THE NINTH COMMUNITY WORKSHOP FOR ACHIEVABILITY AND SUSTAINABILITY OF HUMAN EXPLORATION OF MARS (AM IX)

June 14-16, 2022
Lindner Commons
Elliott School of International Affairs
The George Washington University Washington, DC

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https://ExploreMars.Org/affording-mars/

The Ninth Community Workshop for
Achievability and Sustainability of Human Exploration of Mars

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The Ninth Community Workshop for Achievability and Sustainability of Human Exploration of Mars (AM IX)

Summary and Findings Report

Explore Mars, Inc. hosted the Ninth Community Workshop for Achievability and Sustainability of Human Exploration of Mars (AM IX) on June14-16, 2022 at The George Washington University in Washington, DC.

This invitation-only workshop, hosted by Explore Mars, Inc., a 501(c)(3) non-profit, assembled a diverse group of professionals to identify those activities that are required to prepare for an achievable and sustainable program of future human Mars missions starting in the 2030s. Such activities include preparatory work in areas of human health and performance, Mars science priorities that leverage human presence, operational strategies for transit and surface operations, and technology solutions, many of which can be tested on Earth, in low-Earth orbit, lunar orbit, or on the surface of the Moon.

The annual AM workshops (https://www.exploremars.org/affording-mars/) have been an essential opportunity for a broad community to contribute to the development and justification of valuable elements of NASA's human space flight program. AM IX built on the products of AM VIII: How the Moon can be effectively used to prepare for Mars exploration.

Participants of AM IX noted that a comprehensive plan is needed for the human exploration of Mars that includes a cohesive campaign of Mars missions, both robotic and human, that leverages near-term activities in low Earth orbit, lunar orbit, and the lunar surface. This includes the critical areas of science priorities, architecture, necessary precursor activities, human health, and planetary protection. During the three-day workshop, as well as virtual meetings over the Summer and fall of 2022, participants developed the following summary of recommendations as well as detailed appendices.

1. ARCHITECTURE:

- *MARS CAMPAIGN:* We need a Mars Campaign rather than individual non-defined missions. This means a program (cadence) of robotic and human missions, starting with better defined links between Artemis and future Mars missions. It was agreed that the opportunities offered by the 2033 launch window are not to be dismissed lightly (assuming crew readiness), but no consensus was reached as to the value of an initial orbital mission, and no consensus was reached on an initial conjunction vs. opposition mission.

- With respect to the possible onboarding of nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP), these were met with both enthusiasm but also skepticism regarding readiness for earlier missions. Analog missions on the International Space Station (ISS), Gateway, and the lunar surface have clear value to buy down risks before crews travel to Mars.

- *TRANSIT OPERATIONS AND HUMAN HEALTH:* Surface activities on Mars will not be the only challenge facing human explorers. Transit to and from Mars will be one of the most challenging aspects of human missions. Preparations to assure the continued physical and mental health of the astronauts must be both robust and comprehensive. This should include adequate downtime for the crew, family support communications from Earth, and a well-conceived wellness plan that provides both physical and psychological support. This includes refresher training, privacy in sleep quarters, entertainment opportunities, etc. to build crew cohesion and ensuring that the crew has meaningful work to perform during transit. Artemis missions to Gateway can also serve as a precursor to longer Mars transits.

- *MARS SURFACE OPERATIONS AND MOBILITY:* Crewed and robotic surface mobility is a critical capability to achieve surface science and exploration objectives. Mobility extends the exploration range, greatly enhances the ability to meet many more science objectives, and enables the crew to transit between landed elements.

  There is value to having both pressurized and unpressurized capability, and highly capable pressurized mobility systems with external robotics may reduce the need for extra-vehicular activities (EVA) for simple tasks.

  Mobile robotic systems can provide necessary surface reconnaissance ahead of crew arrival, and can enhance crewed operations by scouting, accessing difficult and/or dangerous areas, carrying equipment and logistics, and deploying instruments.

  The Artemis lunar missions will establish confidence in the operation of mobility vehicles with crew in a remote hazardous environment and demonstrate science operations, including drilling and sample collection. Testing robotic vehicles on the lunar surface can be extremely valuable in advance of using similar or identical robotics systems on Mars, as the Moon is a harsher environment than Mars.

- *DEEP SPACE COMMUNICATIONS:* Future human and robotic missions will require improvements to the communications infrastructure both at Mars and for the Deep Space Network. This is a critical requirement that will need to be executed well before we send humans to Mars. The bandwidth of the current infrastructure is far from adequate to support a human presence at Mars. Investment in new satellites, antennas, and the potential use of laser communications is advised.

2. SCIENCE PRIORITIES:

- The Mars Exploration Program Analysis Group (MEPAG) has done excellent work assessing the potential for human explorers to accelerate science at Mars. However, the MEPAG referred to current robotic science objectives to make those assessments, and, as such, their proposed human science objectives are limited in scope by what can be accomplished using robots at Mars.

  Human missions will significantly enhance the capabilities (mass delivery, power, real time decision making, etc.) available for science. AM IX attendees brainstormed a list of what humans will bring to exploration at Mars (note Appendix D) and strongly encourage the MEPAG to consider these unique capabilities and to build upon this list to draft out a set of exciting science goals that will be worthy of sending humans to the Red Planet.

- AM IX recommends the establishment of a joint Lunar Exploration Analysis Group (LEAG) and MEPAG team with appropriate engineering support, to review the MEPAG's proposed science goals and look for potential synergies between these goals and the tools needed to achieve them, such as mobility, drilling, hand tools, human-tool-interfaces, etc., at both the Moon and Mars. A key deliverable would be an assessment of which lunar science operations could inform future operations at Mars. Identified synergies would also be useful for justifying technology investments for the Moon.

- Understanding where water-ice is (vertical and horizontal extents as well as composition), collecting samples and even extracting ice cores are key elements of future exploration at both the Moon and Mars. These data are key for decadal priority science and for in-situ resource utilization (ISRU). Further, accessing the ice while minimally impacting the samples/cores (i.e. change of state and potential biology) is a highly relevant technology challenge that we encourage NASA to look at as soon as possible. Such investigations will likely require assessments of potential crew safety issues (e.g., planetary protection hazards, challenges associated with operating heavy machinery on ice, etc).

- Human explorers will be both scientific investigators as well as subjects of scientific research to understand how the human body and psyche adapt and change in response to the environmental conditions they will encounter throughout the mission (e.g., extended stays in zero G, transitions to a 1/3G environment, high radiation environments, etc.). For initial missions to Mars, it cannot be assumed that all crewmembers will go to the surface. AM IX attendees recommend that NASA investigate the risks associated with long exposures to zero G, high radiation environments, and extreme isolation (1100 days for a conjunction class trajectory; 700 for opposition class trajectories) to inform potential mitigation strategies.

- AM IX applauds the International Space Station's program ISS4Mars to utilize the space station as an enabling analog for Mars missions. Studies looking at lower body negative pressure countermeasures, Earth independent medical operations (including no communications and time delays), and post landing fitness assessments are key. .

  AM IX sees significant value in extending this research to include landing crews at remote sites and having them perform self-recovery to execute both operations and science as soon as possible. While there are associated risks, landing at Mars will be far more challenging and understanding the operations concepts needed to allow crews to adapt as quickly as possible in a 1/3 G environment will no doubt be critical for both safety and mission success.

- NASA made a key step towards prioritized science objectives at their Science Objectives for Human Exploration of Mars Workshop in March 2022, but most attendees either represented the MEPAG or human spaceflight engineering communities. AM IX also had representatives from the lunar, human research, applied, biological, and physical science communities, and attendees saw significant value in the cross-discipline conversations at the workshop. We know that NASA is planning, and AM IX strongly supports, future workshops to define and prioritize science objectives as well as needed technologies (e.g., drilling, mobility, hand tools) with all of these disciplines represented.

3. IMPORTANT PRECURSOR ACTIVITIES:

- To maximize science return and reduce risk to the crew, workshop attendees recommend that NASA identify and prioritize potential robotic precursor missions to establish baseline measurements for candidate human landing sites to ensure that decadal level science can be accomplished at these sites. HiRISE-class resolution imaging, ice mapping, and weather measurements (on the surface and in space) are emerging priorities for both science and for mission success. For ice science, robotically accessing the ice prior to humans arriving may be a highly valuable control data point.

  Reducing the cost while increasing the cadence of robotic missions to Mars, as envisioned by NASA's Low-Cost Science Mission Concepts for Mars Exploration workshop, may be critical to accomplishing these as well as other critical science objectives.

- *UTILIZING ANALOG MISSIONS:* The use of Moon and Mars analog sites, such as ISS4Mars, Hi-SEAS, etc. - on Earth, in Low Earth Orbit (LEO), and in Cis-Lunar space - should be expanded to address key knowledge gaps such as recovery times for astronauts returning from long duration stays in space. To make these efforts more productive and impactful, a consortium (similar to the Lunar Surface Innovation Consortium) should be established that (1) documents the findings of each mission, (2) enables cooperation and education across all stakeholders, and (3) promotes analogs to combine crew/mission support team training, research, and system/technology validation.

- *CADRE COMPOSITION:* The number of available active astronauts required to support multiple exploration missions will need to be understood along with appropriate support teams (such as Crew Trainers and Flight controllers) and training facilities. In gaining that understanding, a reliable and robust pipeline of qualified candidates must be developed. This should include well defined methods to maintain crew mental health during long missions. With the increasing number of commercial and private astronauts, consideration should be given as to crews that involve a mix of NASA, commercial, and private astronauts and what the roles and responsibilities of each should be. This includes determining how the requirements for astronaut selection for Low Earth Orbit (LEO) and the Moon may differ from missions to Mars.

