National Aeronautics and Space Administration

Moon to Mars Architecture Update

NASA Advisory Council: Joint HEO-Science Committee
July 13, 2022

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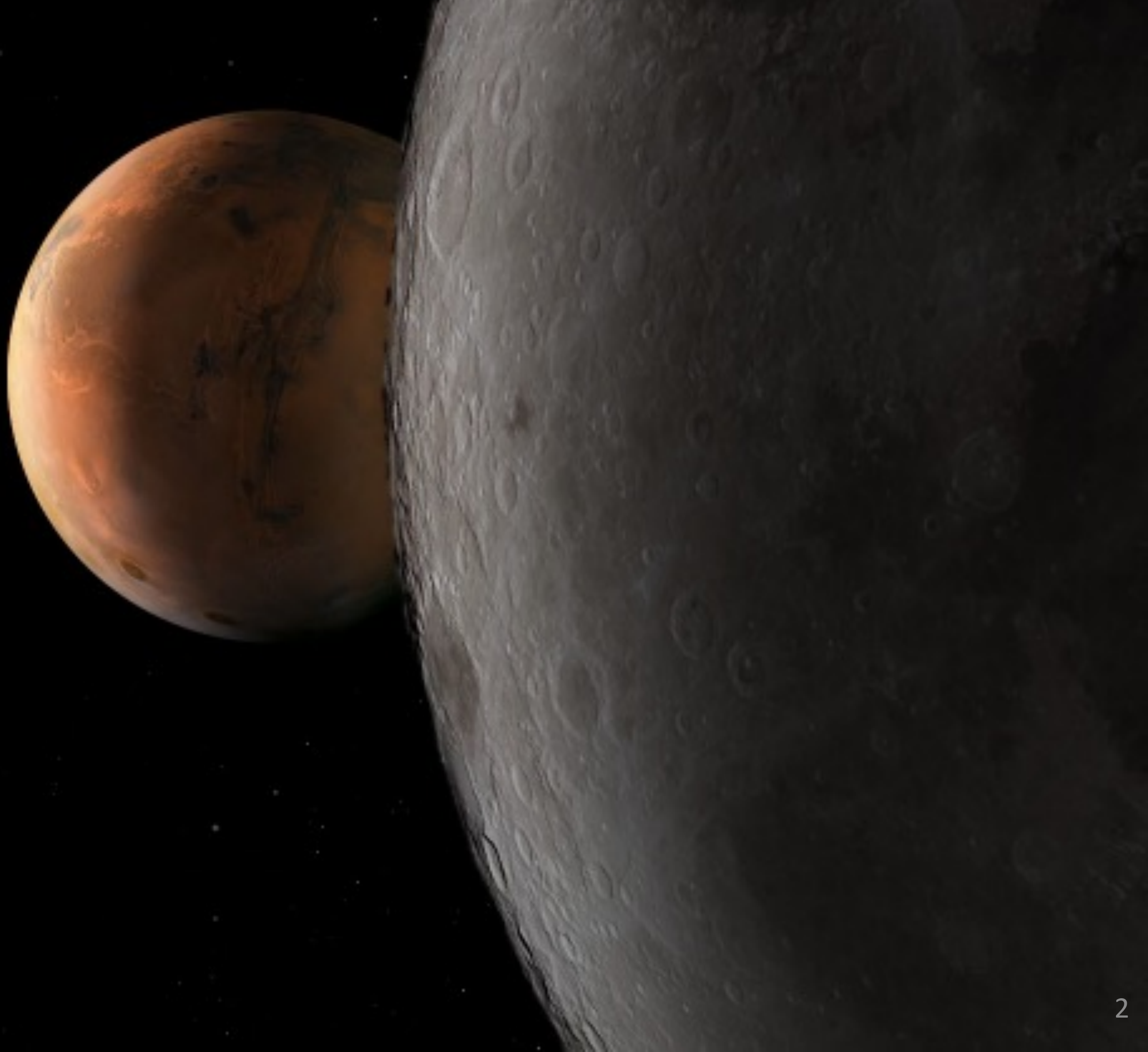
“The United States will Maintain its Leadership in Space Exploration and Space Science”

“Remain a global leader in science and engineering by pioneering space research and technology that propels exploration of the Moon, Mars, and beyond.”

“U.S. human and robotic space exploration missions will land the first woman and person of color on the Moon, advance a robust cislunar ecosystem, continue to leverage human presence in low-Earth orbit to enable people to live and work safely in space, and prepare for future missions to Mars and beyond.”

— The White House U.S Space Priorities Framework, Dec 2021



[United States Space Priorities Framework]
[NASA 2022 Strategic Plan]
[2023 NASA Budget Request]

Human Exploration Focus

SCIENCE

Connects all elements
The "why"

Enables architecture
Ex: In-situ Resource Utilization

Incorporation of Decadal Level Science

ANNUAL LUNAR SURFACE MISSIONS

2025-2031
2 Crew | 6.5-14 days

2031+
4 Crew | 30 days

MARS

Analogs
Space Station | Moon

Robotic Sample Return
Volatiles

EXPANDING PARTNERSHIPS

International
Existing and New Partners

Industry
Economic Development

Other Government Agency Partners (DOE, NSF, NIH)

NASA's Moon to Mars Objectives

A blueprint for future human exploration

SCIENCE

Conduct science on and around the Moon, using humans and robots to address scientific priorities about the Moon.

Demonstrate future science methods astronauts can use beyond Low Earth Orbit:

- Lunar/Planetary
- Heliophysics
- Biological/Physical
- Astrophysics

TRANSPORTATION AND HABITATION

Develop and demonstrate an integrated system to conduct human missions.

Live and work at deep space destinations and safely return to Earth.

LUNAR AND MARS INFRASTRUCTURE

Maintain continuous robotic and human presence on the Moon with multiple international and industry users to develop a robust lunar economy.

Create infrastructure to support initial human Mars demonstration and to continue exploring the solar system.

OPERATIONS

Conduct human missions on and around the Moon followed by missions to Mars.

Use a gradual approach to build, demonstrate, and operate new technologies to live and work on other planetary bodies.

Requested feedback on these objectives in summer 2022 from the following key stakeholders:

NASA workforce: our greatest asset

International partners: our key current and future, anticipated collaborators

U.S. industry, academia, DOE, NIH, NSF, etc.: our national leaders in space research and capabilities

Moon to Mars Objectives Workshops

Space Center Houston
June 28-29, 2022

NASA experts assessed more than 4,400 individual comments received from 900+ commenters to the draft Moon to Mars Objectives and invited 32 U.S. organizations for further discussions based on their feedback.

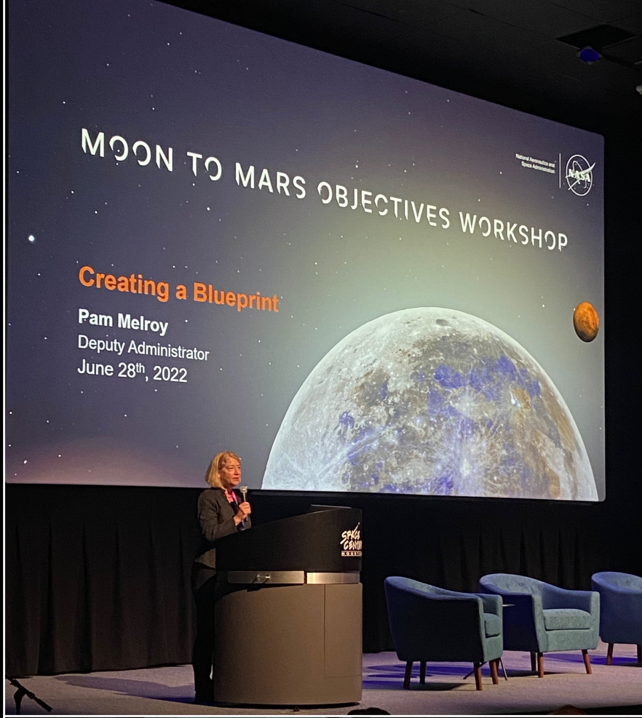
The NASA Subject Matter Experts were represented by cross-directorate team members.

Royal Institution, London
July 20-21, 2022

Workshop is hosted by the U.K. Space Agency.

NASA invited 37 agencies to a multilateral international workshop to refine NASA's draft Moon-to-Mars exploration objectives.

NASA is planning to host a mission directorate panel representing ESDMD, SOMD, STMD, and SMD



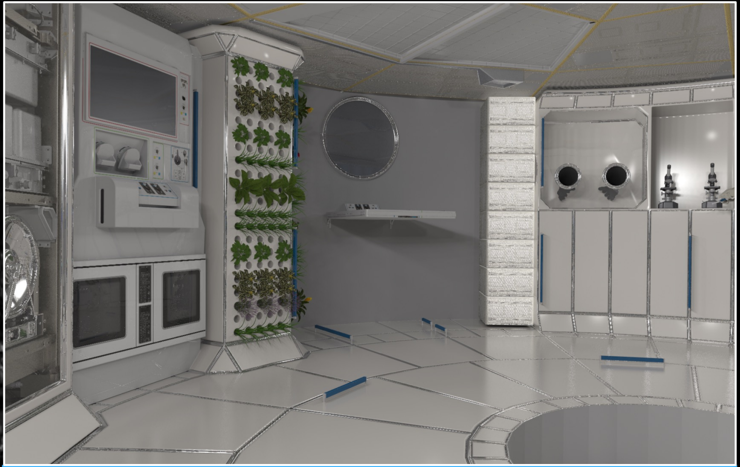
Architecture

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

TRANSPORTATION

In Space:
- SLS
- Orion
- Commercial Launch Providers

To/On the Surface:
- Human Landing System
- Lunar Terrain Vehicle
- Pressurized Rover



HABITATION & LIFE SUPPORT

In Space:
- Orion
- Gateway HALO
- Gateway I-Hab

On the Surface:
- Human Landing System
- Spacesuits
- Surface Habitat
- Pressurized Rover

INFRASTRUCTURE

In Space:
- PPE: Comm and Power
- Deep Space Logistics Deliveries
- LunaNet

On the Surface:
- Fission Surface Power
- Logistics and Science Deliveries

Updates to the Architecture Process

Organization
- As part of the new ESDMD, the architecture office has established its internal structure

Decadal
- With science as our focus, we will work with SMD on responses to and implementation on portions of decadal

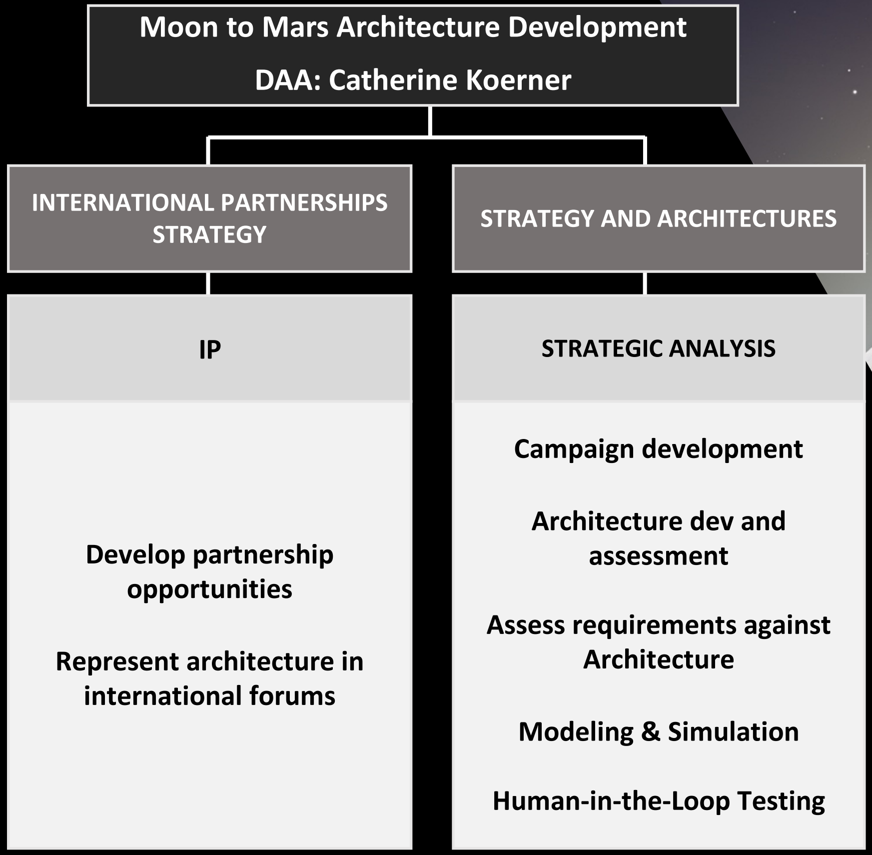
New International Elements
- ASI – Signed study agreement for pressurized element(s)
- Japan – Continued focus on Pressurized Rover
- ESA – Lunar Surface elements and surface science

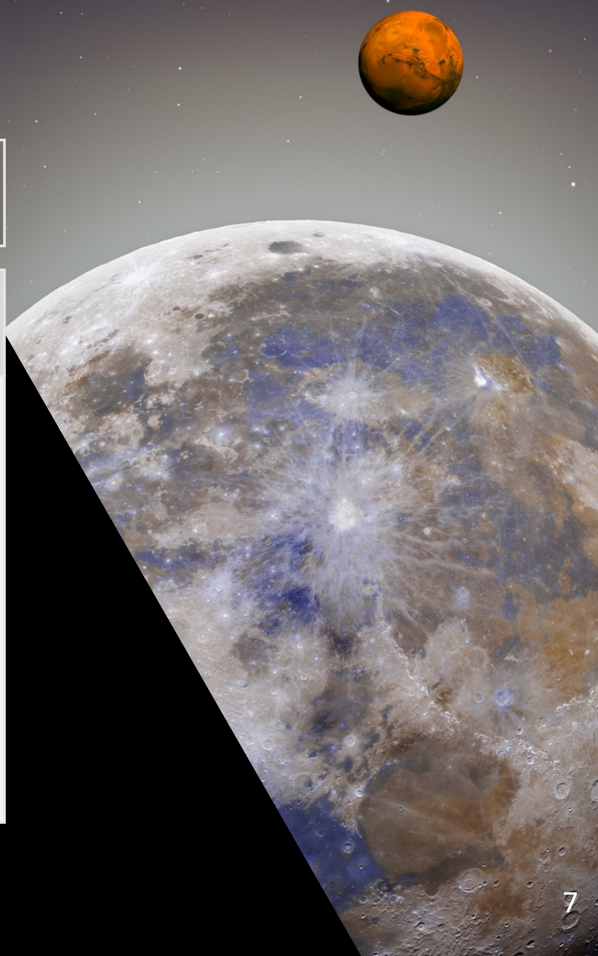
Landing Sites
- Continuing to refine landing site list to refine mission planning and element development for Artemis III

Architecture Concept Review
- Closeout of the objectives integration effort and gap analysis will be an NASA Internal Architecture Concept Review with results shared externally

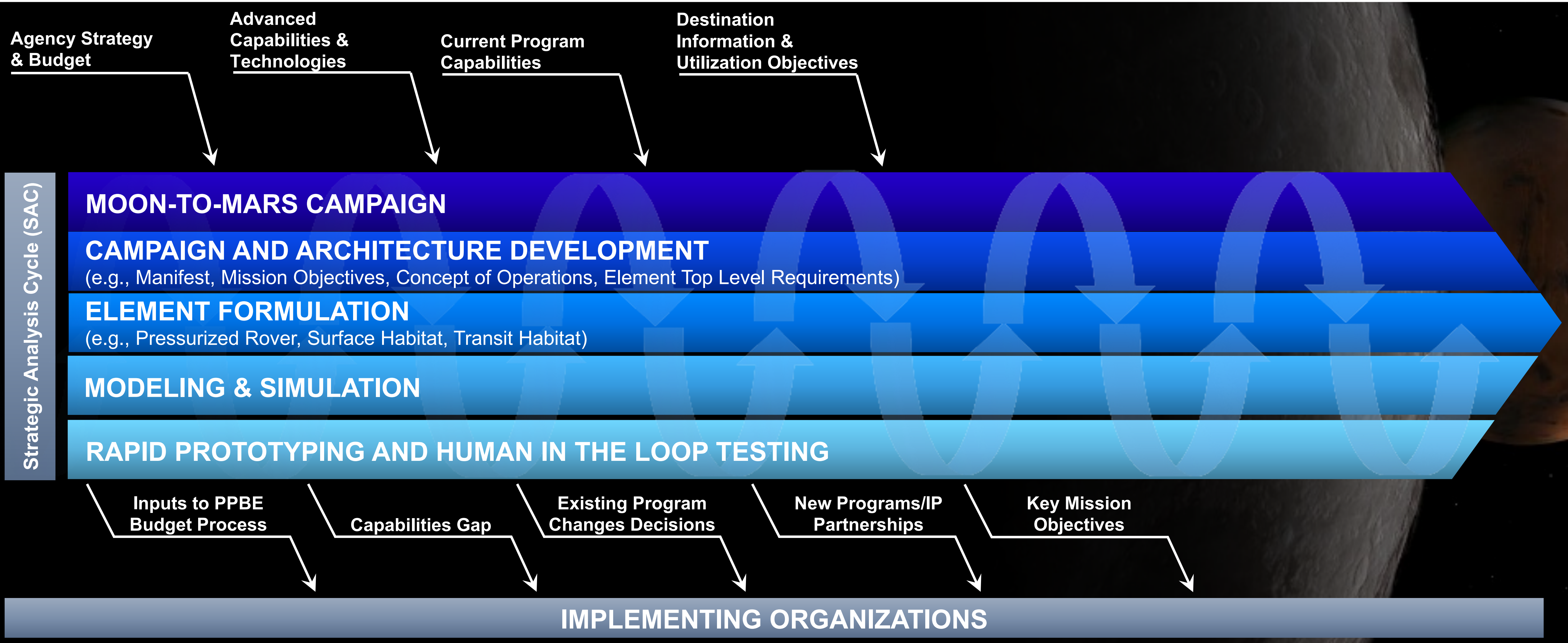
White Papers
- NASA Deputy Administrator has asked ESDMD to deliver a series of short white papers on various aspects of the architecture. Those will begin after the completion of the ACR.

