

Planetary Protection Concepts in the Context of the Evolvable Mars Campaign

J Andy Spry[1]
JPL/Caltech, Pasadena CA91011

James Johnson[2]
NASA JSC, Houston, TX77058

Margaret S Race[3]
SETI Institute, Mountain View, CA94043

and

Bette Siegel[4] and Catharine A Conley[5]
NASA Headquarters, Washington, DC20546

Spacefaring nations have committed to protecting solar system objects from harmful contamination resulting from the activities of interplanetary spacecraft, and of similarly protecting the Earth from uncontrolled release of a putative extra-terrestrial organism from returned extra-terrestrial samples. Planetary protection policies to achieve these goals are mature for outbound missions performing robotic exploration of Mars, having been updated and refined over time as more became understood about the martian environment. Similarly, increased understanding of the limits and capabilities of terrestrial life on Earth continues to inform planetary protection policy.

In considering the future human exploration of Mars, it is clear that the bioburden requirements historically used for robotic missions (<$5x10^5$ microbial spores/mission) would not be sustainable for a crewed mission (~$1x10^{14}$ microorganisms/astronaut in a complex internal and external community related to digestion and a plethora of other functions). This does not mean that the current planetary protection paradigm would be discarded. On the contrary, the intent to prevent harmful contamination would remain, with safeguarding the Earth from potential backward contamination continuing to be the highest planetary protection priority.

It is widely accepted that the greater capability of human explorers can only be beneficial to the astrobiological exploration of Mars if human-associated contamination is controlled and understood, yet for landed missions conducting surface operations, it is likely not practicable for all human-associated processes and mission operations to be conducted within entirely closed systems. Additionally, based on the lunar experiences of the Apollo astronauts, the exposure of crewmembers exploring Mars (and their support infrastructure) to martian materials would be inevitable.

[1] Planetary Protection Engineer, Spacecraft Mechanical Engineering Section, Jet Propulsion Laboratory/California Instutute of Technology (M/S 125-224) 4800 Oak Grove Drive, Pasadena CA91109.
[2] Systems Engineer, Systems Engineering and Test Branch, Engineering Directorate, Johnson Space Center 2101 NASA Parkway, Houston, TX 77062.
[3] Planetary Protection Consultant, SETI Institute, 189 Bernardo Ave, Suite 100, Mountain View, CA 94043.
[4] Human Exploration and Operations Mission Directorate, NASA Headquarters, Washington, DC 20546.
[5] Planetary Protection Officer, NASA Headquarters, Washington DC 20546-0001.

In this paper, we intend to outline the plans and progress towards executable planetary protection policy concepts, particularly since the publication of the NASA Policy Instruction on Planetary Protection Requirements for Human Extraterrestrial Missions in 2014, and including perspectives of the 2015 workshop on Knowledge Gaps for Human Extraterrestrial Missions.

Nomenclature

ARM	*Asteroid Redirect Mission*
ARV	*Asteroid Redirect Vehicle*
BTC	*Break The Chain (of Contact)*
COSPAR	*Committee on Space Research*
EAM	*Exploration Augmentation Module*
ECLS	*Environmental Control and Life Support*
EMC	*Evolvable Mars Campaign*
ESA	*European Space Agency*
EUS	*Exploration Upper Stage*
EVA	*Extravehicular Activity*
ISRU	*In-situ Resource Utilization*
ISS	*International Space Station*
JPL	*Jet Propulsion Laboratory*
JSC	*Johnson Space Center*
LDRO	*Lunar Distant Retrograde Orbit*
LEO	*Low Earth Orbit*
MSL	*Mars Science Laboratory*
NASA	*National Aeronautics and Space Administration*
NPI	*NASA Policy Instruction*
NPR	*NASA Procedural Requirement*
SEP	*Solar Electric Propulsion*
SETI	*Search for Extraterrestrial Intelligence*
SKG	*Strategic Knowledge Gap*
SLS	*Space Launch System*
TRL	*Technology Readiness Level*