- *LUNAR RESOURCES/PRECURSORS/PREPARATION:* Artemis lunar surface robotic and crewed infrastructure elements are being planned as pathfinders and prototypes for Mars surface elements, and this approach should continue and not be compromised. Lunar in-situ resource utilization (ISRU) has different challenges than for Mars, but commonalities should be identified (e.g. H2O electrolysis, more examples…) and implemented as Mars prototypes to the maximum extent possible.

4. HUMAN HEALTH:

HUMAN HEALTH: Although we have gained valuable data and information from human missions aboard the International Space Station that last six months and up to one year, we are severely limited by our understanding of how the human body needs to be supported and reacts to even longer duration spaceflight to deep space environments. New human health performance system guidelines need to be established that fit within the engineering constraints and enable the crew to accomplish mission tasks (space radiation; hostile environment; gravity). This includes the need to create a certifiable food system that can store and/or produce, as well as maintain the freshness and nutritional value of food, for up to 3 years.

5. PLANETARY PROTECTION:

PLANETARY PROTECTION for crewed missions (safe zones for human activities; special regions for robotic exploration). A well-crafted policy should be agreed to well before humans step foot on Mars. Such agreement must entail a sensible balance between the prevention of forward and backward contamination vs. maximizing the value of scientists on the surface of Mars. It should be noted that a human astrobiologist on the surface of Mars would be of great value not only to determine the existence of past or present life, but also to oversee planetary protection protocols.

AM IX

The Ninth Community Achievability and Sustainability of Human Exploration of Mars Workshop

Mars Architecture Session:

Procedure, Process and Findings

Scott Hubbard and Hoppy Price

June 14-16, 2022
Lindner Commons
Elliott School of International Affairs
The George Washington University
Washington, DC

Workshop Deliverables

1. Recommendations on initial steps to develop a robust campaign of human missions that include:
   a. Consensus on high-level priorities in the areas of science, technology demonstration, health, and human performance, etc.
   b. Draft figures of merit for mission architecture assessments
   c. Considerations/recommendations on short vs. long-stay vs. fast transit conjunction
   d. A mission sequence option (e.g., orbit-only, sorties, short-stay landing, long-stay landing) that satisfies recommendations a-c and commonalities across architectures
2. Recommendation on scope and timelines for the first crewed mission to Mars that addresses:
   a. Key initial mission elements/crew tasks to minimize risk and promote sustainability
   b. Requirements on the first mission levied by subsequent missions, including science, infrastructure, astronaut health, technology demonstrations, operations, etc.
3. Recommendations on critical technology, capabilities, and information that can be tested/obtained on ISS, lunar orbit, lunar surface, or at Mars that includes:
   a. Guidelines for technology maturation and infusion
   b. Identification of enhancing versus enabling capabilities
   c. Identification of critical capabilities/processes/data that have long lead times for development

Findings from the Architecture Session (1)

- Having a diverse audience with varied backgrounds was beneficial.
  - This approach should be continued at future AMs
- While no vote was taken, the sense of the workshop seemed to be that planning a program or campaign of human missions would yield the best results when deciding what the initial project should be
- No consensus was reached on whether the first human mission to Mars could usefully be orbital only
- The decision seemed to rest on three issues:
  - Could enough data be gathered on human health and performance to certify a landed first mission
  - Would low latency operations of, *e.g.*, rovers or aerial vehicles, justify human presence
  - Can the engineering complexity and programmatic expense of a landed initial mission be sufficiently minimized to fit within a plausible budget and time horizon of interest to stakeholders
- Proposals that included Nuclear Electric Propulsion (NEP) and/or Nuclear Thermal Propulsion (NTP) were met with both enthusiasm and skepticism. Some attendees cited studies that suggested neither NTP nor NEP would be available in the human exploration time horizon of interest. Clearly no NASA commitment to put NEP/NTP on the critical path of human exploration should be made without further study

Findings from the Architecture Session (2)

- While radiation, psychological factors and other considerations will play a a major role in a human architecture, the critical first data point appeared to be whether fractional "g" was sufficient to prevent harmful degradation in human performance. This effect can be mimicked to some degree on ISS, but the first significant data will come from lunar surface exploration.

- The SpaceX Starship holds forth the promise of a major reduction in the cost per pound of payload to orbit, to the Moon and ultimately to Mars. However, such breakthroughs are dependent on a series of engineering demonstrations yet to be performed. Examples are on-orbit refueling and ISRU at a scale required by the Starship.

- Even with the NTP implementation, the Mars Base Camp (MBC) team prefers the conjunction missions over the opposition missions because of the wide variation in performance of opposition opportunities (some of which are just infeasible) and the much larger delta V required.

- Many Mars architectures, including MBC, could evolve from a chemical propulsion implementation to a NTP implementation

APPENDIX B

TECHNOLOGY AND OPERATIONS IN TRANSIT

Executive Summary: One of the most challenging aspects of human missions to Mars will be the transit period between Earth and Mars and the return trip back to Earth. Extensive preparations need to be made to assure smooth operations, crew health, and preparedness.

- Producing **mission architecture definition** will help to determine the master task list for the habitats and for crew health and performance
- **Data**
  - **Requirements are needed for integrated data architecture** for Human Health and Performance (HHP) and research
  - **Establish resiliency of that data** to be sure it is useful and backed up
  - **Robust server architecture with redundancies and downlink** to handle onboard data (training, entertainment, on-board data storage, and backup)
- Pre-flight and onboard training and bonding activities will be critical in supporting crew cohesion on a long duration mission.
  - Emphasizing the need for **down time** to avoid the possibility of burnout and personal time might be different based on the length of the missions.
  - The emphasis on **family support** and need to prepare for the communication delay and the impact that will have on crew and family on the ground
  - Onboard training, psychological support, entertainment and other crew cohesion activities can **help mitigate boredom and add to the meaningful conversation**.
  - **Technical training** for research and other operations **can happen in transit**. It will provide crewmembers with meaningful work. Actual hardware has been identified that will be used for in-flight sims and training exercises.
- On-board **garden systems** will be useful from a food production perspective and air quality benefit, it will contribute to crew health through harvesting/tending and even the ambiance light provided (more research needed). Meaningful work!
- **Use analogs (LEO and Gateway) maximally**
  - Support and gain improved visibility into the knowledge sharing between NASA and industry related to analog design and needs to conduct early research for human missions and how they can be incorporated into the training pipeline.

The Technology and Operations in Transit working session heard inputs from a number of contributors who had experience in analog operations, training, and human health studies. The Technology and Operation in Transit group debated the focus that should be taken for this area,but it was clear from the discussions that transit involved a complex interaction of human physiological and psychological factors. Therefore, activities needed to be planned out as part of the mission design to take both into account.

While it is good to have a plan and assigned activities, we also noted that it is important to allow for flexibility and modifications as the mission proceeds. Many of our participants with analog experience indicated that certain crew members often had a greater affinity for one type of task, and would naturally adopt the primary responsibility. It is important to allow for some evolution of the roles and responsibilities, while balancing the need to make sure that all required functions get performed.

Another topic discussed was the balance between group activities and team assignments and the need for some private time. One key aspect discussed was the difference in family communications that needs to be accommodated with the latency that will be part of Mars missions. There are a number of possible ways to deal with this issue and our team felt that it is important to start testing some of these in analogs, including on the ISS and Gateway.

The latency effect also impacts engineering and operations on board the vehicle. There is no "back room" of experts available to have real time dialog with if issues arise, as is the case today with Mission Control in Houston. Possible uses of AI technology to fill in part of this gap were discussed. It also stresses the need to ensure that the crew train and refresh their knowledge in onboard systems, even during transit. This is equally important for medical issues and we discussed the requirements for medical training (there is currently not a requirement that one crew member be a physician) and the need to triage and deal with the most acute issues without assistance from medical personnel back home on Earth. AI technology for medical purposes is not thought to be an effective substitute for human interaction and diagnoses.

Another aspect of combatting feelings of isolation is the design of habitats to provide lighting and variety of settings, such as a galley area and a garden area to avoid the feeling of being "locked in a tin can full of instrument racks." Design of the habitats also needs to allow for sufficient personal space for each crew member and it is important to allow them to personalize these areas.

The aspect of rituals, such as meal preparation and dining together, was also discussed as a means of dealing with the distance from home and long duration of the transit phases. The importance of having gardens aboard to provide some fresh foods was also noted. Another ritual was some form of entertainment, such as watching a movie together or even a recorded sporting event like a World Cup match. Many analog participants felt that this was a good mental health break and would lead to higher motivation and productivity.

Finally, of course, to deal with physical de-conditioning, it is vital to have a program of exercise that can mitigate the many effects of long-term exposure to micro-gravity. Having a place in the habitat where the exercise needs of the entire crew can be met, while not causing disturbance to others who may be working or resting, is also a requirement.

The main takeaway from these discussions was that the crew health aspects need to be considered along with engineering requirements right from the very start in the habitat design, mission planning, and operations. It is important not to overload the crew (Skylab revolt was brought up) but at the same time they need to have activities that keep them from getting bored. This is a balance that needs to be further explored through better simulated missions. The need to expand available analog environments and to take advantage of all types – Earthbound, ISS and other LEO platforms, and Gateway – was discussed.