Procurements
- Awarded suits; Sustainable Lander in process; Future elements (e.g. LTV in work)

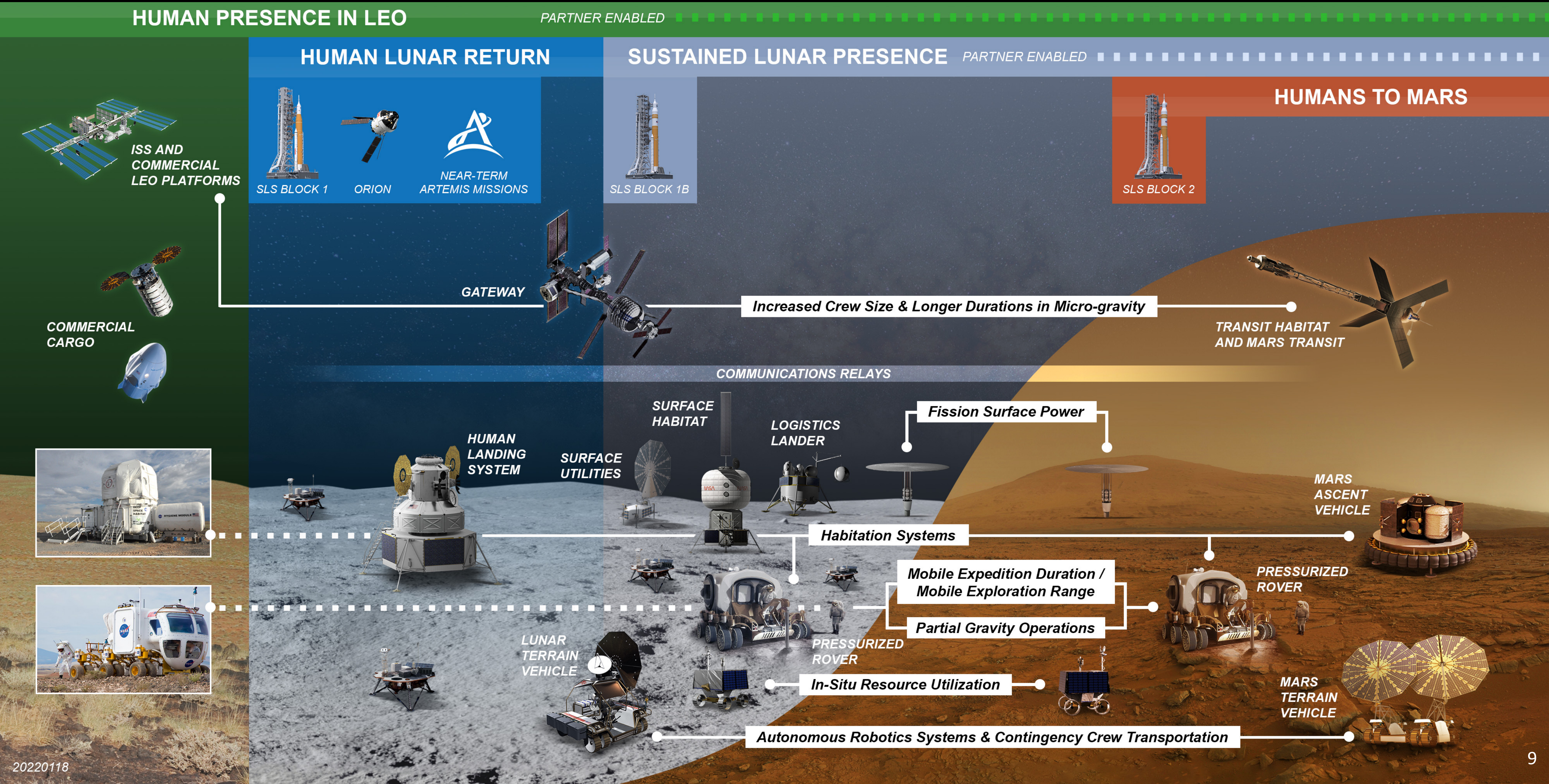




Moon to Mars Architecture and Element Development and Refinement



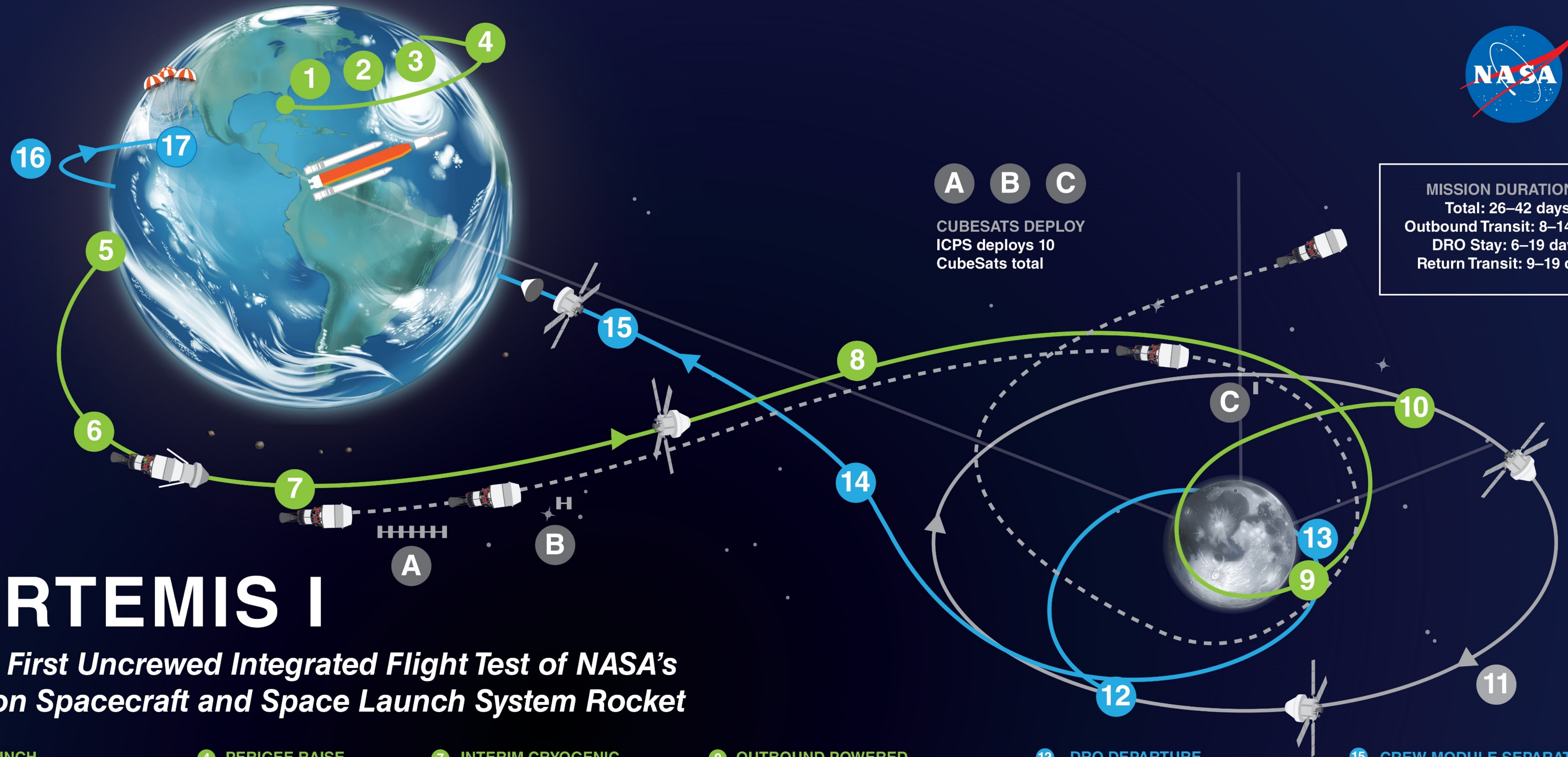
Exploration Campaign & Segments



ARTEMIS I

ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket



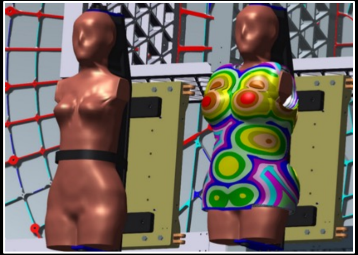
MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

1. **LAUNCH**
   SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **EARTH ORBIT**
   Systems check with solar panel adjustments.
6. **TRANS LUNAR INJECTION (TLI) BURN**
   Maneuver lasts for approximately 20 minutes.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
   ICPS commits Orion to moon at TLI.
8. **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
   As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9. **OUTBOUND POWERED FLYBY (OPF)**
   60 nmi from the Moon; targets DRO insertion.
10. **LUNAR ORBIT INSERTION**
    Enter Distant Retrograde Orbit.
11. **DISTANT RETROGRADE ORBIT**
    Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12. **DRO DEPARTURE**
    Leave DRO and start return to Earth.
13. **RETURN POWERED FLYBY (RPF)**
    RPF burn prep and return coast to Earth initiated.
14. **RETURN TRANSIT**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
17. **SPLASHDOWN**
    Pacific Ocean landing within view of the U.S. Navy recovery ship.

Artemis I Payloads

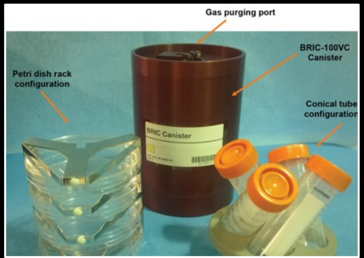
Science and technology investigations and demonstrations paving the way for future, deep space human exploration

Radiation Sensors
There will be three types of sensors, including the ESA Active Dosimeters, Hybrid Electronic Radiation Assessor, and the Radiation Area Monitor.

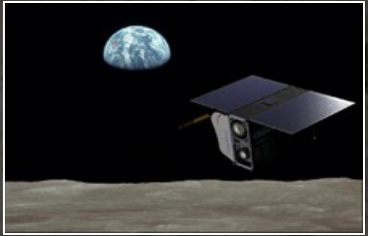


MARE
Radiation shielding Personal Protection Equipment (radiation vest) for astronauts.

Crew Interface Technology Payload (CITP)
Creates an interactive experience between Orion and the public during the mission

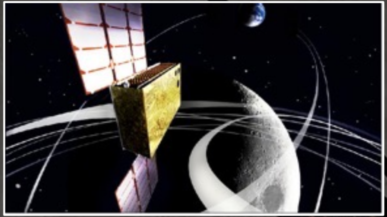


Bio-Experiment-1
Battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO)

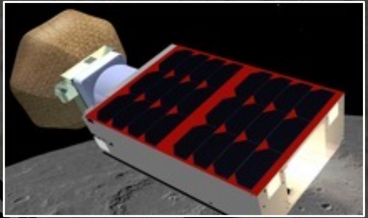


ArgoMoon

LunaH-Map



EQUULEUS



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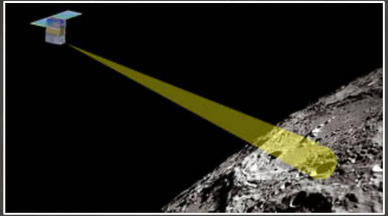
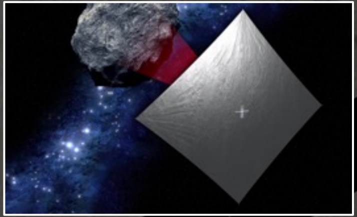
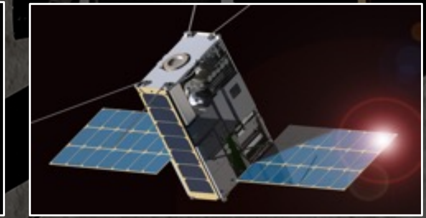


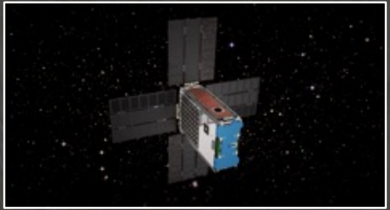
LunIR



Near-Earth Asteroid Scout (NEA Scout)

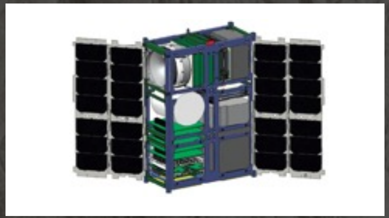


Lunar IceCube



BioSentinel

Team Miles



CuSP

ARTEMIS II

ARTEMIS II CREW MODULE
KENNEDY SPACE CENTER

ARTEMIS II BOOSTER MOTOR
SEGMENTS COMPLETE

ARTEMIS II RS-25 ENGINES COMPLETE

ARTEMIS II SERVICE MODULE
KENNEDY SPACE CENTER

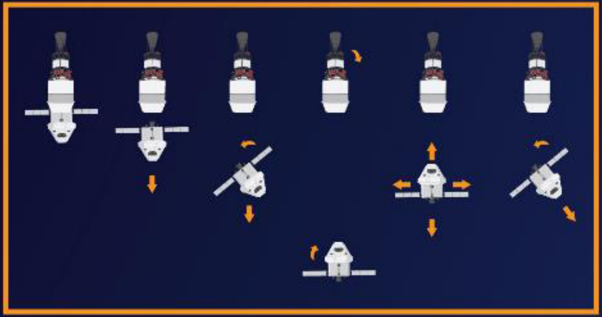
ARTEMIS II 4/5 CORE STAGE ASSEMBLED

ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

1. **LAUNCH**
   Astronauts lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **APOGEE RAISE BURN TO HIGH EARTH ORBIT**
   Begin 24 hour checkout of spacecraft.
6. **PROX OPS DEMONSTRATION**
   Orion proximity operations demonstration and manual handling qualities assessment for up to 2 hours.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) DISPOSAL BURN**
8. **HIGH EARTH ORBIT CHECKOUT**
   Life support, exercise, and habitation equipment evaluations.
9. **TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
   Lunar free return trajectory initiated with European service module.
10. **OUTBOUND TRANSIT TO MOON**
    4 days outbound transit along free return trajectory.
11. **LUNAR FLYBY**
    4,000 nmi (mean) lunar farside altitude.
12. **TRANS-EARTH RETURN**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
13. **CREW MODULE SEPARATION FROM SERVICE MODULE**
14. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
15. **SPLASHDOWN**
    Ship recovers astronauts and capsule.

PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE

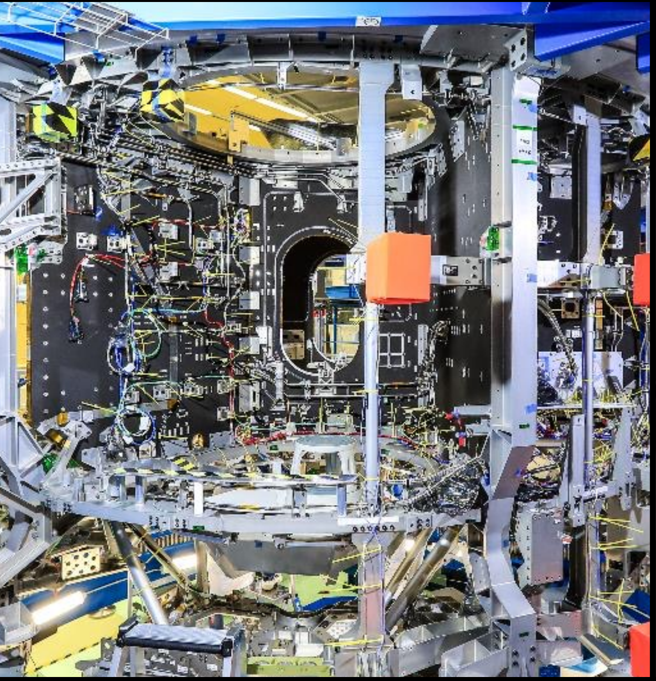


ARTEMIS III

ARTEMIS III CREW MODULE
KENNEDY SPACE CENTER

ARTEMIS III RS-25 FLIGHT
SET PROCESSING

ARTEMIS III
CORE STAGE LH2 TANK



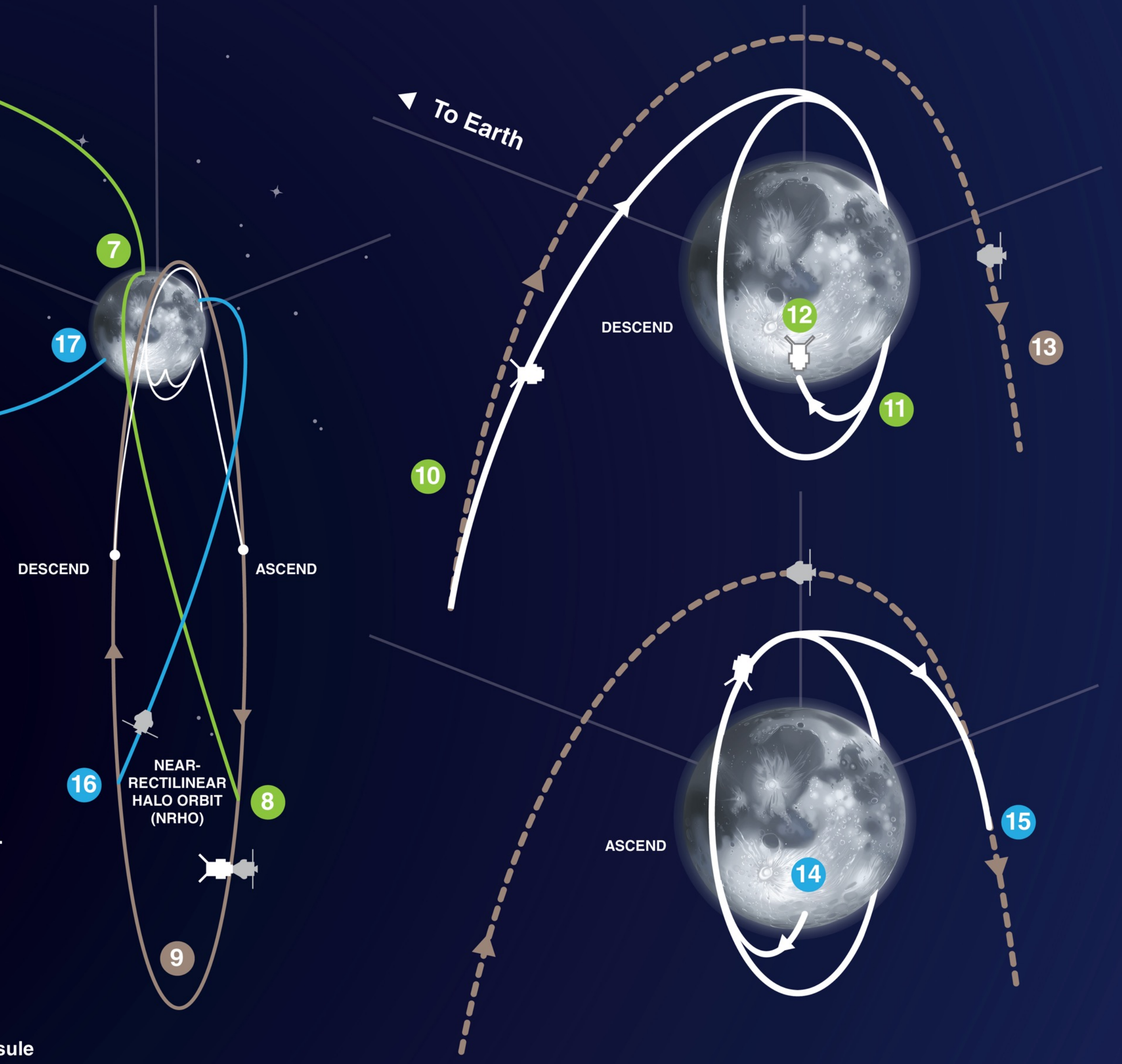
ARTEMIS III ESM3
BREMEN, GERMANY

ARTEMIS III BOOSTER SEGMENTS

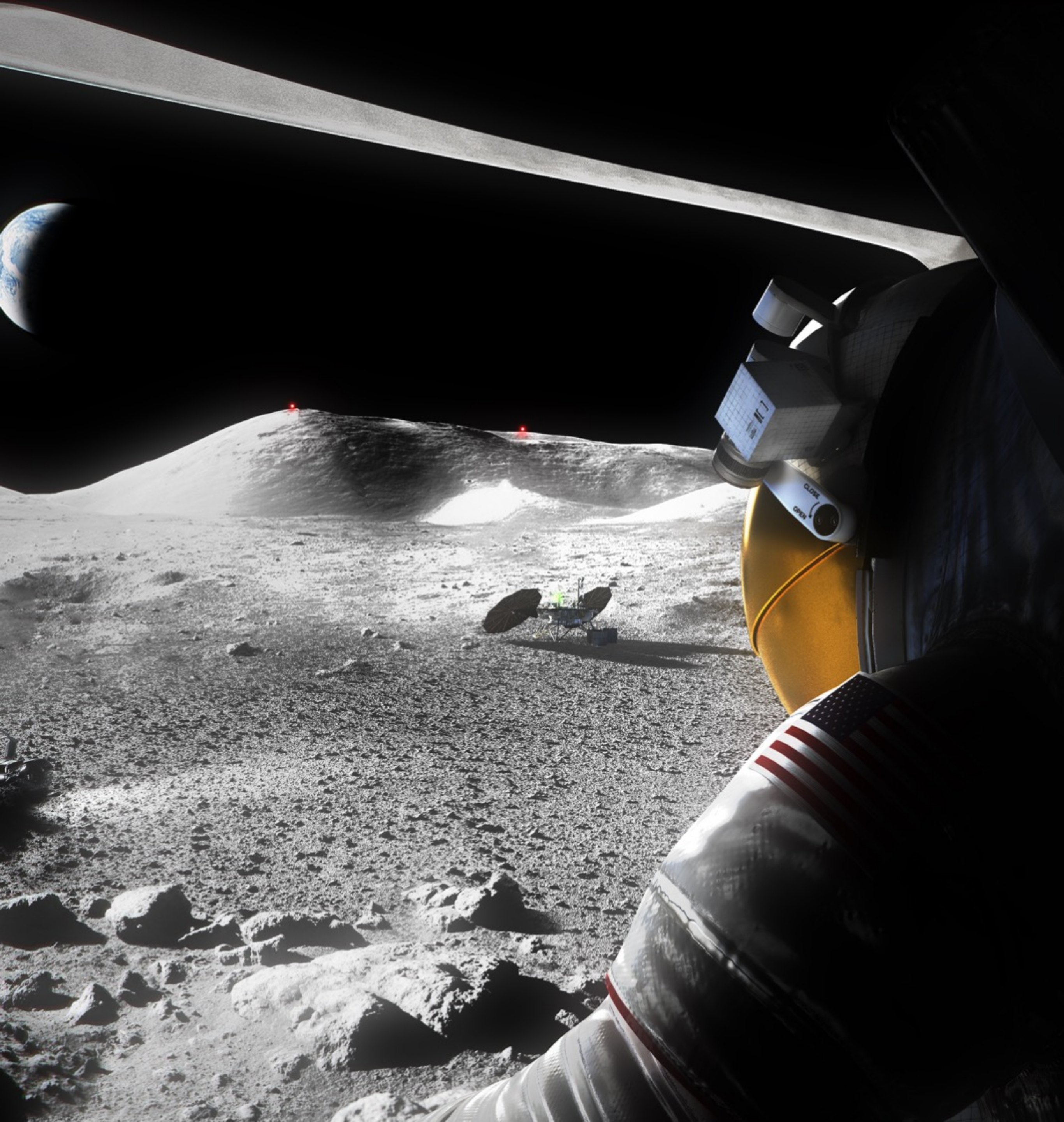
ARTEMIS III ICPS

ARTEMIS III

Landing on the Moon

1. **LAUNCH**
   SLS and Orion lift off from Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **ENTER EARTH ORBIT**
   Perform the perigee raise maneuver. Systems check and solar panel adjustments.
5. **TRANS LUNAR INJECTION BURN**
   Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.
6. **ORION OUTBOUND TRANSIT TO MOON**
   Requires several outbound trajectory burns.
7. **ORION OUTBOUND POWERED FLYBY**
   60 nmi from the Moon.
8. **NRHO INSERTION BURN**
   Orion performs burn to establish rendezvous point and executes rendezvous and docking.
9. **LUNAR LANDING PREPARATION**
   Crew activates lander and prepares for departure.
10. **LANDER UNDOCKING AND SEPARATION**
11. **LANDER ENTERS LOW LUNAR ORBIT**
    Descends to lunar touchdown.
12. **LUNAR SURFACE EXPLORATION**
    Astronauts conduct week long surface mission and extra-vehicular activities.
13. **ORION REMAINS IN NRHO ORBIT**
    During lunar surface mission.
14. **LANDER ASCENDS TO LOW LUNAR ORBIT**
15. **LANDER PERFORMS RENDEZVOUS AND DOCKING**
16. **CREW RETURNS IN ORION**
    Orion undocks, performs orbit departure burn.
17. **ORION PERFORMS RETURN POWERED FLYBY**
    60 nmi from the Moon.
18. **FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**
    Precision targeting for Earth entry.
19. **CREW MODULE SEPARATION FROM SERVICE MODULE**
20. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
21. **SPLASHDOWN**
    Ship recovers astronauts and capsule



Human Landing System

HLS

Sustaining Lunar Transport

Using proven commercial partnership strategies, NASA is working with U.S. industry to build towards regular human lunar landings.

Companies will develop human landing systems and NASA will purchase transport services, while maintaining oversight to ensure safety standards are met.

Advanced SUITS

- Increased flexibility for exploring new regions and advanced sample collection
- Increased size range and modular design accommodate a wider range of crew members
- Rechargeable systems enable more spacewalks and longer stays on surface
- Specialized tools to collect quality samples and returned them safely to Earth
- NASA has selected Axiom Space and Collins Aerospace to build the next generation of spacesuit and spacewalk systems

Pictured left: Artist's render of an astronaut inspecting potential locations to collect samples on the lunar surface

Exploration Extravehicular Activity (xEVA) Systems Development: Not Just Spacesuits

Advanced suits (Exploration Extravehicular Mobility Units or xEMUs)

- Portable Life Support Subsystem (xPLSS) which contains CO_2 removal and thermal control
- Pressure garment subsystem (xPGS)

Vehicle interfaces (VISE)

- Physical interfaces and support equipment such as don/doff fixtures, launch enclosures, umbilicals, battery chargers, and maintenance equipment

Tools and equipment

- Geology equipment for sample collection
- Construction tools for maintenance activities
- Translation support like handrails

Pictured left: ARGOS Suit and tong tool
Pictured right: NASA Astronaut Jessica Meir in an xEMU

GATEWAY

NASA

CSA ASC

esa

JAXA

GATEWAY

Capability

NASA and its international partners will add modules and capabilities, evolving a robust orbiting laboratory and a home away from home for astronauts on their way to and from the lunar surface. The Gateway will serve as a test bed and staging point for future human exploration into deep space.

Power and Propulsion Element (PPE)

- High-power solar electric propulsion spacecraft
- Transfers the initial capability to lunar orbit
- Establishes a communications relay with Earth
- Maintains the Gateway's orbit

Habitation and Logistics Outpost (HALO)

- Houses up to 4 crew for up to 30 days (with Orion)
- Provides high-rate lunar communication relay to support lunar surface activities and command and control systems for Gateway
- Docking port for visiting spacecraft and future modules

Canadian Space Agency (CSA):
External robotics system, robotic interfaces, and end-to-end robotic operations

European Space Agency (ESA):
International Habitat (I-HAB) and refueling modules, along with enhanced lunar communications

The Japan Aerospace Exploration Agency (JAXA):
I-HAB's environmental control and life support system, batteries, thermal control, and imagery components

Early Gateway Science Payloads

Launched with PPE and HALO

ERSA – ESA's radiation instrument package:

- Helps keep astronauts safe by monitoring the radiation exposure in Gateway's unique orbit.