I. Introduction

THE stated NASA objective to "Expand human presence into the solar system and to the surface of Mars", will require a readdressing of the current planetary protection paradigm. Not since the Apollo era has humankind had to address the issue of artificial transport of biologic material between the Earth and another solar system body by a crewed system. Planetary protection is the discipline of protecting solar system objects from harmful contamination resulting from the activities of interplanetary spacecraft, and of similarly protecting the Earth from uncontrolled release of a putative extra-terrestrial organism from e.g., returned extra-terrestrial samples. In the case of the Apollo astronauts traveling to the Moon, robotic precursor missions had established the lunar surface as a very inhospitable environment for terrestrial biology, as it was then understood. Extremely desiccated, with extremes of temperature, bathed in UV radiation and depleted in many elements considered essential for life on Earth, the scientific consensus was that, not only would terrestrial life forms be unable to contaminate such an environment, but also that a "lunar biosphere" could not have evolved in such an environment. Nonetheless, the threat of inadvertent release of a putative "moon organism" (however unlikely) into the terrestrial biosphere was considered too high a risk by the scientific community to ignore, and substantial efforts were put in place during the Apollo program to create systems and processes to avoid such an eventuality, at least for the early missions.

Subject to international treaty, the planetary protection obligations of spacefaring nations are described in the Outer Space Treaty of 1967[1], where Article IX reads:

"...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..."

At the present time, the international consensus on planetary protection is maintained by COSPAR[2], and it is the COSPAR Planetary Protection Policy to which NASA and other spacefaring nations adhere. COSPAR's Resolution 26 of 1964 "affirms that the search for extraterrestrial life is an important objective of space research, that the planet of Mars may offer the only feasible opportunity to conduct this search during the foreseeable future, that contamination of this planet would make such a search far more difficult and possibly even prevent for all time an unequivocal result, that all practical steps should be taken to ensure that Mars be not biologically contaminated until such time as this search can have been satisfactorily carried out, and that cooperation in proper scheduling of experiments and use of adequate spacecraft sterilization techniques is required on the part of all deep space probe launching authorities to avoid such contamination." NASA meets its obligations for robotic missions through the imposition of requirements established in document NPR 8020.12D (Planetary Protection Provisions for Robotic Extra-terrestrial Missions)[3]. However, a detailed description of implementable requirements for crewed missions is not provided in the COSPAR policy, which is limited to principles and guidelines for avoiding harmful contamination of the target (forward contamination) and inadvertent release of unsterilized returned material (backward contamination).

This lack of detail reflects both the immaturity of mission development and the incomplete knowledge of the Mars environment to understand the risks of the human exploration endeavor. However, human exploration of the martian surface is not a new concept, and previous consideration has been given to this problem, most recently in the 2004/5 timeframe when a series of workshops considered and reported on the issue[4-7]. As an input to the current assessment in the context of the Evolvable Mars Campaign, the summary findings of the Hogan *et al*. workshop[6] (developed during the now discontinued Constellation Program era) is included in Table 1.

1. Planetary protection and science constraints may have a significant impact on mission architecture, technology trade options, operations and development costs.
2. Planetary protection and science requirements require definition early in the development cycle. ○ **Definition of "contaminants" is required.** ○ **Establish forward and back contamination limits.** ○ **Define waste containment and disposal requirements.** ○ **Establish Earth return operations and quarantine requirements**
3. Define material inventory and characteristics, process products, and release mechanisms
4. Establish detection standards, response times and back contamination identification methods
5. Currently not possible to provide quantitative planetary protection guidelines
6. Current proposed approach: Do not affect or otherwise contaminate "Special Regions" of Mars (via cleaning, prudent landing site selection)
7. Lunar operations should serve as a test-bed for Mars missions with respect to planetary protection and science operations ○ **Testing can occur without penalty** ○ **Avoid developing two distinct and expensive technology pathways**

Table 1. Summary findings from the 2005 Life Support and Habitation and Planetary Protection Workshop

II. NASA Concepts for the Future Human Exploration of Mars

The current context of a future human exploration of Mars is based on the April 2010 speech of President Obama:

"Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity's reach in space --we will strengthen America's leadership here on Earth."

