

Expanding Options for Implementing Planetary Protection During Human Space Exploration and Robotic Precursor Missions

Interim Report

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Executive Summary/Abstract

Planetary protection policies established by the Committee on Space Research (COSPAR) of the International Council for Science have been in force effectively for five decades, ensuring responsible exploration and the integrity of exploration activities, for both human and robotic missions in the Solar System beyond low Earth orbit (LEO). Currently, operations on the vast majority of objects in the solar system are not constrained by planetary protection considerations because they cannot be contaminated by Earth life in ways that impact future space exploration. In contrast, Mars, Europa, and Enceladus, which represent locations with biological potential, are subject to strict planetary protection constraints for missions of all types because they can potentially be contaminated by organisms brought from Earth.

The contamination of other worlds by Earth-life is referred to as “forward” contamination. Conversely, the potential contamination of the Earth’s biosphere by living entities returned from other worlds is referred to as “backward” or “back” contamination. Forward contamination control for robotic missions is generally accomplished through a combination of activities that reduce the bioload of microbial hitchhikers on outbound spacecraft prior to launch. Back contamination control for robotic missions has chiefly been accomplished by selecting sample-return targets that have little or no potential for extant life (e.g., cometary particles by *Stardust* mission). In contrast, future human missions to Mars, for example, will entail challenges of the sort faced by the *Apollo* missions to the Earth’s Moon, although with a more compelling possibility that astronauts on Mars will encounter habitable environments in their exploration activities. Current COSPAR PP Principles indicate that safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration. Based on long-standing provisions of the Outer Space Treaty, planetary protection policies apply to both governmental and non-governmental entities in the more than 100 countries that are signatories to the Treaty [1].

While guidelines for planetary protection controls on human missions to Mars have been established by COSPAR, detailed engineering constraints and processes for implementation of these guidelines have not yet been developed. Already, it is recognized that planetary protection controls for human missions will often be supportive of other important mission needs, such as maximizing closed-loop and recycling capabilities to minimize mass required, minimizing exposure of humans to planetary materials for multiple health reasons, and minimizing contamination of planetary samples and environments during exploration and science activities.

In this interim report, we outline the progress and plans of a current IAA Study Group that is engaging robotic and human mission developers and scientists in exploring detailed technical, engineering and operational approaches by which planetary protection objectives can be accomplished for human missions in synergism with robotic exploration and in view of other constraints. By integrating planetary protection considerations early in mission design and the satisfaction of precursor requirements, it is possible to address human, environmental, and science considerations through cross-cutting measures of various types. In addition to highlighting important information for the early stages of planning, this study also identifies key research and technology development (R&TD) areas for further consideration and work. These

important R&TD challenges provide opportunities for individuals, institutions and agencies of emerging countries to be involved in international exploration efforts.

Interim *technical recommendations of the Study* (detailed in Section 6 of this report) include the findings that:

- PP *must* be incorporated into both robotic and human missions that go beyond low Earth orbit; PP provisions are essential for ensuring safe human missions and pristine science returns (e.g., by monitoring and limiting microbial exposure;
- It will be essential to provide robust robotic hardware and systems to safeguard both astronauts and science efforts; and
- Minimizing exposure of the crew (and ultimately Earth) to putative martian organisms or unknown environments can be accomplished via careful precursor studies and controlled access.

Other interim recommendations supportive of IAA goals (detailed in Section 7 of this report) highlight:

- The importance of international coordination of PP planning, research and technology development for successful implementation of human missions;
- The need to include PP principles in all types of missions—whether governmental, or commercial;
- The value and opportunity of including new space nations and diverse partners in future work on PP R&D; and
- The need to proactively disseminate PP information in various ways to the broad, international community of planners, engineers and assorted partners who are facing the challenges of future human exploration missions.