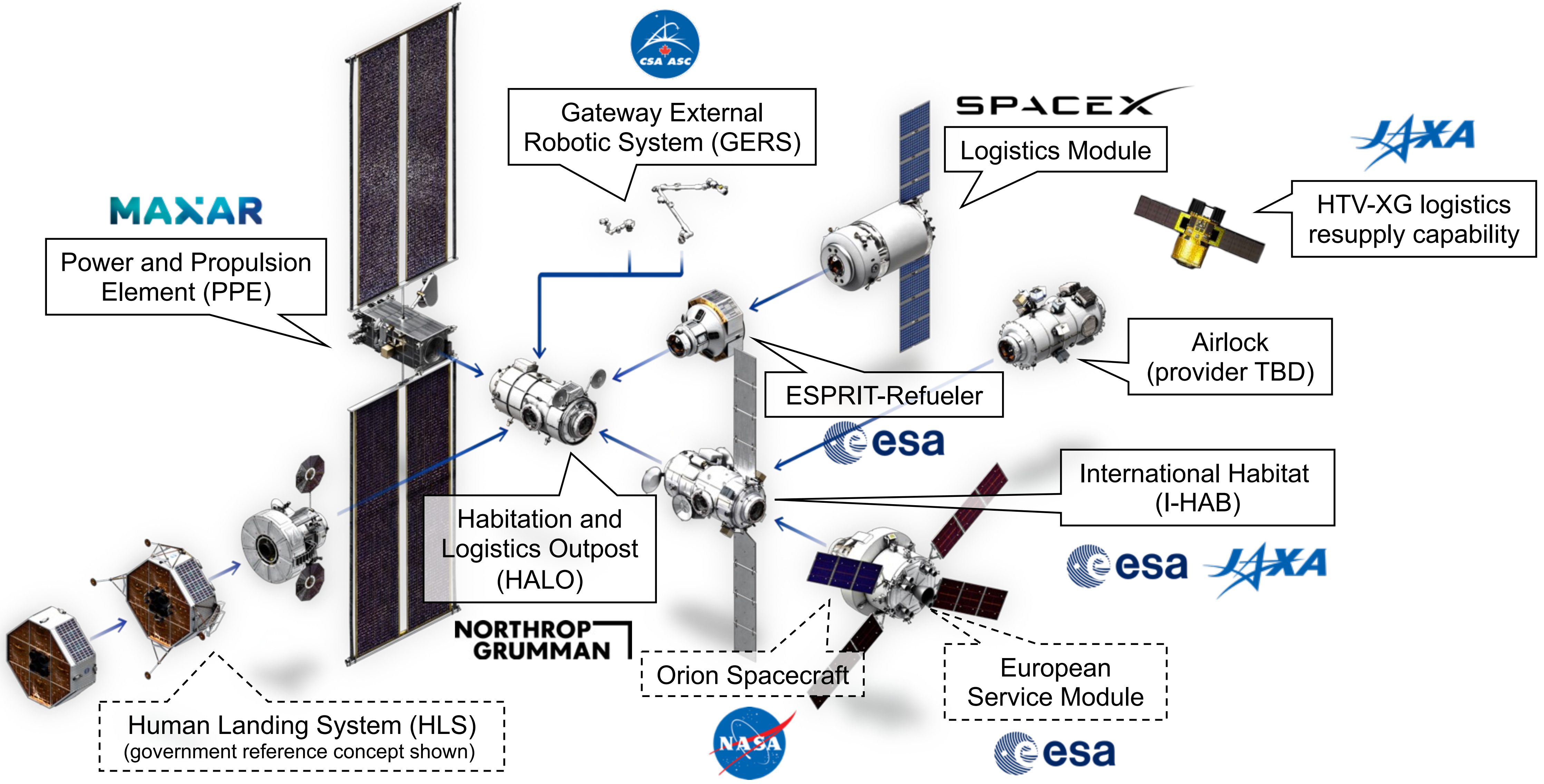
ESA Internal Dosimeter Array:

- Includes instruments provided by the Japan Aerospace Exploration Agency
- Data provided will allow for the study of radiation shielding effects and improve radiation physics models to help assess crew risk on exploration missions.

HERMES:

- NASA's space weather instrument suite will observe solar particles and solar wind created by the Sun.

Gateway Integrated Spacecraft

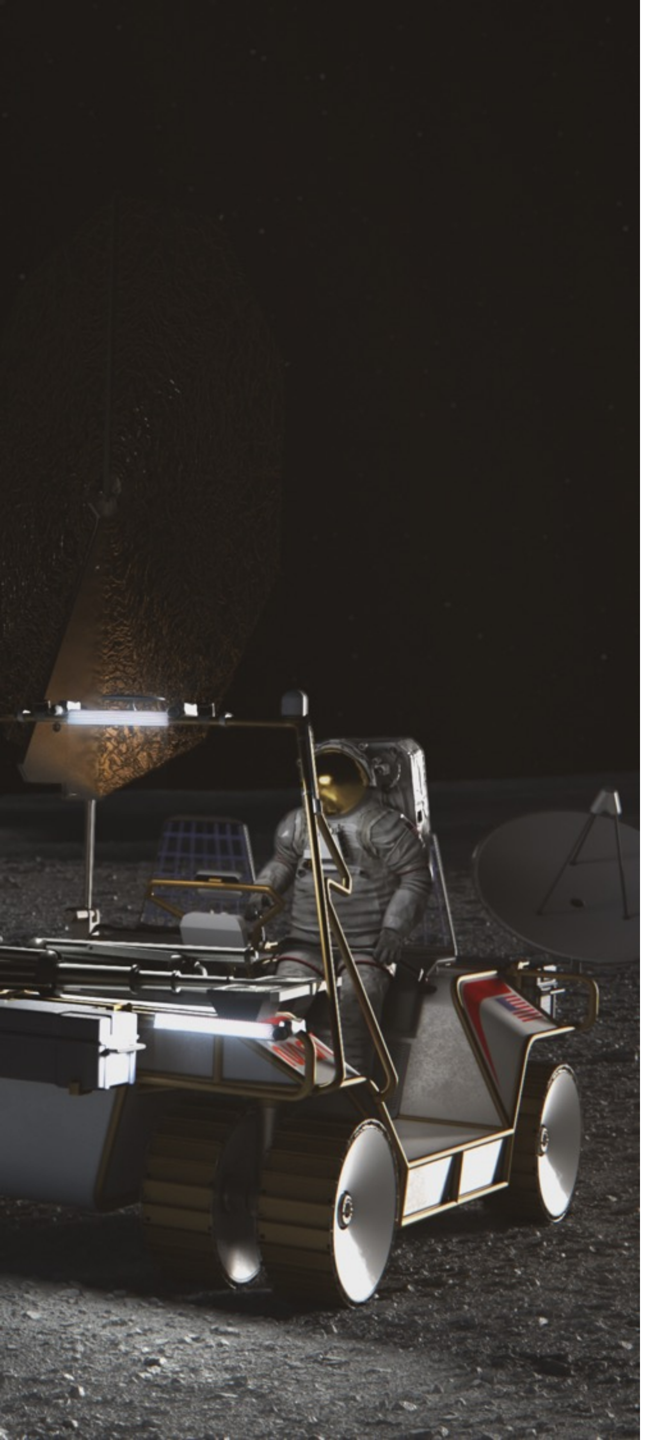


Apollo Mission Sample Collection

	Apollo 11	Apollo 12	Apollo 14	Apollo 15	Apollo 16	Apollo 17	Total
Mission Class	G	H	H	J	J	J	---
Hours on surface	21.5	31.5	33.5	67	71	75	299.5
Number of EVAs	1	2	2	3	3	3	14
Mode of transportation	Walking	Walking	Walking with MET	LRV	LRV	LRV	---
Approximate max distance from landing site	0.062 km	0.45 km	1.4 km	4.7 km	4.4 km	7.5 km	18.5 km
Number of samples	58	69	227	370	731	741	2,196
Weight of samples (kg)	21.8	34.3	42.3	77.3	95.7	110.5	381.7
Mass of Tools & Sample Containers (kg)	22.85	29.17	43.07	50.29	53.03	45.69	---

Mission Classes
G: The initial lunar landing mission
H: Precision manned lunar landing demonstration and systematic lunar exploration.
J: Extensive scientific investigation of Moon on lunar surface and from lunar orbit.

MET: Modular Equipment Transporter
LRV: Lunar Roving Vehicle



Lunar Terrain Vehicle

LTV

Requirements definition is in-work

- Ability to traverse from one landing zone to another and increase exploration range beyond maximum suited walking distance
- Reusable and rechargeable for approximate 10-year service life
- Remote operation from Human Landing System, Gateway, and Earth
- Interface with future science instruments and payloads for utilization or pre-deployment of assets
- Ability to survive eclipse periods

Developing LTV: Survive the Night

- The lunar South Pole is massively cratered, with areas bathed in sunlight and shrouded in darkness
- The craters are brutally cold but elevated areas can grow extremely hot
- NASA has initiated a new study to identify options for addressing lunar night survival
- Potential design solutions will be generated by an internal team and industry partners
- LTV will need to survive up to 100 hours of darkness with at least a 10-year lifespan

Pictured left: Artist’s render of LTV on the lunar surface

The lunar South Pole is massively cratered, with areas that are bathed in sunlight and shrouded in darkness. The craters are brutally cold but elevated areas can grow extremely hot.

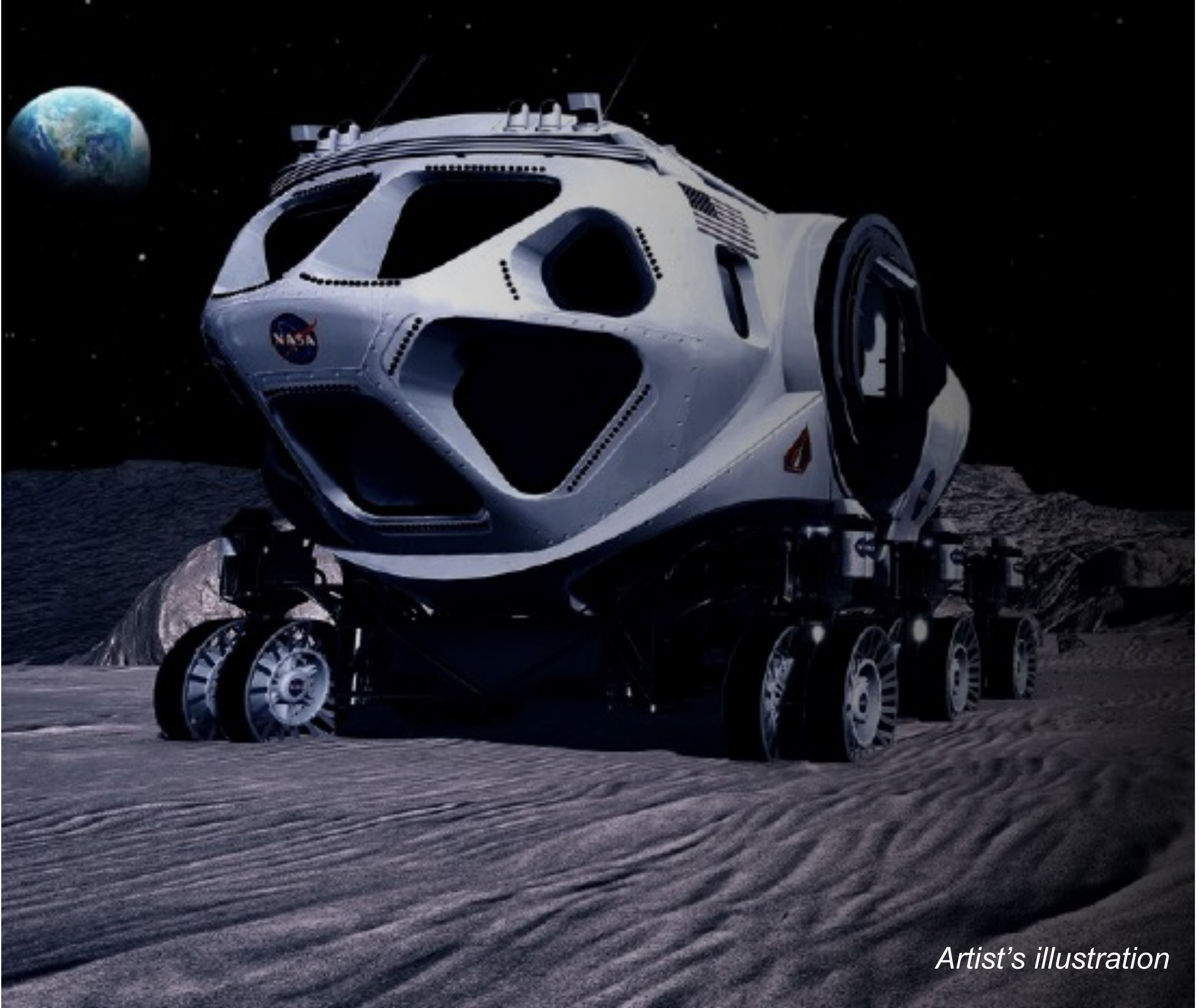
These extremes present new challenges.

Developing LTV: Survive the Night

- Like many spacecraft, the Lunar Terrain Vehicle (LTV) will be solar powered
- Analysis indicates a “follow the sun” strategy will not be feasible in the Moon’s South Pole regions
  - NASA has initiated a new study to identify options for addressing lunar night survival
  - Potential design solutions will be generated by an internal team and Industry partners
    - LTV will need to survive up to 100 hours of darkness with at least a 10-year lifespan

Pictured left: Apollo 15 mission commander David R. Scott with the Lunar Roving Vehicle on the edge of Hadley Rille (Rima Hadley) during the first moonwalk of the mission.

Pressurized Rover

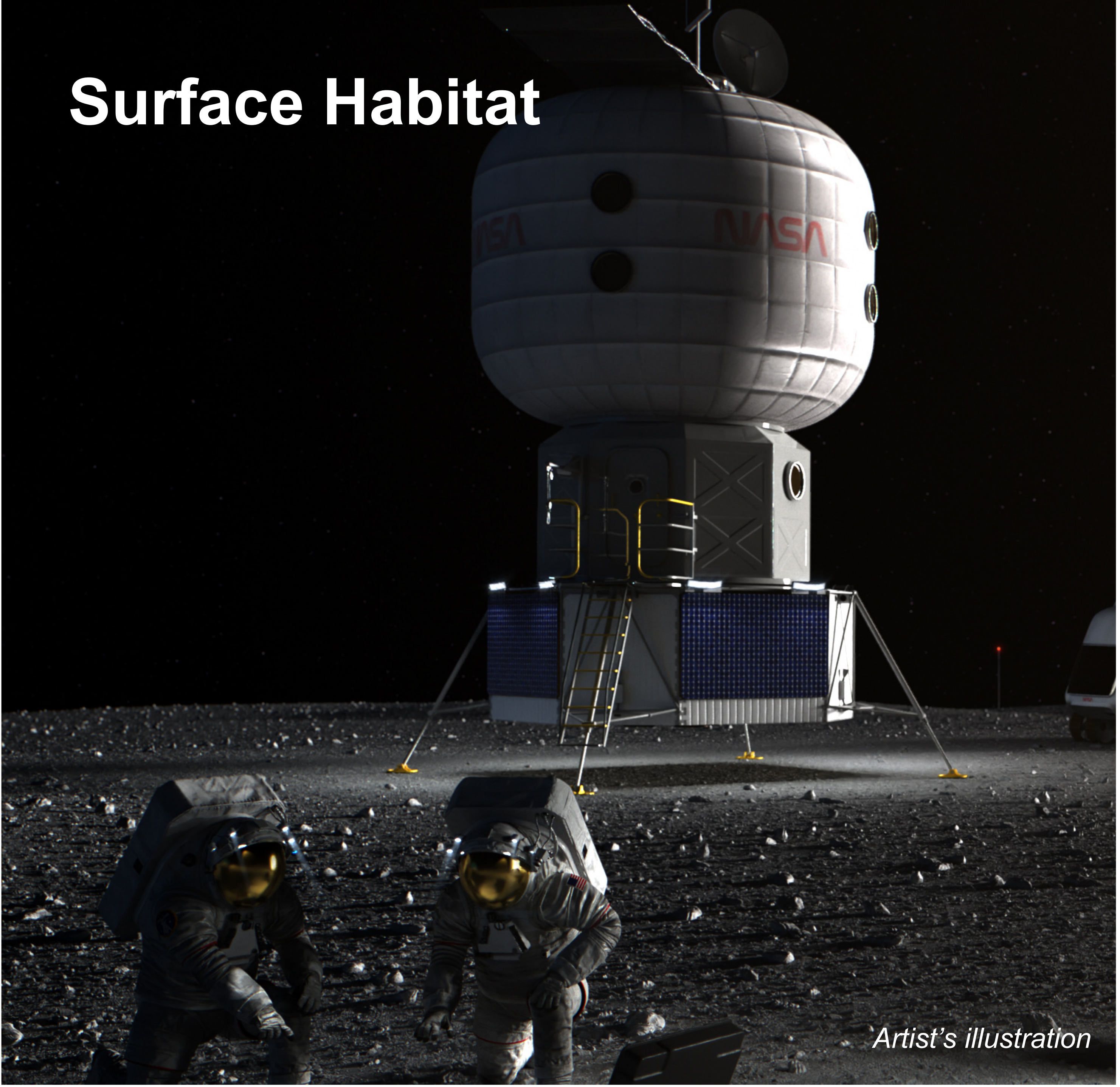


Artist's illustration

Provides pressurized mobile habitation to enable long-range surface exploration in shirtsleeve environment and access to surface.

