Don`t Leave Home Without It:
Planetary Protection for Robotic and Human Missions

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Abstract—In planetary exploration and the search for life beyond Earth, the unique capabilities provided by human explorers will be advantageous to science only if the biological contamination associated with human presence is understood and controlled. The practice of preventing cross-contamination between the Earth and other planetary bodies is called planetary protection. NASA has a planetary protection policy in place for solar system exploration missions, and compliance with it is mandatory. Thus, planetary protection must be incorporated in mission planning and development from the beginning. NASA's planetary protection policy is intended to prevent "forward contamination", contamination of other solar system bodies by Earth microbes and organic materials, and "backward contamination", contamination of Earth by potential alien life. As NASA`s space exploration program expands to encompass human as well as robotic planetary missions, planetary protection will become a more complicated enterprise.1 2

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1. HISTORICAL INTRODUCTION

Planetary Protection covers policies and practices that both protect other solar system bodies from contamination by terrestrial biological material to preserve future opportunities for scientific investigation (forward contamination), and also protect the Earth from harmful contamination by materials returned from outer space via robotic or human missions (backward contamination). The international science community has long recognized that the exploration of other worlds may pose hazards to living organisms associated with the exploration of other worlds have been recognized for many years. Hypothetical scenarios for both forward contamination and backward contamination were published long before the beginning of the space age [e.g., 1, 2]. In the 1950s, Nobel Laureate Joshua Lederberg and others expressed concerns about the risk of transferring biological material inadvertently from one planet to another. In 1956, the International Astronautical Federation considered issues regarding biological contamination of the Moon and other planetary bodies, specifically that the contamination of other planets with Earth life might permanently compromise the ability to do scientific research on potential life indigenous to those bodies, or that returned samples might carry organisms harmful to Earth. [3]

In 1958 the International Council of Scientific Unions developed guidelines for preventing harmful cross-contamination of the planets, and directed its newly-created Committee on Space Research (COSPAR) to work with national space agencies on policies for preventing biological contamination during space exploration. At the same time, the US National Academy of Science formed the Space Studies Board as an advisory body on matters pertaining to human exploration of space, including the potential for interplanetary contamination. Late that year, the United Nations created its Committee on the Peaceful Uses of Outer Space (UN-COPUOS), which was chartered to organize "the mutual exchange and dissemination of information on outer space research", among other activites [4]. One of the first products of UN-COPUOS was a report on legal issues arising from the human exploration of space. This report recommended the development of international agreements to "minimize the adverse effects of possible biological, radiological, and chemical contamination".

Over the next decade, discussions within the UN emphasized the importance of legal principles for space exploration. In 1967 the US and USSR jointly proposed the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the
Moon and Other Celestial Bodies", known as the Outer Space Treaty, in which Article IX addresses Planetary Protection. The article states, in part, that signatories should "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" [5]. The US and USSR signed this treaty within weeks of each other, and the US Senate ratified shortly thereafter. The Outer Space Treaty still serves as the major international law governing the uses of outer space.

NASA has practiced planetary protection since the early exploration of the Moon, when the practice was called Planetary Quarantine. NASA implemented the first quarantine procedures for returned samples and astronauts during the Apollo program.

2. CURRENT PLANETARY PROTECTION POLICY

International policy and implementation guidelines for planetary protection are promulgated by the COSPAR Panel on Planetary Protection, which oversees compliance with the directives given in Article IX of the 1967 Outer Space Treaty. National space agencies may adopt COSPAR policy, or formulate similar or more stringent policies based on COSPAR guidelines. NASA planetary protection policy, requirements, and implementation protocols are described in a set of three documents that detail each subject separately. NASA Policy Directive 8020.7F [6] dictates compliance with COSPAR and NASA policies by all NASA missions that might contaminate other solar system bodies. NASA Procedural Requirements document NPR 8020.12C [7] details specific criteria for missions performing particular activities at different target planetary bodies. Detailed protocols for assessing microbial contamination on spacecraft hardware are described in the NASA Handbook NHB 5340.1, last updated in the 1980s and currently under review for re-release in 2008 as NASA Technical Handbook 6022 [8]. A number of new techniques and technologies for measuring contamination are under review or development, and will be added to the technical handbook as they are approved.