Considering the increase in space activities by new nations and partnerships and the current plans for human missions beyond Low Earth Orbit, it is important to develop ways to integrate planetary protection provisions effectively into missions from the earliest phases. Ultimately, agreement and work at the international level regarding planetary protection research and implementation activities are necessary to ensure that all organizations avoid releasing harmful contamination on bodies with biological potential, thereby ensuring protection of the Earth and astronauts throughout missions and safeguarding the integrity of science exploration—all in compliance with the 1967 Outer Space Treaty.

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1. Introduction/Context of the Study

The overall task of this study traces to a previous IAA Heads of Agencies (HoA) Summit report (2010; [2]) as well as other international studies and reports (e.g., PECB [3]) that identified planetary protection (PP) as one of several important and cross-cutting priorities for future human missions. Building upon these previous efforts, this study will intend to update information on the research and technology development areas that will need additional attention by members of the international community as they begin planning for future human exploration missions and activities beyond Earth orbit. Our ultimate objective is the publication of an IAA Cosmic Vision Study on PP and human missions for use by any and all space faring entities. The ultimate report will provide comprehensive information about planetary protection policies, principles and guidelines that have cross-cutting implications for multiple aspects of human missions beyond Earth orbit, including operational, technical, scientific, procedural, infrastructural, environmental and crew health and safety considerations. In addition to synthesizing and updating information on planetary protection, the report is intended to guide the progress of research and technical developments and address challenges facing future human missions.

In this interim report prepared for presentation at the Heads of Agencies Summit (January 2014, Washington DC), we provide overview information indicative of the early progress in addressing our task, and plans for the remainder of the study effort. Like other IAA studies of this type, the final report will likely take another two years to complete.

2. Scope/Objectives of this Report

For more than 40 years, plans for future human missions beyond the Earth's moon have been studied and analyzed, contributing to various strategic frameworks for the activities of major space agencies (e.g., [4-14]). These studies have been done in the context of ongoing international cooperative missions involving both robotic and human spaceflight, including *Cassini/Huygens* to Saturn, the International Space Station in low-Earth orbit, and numerous destinations both nearer and farther in space. By combining information from both active and past missions with the clear interest in future cooperative endeavors (e.g., [14]), this study will use the lessons of both human spaceflight and various international programs and planning to synthesize information needed to inform and guide future planners. The study will focus on the nature of human operations, procedures, and equipment, as well as the ongoing challenges of keeping humans healthy during future exploration missions, while also protecting planetary environments when away from the Earth and upon return home at missions' end.

Consequently, the main task of this study is to focus on recommending various ways to implement the existing COSPAR policy on planetary protection [15] in the context of international collaborative human missions, and to compile a comprehensive literature and report collection to guide future planners, researchers and technology developers in this area.

3. Background Information on Planetary Protection

The intent of the COSPAR PP policy is the same whether a mission to Mars is conducted robotically or with human explorers. Although the specific implementation requirements may differ, the goals are to avoid both forward and back contamination during all mission phases. As summarized in Box 1, the current PP policy for human missions is based on four main principles and eight implementation guidelines that apply to the mission and its varied activities.

Based on an extensive review of current and past literature, there is a good agreement about the list of technical domains impacted by the COSPAR PP requirements. Without a doubt, PP policy and constraints

will impact diverse systems, operations, and equipment during future human missions (see Box 2). However, the specific approaches to address these concerns remain quite general at this time, with few

Box 1: Overview of COSPAR Principles and Guidelines for Human Missions to Mars [15]

The intent of COSPAR planetary protection policy is the same whether a mission to Mars is conducted robotically or with human explorers. Accordingly, planetary protection goals should not be relaxed to accommodate a human mission to Mars. Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ.

General principles applicable to human missions indicate:

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- For a landed mission conducting surface operations, it will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars, or their support systems, will inevitably be exposed to martian materials.

