Free Executive Summary

Preventing the Forward Contamination of Mars

Committee on Preventing the Forward Contamination of Mars, National Research Council

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Recent spacecraft and robotic probes to Mars have yielded data that are changing our understanding significantly about the possibility of existing or past life on that planet. Coupled with advances in biology and life-detection techniques, these developments place increasing importance on the need to protect Mars from contamination by Earth-borne organisms. To help with this effort, NASA requested that the NRC examine existing planetary protection measures for Mars and recommend changes and further research to improve such measures. This report discusses policies, requirements, and techniques to protect Mars from organisms originating on Earth that could interfere with scientific investigations. It provides recommendations on cleanliness and biological burden levels of Mars-bound spacecraft, methods to reach those levels, and research to reduce uncertainties in preventing forward contamination of Mars.

Executive Summary

The National Aeronautics and Space Administration's (NASA's) goals for space exploration over the coming decades place a strong priority on the search for life in the universe,[1] and the agency has set in place ambitious plans to investigate environments relevant to possible past or even present life on Mars. Over the next decade NASA plans to send spacecraft to search for evidence of habitats that may have supported extinct life or could support extant life on Mars; Europe will also send robotic explorers. These future missions, in addition to the ongoing suite,[2] will continue to deliver scientific data about the planet and reduce uncertainties about the prospects for past or present life on Mars. To ensure that scientific investigations to detect life will not be jeopardized, scientists have pressed, as early as the dawn of the space age, for measures to protect celestial bodies from contamination by Earth organisms that could hitchhike on a spacecraft, survive the trip, and grow and multiply on the target world.[3]

Preventing the forward contamination of Mars is the subject of this report, which addresses a body of policies, requirements, and techniques designed to protect Mars from Earth-originating organisms that could interfere with and compromise scientific investigations. The report does not assess forward contamination with respect to potential human missions to Mars, nor does it explore issues pertaining to samples collected on Mars and returned to Earth, so-called back contamination.[4] Those two dimensions of planetary protection, although extremely important, are beyond the scope of the charge to the Committee on Preventing the Forward Contamination of Mars. The recommendations made in this report do apply to one-way robotic missions that may serve as precursors to human missions to Mars. Included are recommendations regarding levels of cleanliness and biological burden on space-

[1]In its 2003 strategic plan, NASA cites as one of its goals "to explore the universe and search for life" (NASA, 2003). The Mars science community's Mars Exploration Program Analysis Group (MEPAG), in its 2004 report on scientific goals, objectives, investigations, and priorities for Mars exploration (MEPAG, 2004), and NASA's Mars Science Program Synthesis Group (MSPSG), in its published *Mars Exploration Strategy* (MSPSG, 2004), both identify the search for present and past life on Mars as one of four overarching goals of Mars exploration.

[2]NASA's current suite includes the Mars Exploration Rovers, Spirit and Opportunity, and the orbiters Mars Odyssey and Mars Global Surveyor; the European Space Agency's Mars Express is also in orbit.

[3]Letter from Joshua Lederberg, University of Wisconsin, to Detlev Bronk, President, National Academy of Sciences, December 24, 1957, with enclosed memorandum entitled "Lunar Biology?", National Academy of Sciences, Records Office, Washington, D.C.

[4]Back contamination, another aspect of planetary protection, involves the potential for contamination of Earth by any putative martian biota that might be returned to Earth on sample return missions.

craft destined for Mars, the methods employed to achieve those levels, and the scientific investigations needed to reduce uncertainty in preventing the forward contamination of Mars. In addition, this report urges dialogue at the earliest opportunity on broader questions about the role of planetary protection policies in safeguarding the planet Mars and an indigenous biosphere, should one exist.

In the United States, NASA has responsibility for implementing planetary protection policies that are developed in the international scientific community and, specifically, within the Committee on Space Research (COSPAR), a multidisciplinary committee of the International Council for Science (ICSU; formerly the International Council of Scientific Unions). COSPAR policies on planetary protection have evolved over time as scientists have acquired new information about Mars and other planets and about the potential for life to survive there. NASA has requested this National Research Council (NRC) study, and previous studies on the same topic from the NRC's Space Studies Board (SSB), to inform U.S. planetary protection practices; in turn, the NRC studies have provided input to the official COSPAR policies on planetary protection.

The committee evaluated current science about Mars, the ability of organisms to survive at the extremes of conditions on Earth, new technologies and techniques to detect life, methods to decontaminate and sterilize spacecraft, and the history and prior bases of planetary protection policy, as well as other relevant scientific, technical, and policy factors. It found that (1) many of the existing policies and practices for preventing the forward contamination of Mars are outdated in light of new scientific evidence about Mars and current research on the ability of microorganisms to survive in severe conditions on Earth; (2) a host of research and development efforts are needed to update planetary protection requirements so as to reduce the uncertainties in preventing the forward contamination of Mars; (3) updating planetary protection practices will require additional budgetary, management, and infrastructure support; and (4) updating planetary protection practices will require a roadmap, including a transition plan with interim requirements, and a schedule. In addition, the committee found that scientific data from ongoing Mars missions may point toward the possibility that Mars could have locales that would permit the growth of microbes brought from Earth, or that could even harbor extant life (although this remains unknown),[5] and that these intriguing scientific results raise potentially important questions about protecting the planet Mars itself, in addition to protecting the scientific investigations that might be performed there.