- Habitation for 30 days for 2 crew
- Ability for crew to analyze samples in-situ and prioritize materials for return to Earth
- Provides volume for spares and logistics
- Power generation and energy storage for lunar environment
- Dust and radiation protection
- Reuse for multiple missions of 10-year lifetime
- Capability also identified in current concepts for first human mission to Mars

Surface Habitat



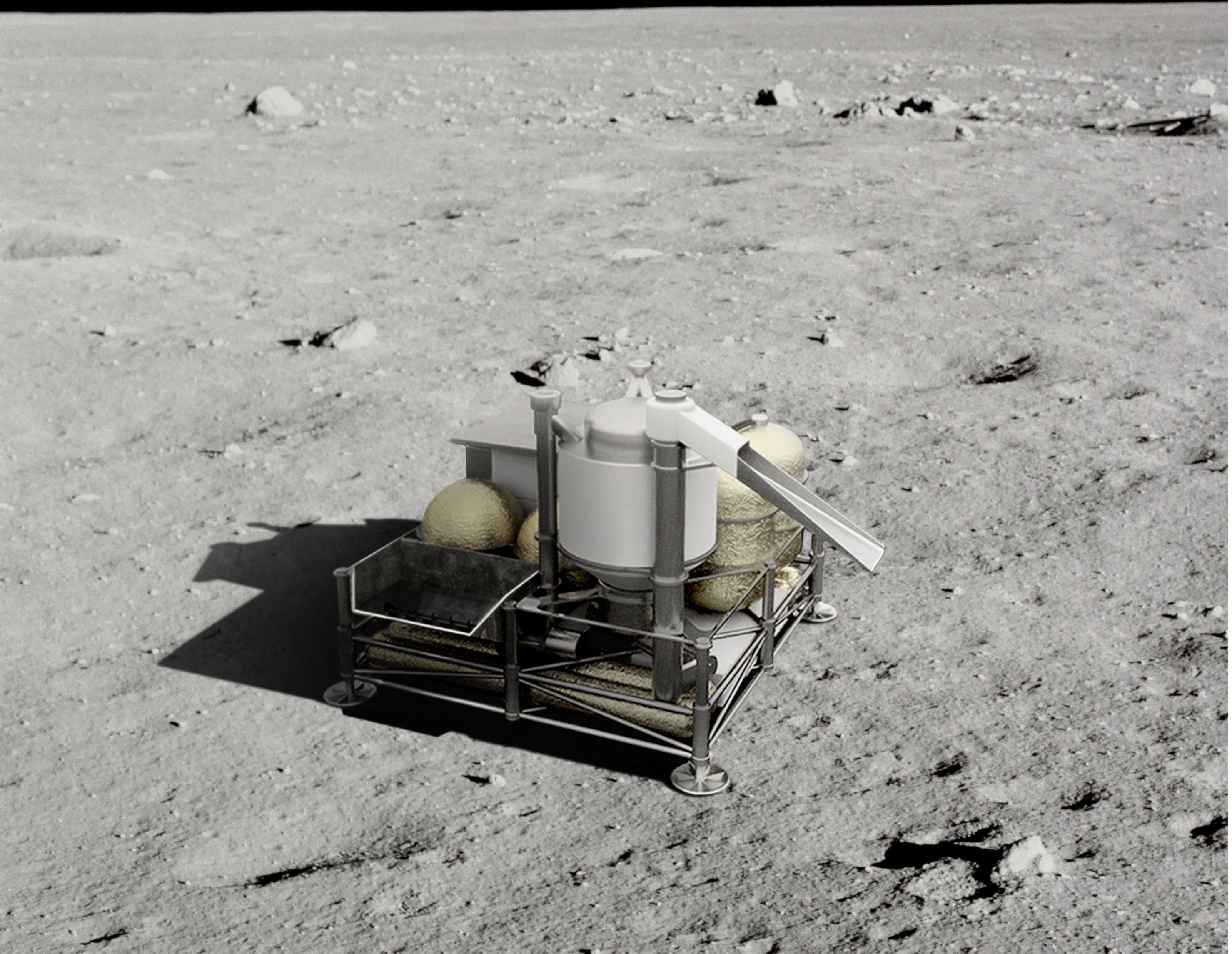
Artist's illustration

Envisioned as a primary asset to achieve a sustained lunar presence.

NASA is working with industry to develop conceptual designs for the Surface Habitat.

- 2-4 crew – medical, exercise, galley, crew quarters, stowage
- 30-60 day capable habitat
- EVA capable with suit maintenance capability
- Recharge capability for surface assets
- Communication hub for surface assets
- Reuse for multiple missions of 15 year lifetime

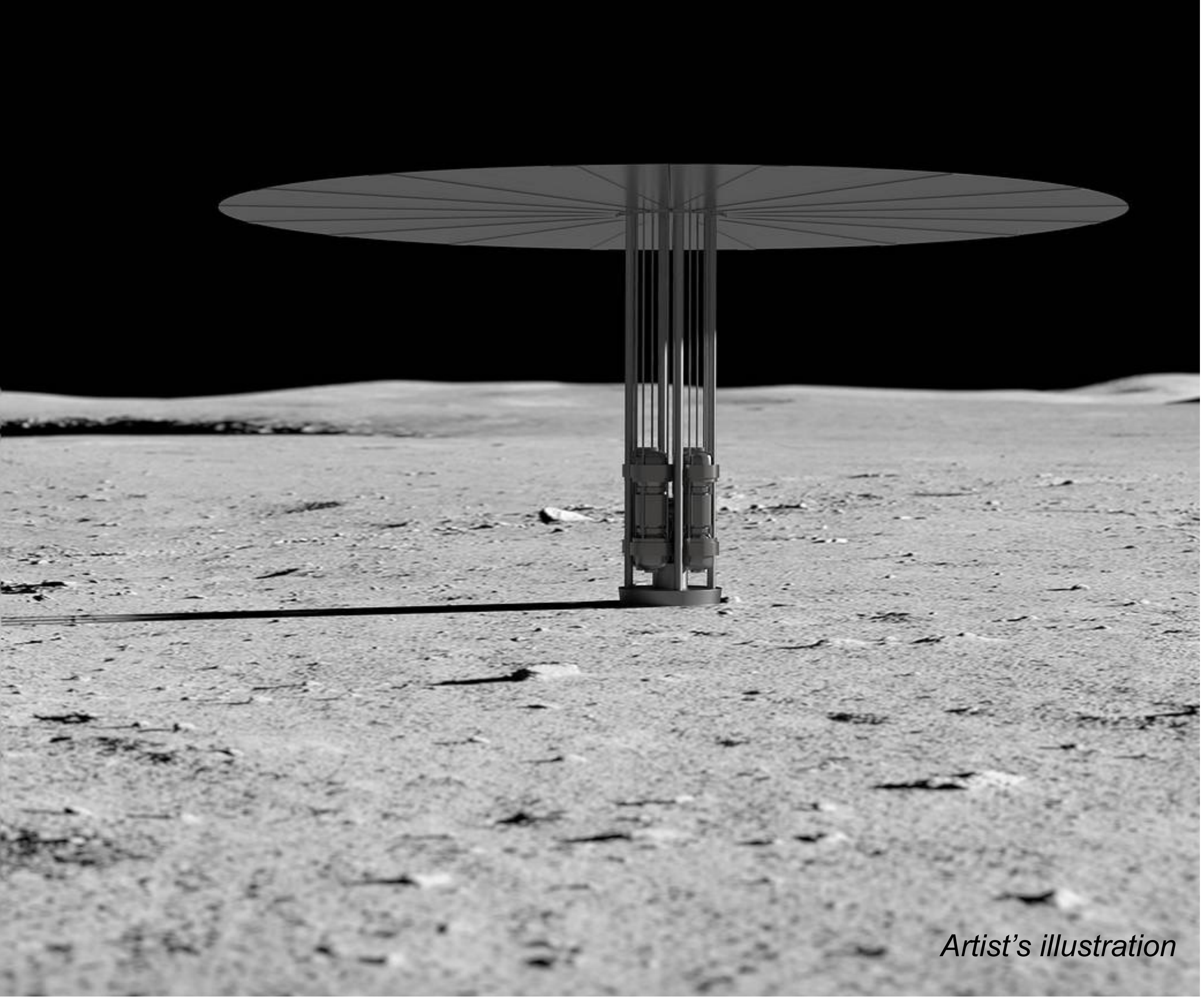
In-Situ Resource Utilization



An Artemis ISRU Pilot Plant to demonstrate a scalable capability to extract and use lunar-based resources.

- **Resource Identification / Mapping:** Perform evaluation of lunar regolith to identify composition for science, future exploration and commercial use. Enable global and detailed local and subsurface mapping of lunar resources and terrain, especially for water in permanently shadowed craters, for science, future exploration, and commercial use
- **Oxygen Extraction:** Enable extraction and production of oxygen from lunar regolith to provide 10's of metric tons per year, for up to 5 years with little human involvement and maintenance, for reusable surface and ascent/descent transportation.
- **Water Mining:** Enable cislunar commercial markets through extraction of water resources to provide 100's of metric tons of propellant per year for reusable landers and cislunar transportation systems.
- **Lunar Surface Construction:** Building of roads, launch/landing pads, dust free zones, foundations, blast protection, radiation shielding, shade structures, unpressurized shelters, and even pressurized habitats.

Fission Surface Power



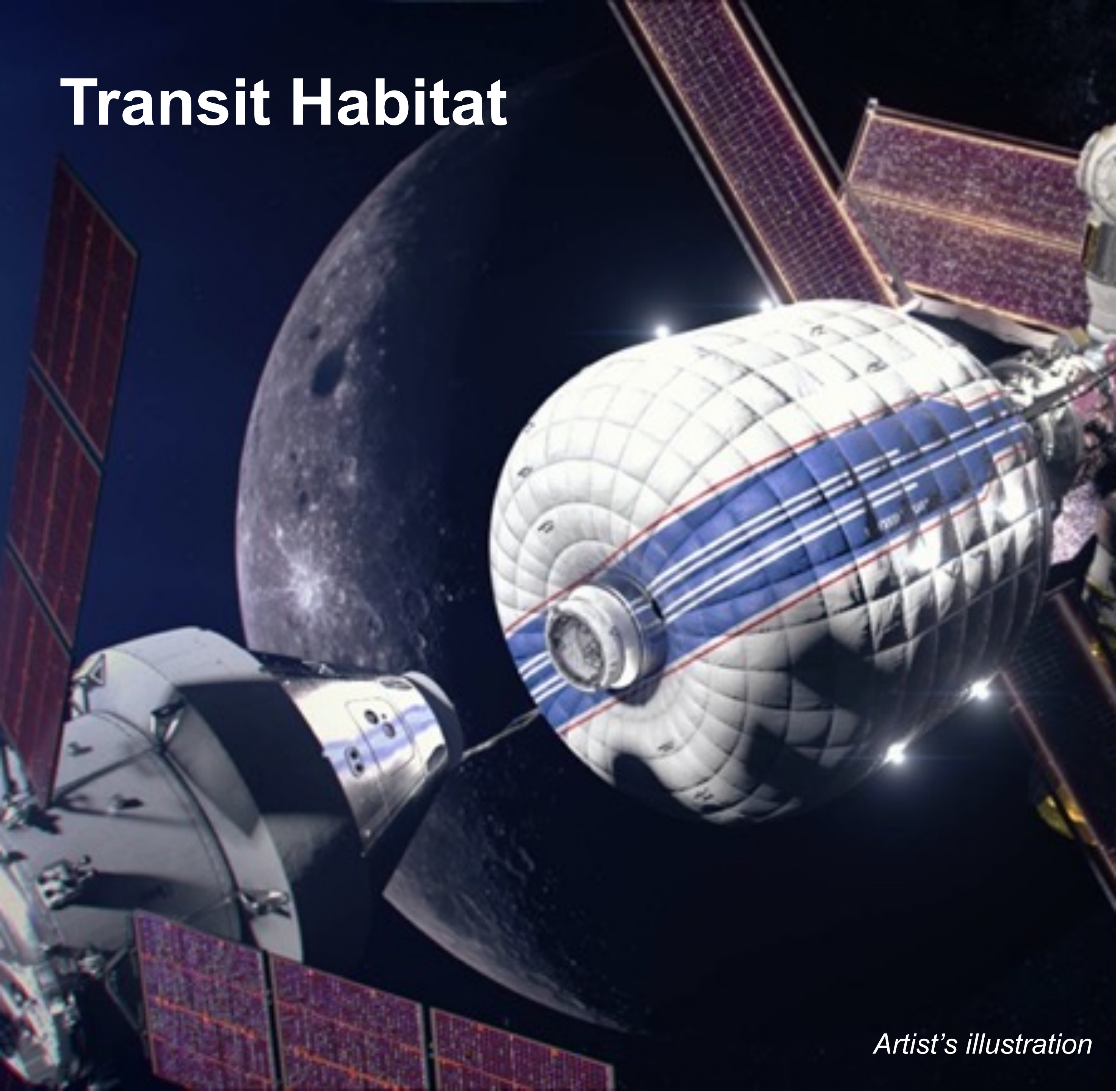
Artist's illustration

Modular nuclear fission power source

Common requirement for an initial human missions to Mars

- Surface architecture depends on power capability delivered with landers
- Power level dependent on propellant type and transfer strategy
- Near-term demonstration on the lunar surface can provide reliable power to human landers, habitats, and ISRU systems continuously through eclipse periods and provide a proving ground to extend the capability as a power source that will enable Mars exploration

Transit Habitat



Artist's illustration

Reused element with 15-year lifetime for multiple missions

- Keep crew healthy and productive during long duration, deep space stays including:
  - Shakedown missions at Gateway and while free-flying with interim propulsion
  - Lunar-Mars analogs
  - Up to 1100-day Mars transit and orbital stays
- Demonstrate needed capabilities to live for long durations beyond low Earth orbit
- Build on ISS and commercial investment in deep space habitation

ARTEMIS ACCORDS

Australia

Bahrain

Brazil

Canada

Colombia

France

Israel

Italy

Japan

Luxembourg

Mexico

New Zealand

Poland

Republic of Korea

Romania

Singapore

Ukraine

United Arab Emirates

United Kingdom

The United States of America

United for Peaceful Exploration of Deep Space

International Partner Architecture Contributions

COMMITMENTS

Canadian Space Agency (CSA)
- Gateway Canadarm3

ESA (European Space Agency)
- Gateway
  - International Habitat (I-Hab)
  - ESPRIT
  - European Radiation Sensors Array (ERSA)
  - Internal Dosimeter Array (IDA)

Japan Aerospace Exploration Agency (JAXA)
- Gateway
  - International Habitat (I-Hab) thermal, ECLSS, batteries, and imagery components
  - Instruments for IDA
  - Logistics resupply via HTV-XG

POTENTIAL AREAS OF FUTURE COLLABORATION

- Power infrastructure and distribution
- Communication and Navigation
- Logistics
- Robotics and Mobility
- Habitation and Crew Health Systems
- Lunar Environment Mitigation
- Utilization Operations
- Lunar sampling and curation
- Exploration Systems and Operations Analog Testing
- Other areas TBD

Study agreement in place with JAXA.
Agreements with CSA, ASI, ESA in work.

Ground-based Analog Missions

DesertRATS-Lite 2021. Crew members operate under lighting simulation conditions with a “portable sun."

DesertRATS

Desert Research and Technology Studies

Location: Black Point Lava Flow, ~40 miles north of Flagstaff, AZ
Duration: Three weeks, October 2022
Primary objectives to evaluate:

- Pressurized rover design and operations (with JAXA integration)
- MCC and Science Evaluation Room (SER) integration, operations, and configuration
- Science Team selected by SMD
- MCC Flight Control Team in Houston (B30/Einstein Room)

Rationale:
Operating and evaluating the pressurize rover with JAXA and Science Evaluation Room support will help inform requirements for the JAXA PR SRR in CY23

HERA

Human Exploration Research Analogs

Location: Johnson Space Center
Duration: Series of 45-day missions
Primary objectives to evaluate:

- Crew performance under isolation, confinement, and remote conditions in exploration scenarios:
    - Behavioral health and performance assessments
    - Communication and autonomy studies
    - Human factors evaluations
    - Medical capabilities assessments

Rationale:

- Allows researchers to study how crew members adjust to conditions associated with deep space travel and exploration.
- Steady cadence of missions provides opportunity to apply multiple mission scenarios across a diverse pool of crew members.

