Acta Astronautica 66 (2010) 792–797

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Planetary protection for human exploration of Mars

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ARTICLE INFO

Article history:
Received 3 March 2009
Received in revised form
18 June 2009
Accepted 23 August 2009
Available online 5 November 2009

Keywords:
Human exploration
Planetary protection
Forward contamination
Backward contamination
Astronaut health
Mars

ABSTRACT

Human astronauts have unique capabilities that could greatly facilitate scientific exploration of other planets. However, when searching for life beyond Earth, these capabilities can be utilized effectively only if the biological contamination associated with human presence is monitored and minimized. This is termed planetary protection, and is a critical element in human exploration beyond Earth. Planetary protection must be incorporated from the earliest stages of mission planning and development, to ensure proper implementation. Issues involve both "forward contamination", the contamination of other solar system bodies by Earth microbes and organic materials, and "backward contamination", the contamination of Earth systems, including astronauts, by biological hazards or potential alien life. Conclusions from a number of international workshops held over the last six years recognize that some degree of forward contamination associated with human astronaut explorers is inevitable. Nevertheless, when humans are exploring space the principles and policies of planetary protection, developed by COSPAR in accordance with the 1967 Outer Space Treaty, still apply. Implementation guidelines include documenting and minimizing contamination of the exploration targets, control at the most stringent levels for locations in which Earth life might grow, and protection of humans from exposure to untested planetary materials. Preventing harmful contamination of the Earth must be of the highest priority for all missions.

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1. Introduction

When searching for life beyond Earth, the unique capabilities of human astronauts can be utilized effectively only if biological contamination associated with human presence is understood and controlled. Regulating biological contamination during planetary exploration is termed planetary protection, and will be a critical element in the human exploration of other solar system bodies. Planetary protection must be incorporated from the earliest stages of mission planning and development, to ensure proper implementation. Issues of concern to planetary protection involve both "forward contamination", which is the contamination of other solar system bodies by Earth microbes and organic materials, and "backward contamination", which is the contamination of Earth systems by potential alien life. Forward contamination involves contamination that might invalidate current or future scientific exploration of a particular solar system body, and that might disrupt the planetary environment or a potential endogenous (alien) ecosystem. Backward contamination involves the potential for harmful contamination of the Earth, and for human missions includes the possible immediate and long-term effects on the health of the astronaut explorers from possible biologically-active materials encountered during exploration.

A number of national and international workshops held over the last six years [1–4] have generated a consensus regarding planetary protection policies and

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0094-5765/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.actaastro.2009.08.015

requirements for human missions to Mars, and a 2007 workshop held by NASA has considered the issues and benefits to planetary protection that might be offered by a return to the Moon [5]. Conclusions from these workshops recognize that some degree of forward contamination associated with human astronaut explorers is inevitable. Nevertheless, the principles and policies of planetary protection, developed by the Committee on Space Research (COSPAR) in accordance with the 1967 Outer Space Treaty, can and should be followed when humans are exploring space.

Implementation guidelines include documenting and minimizing contamination of the exploration targets, protection at the most stringent levels for any target locations in which Earth life might grow, protection of humans from exposure to untested planetary materials, and preventing harmful contamination of the Earth as the highest priority of all missions. These principles should be incorporated in frameworks for future international missions of human exploration. It would be a tragic medical accident were an astronaut on the way to Mars get sick of unknown causes. It would be far more tragic, and of significant concern for planetary protection, should one of several astronauts become ill on the return from Mars to Earth, without sufficient medical information to determine why.

2. International basis for planetary protection policy

Planetary protection entered into international law with Article IX of the 1967 Outer Space Treaty, which states in part that:

"...parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exp loration 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..." [6].

COSPAR is an interdisciplinary committee of the International Council for Science that maintains an international consensus planetary protection policy [7], which serves as the standard for biological contamination avoidance under the 1967 Outer Space Treaty. COSPAR, along with the International Astronautical Foundation, consults with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in assessing "harmful contamination" under the terms of the Treaty.