Taken together, the committee's recommendations constitute a roadmap for 21st-century planetary protection that emphasizes research and development; interim requirements; management and infrastructure for the transition to a new approach; and a systematic plan, process, and time line.

This executive summary presents a subset of the committee's recommendations. All of the committee's recommendations are included and discussed in Chapter 8.

RESEARCH AND DEVELOPMENT FOR 21st-CENTURY PLANETARY PROTECTION

For the most part, the bulk of NASA research and development on techniques to prevent the forward contamination of Mars was conducted during the Viking era, when the agency was preparing to send two landers to Mars that would include life-detection experiments.[6] Since the Viking program, continuing though comparatively little research has been done on planetary protection techniques, owing to the 20-year hiatus in Mars lander missions (Viking in 1976, Mars Pathfinder in 1996), the post-Viking perspective that Mars was a dry and barren place, and the expense and effort required to research, develop, and implement new requirements to prevent the forward contamination of Mars.[7]

[5] See Chapters 4 and 5 and references therein.

[6] During the early 1970s, NASA undertook extensive research and development to better understand how to detect contamination on spacecraft and sterilize the spacecraft, and how methods used for those purposes would affect the spacecraft materials. The Viking mission was designed specifically with planetary protection in mind, which has not been the case for subsequent missions. See Bionetics Corporation (1990).

[7] See, for example, Dickinson et al. (2004a,b), Venkateswaren et al. (2001, 2003), Baker (2001), Baker and Rummel (2005), and Kminek and Rummel (2005).

The techniques currently available to detect contamination of spacecraft by microbes to some extent reflect the technologies that might be used to detect life on solar system bodies such as Mars. Life-detection techniques have advanced considerably, in part because of burgeoning biotechnology sciences and industries, allowing researchers the opportunity to employ molecular methods to identify the kinds and numbers of organisms that might be found in a spacecraft assembly area or on a spacecraft destined for Mars.

Knowledge about the diversity of organisms in clean rooms where spacecraft are assembled or on the spacecraft themselves has several important implications for planetary protection. At present, however, the standard assay method used for detecting microbes on spacecraft—a method that relies on detecting the presence of heat-resistant, spore-forming bacteria, which serve as a proxy for bioburden on the spacecraft—does not provide information about other organisms that might be present on spacecraft. Such organisms include the extremophiles—terrestrial organisms that survive and grow under severe conditions on Earth such as extremes of temperatures (hot and cold) and salinity, low availability of water, high levels of radiation, and other conditions previously considered hostile to life. Based on current understanding of Mars, it is thought that such organisms, especially the cold-loving ones (psychrophiles and psychrotrophs), are among those that might have the best chance of surviving and replicating in martian near-surface environments, as discussed in Chapter 5. Knowing specifically about the organisms present in assembly, test, and launch operations environments that might have the potential to survive a trip to, and possibly grow on, Mars would allow engineers to tailor methods to decontaminate a spacecraft and its instruments more effectively prior to launch than is now done. Other organisms with known intolerances for conditions much less severe than the harshness of interplanetary travel would be of less concern for preventing forward contamination, although efforts to clean[8] spacecraft would still be important for many missions.

A more tailored approach to bioburden reduction could also reduce the costs of implementing planetary protection as compared with the costs of existing approaches such as heat sterilization, which subjects a spacecraft, or specific parts of a spacecraft, to high temperatures over several hours in order to reduce the bioburden to the levels required by NASA for life-detection missions. Furthermore, heat sterilization, which was researched for and applied on the Viking mission in 1976, has not been tested for its effectiveness in eliminating extremophiles or other organisms now known to tolerate high heat. The committee therefore concluded that, ultimately, preventing the forward contamination of Mars requires an understanding of the kinds of organisms that could be present on spacecraft and sterilization or decontamination measures tailored to eliminate those organisms of concern.

To that end, the committee recommends a suite of research and development measures to enable updating of planetary protection practices to reflect the latest science and technology.

- **NASA should require the routine collection of phylogenetic data to a statistically appropriate level to ensure that the diversity of microbes in assembly, test, and launch operations (ATLO) environments, and in and on all NASA spacecraft to be sent to Mars, is reliably assessed. NASA should also require the systematic archiving of environmental samples taken from ATLO environments and from all spacecraft to be sent to Mars. (Recommendation 5, Chapter 8)**
- **NASA should sponsor research on those classes of microorganisms most likely to grow in potential martian environments. Given current knowledge of the Mars environment, it is most urgent to conduct research on psychrophiles and psychrotrophs, including their nutritional and growth characteristics, their susceptibility to freeze-thaw cycles, and their ability to replicate as a function of temperature, salt concentration, and other environmental factors relevant to potential spaceflight and to martian conditions. (Recommendation 6, Chapter 8)**
- **NASA should ensure that research is conducted and appropriate models developed to determine the embedded bioburden (the bioburden buried inside nonmetallic spacecraft material) in contemporary and future spacecraft materials. Requirements for assigned values of embedded bioburden should be updated as the results of such research become available. (Recommendation 7, Chapter 8)**

[8] "Cleaning" refers to reducing any nonliving contaminants of concern as well as living contaminants. Decontamination, bioburden reduction, and sterilization refer to standard methods that have proven to reduce the presence of bacterial spores to quantifiable levels. (See Chapter 2 for details.)

