Assessment of the Report of NASA's Planetary Protection Independent Review Board

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Committee to Review the Report of the NASA Planetary Protection Independent Review Board

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of

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Preface

On August 16, 2019, Thomas H. Zurbuchen, NASA associate administrator for the Science Mission Directorate wrote to Margaret Kivelson, chair of the Space Studies Board (SSB) of the National Academies of Sciences, Engineering, and Medicine, informing her that recent reviews by the NASA Advisory Council (NAC) and the National Academies—specifically *Review and Assessment of Planetary Protection Policy Development Processes*[1] (hereinafter the "2018 report")—have raised concerns as to whether the consensus planetary protection guidelines maintained by the Committee on Space Research (COSPAR) were being outpaced by advances in science and technology (see Appendix A). Through planetary protection policies, all major spacefaring nations since the dawn of the Space Age attempt to minimize, if not preclude, the biological cross-contamination of planetary bodies, including Earth.

As a result of these concerns, Associate Administrator Zurbuchen announced he had chartered a group of experts—the Planetary Protection Independent Review Board (PPIRB)—"to update COSPAR's guidelines on biological contamination" (see Appendix A). Dr. Zurbuchen noted that the report of the PPIRB[2] would be completed by September 2019 and requested that the SSB undertake the task to review the work of the PPIRB. Subsequent discussions between NASA and the National Academies agreed that the requested review would address the following statement of task:

> The National Academies of Sciences, Engineering, and medicine will establish an ad hoc committee to review the findings of the PPIRB report and comment on their consistency with the recommendations of the recent report, *Review and Assessment of Planetary Protection Policy Development Processes.*

In response to NASA's request, the National Academies established the Committee to Review the Report of the NASA Planetary Protection Independent Review Board in early November. The committee held meetings in 2019 at the National Academy of Sciences in Washington, D.C., on November 20-22, and at the Beckman Center in Irvine, California, on December 16-17. A subgroup of the committee's members held a writing meeting at the headquarters of the Planetary Society in Pasadena, California, on January 20-21, 2020, and a complete draft of the report was sent to external reviewers on February 14. The report was revised in response to reviewer comments in March and approved for public release on March 26.

Although the statement of task called for the committee to "review the findings" of the PPIRB report and "comment on their consistency with the recommendations" of 2018 report, the committee interpreted its charge to mean that it was to review the *findings and recommendations* of the PPIRB report for consistency with the *findings and recommendations* of the 2018 report. In cases where the PPIRB report considered issues not addressed in the 2018 report, the committee drew upon other reports from the National Academies, briefings to the committee, or other publicly available information to assess consistency with the content of the 2018 report or to determine whether the committee agreed with the PPIRB's conclusions.

The work of the committee was assisted by many important inputs made by the following individuals: C. Philip Brinkman (Federal Aviation Administration), T. Jens Feeley (NASA Headquarters), Lori Glaze (NASA Headquarters), Christopher Johnson, (Secure World Foundation), Michael Meyer (NASA Headquarters), Michael New (NASA Headquarters), Lisa Pratt (NASA Headquarters), Benjamin

[1] National Academies of Sciences, Engineering, and Medicine, *Review and Assessment of Planetary Protection Policy Development Processes, The National Academies Press*, Washington, D.C., 2018.

[2] Planetary Protection Independent Review Board, *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf.

Roberts (Moon Express), Andrew Spry (SETI Institute), S. Alan Stern (Southwest Research Institute), Ryan Whitley (National Space Council), and Thomas H. Zurbuchen (NASA Headquarters).

The committee reserves special thanks to Jennifer Vaughn and James Bell, respectively, the chief operating officer and president of the Planetary Society, for making their Pasadena headquarters available for the committee's use during its January 2020 writing meeting.

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report: Jerome Apt III (Carnegie Mellon University), Bethany Ehlmann (California Institute of Technology), Dan Hendrickson (Astrobotic), Brian Israel (University of California, Berkeley), James Kasting (NAS; Pennsylvania State University), Robert Lindberg (Independent Consultant, Williamsburg, Virginia), Jonathan I. Lunine (NAS; Cornell University), Melissa A. McGrath (SETI Institute), Eric Rignot (NAS; University of California, Irvine).

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Steven Battel (NAE; Battel Engineering, Inc.). He was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the authoring committee and the National Academies.

Contents

Summary

The goal of planetary protection is to control, to the degree possible, the biological cross-contamination of planetary bodies. Two accepted rationales support this objective. Planetary protection policies seek, first, to preserve the ability to conduct future studies relating to the origin of life and prebiotic chemical evolution in extraterrestrial environments, and second, to protect the Earth's biosphere from potential harm arising from the return to Earth of possibly hazardous materials—for example, replicating biological entities—from other planetary bodies. Other, but equivalent, formulations of these twin rationales exist.

BACKGROUND TO THIS STUDY

The Space Studies Board (SSB) of the National Academies of Sciences, Engineering, and Medicine has been involved in producing reports on planetary protection for 60 years. NASA's planetary protection policies have codified much of the scientific and technical advice contained in these reports.

At the international level, the Committee on Space Research (COSPAR) of the International Science Council develops and maintains consensus planetary protection guidelines. Not surprisingly, many if not most of COSPAR's guidelines are built upon NASA policy and the SSB's recommendations.

In the last half-dozen years or so, concerns arose that new space developments were stressing existing planetary protection policies and the policy development process. Such developments included planning for challenging robotic missions to Mars and the outer solar system addressing important astrobiology goals, the plans and missions of new national and international space agencies, the increasing private-sector space activities, and planning for the resumption of human exploration activities on the Moon and, eventually, on Mars.

Against this backdrop, NASA requested that the SSB undertake a comprehensive review of the planetary protection policy development process. The resulting report, *Review and Assessment of Planetary Protection Policy Development Processes*[1] (hereinafter the "2018 report") was completed in the late spring of 2018. Partially in response to the 2018 report and partially in response to concerns raised by private-sector space enterprises, NASA's Advisory Council (NAC) recommended that the agency establish an internal group "to develop U.S. policies that properly balance the legitimate need to protect against the harmful contamination of the Earth or other celestial bodies with the scientific, social, and economic benefits of public and private space missions" (see Appendix D). The resulting report of the Planetary Protection Independent Review Board (PPIRB)[2] was completed in the early autumn of 2019 (hereinafter the "PPIRB report"). A few weeks prior to the completion of the PPIRB report, NASA's Science Mission Directorate requested that the SSB undertake a study (Appendix A) to assess the consistency between the findings and recommendations in the 2018 report (Appendix B) and those in the PPIRB report (Appendix C). The Committee to Review the Report of the NASA Planetary Protection

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[1] National Academies of Sciences, Engineering, and Medicine (NASEM), *Review and Assessment of Planetary Protection Policy Development Processes*, The National Academies Press, Washington, D.C., 2018.

[2] Planetary Protection Independent Review Board (PPIRB), *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf. For ease of reference, the findings and recommendations contained in the PPIRB report have been numbered sequentially by the committee (see Appendix C) and are referred to in brackets.

Independent Review Board (hereafter the committee) was established in the autumn of 2019 to complete the comparative review of the two reports (Preface and Appendix A).

Additional background information relating to planetary protection and the initiation of this study is found in Chapter 1.

ASSESSMENT OF THE PPIRB REPORT

The PPIRB report contains 77 findings and recommendations organized into seven thematic sections. Chapter 2 contains the committee's point-by-point assessment of each of the PPIRB's findings and recommendations. The committee sorted the 77 findings and recommendations into three categories: (1) where the PPIRB and 2018 reports are consistent, (2) where the reports are inconsistent, and (3) where the two reports are not comparable because the PPIRB introduced a new idea, issue, or approach not discussed in the 2018 report. Sorting the PPIRB's findings and recommendations in this way and organizing the results under the PPIRB report's seven thematic sections yields Table S.1.

The PPRIB and 2018 reports have few inconsistencies (9 percent). A majority (58 percent) of the findings and recommendations of both reports are consistent. However, almost one-third (32 percent) of the PPIRB's findings and recommendations touch upon issues not discussed in the 2018 report.

However, the boundaries of the PPIRB report's thematic sections are somewhat porous and create some issues for comparison with the 2018 report. The committee identified some inconsistencies within the PPIRB report between findings and recommendations in different thematic sections. Moreover, some of the PPIRB's findings and recommendations combine multiple topics, some of which are consistent with the 2018 report and others are inconsistent. In its more granular analysis in Chapter 2, the committee addresses these inconsistencies and their implications for its comparative analysis.

TABLE S.1 Findings and Recommendations of the PPIRB Report Sorted According to Their Consistency or Otherwise with the 2018 Report

Major Sections of the PPIRB Report	Consistent	Inconsistent	Not Comparable
General/Overarching	23	3	8
Planetary Protection Categorization	1	0	5
Human Space Flight	9	0	2
Private Sector Initiatives and Missions	6	1	1
Robotic Mars Sample Return	5	0	4
Ocean World Exploration	0	0	4
COSPAR	1	3	1
TOTALS	45	7	25

Areas of Consistency

Areas where the PPIRB and 2018 reports are consistent include the following:

- The importance of U.S. leadership in the development of planetary protection science, approaches, technologies, and policy in keeping with the obligations contained in the Outer Space Treaty;[3]
- Planetary protection policies are equally applicable to both government and non-government missions;[4]
- Existence of lack of agreement about the implementation of planetary protection policies and associated requirements for private-sector space missions and, in particular, the need to identify, in domestic law, a federal agency to regulate nongovernmental entities on planetary protection;[5]
- The importance of international cooperation and recognition of COSPAR's historical role;[6]
- Changes in exploration and uses of space affecting planetary protection policies:
  - Private sector initiatives in solar system exploration,[7]
  - Humans to Mars,[8] and
  - Mars sample return;[9]
- Need for reassessment of planetary protection policies in order to respond to the changes in the context of space activities:
  - Reorganization of NASA's Office of Planetary Protection,[10]
  - Incorporation of new science and technology,[11]
  - Definition of human exploration zones on Mars,[12] and
  - Planetary protection policy for the human exploration of Mars;[13]
  - The need to resolve issues arising from the application of planetary protection policies to private-sector space activities;[14]
- Need for timely definition of planetary protection requirements;[15]
- Need for input from all stakeholders in the development of planetary protection policies and through advisory processes;[16] and

[3] See PPIRB, 2019 [18] (albeit with a different approach to compliance that that supported by NASEM, 2018) and [34] (albeit with a different approach to US leadership than contemplated in NASEM, 2018), and

[4] See PPIRB, 2019 [2].

[5] See PPIRB, 2019 [10, 11, 53, 58].

[6] See PPIRB, 2019 [18, 76].

[7] See PPIRB, 2019 [1, 52, 57].

[8] See PPIRB, 2019 [41].

[9] See PPIRB, 2019 [62, 63, 65].

[10] See PPIRB, 2019 [8, 9].

[11] See PPIRB, 2019 [5, 20, 21, 22, 23, 24]. However, the following thematically related findings and recommendations relate to topics not discussed in NASEM, 2018: PPIRB, 2019 [69, 70, 72].

[12] See PPIRB, 2019 [38].

[13] See PPIRB, 2019 [43, 45, 46, 49, 50]. However, the following thematically related recommendation relates to topics not discussed in NASEM, 2018: PPIRB, 2019 [47].

[14] See PPIRB, 2019 [55]. However, the following thematically related recommendation relates to areas not discussed in NASEM, 2018: PPIRB, 2019 [56].

[15] See PPIRB, 2019 [13, 14, 15, 25, 26].