36

CHAPEA

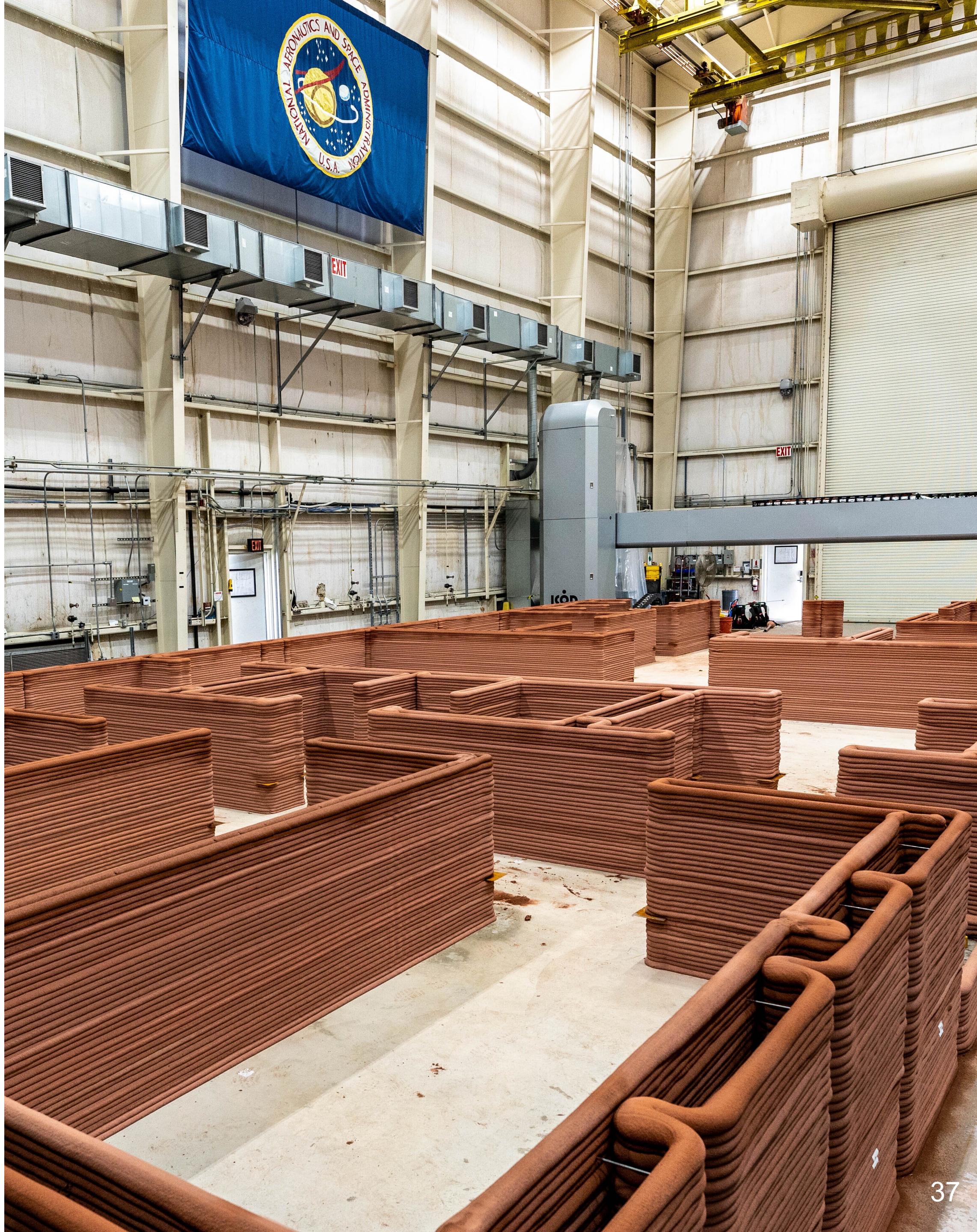
Crew Health and Performance Exploration Analog

Location: Johnson Space Center
Duration: Series of one-year missions
Primary objectives to evaluate:

- Behavioral health and performance (isolation and confinement) with simulated, Virtual Reality assisted EVAs in an external sandbox
- Resource limitations, communications delays
- Nutrition and food systems

Rationale:

- Understanding how crew respond to the rigors of long-duration surface exploration.
- Develop methods and technologies to prevent and resolve potential problems for future human missions to the Moon and Mars.

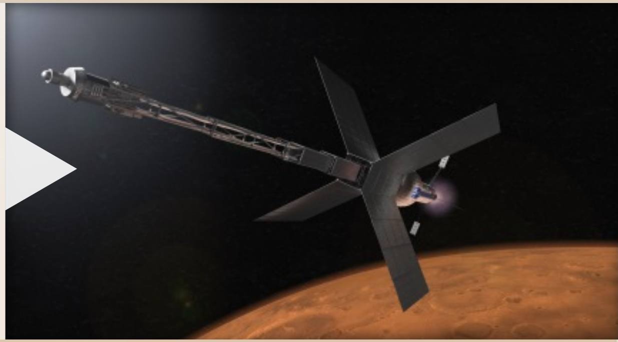


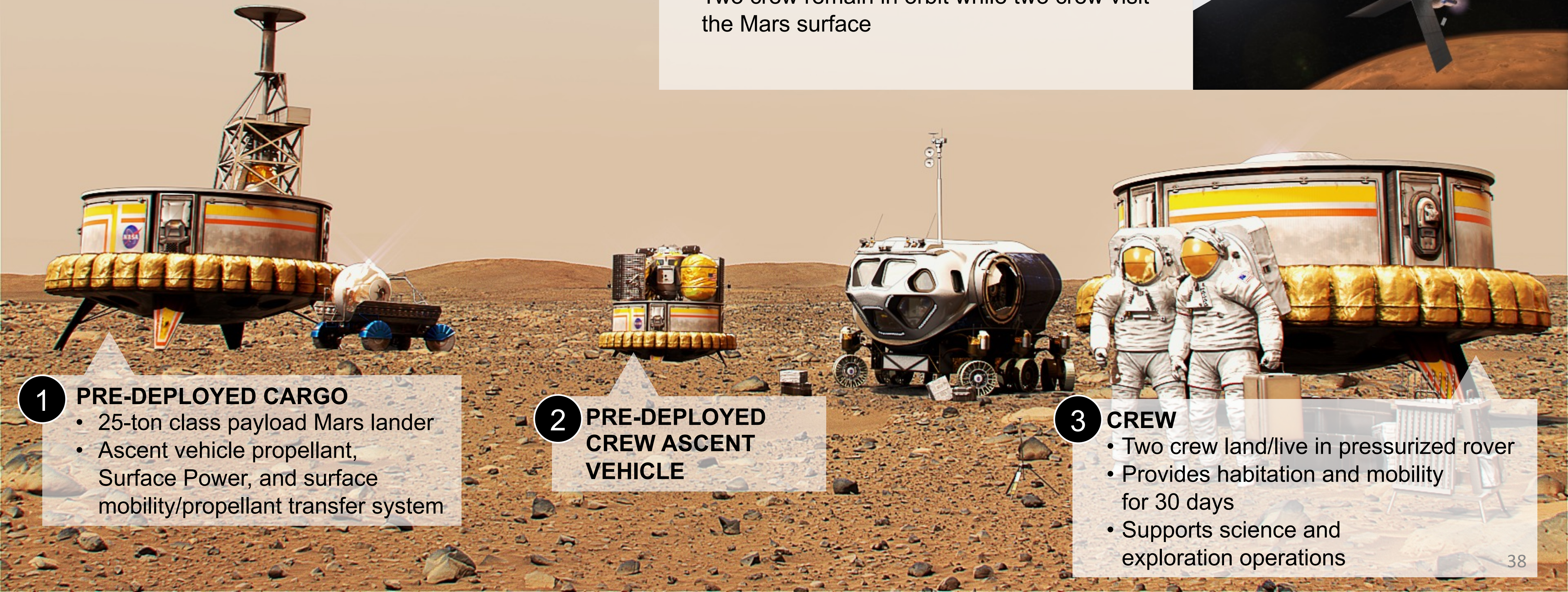
First Conceptual Mars Mission

Reference architecture for *analysis purposes only.*

TRANSIT HABITAT AND HYBRID PROPULSION STAGE

- Supports four crew on the long mission to Mars
- Two crew remain in orbit while two crew visit the Mars surface





1 PRE-DEPLOYED CARGO

- 25-ton class payload Mars lander
- Ascent vehicle propellant, Surface Power, and surface mobility/propellant transfer system

2 PRE-DEPLOYED CREW ASCENT VEHICLE

3 CREW

- Two crew land/live in pressurized rover
- Provides habitation and mobility for 30 days
- Supports science and exploration operations

“The United States will Maintain its Leadership in Space Exploration and Space Science”

“Remain a global leader in science and engineering by pioneering space research and technology that propels exploration of the Moon, Mars, and beyond.”

“U.S. human and robotic space exploration missions will land the first woman and person of color on the Moon, advance a robust cislunar ecosystem, continue to leverage human presence in low-Earth orbit to enable people to live and work safely in space, and prepare for future missions to Mars and beyond.”

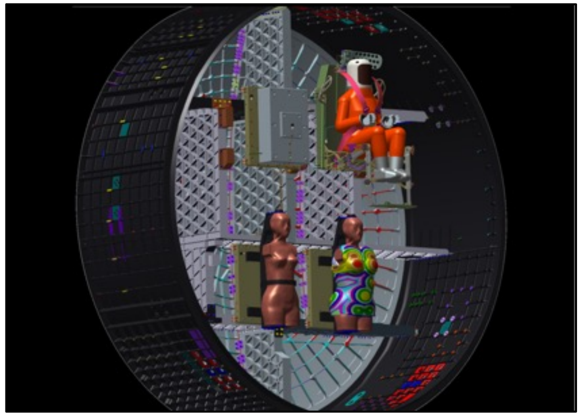
— The White House U.S Space Priorities Framework, Dec 2021

United States Space Priorities Framework
NASA 2022 Strategic Plan
2023 NASA Budget Request

BACKUP

Artemis I Pressurized Payloads

Payloads that will fly inside of the Orion crew module, returning data during and after the mission

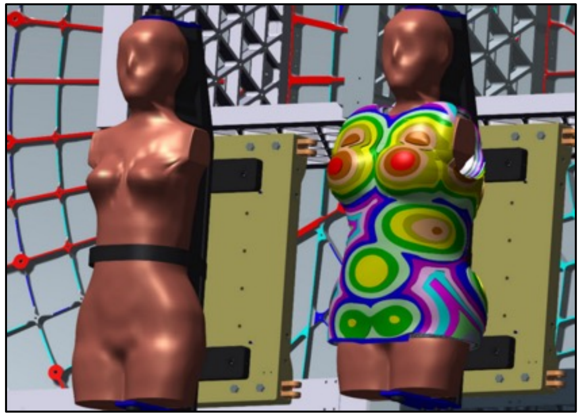


ESA Active Dosimeters *

Radiation monitoring system that will fly up to 5 monitoring units

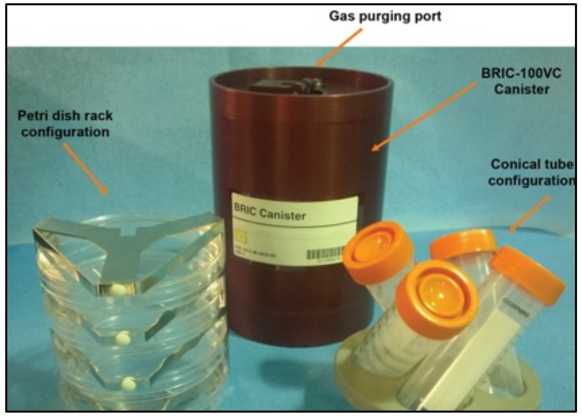
Crew Interface Technology Payload (CITP)

Creates an interactive experience between Orion and the public during the mission



Matroshka AstroRad Radiation Experiment (MARE) *

Radiation shielding Personal Protection Equipment (radiation vest) for astronauts



Bio-Experiment-1

Battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO)

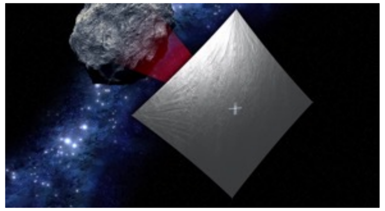
*International Collaboration

Artemis I Payloads

Science and technology investigations and demonstrations paving the way for deep space human exploration

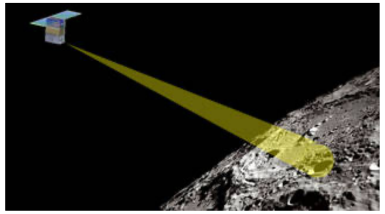
ArgoMoon *

Photograph the Interim Cryogenic Propulsion Stage (ICPS) CubeSat deployment, the Earth and Moon using HD cameras and advanced imaging software.



Near-Earth Asteroid Scout (NEA Scout)

Detect target NEA, perform reconnaissance and close proximity imaging.

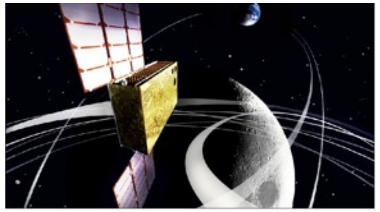


LunIR

Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface.

LunaH-Map

Perform neutron spectroscopy to characterize abundance of hydrogen in permanently shaded craters.

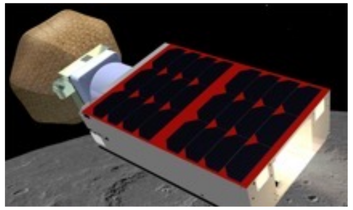


EQUULEUS *

Demonstrate trajectory control techniques within the Sun-Earth-Moon region and image Earth's plasmasphere.

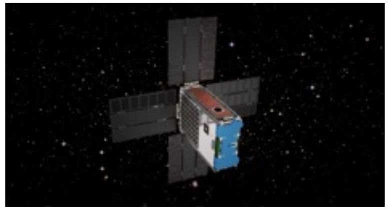
Team Miles

Demonstrate propulsion using plasma thrusters; compete in NASA's Deep Space Derby.



OMOTENASHI *

Develop world's smallest lunar lander and observe lunar radiation environment.

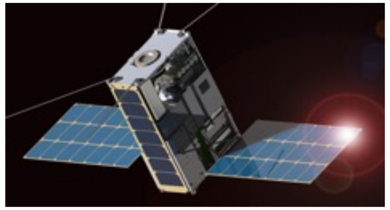


BioSentinel

Use yeast as a biosensor to evaluate the effects of ambient space radiation on DNA.

CubeSat to Study Solar Particles (CuSP)

Measure incoming radiation that can create a wide variety of effects on Earth.



Lunar IceCube

Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer.

*International Collaboration

CAPSTONE CubeSat

Cislunar Autonomous Positioning System
Technology Operations and Navigation Experiment

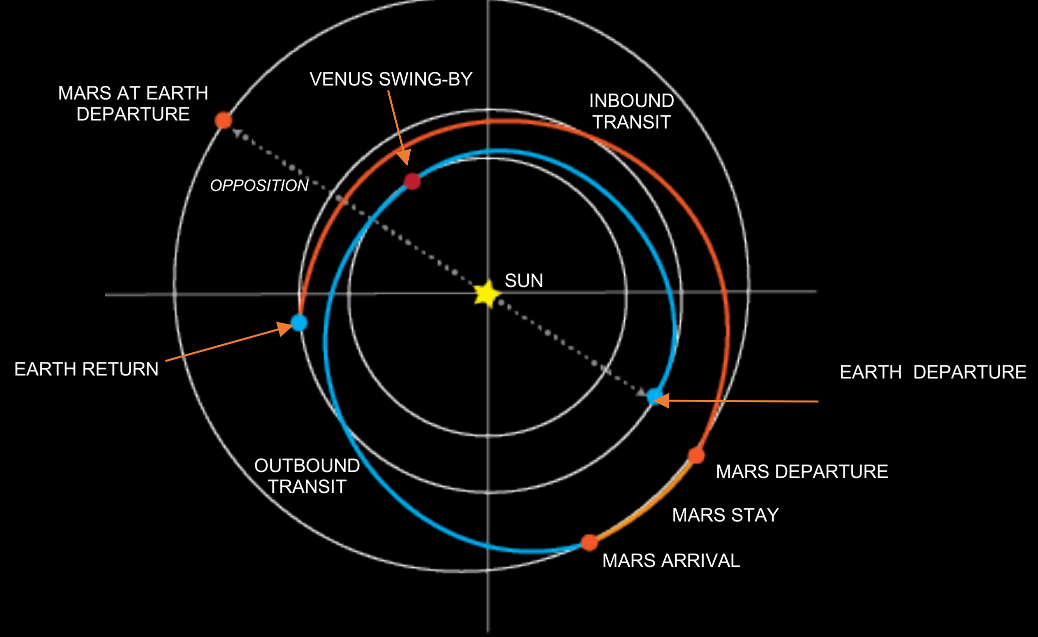
- The mission launched at 5:55 a.m. EDT (09:55 UTC) on Rocket Lab's Electron rocket from the Rocket Lab Launch Complex 1 on the Mahia Peninsula of New Zealand on June 28, 2022.
- Will demonstrate how to enter and operate in a Near Rectilinear Halo Orbit (NRHO), the unique orbit where Gateway will operate
- Once in the NRHO, CAPSTONE will fly within 1,000 miles of the Moon's North Pole on its near pass and 43,500 miles from the South Pole at its farthest. It will repeat the cycle every six and a half days and maintain this orbit for at least six months to study dynamics.
- Will test a new navigation capability to help validate Gateway operational models.