The Ninth Community Workshop for Achievability and Sustainability of Human Exploration of Mars (AM IX)

Session 4: **Mars Surface Operations and Mobility**

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Key Summary Findings:

- How does mobility enable surface operations?
  - Extending exploration range
  - Enhancing ability to meet more science objectives
  - Crew transit between elements
- How do the plans for Artemis surface operations feed forward to Mars?
  - Establish confidence in operation of mobility vehicles with crew in a remote hazardous environment, shirt sleeve and EVA
  - Science operations, including drilling, sample collection

Session 4: **Mars Surface Operations and Mobility**

- What capabilities do crewed rovers require?

– Maximize shirt sleeve environment time (science, transfer, etc.).

– Intuitively controlled, very capability robotic arms to manipulate environment, take samples

– Operated by crew on the vehicle, telerobotically by crew in Mars system, remote from Earth

– Minimum viable distance capability at least the distance between landing sites

– Total system support includes navigation, communication, power, a few steps beyond what we've done before with robotic Mars systems

– Drilling systems

– Navigation capability important for increased autonomy, much higher speeds to get more done

– Ability to navigate around or over obstacles like boulders

– AI/autonomy

– ECLSS systems that minimize logistics mass when balanced with vehicle mass/power constraints

– Major science tools when crew are not there (untended operations)

– Robust internal power generation capability (nuclear given dust storms)

– Long design lives to support multiple crew missions and untended operations between crew missions

Session 4: **Mars Surface Operations and Mobility**

- How can crewed unpressurized and pressurized operations work together? and
- Can certain rover capabilities replace some of the need for EVA operations?

- Value to having both types: safety redundancy, unpressurized can access more difficult terrain
- Highly mobile pressurized rover with suit ports may not need to be paired with an unpressurized rover
- Need to carefully work out requirements for paired rover ops, trading habitation capability with higher mobility, redundancy (could result in Mars Segway, etc.)
- Define mobility requirements first, then define particular implementation
- Reduce need for EVA (reserve for cases where scientist-astronauts need to be more in the environment, more study and trades needed, between robotic manipulators and being in a suit for example)
  - Intuitively controlled, very capability robotic arms to manipulate environment, take samples
  - Docking ports
  - Sample transfer system / science airlock
  - Highly capable cameras and sensors that can be viewed from inside the vehicle
  - Teleoperated robotic systems (drones, small rovers, helicopters
  - Task optimization tools are needed to allow in situ astronauts to plan how to minimize EVA time

Session 4: **Mars Surface Operations and Mobility**

- How can robotic vehicles enhance crewed operations?
  - Aircraft mapping
  - Fetch vehicles– for samples, but also in general to retrieve things like tools, resupply and logistics
  - Systems to access very difficult areas (RSL)
  - Tool caddy
  - Biologically sensitive area access and activity
  - Inspection and maintenance, commissioning and decommissioning
  - Environmental monitoring
  - Scouting and deployment of instrument packages
  - Teleoperations
  - Supporting injured or incapacitated crew

Session 4: **Mars Surface Operations and Mobility**

- Given orbital robotic reconnaissance, is surface robotic reconnaissance required before humans?
  - **Yes**, additional benefits depend on quality of orbital data
  - Level of utility based on how detailed the survey needs to be
  - Monitoring for things that change frequently
  - Allows for informed risk assessment of needed capabilities and efficient science planning, gives time for ground processing of data, very important for short stay missions
  - Identify crew hazards
  - Identify sensitive areas
  - Could be remote operation of crewed mobility vehicle (like MTV Mars Terrain Vehicle)
  - Civil engineering (pebbles, building material) and ISRU measurements like contaminants, amount of resource

Session 4: **Mars Surface Operations and Mobility**

- Should only robotic assets be used to explore sensitive/extreme environments (teleoperations; ice sampling)?
  - We don't know yet
  - Could verify environments with robotics to be safe for humans
  - Drilling may requirement human interaction

Session 4: **Mars Surface Operations and Mobility**

- What environments and science objectives for Mars that drive mobility requirements are unique?
- Environments
  - Life potential / planetary protection
  - Thermal
  - Dust storms
  - Atmospherics
- Objectives
  - Life potential
  - Atmospherics

Session 4: **Mars Surface Operations and Mobility**

- Can systems be identical for the Moon and Mars, and if not, why?

– It can be to some extent, if you design the lunar systems for Mars

– Thermal difference may drive differences

– Not wildly different

– Pure vacuum motors can't be used on Mars

– Dust: might be able to design for the moon and then will work for Mars (sharpness of moon may be a driver, smaller particle size on Mars may be a driver

– 1/3g Mars environment will be a driver compared to 1/6g (particularly for suits, traction, suspension systems)

– Mars resupply chain much more difficult

– Solar power generation easier on the moon

– Landing systems very different

– Power storage for lunar night is more of a driver

– Atmospheric flight on Mars

Session 4: **Mars Surface Operations and Mobility**

- What key operations should be practiced on the Moon?
  - Shirt sleeve transfer
  - “Drill baby drill”
  - Fix a stuck bit
  - Contamination management
  - Hab and a lab
  - Suit ports
  - Autonomy and collaborative operations
  - The more synchronized the lunar and Mars architecture is, the more benefit there is
  - Earth independent navigation

Reference

Lunar Surface Science Workshop : Science Enabled by Mobility - Summary

Workshop held October 28, 2020

- Participants collectively agreed and emphasized that mobility systems:
  - Extends the physical range of exploration
  - Extends range of our scientific understanding of the Moon
  - Building geological context is critical with the ability to traverse 100s of km, within which individual sample data can be interpreted and understood
- Science-driven exploration activities enabled by mobility:
  1. Scouting of scientifically interesting areas in advance of crew to determine the accessibility, benefit, and risk factors associated with astronaut scientific exploration
  2. Transport of crew, science instruments, tools, and samples further and more efficiently than crew alone
  3. Exploration of scientifically interesting areas that are inaccessible to astronauts
  4. Autonomous and/or teleoperated systematic mapping that would be tedious and time consuming for astronaut crews
  5. Conducting unique geotechnical experiments enabled by the range and payload of the mobility assets
  6. Deployment and retrieval of instrumentation arrays across large areas.

Lunar Surface Science Workshop : Science Enabled by Mobility

- Additional benefits from Breakout Group 1: Capabilities of rover mobility systems without crew carrying capabilities
  - Exploration and scientific characterization of inaccessible or dangerous areas on the Moon
  - Systematic mapping and exploration (geochemical and geophysical; vertically and horizontally)
  - Mobile deployment and retrieval of instrumentation
  - Science amplification during a human mission: Scouting, systematic and/or repetitive observations that would require large amounts of crew time, additional detailed follow-up observations post-crew departure
  - Engineering science opportunities: Wheel-soil interaction mechanics, robotic failure modes and implications for human rovers, human-robotic interactions, etc.

- Breakout Group 2: Determining the scientifically enabling and/or enhancing capabilities of crewed/uncrewed mobility systems
  - Mobility systems should have 100+km ranges so that they can be used to map extensively and comprehensively, and to move between and within various geological terrains and thermal environments
  - Science is most enabled by mobility at the scales of 100 m to multiple kms, regardless of location
  - Tasks that might be repetitive could warrant a greater degree of autonomy versus those tasks potentially better conducted with human-in-the-loop teleoperation
  - Mobility systems should have robotic arms for uncrewed opportunistic sampling
  - Ground Penetrating Radar (GPR) and Neutron Spectrometer capabilities should be standard payloads
  - Between crewed missions, vehicles should be leveraged for interpolation, extrapolation, and/or reconnaissance activities
  - It would be valuable to enable the systems to deploy other smaller mobility systems

Science Objectives for Human Exploration of Mars Workshop – Summary
Workshop held May 4-6, 2022

- Goal: update and constrain science objectives for humans to address on Mars
- Breakouts explored both different types of science (search for life, geology, climate, etc.) and different architectures: short stay and long stay missions with and without mobility
- MEPAG Study on Benefits of Human Presence for Science:
  - No investigation was detrimental to have humans: trade on capability vs contamination always favors humans given the better sample selection
  - Allows for analyzing samples before any degradation
  - Larger sample mass
  - Deep drilling easier
  - Better ability to deploy complex instruments
  - Should plan for lab work on the way home

Science Objectives for Human Exploration of Mars Workshop

- Preliminary Takeaway: Science menu for human missions is robust
  - Short stay and long stay: Shallow drilling, surface sampling, deep drilling, deploy instruments, rugged terrain
- Major takeaways:
  - **Laboratory** capability on the surface needed to fully use human capabilities and select best samples to return, scaled to the duration of the mission
  - Most scientific disciplines want to perform **drilling**
  - Based on science experience on Earth, it always requires humans to solve issues during drilling
    - Modern oil and gas more adept at robotics
  - Biosignatures degrade after removal from environment so best to do science in situ
  - Likely need to do robotic due diligence before humans land at a site to confirm it is what we expect
  - Short stay mission increases importance of robotic activity before and after the mission
  - Since one major reason for short stay missions is to minimize surface infrastructure, this puts pressure on the mass, size, and volume allocation for scientific instruments on mobility vehicles and increases importance of hand-held instruments

- Discussion on activities to perform on the Moon to benefit Mars Exploration:
  - Drilling
  - Practicing deployment
  - Take forward contamination data
  - Practice incorporating robots pre and post mission
  - Sample triage
  - Geophysical instruments and active surveying by crew
  - Cold sample collection and handling
  - Space weather monitoring, contamination control, maintenance ConOps,
  - Standard geological instrument packages
  - Laboratory capabilities: glovebox style instruments, handheld instruments, teleoperation from orbit
  - Short stay vs. long stay practices
  - Practice real time science decision making, remote science teams, human robotic partnership
  - Human expertise and training needs
  - Communication strategies and requirements

