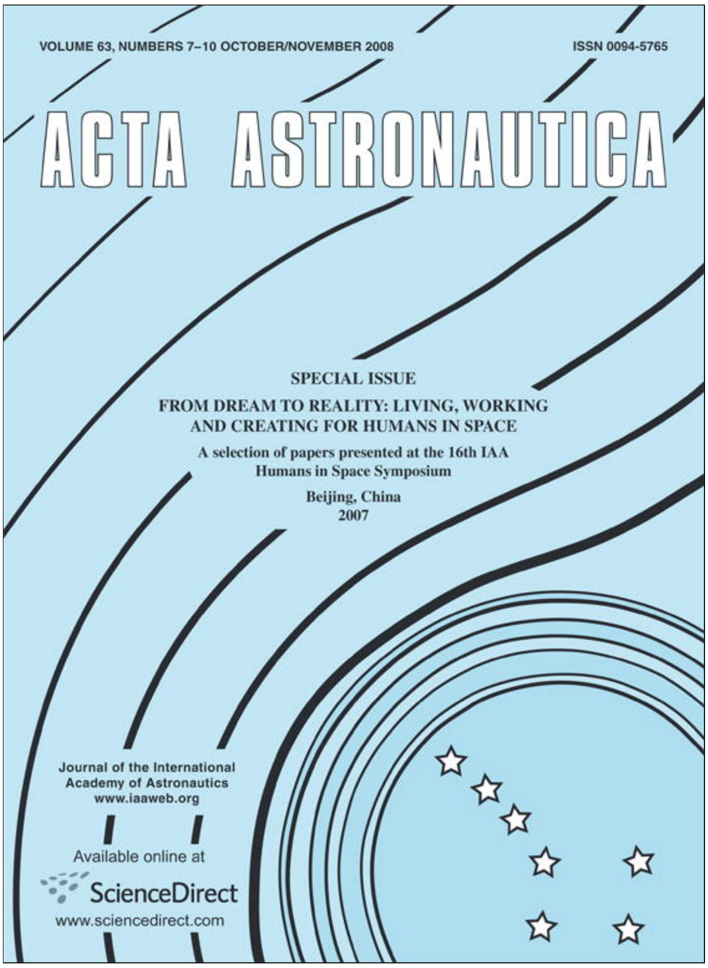
VOLUME 63, NUMBERS 7–10 OCTOBER/NOVEMBER 2008
ISSN 0094-5765
ACTA ASTRONAUTICA
SPECIAL ISSUE
FROM DREAM TO REALITY: LIVING, WORKING AND CREATING FOR HUMANS IN SPACE
A selection of papers presented at the 16th IAA Humans in Space Symposium
Beijing, China
2007
Journal of the International Academy of Astronautics
www.iaaweb.org
Available online at
ScienceDirect
www.sciencedirect.com

PERGAMON

Available online at www.sciencedirect.com
ScienceDirect

Acta Astronautica 63 (2008) 1025–1030

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

Planetary protection for humans in space: Mars and the Moon

Catharine A. Conley*, John D. Rummel

NASA Headquarters, Science Mission Directorate 3X63, Washington, DC 20546, USA

Received 17 October 2007; received in revised form 15 March 2008; accepted 26 March 2008
Available online 19 May 2008

Abstract

When searching for life beyond Earth, the unique capabilities provided by human astronauts will only be advantageous if the biological contamination associated with human presence is monitored and minimized. Controlling biological contamination during planetary exploration is termed 'planetary protection,' and will be a critical element in the human exploration of other solar system bodies. To ensure the safety and health of the astronauts and the Earth, while preserving science value, planetary protection considerations must be incorporated from the earliest stages of mission planning and development. 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 concerns include contamination that might invalidate current or future scientific exploration of a particular solar system body, and that may disrupt the planetary environment or a potential endogenous (alien) ecosystem. Backward contamination concerns include both immediate and long-term effects on the health of the astronaut explorers from possible biologically active materials encountered during exploration, as well as the possible contamination of the Earth. A number of national and international workshops held over the last seven years have generated a consensus regarding planetary protection policies and 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. Conclusions from these workshops recognize that some degree of forward contamination associated with human astronaut explorers is inevitable. Nonetheless, the principles and policies of planetary protection, developed by COSPAR in conformance 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 for all missions. These considerations should be incorporated in planning for future human exploration missions.
Published by Elsevier Ltd.