[16] See PPIRB, 2019 [6, 7, 27, 48, 58, 59, 68]. However, the following thematically related finding is inconsistent with NASEM, 2018: PPIRB, 2019 [74].

- Clear public communication of planetary protection policies, issues, and mission-implementation strategies.[17]

Areas of Inconsistency and Concern

Areas where the PPIRB and 2018 reports are inconsistent or raise concerns—because they highlight in different ways the contexts in which government and private-sector stakeholders confront a lack of clarity about the development, application, and implementation of planetary protection policy concerns—include the following:

- The respective roles of COSPAR and the U.N. Committee on the Peaceful Uses of Outer Space in the development of planetary protection policies;[18]
- The legal relevance of the obligations in the Outer Space Treaty for private-sector space missions;[19]
- The idea of needing to balance planetary protection and various mission objectives as if they were competing aims;[20] and
- The term "planetary protection" is confusing;[21]

Areas Not Comparable

As mentioned above, almost one third of the PPIRB's findings and recommendations address topics not discussed in the 2018 report. These findings and recommendations are concerned with topics such as the following:

- Re-categorization of spacecraft missions to the Moon, Mars, and small solar system bodies (e.g., asteroids);[22]
- The potential cost challenges for small,[23] low-cost, spacecraft (e.g., SmallSat and CubeSat) missions in implementing planetary protection measures;[24]
- NASA's potential role in providing planetary protection assistance to new, private-sector space activities;[25]
- Opportunities for future NASA contracts as a means of enforcing planetary protection policies;[26]
- Sanctions for private-sector actors that do not follow planetary protection policies;[27]
- What martian meteorites can potentially reveal about planetary protection policies designed to protect Earth from back contamination;[28]

[17] See PPIRB, 2019 [42, 44, 64].
[18] See PPIRB, 2019 [32, 33].
[19] See PPIRB, 2019 [73].
[20] See PPIRB, 2019 [54].
[21] See PPIRB, 2019 [75]. However, the thematically related recommendation [77] is not discussed in NASEM, 2018.
[22] See PPIRB, 2019 [35, 36, 37, 39, 71].
[23] The committee defines a small spacecraft as one with a mass of less than 600 kg.
[24] See PPIRB, 2019 [28, 29].
[25] See PPIRB, 2019 [12].
[26] See PPIRB, 2019 [16, 17].
[27] See PPIRB, 2019 [30, 31].
[28] See PPIRB, 2019 [19, 60, 61].

- Impact of bioload-reduction sterilization techniques on science;[29] and
- Whether Mars is already contaminated by previous robotic missions and whether the impacts of future robotic and human missions are "likely to be minimal."[30]

AREAS OF STRATEGIC IMPORTANCE

From its comparative review of the PPIRB and 2018 reports, and its examination of the topics considered only in the PPIRB report, the committee identified the following areas of strategic importance in the development of future planetary protection policy common to both reports:[31]

- Establishing a new advisory process;
- Clarifying legal and regulatory issues; and
- Building the scientific and technical foundations of planetary protection policies for human missions to Mars.

Subsequent sections cover each of these strategic areas in turn.

Establishing a New Advisory Process for Planetary Protection Policy

The PPIRB and 2018 reports, independently and together, make the persuasive case for NASA to establish a new process for gathering input on planetary protection policy from all relevant stakeholders. Such an advisory process is necessary to ensure that the planetary protection policy comprehensively reflects the new environment of public and private space activities, contributes to the success of government and private-sector space missions, and reinforces U.S. leadership on planetary protection.

Recommendation: NASA should establish a new, permanent, and independent advisory body formally authorized to provide NASA with information and formulate advice from representatives of the full range of stakeholders relevant to, or affected by, planetary protection policy.

The execution of planetary protection policy necessarily requires international coordination. However, the United States has shown leadership in developing planetary protection policy and most, if not all, of these policies have been adopted internationally. However, there are U.S. issues—for example, back contamination associated with current planning for a robotic Mars sample return mission in this decade and the complex scientific, technical, and policy ramifications that must be addressed to enable the human exploration of Mars in the next decade—that require immediate attention.

Recommendation: The initial focus of the new advisory body should be on the needs of upcoming private-sector and government missions.

Clarifying Legal and Regulatory Issues Concerning Planetary Protection

The persistence of disagreements about how the United States fulfills its obligations under the Outer Space Treaty in connection with private-sector space activities with planetary protection

[29] See PPIRB, 2019 [66, 67].
[30] See PPIRB, 2019 [40, 51].
[31] See Chapter 3.

implications creates uncertainty for the private sector and potentially harms the objective of the U.S. government to facilitate exploration and uses of space by the private sector.[32,33]

> **Recommendation**: **NASA should work with other agencies of the U.S. government, especially the U.S. Department of State, to provide the private sector with a clear and authoritative explanation of the U.S. government's obligations under the Outer Space Treaty to authorize and continually supervise the space activities of non-governmental entities that raise planetary protection issues.**

Problems persist with whether and how U.S. federal law regulates private-sector space activities for planetary protection purposes concerning launch, on-orbit, and re-entry activities. [34] These problems create challenges for U.S. compliance with the Outer Space Treaty's obligations concerning the authorization and continual supervision of activities of non-governmental entities. The problems also undermine the private sector's need for a transparent and efficient legal and regulatory framework to support expanding private-sector exploration and uses of space.

> **Recommendation**: **NASA should work with other agencies of the U.S. government, especially the Federal Aviation Administration, to produce a legal and regulatory guide for private-sector actors planning space activities that implicate planetary protection but that do not involve NASA participation. The guide should clearly identify where legal authority for making decisions about planetary protection issues resides, how the United States translates its obligations under the Outer Space Treaty into planetary protection requirements for non-governmental missions, what legal rules apply to private-sector actors planning missions with planetary protection issues, and what authoritative sources of information are available to private-sector actors that want more guidance on legal and regulatory questions.**

Building the Scientific and Technological Foundation for Planetary Protection Policy on Human Missions to Mars

Although NASA recognizes that existing planetary protection policy is inappropriate for human missions to Mars, it has not developed a strategy for producing practical planetary protection measures for such human missions.[35] The lack of a strategy arises, in large measure, because NASA has not conducted the research and development needed to build the scientific and technological foundation for planetary protection measures designed specifically for human missions to Mars.[36] For example, the current state of research is not yet adequate to determine whether there are regions on Mars where human explorers or commercial missions might land with minimal planetary protection implications.

> **Recommendation: NASA should make the development and execution of a strategy to guide the adoption of planetary protection policy for human missions to Mars a priority.**

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[32] See NASEM, 2018t, pp. 85-89, and the section "Domestic Law: Legal Authority, Substantive Rules, and Enforcement" in Chapter 3 of this report.

[33] National Space Council, Space Policy Directive-2, Streamlining Regulations on Commercial Use of Space, Executive Office of the President, Washington, D.C., May 24, 2018.

[34] See NASEM, 2018, pp. 86-88, the section "Domestic Law: Legal Authority, Substantive Rules, and Enforcement" in Chapter 3, and the PPIRB, 2019 [73].

[35] See NASEM, 2018, pp. 79-84, and the section "Building the Scientific and Technological Foundation for Planetary Protection Policy on Human Missions to Mars" in Chapter 3 of this report.

[36] See NASEM, 2018, pp. 83-84 and 108-111, and Figure 3.1 of this report.

Essential elements of such a strategy could include the following:[37]

- A process to identify the most promising concepts for achieving planetary protection objectives in the context of human missions, such as high-priority astrobiological zones and human exploration zones, building upon the work done to date by COSPAR, NASA and the European Space Agency (ESA);
- Establishment of an adequately funded program of research and development to answer questions and address challenges raised by the most promising concepts for integrating planetary protection measures in human missions; and
- A plan to develop planetary protection policy for human missions to Mars on a timeline that permits the integration of such research and development into mission planning and implementation at the earliest possible stages.

The committee has chosen to emphasize the need for a strategy for humans to Mars because of the magnitude of the task and because this topic is emphasized in both the PPIRB and 2018 reports. However, it could be argued that the same kind of effort will be needed to address topics not discussed in the 2018 report and, thus, technically beyond the scope of the current study. Such topics include, for example, relaxing the planetary protection requirements for large areas of the Moon and thus opening them up to private-sector missions and addressing other planetary protection issues associated with the future exploration of ocean worlds and other astrobiologically significant environments.

EXPEDITING THE DEVELOPMENT OF NEW APPROACHES TO PLANETARY PROTECTION

The committee recognizes that NASA needs time to implement fully the recommendations contained in the PPIRB and 2018 reports and those offered above. However, NASA has an opportunity to make some rapid progress on important aspects of a new approach to planetary protection policy by leveraging the potential that small, low-cost spacecraft offer for governmental, academic, and private-sector exploration and utilization of space.

The PPIRB report drew attention to the challenges that small spacecraft missions can present in terms of the costs of compliance with planetary protection measures, even for Category II mission requirements[38] related to undertaking trajectory analysis and completing an organic inventory for a spacecraft. Because of limited budget resources and time, small spacecraft require a more refined balance between risk and cost than is typical for large spacecraft. The committee agrees with the PPIRB's emphasis on this issue and notes that small, low-cost spacecraft present an ideal environment for experimentation and innovation in the implementation of specific planetary protection policies.[39]

Recommendation: NASA should undertake the following actions:

- **Develop a broad-based, representative advisory process to inform the development of planetary protection policy for small, low-cost spacecraft;**

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[37] See NASEM, 2018, pp. 83-84, and the section "Building the Scientific and Technological Foundation for Planetary Protection Policy on Human Missions to Mars" in Chapter 3 of this report.

[38] The mission type categories as specified in COSPAR's Planetary Protection Policy are provided in Appendix E.

[39] See the section "Expediting the Development of New Approaches to Planetary Protection" in Chapter 3 of this report.

- **Identify, fund, and complete research and development priorities related to small, low-cost spacecraft missions (e.g., on analyzing base costs for planetary protection compliance and on crafting a standard planetary protection template);**
- **Clarify the legal and regulatory environment for small, low-cost spacecraft used in missions that are not subject to agreements or contracts with NASA; and**
- **Record, analyze, and communicate the lessons learned from specific small, low-cost spacecraft efforts in order to inform the development and implementation of the new approach to planetary protection policy as recommended in NASA's 2019 Planetary Protection Independent Review Board report and the National Academies of Science, Engineering, and Medicine's 2018 report *Review and Assessment of Planetary Protection Policy Development Processes*.**

1

Introduction

Planetary protection, as practiced by NASA and other national and international space agencies for the past 70 years, has two rationales: ”to protect the biological and environmental integrity of other solar system bodies for future science missions” and “to preserve the integrity of Earth’s biosphere.”[1] A more recent statement from the Committee on Space Research’s (COSPAR’s) Panel on Planetary Protection (PPP) contains a somewhat longer, but equivalent, pair of rationales. First, “the conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized.” Second, “The Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet.”[2]

In 1958, a subcommittee of the International Council of Scientific Unions[3] issued the first code-of-conduct for planetary quarantine (as the topic was then called) and recommended that the recently established COSPAR assume responsibility for deliberating on matters of planetary protection.[4] The 1967 Outer Space Treaty formalized the international legal requirements for states parties to avoid “harmful contamination” of celestial bodies and “adverse changes in the environment of the Earth.” COSPAR guidelines have evolved in response to new scientific and technical developments, and all major space-faring nations have adopted these guidelines in connection with their exploration and study of solar system bodies.[5]

BACKGROUND AND CONTEXT

Tensions developed in the earliest years of the Space Age between the space science and engineering communities concerning the need for and implementation cost of planetary protection policies.[6] According to one perspective, planetary protection policies represent a prudent balance between humanity’s desire to explore the solar system in a responsible manner and avoid risks that could, potentially, preclude future investigations. Accordingly, exploration conducted in an irresponsible manner could have consequences ranging in scope from the introduction of false positives in life-detection experiments—caused by organisms inadvertently transferred from Earth—to low-probability, high-consequence events arising from the introduction of a replicating extraterrestrial entity into Earth’s environment. A different perspective holds that current planetary protection policies are outmoded, based on scientific speculations and extrapolations, costly to implement, and impede scientific studies and other

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[1] National Academies of Sciences, Engineering, and Medicine (NASEM), *Review and Assessment of Planetary Protection Policy Development Processes*, The National Academies Press, Washington, D.C., 2018, p. 9.