- **NASA should sponsor studies of bioburden reduction techniques that are alternatives to dry-heat sterilization. These studies should assess the compatibility of these methods with modern spacecraft materials and the potential that such techniques could leave organic residue on the spacecraft. Studies of bioburden reduction methods should also use naturally occurring microorganisms associated with spacecraft and spacecraft assembly areas in tests of the methods. (Recommendation 8, Chapter 8)**
- **NASA should sponsor research on nonliving contaminants of spacecraft, including the possible role of propellants for future Mars missions (and the potential for contamination by propellant that could result from a spacecraft crash), and their potential to confound scientific investigations or the interpretation of scientific measurements, especially those that involve the search for life. These research efforts should also consider how propulsion systems for future missions could be designed to minimize such contamination. (Recommendation 9, Chapter 8)**
- **NASA should take the following steps to transition toward a new approach to assessing the bioburden on spacecraft:**
  —Transition from the use of spore counts to the use of molecular assay methods that provide rapid estimates of total bioburden (e.g., via limulus amebocyte lysate (LAL) analysis) and estimates of viable bioburden (e.g., via adenosine triphosphate (ATP) analysis). These determinations should be combined with the use of phylogenetic techniques to obtain estimates of the number of microbes present with physiologies that might permit them to grow in martian environments.
  —Develop a standard certification process to transition the new bioassay and bioburden assessment and reduction techniques to standard methods.
  —Complete the transition and fully employ molecular assay methods for missions to be launched in 2016 and beyond. (Recommendation 11, Chapter 8)

INTERIM REQUIREMENTS FOR USE UNTIL R&D EFFORTS ARE COMPLETE

Until the above-recommended R&D activities have been completed, the committee believes that the existing framework for planetary protection methods should be updated to reflect recent science regarding environments on Mars and knowledge about extremophiles. There is too much new information about the planet and new science about microorganisms not to update the existing framework of planetary protection requirements while research efforts are being conducted.

The most critical issue regarding Mars science and the potential forward contamination of Mars concerns so-called special regions. A "special region" is defined by COSPAR planetary protection policy as being "a region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high potential for the existence of extant martian life forms" (COSPAR, 2003, p. 71). Under existing COSPAR policy, missions to Mars are categorized as IVa (those without life-detection instruments), IVb (those with life-detection instruments),[9] or IVc (those going to special regions, regardless of instrumentation), and COSPAR policy sets levels of bioburden reduction differently for missions categorized as IVa, IVb, or IVc. Missions categorized as IVa are allowed higher levels of bioburden than missions that will carry life-detection instruments (IVb) or missions going to special regions (IVc).

The committee found, as discussed in Chapter 4, that there is at this time insufficient data to distinguish confidently between "special regions" and regions that are not special. Scientific results from the Mars Exploration Rovers and Orbiter missions have provided evidence for the existence of past water on Mars and suggest that it is substantially more likely that transient liquid water may exist near the surface at many locations on Mars. It is very difficult on the basis of current knowledge to declare with confidence that any particular regions are free of this possibility. Additional information is needed to identify the presence of liquid water, and collection of such data should continue to be a high priority.

[9]The previous NRC report on forward contamination, *Biological Contamination of Mars: Issues and Recommendations* (NRC, 1992), recommended the categories of Mars missions with life-detection instruments and those without life-detection instruments. A third category, special regions, was added to the COSPAR classification scheme in 2002.

• **NASA's Mars Exploration Office should assign high priority to defining and obtaining measurements needed to distinguish among special and nonspecial regions on Mars. (Recommendation 10, Chapter 8)**

The committee developed a new set of categorizations for Mars missions, IVs (missions to special regions) and IVn (missions not going to special regions). In the absence of sufficient data to distinguish IVs from IVn, the committee recommends that all landed missions to Mars be treated as IVs until additional data indicate or allow otherwise.

• **For the interim period until updated planetary protection methods and techniques can be fully implemented,**

—NASA should replace Categories IVa through IVc for Mars exploration with two categories, IVn and IVs. Category IVs applies to missions that are landing or crashing in, or traversing, excavating, or drilling into, special regions; Category IVn applies to all other Category IV missions.

—Each mission project should (in addition to meeting the requirements imposed by Categories IVn and IVs) ensure that its cleanliness with respect to bioburden and nonliving contaminants of concern is sufficient to avoid compromising its experiments, in consultation with NASA's planetary protection officer. (Recommendation 12, Chapter 8)

• **Until measurements are made that permit distinguishing confidently between regions that are special on Mars and those that are not, NASA should treat all direct-contact missions (i.e., all Category IV missions) as Category IVs missions. (Recommendation 13, Chapter 8)**

In addition to the issue of special regions, the committee analyzed several other issues pertinent to Category IV missions, including the kinetics of the growth of microorganisms that could potentially reproduce on Mars, the possibility of long-lived water, the probability of a mission crash, and the potential for radioisotope thermal generators (RTGs) to create liquid water. Based on this analysis, the committee devised five levels of bioburden reduction for application to Mars missions (see Table 8.1, Chapter 8).