By COSPAR and NASA policy, every mission to a planetary target body is assigned a Planetary Protection Category, which can range from I to V depending on the combination of planetary target and mission goals. [7] Category I includes any mission to locations considered not of direct interest for understanding chemical evolution or the origins of life. Category I missions have no implementation requirements beyond the categorization itself. Category II includes any mission to a body of significant interest relative to chemical evolution that poses only a remote chance of contamination that could jeopardize future exploration. Category II missions have implementation requirements of documentation only. Any mission planning to fly by or orbit a body of significant interest relative to chemical evolution and the origins of life or for which contamination would jeopardize future exploration is assigned to Category III. Requirements imposed on Category III missions include significant documentation, as well as cleanliness and/or orbital lifetime restrictions. Category IV missions include landers and probes to the surfaces of planetary bodies of significant interest to chemical evolution and the origins of life, or for which contamination would jeopardize future exploration. Requirements for Category IV missions include thorough documentation as well as cleanliness requirements designed to minimize biological contamination of the target body.

All sample return missions are assigned to Category V for the return leg, with the outbound leg assigned the appropriate category for that mission and target combination. Category V missions are categorized as either 'unrestricted Earth return' for samples from locations not of biological concern, in which case documentation is the only requirement, or 'restricted Earth return' for samples from planetary bodies of biological concern. Samples designated 'restricted Earth return' are automatically considered hazardous to Earth until demonstrated otherwise by appropriate testing. For these samples the strictest possible precautions are mandated, including containment that will protect both the Earth from the sample and the sample from the Earth. This will require the construction of a facility operating at better than Biosafety Level Four (the most stringent containment available for pathogens such as the smallpox or ebola viruses).

Missions assigned to Category III or Category IV must meet specific constraints on spacecraft cleanliness before launch as well as operations during the mission. However, the specific requirements a mission must meet to minimize forward biological contamination will depend on the target planetary body, and are determined based on advice from the Space Studies Board, as well as the Planetary Protection Subcommittee of the NASA Advisory Council. For example, missions to Europa must fulfill the requirement of maintaining a less than $10^{-4}$ probability of contaminating an europaean ocean over the lifetime of the mission. The Planetary Protection Subcommittee has recently recommended that other icy moons in the outer Solar System should be protected using a similar probabilistic approach, with a maximum $10^{-4}$ probability of introducing a viable Earth microbe into a liquid water body on any icy moon, whether the liquid water is present naturally or induced by a spacecraft. [9]
3. PLANETARY PROTECTION FOR MARS

For missions to Mars, limits on contamination are based on those established for the Viking missions, which set numerical limits on the number of heat-resistant culturable organisms, termed 'spores', that are most likely to survive heat sterilization treatment and also the trip to Mars. At that time, Mars was protected based on a probability of contamination requirement, so Viking mission planners calculated the maximum number of spores allowable at launch that would meet the probabilistic requirement. In the early 1990s COSPAR updated the policy for Mars, so subsequent lander missions to Mars must meet numerical rather than probabilistic limits. As it did for Viking, NASA currently utilizes a traditional, cultivation-based assay to evaluate the number of spores present on a spacecraft. This number is accepted as a proxy for spacecraft cleanliness, and newer methods are being approved that can identify more of the contaminants known to be present but missed by the spore assay. Category III missions, with spacecraft intended to fly by or orbit Mars, are allowed to carry no more than 300 spores per square meter. Lander missions are designated Category IVb. Spacecraft or lander subsystems that are assigned either Category IVb or Category IVc may carry no more than 30 spores total on the exposed spacecraft surfaces. This level of cleanliness is obtained by meeting the Category IVa requirement of $3 \times 10^5$ spores for the total surface area and then performing a sterilization treatment, such as Dry Heat Microbial Reduction (DHMR), that has been demonstrated to reduce the initial spore load by four orders of magnitude.

Further definition of Special Regions is likely to involve a combination of specific parameters that can be measured accurately. The Mars Exploration Program Analysis Group has proposed two suitable parameters: temperature and water activity. Water activity is a measure of the availability of water to participate in chemical or biological reactions. In most cases, water activity can be considered as equivalent to the relative humidity of an environment divided by 100. The Planetary Protection Subcommittee has recommended setting limits on these two parameters to define Special Regions: a “water activity” of 0.5 or greater, and (simultaneously) a temperature of -25°C or warmer. 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. Based on our current understanding of Mars, this special regions designation encompasses only a small fraction of the surface of the planet, excluding both equatorial and polar latitudes.

