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Issues in planetary protection: policy, protocol and implementation

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Abstract

Planetary protection is NASA's term for the practice of protecting solar system bodies from Earth life while protecting Earth from life that may be brought back from other solar system bodies. Spacefaring nations will soon begin retrieving samples from Mars and other solar system bodies. For these samples, planetary protection is in order, and measures are already in place to prevent the forward contamination of Mars and other bodies by Earth microbes and the backward contamination of Earth by possible extraterrestrial life. A major goal of planetary protection controls on forward contamination is to preserve the planetary record of natural processes by preventing human-caused microbial introductions.

Keywords: Astrobiology; Planetary protection; Sample return; Solar system exploration; Space science

1. Introduction

Planetary protection is NASA's term for the practice of protecting solar system bodies (planets, moons, asteroids, and comets) from Earth life while protecting Earth from life that may be brought back from other solar system bodies. Earth, we know, harbors life, and now scientists are beginning to learn about locations on or beneath the surface of other planets and moons where Earth life, at least, might thrive. Whether such bodies host indigenous life, and whether such life would be related to Earth life, are matters of critical scientific (and popular) interest.

The US Apollo and Soviet Luna missions of the 1960s and 1970s established a precedent of returning extraterrestrial materials to Earth. This practice is continued today in ongoing comet and asteroid sample-return missions. And in the not too distant future, spacefaring nations will begin retrieving samples from the martian surface and subsurface and bringing them back to Earth for in-depth analysis. For these samples, planetary protection is in order, and measures are already in place to prevent the backward contamination of Earth by possible extraterrestrial life and the forward contamination of Mars and other bodies by Earth microbes.

A major goal of planetary protection controls on forward contamination is to preserve the planetary record of such natural processes by preventing human-caused microbial introductions. Such introductions would be most likely to cause harm on those planetary bodies that are of most interest to astrobiologists, those that show evidence of materials and environments that support life on Earth and thus might also support Earth life transported to those bodies—Mars and Europa, for example, or Saturn's moon Titan.

2. Microbes in space

Planetary protection is presently drawing increasing attention in part because of advances in scientific understanding of the boundary conditions within which Earth life can thrive. Scientists have found that Earth microorganisms are tough, some able to survive in the space environment [1] as well as in extreme Earth environments such as deep-sea hydrothermal vents [2], Antarctic rocks, and regions more than three kilometers beneath the continental surface. Such extreme Earth environments may have analogs on other solar system bodies—Mars, for example. Mars seems to possess all the materials and some of the environments associated with life on Earth. While the surface of Mars is currently cold and dry, planetary scientists believe that conditions on the planet may have been much like those on Earth

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early in solar system history. And Mars subsurface conditions are now, and may always have been, quite different than those on the martian surface [3,4].

If life ever did evolve on Mars, it could have originated independently of life on Earth. Another possibility is that any life on Mars could be related to life on Earth. In addition to the possibility of finding extraterrestrial life, scientists are interested in the possibility of interplanetary transfer of life. Researchers have examined the potential for a natural interplanetary transfer of micro-organisms by the high-velocity ejection of soil and rock resulting from planetary impacts of comets and other small bodies [5–9]. Addressing the potential for transfer of organisms from Mars to Earth, researchers have concluded that, if microbes have ever existed on Mars, their viable transfer to Earth would be not only possible but also highly probable. They have also considered the possibility of viable transfer of Earth life to Mars and estimated that, while the number of ejecta from Earth landing on Mars has been one to two orders of magnitude lower than the number of martian meteorites landing on Earth over the past four billion years, this quantity is nonetheless substantial, totaling about a billion. Further studies of Mars and other worlds may be able to determine what has happened to any traveling Earth microbes and whether any extraterrestrial microbes have ever reached Earth (and, if so, what may have happened to them).