• **NASA should ensure that all category IVs missions to Mars satisfy at least level 2 bioburden reduction requirements.[10] For each Category IVs mission, NASA's planetary protection officer should appoint an independent, external committee with appropriate engineering, martian geological, and biological expertise to recommend to NASA's planetary protection officer whether a higher level of bioburden reduction is required. This analysis should be completed by the end of Phase A (performance of the concept study) for each mission. (Recommendation 14, Chapter 8)**

[10]In Chapter 8, the committee defines level 2 as corresponding to the Viking-level pre-sterilization required for the bulk spacecraft plus Viking post-sterilization for all exposed surfaces; the latter is to be understood as an areal (surface density) measurement. Explicitly, Viking post-sterilization levels correspond to a reduction of 1×10^{-4} times the Viking pre-sterilization upper limit of 300 spores per square meter. Level 2 requirements (see Table 8.1) are not identical to those previously applied to Category IVs missions (Table 2.2), as is readily seen by comparing Tables 8.1 and 2.1. The committee also draws a distinction between mission categorization (based on mission destination) and bioburden reduction levels; e.g., Category IVs missions will typically be level 2 missions, but under some circumstances a decision could be made to require level 3 or higher for a particular Category IVs mission.

Note added in proof—The following text changes were approved and made after release of the prepublication copy of this report: (1) The phrase "in consultation with NASA's planetary protection officer" was added to Recommendation 12. (2) In Recommendation 14, the word "determine" was replaced by the phrase "recommend to NASA's planetary protection officer." (3) Two new sentences ("Level 2 requirements . . . for a particular Category IVs mission") were added to footnote 10.

MANAGING THE TRANSITION TO NEW PLANETARY PROTECTION POLICIES AND PRACTICES

Transitioning NASA's planetary protection practices to reflect current scientific understanding of Mars and advances in microbiology and to benefit from advanced technologies will require investments in a series of research and development efforts and assessments of new technologies that can be applied to the implementation of planetary protection policies. A successful transition will also depend on an infrastructure for managing these research efforts and on coordination with the engineering, spacecraft/instrument development, and science communities at NASA headquarters, NASA centers, industry, universities, research laboratories, and with the international community, especially COSPAR.

The committee recognizes that the research activities it recommends have cost implications. But it points out that the search for past and present life is cited as the second of NASA's 18 strategic objectives (NASA, 2005), and the attention to identifying potential habitats for life on Mars is reflected in the ambitious series of missions comprised by the Mars Exploration Program. Additional resources for updating planetary protection practices are critical for ensuring the integrity of these important scientific investigations. Such an investment could also introduce innovation into the planetary protection process, such as advanced technologies and methods that could potentially lead to faster and more effective practices for assessing and reducing the bioburden on Mars-bound spacecraft.

- **NASA should establish and budget adequately for, on an ongoing basis, a coordinated research initiative, management capability, and infrastructure to research, develop, and implement improved planetary protection procedures. The research initiative should include a training component to encourage the growth of national expertise relevant to planetary protection. (Recommendation 2, Chapter 8)**

In addition, recognizing the rapid advances in scientific understanding being gained from existing Mars missions and anticipated as a result of future missions, advances in life-detection technologies, and growth in research on and understanding of extremophiles, the committee concluded that NASA's planetary protection practices should be revisited on a 3-year basis to allow regular updates, as necessary.

- **NASA should establish an independent review panel that meets every 3 years to (1) consider the latest scientific information about Mars, as well as about Earth microorganisms, and recommend to NASA appropriate modifications to NASA's planetary protection implementation requirements as needed in light of new knowledge; and (2) identify and define the highest-priority measurements needed at Mars to inform future assessments and possible modifications of planetary protection requirements. (Recommendation 4, Chapter 8)**

The first meeting of the review panel should be held in 2008, and meetings should occur every 3 years thereafter, unless major changes in understanding of Mars or other factors related to planetary protection require meetings on an urgent basis.

RECONSIDERING PLANETARY PROTECTION: PROTECTING THE SCIENCE AND PROTECTING THE PLANET

Historically, planetary protection policy has addressed the concern that the forward contamination of planetary environments by terrestrial organisms could compromise current or subsequent spacecraft investigations sent to search for indigenous life. As a result, current practice imposes the strictest standards of cleanliness on those spacecraft that will conduct life-detection experiments, whereas spacecraft that will not search for life are required to meet less stringent standards. Nevertheless, current practice recognizes that missions intended to access "special regions" on Mars must comply with stricter standards, regardless of whether they carry life-detection instruments.

