest days after 3-4 days
- Possibility of 2 excursions per day (a day's EVA may be split into 2 parts)
- Notional timeline: Landing day, 3 days of EVA, rest day, 3 days of EVA, rest day, 3 days of EVA, rest and ascent prep day, ascent day

- Total number of EVAs: Up to 10 per EV pair possible for a 14-day mission
- Includes 2 rest days
- Total of up to ~20 EVAs possible for both EV pairs
- Possibility of 20 excursions out of the vehicle if an EVA is split into two parts on a day (20 cycles on suit and airlock)
- Traverse distance from lander:
    - ~7.5-10 km with unpressurized rover (5 hr walk from failed rover) (Note: Apollo 17 traveled 7.6 km from lander)
    - ~12 km with a single pressurized rover (< 8 hr walk back)
- LEA (OCSS) suits down/up: 4/4
- xEVA suits down/up: 4/0
- Science return:
    - Diverse sample set
    - In-situ instrument deployment
    - Multiple long-lived experiment packages deployed
- ISRU demonstration

<u>EXTENDED STAY MISSIONS (LUNAR DAY & NIGHT, FOUR CREW)</u>

Extended stays on the lunar surface will allow for accomplishment of the primary science themes. Also, as Mars is the ultimate destination goal for human exploration of the inner solar system, an extended stay mission provides risk reduction and capability development necessary for a Mars surface mission.

The extended stay lunar architecture assumes 42-day missions, occurring over two lunar days and one lunar night (lunar day and night are both approximately equivalent to 15 Earth days). Two pressurized rovers will be pre-positioned for crew habitation on the lunar surface, which allows all four crewmembers to stay on the surface (two each in the two rovers). Rovers would allow long range traverses away from the lander. The rover pairs will operate together to complete science objectives, while always staying within rescue range of each other. This rescue range is the distance from which the rescuing rover can reach the EV crew (from other rover) and get them to a safe configuration within one hour (capability of secondary suit consumables). Scientific exploration activities, including EVA, are expanded to include long-range traverses away from the landing site with the aid of surface mobility assets.

Unlike the short stay missions where EVA dominates the surface operations, a more balanced schedule of EVA and IVA occurs during longer duration crew missions. This is primarily due to the fatiguing nature of EVA over the long-term, but it is also attributable to consumable availability on the surface to support the EVAs. During the surface stay, EVAs will nominally be conducted by crews of two, however the crew has the capability to conduct EVAs with all crewmembers on the surface simultaneously. EVAs will be conducted to gather scientific samples and demonstrate in-situ resource utilization techniques.

Per the ISECG May 2018 draft con ops, a lunar campaign mission scenario is as follows:

- 1st pre-deploy mission lands two pressurized rovers (mobility & habitation)
- 2nd delivers cargo for first human mission
  - One large cargo mission
  - One small cargo mission
- 3rd mission delivers Human Lunar Lander to Evolvable Deep Space Habitat in cislunar space
- Next mission lands four crew in Human Lunar Lander near the two pressurized rovers
- 42 days on surface - two lunar days and one lunar night
- Two crew in each pressurized rover
- Stay within 100 km of ascent vehicle during lunar day (exact distance still in work)
- Stay within 1 km of ascent vehicle during lunar night (exact distance still in work)
- Conduct three - four EVAs each week (per rover crew pair)
- Pressurized rovers are controlled from Earth to autonomously traverse to next landing site between crewed missions

Mission parameters and capabilities:

- Surface stay duration: 42 days during 2 lunar days & 1 night
- Crew in Gateway: 0
- Crew on surface: 4
- Egress method:
  - Suitlock/airlock on lander
  - Suitlock/airlock on rover
- Rover: Pressurize
- Crew on EVA: 2-4
- 2 EV crew from each rover, alternating EVA days
- All 4 go EVA for transfer from/to the ascent vehicle
- EVA duration (PET): 2-8-hour excursions
- EVA frequency: 3-4 EVA days per week per EV pair for 42 days (6 weeks)
- EV pair alternate EVA days
- Possibility of 2 excursions per day (a day's EVA may be split into 2 parts)
- Total number of EVAs: Up to 48 EVAs per mission
- Up to 24 EVAs per rover (EV pair)
- Includes 3-4 rest days each week for each rover crew (EV pair)
- Possibility of 48 excursions out of each vehicle/rover if an EVA is split into two parts on a day (48 cycles on suit and airlock)
- Traverse distance from lander:
  - ~7.5-10 km with unpressurized rover (5 hr walk from failed rover) (Note: Apollo 17 traveled 7.6 km from lander)