In accordance with these principles, **specific implementation guidelines** for human missions to Mars should include:

- Human missions will carry microbial populations that will vary in both kind and quantity, and it will not be practicable to specify all aspects of an allowable microbial population or potential contaminants at launch. Once any baseline conditions for launch are established and met, continued monitoring and evaluation of microbes carried by human missions will be required to address both forward and backward contamination concerns
- A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a martian life-form occurs.
- A comprehensive planetary protection protocol for human missions should be developed that encompasses both forward and backward contamination concerns, and addresses the combined human and robotic aspects of the mission, including subsurface exploration, sample handling, and the return of the samples and crew to Earth.
- Neither robotic systems nor human activities should contaminate “Special Regions” on Mars, as defined by this COSPAR policy.
- Any uncharacterized martian site should be evaluated by robotic precursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission.
- Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.
- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.
- Planetary protection requirements for initial human missions should be based on a conservative approach consistent with a lack of knowledge of martian environments and possible life, as well as the performance of human support systems in those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

indications about the relative criticality of the different raised topics, or the specific criteria or approaches to be used. Thus, there is considerable value to any study that aims to provide technical and operationally constrained mission design information to help engineers and planners understand more fully how PP requirements should be practically implemented on future human missions. By being aware of how PP constraints might overlap with other critical mission needs, it will be possible to optimize the combination of the goals and constraints expressed in the various mission domains—including such areas PP policy, science return, development and operational costs, astronaut safety, programmatic risk, and safeguarding the Earth upon return.

Box 2: Types of Systems, Operations & Equipment Likely to be Impacted by PP Concerns	
<ul style="list-style-type: none"> • Biological monitoring to identify microbes <i>in situ</i> • Equipment decontamination & sterilization methods • Biodiagnostics, medical treatment for crew health • Advanced life support system (ALS) • Extra-vehicular activity (EVA) & EVA equipment • Spacesuit designs including mobile ALS • Ingress and Egress of crew, materials & equipment • Subsurface drilling equipment for sample collection • ISRU systems 	<ul style="list-style-type: none"> • Sample containment, handling and transfer • Understand forward & back contamination pathways • Quarantine facilities for individuals & entire crew • Waste disposal processes and containment. • Updated human PP protocol • Material inventory, process products and streams • Leakage & release mechanisms from habitat • Biocontainment and handling in labs • Closed loop & recycling capabilities to minimize mass

4. Study Methods

The work of this study will continue over the next two years, largely via telecons and virtual work, combined with email communications for deliberations, writing and reviews. When appropriate, individuals or subgroups may be tasked with gathering specific information from different international sources.

The completed report will contain a systematic compilation of international policies, national directives, technical studies, literature, websites, and other information on PP relevant to human missions and associated robotic elements. In addition, information from extensive human space activities in LEO and other space missions will be analyzed to identify important science, technological and operational information and its synergies with PP needs. Overall, this compilation of information will be important for the international community of engineers and designers who may be unfamiliar with planetary protection requirements and needs (which are not required in LEO)..

Looking ahead, we may add sections or information on additional areas of particular relevance to PP, such as :

- Survival of Earth organisms in space and during interplanetary transfers-- (international literature and experiences—Skylab, ISS, shuttle, etc.); and
- Overview of human health/ safety requirements and biomedical monitoring during human space flights (compiled from the extensive international experiences in LEO and ISS).

5. Work Process and Anticipated Deliberations

Our stepwise work process will first develop a “scope of needs” on the path to analyzing information on the various requirements for future human exploration missions. We will then consider the advisability of using current capabilities and approaches to address particular planetary protection needs, or alternatively, highlight areas with gaps that may require new approaches as part of mission preparations. Anticipated steps and key areas of study deliberations are likely to include:

- 5.1 Identify and elaborate specific technical, process and operational needs related to PP and human missions and robotic precursors.

This section will include the identification of varied important Technical, Process & Operational needs for both PP and human health during missions beyond LEO (Based on 2008 COSPAR Principles and Guidelines for Human Mars Missions and various prior studies of humans and planetary protection).