As discussed in Chapter 4, recent discoveries suggest that there may be numerous (and potentially difficult to detect) environments on Mars where the potential for terrestrial organisms to grow is substantially higher than previously thought. For that reason, the committee recommends increased requirements for bioburden reduction until the results of new research and development make it possible to reduce the uncertainty in preventing the forward contamination of Mars. There remains the potential that lower standards of bioburden reduction permitted for spacecraft that do not include life-detection experiments may permit the introduction of terrestrial organisms into sensitive environments where they may reproduce over long time scales—posing a potential long-term threat to any indigenous biosphere that may exist.

Although ethical issues concerning the introduction of terrestrial organisms into sensitive extraterrestrial environments fall outside the mandate of the current committee, the committee believes that they should be given consideration at the earliest opportunity. The need for urgency in this deliberation is underscored by the current uncertainty regarding the extent and distribution of sensitive martian environments, the failure rate and cleanliness levels of past Mars landers, and the projected rapid pace of future spacecraft investigations. For these reasons, the committee recommends that NASA and its international partners address this issue as expeditiously as possible.

- **In light of new knowledge about Mars and the diversity and survivability of terrestrial microorganisms in extreme environments, NASA should work with COSPAR and other appropriate organizations to convene, at the earliest opportunity, an international workshop to consider whether planetary protection policies for Mars should be extended beyond protecting the science to include protecting the planet. This workshop should focus explicitly on (1) ethical implications and the responsibility to explore Mars in a manner that minimizes the harmful impacts of those activities on potential indigenous biospheres (whether suspected or known to be extant), (2) whether revisions to current planetary protection policies are necessary to address this concern, and (3) how to involve the public in such a dialogue about the ethical aspects of planetary protection. (Recommendation 1, Chapter 8)**

PLANETARY PROTECTION IN THE 21st CENTURY: A ROADMAP

The committee urges that its recommendations be considered as a roadmap; the recommendations build on each other to outline a modern planetary protection regime. (See Figure ES.1.) The committee also encourages NASA to implement these recommendations according to a transition plan and time line, as illustrated in Figure ES.2.

TRANSITION PLAN, PROCESS, AND TIME LINE

Given the rapid advancement in in situ science instrument capabilities and the possibility of contamination in a Mars environment potentially more water-rich than previously believed, it is important to review and adjust Mars forward contamination requirements and procedures as expeditiously as possible.[11] That said, the earliest chance to alter planetary protection procedures for Mars and begin to demonstrate, verify, and validate new methods from the ground up would likely be on the next new (not yet in development) flight project, i.e., the 2011 Mars Scout mission. The next program-directed mission, possibly a Mars Sample Return mission to be flown in 2013, will probably also begin its development at the same time as the 2011 Mars Scout mission, because it is expected to be a more complex mission and to require more development time before launch. Hence, there will be an opportunity during Fiscal Year 2008, when development of both the 2011 and the 2013 Mars missions is expected to start, to begin to test and demonstrate the effectiveness of new bioburden reduction requirements and procedures. Implementation of a new, completely validated planetary protection protocol that employs advanced bioassay and bioburden reduction methods would more realistically be accomplished on a mission developed for launch early in 2016. Such a transition would have to be initiated no later than the beginning of Fiscal Year 2012.

A set of four objectives for development of a new planetary protection plan and a schedule based on these

[11]A FY 2006 start date for the committee's recommended time line could depend on NASA's ability to access or reprogram resources to devote to research efforts.