NASA's Strategic Plan, responsive to the Administration's stated goal, includes the objective to: "Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration."

However, this objective is set in a constrained budget environment, requiring NASA's future planning to be developed under a set of strategic principles to ensure the exploration is sustainable. Specifically, the planning for the future human exploration of Mars needs to be implementable in the near-term with the buying power of current budgets and in the longer term with budgets commensurate with economic growth. High Technology Readiness Level (TRL) technologies are being deployed for near term missions, while focusing sustained investments on the needed technologies and capabilities to address challenges of future missions. In this way, a defined cadence of compelling and integrated human and robotic missions provide for an incremental buildup of capabilities for more complex missions over time, developing multi-use, evolvable space infrastructure, with each mission leaving something behind to support subsequent missions.

Within this framework, the Evolvable Mars Campaign[8] has been developed to define and execute a "pioneering" strategy (as opposed to merely "exploring"). This strategy is focused on identifying and developing the operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s. This plan provides guidelines for near term activities and investments that link to and leverage current investments in ISS, SLS, Orion, ARM, EAM, technology development investments and science activities. In the longer term, it emphasizes prepositioning and reuse/repurposing of systems when it makes sense, particularly in the use of cis-lunar space for proving, aggregation and refurbishment of systems.

Within this program, a series of technology capability pathfinder and strategic knowledge gap (SKG) precursor missions and activities have been identified, to: identify human Mars exploration and science objectives and identify potential Mars landing sites; demonstrate ISRU, dust characterization, and potential ground truth of human mission landing site(s); demonstrate mobility, prospecting, and science capabilities through geological surveys of Phobos and Deimos to support infrastructure for characterizing gravitational fields, scientific regions of interest, soil mechanics, useful resource materials, and potentially low-latency tele-operations; demonstrate human-relevant scale aerocapture, aeroentry, descent, & landing, with potential opportunities for demonstration of surface power and larger scale ISRU which could lead to alternate sample return strategies; demonstrate ISRU acquisition and processing on the lunar surface to produce oxygen. All of these would need to be in compliance with an appropriate planetary protection approach, based on current knowledge and the anticipated future use in supporting the crewed exploration activities.

III. Planetary Protection for Crewed Exploration Missions

In November 2012, the NASA Advisory Council (NAC), an advisory group to NASA's senior leadership on challenges and solutions facing the agency, recommended the development of an implementing document for planetary protection requirements for future crewed exploration missions beyond Earth orbit[9]. This recommendation sought to establish guidance on the application of COSPAR Principles and Guidelines for Human Missions to Mars for the teams developing future mission architectures and hardware. In March of 2013, NASA acknowledged the recommendation and established a multi-disciplinary team to create a set of planetary protection requirements for human missions which would parallel the existing NASA Procedural Requirement (NPR) 8020.12 Planetary Protection Provisions for Robotic Extraterrestrial Missions.

As the team deliberated, it was concluded that insufficient data were available on human exploration systems and their potential interactions with the Mars system environments (including Phobos and Deimos) to construct effective, quantifiable requirements. This team instead created a NASA Policy Instruction (NPI) document to raise programmatic awareness of the current COSPAR policy on human missions while formalizing a process for collecting the needed scientific and technological data to formulate an NPR document at a future date. NPI 8020.7 NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions was released on May 28, 2014 as NASA's roadmap to a planetary protection requirement set for human missions to Mars[10].