3. NASA and COSPAR policies

Questions of life—the fate of life on Earth and the possibility of life elsewhere—have driven space exploration from its beginnings, and the search for evidence of extraterrestrial life is a primary focus of NASA's current solar system exploration program. Consequently, planetary protection has been a concern from the start of the Space Age [10] and remains important today. In 1958, after the launch of Sputnik, the International Council of Scientific Unions (ICSU) introduced planetary quarantine standards for solar system exploration missions [11,12], and the US National Academy of Sciences recommended non-contaminating space exploration practices in its 1958–1960 studies [13]. By 1967 spacefaring nations had reached agreement to regulate interplanetary contamination, as articulated in Article IX of the United Nations Outer Space Treaty that entered into force on October 10 of that year. The treaty states that exploration of planetary bodies will be conducted "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".

Also in 1958 ICSU formed an interdisciplinary Committee on Space Research (COSPAR), which became, and still is, the focal point of international activities relating to planetary protection. COSPAR and the International Astronautical Federation consult with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) on Space Treaty matters, and COSPAR maintains an international planetary protection policy, most recently updated in October 2002. The COSPAR Panel on Planetary Protection develops and makes recommendations on planetary protection policy.

NASA maintains a planetary protection policy, detailed below, and develops and administers associated procedures to ensure policy compliance [14,15,1]. NASA's Associate Administrator for Space Science is in charge of planetary protection at NASA, and the Planetary Protection Officer in the Office of Space Science oversees the policy and assigns implementation requirements to each mission. In accordance with the NASA policy, requirements are based on the most current scientific information available about target bodies. Solar system exploration missions are categorized according to the type of encounter they will have (e.g., flyby, orbiter or lander) and the nature of their destination. The Planetary Protection Officer may seek recommendations on requirements for a specific body, or class of solar system bodies, from internal and external advisory committees, most notably the Space Studies Board (SSB) of the US National Research Council. Because of the accelerating pace of solar system exploration, including planned sample-return missions, the NASA Advisory Council chartered a Planetary Protection Advisory Committee in 2002 for internal advice to the agency.

3.1. Scientific advice

In recent years the SSB has provided advice to NASA on planetary protection requirements for Mars and Europa exploration missions and also sample return missions to a variety of small solar system bodies such as moons, comets and asteroids [16–22]. The SSB recommended in 1992 [20] that Mars orbiters, landers, and landers carrying instruments for investigation of possible martian life should be required to meet differing levels of cleanliness. The goal is to reduce any potential contamination of Mars by terrestrial microorganisms to a level low enough to keep Earth life from surviving there or being identified by mistake as martian life. The SSB recommended in 2000 that any mission to Jupiter's moon Europa be designed, cleaned, and operated so that it will not exceed a one in ten thousand chance of introducing any viable Earth life to the Europan ocean [18].

The SSB has recently urged NASA to launch its first Mars sample return mission no later than 2011 and proceed immediately with planning and development for a Mars sample handling facility [16]. A 2011 launch date for a sample return mission requires that NASA start work immediately on a Mars sample return facility, a project that will require at least seven years to complete in addition to "the time needed to clear an environmental impact statement" and plan the design and operation of the facility. (It should be noted that NASA is currently considering the option of a Mars sample return mission to be launched no earlier than 2013.) NASA's Jet Propulsion Laboratory is now consulting prospective contractors regarding development of a biosafety-level-4 (BSL-4) sample handling facility that would receive, analyze and distribute martian materials. (BSL-4 is the strictest security requirement established by the US government for facilities dealing with biological agents.)

Research should be initiated now, the SSB reported, on questions that will affect Mars sample handling facility design, such as how to combine biological isolation with clean-room conditions and how to determine the positive and negative effects of sterilization techniques. The SSB also called for the development of more sensitive life detection techniques and "a life detection protocol to be implemented and tested in the Mars Quarantine Facility". The Board noted that NASA needs to develop new techniques "for the collection, packaging, and return of samples". NASA's Office of Space Science is sponsoring research on new life detection techniques and sample processing methods. NASA has also drafted a protocol for Mars sample return, containment and handling (see below).