A number of nations have expressed interest in future missions involving humans in space that have objectives at the Moon (again) and beyond to Mars. Thus, an international consensus on planetary protection policy and implementation guidelines is essential to facilitate such missions. A set of basic assumptions has been developed by ESA and NASA regarding human mission activities and their utility, and these assumptions underlie an emerging consensus on planetary protection policy and requirements. These include, in particular, that human missions to Mars should provide for an improved capability in the search for martian habitable environments and life, and that the Earth should be protected from potential risks from returned martian materials. These assumptions have been used as a basis to develop COSPAR policy to provide a set of fundamental principles and guidelines for human missions, with an emphasis on Mars. New language to that effect was added to the COSPAR planetary protection policy, and approved by the COSPAR Bureau and Council, in July of 2008.

3. COSPAR policy on human missions

The introduction to the COSPAR policy on planetary protection recognizes that the primary goals of planetary protection, protecting the Earth and preventing forward and backward contamination, do not change when humans are involved. However, the essential association of humans with commensal microbes requires that certain variations will have to be developed in order to implement planetary protection on human missions. To mitigate the potential for danger to astronauts and to Earth, planetary protection must be considered a critical element for the success of human missions, and evaluation of planetary protection requirements should be considered in all human mission subsystems development.

Principles for human missions to Mars: The intent of this 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 include:

- 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.

Astronaut safety is one of the highest priorities for human missions. The Space Studies Board of the US National Research Council has recommended that a set of operational constraints be implemented for human mission activities that are designed to ensure the safety of astronauts [8]. These constraints include the designation of "Safe Zones", regions that have been demonstrated to be safe for humans, and astronauts will only be allowed in areas that have been demonstrated to be safe. Initial identification of safe zones for human landing sites should be performed through direct investigation by precursor missions, either on the ground or remotely. Areas around human habitats should be cleared as "safe" through appropriate robotic exploration, after which human extravehicular activity (EVA) activity would be allowed. Special regions should only be accessed using sterilized clean equipment, to prevent forward contamination. Facilities for transfer of collected samples under appropriate contamination control will be required to prevent backward contamination.

The surface of Mars is very cold and dry–too cold or dry in most places to permit the growth and reproduction of Earth organisms. However, the subsurface of Mars is likely to be warmer and wetter, and therefore more hospitable to Earth life. Widespread geological features on the martian surface suggest that liquid water may occasionally be present even up to the present. Such formations have been termed "special regions" and require careful protection under COSPAR policy. A Mars special region is defined by COSPAR as "*a region within which terrestrial organisms are likely to replicate*" and also include "*any region that is interpreted to have a high potential for the existence of extant martian life forms,*" though we have no data currently that address this component of the definition. Thus, special regions as currently defined encompass both specific features on the surface of Mars, and, conservatively, the entire subsurface below a shallow depth.

In July 2008 COSPAR refined the definition of "Special Regions" to include measurable parameters that can be used to determine whether a particular location on Mars requires additional protection. Temperature and "water activity" (availability of water for chemical reactions) had been proposed as useful parameters for defining special regions by the Mars Exploration Program Analysis Group [9]. In addition to the verbal definitions above, any region on Mars that may reach both a temperature of $-25\,^{\circ}C$ and a water activity of 0.5 is defined as a Mars special region. These numeric limits will be revisited regularly and modified as appropriate based on the most up-to-date scientific information. The intent is to define as special regions only those locations on Mars that have available water, at a temperature that could support life.

4. Implementation guidelines

In addition to general principles on human exploration, COSPAR has formulated a number of guidelines that can be used to inform the development of mission scenarios.

Guidelines for human missions to mars: In accordance with these principles, specific implementation guidelines for human missions to Mars 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.

The ability to maintain the crew in a healthy state is critical for mission success. As part of normal crew health monitoring, basic tests of the medical condition of the crew and their responses to pathogens or adventitious microbes should be developed, provided, and employed regularly during the mission. This information will also be essential for evaluating the effects of exposure events, to understand their severity and assess the need for quarantine measures.

- 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 lifeform occurs.

To permit the isolation of potentially contaminated or infectious crew member(s), a quarantine capability for both the entire crew and for individual crewmembers should be provided during the mission. Individual crewmembers might be quarantined by providing for physical separation and air filtration using a tent-like structure. After the mission, a quarantine capability and appropriate medical testing should be provided for the crew. This would likely be implemented in conjunction with a health monitoring and stabilization program that would be necessary to protect an immune-compromised crew from infection as they are integrated back into the general population.