While the NPI acknowledges the process for developing procedural requirements for human missions beyond Earth may take a few years, it provides insight into needed areas of scientific and technological study that can begin now. Three primary areas of focus are identified in the NPI:

1. Developing capabilities to comprehensively monitor the microbial communities associated with human systems and evaluate changes over time;
2. Developing technologies for minimizing/mitigating contamination release, including but not limited to closed-loop systems; cleaning/re-cleaning capabilities; support systems that minimize contact of humans with the environment of Mars and other solar system destinations;
3. Understanding environmental processes on Mars and other solar system destinations that would contribute to transport and sterilization of organisms released by human activity.

The NPI provides further direction as to how collecting knowledge from such areas of focus will feed into the development of an NPR under the guidance of an ad-hoc team:

- Conducting a literature review to identify completed studies and investigations relevant to the development of verifiable planetary protection requirements for human missions;
- Seeking input from scientific and space operations community through a variety of sources, including a workshop;
- Oversight of the recommended studies and following through on their completion to the development of specific requirements;
- Developing a draft NPR document for planetary protection for human spaceflight that includes these specific requirements for mission development, and following the necessary NASA coordination and approval processes to be issued as a full NPR;
- Coordinating with relevant mission management teams within NASA, to ensure understanding of the requirements in order to achieve compliance.

While the results of the literature review are awaiting publication, NASA planned and conducted the *Workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions*, to solicit input from a broad community on the current state of knowledge with respect to the three main study areas identified in the NPI. Combining the literature review results with findings from this recent workshop will create a significant knowledge base from which to identify research, studies, and tests needed in the development of a requirement set for future human missions to the Mars system, based on the COSPAR Principles and Guidelines.

IV. Workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions

The previous studies mentioned in Section I took a system-related view of the relationship between the exploration endeavor and planetary protection, and provided valuable contributions to the development of the current COSPAR guidelines. However, this most recent workshop sought to look at synergies within core study areas and across mission phases; from prelaunch, cruise, surface operations (inclusive of ISRU, EVA's, science exploration/instruments, exploration of Mars "special regions", and waste disposal), return preparations, launch from Mars, and the return flight thru re-entry. The scope of the workshop did not consider any sample handling/crew quarantine/sample testing on Earth.

After a series of plenary presentations on mission architecture concepts, current planetary protection policy and the descriptions of the state-of-knowledge across a broad range of disciplines related to planetary protection[11], the participants split into three breakout sessions to consider the following sub-topics: microbial and human health monitoring; technology and operations for contamination control; and natural transport of contamination on Mars.

In particular, breakout groups were asked to consider for respective sub-topic areas, the planetary protection research activities or technical developments critical for inclusion, identifying and building on work/research that is already underway or completed. Further, breakout participants were asked to identify any special information or technology needed to plan for non-nominal (as opposed to nominal or planned) situations. Groups were asked whether there are existing options for mitigating contamination that are adaptable for planetary protection needs on the Martian surface. Finally, groups were asked to identify any significant stumbling blocks ahead that are evident, within and across the communities of planetary protection, science exploration, engineering, operations and space medicine that were represented at the workshop.

A. Microbial and Human Health Monitoring breakout group participants were asked to consider:

- Monitoring of growth and survival of human & habitat associated microbial populations in space environments, including the human body; internal hab/lab spaces; external martian
- The availability and state-of-the-art of adaptable or new biological assay techniques, particularly those with minimal mass/volume & low consumable/waste products
- Crew quarantine measures for preventing back contamination (in scenarios including nominal vs. off-nominal; on surface vs. en-route; individual vs. entire crew)
- The impacts from Mars material exposure on crew health & the habitat microbiome
- The microbiome research needed and the ability to detect extraterrestrial perturbations (in human explorers, in enclosed spaces, external to the habitat, etc.)
- What are the suitable indicator tests and warning/screening systems for PP relevant contaminants
- The additional factors associated with deployment of ISRU technologies