- ~12 km with a single pressurized rover (< 8 hr walk back)
- >100 km with dual pressurized rovers

- LEA (OCSS) Suits down/up: 4/4
- xEVA Suits down/up: 4/0
- Science return:
    - Diverse sample set
    - In-situ instrument deployment
    - Multiple long-lived experiment packages deployed
- ISRU demonstration

<u>LONG DURATION MISSIONS (SUSTAINED HUMAN PRESENCE)</u>

A Long Duration Mission is designed to provide additional exploration capability, but may also be used for outpost construction, maintenance of outpost or other surface assets, or to provide logistics. This mission will involve building an infrastructure and will include a habitat and two pressurized rovers for crew habitation on the lunar surface. This type of mission will also likely include unpressurized rovers for traverses closer to the habitat, and for longer and quicker traverses than can be done on foot. In addition, there may be more robotic assets that can assist the EVA crew. EVA tools and sampling protocols would be evaluated.

These missions will also act as a “Mars Test on the Moon” and may extend a 42-day campaign mission to six months or more. Each crewmember will conduct three to four EVAs per week. These missions will likely involve considerable maintenance of the suits, and the crew will need an area to perform that work on the suit.

Mission parameters and capabilities:

- Surface stay duration: 42 days during 2 lunar days & 1 night
- Crew in Gateway: 0
- Crew on surface: 4
- Egress method:
    - Suitlock/airlock on lander
    - Suitlock/airlock on rover
    - Suitlock/airlock on habitat
- Rover: Pressurize
- Crew on EVA: 2-4
- EVA frequency: 3-4 EVAs per week for 6 months
- EVA duration (PET): 2-8-hour excursions
- Total number of EVAs: Up to 48 EVAs per mission
- 1-2 EVAs per day (a day’s EVA may be split into 2 parts)
- Total of 104-208 EVAs per mission (104 for single EVA in a day, 208 if an EVA is split into two parts on a day)
- Crew on EVA: Nominally 2
- Potential to have 1, 3, or 4 crew on an EVA

- All 4 go EVA for transfer from/to the ascent vehicle

APPENDIX J
DOCUMENT TREE & INFORMATION FLOW FOR XEVA SYSTEM CON OPS

This appendix shows both the systems engineering & integration (SE&I) document tree and the information flow for the xEVA system concept of operations.