- 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.

Planetary protection risks are among the many risks a mission faces that should be identified and evaluated together with other mission risks, and they must be reduced, mitigated, or eliminated to enable mission success. Accordingly, to ensure proper implementation of planetary protection provisions during the mission, general human factors will need to be considered along with planetary protection issues when developing technologies and procedures. Likewise, planetary protection considerations should be included in human mission planning, training, operations protocols, and mission execution.

Living humans invariably carry associated microbial populations that are necessary for our survival, and treating humans by the same methods used to reduce microbial contamination on robotic systems would kill them. Thus, forward contamination is a significantly greater risk with human missions than robotic missions. Advances in human support technologies, such as improvements in "closing the loop" on life support systems, increased waste recycling capabilities, and the development of minimal-release space suits and EVA equipment, will assist planetary protection and also reduce the amount of upmass required to support human exploration. However, it will be not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.

- Neither robotic systems nor human activities should contaminate "Special Regions" on Mars, as defined by this COSPAR policy.

In line with current planetary protection policy for robotic missions, human missions to Mars shall avoid the inadvertent introduction of Earth organisms or organic molecules into Mars special regions, as well as the inadvertent exposure of humans to martian materials. Mission cleanliness and containment capabilities will feed directly into landing site selection and operational accessibility to scientifically desirable locations on Mars. Exploration of special regions, including access to subsurface ice or water, will need to be restricted appropriately relative to the microbial and organic cleanliness of the human-associated or robotic systems utilized. Considerations must based on this approach in order to determine the levels and kinds of contamination allowed for any particular human mission activity.

- 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.

Protocols for initial human missions should be designed to minimize the potential for harmful exposure to untested materials, allowing isolation of the crew from direct contact with planetary materials until initial testing constrains the potential danger exposing humans to them. As the missions progress, base-related activities, and further exploration and sample collection procedures also should be crafted with the requirement to minimize exposure to untested materials. It may be that the initial landing site will be selected far in advance, and tested by robotic precursor missions, but additional robotic capabilities should be included to allow remote access to samples from untested areas or depths. Such capabilities will put an emphasis on field sterilization methods and recleaning techniques for the robots to be used. Likely, direct human sampling of untested areas will be considered impractical (due to cleaning constraints) or unwise (due to the inherent risks of uncontrolled exposure to martian materials).

- 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.

Backward contamination is an ongoing risk for human missions during operations and return to Earth, in contrast to robotic missions for which contamination can be controlled effectively by containment of samples after return. Crewmembers exploring other planets will inevitably be exposed to planetary materials, as was first demonstrated during the Apollo program. The recent consensus on planetary protection for human missions argues that, to the maximum extent practicable, these exposures should occur under controlled conditions. It us understood that exposure cannot be eliminated entirely, so careful planning will be required to avoid the need for decisions about whether crew members are allowed to return to Earth. For some missions, the potential that human explorers may be exposed to extraterrestrial life must be assumed, and appropriate precautionary measures taken. In all cases, safeguarding the Earth from harmful backward contamination must always be the highest planetary protection priority.

- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.

To facilitate compliance and rapid mitigation when required, a crewmember onboard the mission should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission. Planetary protection provisions are too important, and in a crisis may become too urgent, to build in the requirement that discussions are subject to long communications delays, which could be 20 minutes for a round-trip message from Mars to Earth and back.

- 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.

Several factors will contribute to the control of forward contamination during human missions. Exploration, sampling, and base activities must be designed and developed to assure effective operations while maintaining the required level of planetary protection activity. Particular challenges involve processes associated with exploration, including EVA activities: egress/ingress-specific technologies and procedures will need to be developed, characterized and optimized. Systems will be required to allow controlled, sterile, surface and subsurface sampling operations, so that uncontaminated samples can be obtained, probably using robotic assistants. An inventory of microbial populations and organic materials carried aboard the spacecraft should be established prior to launch and maintained throughout the mission, as a record of contamination potentially released by human-associated spacecraft and transportation systems. Monitoring technologies will be required to evaluate the level of contamination released by human-associated activities on an ongoing basis, as will technologies to mitigate contamination resulting from an off-nominal release event. The inventory and monitoring activities will support both planetary protection and crew-health objectives.