[2] A. Coustenis, G. Kminek, N. Headman, E. Ammannito, E. Deshevaya, et al., “The COSPAR Panel on Planetary Protection Role, Structure and Activities,” *Space Research Today*, Number 205, 2019, pp. 14-26.

[3] This organization later changed its name to the International Council for Science, but retained its original acronym, ICSU. In 2018, ICSU merged with the International Social Science Council to create the International Science Council.

[4] For more about COSPAR and its activities, see https://cosparhq.cnes.fr.

[5] G. Kminek, C. Conley, V. Hipkin, H. Yano, “COSPAR’s Planetary Protection Policy,” *Space Research Today*, Number 200, December 2017, https://cosparhq.cnes.fr/assets/uploads/2019/12/PPPolicyDecember-2017.pdf.

[6] M. Meltzer, *When Biospheres Collide: A History of NASA’s Planetary Protection Programs*, NASA SP-2011-4234, NASA History Program Office, Washington, D.C., 2011, pp. 46-51.

activities in planetary environments. As we shall see, new issues concerning the development of planetary protection policies and their implementation have arisen in recent years.

The advent of new space activities and new players in the exploration and use of space have again put a spotlight on the already complicated planetary protection landscape. These new developments include the following:

- National and international space agencies are working with the worldwide science community to develop robotic missions to collect Martian samples and bring them to Earth, thus raising the possibility, however unlikely, of potential harm to the biosphere supporting all life on Earth.
- Space agencies are also planning to dispatch missions to explore the so-called ocean worlds—those astrobiologically important satellites of the giant planets—for example, Europa, Enceladus, and Titan—possessing large quantities of liquid water beneath their icy surfaces.[7] The physical conditions in such oceans are believed to be similar to those found in Earth's deep oceans. In contrast, terrestrial organisms exposed on the martian surface will likely not survive prolonged exposure to the ambient ultraviolet radiation and oxidizing chemical species on Mars. The global nature of such subsurface oceans means that terrestrial biological contamination would likely not remain localized if it reached the ocean.
- Burgeoning interest in the return of astronauts to the Moon and their eventual voyages to Mars is creating planetary protection issues. Human missions to the Moon raise some planetary protection concerns, especially in connection with in situ resource utilization for supporting the human presence on the Moon (e.g., the potential for the contamination or depletion of polar ice deposits and thus a loss of scientific information about the history of the flux of volatile materials over the history of the inner solar system). However, sending astronauts to Mars raises far more serious planetary protection issues because the policies and procedures developed for robotic missions to Mars are incompatible with human health, safety, and activities on Mars.
- The rapid evolution in the number and sophistication of private-sector space companies and activities is presenting new challenges for planetary protection policy. First, current policies focus almost exclusively on government-led, scientific, and robotic spacecraft missions. New types of private-sector space activities offer a potentially more diverse set of missions. Second, past private-sector space activities conducted without NASA involvement, such as launching and operating satellites, did not implicate planetary protection, which means that private-sector actors did not participate in the processes used to develop planetary protection policy. Thus, with the advent of private-sector space activities that create planetary protection questions, integrating private-sector input into these policy development processes has become necessary.

The convergence of these various concerns produced a number of important actions. First, NASA commissioned a study by the National Academies of Sciences, Engineering, and Medicine to examine planetary protection policy development processes. Second, COSPAR reformed and re-organized its Panel on Planetary Protection, and NASA made major changes in its Office of Planetary Protection. Third, NASA established the Planetary Protection Independent Review Board (PPIRB) to provide more input on the challenges facing planetary protection policy in the future. The next three sections summarize these actions. This committee's statement of task (see Preface and Appendix A) encompasses the study from the National Academies and the PPIRB's input, so these actions are examined more closely below.

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[7] For more about ocean worlds see, for example, A.R. Hendrix, T.A. Hurford, L.M. Barge, M.T. Bland, J.S. Bowman, et al., The NASA Roadmap to Ocean Worlds, *Astrobiology* 19: 1-27, 2019.

THE NATIONAL ACADEMIES' STUDY OF THE PLANETARY PROTECTION POLICY DEVELOPMENT PROCESSES

In response to the evolving planetary protection landscape, NASA's Science Mission Directorate (SMD) requested in February 2016 that the Space Studies Board (SSB) study the current process by which planetary protection policy is developed and recommend actions or options for NASA. Subsequent discussions between the SSB and NASA resulted in the formulation and adoption of the following statement of task for the study:

> The National Academies of Sciences, Engineering, and Medicine will appoint an ad hoc committee to carry out a study that will describe how international and national planetary protection policy has been formulated and adopted and identify associated lessons to inform future policy development. Specifically, the committee will assess the current state of planetary protection policy development, and the extent to which the current policy-making process is responsive to the present state of science, technology, and engineering, including biological science, as well as the exploration interests of state and non-state actors. The committee's review will lead to recommendations on how to assure the planetary protection policy process is supportive of future scientific and societal interests, as well as spaceflight missions.
>
> It is suggested that the committee organize its review around three themes:
>
> - Historical context and the current policy development process; including a working definition of planetary protection and its goals;
> - Key factors in the current policy development process; and
> - The future of the policy development process.

In response to NASA's request, the SSB established the Committee on the Review of Planetary Protection Policy Development Processes. The committee began its work in March 2017, and issued its report, *Review and Assessment of Planetary Protection Policy Development Processes*[8] (hereafter the "2018 report"), in June 2018. This report did not address the substance of planetary protection policies, the specific requirements flowing from those policies, or the mission-level methodologies and techniques for implementing the requirements. It concerned itself exclusively with the processes that developed planetary protection policy. The 130-plus page report contained 27 findings and 17 recommendations (reprinted in Appendix B).

In its analysis, the 2018 report identified a number of fundamental aspects of the planetary protection policy development process that remain relevant and vital today, including the following:

- The Outer Space Treaty as the policy and legal foundation for both government-sponsored and non-governmental space activities;
- COSPAR's role in fostering international cooperation on planetary protection guidelines;
- The centrality of science-based decision making;
- The involvement of many scientific communities; and
- U.S. leadership in planetary protection policy making.

The report also found that NASA needs to address the following issues:

- Managing policy implementation;
- Securing cutting-edge, outside expert advice for NASA;
- Developing a long-range forecast of future solar system exploration missions having planetary protection implications;
- Setting planetary protection research and technology investment priorities; and

[8] NASEM, 2018.

- Creating plans for dealing with major policy issues, such as Mars sample-return, human missions to Mars, and private-sector space activities.

The 2018 report recommended that NASA develop a strategic plan for planetary protection that responds to each of the aforementioned priority issues.

With respect to private-sector activities, the 2018 report reached the following conclusions:

- Planetary protection policy applies to missions to all solar system bodies; however, only missions to those objects that may be likely to support life require substantial planetary protection actions (meaning, for the near term, missions to Mars, Europa, and Enceladus);
- Planetary protection policies and requirements for forward and back contamination apply equally to government-sponsored and private-sector missions; and
- A "regulatory gap" exists in U.S. federal law governing private-sector activities in space that poses a problem for U.S. compliance with the mandate in Article VI of the Outer Space Treaty that states parties authorize and continually supervise the space activities of non-governmental entities.

In response to private-sector input, the report recommended that NASA ensure that its policy-development processes, including advisory mechanisms, make appropriate efforts to incorporate the views of the private sector. Moreover, the report encouraged COSPAR to support efforts to increase private-sector participation in the organization's planetary protection activities.

With respect to the "regulatory gap," the report recommended that Congress promulgate legislation that grants jurisdiction to an appropriate federal regulatory agency to authorize and supervise private-sector space activities that raise planetary protection issues. Moreover, the enactment of such legislation would ensure that the authority granted be exercised in a way that is based on the most relevant scientific information and best practices on planetary protection.

REORGANIZATION OF COSPAR'S PANEL ON PLANETARY PROTECTION AND NASA'S OFFICE OF PLANETARY PROTECTION

The National Academies' 2018 report was conducted while two key players in planetary protection underwent significant changes. For decades, NASA's Office of Planetary Protection (OPP) was located in the agency's Science Mission Directorate (and its predecessor organizations).[9] The 2018 report noted that this placement created "an inherent conflict of interest because the dispute resolution official was directly responsible for science missions as well as planetary protection."[10] Moving OPP to the Office of Safety and Mission Assurance (OSMA) would allow OPP to "function more like a NASA technical authority and disagreements between the OPP and flight projects on planetary protection issues can be resolved through formal OSMA conflict resolution procedures that have worked well in other areas within OSMA's purview."[11]

One concern the 2018 report raised about moving OPP from SMD to OSMA focused on the small planetary protection research program (see Figure 3.1), a component of NASA's annual Research Opportunities in Space and Earth Science (ROSES) call for research and analysis proposals. SMD, the home of ROSES, provided a more appropriate environment for the planetary protection research than OSMA, which does not run research programs. For this reason, NASA kept the planetary protection research program in SMD and hired a new program manager.

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[9] For much of this period, the OPP and its one permanent staff member, the NASA planetary protection officer (PPO), were virtually synonymous.

[10] See NASEM, 2018, p. 60.

[11] See NASEM, 2018, p. 60.

In addition, COSPAR was re-organizing its PPP while the 2018 report was in progress. Prior to the summer of 2018, the PPP consisted of a chair and one or more vice chairs—typically planetary-protection practitioners—appointed by the president of COSPAR for a 4-year term. The remainder of the participants in the PPP's activities were those individuals who attended PPP-organized events at COSPAR scientific assemblies and other venues—mainly planetary-protection experts and planetary scientists and astrobiologists. In response to criticism, COSPAR's leaders realized that the manner in which the PPP operated did not reflect the important role COSPAR played in developing international scientific consensus on planetary protection guidelines.[12]

COSPAR initiated reforms to formalize the linkages between the PPP, national space agencies, and the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS). These reforms included actions in five areas. First, the PPP chair would not be a planetary-protection expert but, rather, a senior scientist active in the robotic exploration of the solar system. Second, the PPP would have two vice chairs, one nominated by COPUOS and the other drawn from the planetary protection community. Third, national space agencies would formally nominate individuals to serve as members on the PPP. Fourth, COSPAR's Scientific Commission B (planetary science) and Commission F (space life sciences) would nominate scientists from the planetary science and biological communities to be PPP members. Fifth, the PPP would meet regularly and not just during COSPAR's scientific assemblies. PPP meetings would still be open to all interested participants, but the panel's decision-making process would involve only appointed members.[13]

COSPAR implemented the reforms during its 2018 scientific assembly, and the PPP has, as of this writing, held two meetings in its reconstituted form. At its January 2019 meeting—held at the United Nations Center in Vienna, Austria—the panel discussed and reached consensus on two major items.[14] First, in response to input from the Japan Aerospace Exploration Agency (JAXA), a consortium supported by the European Space Agency, and the National Academies, the PPP proposed recommendations on the categorization of samples of Phobos or Diemos to be returned to Earth by JAXA's Martian Moons Exploration spacecraft.[15] Second, based on input from an international consortium organized by the European Science Foundation, the PPP made recommendations on planetary protection issues for missions to the icy satellites of the giant planets. At its March 2019 meeting, the COSPAR Bureau approved PPP's recommendations on these two topics. PPP's second meeting after its reorganization took place in December 2019, also in Vienna, and, among other things, the PPIRB briefed the PPP on its report, and the PPP discussed the report's implications.