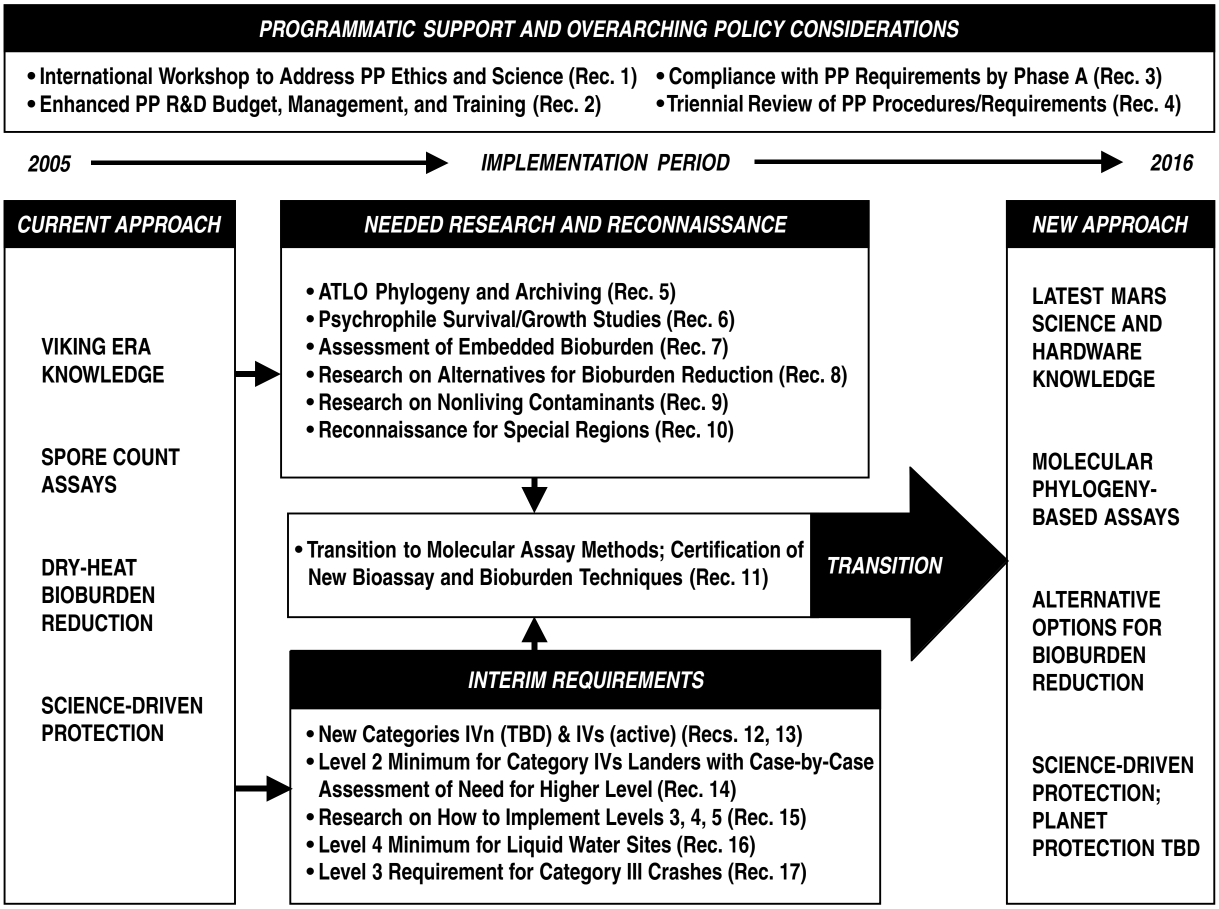
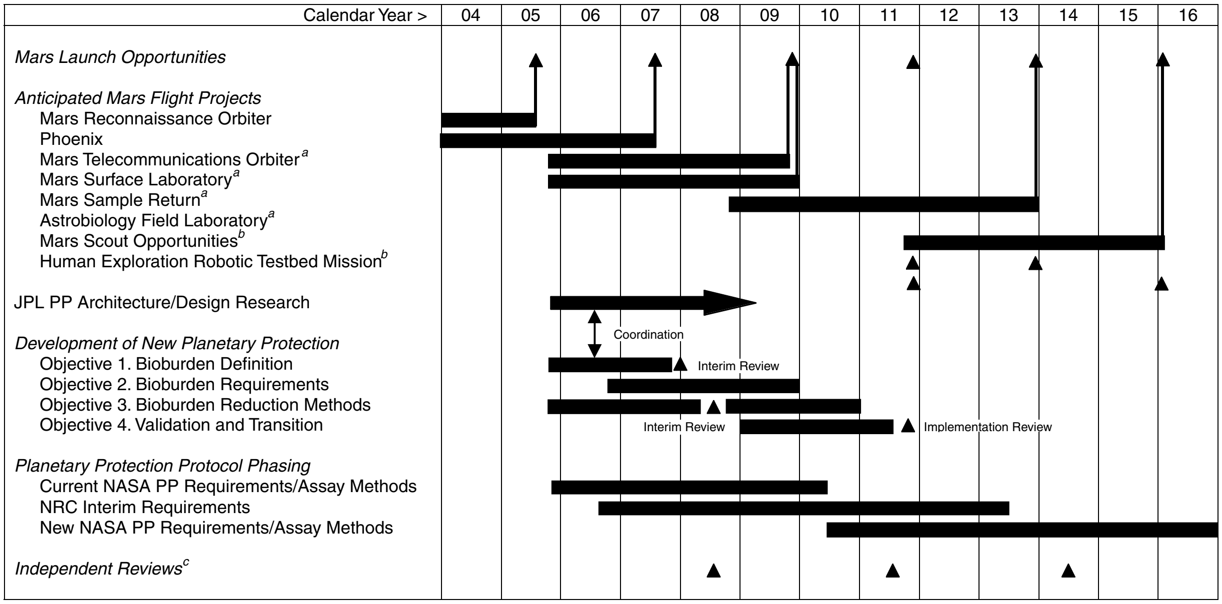


FIGURE ES.1 The proposed framework for moving from the current approach to the new approach to planetary protection (PP), along with the programmatic support and overarching policy considerations required to make the transition.

considerations, along with the development periods for all current and planned missions through the 2016 launch, is depicted in Figure ES.2. The four objectives are as follows:

- *Objective 1: Assessment of spacecraft contaminants.* The first step is to determine what microbes present in the construction, testing, and launch of Mars missions actually constitute potential threats either to Mars science or for contamination of the planet Mars itself. Assaying to know exactly what constitutes the bioburden within spacecraft development, assembly, and test facilities should be followed by determining what fraction of this bioburden could actually threaten to contaminate the Mars environment or confound planned life-detection measurements.
- *Objective 2: Definition and development of revised requirements for reduction of bioburden.* Review and revision of existing standards for reduction of bioburden (specifications), in terms of both parameters and limits, would follow from the ability to expressly target those microbial populations of greatest concern as potential contaminants (objective 1).
- *Objective 3: Improvement of bioburden reduction techniques.* Alternative bioburden reduction techniques could offer more effective and/or less stressful means of reducing or eliminating species-specific bioburdens. Knowing where and what bioburden must be reduced is necessary to determining when and how bioburden reduction can be accomplished and maintained throughout the mission development process.