5. Practical implementation

It appears premature to adopt specific requirements for human missions to Mars, but (as of July 2008) COSPAR has assembled a set of guidelines as part of, and consistent with, its consensus planetary protection policy. Locations on Mars that are consistent with current mission requirements to land on most of Mars (category IVa) are locations that likely would be allowed for human exploration, as being too cold, and too dry, for surface microbial contamination—given that EVA suits and other equipment would be designed to minimize leakage. Under such conditions, some local human-associated contamination could not be avoided, but specific guidelines for human missions would constrain the contributions of landing operations, habitats, EVA, and *in situ* resource utilization (ISRU) to that contamination. The overall goal of planetary protection measures for human missions will be to prevent the contamination of "Special Regions" on Mars (as defined by the COSPAR policy), which are areas where Earth organisms might grow and thrive, or which might support indigenous martian life.

Prior planning will need to focus not only on avoiding contamination during normal operations, but to anticipate off-nominal mission operations, as well, and avoid the contamination of Spacial Regions even in the event of an accident.. Planning will also have to ensure that cold, dry, areas of Mars are not artificially warmed and made wet by human-associated technologies (e.g., nuclear materials) that could produce "mission-induced Special Regions." Such considerations will affect the selection and operations of mission systems, including habitats and life-support systems.

5.1. Responding to off-nominal events

If an accident or other damaging, non-nominal event occurs, planning must become action to address the situation. Avoiding contamination in the event of a spacecraft crash/hard landing, a micrometeorite impact that breaches a habitat or mobility system, damage to waste containment systems, or a rip/tear or other degradation of an EVA suit will take an effective response. Most importantly, potential contamination events that directly impinge on crewmembers, such as a breach in a sample containment system, or a fire that requires the evacuation of a habitat, will be problematic—most particularly because the proximate danger of the event will tend to obscure the potential danger of contamination with martian materials. Yet, contamination with martian materials might result in an astronaut having to endure a long quarantine upon return to Earth, or keep the astronaut from being able to return at all. Should an astronaut bcome sick on the mission with an unidentified/unidentifiable illness, the very careful prior consideration of the proper response by the mission will be essential if the mission is to be judged a success.

5.2. Testbeds for technology development

The Moon is likely to prove an excellent testbed to develop planetary protection procedures and practices in an environment sufficiently harsh to prove an adequate challenge. Because the Moon is currently recognized as being of interest for understanding prebiotic chemistry and the origin of life but is not hospitable to contamination by Earth life, the only restrictions to operations on the Moon are documentary in nature. There are no limits on contamination similar to those in place for more distant bodies such as Mars, which means that technologies developed for use on the Moon are not prohibited from releasing high levels of contamination. However, due to planetary protection requirements for Mars, highly contaminating equipment or technologies would not be allowed on Mars. Re-design could be prohibitively expensive, so the longer term goals of planetary exploration must be considered even when designing near term approaches.

6. Conclusions

The movement of humans off-planet is one of the hopes for sustaining our civilization and our species. Preserving that value of that movement in terms of exploration and science is an important component of human spaceflight. Planetary protection considerations are essential to protecting the Earth, and protecting the potential to perform scientific exploration of the solar system without jeopardizing investigations into the origins and evolution of life. Although humans are inevitably associated with microbial contamination, an international consensus has been developed that human exploration of interesting locations can be productive if appropriate precautions are put in place.

Essential to forward contamination control are monitoring and minimizing contamination associated with human exploration; selecting landing sites so that release of contamination will remain local; and developing technologies to mitigate excessive releases. Preventing backward contamination requires that astronauts must not be exposed to martian materials that could be significantly hazardous to their long-term health or cause infections that would potentially contribute to biohazards after a return to Earth. In addition, astronaut health must be monitored throughout the mission so that diseases caused by Earth organisms or non-living planetary materials can be distinguished from potential effects of extraterrestrial organisms. To protect the Earth in the event of exposure of the crew to alien life, appropriate quarantine protocols and procedures will need be developed and agreed upon with the crew. Planning for human exploration must include planetary protection constraints from the outset, and effective engineering and implementation of planetary protection requirements will be critical for mission success.

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