The space community has expended considerable effort on planning for sample return missions to Mars, since such a mission was first proposed several decades ago. The Space Studies Board has produced a number of advisory reports, and NASA has held a series of workshops yielding a 'Draft Protocol' for the containment and assessment of samples returned from Mars. The primary objective of the protocol is to protect the Earth against potential biological contamination from martian samples. However, the more difficult task is likely to be protecting the samples from contamination by biological materials from Earth, since contamination by Earth organisms or compounds could jeopardize the detection of martian life, past or present. Samples that are returned from Mars shall be held in the highest possible level of containment, to protect Earth from the samples and to protect the samples from Earth. The Space Studies Board recommends that samples demonstrated to contain no biohazardous materials may be released from the containment facility. However, samples for which this demonstration is not possible shall remain in containment unless they are sterilized prior to release. A resurgence of interest in Mars sample return, exemplified by the recent plan to collect samples in a 'cache' on the Mars Science Laboratory for collection and return by a future
mission, has highlighted the need for updates to the Draft Protocol and sample containment facility design.

4. PLANETARY PROTECTION FOR HUMAN MISSIONS

Workshops held in the 1990s and early 2000s, in the US and jointly with international partners, have resulted in an international consensus on planetary protection policy for human missions [10-14]. This international consensus will serve as a basis for COSPAR guidelines and new NASA Procedural Requirements documents for human mission implementation. One outcome of these workshops has been the recognition that there are no basic differences between planetary protection principles for human and robotic missions. The highest priority is to protect Earth, and by extension the astronaut explorers. Forward contamination of the target body that might endanger scientific research must be avoided to the greatest extent feasible.

Some fundamental assumptions regarding human mission activities underlie current thinking about planetary protection policy and requirements. Humans invariably carry associated microbial populations that are necessary for survival, 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. Even with technology improvements, it will be not be possible to eliminate contamination by conducting all human-associated processes and mission operations within entirely closed systems. For exploration targets like Mars, it may be sufficient to protect certain areas of the planet stringently—the so-called 'Special Regions' in which Earth organisms might be able to propagate—and allow limited contamination at other locations.

Backward contamination is an ongoing risk for human missions during operations and return of the crew to Earth, in contrast to robotic missions for which contamination can be controlled 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. According to the recent consensus on planetary protection for human missions, these exposures should occur, to the maximum extent practicable, under controlled conditions. It is understood, however, that exposure cannot be prevented entirely. Accordingly, careful planning will be required to understand the nature and consequences of such exposures, and to avoid the need for decisions about whether crew members are allowed to return to Earth. For some missions, the potential for human exposure to extraterrestrial life must be addressed in the plan. Nevertheless, safeguarding the Earth from harmful backward contamination must always be the highest planetary protection priority.

These assumptions help to define a set of general policy considerations that apply to all human missions. To mitigate risk to astronauts and to the Earth, planetary protection must be considered a critical element for successful human missions. Compliance with planetary protection requirements should be addressed in the development of all human mission subsystems. Planetary protection risks should be identified and evaluated together with other mission risks to be reduced, mitigated, or eliminated. To ensure proper implementation of planetary protection provisions during the mission, general human factors must 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.

Finally, to facilitate compliance and rapid mitigation when necessary, every human mission should have a crew member onboard the mission assigned primary responsibility for the implementation of planetary protection requirements. Planetary protection provisions are too important, and in a crisis may become too urgent, to subject discussions to a potential 20 minute round-trip communication delay.

Considerations for Planetary Protection Implementation

Astronaut safety is one of the highest priorities for human missions. The Space Studies Board has recommended operational constraints for human mission activities that are designed to ensure the safety of astronauts. These constraints include the designation of "Zones of Minimum Biological Risk" (ZBRs), regions that have been demonstrated to be safe for humans. Astronauts will only be allowed in areas that have been demonstrated to be safe [10]. ZBRs for human landing sites can be identified 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 activity would be allowed. Special Regions shall only be accessed using sterilized clean equipment, and facilities for transfer of collected samples under appropriate contamination control will be required.

Crew health maintenance is critical for mission success. Standard tests on the medical condition of the crew and their responses to pathogens or adventitious microbes should be developed, provided, and employed regularly during the mission as part of routine health monitoring. 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 individual crewmembers and for the entire crew should be provided during the mission. After the mission, a quarantine capability and appropriate medical testing should be provided, and could be implemented in conjunction with a health monitoring and stabilization program as the crew are integrated back into the general population.