Mars Trajectory Design Reference Architecture

Short-Stay Missions

Variations of missions with short Mars surface stays and may include Venus swing-by

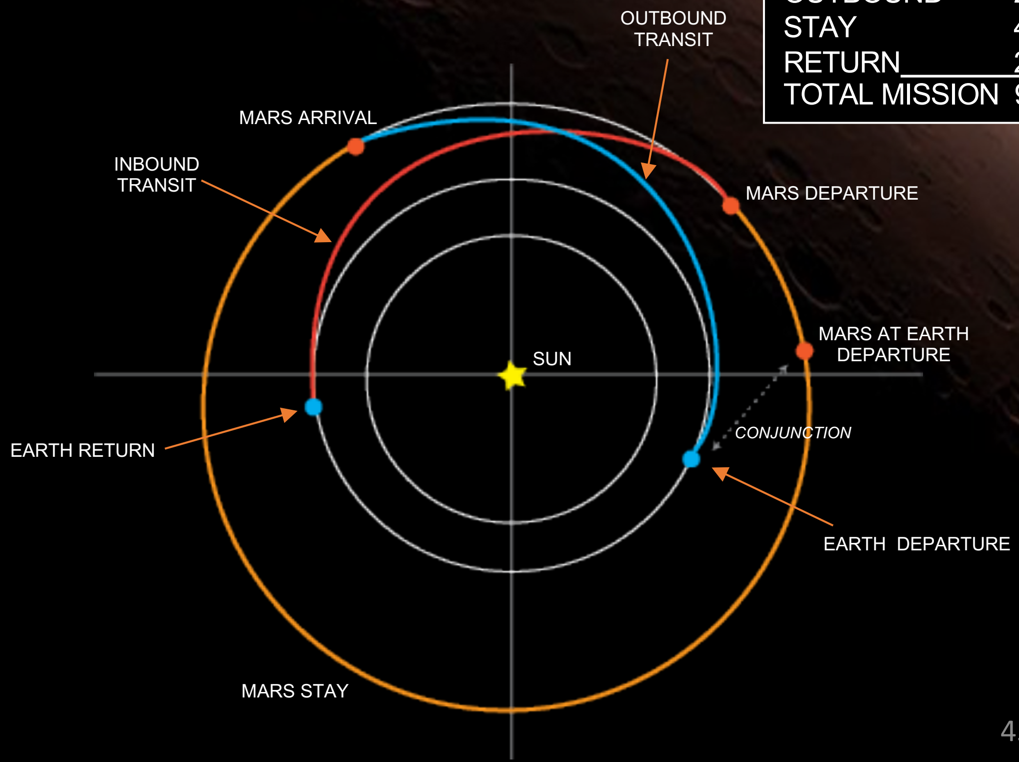
MISSION TIMES	
OUTBOUND	217 days
STAY	30 days
RETURN	403 days
TOTAL MISSION	650 days



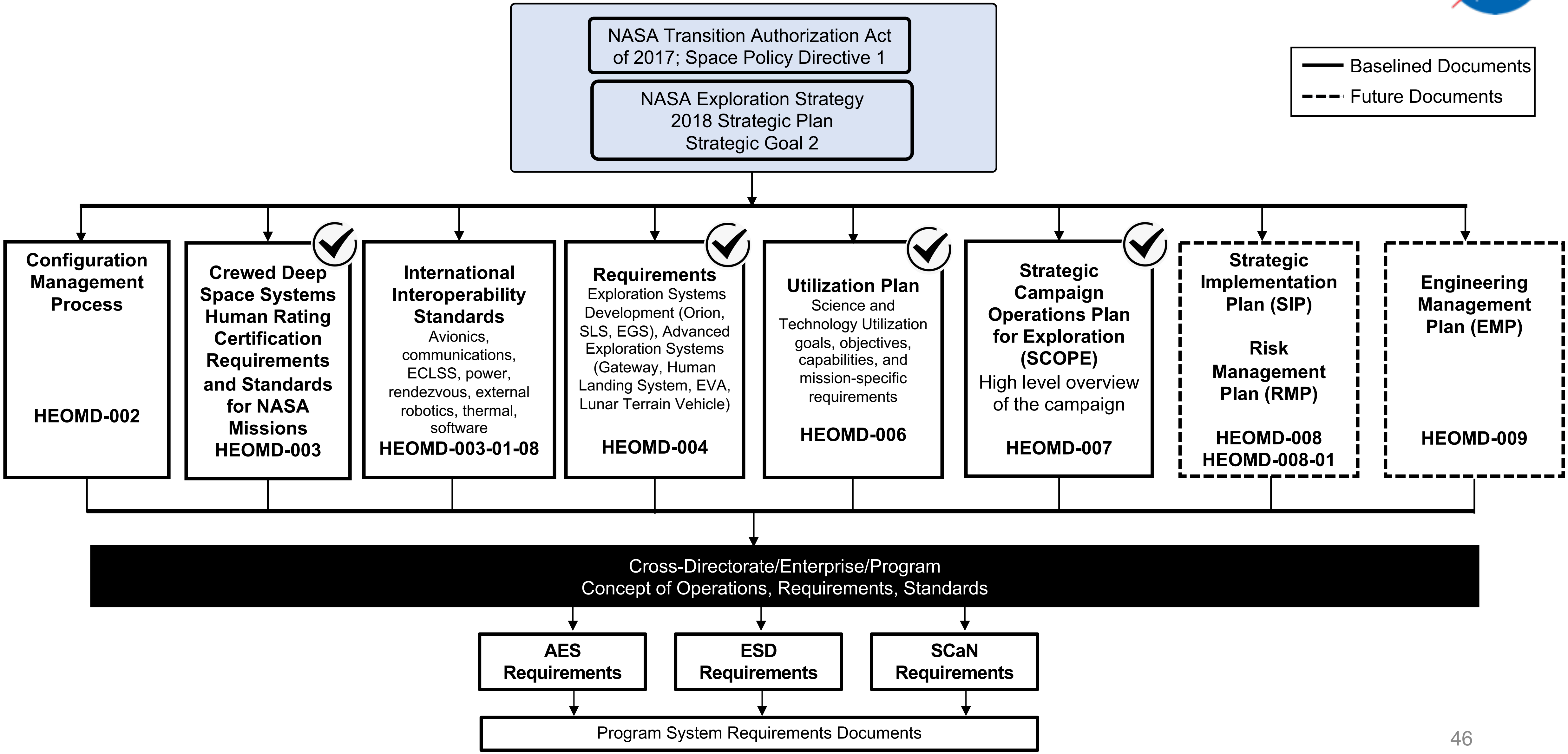
Long-Stay Missions

Variations about the minimum energy mission

MISSION TIMES	
OUTBOUND	210 days
STAY	496 days
RETURN	210 days
TOTAL MISSION	916 days



HEO Products – Current and Planned



SCIENCE & TECHNOLOGY UTILIZATION

INTEGRATING ACROSS MISSION DIRECTORATES

Integrate science and technology goals from mission directorates and international partners to develop HEO utilization goals, objectives and requirements for Artemis missions, and the cross-platform research strategy to prepare for human missions to Mars.

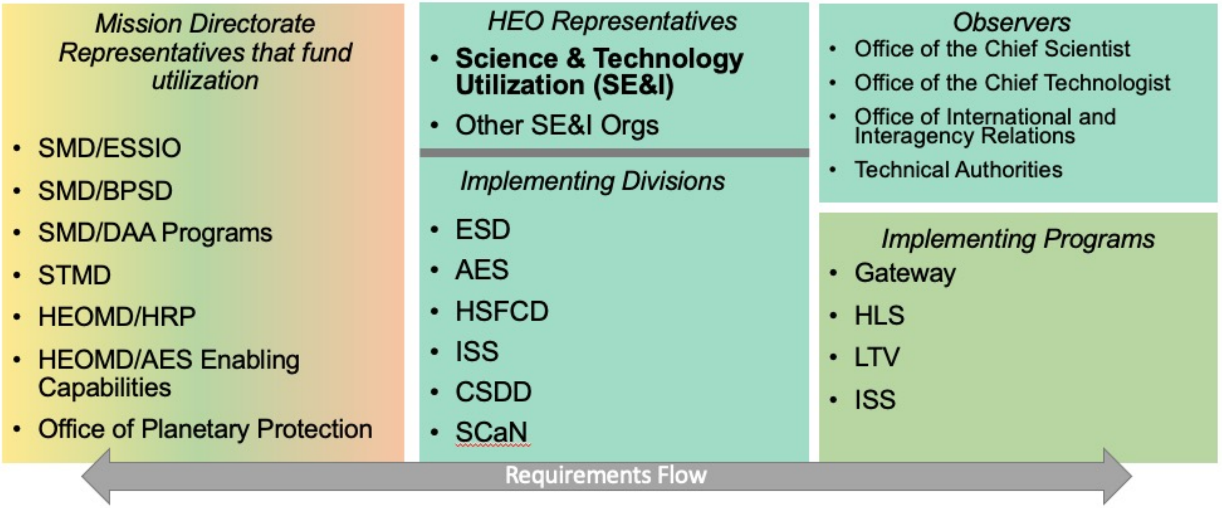
EXAMPLES:

- HEO-006 Utilization Plan joint with SMD and STMD - High level utilization goals, objectives and requirements
    - Utilization capabilities and their phasing over time
    - Mission-specific annexes with mission directorate requirements to enable research solicitations
    - Includes ISS, Commercial LEO, Artemis and Mars
- Co-chair the Utilization Coordination and Integration Working Group (UCIG) with SMD & STMD
- Leading the Cross-Artemis Site Selection Analysis (CASSA)
- Coordinating HEO process for using our CLPS mass allocations and representative to SMD CLPS manifest selection board

INTEGRATING WITH HEO DIVISIONS

- Work with divisions and users on high-level goals, objectives, and strategic plans
- Interface with AES and ESD on approach to implementation and payload manifest for Artemis
- Ensure science and technology inputs are integrated into SE&I formulation activities

UTILIZATION COORDINATION AND INTEGRATION WORKING GROUP (UCIG) REQUIREMENTS FLOW



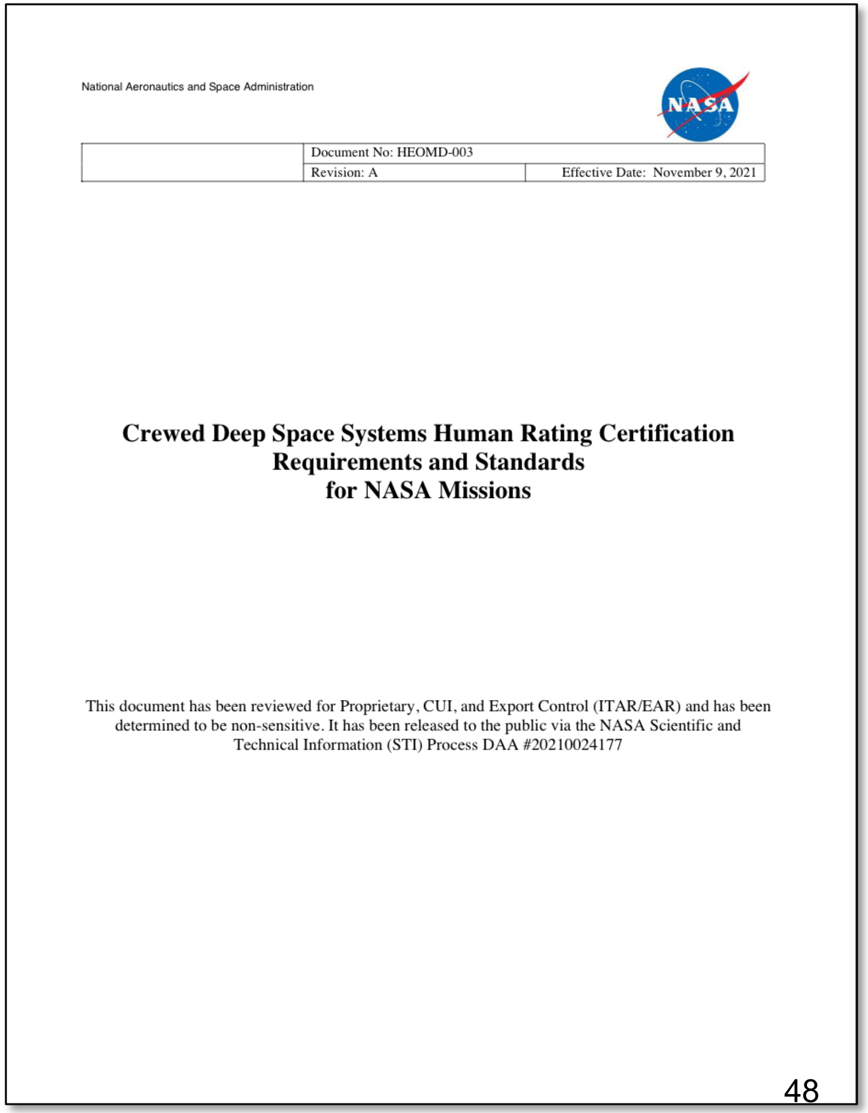
Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions, Rev A (HEOMD-003)

Consolidated set of technical requirements, standards, and processes that NASA Program Managers shall implement for human rating certification of Crewed Deep Space Systems.

Defines requirements, standards, and human rating certification process and products that will be used to certify systems as acceptably safe to carry NASA or NASA-sponsored crewmembers on deep space missions for those programs that are not governed by NPR 8705.2, Human Rating Requirements for Space Systems.

- Orion, SLS, and EGS are governed by NPR 8705.2.

Baselined in March 2021, Rev A added two new requirements for Crew Support and clarified autonomy requirement in support of Sustaining Phase of Artemis. Revised Certification Process section to no longer require a Human Rating Certification Package, rather allow responsible programs to define a Human Rating Plan that leads to the final Certification (Approved at the Directorate Program Management Council (DPMC) on November 9, 2021.