3.2. *Current requirements*

Ensuring planetary protection requires keeping up with scientific advances, and planetary protection recommendations are intended to be revisited as new information becomes available about the target bodies. Knowledge of environments that may contain life or that could be contaminated by Earth life keeps growing as solar system exploration advances, and characterization of biological contamination keeps improving, especially since the advent of molecular-level methods of analysis. Planetary protection measures are accordingly subject to continual re-evaluation and change, in consultation with the science community, as noted above. Planetary protection requirements for Mars and other missions evolved throughout the 1990s in response to the many remarkable discoveries made in that decade about life in extreme environments on Earth, discoveries that significantly advanced understanding of the boundary conditions for life as we know it.

The golden rule of planetary protection is "keep it clean". During the US Viking missions of the 1970s NASA cleaned its Mars landers until their total surface bioburden was less than 3×10^5 bacterial spores, with an average of fewer than 300 bacterial spores per square meter. After cleaning, each lander was packaged in a fully enclosing "bioshield" (resembling a large casserole dish) and baked in an oven at 111.7°C for 30 h in a dry-heat sterilization procedure. The Viking missions revealed that the surface of Mars was much drier and less benign than expected. While some experiments aboard the Viking landers were designed to detect evidence of biological activity and some lander findings were suggestive of life [23], data collected by the Viking missions led scientists to believe that the martian environment was harsher than previously thought and thus would likely be devoid of life. In 1992 the SSB recommended that NASA ease its Viking-era forward contamination requirements for missions to Mars [20]. NASA consequently altered its planetary protection standards for Mars lander missions, establishing the Viking pre-sterilization surface bioburden standard as the requirement for Mars landers not attempting life detection experiments, and the full Viking standard as the requirement for missions focused on life detection.

For planetary protection purposes today, a spacecraft going to a target body that has the potential to provide clues about life or prebiotic chemical evolution must meet a higher level of cleanliness and some operating restrictions. Spacecraft going to target bodies with the potential to support Earth life must undergo stringent cleaning and sterilization processes. Planetary protection techniques applied to spacecraft bound for Mars, for example, currently include clean manufacturing processes for spacecraft components and the use of clean-room techniques during spacecraft assembly, test and launch operations. Bioloads are reduced by methods such as alcohol wiping, dry heat treatment and hydrogen peroxide sterilization [24]. Radiation treatment is an option for some assemblies, and molecular detection methods such as Limulus amoebocyte lysate assay, polymerase chain reaction and adenosine triphosphate (ATP) measurement may also be employed to characterize bioload.

4. Mission categories

Both NASA and COSPAR planetary protection policies now describe five categories of planetary protection defined by the nature of the mission to be launched and the target body to be studied [25]. No planetary protection procedures are required for Category I missions, which include any missions to the Sun, Mercury and Pluto except for Earth return missions. Category II missions are those for which the target body is of interest to researchers studying organic chemical evolution and the origin of life, but where biological contamination is not thought to be possible; they include any solar system exploration missions except for those to the Sun, Mercury, Pluto (covered in Category I) and Mars, Europa, Ganymede and Callisto (covered in Categories III, IV and V). The first steps in planetary protection for Category II missions are to document spacecraft trajectories, inventory onboard organic materials, and possibly to provide for the archival storage of certain spacecraft materials. For Category III missions, flying by or orbiting planets that could possibly be contaminated by Earth organisms, measures include those for Category II plus other restrictions such as spacecraft operating constraints (for instance, trajectories planned to avoid impact with the planet and minimum orbital lifetime requirements), or limitations on a spacecraft's viable bioburden.

Category IV missions are those intended to make direct contact with Mars. For Category IV Mars missions, all Categories II and III requirements may apply (except for orbital lifetime), and restrictions on biological contamination are generally more severe, possibly including comprehensive decontamination and sterilization of the spacecraft, depending on its precise destination. Missions designated Category V are those that include an Earth return component. These missions may entail all Categories II, III and IV planetary protection restrictions plus severe restrictions on the handling of returned samples until their biological status is determined.