1. Introduction

In the exploration of other planets and the search for life outside of Earth, the unique capabilities provided by human astronauts will only be advantageous if the biological contamination associated with human presence is understood and controlled. Thus, planetary protection is a critical element in the human exploration of other solar system bodies, and should be incorporated from the earliest stages of mission planning and development. Both 'forward contamination,' the contamination of other solar system bodies by Earth microbes and organic materials, and 'backward contamination,' the contamination of Earth systems by potential alien life, must be avoided. Forward contamination concerns include contamination that might invalidate

* Corresponding author. Tel.: +1 202 358 3097.
E-mail address: cassie.conley@nasa.gov (C.A. Conley).

0094-5765/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.actaastro.2008.03.012

current or future scientific exploration of a particular solar system body, and/or might disrupt the planetary environment or a potential endogenous (alien) ecosystem. Backward contamination concerns include both immediate and long-term effects on the health of the astronaut explorers from possible biologically active materials encountered during exploration, as well as the possible contamination of the Earth. Although some degree of forward contamination associated with human astronaut explorers is inevitable, the principles and policies of planetary protection that have been imposed on robotic missions by the 1967 Outer Space Treaty should be followed to the greatest extent possible when humans are exploring space.

2. Basis for planetary protection policy

A strong motivating factor for the exploration of the solar system is the search for extraterrestrial life. However, this search could be permanently compromised if spacecraft carry Earth life with them and contaminate the places they explore. Additionally, samples returned to Earth from other places may contain living organisms that could reproduce on Earth and damage our biosphere. The practice of minimizing the probability of either type of contamination occurring is called 'planetary protection'.

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 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…" [1].

The Committee on Space Research (COSPAR), a committee of the International Council for Science, maintains an international planetary protection policy that serves as the consensus standard for biological contamination avoidance under the 1967 Outer Space Treaty. COSPAR, along with the IAF, consults with the United Nations Committee on the Peaceful Uses of Outer Space on matters related to the Treaty.

NASA Planetary Protection Policy is consistent with the COSPAR policy, and is documented in NASA Policy Directive NPD 8020.7 [2]. This current policy is applicable to human interplanetary missions, although a specific requirements document for human missions has not yet been issued. The requirements for robotic missions are given in the NASA Procedural Requirements document NPR 8020.12 [3]. In general, planetary protection requirements depend on the nature of the mission and on the target planet, with landed missions to planets of interest for biological evolution being protected to the greatest extent. These requirements are determined "through recommendations from both internal and external advisory groups, but most notably from the Space Studies Board of the National Academy of Sciences," according to NASA policy. Specific measures may include: constraints on spacecraft operating procedures; inventory of spacecraft organic and biological contamination; reduction of such contamination; and for sample return missions, restrictions on the handling of returned samples.

The Planetary Protection Subcommittee of the Science Committee of the NASA Advisory Council was formed to provide detailed review and advice regarding the specific requirements levied on each outgoing mission that might pose a contamination hazard, and every sample return mission. The detailed requirements for each mission are documented in a 'Planetary Protection Plan,' which represents the contract between the mission management and the Planetary Protection Officer regarding the means by which the mission will meet its planetary protection objectives.

3. Planetary protection for human missions

A number of workshops were held in the early and mid-2000s [4–7], both within the US and jointly with international partners, that have resulted in an international consensus on planetary protection policy and implementation for human missions. This international consensus is being used as a basis to develop COSPAR guidelines, and together those will feed into the development of a NASA Procedural Requirements document for human mission implementation. One outcome of these workshops has been the recognition that a set of basic assumptions regarding human mission activities underlies the emerging consensus on planetary protection policy and requirements.