National Aeronautics and Space Administration

	Document No: HEOMD-003	
	Revision: A	Effective Date: November 9, 2021

Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions

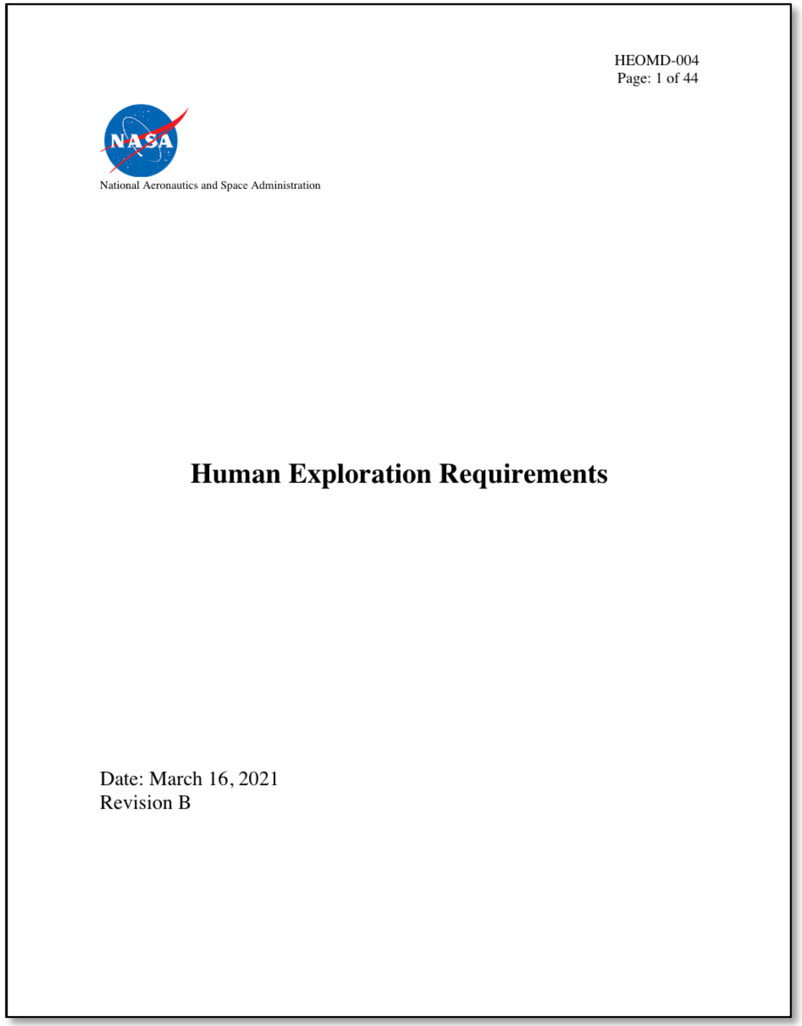
This document has been reviewed for Proprietary, CUI, and Export Control (ITAR/EAR) and has been determined to be non-sensitive. It has been released to the public via the NASA Scientific and Technical Information (STI) Process DAA #20210024177

Human Exploration Requirements (HEOMD-004), Rev C

Captures requirements controlled by the Human Exploration and Operations Mission Directorate (HEOMD) for the Programs responsible for design, development, and operation of systems to meet HEOMD goals and objectives. These requirements include established Artemis Programs (Orion Crew Vehicle, Space Launch System (SLS), Exploration Ground Systems (EGS)), Human Landing System (HLS), the Gateway(including Exploration Extra Vehicular Activity (xEVA) and Programs/Projects in formulation (Lunar Terrain Vehicle (LTV) and new requirements levied on other HEO divisions from this point forward.

HEOMD-004 is intended to be utilized in conjunction with HEOMD-003, Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions.

Rev C updates included expanded timeframe of requirements effectivity, covering initial lunar missions, sortie missions, and Artemis Base Camp missions. Additional requirements updates were discussed for Gateway, Lunar Terrain Vehicle, and the Human Landing System. New requirements for lunar communications and navigation under Rev C were also covered.


HEOMD-004
Page: 1 of 44

National Aeronautics and Space Administration

Human Exploration Requirements

Date: March 16, 2021
Revision B

Human Exploration and Operations Utilization Plan (HEO-006)

Identifies and describes NASA's science and technology utilization goals and objectives that will be enabled by human missions.

These goals and objectives have been defined by NASA's Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD), and HEO Mission Directorate (HEOMD).

The goals and objectives will be used to identify how human missions will support the science and technology communities to conduct fundamental research about our universe and solve the scientific and technological challenges for sustaining and expanding human exploration.

The scope of the Utilization Plan is applicable to Artemis lunar exploration missions; SMD, STMD, and HEOMD utilization goals for HEOMD platforms; and agency exploration strategy using the International Space Station (ISS), the Gateway, Human Landing System (HLS), and lunar missions to prepare for future missions to Mars.

National Aeronautics and Space Administration

Human Exploration and Operations
HEOMD-006
INITIAL BASELINE
RELEASE DATE: 10/04/2021

HUMAN EXPLORATION AND OPERATIONS UTILIZATION PLAN

This document is publicly available with approval from the NASA Office of Primary Responsibility (OPR), Exploration Systems Development Mission Directorate, Systems Engineering & Integration, Science and Technology Utilization Office

This document was approved by the Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD)

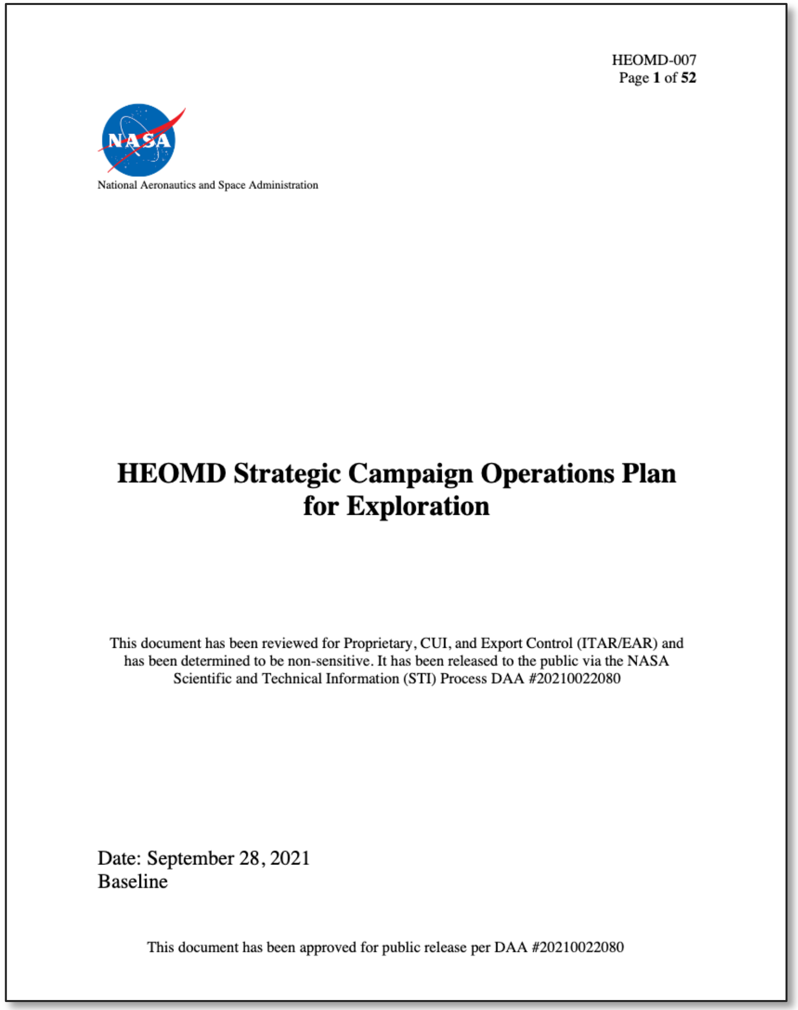
October 2021

HEOMD Strategic Campaign Operations Plan for Exploration (HEO-007)

ESDMD SE&I released HEO-007, Strategic Campaign Operations Plan for Exploration (SCOPE) on the NASA Technical Reports Server, making it publicly available. The SCOPE, baselined in August, connects national policy and NASA's strategic plan with the agency's human spaceflight activities and implementation at the division and corresponding program levels.

The document introduces exploration goals and ground rules and assumptions, including high-level concepts of operations, across four human exploration campaign segments, from low-Earth orbit to Mars.

Having the SCOPE publicly available will help facilitate discussions with existing and potential partners who may offer contributions to Artemis or initial human missions to Mars.


HEOMD-007
Page 1 of 52

National Aeronautics and Space Administration

HEOMD Strategic Campaign Operations Plan for Exploration

This document has been reviewed for Proprietary, CUI, and Export Control (ITAR/EAR) and has been determined to be non-sensitive. It has been released to the public via the NASA Scientific and Technical Information (STI) Process DAA #20210022080

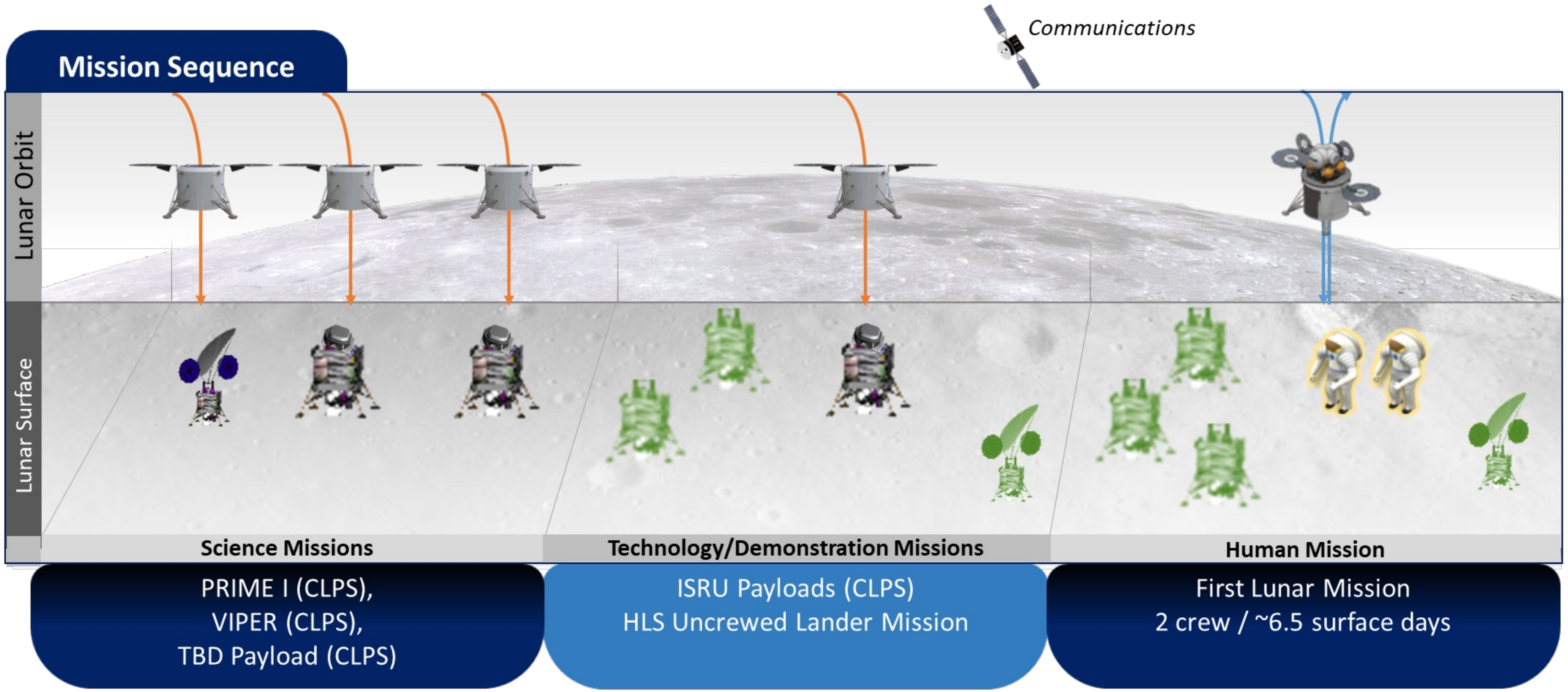
Date: September 28, 2021
Baseline

This document has been approved for public release per DAA #20210022080

Available on NASA Technical Reports Server: https://ntrs.nasa.gov/citations/20210022080

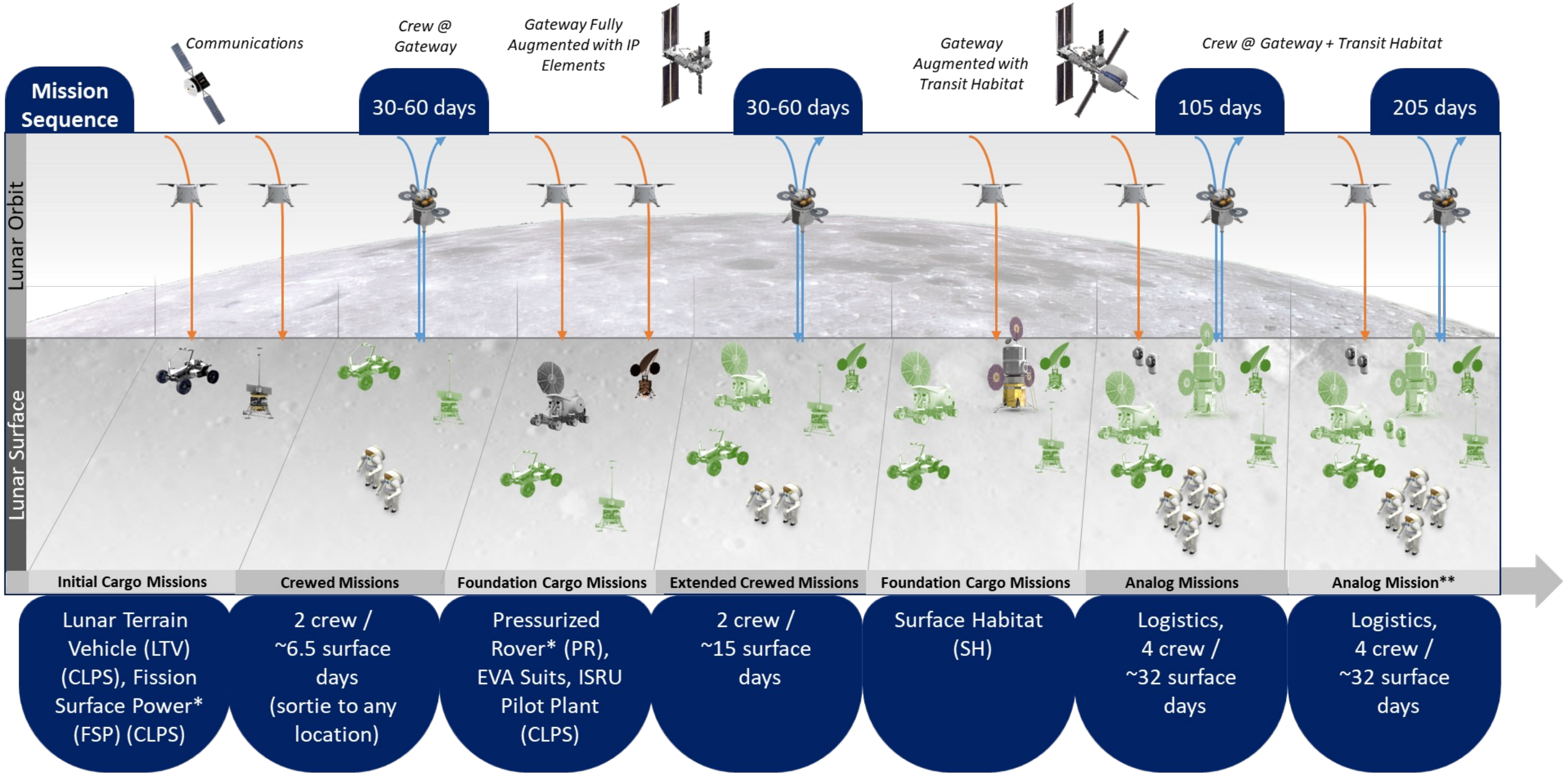
Exploration Campaign Segment – Human Lunar Return

- Includes all activities on or around the Moon that contribute to the return of humans to the lunar surface and allow for lunar exploration.
  - Encompasses Artemis I through the first Artemis crewed lunar landing, including both crewed and uncrewed missions.



Exploration Campaign Segment – Sustained Lunar Presence

- Includes all activities on or around the Moon that contribute to both the establishment of a sustained human lunar presence and to risk reduction for human Mars exploration.



NOTE: Crew mission duration driven by budget and mission objectives

Representative Sequence

* *Robotic deployment of the FSP and Pressurized Rover operations are critical Mars-forward tests*

** *Initial emphasis on Mars Analog missions transitioning to lunar sustained missions; Sustained Human Lunar Surface missions continue indefinitely*