APPENDIX D

Science Team
Together for the First Time: Human Research, Biological & Physical Science, Lunar and Mars Science

Name	Affiliation	Specialty
Dave Beaty	NASA JPL	Mars Science
Penny Boston	NASA Ames	Field Science & Astrobiology
Lashawn Boulware	Lockheed Martin/JSC	Human Systems
Phil Christensen	ASU	Mars Planetary Decadal Science
Tim Cichan	Lockheed Martin	Mars Architecture
Bob Collom	NASA HQ	Integration Lead/Dep. Team Lead, Mars Recon Team
Rick Davis	NASA JSC	Mars Architect, Technology
Sydney Do	JPL	Water Mapping Efforts at Mars
Christy Edwards	Lockheed Martin	Mars Architecture
Jen Heldmann	NASA Ames	Decadal Survey Author
Scott Hubbard	Stanford University	Strategy, Policy
Stephen Indyk	Honeybee Robotics	ISRU
Linda Karanian	Karanian Consulting	Aerospace Engineering Management, Business Development
Belinda Lopez	Lockheed Martin/JSC	Flight Operations Training Lead, Human Lander Systems
Kennda Lynch	LPI	Astrobiologist, Geomicrobiologist
Steve Mackwell	Rice University	Geophysics
Margarita Marinova	Amazon	Mars Architecture and Astrobiology
Saralyn Mark	SolaMed Solutions	Space Medicine
Lisa May	Lockheed Martin	Chief Technologist, Advanced Concepts
Torin McCoy	NASA JSC	Human Health and Performance
Chris McKay	NASA Ames	Astrobiology
Jancy McPhee	Aerospace/NASA	HRP
Michael Meyer	NASA HQ	Mars Science
Michael Mischna	JPL	Mars Science
Clive Neal	Notre Dame	Lunar Geology
Hoppy Price	NASA JPL	Mars Scenarios
Michelle Rucker	NASA JSC	Mars Integration Lead
Kevin Sato	NASA BPS Program Scientist for Exploration	Biology and Physical Science
Andy Spry	NASA HQ (SETI)	Overview of Planetary Protection
Michelle Viotti	NASA JPL	Mars Exploration Program Office Strategy
Jim Way	American Astronautical Society (Exec. Director)	Strategic Marketing and Communications

Key Findings and Recommendations

1. The Mars Exploration Program Analysis Group (MEPAG) has done excellent work assessing the potential for human explorers to accelerate science at Mars. However, the MEPAG referred to current robotic science objectives to make those assessments, and, as such, their proposed human science objectives are limited in scope by what can be accomplished using robots at Mars. Human missions will significantly enhance the capabilities (mass delivery, power, real time decision making, etc.) available for science. AM IX attendees brainstormed a list of what humans will bring to exploration at Mars (note Appendix X) and strongly encourage the MEPAG to consider these unique capabilities and to build upon this list to draft out a set of exciting science goals that will be worthy of sending humans to the Red Planet.

2. AM IX recommends the establishment of a joint Lunar Exploration Analysis Group (LEAG) and MEPAG team with appropriate engineering support, to review the MEPAG's proposed science goals and look for potential synergies between these goals and the tools needed to achieve them, such as mobility, drilling, hand tools, human-tool-interfaces, etc., at both the Moon and Mars. A key deliverable would be an assessment of which lunar science operations could inform future operations at Mars. Identified synergies would also be useful for justifying technology investments for the Moon.

3. Understanding where water-ice is (vertical and horizontal extents as well as composition), collecting samples and even extracting ice cores are key elements of future exploration at both the Moon and Mars. These data are key for decadal priority science and for in-situ resource utilization (ISRU). Further, accessing the ice while minimally impacting the samples/cores (i.e. change of state and potential biology) is a critical technology challenge that we encourage NASA to look at as soon as possible. Such investigations will likely require assessments of potential crew safety issues (e.g., planetary protection hazards, challenges associated with operating heavy machinery on ice, etc).

4. Human explorers will be both scientific investigators as well as subjects of scientific research to understand how the human body and psyche adapt and change in response to the environmental conditions they will encounter throughout the mission (e.g., extended stays in zero G, transitions to a 1/3G environment, high radiation environments, etc.). For initial missions to Mars, it cannot be assumed that all crewmembers will go to the surface. AM IX attendees recommend that NASA investigate the risks associated with long exposures to zero G, high radiation environments, and extreme isolation (1100 days for a conjunction class trajectory; 700 for opposition class trajectories) to inform potential mitigation strategies.

5. To maximize science return and reduce risk to the crew, workshop attendees recommend that NASA identify and prioritize potential robotic precursor missions to establish baseline measurements for candidate human landing sites to ensure that decadal level science can be accomplished at these sites. HiRISE-class resolution imaging, ice mapping, and weather measurements (on the surface and in space) are emerging priorities for both science and for mission success. For ice science, robotically accessing the ice prior to humans arriving may be a critical control data point. Reducing the cost while increasing the cadence of robotic missions to Mars, as envisioned by NASA's Low-Cost Science Mission Concepts for Mars Exploration workshop, may be critical to accomplishing these as well as other critical science objectives.

6. AM IX applauds the International Space Station's program ISS4Mars to utilize the space station as an enabling analog for Mars missions. Studies looking at lower body negative pressure countermeasures, Earth independent medical operations (including no communications and time delays), and post landing fitness assessments are key. AM IX sees significant value in extending this research to include landing crews at remote sites and having them perform self-recovery to execute both operations and science as soon as possible. While there are associated risks, landing at Mars will be far more challenging and understanding the operations concepts needed to allow crews to adapt as quickly as possible in a 1/3 G environment will no doubt be critical for both safety and mission success.

7. NASA made a key step towards prioritized science objectives at their Science Objectives for Human Exploration of Mars Workshop in March 2022, but most attendees either represented the MEPAG or human spaceflight engineering communities. AM IX also had representatives from the lunar, human research, applied, biological, and physical science communities, and attendees saw significant value in the cross-discipline conversations at the workshop. We know that NASA is planning, and AM IX strongly supports, future workshops to define and prioritize science objectives as well as needed technologies (e.g., drilling, mobility, hand tools) with all of these disciplines represented.

BACKGROUND

The Achieving Mars IX (AM IX) workshop brought together multidisciplinary experts (e.g., Mars geology, climatology, astrobiology, human biology, human physics, and environmental science) to collaborate in developing potential scientific objectives for a campaign of regular and progressive human missions to Mars. The goal is to shape coherent priorities for multiple Mars missions in a discovery-driven manner. Science and supporting instruments and technologies are scoped to the mission type and duration and build on those over time. This will enable profound discoveries about the evolution of Mars, its relationship to Earth, the potential for past or present microbial life, fundamental biological and physical principles, human psychosocial/physiological adaptation, and the prospects for sustainable human exploration. The information from the workshop is designed to further the conversation among multidisciplinary experts to ensure that both the mission crews and mission architecture are prepared to conduct meaningful scientific assignments for the three-year round-trip missions, determine the best way to use human intellect, agility, and ingenuity for discovery, and define scientific priorities that maximize a return-on-investment worthy of sending humans to the Martian system.

ASSUMPTIONS

1. Early reconnaissance to characterize candidate landing sites is important to understand the most scientifically rich locations for human exploration, assess local Martian resources, and demonstrate their means of production.
2. The first human missions may be orbital or short surface stays, designed to assess the candidate site(s) worthy of and conducive to a sustained human presence and potentially to set up critical infrastructure for tasks enabled or enhanced by human capabilities.
3. Candidate landing sites will be in mid-latitude, ice-rich locations where human missions are more operationally viable and where we can answer decadal science questions.
4. The highest-priority science worthy of sending humans drives the location(s) for human exploration and developing a human-mission architecture.

SCIENCE SESSION DISCUSSION SUMMARY

Science priorities for human missions to Mars are still in formation. At the workshop, the team sought to address some key questions:

1. What advantages do human explorers with robots bring in enabling science and deploying science instrumentation (e.g., real-time decision-making, more power, heavier equipment, etc.)? In which scientific investigations are human capabilities most strategically employed?
2. What are the preliminary, priority science objectives enabled by humans on the surface of Mars, in transit, and in orbit?
3. What precursor information do you need from the Martian system before human missions to maximize science?
4. Does priority science require equipment on the Mars Transfer Vehicle?
5. What is unique about the environments in which the astronauts will find themselves?

1. What advantages do human explorers with robots bring in terms of enabling science and deploying science instrumentation (e.g., real-time decision making, more power, heavier equipment, etc.)? In which scientific investigations are human capabilities most strategically employed?

AM IX participants discussed what advantages human explorers with robots bring to enable science and deploy science instrumentation.

Human missions necessarily bring more power and mass to the Martian system (both in orbit and on the surface) than previous robotic missions. Crewed missions offer a unique opportunity to return more sample mass than planned with robotic missions. Properly trained human explorers can select better samples and perform real-time analysis to advance scientific objectives while on the surface before the samples' ephemeral properties (e.g., volatiles, temperature conditions, etc.) degrade. Further, humans can reassess their objectives based on surface conditions, improve processes based on lessons learned, and recognize the environmental context of their investigations. We expect properly trained human explorers to collect, assess, and down-select better samples for return than modern robots.

On-site subject-matter expertise, versatility, and mobility are critical features of human explorers, so rigorous training of astronauts is needed. For example, the crew can configure and deploy instrumentation that lasts on the surface after their departure with more finesse and contextual awareness than robots. Similarly, humans will be crucial to deploying, operating, and maintaining deep-drilling equipment because of their dexterity and adaptability.

