National Aeronautics and
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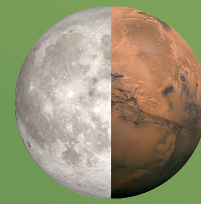

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Moon to Mars
Architecture

white paper

Architecture-Driven Planetary Protection Considerations

Introduction

NASA planetary protection policies guide missions to control contamination of exploration destinations with material from Earth and prevent the potential for adverse consequences when returning material from exploration destinations back to Earth. These policies protect pristine scientific environments at exploration destinations (i.e., from contamination by Earth-origin organisms) and protect the health and safety of crew and Earth's biosphere (i.e., from contact with hazardous materials from exploration destinations).[1]

Currently, a policy directive,[2] procedural requirement,[3] standard,[4] and handbook[5] constitute NASA's planetary protection policies for robotic missions. A 2020 interim directive[6] directed NASA to develop risk-informed planetary protection implementation strategies for human deep space missions, including:

- Capabilities to monitor biological processes associated with the human presence in space exploration and to evaluate changes over time.
- Technologies for mitigating contamination release or intrusion, potentially including closed-loop systems; cleaning/re-cleaning capabilities; quarantine, support systems, and biological waste disposal that minimize impact of humans on the environment of Mars.
- An understanding of environmental processes on Mars that would contribute to transport and inactivation of terrestrial organisms released by human activity.

For more information about NASA's planetary protection policy framework, refer to the summary table at the end of this paper (Table Two).

Planetary protection is also an obligation of the Outer Space Treaty of 1967:[7]

> *"States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."*

The first human missions to Mars will require NASA to implement clear and consistent planetary protection policies. This paper discusses the challenges of planetary protection in detail, as well as NASA's efforts to address those challenges within the agency's Moon to Mars Architecture.

KEY TERMS	
Forward Planetary Protection	Harmful contamination of other planetary bodies (e.g., planets, moons, and asteroids) by Earth-origin material.
Backward Planetary Protection	Introduction of potentially hazardous material from exploration destinations to Earth's biosphere.
Bioburden	The number of microorganisms present on or in an object (e.g., spacecraft hardware)
Biosphere	The area of a planetary body and its atmosphere occupied by living things.
Harmful Contamination	Unwanted material that damages the integrity of scientific investigations or has negative consequences for humans or Earth's biosphere.

Planetary Protection

Forward Planetary Protection

Forward planetary protection is primarily a science and stewardship consideration. Forward planetary protection ensures scientific rigor by preventing contamination during exploration activities. In the context of a Mars mission, forward planetary protection aims to control the introduction of contamination from Earth that could be harmful to science.

This is especially critical for the search for evidence of present or past life. For example, forward contamination could contribute to false positives (e.g., finding biosignatures on Mars that are actually from Earth-origin organisms or materials) or false negatives (e.g., being unable to detect a true Mars biosignature because of background noise from Earth-origin contamination).

Backward Planetary Protection

Backward planetary protection is a safety consideration. Backward planetary protection safeguards Earth's biosphere (which encompasses the environment, flora, and fauna, including humans) from returned material that may contain hazardous extraterrestrial organisms or bioreactive molecules.

Historical Approaches to Planetary Protection

The Apollo and Viking programs laid the foundation for current planetary protection approaches. While many of the principles and practices they established remain relevant, human missions to Mars will require additional planetary protection implementation approaches to control harmful contamination and to safeguard crew and Earth's biosphere.

Forward Planetary Protection

The Viking missions established forward planetary protection processes, including the **bioburden accounting practices** used for robotic missions to Mars. Bioburden is the number of microorganisms present on or in an object such as spacecraft hardware. These processes allow for the detection and mitigation of the microbial contamination of spacecraft bound for exploration destinations.

The forward planetary protection approach established for robotic Mars missions includes directly sampling robotic mission hardware to identify contaminants, heating and/or chemically treating select components to further decrease bioburden, and then verifying that the overall bioburden meets a required cleanliness level prior to launching the hardware.[8]

Historically, NASA calculated required cleanliness levels based on an acceptable limit of contamination. However, this pre-calculated cleanliness level will not be an appropriate metric for crewed Mars missions. While a robotic spacecraft bioburden can be measured before launch and treated as static (i.e., a set level), crew members' microbiomes and habitation environments will be active sources of microbial growth. Regardless of the cleanliness of spaceflight hardware, humans on the Martian surface represent a continuous contamination source.

To address the challenge of forward planetary protection for human missions to Mars, NASA needs to model the types and amount of contamination crew would generate.[9] In addition, NASA needs to improve Mars environment models to better understand the transport, growth potential, and survivability of terrestrial contamination. Based on this information, NASA can establish robust design and operational guidelines, mitigations, and verifications to manage the human contamination risk.