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. For this reason, the greater capabilities of human explorers can contribute to the astrobiological exploration of the solar system only if human-associated contamination is controlled and understood. 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.

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 is 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.

These assumptions lead directly to a set of general policy considerations that should be applied to all human missions:

- To mitigate potential 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.
- 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.
- 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 min for a round-trip message from Mars to Earth and back.

4. Considerations for planetary protection implementation

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.

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. 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 crew members 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.

To minimize the potential for harmful exposure events, protocols for human missions shall include isolation of humans from direct contact with planetary materials, until initial testing can provide verification that exposure to the material is safe for humans. Exploration, sampling, and base activities shall be performed in a manner to limit inadvertent exposure of humans to material from untested areas. The initial landing site will most probably be selected only after testing by precursor mission activities, but a means for allowing controlled access to untested areas, or areas that are considered unsafe, must be provided during human missions. Sterilized and recleanable robots, under appropriate operational constraints, are one suitable approach for ensuring appropriate access.

5. Operational constraints for human missions to Mars

The surface of Mars is very cold and dry—in most places, too cold or dry 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. Certain geological formations on the martian surface suggest that liquid water may occasionally be present, and such formations have been termed 'special regions' that merit special protection under COSPAR policy. Mars special regions are defined by COSPAR as "a region within which terrestrial organisms are likely to propagate" and also include "any region that is interpreted to have a high potential for the existence of extant martian life forms." 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 2006 the Mars Exploration Program Analysis Group (MEPAG) released a report describing scientific data and findings for consideration when developing a definition of special regions [8]. The most useful definition of special regions would include a combination of specific parameters that can be measured accurately. Temperature and 'water activity' (availability of water for chemical reactions) were proposed by MEPAG as useful parameters for defining special regions, and are at writing being considered by COSPAR. In addition to the verbal definitions above, any region on Mars that may reach both a temperature of $-25\,^{\circ}\mathrm{C}$ and a water activity of 0.5 will probably be 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.

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, shall be restricted appropriately relative to the microbial and organic cleanliness of the human-associated or robotic systems utilized. Calculations based on this approach will determine the levels and kinds of contamination allowed for any particular human mission activity.

Astronaut safety is one of the highest priorities for human missions. The Space Studies Board of the US National Academies has recommended that a set of operational constraints be implemented for human mission activities that are designed to ensure the safety of astronauts [9]. These constraints include the designation of "Safe Zones," regions that have been demonstrated to be safe for humans, so astronauts will only be allowed in areas that have been demonstrated to be safe. Initial identification of safe zones for human landing sites shall be performed through direct investigation by precursor missions, either on the ground or remotely. Areas around human habitats shall be cleared as "safe" through appropriate robotic exploration, after which human EVA activity would be allowed. Special regions shall 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.

6. Guidelines for practical implementation

Although specific requirements for human missions to Mars have not yet been established, a set of guidelines to assist planning and early decision-making can be assembled based on the consensus outcomes from the various NASA and international workshops held over the last decade. In general, locations on Mars to which clean but non-sterile robots are allowed access (Planetary Protection Category IVa) are locations to which humans might be allowed direct access. It is expected that space suits and EVA equipment will be designed to release minimal contamination, but recognized that some local contamination from human activities cannot be avoided. Specific guidelines for human missions cover four major areas of human activity: initial landing sites, human habitats, EVA activities, and the potential for in situ resource utilization (ISRU).

Landing sites shall be selected such that nominal or off-nominal mission operations shall have a low probability of allowing mission-associated microbial or organic contamination to enter Mars special regions either horizontally or vertically. This includes mission-induced special regions.

Human habitation modules shall be located and operated to ensure that mission-associated microbial or organic contamination shall have a low probability of entering Mars special regions. Closed-loop life support and recycling systems that release minimal contamination should be developed. Distances from special regions should be determined based on determinations of contaminants released and data addressing transport of material by surface winds and other processes. Calculations should include a conservative safety margin.