Category V missions may be deemed unrestricted Earth return missions, with no additional planetary protection requirements imposed on the return portion of the mission, or restricted Earth return missions. For unrestricted Earth return missions, science and mission safety requirements should cover any concerns about sample return, landing site targeting and retrieval, and sample condition. For restricted Earth return missions, the primary challenge is to devise a return sample containment system that provides a reliability perhaps as high as 0.999999 percent while meeting mass and cost constraints. It is also important to ensure that contained samples do not inadvertently incorporate other materials from the target body. The cost of meeting stringent Category V requirements on a Mars sample return mission is estimated at about 5–10 percent of the budget for the project. How these requirements will affect overall mission success is also a consideration.

Because the martian atmosphere is a significant factor in the potential for spreading Earth microbes on the planet, the greatest planetary protection challenge for Mars spacecraft is surface cleanliness. Europa, on the other hand, has no atmosphere to speak of and features a brutal radiation environment that could kill any exposed Earth organisms on a spacecraft. However, this radiation may not necessarily reach any organisms buried deep within the radiation shielding of a spacecraft. Thus spacecraft bound for Europa will have to be cleaned from the inside out. Species-specific microbial assays may help to eliminate some of the more radiation-tolerant organisms. Mission designers will have to ensure that a spacecraft's interior is protected from recontamination after clean assembly.

Planetary protection requirements can be met in part through mission and spacecraft design. If a spacecraft is an orbiter and the probability that it will touch the surface of its target body is small, cleanliness requirements are reduced. At the end of a mission, a spacecraft may be placed into a long-term orbit so that radiation and other elements of the local space environment can eliminate any Earth organisms that might be on board. For spacecraft such as landers, a higher level of cleanliness generally is required. Such spacecraft can be designed so that only some parts are exposed to the surface of a planet. In such cases, only exposed spacecraft parts have to meet the most stringent cleanliness requirements.

Cultivation-based microbial assays [15] are still NASA's standard method of measuring spacecraft bioburden, in part because of lack of comparability with the more recent molecular methods and also because of personnel training requirements associated with molecular methods. These newer molecular methods have not yet been certified for use. They are attractive, however, because a bioload measurement that could take three days to complete with a cultivation assay may be made in less than 1 h using a molecular method. In an operational first, NASA supplemented its standard cultivation-based assays with a Limulus amoebocyte lysate assay (a test using a sensitive component of horsehoe-crab blood to detect contamination) in the course of preparing its two Mars Exploration Rovers for launch in 2003.

5. Future considerations

NASA has more than a dozen solar system exploration missions in development or already under way for which planetary protection is a consideration. The most pressing needs in planetary protection are currently to ensure that relevant missions are in full compliance with policies and requirements and to keep these policies and plans up to date, in line with scientific findings. Other spacefaring nations are launching their own solar system exploration missions, and the number of nations engaging in solar system exploration is rising. The NASA and COSPAR planetary protection policies stand as models for other nations that may be considering establishing their own planetary protection policies.

An issue that has recently surfaced in planetary protection is the possibility that Earth organisms may have already contaminated Mars. Some scientists have raised this issue given that three Soviet spacecraft (Mars 2, Mars 3, Mars 6) and two NASA spacecraft (Mars Climate Orbiter and Mars Polar Lander) have already crashed on the planet. One proposal put forth to address the possibility of any contamination that might be caused by these crashes is remediation. It has been suggested that, if life is ever detected on Mars, NASA should be prepared to reverse its Mars exploration campaign and remove all the space hardware it has left on the surface of Mars, with the aim of reducing the risk that any dormant bacteria surviving on these spacecraft might be transported to more hospitable subsurface environments.