NASA'S PLANETARY PROTECTION INDEPENDENT REVIEW BOARD

On November 15, 2018, NASA Administrator James Bridenstine approved the terms of reference of the NASA Advisory Council's (NAC's) new Regulatory and Policy Committee (RPC). The scope of the RPC "includes advising on NASA-related civil space regulation and policy, broadly defined, including but not limited to regulation, legislation, and interagency and international governance issues, to catalyze America's civil space economy and advance other policy objectives." One of the items on RPC's agenda during its first meeting (held on November 16, 2018) was COSPAR and, in particular, its role in planetary protection policy. The RPC adopted two findings and two recommendations on the COSPAR agenda item (see Appendix D). The NAC addressed the RPC's findings and recommendations at its

[12] See NASEM, 2018, pp. 72-74.

[13] For more details about the reorganization of the PPP, see A. Coustenis, G. Kminek, N. Hedman, E. Ammannito, E. Deshevaya, et al., "The COSPAR Panel on Planetary Protection: Role, Structure and Activities," *Space Research Today*, Number 205, August 2019, https://cosparhq.cnes.fr/assets/uploads/2019/07/PPP_SRT-Article_Role-Structure_Aug-2019.pdf.

[14] *Space Research Today*, Number 205, August 2019, pp. 23-24.

[15] NASEM and European Science Foundation, *Planetary Protection Classification of Sample Return Missions from the Martian Moons*, The National Academies Press, Washington, D.C., 2019.

December 10-11, 2018, meeting. The NAC issued a recommendation stating, in part, that "NASA should establish a multi-disciplinary task force of experts from industry, the scientific community, and relevant government agencies, to develop U.S. policies that properly balance the legitimate need to protect against the harmful contamination of the Earth or other celestial bodies with the scientific, social, and economic benefits of public and private space missions" (see Appendix D). Moreover, the NAC stated that, if "NASA adopts the COSPAR guidelines without any review or revision they will have a chilling effect on robotic, human spaceflight, and private-sector missions."

Prompted by the NAC's recommendation, NASA issued the following response:

> NASA concurs with the recommendation. The NASA Science Mission Directorate (SMD) currently is establishing a Planetary Protection Independent Review Board, of approximately 10-15 members and short-term in nature, to assess and provide updates to biological contamination guidelines developed by the international Committee on Space Research (COSPAR). The Planetary Protection Independent Review Board's assessment will include analysis of the scientific, engineering, industrial, legal, and program management aspects of planetary protection. Results of the assessment will be documented in a non-consensus final report presentation, and the Independent Review Board will brief NASA, NASA advisory committees, and external stakeholders as appropriate.[16]

The PPIRB held an organizing conference call in late June 2019 and its first face-to-face meeting at NASA Headquarters on July 10-11 (see Appendix D). It held multiple meetings in the summer of 2019 and issued its report, *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*[17] (hereafter the "PPIRB report"), in September 2019.

The PPIRB report reflected the input by experts from many scientific disciplines, policy communities, and private-sector enterprises that the board commendably compiled into its report a very brief period of time in order to meet the deadline set by NASA. Generally, the PPIRB provided little or no supporting evidence, information, or narrative explanations for most of its findings and recommendations.[18] The lack of supporting evidence, information, or explanatory text makes the basis and reasoning behind many findings and recommendations difficult to understand and assess. The committee appreciates the efforts the chair of the PPIRB, S Alan Stern, made to help the committee review the PPIRB report and compare it with the 2018 report.

Chapter 2 contains the committee's point-by-point comparison of the PPIRB report's findings and recommendations with the 2018 report. The committee notes that, strictly speaking, its statement of task calls for it to "review the findings" of the PPIRB report and "comment on their consistency with the recommendations" of 2018 report.[19] For obvious reasons, the committee has interpreted its charge to mean that it review the *findings and recommendations* of the PPIRB report for consistency with the *findings and recommendations* of the 2018 report. The committee also notes that the PPIRB report's thematic organization means that some topics appear more than once. As a result, the committee's point-by-point assessment of the PPIRB's findings and recommendations in Chapter 2 contains some necessary repetition.

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[16] Planetary Protection Independent Review Board (PPIRB), *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf, Appendix C.

[17] See PPIRB, 2019.

[18] The PPIRB report's findings and recommendations vary in length from a single sentence to a paragraph, with 25 items listed as findings or recommendations incorporating a sentence or two of explanatory text. See PPIRB, 2019 [5, 6, 30, 36, 37, 39, 41, 43, 45, 46, 47, 48, 51, 54, 58, 60, 61, 62, 64, 68, 69, 71, 72, 74, 75]. Only five of the findings and recommendations contain references to supporting information or evidence. See PPIRB, 2019 [37] (one reference), [40] (four references), [54] (two references), [60] (two references), and [69] (two references). In sum, 52 of the 77 total findings and recommendations lack supporting evidence, information, or explanatory text.

[19] See Preface and Appendix A for the full wording of the committee's statement of task.

Chapter 3 summarizes those areas of consistency and inconsistency between the two reports. The chapter also identifies a number of issues covered in the PPIRB report but not discussed in the 2018 report because those issues were beyond the 2018 report's statement of task or involve events transpiring after the 2018 report was completed. Then Chapter 3 discusses, and makes recommendations to address, three challenges that the two reports identify as priorities for NASA. The committee concludes with recommendations concerning ways that NASA can expedite the development of a new approach to planetary protection policy through a focus on addressing planetary protection challenges faced by public and private actors interested in small,[20] low-cost, spacecraft.

[20] The committee defines a small spacecraft as one with a mass of less than 600 kg.

2

Assessment of the PPIRB's Findings and Recommendations

INTRODUCTION

The Planetary Protection Independent Review Board (PPIRB) report[1] includes 34 major or supporting findings and 43 major or supporting recommendations. This chapter reviews those findings and recommendations for their consistency with the 2018 report of the National Academies of Sciences, Engineering, and Medicine, *Review and Assessment of Planetary Protection Policy Development Processes*[2] (hereinafter the "2018 report"). The PPIRB report organized its findings and recommendations into seven categories. The first category, "General/Overarching," includes 15 findings and 19 recommendations. The section includes items regarding the changing context of planetary protection, development of planetary protection requirements, and compliance enforcement, among others.

The PPIRB organized its remaining findings and recommendations in the following six categories:

- Planetary protection categorization,
- Human spaceflight,
- Private sector initiatives and missions,
- Robotic Mars sample return,
- Ocean Worlds exploration, and
- COSPAR.

In the sections below, the committee presents the PPIRB's findings and recommendations in italics, followed by the committee's analysis of those conclusions. For ease of reference, the committee has assigned sequential numbers to the PPIRB's findings and recommendations (see Appendix C), which appear in square brackets in this report. In keeping with its statement of task, the committee reviewed whether the PPIRB's findings and recommendations are consistent with the 2018 report. In cases where the PPIRB report considered issues not addressed in the 2018 report, the committee drew upon other reports from the National Academies, briefings to the committee, or other publicly available information to assess consistency with the content of the 2018 report or determine whether the committee agrees with the PPIRB's conclusions. Because many of the PPIRB's findings and recommendations came with no supporting information or explanation that provided insight into how the board reached its conclusions or worded its statements, the committee based its review as much as possible on reasonable interpretations of the PPIRB's findings and recommendations.

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[1] Planetary Protection Independent Review Board (PPIRB), *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf.

[2] See National Academies of Sciences, Engineering, and Medicine (NASEM), *Review and Assessment of Planetary Protection Policy Development Processes*, The National Academies Press, Washington, D.C., 2018.

GENERAL AND OVERARCHING FINDINGS AND RECOMMENDATIONS

The PPIRB's first seven findings and recommendations consider the advent of new types of private-sector missions, the evolution of the scope of planetary protection policy, scientific and technological advancements, and the need for independent, outside advice to NASA on planetary protection issues.

> *Major Finding: With the advent of private sector robotic and human planetary missions, as well as new ultra-low cost (e.g., CubeSat-class) planetary missions, the context in which PP is conducted is profoundly and rapidly changing.* [1]

> *Major Finding: For planetary missions involving locations of high astrobiological potential, it is essential that forward and backward contamination consideration be integral to mission implementation. This applies to both government and private sector missions.* [2]

> *Supporting Finding: The PPIRB did not assess planetary exploration historical site preservation or the implications of the human modification of celestial bodies in the Solar System, for example, for resource recovery.* [3]

The PPIRB and 2018 reports are fundamentally in agreement on these issues. However, the 2018 report noted that planetary protection policy does not involve "significant actions beyond documentation and inventory of organic materials for the vast majority of ongoing and planned private-sector space activities,"[3] with the possible exception of potential private-sector missions to Mars (see below).

> *Supporting Finding: The scope of Planetary Protection landscape is complex, broad, nuanced, sometimes politically charged. The PPIRB could only evaluate it at a top level in the time and resources allocated for our review.* [4]

The statement of task for the 2018 study mandated that the report examine all aspects of planetary protection policy development—from policy formulation to the policy implications of implementing planetary protection requirements. The committee responsible for the 2018 report had sufficient time to complete this top-to-bottom study of planetary protection policy development processes.

> *Major Recommendation: Because of advances in knowledge and technologies since the Viking era, NASA's PP* [planetary protection] *policies and implementation procedures should be reassessed.*[4] [5]

> *Major Recommendation: Owing to the changing PP context and the rapid advancement of scientific, technological, and private sector planetary mission capabilities, NASA should reassess its PP guidelines at least twice per decade with an IRB-like body that includes representatives of all major stakeholder communities.* [6]

> *Major Recommendation: NASA should establish a standing forum for the discussion and resolution of emergent PP issues that includes input from government, private sector, and perhaps even non-U.S. private sector enterprises.* [7]

These three major recommendations are consistent with recommendations in the 2018 report, with one possible exception. The PPIRB's Major Recommendation [7] appears to envision a forum that would be involved in the "resolution" of issues. The committee understands that "resolution" can have different meanings, but it notes that final disposition of policy questions or disputes is a government

[3] See NASEM, 2018, p. 86.

[4] Some PPIRB findings and recommendation are accompanied by brief supporting text. For the sake of conciseness, the committee has not reproduced the supporting text for those items.

responsibility. More centrally, both reports emphasize the need for planetary protection efforts to reassess continually and, where appropriate, utilize new scientific and technological advances. In particular, the 2018 report included five relevant recommendations, as follows:

> Recommendation 3.2: NASA should assess the completeness of planetary protection policies and initiate a process to formally define the planetary protection requirements that are missing.
>
> Recommendation 3.6: NASA should reestablish an independent and appropriate advisory body and process to help guide formulation and implementation of planetary protection adequate to serve the best interests of the public, the NASA program, and the variety of new entrants that may become active in deep space operations in the years ahead.
>
> Recommendation 3.7: NASA should engage the full range of relevant scientific disciplines in the formulation of its planetary protection policies. This requires that scientific leaders outside of the standard planetary protection community in NASA participate in revisions to NASA and COSPAR planetary protection policies and requirements."
>
> Recommendation 3.8: NASA should adequately fund both the Office of Planetary Protection and the research necessary to determine appropriate requirements for planetary bodies and to enable state-of-the-art planetary protection techniques for monitoring and verifying compliance with these requirements.
>
> Recommendation 4.3: The SSB and NASA should pursue new mechanisms to anticipate emerging issues in planetary protection, respond more rapidly, and address new dimensions such as private-sector missions and human exploration.