In addition to their ability to accomplish meaningful science, humans can tell the Martian story, engage the public, inspire people, and sustain political will over multiple years. First-hand accounts of scientific discoveries from Mars that recount the excitement and the challenges will be critical to bringing Mars to the people of Earth.

2. What are the preliminary, priority science objectives enabled by humans on the surface of Mars, in transit, and in orbit?

As mission planners prioritize Mars robotic and human-tended science, multidisciplinary scientists must also provide their input and expertise so that synergies, specialized mission-enabling measurements, and fundamental science are given due consideration. Broadly studying the Martian landscape's physical, geological, and chemical properties, atmosphere, and volatile exchanges relevant to human-class landing and launch, surface operations (including ISRU and civil engineering), and mobility will be valuable to inform mission design. Biological and physical science interests include studies of terrestrial organisms in the context of the Martian environment, fundamental physics principles (like the behavior of fire in <1 G environments), and assessments of the crew and spacecraft microbiomes. Anticipating how humans will adapt to alien and highly challenging environments physically, sociologically, and psychologically is another research priority.

Fundamental science is a vastly larger category in which many but not all mission-enabling investigations can be conducted. For example, while space biology investigations address some fundamental science questions, other aspects only make sense within the specific context of a contained built environment subject to a specific set of environmental forcing factors. On the other hand, a great deal of astrobiological, mineralogical, and geological information is aimed at fundamental science. Still, a significant and identifiable subset of such questions has immediate and essential application to enabling missions, ensuring planetary protection compliance and avoiding materials contamination and other environmental hazards.

3. *What precursor information do you need from the Martian system before human missions to maximize science?*

Mission personnel must determine required vs. desired information. Future workshops should develop an assessment of how different precursor missions reduce the risk for human mission elements. How do budget expectations impact these questions? How does planning for a more extended campaign of missions change the answers? There will be unknowns, but new information will be gathered every time humans visit Mars. The first mission will highlight many knowledge gaps that may be closed before the second.

More data helps reduce risk and provide mission planners with enough information to enable the first mission. Among the most critical data sets will be orbital characterization and ground-truthing of subsurface ice deposits. Understanding the location, extent, and accessibility of these deposits will inform not only science planning, but also ISRU strategies. Planetary protection Treaty obligations may require data sets demonstrating these missions would be safe for the return to Earth.

Specifically, the lethality of the Martian surface environment to terrestrial organisms informs the need to develop a strategy that confirms team members avoid returning uncontained viable Martian organisms to Earth, as well as harmful contamination of Mars. We know how to acquire pristine samples on Earth, and human contamination is not as big of a concern as one may think. Planners can look to protocols used on Earth.

Characterizing the local environment before human arrival will be necessary for baseline scientific measurements. Human explorers might not be detrimental to any specific scientific investigation. Persistent human microbial environments, such as in and around habitats, would likely change the local environmental conditions and the scope of possible science.

Living and working on Mars, in the Martian system, and on the voyage between Earth and Mars will be highly taxing on human systems. Crew characteristics and dynamics will vary, as will mission types and durations. “Margins” in what human systems can accommodate will need to be identified.

ISS has been a critical testbed as an analog for the hazards of a microgravity transit to Mars. The ISS4Mars international coordination and visioning had the expected outcome of assessing the validity and feasibility of analog concepts, imagining possible implementation procedures (even if different than in the past), involving the whole partnership, incorporating this strategy into national programs, and proposing technical and scientific calls toward this

ISS4Mars initiative.

Mars analog activities can close knowledge gaps that cannot be accomplished on Earth and benefit the future of international deep space exploration. ISS4Mars can provide ISS enhanced fidelity for Mars risk-reduction research across all five hazards of human spaceflight (gravity changes, radiation, isolation and confinement, distance from Earth, and hostile closed environments) .

4. *Does your priority science require equipment on the Mars Transfer Vehicle?*

Priority science may require equipment on the Mars Transfer Vehicle (MTV), including cryogenic storage and crew monitoring. Subsequent and concurrent robotic missions may augment sample return limitations with a human crew. Planners must determine the trade between *in situ* and returned sample analysis and the minimum success criteria for the sample mass. If built as a flexible modular system, the MTV presents unique opportunities for evolving science and engineering.

Other priorities include subsurface ice location and depth, meteorological data, mission duration and objectives, and dust and radiation environment[1].

5. *What is unique about the environments in which the astronauts will find themselves?*

Astronauts will experience extended periods in Zero-G and radiation environments—potentially up to 1,100 days. The total length of time significantly exceeds the current baseline. Mission planners need to understand how living and working in chronic partial gravity may affect physiology or readaptation and if the astronauts' partial gravity experience will affect conditioning. Another challenge is that galactic cosmic rays are pervasive and hard to shield against. Strategies for overcoming these challenges, and others discussed below, could potentially be assessed by explorers at the Moon.

Isolation with a small crew is also a concern. Planning teams should consider astronauts' physical and mental health. Preparations might include consideration of crew downtime, family support communications from Earth, boredom mitigation, and crew cohesion. Other considerations should include a well-conceived wellness plan that provides both physical and psychological support, refresher training, privacy in sleep quarters, entertainment opportunities, and meaningful research for the crew to conduct during the mission.

The time delay poses additional challenges for communication with Earth. Communications relay might mitigate the potential for up to two-week communication blackout periods. The current communications infrastructure is aging and insufficient for robotic and human exploration. Crew interactions and dynamics will likely change over the mission's course, and mission planners must understand how their comradery may change.

The extremely cold temperature will pose an infrastructure challenge. Sunlight is decreased compared to Earth and could affect human perceptions. Dust storms may block sunlight for months at a time. The day is slightly longer on Mars and could affect the astronauts directly, including potentially changing their circadian rhythm and how they interact with Earth. At what point do astronauts switch from Earth time to Mars time? Planners must also understand how transitioning from artificial lighting to Mars and back affects the crew. One thing is clear, human missions to Mars will require consistent access to reliable power sources to meet the needs of the crew for the entire duration.

[1] Novel ways to use the International Space Station as an exploration analog: International Progress in Planning "ISS-4MARS" (https://ntrs.nasa.gov/citations/20210021997)

Achieving Mars IX, Day 2: Landing Sites and Synopsis Overview

Introduction: Martian landing site selection is a critical step that must be addressed long before human surface missions are conducted. Site selection can impact mission architecture decisions, science objectives, and planetary protection protocols.

1. WATER RESOURCES
    a. Little is known about the composition of the ice
        i. Ice exposing impacts give us some insight into the purity and composition
    b. Will Rodriguez Wells (“Rodwells”) (where heat exchangers and a submersible pump to create a cavity deep under the ice’s surface and cycle the heated water up an ice shaft) negatively impact the surface stability above the well?
        i. They work well in Antarctica without collapsing
        ii. The geotechnical properties of the Martian overburden need to be better understood to answer this question.
2. INTERNATIONAL-ICE MAPPER MISSION – MEASUREMENT DEFINITION TEAM (I-MIM MDT)
    a. Ice mapping and ice characterization is likely a key precursor to inform both science and in-situ resource utilization (ISRU)
3. PLANETARY PROTECTION
    a. Human missions may dispose of trash outside of the Mars Transit Vehicle (MTV) while in Mars orbit. Depending on how long this trash stays in orbit, it may or may not pose challenges for planetary protection.
    b. Detections of near-surface extant life near a candidate landing site would likely dictate changes in our human mission architecture
    c. It is important to take an “assurance case” approach to risk assessments to estimate the likelihood of contamination without undue bias
        i. There are lessons learned from the nuclear industry
    d. The crew will likely need to be in quarantine after returning to Earth. If they are in quarantine, what measurements would we need to take to demonstrate they are safe?
        i. Astronauts will be in their worst condition when they return to Earth. The tools they will have available on the MTV will not be sufficient to make a medically informed decision of their health.
        ii. The medical and astrobiological communities do not and will not have sufficient guidelines to make informed decisions about quarantine policies
        iii. Any quarantine will likely be a political decision to assuage public fears
    e. We have robotic models for the relationship between atmospheric entry and spacecraft sterilization, but additional work is required to extrapolate to human sized craft

SYNOPSIS

1. TRANSIT OPS
    a. How do we give the Human Health and Performance (HHP) community more runway to address the challenges and define the requirements for human missions well before the mission is approaching a launch date?
        i. Engineers and doctors/nurses/pharmacists do not speak the same language
    b. Exercise on an extended mission may require more complex equipment or operations than that for which we are currently planning. It will be important to improve our understanding of the time required to keep the crew physically healthy
    c. "Meaningful work during the mission" is a critical statement as we prepare to send humans to Mars
        i. Giving the crew choices and flexibility to define their own meaningful activities might give them more ownership and feel less forced upon them
    d. What capabilities of Mission Control do we need to replicate on the MTV, and what tasks can be managed by intelligent systems to reduce the burden on the crew?
        i. How do we balance human-AI teaming? Can we reduce the data delivered to the crew for decision making but preserve the analysis that enables the crew to make good decisions?
2. SCIENCE PRIORITIES
    a. Human Capabilities
        i. Giving the crew flexibility to tell their own story while they are on the mission would be valuable not only for crew health, but also for public outreach. We should not make to crew perform.
    b. Precursor Requirements
        i. Requirements are value judgments determined by a chain of command. Without a clear assignment of responsibility for determining these value judgments, these decisions may be delayed indefinitely. Risk thresholds need to be identified that are in consideration of what we want vs what is realistic. Achieving Mars Workshop attendees could highlight which decisions are important and encourage NASA to make the process more transparent.
        ii. Something being a "red risk" does not mean that we are unable to achieve it. Technology development is ongoing and we have plans in place to address them
    c. MTV Leans:

Making a list of common/complimentary equipment is hard and needs time and budget. Who pays for it and how do we convince folks that it is valuable

AM IX
The Ninth Community Achievability and Sustainability of Human Exploration of Mars Workshop

Session 1: Human Health Performance (HHP)

Day 1 – June 14, 2022

Led by Belinda Lopez & LaShawn Boulware, CPE

High priorities for human health performance (HHP):
Key initial mission crew tasks to minimize risk and promote sustainability (CT)

Crew cadre size and selection

- Define mission priorities to inform the following:
  - Mission duration
    - Defines how much risk maybe present to crew
  - Mission tasks
    - Enables adequate hardware design
      - Spares vs 3D printing
    - What is being asked of crew depends on type of mission
      - Fly-by or Mars surface landing
    - Define a master task list to enable mission design
  - Crew size
    - Interpersonal relationships such as sex and pregnancy
    - Reproductive health
- Develop a sustainable Human System Integration Process
  - Mission architecture and HHP group coordination
  - Leverage technology such as AI, digital twin, MBSE, AR/VR
  - **Define a crew health human performance system that fits within the engineering constraints and enable the crew to accomplish the mission tasks**

Isolation & Confinement

- Consumables
  - Medicine
    - **Additional medicine shelf-life research**
  - Nutrition / food preparation
    - **Create a certifiable food system suitable for mission duration**
      - **Explore dissimilar redundancy food systems for meeting crew needs**
      - A fundamental risk given current food system capabilities
      - If not adequate, may have negative affect on health and performance

High priorities for human health performance (HHP):

Considerations/recommendations on short vs. long-stay vs. fast transit conjunction

Requirements on the first mission to enable subsequent missions

Space Radiation

- Buy down or characterize and mitigate risk by providing funding research in non-cancerous affects, develop partnerships with groups included but not limited to NASA, DoD, and HHS
  - Prioritize **in-mission risks** vs. long term post mission risks
    - In mission risks: Cardiovascular disease (CVD) and Central Nervous System (CNS), chronic immune system dysfunction
  - Exposure affects mission duration and crew performance to complete mission tasks
- Investment in **medical countermeasures** that can prevent or reduce harm from in-mission risks such as **early detection** and **monitoring**
- Consider further investments that would **reduce solar cycle uncertainties and improve space weather forecasting**
- Scope risk decisions based on both nominal and contingency concerns

Hostile Environment and Gravity Effects

- Investment in research **dose response curve of partial gravity physiology performance**
  - Understand biological variability
  - Optimizing countermeasures and strategize for self recovery upon initial Mars landing

High priorities for human health performance (HHP):

Requirements on the first mission to enable subsequent missions, including science, infrastructure, astronaut health, technology demonstrations, operations, etc.

Analogs for Mars mission

- Human System Integration (HSI) **education for all stakeholders** such as spacecraft designers and scientists
- Creation of a consortium (similar to Lunar Surface Innovation Consortium) that enables:
  - Cooperation and education across all stakeholders
  - Discussion about **utilizing Analogs for combine crew/mission support team training, research, system/technology validation**
  - Prioritization of needs for risk reduction

Session 1: Human Health and Performance – Part 1 (Lindner Common Rm 602)

Time	Topic	Duration	Speaker	Details
10:15 AM	Goals & Deliverables; Framework for discussion: • Risk Reduction • Timeline • What we need to start now • Crew Selection/ Requirements – including commercial crews • Crew Roles & Assignments – now through Crew 1 • How it affects mission design & hardware architecture	15 min	Belinda Lopez	The framework will set the stage for all other sessions. We can develop a scoring/rating criteria to use to help guide this. Overall goal is risk reduction/safety for a human crew.
10:30 AM	Brain/Bio Break	20 min	All	
10:50 AM	• Cadre & Crew Selection/Requirements/ Quantity • Epigenomics • Psychological OIG says not enough astronauts!	20 min	Lauren Landon (virtual)	• What is the minimum acceptable Crew compliment? (Too few and mission could be compromised by health/other issues. Too many and logistics get larger.) • What size Cadre will be needed to fully support each mission? • What requirements/pre-requisites will be different for Mars Crews than Artemis & ISS? • Skillsets
11:20 AM	Q&A and Discussion	30 min	All	
11:40 AM	Isolation & Confinement, Closed Environments & Distance from Earth	20 min	Bailey Burns (virtual)	• Habitat design considerations for health and mental wellness • Nutrition – food growing
12:10 PM	Q&A and Discussion	30 min	All	
12:30 PM	Lunch	60 min		

Session 3: Human Health and Performance - Part 2 (Lindner Common Rm 602)

Time	Topic	Duration	Speaker	Details
2:00 PM	Space Radiation	20 min	Lisa Simonsen	• Current radiation protection requirements and the various options for mitigation • Mitigation strategies: habitat/cabin design, suits, medical/pharmaceutical
2:20 PM	Q&A and Discussion	30 min	All	
2:50 PM	Hostile Environment and Gravity Affects	20 min	Marissa Rosenberg	• Assessing ISS astronauts immediately after they land back on Earth as an analog for how crews on Mars will perform just after landing.
3:10 PM	Q&A and Discussion	30 min	All	
3:40 PM	Analogs for Mars mission – ISS-Earth surface and Gateway-Lunar surface	30 min	Erin Bonilla	• Earth – ISS – Earth • Gateway – Lunar Surface – Gateway • Issues of cost / time / expected returns on investment- what is needed
4:10 PM	Panel and discussion	20 min	Panel of the speakers	• What is needed now to prepare for humans to Mars? • Can the Moon provide suitable analog activities to reduce risk for humans to Mars?
4:30 PM	Report Out to Plenary	30 min	All	Report out to Plenary

National Aeronautics and Space Administration

Overview of Planetary Protection Considerations for Human Missions

J. Andy Spry, Senior Scientist SETI / PP Consultant
J. Nick Benardini, Planetary Protection Officer
Elaine Seasly, Deputy Planetary Protection Officer
Bette Siegel, ESDMD POC

AMIX

June 15, 2022

Office of Planetary Protection

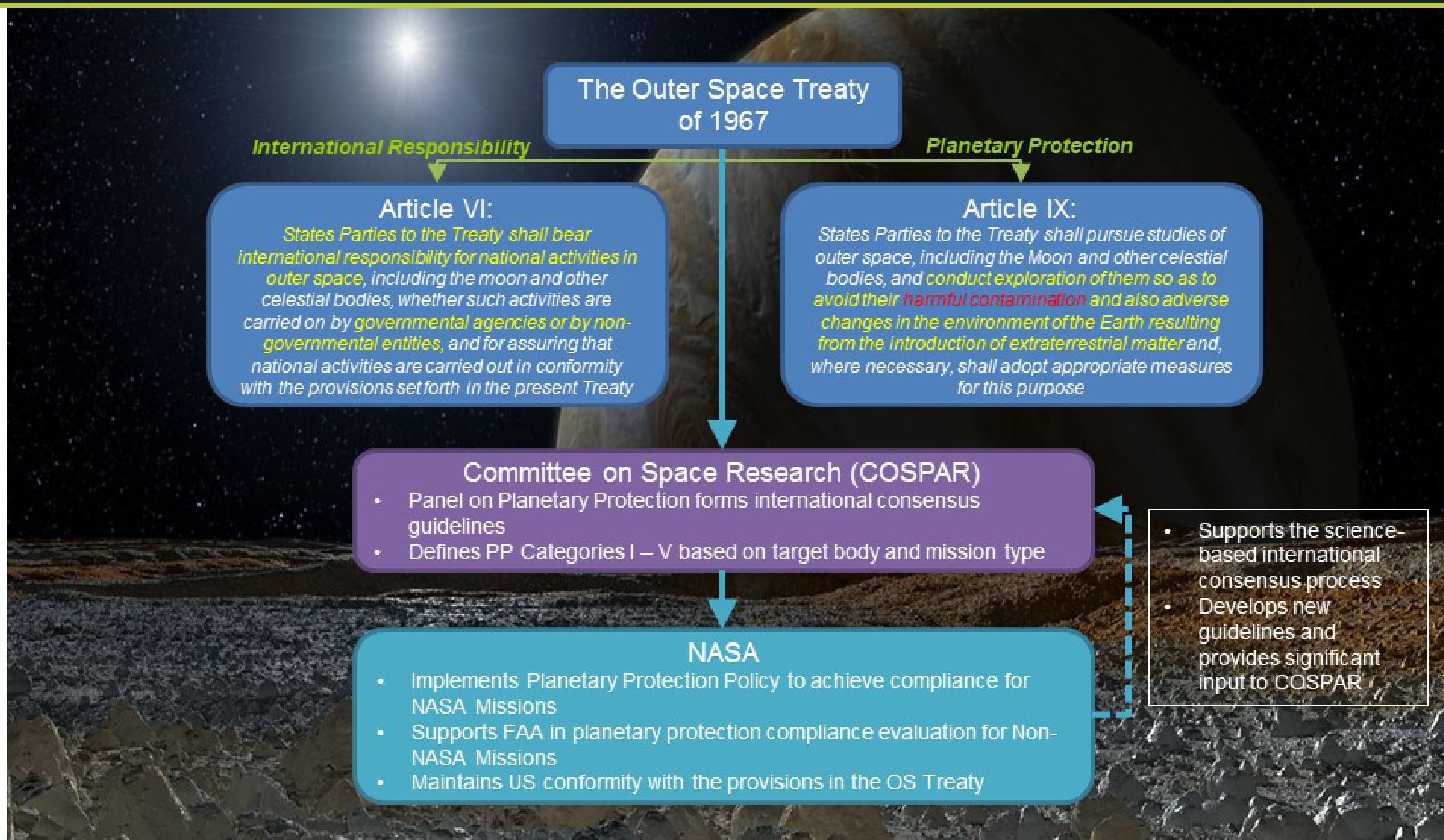
sma.nasa.gov

OSMA OFFICE OF SAFETY & MISSION ASSURANCE

Overview

- Introduction to Planetary Protection Policy and Implementation
- Knowledge Gaps in Planetary Protection for Crewed Missions
- Way Forward
- Take Home