To minimize the potential for harmful exposure events, operations for human missions shall include isolation of humans from direct contact with planetary materials until testing can verify that exposure to the material is safe. Exploration, sampling, and base activities shall be performed in a manner to limit inadvertent exposure of humans to material from untested areas. For the initial landing site, testing will probably have been performed as a part of 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.

Operational Constraints for Human Missions to Mars

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. Cleanliness and containment capabilities must be factored into landing site selection and decisions about operational access to scientifically desirable locations. Exploration of Special Regions, including access to subsurface ice or water, shall be restricted as appropriate relative to the microbial and organic cleanliness of the human-associated or robotic systems utilized. Appropriate technological capabilities will be critical factors in establishing the levels and kinds of contamination allowed for any particular human mission activity.

To control forward contamination during human missions, exploration, sampling, and base activities must be designed and developed to ensure safe and effective operations while maintaining the required level of planetary protection compliance. One particular challenge is extravehicular activities–specific technologies and procedures for field operations will need to be developed, characterized and optimized. For example, systems will be required to allow controlled, sterile, surface and subsurface sampling operations, so that uncontaminated samples can be obtained. Sterilized and recyclable robots, under appropriate operational constraints, are one suitable approach for ensuring appropriate access.

To assess levels of biological contamination and monitor changes, an inventory of microbial populations and organic materials carried aboard the spacecraft should be established prior to launch and updated throughout the mission. This will serve as a record of contamination potentially released by human-associated spacecraft and transportation systems, as well as a baseline in the case of unexpected developments. Monitoring technologies will be required for ongoing evaluation of contamination released by human-associated activities, as will technologies to mitigate contamination resulting from off-nominal release events. These inventory and monitoring activities will support both planetary protection and crew-health objectives.

5. Summary

For space exploration to proceed safely, and to continue expanding our understanding of the Solar System, planetary protection must be an integral part of overall mission planning and execution. Robotic missions currently comply with planetary protection requirements based on mission objectives and target planetary body. Requirements for human missions are not fully developed, but the basic principles of planetary protection—protecting science and protecting the Earth—will not change. Human missions to Mars will be subject to planetary protection requirements that will protect astronauts, the Earth, and the potential for scientific discovery. Compliance with the requirements will be challenging, but is both necessary and worthwhile.

Decades of experience with robotic missions, and lessons learned from the Apollo experience, have provided important insights into the nature and timing of planetary protection requirements. Proper planetary protection makes sense to ensure the success of future missions, and to protect the Earth from unknowns that missions are sent to explore. Accordingly, the design of appropriate technologies and procedures for planetary protection must be included in the development of both robotic and human missions. The result will be scientifically sound and productive missions that preserve the pay-off potential of future exploration, and ensure the safety of Earth and that our astronauts can come safely home.
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BIOGRAPHIES

Catharine Conley is currently acting as the NASA Planetary Protection Officer. Prior to her detail as PPO, Conley's research at NASA Ames Research Center focused on the biochemistry and evolution of muscle tissue, the basis for motility in all multicellular organisms. A recent offshoot of this work explores the adaptation of multicellular organisms to extreme environments, including the Atacama Desert in South America and the Arctic tundra. Dr. Conley has been involved in several spaceflight experiments using the nematode worm Caenorhabditis elegans, the first of which was flown on the last mission of the Space Shuttle Columbia. Flight hardware was recovered after the tragic accident, and when opened it was seen that the spaceflown experimental animals were still alive, a finding of considerable relevance to Planetary Protection. In 1999, Dr. Conley joined NASA after completing postdoctoral studies at the Scripps Research Institute in La Jolla, CA, where she characterized a family of proteins involved in regulating the actin cytoskeleton that are required for proper muscle contraction. Dr. Conley received a Ph. D. in Plant Biology in 1994 from Cornell University in Ithaca, NY, where her graduate research focused on characterizing functional defects in petunias that are mutant for male sexual reproduction. She earned two B.S. degrees from the Massachusetts Institute of Technology, one in Life Sciences and one in Humanities, involving a major in Russian and French languages and a minor in music performance.

Linda Billings is a research associate with the SETI Institute. She has been conducting science and risk communication studies for NASA’s Planetary Protection Office since September 2002. Dr. Billings obtained a Doctor of Philosophy at the School of Journalism, Indiana University. She earned her B.A. in social sciences from the State University of New York at Binghamton and her M.A. in international transactions from George Mason University. She has worked for more than 25 years in Washington, D.C., as a journalist, freelance writer, and consultant to the government. As a journalist, she covered energy, environment, labor relations, and aerospace, primarily for the trade press.