B. Technology and Operations for Contamination Control breakout group participants were asked to consider:

- What are the cleaning, sterilization, re-contamination prevention, and associated verification technologies for in-situ planetary protection application
- What is needed in terms of Environmental Control and Life Support (ECLS) loop closure and mitigation of spacecraft effluent
- The needed technologies for contamination control of human surface mobility systems and spacesuits
- How contamination control and preventing creation of localized habitable environments by support systems (i.e. In-situ Resource Utilization (ISRU), induced special regions from power systems, etc.) can be achieved
- The Human surface exploration operational strategies needed for mitigating of contamination and effects
- The required sample acquisition, containment and breaking-the-chain (BTC) of contact technologies needed
- What capabilities need to be in place for environmental clean-up following inadvertent release of unsterilized terrestrial material

C. Natural Transport of Contamination on Mars breakout group participants were asked to consider:

- What are the characteristics of Transport of contamination on Mars (biological, organic, molecular [particulate and volatile])
- What are the effects of the Mars environment (e.g. UV effects), on organisms; on EVA; as passive mitigation.
- What terrestrial research can/must be done to gain knowledge prior to the exploration mission, based on e.g., analogues for dispersal; balloon experiments as Mars environment analogues; contamination transport; empirical & modeling studies to help identify unknown/unaddressed issues in context of candidate exploration strategies; aerial dispersion and modeling
- What are the effects of people, habitats in relation to contaminants
- What are the effects of specific exploration activities (options/trades for activities)
- What are considerations for sub-surface activities (drilling; aquifers, ISRU, models & measurements, etc.), particularly with regard to “special regions”
- What are the robotic precursor measurements of importance
- What are the issues around the general Mars environments compared to issues specific to human landing sites

V. Conclusion

As a community building activity, the workshop seemed to have performed very effectively. Presentations delivered during the workshop can be accessed at the NASA planetary protection web site (http://planetaryprotection.nasa.gov/). NASA is currently considering the data gathered and will use it to identify and prioritize needed capabilities as well as presenting it in a workshop report intended for release in the fall of 2015. Future steps towards transitioning from the NPI to an NPR will also be identified.

VI. Acknowledgements

This work was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

1. United Nations. 1967. The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. United Nations Treaty, U.N. Doc A/Res/2222(XXI): TIAS # 6347, New York, NY

2. COSPAR Planetary Protection Policy (2002, as amended 2011). Retrieved from https://194.199.174.76/sites/default/files/pppolicy.pdf

3. NASA, 2011.Planetary Protection Provisions for Extraterrestrial Missions, NPR 8020.12D. Retrieved from http://planetaryprotection.nasa.gov/documents/

4. National Research Council, Space Studies Board, 2002, Safe On Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface. National Academy Press, Washington, D.C., www.nap.edu.

5. Criswell, M. E. *et al.* (2005) NASA Conference Proceedings NASA/CP- 2005-213461 Planetary Protection Issues in the Human Exploration of Mars Final Report

6. Hogan, J.A. *et al.* (2006) NASA Technical Memorandum NASA/TM-2006-213485 Life Support and Habitation and Planetary Protection Workshop Final Report

7. Kminek, G. *et al.* (2007) Joint ESA/NASA Workshop: Planetary Protection & Human System Research and Technology; ESA WPP-276, European Space Agency, Paris.

8. National Aeronautics and Space Administration. (2014). NASA's Evolvable Mars Campaign. Retrieved from http://www.nasa.gov/sites/default/files/files/20140429-Crusan-Evolvable-Mars-Campaign.pdf

9. National Aeronautics and Space Administration. (2013). Letter from NASA Administrator Bolden to NASA Advisory Committee Chair Dr. Steve Squyres Retrieved from: http://www.nasa.gov/offices/nac/meetings/12-11_presentations.html

10. National Aeronautics and Space Administration. (2014). NASA policy on planetary protection requirements for human extraterrestrial missions (NASA Publication No. NPI 8020.7). Retrieved from http://planetaryprotection.nasa.gov/documents/

11. Lunar and Planetary Institute (2015) Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions Program Retrieved from http://www.hou.usra.edu/meetings/ppw2015/pdf/program.pdf