While a primary focus of NASA's solar system exploration activities is the search for evidence of life on Mars, the agency's current approach to planetary protection is "all of the planets, all of the time". NASA's planetary protection policy goals are to ensure that all its solar system exploration missions establish appropriate precautions against forward and backward contamination, that the agency's planetary protection procedures and requirements are in tune with the latest relevant scientific findings, that advanced technologies continue to be developed and applied to meet evolving planetary protection requirements, and that the agency continues to coordinate with other national and international agencies on planetary protection issues and implementation.

In addition to science and technology, communication plays a key role in the implementation of NASA's planetary protection policy. The agency has studied a range of legal and ethical issues relating to planetary protection and is taking steps to ensure that communications about any possible contamination risks associated with solar system exploration are timely and thorough. In 2003, NASA's Planetary Protection Office initiated a course on planetary protection policies and practices for those involved in planetary protection activities to ensure that all are up to date on the latest scientific, technical, and policy developments. The agency's communications with the international scientific community about planetary protection have been, and will continue to be, extensive and wide-ranging, and communications with other public audiences will continue to expand.

One development in 2003 that focused attention on the need for planetary protection was the end of NASA's Galileo mission to Jupiter. Planetary protection concerns mandated that Galileo mission managers revise plans for the end of the mission to ensure that the spacecraft would burn up in the atmosphere of Jupiter. This change in plans was intended to prevent the spacecraft from inadvertently crashing onto the surface of Callisto, Europa, or Ganymede, Jovian moons where the Galileo spacecraft itself detected signs of possible liquid water oceans beneath their frozen surfaces. Media coverage of the end of the Galileo mission generally acknowledged the planetary protection element of this event. The landing of NASA's two Mars Exploration Rovers in January 2004 will again draw attention to planetary protection requirements for missions exploring extraterrestrial environments that might possibly support life.

Another planetary protection issue that is receiving increased attention is requirements for Mars sample return. With Mars mission planning tentatively calling for sample return missions starting in the second decade of this century, NASA, with participation and support from the Centre National d'Etudes Spatiales (CNES), has developed criteria for Mars sample handling before release from post-flight containment. These criteria are described in "A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth" [26], specifying tests and procedures needed to safeguard samples against contamination. Among the assumptions underlying this protocol are that samples will not be sterilized before return to Earth, sample containers will be opened only in designated receiving facilities, and only small amounts of sample material (500–1000 g) will be returned. Of that material, the amount of sample material used to determine whether any biohazard is present will be the minimum necessary. This sample return protocol will remain in draft form and subject to updating until shortly before the first martian samples are returned to Earth.

Questions of life and needs for planetary protection will continue to limit the acceptable range of missions into the solar system. As knowledge of the solar system grows, implementation of planetary protection policies and practices will grow more precise, guided by knowledge of the potential for Earth contamination, and the ability to measure and control it, as well as by the continuing quest to discover extraterrestrial life. COSPAR will continue to oversee global planetary protection knowledge, policy and plans for preventing the harmful contamination of solar system bodies, including Earth, and to provide an international forum for exchanging information. Meanwhile, NASA will work towards maintaining a long and fruitful tradition of global cooperation in planetary protection by working closely with COSPAR and other national space agencies as the exploration of our solar system moves forward.

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References

[1] Nicholson WL, Munakata NHG, Melosh HJ, Sellow P. Resistance of Bacillus endospores to extreme terrestrial and extraterrestrial environments. Microb Mol Biol Rev 2000;64: 548–72.

[2] Corliss JB, Ballard RD. Oases of life in the cold abyss. National Geographic 1977;152:441–53.

[3] McKay DS, Gibson Jr EK, Thomas-Keprta KL, Vali H, Romanek CS, Clemettt SJ, Chillier XDF, Maechling CR, Zare RN. Search for past life on Mars: possible relic biogenic activity in martian meteorite ALH84001. Science 1996;273:924–30.

[4] Mitrofanov IG, Zuber MT, Litvak ML, Boynton WV, Smith DE, Drake D, Hamara D, Kozyrev AS, Sanin AB, Shinohara C, Saunders RS, Tretyakov V. CO_2 snow depth and subsurface water–ice abundance in the northern hemisphere of Mars. Science 2003;300:2081–4.