- 5.2 Synthesize and examine technical needs and critical pathways for PP during human missions beyond Earth orbit compared to the current state of the art.

This task will draw from earlier PP studies in 2001-05, as well as input on biomedical and health/safety perspectives (drawn from experiences and studies on ISS and other human missions in LEO). Examples include: elaboration of mission aspects and critical pathways, including those where synergistic approaches between PP controls and anticipated mission design/operational constraints could be helpful beyond LEO (e.g., closed loop and recycling capabilities to minimize mass required; vehicles, suits, habitats, EVA, ALS; systems/operations for minimizing exposure of humans to planetary materials for multiple health reasons; minimizing contamination of planetary samples and environments for science purposes; waste control and disposal concerns; possible in-flight or on surface methods for sterilization/isolation/quarantine etc.).

- 5.3 Assess areas of current capability and identify gaps in knowledge.

This section will discuss the advisability of using /adapting existing vs. new approaches for addressing needs and pathways. The task will consider the use or adaptation of existing approaches vs. the need for new technical, process and operational approaches for supporting humans beyond Earth orbit. This task will use information from IAA 2010 studies, ISECG documents and roadmaps, NASA Design Reference Architecture (DRA 5.0) for human mission and other relevant reports.

- 5.4 Analyze and examine options for cross-cutting work.

Evaluate potential options for cross-cutting work towards co-development of science, technical, operational and engineering capabilities while addressing the implementation of PP policy and

guidelines, as well as issues associated with human health (building upon previous technical areas identified).

6. Overview of Interim Technical/Science Recommendations

There will be a list of recommendations arising from the full study, but it is already possible to present the following technical findings and recommendations:

- 6.1 Planetary protection provisions, as promulgated by COSPAR, are essential to safe solar system exploration, and should be incorporated into mission planning, development, and operations for all human and robotic missions that go beyond low-Earth-orbit.
- 6.2 The ability to closely monitor both human-associated microbes and human health consequences of microbial exposure is an essential capability for future human missions, and is complementary to the incorporation of planetary protection provisions into human space exploration.
- 6.3 For mission success it will be essential to provide robust robotic hardware capabilities that minimize/mitigate release of biological contamination during exploration, as well as collection and containment systems that are compatible with samples obtained robotically or directly by human crewmembers (whether by drilling or other means).
- 6.4 Environments on Mars (and other targets of exploration) that may provide habitats for either Earth organisms or potentially for martian life (indigenous extraterrestrial organisms). Accordingly, they must be appropriately defined, and thoroughly characterized and mapped by robotic missions prior to being carefully accessed by human explorers.

7. Other Interim Recommendations Supportive of the Way Forward

The integration of PP into human mission planning and implementation will be supportive of IAA's interests in fostering international coordination across disciplines and sectors. In particular:

- 7.1 International coordination of planetary protection planning, research, and technology development, will be essential for successful implementation on future human missions.
- 7.2 International partnerships should insist on the incorporation of planetary protection principles in all aspects of future mission planning, including road-mapping and strategic planning, whether by governmental or private entities.
- 7.3 The principles and methods essential to planetary protection for human missions have a high degree of utility on Earth and can provide a means by which to secure and facilitate the involvement of new international space nations and partners in work related to space exploration.
- 7.4 Future mission planning will include the development of detailed human mission planetary protection designs and protocols. In order to ensure a common understanding of the principles behind such planning and designs, international partners should ensure the availability of an international course and ongoing workshops for those planning human missions or activities beyond Earth orbit, as well as the proactive dissemination of information related to planetary protection (including this report) through journal articles, professional publications, and presentations at conferences etc.

8. References

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A more complete compilation of references will be included in the final study report. The references below provide a limited selection of key international reports and papers specifically focused on planetary protection and/or human missions. In addition, the NASA Planetary Protection website has an online library of diverse reports related to human missions beyond Earth orbit.

See <www.planetaryprotection.nasa.gov> under the link for “Documents,” and the following documents in the literature:

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