The PPIRB report has one major finding and one major recommendation that focus on the NASA Office of Planetary Protection (OPP):[5]

> *Major Finding: The PPIRB applauds SMD's* [Science Mission Directorate's] *and OSMA's* [Office of Safety and Mission Assurance's] *recent revamping of the PPO and the work of the new PP Officer, which has increased communication, clarity, and responsiveness to community needs and concerns.* [8]
>
> *Major Recommendation: NASA should establish explicit processes such as an ongoing process of independent review to ensure that PPO policies and procedures are consistently applied regardless of specific PPO personnel.* [9]

The 2018 and PPIRB reports are consistent in supporting both the OPP's move from NASA's Science Mission Directorate (SMD) to the Office of Safety and Mission Assurance (OSMA) and the need that missions have for consistency in the application of planetary protection policy, requirements, and processes. Two recommendations in the 2018 report addressed these points explicitly:

> Recommendation 3.4: NASA should expeditiously complete the transition of the OPP to OSMA and clarify the remaining issues concerning roles, responsibilities, resources, and locations of OPP functions.
>
> Recommendation 3.6: NASA should reestablish an independent and appropriate advisory body and process to help guide formulation and implementation of planetary protection adequate to

[5] The PPIRB report uses "PPO" for Planetary Protection Office. However, the organization's correct title is Office of Planetary Protection (OPP). This report and NASEM, 2018, use the latter terminology and reserves "PPO" as the acronym for the planetary protection officer. In practice, OPP and PPO are virtually synonymous.

serve the best interests of the public, the NASA program, and the variety of new entrants that may become active in deep space exploration in the years ahead.

Both reports agree that planetary protection policy should apply equally to governmental and private-sector space activities. The PPIRB report contains six findings or recommendations regarding the clarity and timeliness of the development and implementation of planetary protection requirements. With respect to clarity, the report states as follows:

> *Major Finding: There is a general lack of clarity concerning PP requirements and implementation processes, particularly for non-NASA missions; this impedes the development of private sector planetary exploration.* [10]

The PPIRB and 2018 reports are consistent in recognizing a lack of clarity in the planetary protection requirements and implementation processes for non-NASA, private-sector missions. Indeed, the 2018 report identified a critical need for the federal government to clarify where legal and regulatory authority rests for overseeing planetary protection issues implicated by private-sector space activities that have no NASA participation. This “regulatory gap” is discussed in detail later in this chapter.

> *Major Recommendation: NASA should clarify its policy for exercising PP authority over primarily non-NASA space activities that have some level of NASA involvement.* [11]

The 2018 report did not analyze how NASA implements its planetary protection policies concerning non-NASA space activities that involve some NASA participation. However, the policy is clear. For space activities that NASA sponsors or that utilize NASA resources, NASA requires all aspects of those activities—whether undertaken by a foreign government or a private-sector entity—to comply with NASA’s planetary protection requirements. In fact, NASA’s documents state the formal policy in NPD8020.12D (section 2.2.2):

> NASA shall provide hardware, services, data, funding, and other resources to non-NASA missions (including but not limited to resources provided through international agreements, contracts, Space Act agreements, grants, and *cooperative* agreements) only if the recipient organization(s), whether governmental or private entity, demonstrate adherence to appropriate policies, regulations, and laws regarding planetary protection that are generally consistent with the COSPAR Planetary Protection Policy and Guidelines.

The committee—and both reports—agree that planetary protection policy be clear.

> *Major Recommendation: To further encourage the development of private sector planetary activities, NASA should offer a greater degree of PP expertise and tools to new and emerging actors in planetary exploration.* [12]

The 2018 report did not discuss whether NASA could support possible new entrants into the exploration and use of space, but the committee agrees that such NASA support would be appropriate. Having NASA share planetary protection expertise and tools with private-sector entities would be similar to NASA’s traditional role in working with the private sector in aeronautics.

The PPIRB report offers one major finding and two recommendations about the importance of timely completion of planetary protection requirements.

> *Major Finding: The late addition of PP requirements to some projects has been costly and inefficient to implement.* [13]

Major Recommendation: To reduce project inefficiencies, PP requirements should be finalized early in mission formulation and should avoid past practices of adding new or unexpected PP requirements, including in categorization letters. [14]

Major Recommendation: PP requirements on missions should be written to define PP intent, rather than detailed implementation methods, thereby allowing projects to select and/or develop implementations most suitable to meet their PP requirements from a systems standpoint. [15]

This finding and these recommendations are consistent with the 2018 report, which included two relevant findings and a recommendation:

Finding: Because NASA planetary protection policies have been incomplete with respect to unique aspects of new, first-of-a-kind missions, requirements for these spaceflight missions have not always been clearly defined at the beginning of a project or communicated to projects in accordance with NASA's standard protocols for imposing headquarters-level requirements (2018 report, p. 58).

Finding: The NASA Office of Planetary Protection and the mission project teams have not been following standard NASA spaceflight program and project management and systems engineering practices. In particular the PPO has been issuing level-1 requirements informally through letters, email, and verbal direction, and the project teams have accepted this practice even though this methodology is inconsistent with normal NASA practices. NASA officials delayed unnecessarily in taking advantage of NASA's established conflict resolution process (2018 report, p. 58-59).

Recommendation 3.2: NASA should assess the completeness of planetary protection policies and initiate a process to formally define the planetary protection requirements that are missing. …. For future new situations such as private sector missions to other bodies or human exploration of Mars, the policies and their potential impacts should be evaluated and examined well in advance of a mission start.

The 2018 report made clear its view that it is more appropriate to define planetary protection requirements by their intended goal and not by specific implementation methods in its discussion of the European Space Agency's (ESA's) approach to planetary protection. That discussion concluded with a finding and recommendation for an approach very similar to that advocated for in the PPIRB's major recommendation [15]:

Finding: ESA's planetary protection process reduces organizational conflicts of interest by separating lines of responsibility for formulating policy, establishing requirements, and implementing requirements and by giving more authority to mission project managers to translate top-level requirements into implementation approaches (2018 report, p. 66)

Recommendation 3.9: NASA should evaluate the ESA process for planetary protection implementation and strongly consider incorporating the elements of that process that are effective and appropriate.

The PPIRB report includes one finding and recommendation regarding NASA's legal authority over non-governmental missions:

Major Finding: Although NASA is not a regulatory agency, the Agency can likely affect control over non-NASA U.S. missions by linking PP compliance to eligibility for current or future NASA business or NASA support. However, overreaching application of such control could result in reduced opportunities for collaboration with private sector missions. [16]

Supporting Recommendation: Policy regarding such application of Agency authority to affect PP implementation should be carefully reviewed above the PPO level. [17]

The 2018 report also noted that NASA is not a regulatory agency, but that the agency uses contracts or other formal agreements to require non-NASA missions that involve NASA participation or use NASA resources to follow NASA's planetary protection requirements. When requested, NASA advises the Federal Aviation Administration (FAA) on planetary protection when the latter conducts payload reviews of proposed launches of non-NASA missions (e.g., as happened with Moon Express, SpaceX, and SpaceIL missions). However, the 2018 report did not discuss whether NASA could make private-sector compliance with NASA planetary protection policy for missions not involving NASA participation a condition for NASA to enter into future contracts and agreements with such entities.

The "General/Overarching" section of the PPIRB report presents one finding and one recommendation pertaining to COSPAR. The finding states:

> *Supporting Finding: COSPAR PP guidelines have evolved to be an internationally recognized, voluntary standard for protection of scientific interests in celestial bodies. Adherence to the COSPAR guidelines has been considered an acceptable mechanism for establishing a State party's compliance with the harmful contamination aspects in Article IX of the OST [Outer Space Treaty]. Adherence to COSPAR PP guidelines have constituted one type of mechanism for establishing compliance with Article IX, but this is not the only such compliance mechanism; other mechanisms that may be more appropriate also exist.* [18]

The 2018 report also found that, while COSPAR guidelines are not legally binding, they have become widely recognized international standards used by all space-faring countries to guide compliance with Article IX of the Outer Space Treaty (OST):

> Finding: For five decades, the states parties to the Outer Space Treaty have used COSPAR policy as part of complying with their planetary protection obligations under the treaty and, thus, have made COSPAR interdependent with their respective national rules, institutions, and processes on planetary protection.
>
> Finding: All spacefaring nations, including new entrants to space exploration, have declared they will comply with COSPAR guidance on planetary protection. Such commitment highlights the importance of the COSPAR planetary policy development process to the behavior of spacefaring nations, including state party efforts to comply with their planetary policy obligations in the Outer Space Treaty.[6]

The 2018 report identified no international mechanism other than COSPAR that states parties to the OST have used, or proposed to use, for guiding compliance with Article IX.

This history raises questions about what the PPIRB meant when it claimed in Supporting Finding [18] that "more appropriate" mechanisms "also exist" for "establishing compliance with Article IX." In response to questions from the committee, the chair of the PPIRB stated that, in formulating Supporting Finding [18], the PPIRB had in mind the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS), which connects to the PPIRB's recommendation on this issue:

> *Supporting Recommendation: Whenever updating U.S. PP policy and implementation practices, the U.S. government should work with the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) to communicate new U.S. PP approaches to the international community, share best practices, and encourage the international community to address such issues.* [34]

[6] See NASEM, 2018, p. 18.

The combination of Supporting Finding [18] and Supporting Recommendation [34] suggests that the PPIRB is advising the U.S. government to transition its involvement in international cooperation on planetary protection from COSPAR to COPUOS.

Such an approach is not consistent with the 2018 report, which focused on improving COSPAR as the international forum for cooperation on planetary protection policy.[7] The approach also departs from how the U.S. government has engaged in international cooperation on planetary protection policy development in the 50 years since the adoption of the OST.

As the 2018 report described, the practice of the U.S. government has involved NASA, with input from the Space Studies Board of the National Academies, developing new planetary protection approaches and taking those approaches, and the supporting scientific information, to COSPAR for international cooperation involving other countries and the scientific communities involved in planetary protection. COPUOS has not been directly involved in planetary protection issues since the late 1950s. In 2017, COPUOS itself identified "COSPAR as the appropriate international authority for creating consensus planetary protection guidelines."[8] The 2018 report observed that "COSPAR and COPUOS have discussed" the possibility of a "closer relationship" between COSPAR and the United Nations but "concluded that it was not appropriate at this time."[9] The PPIRB report contained no information or explanation for why the board believed that COPUOS was a more appropriate international forum for cooperation on planetary protection than COSPAR. Nor does it explain advantages accruing from bringing planetary protection issues within the scope of COPUOS activities.