[5] Gladman B, Burns JA. Martian meteorite transfer: simulation. Science 1996;272:161–2.

[6] Gladman BJ, Burns JA, Duncan M, Lee P, Levison HF. The exchange of impact ejecta between terrestrial planets. Science 1996;271:1387–92.

[7] Melosh HJ. Impact ejection, spallation and the origin of meteorites. Icarus 1984;59:234–60.

[8] Melosh HJ. Ejection of rock fragments from planetary bodies. Geology 1985;13:144–8.

[9] Mileikowsky C, Cucinotta F, Wilson JW, Gladman B, Horneck G, Lindgren L, Melosh J, Rickman H, Valtonen M, Zheng JQ. Natural transfer of viable microbes in space, Part 1: from Mars to Earth and Earth to Mars. Icarus 2000;145:391–427.

[10] DeVincenzi DL, Stabekis PD, Barengoltz JB. A proposed new policy for planetary protection Adv Space Res 1983;3(8):13–21.

[11] CETEX. Development of international efforts to avoid contamination by extraterrestrial exploration. Science 1958;128:887–89.

[12] CETEX. Contamination by extraterrestrial exploration. Nature 1959;183:925–8.

[13] Derbyshire GA. Resume of some earlier extraterrestrial contamination activities, in A Review of Space Research, Washington, DC: National Academy of Sciences; 1962, p. 11 (Chapter 10).

[14] NASA. Planetary protection provisions for orbotic extraterrestrial missions. NASA Procedures and Guidelines (NPG) 8020.12B. Washington, DC: NASA Headquarters; 1999.

[15] NASA. NASA standard procedures for the microbial examination of space hardware. NASA Procedures and Guidelines (NPG) 5340.1C. Washington, DC: NASSA Headquarters; 1999.

[16] National Research Council, Space Studies Board, Committee on Lunar and Planetary Exploration. Assessment of Mars Science and Mission Priorities. Washington, DC: National Academies Press; 2003.

[17] National Research Council, Space Studies Board. Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision-making. Washington, DC: National Academies Press; 1998. http://www.nap.edu/books/0309061369/html/index.html.

[18] National Research Council, Space Studies Board. Preventing the Forward Contamination of Europa. Washington, DC: National Academies Press; 2000. http://www.nap.edu/books/N1000231/html.

[19] National Research Council, Space Studies Board. The Quarantine and Certification of Martian Samples. Washington, DC: National Academies Press; 2002. http://www.nap.edu/books/0309075718/html/index.html.

[20] National Research Council, Space Studies Board, Task Group on Planetary Protection. Biological Contamination of Mars: Issues and Recommendations. Washington, DC: National Academies Press; 1992.

[21] National Research Council, Space Studies Board. Mars Sample Return: Issues and Recommendations. Washington, DC: National Academies Press; 1997. http://www.nap.edu/books/0309057337/html/index.html.

[22] National Research Council, Space Studies Board, Solar System Exploration Survey Committee. New Frontiers in the Solar System: An Integrated Exploration Strategy. Washington, DC: National Academies Press; 2002.

[23] Levin GV, Straat PA. J Mol Evol 1979;14:167.

[24] Debus A, Runavot J, Rogoski G, Bogomolov V, Khamidullina N, Darbord JC, Plombin BJ, Trofimov V, Ivanov M. Mars 96 small station biological decontamination. Adv Space Res 1998; 22:401–9.

[25] NASA. Biological contamination control for outbound, inbound planetary spacecraft. NASA Policy Directive (NPD) 8020.7E. Washington, DC: NASA Headquarters; 1999.

[26] NASA. A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth (NASA/CP-2002-211842). Hanover, MD: NASA Center for AeroSpace Information. 2002. http://a257.g.akamaitech.net/7/257/2422/14mar20010800/e-docket.access.gpo.gov/2003/03-19287.html.