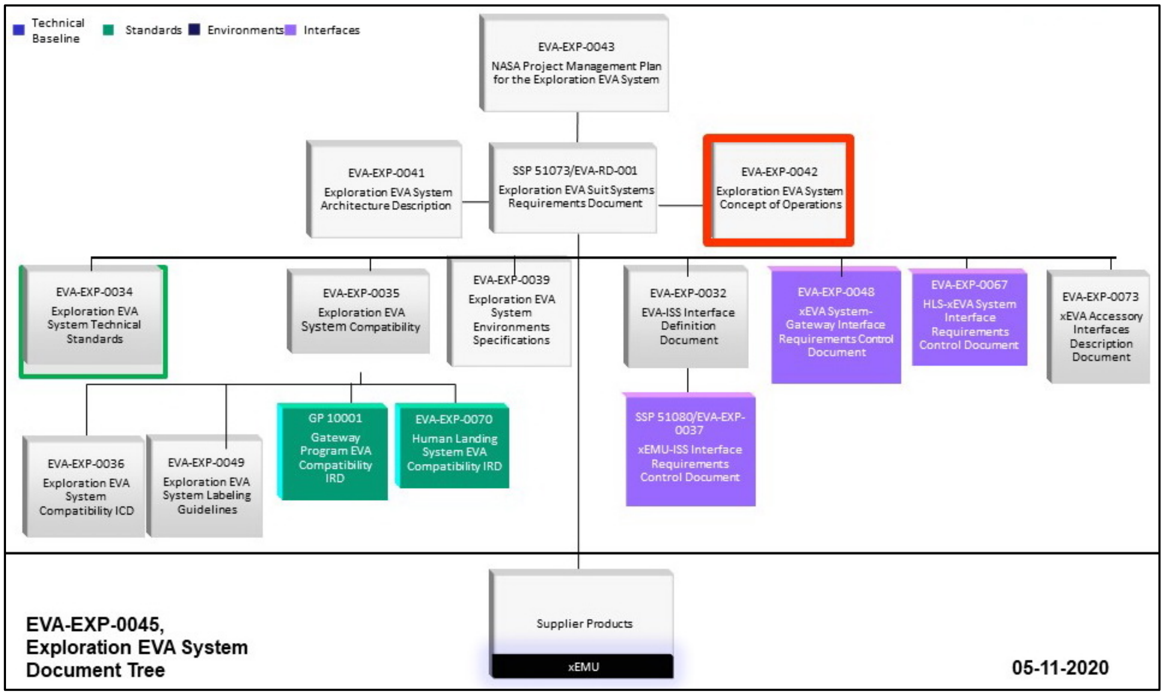

FIGURE J-1: XEVA SYSTEM DOCUMENT TREE PER EVA-EXP-0045

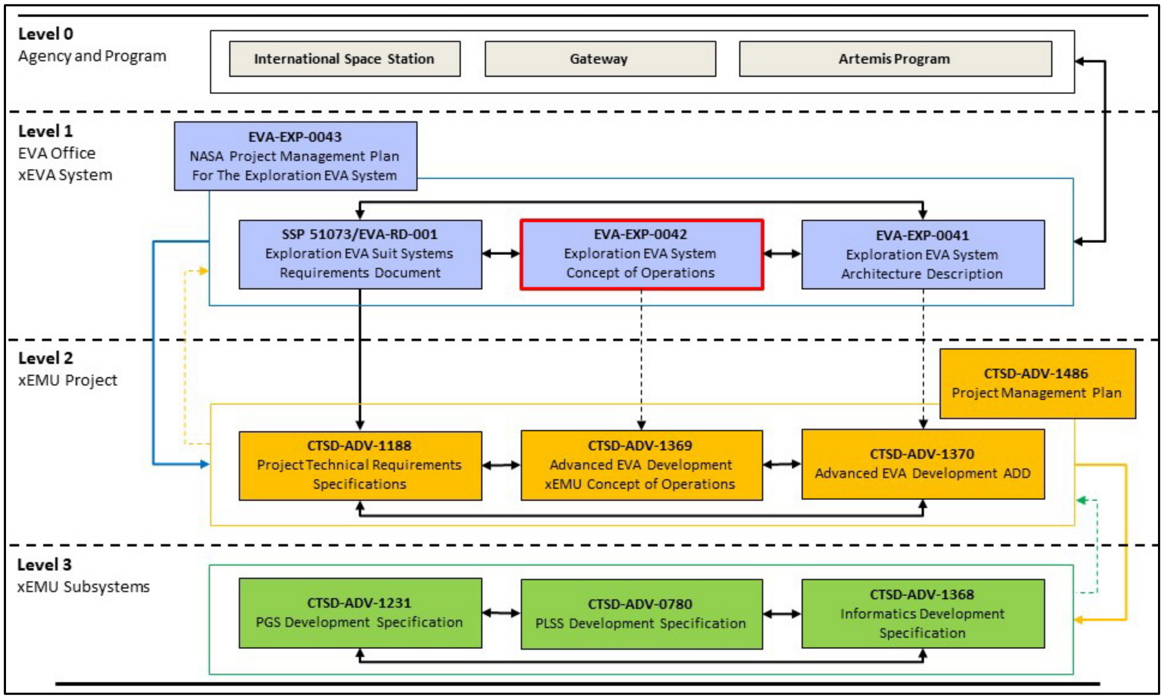

FIGURE J-2: XEVA SYSTEM INFORMATION FLOW FOR THE CON OPS