Introduction to Planetary Protection



NASA's Planetary Protection Documents (current)

NPD 8020.7G
Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (Revalidated 05/17/13 w/change 1)
Expiration Date: June 19, 2022

NASA Policy Directives (NPDs)
- Documents Agency policy statements
- Describe what is required by NASA management to achieve NASA's vision, mission, and external mandates

NPR 8715.24
Replaced NPR 8020.12D/NID 8020.109A
Planetary Protection Provisions for Robotic Extraterrestrial Missions
Effective Date September 24, 2021
Expiration Date: September 24, 2026

NASA Procedural Requirements (NPRs)
- Provide detailed procedural requirements to implement policy
- Guide how policy directives are implemented in the context of specific missions

NID 8715.129 ("Mars NID")
Biological Planetary Protection for Human Missions to Mars
Expiration Date: July 9, 2022

NASA Interim Directives (NIDs)
- Documents an immediate, short-term statement of the Agency's policies, requirements, and identifies responsibilities for implementation
- Temporarily modify policy directives or implementation requirements

NASA Standards
- Provide technical requirements
- Each NASA Technical Standard is assigned to a Technical Discipline

NASA-STD-8719.R
Implementing Planetary Protection Requirements for Space Flight
Expiration Date: TBD
Status: Estimated Release ~7/22

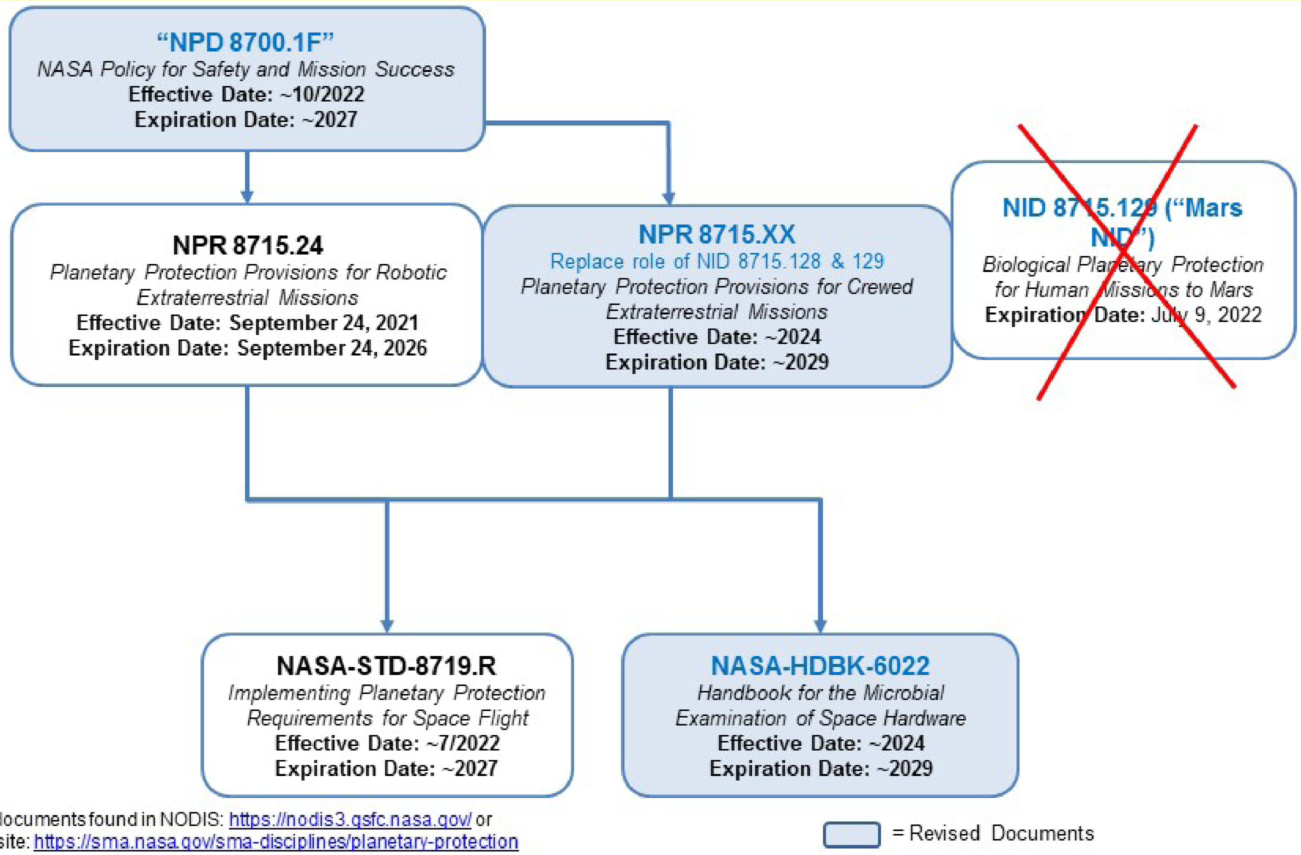
NASA-HDBK-6022
Handbook for the Microbial Examination of Space Hardware
Expiration Date: N/A
Status: Revision planned. Last draft revision released Aug 17, 2010

NASA Handbooks
- Companion documents to NPRs and NASA Standards
- Provide supporting material such as guidelines, lessons learned, procedures, and recommendations

All published documents found in NODIS: https://nodis3.gsfc.nasa.gov/ or the OPP website: https://sma.nasa.gov/sma-disciplines/planetary-protection

= New Documents

NASA's Planetary Protection Documents (Notional Future Path)



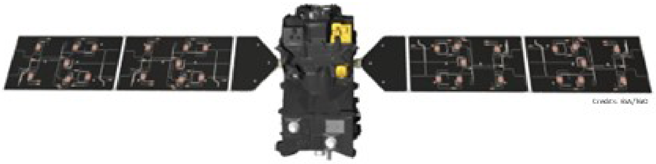
All published documents found in NODIS: https://nodis3.gsfc.nasa.gov/ or
the OPP website: https://sma.nasa.gov/sma-disciplines/planetary-protection

Planetary Protection Implementation for Robotic Missions

Typical implementation - Lander:

- Bioburden reduction of flight hardware using solvent cleaning, dry heat, ionizing radiation and gases
- Recontamination prevention using flight and non-flight filters and barrier systems
- Bioburden control of assembly, test and launch operations
- Bioburden verification with assays

Intent is to meet numeric bioburden limit



Typical implementation - Orbiter:

- Probability of Mars impact assessment for launcher upper stage and spacecraft
- Launch, cruise to Mars, MOI and orbital mission phases
- Hardware, software and operational reliability
- Micrometeoroid impact and effect analysis

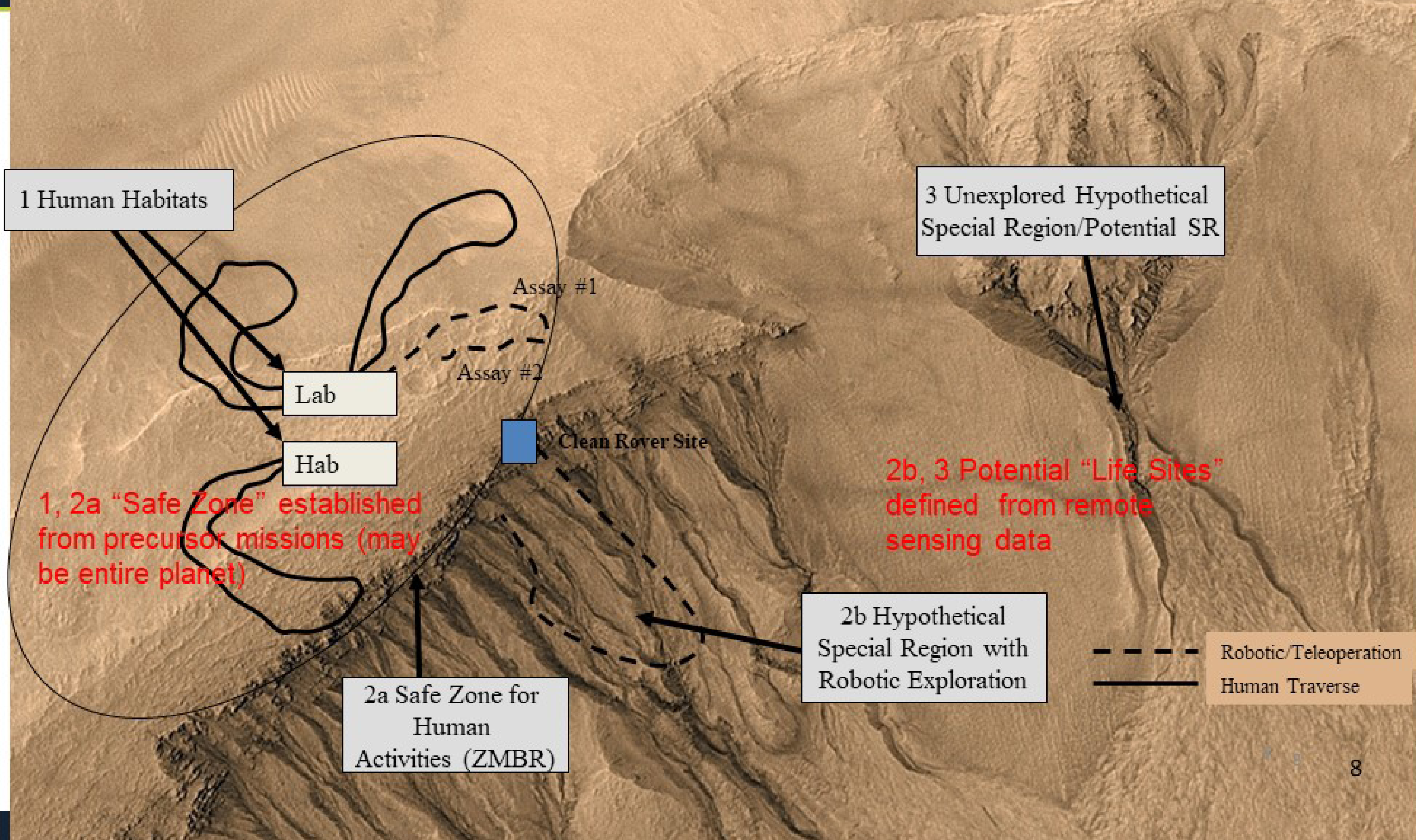
Alternative approach is bioburden control of spacecraft, including break-up/burn-up analysis