[a]Flight projects in concept definition stage subject to changes in definition and launch date.
[b]Mars program elements with repetitive flight projects (opportunities shown are placeholders).
[c]Triennial reviews of Mars knowledge base, program plans, and planetary protection requirements (recommendation 4).

FIGURE ES.2 Proposed schedule for the revision of Mars planetary protection requirements.

- *Objective 4: Validation of and transition to new standards and techniques.* Changes in planetary protection practices enabled by meeting objectives 1 through 3 and proposed in response to the committee's recommendations must be validated. Hence new practices should be demonstrated and tested during a validation period in which existing bioburden reduction requirements continue to apply. Once validated and certified, new practices can then be applied with the confidence that they will provide the benefits expected, and old approaches can be phased out.

A complete transition to applying modern methods (without concurrent application of existing bioassay and bioburden reduction techniques) would most realistically be accomplished on a mission developed for launch early in 2016. Such a transition would have to be initiated no later than the beginning of Fiscal Year 2012. Assuming that a detailed research plan embracing the objectives outlined above is developed, reviewed, and funded within the next few years, NASA could accomplish the first three objectives outlined above within the next 6 years, as suggested in the proposed timeframe shown in Figure ES.2. Addressing the four objectives in the committee's recommended approach to updating planetary protection is an effort that clearly should be coordinated with a planned research effort at the Jet Propulsion Laboratory (JPL) (shown in Figure ES.2 as the JPL Planetary Protection Architecture/Design Research component) that shares several of the objectives of the approach outlined here. At NASA's discretion, this JPL work could even be integrated with the approach and schedule suggested here.

Because the results of each objective discussed above feed into and affect the subsequent objectives, periodic review of research progress by an independent panel is strongly recommended. As a separate matter, the committee recognizes that there would be an important interface to maintain with COSPAR to gain concurrence on a process that would clearly change how NASA complies with internationally acceptable planetary protection protocol.

The objectives for updating Mars planetary protection clearly illustrate that changing NASA's current approach to embrace advances in microbiology and growing understanding of Mars cannot be done quickly. Even an aggressive plan such as that outlined here will take the better part of a decade to complete and fully apply to the Mars Exploration Program. There is, therefore, every reason to begin the work at hand as quickly as possible.

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PREVENTING THE FORWARD CONTAMINATION OF MARS

Committee on Preventing the Forward Contamination of Mars

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Preface

Mars has been called "the most nearly similar to Earth of all the planets and one of the most likely repositories for extraterrestrial life among them."[1] Its proximity to Earth and its moderate climate make the planet more accessible for study than others in the solar system. The Viking lander missions in the 1970s explored two locations on Mars that suggested a dry, barren environment hostile to life.[2] However, recent spacecraft and robotic probes to Mars, including the Mars Global Surveyor, Mars Odyssey, the twin Mars Exploration Rovers Spirit and Opportunity, and the European Mars Express mission, have yielded a wealth of data that are significantly changing our understanding of the planet. Mars is now recognized as a heterogeneous planet of multiple environments, some of which might offer conditions suitable for extant or past life. In addition, studies of biology in extreme environments continue to expand the known range of environmental parameters compatible with life, and life-detection techniques have become ever more sensitive, enhancing the capabilities to find past or present life on the planet, should it exist. Indeed, the search for past and present life on Mars is the first of four nearly equal objectives in the Mars exploration strategy of the National Aeronautics and Space Administration (NASA).[3]

In light of these developments, the need to protect against contamination from Earth-borne organisms has become increasingly important. NASA thus requested that the National Research Council's (NRC's) Space Studies Board (SSB) examine existing planetary protection measures for Mars and recommend changes and further research to improve such measures.

Specifically, the Space Studies Board's Committee on Preventing the Forward Contamination of Mars accepted the following statement of task:

[1]National Research Council, *Assessment of Mars Science and Mission Priorities*, National Academy Press, Washington, D.C., 2001, p. vii.

[2]National Research Council, *Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan*, National Academy Press, Washington, D.C., 1978, pp. 3-13.

[3]"The overarching objectives for MEP [NASA's Mars Exploration Program] are: Life, Climate, Geology, and Preparation for Human Exploration. First among these objectives of nearly equal priority is Life." See MSPSG, *Mars Science Program Synthesis Group: Mars Exploration Strategy, 2009-2020,* D.J. McCleese, ed., JPL 400-1131, Jet Propulsion Laboratory, Pasadena, Calif., 2004, p. 4. In 2004, the Mars Exploration Program Analysis Group (MEPAG) endorsed the same four objectives but explicitly did not prioritize them. See MEPAG, *Scientific Goals, Objectives, Investigations, and Priorities: 2004*, unpublished document, available at <mepag.jpl.nasa.gov/reports/index.html>.