As mentioned in Chapter 1 of this report and discussed in the 2018 report, COSPAR has reorganized its Panel on Planetary Protection (PPP) in order to make it more effective in developing policies that reflect the changing complexion of planetary exploration.[10] The PPP's most recent terms of reference state that these policies "should be based upon the principle that COSPAR planetary protection policies should enable the exploration and use of the solar system, not prohibit it. It is not the purpose of the Panel to specify the means by which adherence to the COSPAR planetary protection policy is achieved; the best and most cost effective means to adhere to the COSPAR planetary protection requirements is reserved to the engineering judgment of the organization responsible for the planetary mission."[11]

After Supporting Finding [18] on COSPAR, the first section of the PPIRB report turns to three findings and three recommendations addressing the scientific basis of planetary protection requirements. The findings are as follows:

> *Supporting Finding: For many of NASA's scientifically driven planetary exploration missions to astrobiologically relevant targets, scientific cleanliness requirements often exceed PP bioburden requirements.* [19]

> *Supporting Finding: Anachronistic, and sometimes unrealistic, PP requirements (e.g., delivery of <1 viable organism to Europan liquid water for Europa Clipper) have driven a great deal of costly and sometimes questionable effort, often involving requirements or implementation waivers.* [20]

> *Supporting Finding: The PPIRB applauds and encourages flexible ways to address PP intent using novel methods.* [21]

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[7] See NASEM, 2018, pp. 72-76 and 89.

[8] See NASEM, 2018, p. 42.

[9] See NASEM, 2018, p. 76.

[10] See NASEM, 2018, pp. 73-76.

[11] COSPAR Planetary Protection Panel Terms of Reference approved by the COSPR Bureau, March 21, 2019. Available at https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp.

The 2018 report did not discuss whether mission science requirements are often more stringent than planetary protection bioburden requirements. That is, are there situations in which the biological or organic cleanliness requirements for a scientific instrument to meet its performance objectives are more demanding than the requirements for planetary protection? The PPIRB report does not cite any examples of such cases, but the committee is aware that such cases have happened and may occur again.[12]

The two reports are consistent in that both identify cases in which planetary protection requirements that have been levied on missions are unrealistically demanding and costly, and that evidence-based openness to flexibility and innovation in implementing planetary protection requirements is desirable in preventing such situations from causing delays and unneeded mission costs.

Three recommendations in this section of the PPIRB report build on the idea of being open to new techniques and approaches for meeting both forward and back contamination objectives:

> *Supporting Recommendation: The PPO should exploit new discoveries and new technologies to better categorize exploration targets, create better forward and backward PP implementation protocols, and lower PP cost and schedule impacts on projects.* [22]
>
> *Supporting Recommendation: For forward contamination, NASA PP policy should move beyond exclusive adherence to spore counts, which is an outdated legacy of the 1970s Viking era. PP policy should encourage the use of proven modern techniques and well-established genomic tools for monitoring and characterization of bioburden of cleanroom facilities and flight hardware. NASA should also encourage the broader use of probabilistic models of the risk of "harmful" forward contamination based on likely scenarios and acceptable risk outcomes.* [23]
>
> *Supporting Recommendation: For both forward and backward contamination requirements, NASA should continue to allow novel approaches, such as crediting for time spent in the harsh space environment or on harsh planetary surfaces (e.g., UV, radiation, temperature extremes, lack of liquid water). To enable this, NASA should support quantitative laboratory studies of such approaches to demonstrate quantitative PP credits.* [24]

All three recommendations are consistent with the 2018 report, which recommended that NASA recognize relevant advances in biotechnology and engage the broader scientific community in capitalizing on those developments:

> Finding: The field of planetary protection science fills a rather small sector of modern science, and it has not been able to engage a substantial number of scientists who have been leading in important areas of modern sciences. For example, while the field of biology has made enormous advances in recent years many of those advances that could be applicable to improving approaches to planetary protection have not yet been fully integrated into the development of planetary protection policy or translated into practical approaches to implement policies.[13]
>
> Recommendation 3.7: NASA should engage the full range of relevant scientific disciplines in the formulation of its planetary protection policies. This requires that scientific leaders outside of the standard planetary protection community in NASA participate in revisions to NASA and COSPAR planetary protection policies and requirements."
>
> Recommendation 3.8: NASA should adequately fund both the Office of Planetary Protection and the research necessary to determine appropriate requirements for planetary bodies and to enable state-of-the-art planetary protection techniques for monitoring and verifying compliance with these requirements. The appropriate investment in this area should be based on a strategic

[12] For an example in the case of the Mars 2020 mission, see NASEM, 2018, p. 50. A better example is the very stringent organic (and associated bioburden) requirements levied on the OSIRIS REx asteroid sample-return mission to satisfy the scientific objectives of measuring organic compounds on a pristine, but abiotic, body.

[13] See NASEM, 2018, p. 64.

assessment of the scientific advances and technology needs to implement planetary protection for likely future missions.

Both reports addressed the need for clear requirements that are developed through a participative process and communicated clearly to mission teams. The PPIRB report recommended the following:

Supporting Recommendation: NASA's PP requirements should be completely specified in NASA Procedural Requirements (NPRs)/NASA Policy Directives (NPDs) so that projects subject to NASA PP requirements know what to expect and can better plan in advance to a known, fixed set of project requirements. [25]

Supporting Recommendation: The PPO should implement both well-documented and transparent PP requirements and requirements waiver processes for all missions with NASA involvement. [26]

Supporting Recommendation: NASA should provide external stakeholders with clear information and better insight and outreach on its PP standards and processes. This should include a rollout plan for new PP processes, followed by regular stakeholder engagement opportunities to ensure widespread awareness and understanding of PP standards and processes. [27]

The related recommendations in the 2018 report similarly emphasized the importance of broad stakeholder engagement in developing and communicating planetary protection policies and requirements:

Recommendation 3.2: NASA should assess the completeness of planetary protection policies and initiate a process to formally define the planetary protection requirements that are missing. … For future new situations such as private sector missions to other bodies or human exploration of Mars, the policies and their potential impacts should be evaluated and examined well in advance of a mission start.

Recommendation 3.6: NASA should reestablish an independent and appropriate advisory body and process to help guide formulation and implementation of planetary protection adequate to serve the best interests of the public, the NASA program, and the variety of new entrants that may become active in deep space exploration in the years ahead.

The PPIRB report devotes one finding and recommendation to concerns about streamlining planetary protection measures for ultra-low-cost missions, as follows:

Supporting Finding: Without further changes to streamline low-cost mission PP implementation, ultra-low-cost planetary missions (e.g., CubeSats) will likely have a PP implementation cost burden that is a larger percentage of their total budget than larger missions, which in turn could threaten their low cost, particularly for those missions beyond PP Category II. [28]

Supporting Recommendation: NASA should assess how to streamline PP implementation for ultra-low-cost planetary missions. [29]

The 2018 report did not address ultra-low-cost missions, and, therefore, the two reports are not directly comparable on this issue. Subsequent to publication of the 2018 report, interest in small, low-cost planetary mission concepts (e.g., SmallSats and CubeSats) has increased.[14] For example, SmallSat concepts comprise a significant portion of responses to a recent call for future flight mission ideas from

[14] For background information concerning CubeSats and SmallSats, see, for example, https://www.nasa.gov/content/what-are-smallsats-and-cubesats.

the Mars science community.[15] The committee addresses the issues of small, low-cost missions below in the section on categorization and again in Chapter 3.

However, the committee notes, first, that providing basic spacecraft information, such as a master equipment list, is required to obtain NASA or FAA launch approval and would suffice for planetary protection purposes for most missions, especially for Category I missions, and possibly for Category II missions (see Appendix E). Thus, only missions to Mars and the icy moons of Jupiter and Saturn (and, by extension, the other ocean worlds) may have substantial planetary requirements that would add unique efforts or costs.

Second, the committee emphasizes that all missions are required to respect planetary protection objectives by ensuring space activities take into account the cost of implementing applicable planetary protection measures. Finally, the committee notes that, as a general rule, all missions can benefit from approaches designed to streamline implementation of planetary protection measures and minimize their costs.

The PPIRB report has findings and recommendations regarding enforcement of reporting requirements and contractual requirements for planetary protection. The finding and associated recommendation addressing enforcement state:

> *Supporting Finding: It is impractical for launch providers or satellite hosts to definitively determine the biological content of every payload. Biological materials intentionally added by a bad actor are especially challenging for launch providers to monitor or report, as they can be further obscured by falsified verification or inaccurate documentation.* [30]

> *Supporting Recommendation: Breaches of PP reporting or other requirements should be handled via sanctions that hold the root perpetrator accountable, rather than increasing the verification and regulatory burden on all actors.* [31]

This finding and recommendation arise from PPIRB's evaluation of the rule-breaking incident associated with the Beresheet mission. Built by SpaceIL,[16] an Israeli nonprofit organization, and launched by SpaceX, this commercial lunar lander carried a variety of payloads, including a laser retroreflector experiment supplied by NASA via an agreement with the Israeli Space Agency.[17] Unbeknownst to SpaceIL, SpaceX, or NASA (which also provided tracking and communications support), another payload aboard Beresheet contained undisclosed organisms and, possibly, other biological materials.[18] As such, this was a clear case of a payload owner not providing the launch operator or NASA with full information about the payload's biological content. This incident happened after publication of the 2018 report, so that report contained no discussion of the issues the incident generated.

The committee addresses the implications of the SpaceIL incident in Chapter 3 below, because the incident connects to persistent questions about the legal authority and rules applicable to private-sector space activities conducted with or without NASA participation that implicate planetary protection.

> *Supporting Finding: Space Act Agreements and some NASA contracts require NASA 8020.12 PP compliance, which in turn invokes COSPAR policy/guidelines.* [32]

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[15] See, the "Mission Concept Template" issued by NASA's Mars Architecture Strategy Working Group. Available on request from MASWGcomments@jpl.nasa.gov.

[16] For more information, about SpaceIL and Berensheet, see, for example, http://www.spaceil.com/mission.

[17] See, for example, https://www.nasa.gov/press-release/nasa-israel-space-agency-sign-agreement-for-commercial-lunar-cooperation.

[18] C.D. Johnson, D. Porras, C.M Hearsey, and S. O'Sullivan, "The Curious Case of the Transgressing Tardigrades (Part 1)," *The Space Review*, August 26, 2019; and C.D. Johnson, D. Porras, C.M Hearsey, S. O'Sullivan, and M. Vidauri, "The Curious Case of the Transgressing Tardigrades (Part 2)," *The Space Review*, September 3, 2019. Both available at https://www.thespacereview.com.

Supporting Recommendation: These contractual requirements should be reviewed by NASA to simplify compliance where possible and to avoid overconstraining the means of meeting NASA intent. [33]

The 2018 report mentioned that NASA includes its planetary protection requirements in contracts or agreements with non-NASA entities for missions that involve NASA participation or that use NASA resources. NASA planetary protection requirements in NPD (NASA Policy Directive) 8020.12 are consistent with COSPAR guidelines, and, as noted above, all space faring nations use COSPAR guidelines in their efforts to comply with Article IX of the OST. Given that NASA participates in the activities under such contracts or agreements, NASA complies with its planetary protection requirements in activities the agency undertakes. It would not be appropriate for such contracts or agreements to permit private-sector entities to work under less rigorous planetary protection requirements or processes than would NASA personnel. However, the 2018 report did not analyze whether Space Act agreements or NASA contracts that include requirements for compliance with NASA planetary protection requirements (1) impose unnecessary burdens on private-sector entities working with NASA or (2) could include simplified means of planetary protection compliance for space companies.

PLANETARY PROTECTION CATEGORIZATION

The PPIRB report has one finding and four recommendations specific to the categorization of missions to the Moon, Mars, or small solar system bodies for planetary protection purposes. The finding states:

Major Finding: As more is learned about each celestial body, more detailed and tailored approaches to forward contamination become advisable. These include variable categorization based on surface/subsurface location, where and how many times past missions have investigated the body, and the survivability and propagation of terrestrial organisms in the body's environments. [35]

The 2018 report similarly concluded that more scientific information is needed to inform future approaches to planetary protection. The 2018 report described how planetary protection policy has, in fact, changed significantly over time in light of new scientific information about solar system bodies.