Knowledge-Based Robotic to Crewed Transition Assumptions*

- Human spaceflight hardware leaks (in nominal and off-nominal operation), so the old robotic paradigm of managing a fixed bioload is inappropriate.
- The introduction of a maintained temperate terrestrial environment at the martian surface affords the opportunity for many more organisms (in type and quantity) to escape into the martian environment.
- This exploration is taking place in a post-Mars Sample Return (MSR) context where martian life was NOT (yet?) discovered at the martian surface/shallow subsurface in returned Mars material, but we know a lot more about Mars from those samples.
- Knowledge gaps need to be understood and preferably closed before launch to protect science return and the Earth.

* Developed as ground rules for the 2020 COSPAR "4th Workshop on Refining Planetary Protection Requirements for Human Missions" – see the Conference Documents section at https://sma.nasa.gov/sma-disciplines/planetary-protection

Planetary Protection Concept* for A Crewed Mission to Mars



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*Criswell, M.E., et al., 2005. Planetary Protection Issues in the Human Exploration of Mars, Final Report May 9, 2005 (workshop held June 2001), NASA, Ames Research Center, Moffett Field CA, NASA/CP – 2005-213461

Path to Closing Knowledge Gaps and Establishing PP Requirements

Workshops Timeline

2015	2016	2018	2018 & beyond
NASA Workshop at Ames	1st COSPAR Meeting at LPI	2nd COSPAR Meeting at LPI	COSPAR Working Meeting on Contamination Transport on Mars at LPI, May 2018 COSPAR Working Meeting on Microbial Monitoring & Health at LPI, May 2019 COSPAR Working Meetings on Spacecraft Systems (virtual) May 2020 and June 2022
Identification of Planetary Protection Knowledge Gaps for human missions to Mars	Refinement and prioritization of Planetary Protection Knowledge Gaps for human missions to Mars	Mission Opportunity identification for addressing Planetary Protection Knowledge Gaps for human missions to Mars	Measurements and Payload/Operation Concepts for addressing Planetary Protection Knowledge Gaps for human missions to Mars
What Knowledge Gaps…	…in what order…	…using what missions…	…to make what measurements…

…to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Planetary Protection Knowledge Gaps for Human Mars Missions

1st COSPAR Workshop (2016)

Each Group
Analyzed & Ranked
Knowledge Gaps (KGs)
by
Time Priority
& Mission Criticality

TABLE X: All Splinter Group Findings	Priority/Criticality	
GROUP 1: Microbial & Human Health Monitoring	TIME	MISSION
1A. Microbial Monitoring of Environment	H	
1B. Microbial Monitoring of Humans	H	
1C. Mitigation of Microbial Growth in Spacecraft Systems	H	
1D. Operational Guidelines for PP and Crew Health	L	
GROUP 2: Technology & Operations for Contamination Control		
2A. Bioburden/Transport /Ops during Short v. Long Stays	M	M
2B. Microbial/Organic Releases from humans and support systems	H	H
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases	M	H
2D. Design of Quaratine Facilities/Methods -for different phases	L	L
2E. How do MarsEnv Conditions vary over time wrt growth of Earth mcirobes	L	H
2F. Res. needed to make ISRU & PP goals compatible	M	M
2G. "acceptable contam' of wastes left behind? Constraints on vented matls.	L	L
FORMER 2H. DELETED		
2 I. Approach to Achieve 'Break the Chain" Requirements?	L	L
2J. Global Distrib/Depth of subsurf. Ice-- and evidence of Extant life?	H	H
2K. Evolution of PP Reqmets/goals from robotic to Human Missions & zones?	H	M
GROUP 3: Natural Transport of Contamination on Mars	Time/Mission	
3A. Measurements/Models for Mars atm. transport of contaminants	H	
3B. Measurements/Models for subsurf. transport of contaminants	M	
3C. Effect of Biocidal Factors on surv./growth/adapt of microbes on Mars	H	
3D. Determine Acceptable Contam. Rates & Thresholds	H	
3E. Protection Mechanisms for organisms on Mars	M	
3F. Degradation of Landed Materials by martian envmt	M	
3G. Induced Env Conditiosn around Struture?	M	
3H. Sensitivity of non-culturable spp to biocidal factors	M	

Planetary Protection Requirements for Human Missions
6th Meeting Overview

Day 1 The Knowledge Gaps around Quarantine of the crew and related assumptions/questions:

> 2D What considerations should go into the design of quarantine facilities and methods for use on Mars, returning from Mars, and in the Earth-Moon system?

Day 2 The Knowledge Gaps around how to handle the samples that would be taken during the mission, and upon the return:

> 2I What approach should be taken to achieve the requirements to "Break the Chain of Contact" with the Martian environment for human missions?

...to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Day 1 The Knowledge Gaps around Quarantine of the crew and related assumptions/questions:

2D What considerations should go into the design of quarantine facilities and methods for use on Mars, returning from Mars, and in the Earth-Moon system?

Draft Finding: Isolation of individuals is not practicable, crew should be quarantined as a unit, quarantine on return despite in-space pseudo isolation

Day 2 The Knowledge Gaps around how to handle the samples that would be taken during the mission, and upon the return:

2I What approach should be taken to achieve the requirements to "Break the Chain of Contact" with the Martian environment for human missions?

Draft Finding: Containment of all Mars samples should be maintained, even if i) MSR shows no life, and ii) crew are previously exposed, until samples are demonstrated to be "safe".

...to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Path to Closing Knowledge Gaps and Establishing PP Requirements

Workshops Timeline

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What Knowledge Gaps...	...in what order...	...using what missions...	...to make what measurements...

…to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

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Office of Planetary Protection

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Path to Closing Knowledge Gaps and Establishing PP Requirements

Workshops Timeline

2015

NASA Workshop at Ames

Identification of Planetary Protection Knowledge Gaps for human missions to Mars

What Knowledge Gaps...

2016

prioritization of Planetary Protection Knowledge Gaps for human missions to Mars

...in what order...

2018

identification for addressing Planetary Protection Knowledge Gaps for human missions to Mars

...using what missions...

2018 & beyond

COSPAR Working Meeting on Contamination Transport on Mars at LPI, May 2018

Meeting on Microbial Monitoring

Meetings on Spacecraft Systems

and June 2022

Payload/Operation Concepts for addressing Planetary Protection Knowledge Gaps for human missions to Mars

...to make what measurements...

NASA will likely adapt COSPAR workshop findings in an update to the NID8715.129 to establish planetary protection requirements for the first crewed mission to Mars

...to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Way Forward

- Tactical
  - Report from 2022 Meeting
  - Summary paper
  - Continued incorporation into NASA Capability Gaps
  - Continued incorporation into NASA Policy documents
- Strategic
  - COSPAR Process for Policy/Guidelines Revision
  - Iteration to align implementation with COSPAR core policy and knowledge of Mars
  - Acquisition of Data to Close Knowledge Gaps

Take Home

Does Planetary Protection permit crewed exploration of Mars?

- Yes, if …
  - Mars is explored so as to avoid harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter.

How will this be achieved?

- Policy still being evolved, but likely to include:
  - Requirements to manage cleanliness and operations on the surface, based on best available scientific data (→ impact on landing site selection).
  - Requirements to quarantine and contain returning crew and martian samples, respectively, until shown to be safe.
  - And likely to advocate an assurance-based, risk-informed decision-making process.

Questions?

Planetary Protection Categorization

Types of Planetary Bodies	Mission Type	Misson Category
Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
Of significant interest relative to the process of chemical evolution, but only a remote chance that contamination by spacecraft could jeopardize future exploration. Documentation is required.	Any	II IIa, IIb (Moon)
Of significant interest relative to the process of chemical evolution, and/or the origin of life or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment. Substantial documentation and mitigation is required.	Flyby, Orbiter Mars, Europa, Enceladus	III
As above	Lander, Probe Mars, Europa, Enceladus	IV IVa, IVb, IVc (Mars)
Any solar system body. Unrestricted applies only to bodies deemed by scientific opinion to have no indigenous life forms.	Earth Return Restricted or Unrestricted	V

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HTTPS://EXPLOREMARS.ORG