- Assess and recommend levels of cleanliness and bioload reduction required to prevent the forward contamination of Mars by future spacecraft missions (orbiters, atmospheric missions, landers, penetrators, and drills), given current understanding of the martian environment and of terrestrial microorganisms. The committee's recommendations should take into account the full spectrum of environments on, above, and under present-day Mars, and the various ways that spaceflight missions may access them, intentionally or inadvertently.
- Review methods used to achieve and measure the appropriate level of cleanliness and bioload reduction for Mars spacecraft and recommend protocol revisions and/or additions in light of recent advances in science and technology.
- Identify scientific investigations that should be accomplished to reduce the uncertainty in the above assessments.

The task specified that, to the maximum possible extent, the recommendations should be developed to be compatible with an implementation that would use the regulatory framework for planetary protection currently in use by NASA and the Committee on Space Research (COSPAR).

STUDY APPROACH AND PROCESS

The membership and qualifications of the Committee on Preventing the Forward Contamination of Mars are shown in Appendix A. The committee's work follows the NRC's previous advice to NASA on Mars planetary protection as provided in *Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan* (NRC, 1978) and *Biological Contamination of Mars: Issues and Recommendations* (NRC, 1992); advice provided on the planetary protection of Europa in *Preventing the Forward Contamination of Europa* (NRC, 2000); advice provided in *Mars Sample Return: Issues and Recommendations* (NRC, 1997) on back contamination from samples collected on Mars and delivered to Earth; and advice in *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies* (NRC, 1998) on samples returned from other solar system bodies. The recommendations relevant to the current study that were made in the 1992 and 2000 reports are summarized in Appendix B.

The committee explored a number of issues. It revisited arguments on the probability of contamination and the probability for the growth of Earth microorganisms on Mars as detailed in previous NRC reports, and it reevaluated that material in light of new knowledge. The committee took into account the question of liquid water on Mars; new knowledge about extremophilic microorganisms on Earth; new life-detection and bioburden-reduction techniques; the upcoming Mars Exploration Program; the potential for orbiter and lander crashes on Mars; the possible natural delivery of terrestrial microorganisms to Mars via meteorites launched from Earth; the implications for planetary protection of past spacecraft landings and crashes on Mars; and the COSPAR mission categories that are used to assign planetary protection requirements. It also discussed questions of the scope of planetary protection policy, including the protection of scientific investigations and the protection of the planet itself.

The committee held four meetings: a data-gathering meeting at the National Academies' Keck Center in Washington, D.C.; a mini-workshop at Diversa Corporation in San Diego, California; a writing meeting at the SETI Institute in Mountain View, California; and a subcommittee writing session at the National Academies' Beckman Center in Irvine, California. In addition, the committee held several teleconference calls to continue its deliberations and to discuss the draft report. In conducting its study, the committee considered input from several sources, including previous NRC reports as well as briefings and materials provided by NASA, the Jet Propulsion Laboratory, representatives from private industry, and the science and engineering community. In addition, the committee and meeting participants toured Diversa Corporation, a biotechnology company focused on cultivation-independent methods for recovery of and evolutionary studies on genes and biomolecules from the environment. One member of the committee visited a clean room for spacecraft assembly at the Jet Propulsion Laboratory to ascertain how planetary protection measures are implemented in practice, and two members visited associated research laboratories involved in advancing planetary protection techniques. Similarly, one committee member and staff visited the Lockheed Martin Astronautics Corporation to understand how the company has addressed planetary protection for Mars spacecraft and the lessons, challenges, and issues involved in implementing planetary protection measures during spacecraft assembly.

ACKNOWLEDGMENTS

The committee acknowledges the many individuals who participated in and provided presentations at meetings: Peter Annan, Sensors and Software, Canada; Amy Baker, Technical Administrative Services; David Beaty, Jet Propulsion Laboratory (JPL); William Boynton, Lunar and Planetary Laboratory; Karen Buxbaum, JPL; Cathy Chang, Diversa Corporation; Benton Clark, Lockheed Martin Astronautics; James Garvin, NASA Headquarters; Bruce Jakosky, University of Colorado, Boulder; Robert Koukol, JPL; Brad Lobitz, San Jose State University Foundation; Gerald McDonnell, Steris Corporation; Brian Muirhead, JPL; Kenneth Nealson, University of Southern California; Laura Newlin, JPL; Roger Phillips, Washington University, St. Louis; John Rummel, NASA Headquarters; Andrew Spry, Open University, United Kingdom; Pericles Stabekis, The Windermere Group; Andrew Steele, Carnegie Institution; Kasthuri Venkateswaran, JPL; and Norman Wainwright, Marine Biological Laboratory.

Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Michelle Alfa, University of Manitoba,
Philip R. Christensen, Arizona State University,
Edward F. DeLong, Massachusetts Institute of Technology,
Gerda Horneck, Institute of Aerospace Medicine, German Aerospace Center,
Bruce M. Jakosky, University of Colorado,
Jeffrey S. Kargel, U.S. Geological Survey,
Tullis Onstott, Princeton University,
David A. Stahl, University of Washington,
Peter Staudhammer, Alfred E. Mann Institute for Biomedical Engineering, and
James M. Tiedje, Michigan State University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Mary Jane Osborn, University of Connecticut Health Center. Appointed by the National Research Council, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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