However, the PPIRB report perpetuates confusion about planetary protection terminology. The report suggests that much of the Moon can be re-defined as Category I, while areas of Mars may be re-assigned to Category II (see Appendix E). However, in planetary protection policy, *missions* are categorized and not planetary bodies and their surfaces. NASA OPP typically reviews a mission's objectives and provides the mission with a categorization letter, and the assigned category determines the planetary protection requirements for the mission.

As scientific understanding progresses, certain missions to the Moon, Mars, ocean worlds, and small bodies could receive a categorization that imposes fewer planetary protection requirements. The space exploration community is moving away from treating planets and other solar system bodies as monoliths and toward viewing them potentially as entities with diverse areas of interest for different purposes.[19] This evolution of mission categorization would benefit not only the traditional planetary science community but also private-sector activities and human-exploration missions. Indeed, the question of mission categorization is a cross-cutting topic that touches on the affordability of entrepreneurial space missions as well as the feasibility of human "exploration zones." The committee believes that the proper way to address a categorization decision is to evaluate the science or other objectives for visiting a given area and thus assigning whichever mission category may be appropriate.

[19] See, for example, NASEM, 2018, pp. 79-81.

Lunar Missions

The PPIRB report makes a specific recommendation concerning the planetary protection categorization of lunar missions:

> *Major Recommendation: NASA should study how much of the Moon's surface and subsurface could be designated PP Category I versus Category II. Establishing different categories for different locations on the Moon could significantly simplify and enhance exploration opportunities for both the civil and private sectors.* [36]

The 2018 report did not address whether NASA could study how many missions to the Moon could be designated Category I rather than Category II (see Appendix E). However, the Moon has been called a "witness plate" of near-Earth impact history over the last 4 billion years or more. The record of meteoritic and cometary strikes since the Moon was formed comprise an important piece of planetary evolution that has been lost or severely eroded on Earth. What this historical record reveals has direct bearing on understanding the astrobiology of the early Earth, the rise of life after the period of heavy bombardment, and the possibility that certain permanently shadowed regions may retain a record of volatile materials, including water ice, from billions of years of meteoritic and cometary impacts. Subsequent to the discovery of water ice in permanently shadowed regions of the Moon, NASA OPP has classified lunar missions to be Category II.

The differences between Category I and Category II would appear to be minimal for any experienced space hardware developer. Category I missions require no planetary protection documentation, and Category II missions require only brief documentation and an inventory of organic compounds in excess of 1 kg for lunar missions. In the case of fleets of CubeSats, the current requirement is for an inventory of organics in excess of 10 g per element.[20] NASA OPP has developed a single-page organic inventory template to reduce the workload for lunar CubeSat teams.[21] Therefore, the lunar Category II requirement does not, at first blush, seem onerous. As a practical matter, even a student-led CubeSat mission will have a so-called master equipment list and a simple project plan that would satisfy or nearly satisfy the Category II requirements. However, the committee believes that a more rigorous scientific evaluation of the appropriate number for the organic inventory for CubeSats is required (see Chapter 3).

However, according to the OPP,[22] planetary protection policy includes requirements associated with trajectory calculations and landing-site analyses for impacts, pre-launch and post-launch assessments, and the like. During the committee's first meeting, the PPO described the burden faced by small satellite entrepreneurs and academics when required to demonstrate at some level of statistical confidence that a spacecraft would not inadvertently impact an object, such as Mars. The committee foresees that under certain circumstances, a secondary SmallSat payload developer might not have the budgetary capability to conduct all required pre-and post-launch analyses for the Moon. In addition, the PPIRB chair stated to the committee that the PPIRB sensed that there might some irreducible cost for meeting planetary protection measures that even the smallest and simplest spacecraft would have to bear.

In the time available, the committee could not verify whether planetary protection requirements impose such a minimum cost and, therefore, suggests that the OPP undertake a study to see if such a cost

[20] See, "Guidelines on the implementation of an organic inventory" in G. Kminek, C. Conley, V. Hipkin, H. Yano, "COSPAR's Planetary Protection Policy," *Space Research Today*, Number 200, December 2017, https://cosparhq.cnes.fr/assets/uploads/2019/12/PPPolicyDecember-2017.pdf.

[21] Private communication from J. Andy Spry to G. Scott Hubbard, January 8, 2020. The current organic inventory threshold for NASA's Artemis program is 1 kg, but for13 individual CubeSats carried as secondary payloads on Artemis 1, "the inventorying is at the 10 gram level of fidelity, to allow for meaningful aggregation into the Artemis system totals."

[22] See, for example, the OPP website, https://sma.nasa.gov/sma-disciplines/planetary-protection.

exists and, if so, at what level. NASA's own Commercial Lunar Payload Services program may afford an opportunity to evaluate this question.[23] As a possible solution to be considered for the small spacecraft community, the committee notes that NASA, through the OPP, might provide some analytic support for trajectory calculations and impact analyses. The committee will return to the need for further study of both appropriate guidelines for organic inventories and planetary protection costs for small spacecraft missions in Chapter 3.

At the other end of the size-and-cost spectrum, current U.S. government initiatives, such as the Artemis program, contemplate human missions to the surface of the Moon for "long-term exploration and utilization."[24] Such missions could produce scientific and commercial activities on the lunar surface that include mining regolith for in situ resource utilization (ISRU). In these circumstances, providing an inventory of organics greater than 1 kg will be essentially impossible given the presence of humans and the widespread civil engineering machinery required. Such an effort would justify Category I requirements for lander missions to regions of interest, provided such regions had been previously explored and evaluated for their scientific value.

Therefore, the committee concurs with the PPIRB that action on the part of NASA and the lunar science community is required to study the possibility that some lunar lander missions could be subject to Category I requirements. For example, a properly constituted expert group, such as the NASA Lunar Exploration Analysis Group or the SSB Committee on Astrobiology and Planetary Science, could review the data from Apollo as well as more recent missions (e.g., Lunar Prospector, Lunar Reconnaissance Orbiter, and LCROSS) to determine whether the contemplated regions are sufficiently well explored and documented so that activities such as a human landing base or ISRU, would not burden future science.

Furthermore, the lunar science community needs to know whether remote sensing measurements of the presence of approximately 30 percent (by weight) water ice in certain shadowed regions on the Moon are correct. Previous studies have considered how a mission to examine these ice deposits could be executed.[25] Any such endeavor contacting the lunar surface will remain at least a Category II mission until the organic and chemical composition is known and the astrobiological implications are assessed, before ultimately determining whether the resources might be declared available for ISRU.

Finally, the incident involving SpaceIL's Beresheet lunar lander has drawn widespread attention to the organic inventory currently required for a Category II mission. However, if missions intended to land anywhere in large areas of the Moon could receive a Category I, spacecraft such as Beresheet would have a logical destination where the payload was of no consequence.

Mars Missions

The PPIRB report makes two recommendation and offers one finding concerning the planetary protection categorization of Mars missions:

> *Major Recommendation: NASA should reconsider how much of the Martian surface and subsurface could be Category II versus IV by revisiting assumptions and performing new analysis of transport, survival and amplification in order to reassess the risk of survival and propagation of terrestrial biota on Mars.* [37]

[23] For more information about NASA's Commercial Lunar payload Services program see, for example, https://www.nasa.gov/content/commercial-lunar-payload-services.

[24] Executive Office of the President, "Presidential Memorandum on Reinvigorating America's Human Space Exploration Program," The White House, Washington, D.C., December 11, 2017, https://www.whitehouse.gov/presidential-actions/presidential-memorandum-reinvigorating-americas-human-space-exploration-program.

[25] See, for example, NASEM, *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011, pp. 359-360. See also, https://www.nasa.gov/feature/new-viper-lunar-rover-to-map-water-ice-on-the-moon.

Major Recommendation: NASA should consider establishing (i) high priority astrobiology zones, i.e., regions considered to be of high scientific priority for identifying extinct or extant life, and (ii) human exploration zones, i.e., regions where the larger amounts of biological contamination inevitably associated with human exploration missions, as compared to robotic scientific missions, will be acceptable. [38]

Supporting Finding: Various scientific studies[26] *suggest that the survival and amplification of terrestrial biota are unlikely on the Martian surface, which would support classification of much of the Martian surface as Category II.* [40]

As the 2018 report discussed, the exploration of Mars presents a far more complex planetary protection challenge than the Moon. Mars has a thin atmosphere, at least 44 distinct geologic units,[27] significant amounts of water ice distributed at a variety of latitudes, possible liquid water aquifers below the surface, complex organics, and unexplained methane releases. As such, Mars is a very complex world containing multiple environments that could potentially harbor evidence of extinct or extant life.

Categorization of Mars missions as either III, IV, or restricted sample return V (see Appendix E) is grounded in scientific data collected over the past 50 years, but particularly in the last 20 years of the "follow the water" Mars Exploration Program. Now, however, Mars is an attractive object for not only scientific exploration but also commercial space ventures and human exploration.

The 2018 report noted that commercial interests want to minimize uncertainty and expense and that human exploration faces particular planetary protection challenges. That report did not recommend moving some missions (i.e., Mars landers) to Category II, but it did recommend that "NASA's process for developing a human Mars exploration policy should include examination of alternative planetary protection scenarios and should have access to the necessary research that informs these alternatives."[28]

Human explorers can never be cleaned like robotic spacecraft, and space suits and human habitats will leak or may have catastrophic blowouts. To accommodate the competing interests of robotic science and human exploration missions, so-called "exploration zones" have been proposed. Both the human exploration and science communities have participated in initial workshops in recent years to identify potential exploration zones.[29]

The research citations noted in the PPIRB report (see Supporting Finding [40]) are an interesting, albeit inconclusive, addition to the discussion of what constitutes a so-called "Special Region" or an exploration zone. The current state of research does not yet appear to be adequate to determine whether there are regions on Mars where human explorers or commercial missions might land with minimal planetary protection implications.

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[26] Pavlov, A.A., Vasilyev, G., Ostryakov, V.M., Pavlov, A.K., Mahaffy, P., 2012. Degradation of the organic molecules in the shallow subsurface of Mars due to irradiation by cosmic rays. Geophys. Res. Lett. 39 (13); Khodadad, C.L., Wong, G.M., James, L.M., Thakrar, P.J., Lane, M.A., Catechis, J.A., Smith, D.J., 2017. Stratosphere conditions inactivate bacterial endospores from a Mars spacecraft assembly facility. *Astrobiology* 17 (4), 337-350; Shotwell, R.F., Hays, L.E., Beaty, D.W., Goreva, Y., Kieft, T.L., Mellon, M.T., Moridis, G., Peterson, L.D. and Spycher, N., 2019. The potential for an off nominal landing of a multimission radioisotope thermoelectric generator-powered spacecraft on Mars to induce an artificial special region. *Astrobiology* (in press) V. 19, # 11, DOI: 10.1089/ast.2017.1688; Rummel, J.D., Beaty, D.W., Jones, M.A., Bakermans, C., Barlow, N.G., Boston, P.J., Chevrier, V.F., Clark, B.C., de Vera, J.P.P., Gough, R. V., Hallsworth, J.E., et al., 2014. A new analysis of Mars ''special regions": findings of the second MEPAG Special Regions Science Analysis Group (SR-SAG2). *Astrobiology* 14 (11), 887-968.

[27] K.L. Tanaka, J.A. Skinner Jr., J.M. Dohm, R.P. Irwin III, E.J. Kolb, et al., *Geologic Map of Mars*, Scientific Investigations Map 3292, U.S. Geological Survey, Flagstaff, Arizona, 2014.