Backward Planetary Protection

The Apollo Program addressed backward contamination issues through **sample isolation and assessment** and **crew quarantine**. The Apollo Program's backward contamination mitigation efforts offer a key lesson: it takes time to properly prepare for and implement backward planetary protection, especially when engaging the wide range of stakeholders involved.[10]

Receiving, handling, curating, and conducting safety analyses or sterilization protocols for returned samples requires highly specialized facilities, which can take years to develop. These facilities must account for both pristine science samples and biocontainment needs. NASA designed its Lunar Receiving Laboratory[11] at NASA's Johnson Space Center in Houston to isolate astronauts and conduct safety assessment of Apollo lunar samples. Upon demonstrating that astronauts and samples were safe, samples were moved to a specialized pristine astromaterials handling and curation facility focused on contamination control without strict biocontainment. Mars samples will require similar dedicated facilities.

Crewed missions must address both design and operational planetary protection considerations. For example, a vehicle returning astronauts to Earth may require additional containment processes prior to hatch opening to achieve a desired level of containment to prevent contamination release. During the Apollo 11 mission, the crew exited the spacecraft in the ocean before entering quarantine. If NASA decided this procedure was insufficient for Mars missions, the agency would need to implement alternate designs and operations to meet the desired level of containment.

Contemporary approaches to backwards planetary protection can be found in robotic sample return missions. The OSIRIS-REx — the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer — returned samples from near-Earth asteroid Bennu on Sept. 24, 2023. NASA classified those samples for unrestricted Earth-return due to scientific consensus that it harbored no indigenous lifeforms.[12]

In contrast, Mars samples — whether returned by crewed or robotic missions — would be classified for restricted Earth-return due to the potential for Mars-origin organic or bioreactive materials that could have adverse effects on Earth's biosphere. Sample curation and mission planning teams for Mars sample return missions will have to follow and/or develop planetary protection procedures to meet NASA requirements.

Figure One: *The Apollo 11 Command Module Columbia arrives at the Lunar Receiving Laboratory, with the Mobile Quarantine Facility docked to the building. (Image courtesy Tiziou News Service)*

Planetary Protection Policy Participants

In addition to its own agency policies governing planetary protection, NASA coordinates with international partners and other government agencies. As noted above, the Outer Space Treaty governs planetary protection.[13] As a party to the treaty, the United States government is responsible for activities of both governmental and non-governmental space actors (e.g., industry and academia). NASA contributes to the Committee on Space Research (COSPAR) Planetary Protection Policy, the accepted standard for international planetary protection compliance under the Outer Space Treaty.[14]

For backward planetary protection, NASA implementation practices would require presidential approval, as outlined in Presidential Directive/National Security Council #25.[15] NASA also anticipates the need for coordination with other government agencies, such as with the U.S. military, Federal Aviation Administration for launch and re-entry licenses, the Centers for Disease Control and Prevention for biohazard expertise, and the Environmental Protection Agency for sample return landing site considerations.[16]

In preparation for future crewed missions to Mars, NASA — in partnership with the European Space Agency, COSPAR, and other stakeholders — hosted a series of workshops between 2015 and 2022. These workshops identified key planetary protection knowledge gaps and outlined principles for planetary protection for human exploration missions, recognizing the inadequacy of traditional robotic mission protocols.[17] These knowledge gaps inform the development of Mars mission architectures and planetary protection strategies and policies.

Architectural Implications for Crewed Mars Missions

The planetary protection strategies that NASA adopts for human missions to Mars will have wide-reaching, cross-cutting implications for the Mars architecture. The agency and its partners must consider planetary protection throughout the development of Mars missions and early in the design lifecycle of individual systems. The architectural implications and potential mitigation strategies highlighted in this paper reflect a trade space that NASA, partners, and stakeholders will need to explore and address when architecting crewed missions to Mars.

For example, mission planners may wish to control crew access to (and avoid contamination of) regions that are more likely to harbor evidence of life, leaving those exploration tasks to "clean" robots. Identifying these locations could require additional landing site data to inform planning. Activities like core sample drilling or nuclear fission power generation may require NASA to establish regions with special planetary restrictions beyond the baseline for other activities. Finally, NASA will need to design methods for sample collection, processing, conditioning, and storage on Mars that are compatible with containment and curation methods on Earth.

Planetary protection will likely be a key factor in the design of specific systems for Mars. The space suits designed for the International Space Station and the Artemis missions operate at positive pressure, meaning that the atmospheric pressure inside the suit is higher than the pressure outside the suit (e.g., the vacuum of space). These designs tolerate small amounts of leakage,[18] but uncontrolled leakage from a space suit on Mars presents a potential planetary protection risk by releasing human contaminants onto the Martian surface. Considering this, designing spacesuits for the Martian surface could require a characterization of a design's contamination potential and/or systems that monitor contamination or control leakage differently.