Human EVA activities shall be planned and executed to ensure that mission-associated microbial or organic contamination shall have a low probability of entering Mars special regions. Tools capable of attaining and retaining the required cleanliness shall be used to explore and sample Mars special regions. Appropriate equipment shall be provided to enable transfer of materials from collection devices to study facilities while maintaining the required levels of cleanliness and containment.

ISRU activities shall be planned and executed to ensure that mission-associated microbial or organic contamination shall have a low probability of entering Mars special regions. Approaches for ISRU shall protect humans and human-associated systems from uncontrolled contact with material from Mars special regions.

7. Responding to off-nominal events

Off-nominal events must be anticipated for any mission, and appropriate planning used to mitigate the effects. Example events that could result in forward contamination of Mars include a spacecraft crash, habitat or mobility systems breach, waste containment breach, poor sterilization of systems accessing special regions. Example events that could produce backward contamination of human astronauts and their support systems include laboratory accidents, breaches in a Mars sample containment facility, or damage to a habitat and/or mobility systems. Of immediate concern for astronaut survival would be failures in human support systems, including advanced life support systems, components, or habitat integrity, EVA systems such as suits or rovers, power systems, and others.

Amelioration of planetary protection concerns would involve identification and documentation of the incident, then remediation when possible.

8. 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 considered 'not of interest' for understanding prebiotic chemistry and the origin of life, there are no restrictions on contamination similar to those in place for more distant bodies such as Mars. This 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 and re-design could be prohibitively expensive, thus the longer term goals of planetary exploration must be considered even when designing near term approaches.

Earth-based analogues are also potential sites for testing equipment and processes, with some research activities, e.g., developing technologies and techniques for human-robotic cooperation in cleaning and re-cleaning robotic sample collection equipment, already under way. Establishment and testing of protocols for responding to off-nominal events is much better done in environments that are not susceptible to damage from released contamination.

9. Conclusions

The movement of humans off-planet is one of the hopes for sustaining our civilization and our species. Preserving the 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 future investigations into of 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. Protecting against backward contamination requires that sites explored by humans be safe; that astronaut health 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; and that an appropriate quarantine procedures are available to protect the Earth in the event of exposure of the crew to alien life. 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.

References

[1] United Nations, Treaty on principles governing the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies, Available at ⟨http://www.state.gov/t/ac/trt/5181.htm⟩, 1967.

[2] National Aeronautics and Space Administration, Biological contamination control for outbound and inbound planetary spacecraft, NPR 8020.7F, Washington, DC, 1999, Available at: ⟨http://nodis3.gsfc.nasa.gov/displayDir.cfm?t = NPD&c = 8020 &s = 7F⟩.

[3] National Aeronautics and Space Administration, Planetary protection provisions for robotic extraterrestrial missions, NPR 8020.12C, Washington, DC, 2005, Available at: ⟨http://nodis3.gsfc.nasa.gov/displayDir.cfm?t = NPR&c = 8020 &s = 12C⟩.

[4] M.E. Criswell, M.S. Race, J.D. Rummel, A. Baker (Eds.), Planetary protection issues in the human exploration of Mars, Pingree Park Final Workshop Report, NASA/CP-2005-213461, 2005.

[5] J.A. Hogan, J.W. Fisher, M.S. Race, J. Joshi, J.D. Rummel (Eds.), Life Support & Habitation and Planetary Protection Workshop Final Report, NASA/TM-2006-213485, 2006.

[6] Joint NASA/ESA Workshop on Mars Planetary Protection and Human Systems Research and Technology, in: European Space Research and Technology Centre (ESTEC) in Noordwijk, Netherlands, 19–20 May 2005.

[7] NASA Advisory Council Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, AZ, USA, February 27–March 2, 2007Workshop website: ⟨http://www.lpi.usra.edu/meetings/LEA/⟩.

[8] The MEPAG Special Regions-Science Analysis Group, Findings of the Mars special regions science analysis group, Astrobiology 6 (2006) 677–732.

[9] National Research Council, Space Studies Board, Safe On Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface, National Academy Press, Washington, DC, Available at: ⟨http://www.nap.edu/catalog.php?record_id = 10360⟩, 2002.