Waste management also presents forward contamination risks. Apollo missions discarded human waste on the lunar surface, where microbes were unlikely to survive. Mars missions will likely require a different operational paradigm, as human waste contains microbial contaminants that forward planetary protection practices guard against. NASA may determine that Mars missions must securely contain, destroy, or return with astronaut waste.

Mars transportation systems may also require planetary protection–specific design considerations. Examples could include sterilization of landers and ascent vehicle hardware elements, or "break the chain" protocols, in which crew members and sealed samples are transferred from a potentially contaminated Mars ascent vehicle to "Mars-free" Earth transfer vehicle.

Table One captures example planetary protection considerations for Mars exploration elements.

Conclusion

NASA must consider thoughtful approaches to planetary protection policy compliance throughout the element design lifecycle, from the pre-project phase, through requirements development and design maturation, to flight certification. Planetary protection is not a sub-system that can be added to an architecture; instead, engineers and mission planners must account for planetary protection at the system and sub-system level for any hardware element.

To this end, NASA has identified planetary protection knowledge gaps for the agency to address in a responsible management and mitigation approach. These knowledge gaps include capability shortfalls in microbial and human health monitoring; technology and operations for contamination control; and in understanding the natural transport of contamination on Mars.[9] The agency is developing a roadmap to manage these knowledge gaps and integrate planetary protection into NASA's Moon to Mars Architecture as design concepts evolve.[19]

Exploration efforts will need to consider robust, comprehensive planetary protection approaches that consider unique environments of, and support exploration objectives for, the Moon, Mars, and other destinations. Forward planetary protection policies will ensure the scientific integrity of exploration destinations, particularly with regard to the search for life beyond Earth. Backward planetary protection policies are critical to protect Earth from exposure to harmful extraterrestrial materials and maintain the integrity of samples returned to Earth.

Table One: *Example Design Considerations for Planetary Protection*

	Architecture Element	Planetary Protection Considerations	Example Mitigation
Forward	**EVA Suits**	Leaks on joints and seals	Microbial monitoring, particle control and filtration technologies
Forward	**Waste Management**	Disposal on surface	Containment, sterilization of waste
Forward	**Surface Habitat/Airlocks**	Leaks or venting into atmosphere or surface from habitat	Microbial monitoring, particle control and filtration technologies
Forward	**Surface Mobility Element**	Sample collection cleanliness, hardware cleanliness, leaks or venting into the atmosphere or surface from hardware	Microbial monitoring, particle control and filtration technologies, microbial reduction/sterilization techniques
Backward	**Sample Return**	Break the chain of contact with Mars for collection systems	Particle control, filtration technologies, sterilization techniques
Backward	**Earth Return Facility**	Crew quarantine capability, post-mission vehicle isolation	Biosafety quarantine, sterilization techniques, sample safety assessment protocols, crew health monitoring

Key Takeaways

Planetary protection policies must address science, engineering, and programmatic considerations to enable high-quality science at exploration destinations (through forward planetary protection) and to avoid adverse consequences to Earth's biosphere (through backward planetary protection).

NASA is developing refined planetary protection policies and practices to mitigate forward and backward contamination risks from crewed missions to Mars early in the architecture development effort, because these policies have implications at all phases of crewed Mars mission design.

NASA has identified — and is working to manage and mitigate — planetary protection knowledge gaps for crewed missions.

Table Two: *NASA Planetary Protection Policy Framework*

Document	Description
Directive NASA Policy for Safety and Mission Success *(NPD 8700.1F)*	**NASA Policy Directives (NPDs)** document agency policy statements, describing what is required to achieve NASA's vision, mission, and external mandates. This NPD outlines NASA's policy to protect the terrestrial and planetary environments, and the public.
Procedural Requirements Planetary Protection Provisions for Robotic Extraterrestrial Missions *(NPR 8715.24)*	**NASA Procedural Requirements (NPRs)** provide detailed procedural requirements to implement policy, including guidance on how policy directives are implemented in the context of specific missions. This NPR contains content on mission planetary protection categorization and project roles and responsibilities.
Standard Implementing Planetary Protection Requirements for Space Flight *(NASA-STD-8719.27)*	**NASA Standards** provide technical requirements, with each NASA technical standard being assigned to a technical discipline. This standard outlines requirements for planetary protection forward and backward contamination control and cleanliness assays.
Handbook NASA Planetary Protection Handbook *(NASA/SP-20240016475)*	**NASA Handbooks** are companion documents to NPRs and NASA standards, providing supporting material such as guidelines, lessons learned, procedures, and recommendations. This handbook is intended to be a one-stop-shop for current planetary protection implementation knowledge and practice.

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