[28] See NASEM, 2018, Recommendation 5.1.

[29] See, for example, https://www.nasa.gov/journeytomars/mars-exploration-zones.

Through information obtained from past and future Mars missions and complementary research, some regions may have sufficiently low risk of forward or back contamination so that a lander would only be required to follow the current Category II requirements. Human exploration mission planners require access to the necessary research that informs the categorization of missions to Mars.[30]

The committee agrees with the PPIRB report concerning the need for more research to provide a basis for a more flexible approach to mission categorization for Mars. In that regard, the committee emphasizes in particular the suggestions in the 2018 report that research concerning Mars is needed to address the following questions: [31]

> 1. Because some releases of gases, dust, or other emissions from a human landing site or base are inevitable, how far would such contamination travel in the very thin atmosphere of Mars? Would it be diluted extensively and/or sterilized before reaching the science region of interest?
>
> 2. If a human habitat on Mars were to suffer a catastrophic blowout event and release microbes from the astronauts, how far would the contamination travel and what effect could it have on the scientific exploration regions?
>
> 3. Using the current knowledge of Mars and modern biological expertise, is there credible evidence that any terrestrial microbes would survive in the harsh radiation and dry, oxidizing conditions on the surface of Mars?
>
> 4. To what extent might modern genomic techniques be applied to assessing contamination and possibly even eliminate the need for some contamination control requirements?

Previous OPP and COSPAR planning documents have recommended research on these topics, but such studies have not yet been funded.[32] Answers to these and related questions would advance the needs of future science, commercial activities, and human exploration.

Small Bodies

The PPIRB report makes one recommendation and offers one finding concerning the planetary protection categorization of missions to small bodies in the solar system:

> *Supporting Recommendation: In cases of missions to Solar System destinations where there is a large population of similar Category I and II objects (e.g., comets, asteroids, Kuiper Belt Objects), NASA should allow classification of individual objects as Category I to simplify missions to them.* [39]

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[30] See NASEM, 2018, Recommendation 5.1.

[31] See NASEM, 2018, pp. 83-84.

[32] See, for example: M.S. Race, J.E. Johnson, J.A. Spry, B. Siegel, and C.A. Conley (eds.), *Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions—Final Report*, DAA_TN36403, NASA Human Exploration and Operations Mission Directorate and NASA Planetary Protection Office, Washington, D.C., 2015; G. Kminek, B.C. Clark, C.A. Conley, M.A. Jones, M. Patel, M.S. race, M.A. Rucker, O. Santolik, B. Siegel, and J.A. Spry (eds.), *Report of the COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions*, NASA Science Mission Directorate and Human Exploration and Operations Mission Directorate, Washington, D.C., 2016; and M.S. Race, J.A. Spry, B. Siegel, C.A. Conley, and G. Kminek (eds.), *Final Report of the Second COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions and COSPAR Work Meeting on Developing Payload Requirements Addressing PP Gaps on Natural Transport of Contamination on Mars*, COSPAR, Paris, France, 2019. All three documents are available at https://sma.nasa.gov/sma-disciplines/planetary-protection.

The PPIRB report makes a population argument for classifying missions to some small bodies as Category I:

> [J]ust as the lunar and Martian surfaces in their entirety do not need to bear the same planetary protection classification, in the case of small bodies where there are numerous potential targets, the contamination of any individual does not cause significant contamination to the class as a whole. If chemical evolution or origin of life experiments are planned for such objects, there are myriad to choose from that will not have been previously visited by robotic probes.

Most missions to such small bodies fall under Category II, and some asteroid missions are already assigned to Category I. As with the Moon, a small mission might not be able to satisfy the trajectory and launch analyses required to obtain a Category II designation. However, a planetary protection advisory committee could survey the small bodies' community and assess whether the population argument in the PPIRB report holds across the solar system. That is, are there enough similar asteroids and comets with pre-biotic composition such that, if one is contaminated, significant scientific knowledge is not lost?

HUMAN SPACEFLIGHT

The PPIRB report has much to say about human missions to Mars that is consistent with the 2018 report. The first major PPIRB finding on human spaceflight states:

> *Major Finding: Human missions to Mars will create new opportunities for science and exploration.* [41]

Previous studies of the U.S. human spaceflight program, such as the Augustine report, noted that "science can be enhanced by human exploration, particularly of complex environments, and by providing the ability to service scientific facilities in space."[33] The decadal survey for solar system exploration added, "On the basis of the importance of questions relating to life, the committee concluded that for the more distant future, human explorers with robotic assistance may contribute more to the scientific exploration of Mars than they can to any other body in the solar system."[34]

Eight PPIRB findings and recommendations then deal with the immaturity of planetary protection policy for human exploration and the need to develop the policy expeditiously. Those findings and recommendations address forward contamination, crew return and back contamination, national policy, and communications with the public, as follows:

> *Major Finding: PP planning for human missions to Mars and the communication of those plans to the public are presently immature.* [42]
>
> *Major Recommendation: NASA should expeditiously develop PP guidelines for human missions to Mars, whether those missions are conducted by NASA, other international agencies, or private entities.* [43]
>
> *Major Recommendation: NASA should begin planning for the public communication of all aspects of PP planning for human missions to Mars sooner rather than later, and should pay special attention to public PP concerns, similarly to NASA's proactive treatment of NASA missions involving radioisotope power systems.* [44]

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[33] Review of U.S. Human Spaceflight Plans Committee [a.k.a. Augustine report], *Seeking a Human Spaceflight Program Worthy of a Great Nation*, Office of Science and Technology Policy, Washington, D.C., 2009, https://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf, p. 78.

[34] NASEM, *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011, pp. 56-63.

Major Finding: Human missions to Mars will inevitably introduce orders of magnitude more terrestrial microorganisms to Mars than robotic missions have done or will do. [45]

Major Finding: NASA's current policies for robotic Category V Restricted Earth Return from Mars appear to be unachievable for human missions returning from Mars. [46]

Major Recommendation: Regarding the return of humans and equipment from Mars, NASA should invest in developing more informed, backward contamination PP criteria, considering protection of Earth's biosphere, the feasibility of mission implementation, and the potential for in situ hazard characterization on Mars. [47]

Supporting Recommendation: In considering crew return from Mars, NASA should assess the acceptability of the multi-month return trajectory as a PP quarantine and evaluation period, potentially simplifying terrestrial quarantine scenarios, requirements, and timescales. [49]

Supporting Recommendation: NASA should review COSPAR's humans to Mars principles and guidelines to assess which should be followed, discarded, or updated for NASA's first human Mars expedition. [50]

Both the PPIRB and 2018 reports generally agree on these topics. However, a previous National Academies' report has questioned the utility of the suggestion of using long-return flights to mitigate back-contamination concerns, as suggested in Supporting Recommendation [49].[35] Moreover, return flight times may not always be long, given appropriate technological advances. The 2018 report noted that neither NASA nor COSPAR has developed policies that deal with planetary protection for human exploration of Mars and that current "principles and guidelines may be impossible in any practical manner for human missions" and that "[t]he planetary protection challenges generated by human missions to Mars will require policy makers to adapt existing approaches and develop new strategies."[36]

The committee reiterates a point in the 2018 report that scientific studies are especially needed to provide a basis for:[37]

1. Establishing exploration zones (perhaps through an international process) where humans are allowed to explore;
2. Setting requirements for human missions that are relaxed from current COSPAR standards based on realistic engineering considerations and the outcome of the research and technologies studies addressing specific items in COSPAR policy; and
3. Delineating, through international agreement, areas of scientific interest that human missions cannot access and ensure that these zones have sufficient buffers to protect the scientific endeavors from human contamination until scientific studies are completed.

The scientific issues that underpin decisions about how to organize areas of Mars for future robotic and human exploration constitute a strategic need for the next phase of planetary protection policy to which the committee returns in Chapter 3.

The 2018 report did not address communications with the public about potential public concerns over human missions to Mars.[38] However, the 2018 report did note that the formal interagency review process by which the U.S. government reviews and approves space activities that could potentially have large-scale adverse environmental effects on Earth was established through a presidential directive issued

[35] National Research Council, *Scientific Prerequisites for the Human Exploration of Space*, National Academy Press, Washington, D.C., 1993, pp. 30-31.

[36] See NASEM, 2018, p. 79.

[37] See NASEM, 2018, p. 83.

[38] See PPIRB, 2019 [44].

in 1977.[39] The 2018 report found that this directive is out of date and recommended that it be revisited "in light of NASA plans for Mars sample-return missions and human-crewed missions to Mars and revise or replace its provisions for engaging relevant federal agencies in developing back-contamination protection policies."[40]

The PPIRB report also recommends paying more attention to how to conduct astrobiological studies in the presence of human activities:

> *Major Recommendation: Special attention should be paid to assess how astrobiological research can be carried out in the presence of human activities.* [48]

This recommendation is consistent with the 2018 report, which evaluated the same topic in the following way:[41,42]

> As noted in the discussion below of future studies, this approach assumes exploration activities can protect large parts of Mars for scientific study and that contamination from the human habitats will not expand into these other regions of interest.
>
> The feasibility and limitations of a policy that allows for protected science zones or unprotected human exploration zones depend on the extent to which contaminants can be transported across Mars. After many decades of intensive scientific Mars exploration, the only known truly global phenomena are dust storms. … it is conceivable that some release of contaminants might be (or might have been in the past) carried a significant distance by those dust storms.

As noted earlier in the committee's discussion of categorizing missions to Mars, important studies are required to address questions of atmospheric transport of contaminants, the survivability of terrestrial microbes on the surface of Mars, and the utility of modern genomic techniques for monitoring contamination control.

Finally, PPIRB Major Recommendation [47] and Supporting Finding [51] deal with related topics. In text accompanying Major Recommendation [47], the PPIRB report says Mars sample return "policies should take into consideration current understanding of the ongoing natural transport of material from Mars to Earth since the formation of the planets ~4.5 billion years ago."

Scientists have identified more than 220 meteorites on Earth that are believed to have originated on Mars because of their unique isotopic signatures and the presence of trapped gases matching those found in the martian atmosphere but not in Earth's. Analyses of such objects have led to claims of the detection of organic compounds and even controversial claims concerning the presence of ancient martian "microfossils."[43] While the case for the presence of organic compounds of martian origin have stood the test of time, meteorite experts and astrobiologists now discount the findings about microfossils as contamination from impact on Earth, misinterpretation of surface morphology, and inorganic processes. In any event, the Mars meteorites on Earth have no identifiable context because their region of origin on Mars is unknown. This fact limits the scientific utility of such objects. Further, the rocks have been altered by being subject to unknown and extreme conditions as they traveled from Mars to Earth. While one cannot discount all possibilities, the notion that life on Earth was "seeded" from Mars is speculative

[39] The White House, "Scientific or Technical Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space," Presidential Directive NSC-25, December 14, 1977. Available at https://fas.org/irp/offdocs/pd/pd25.pdf.

[40] See NASEM, 2018, Recommendation 3.1.

[41] See NASEM, 2018, p. 83.

[42] See NASEM, 2018, p. 92.

[43] D.S. McKay, E.K. Gibson Jr., K.L. Thomas-Keprta, H. Vali, C.S. Romanek, et al., "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001." *Science* 273, 1996, pp. 924-930.

and does not eliminate the need to exercise due care and diligence when handling samples brought back to Earth taken from formerly habitable areas on Mars.

Regarding forward contamination of Mars, the PPIRB report provides the following finding:

> *Supporting Finding: Terrestrial biology has been transported to Mars by previous robotic missions at discrete locations, although at low levels as compared to what is likely on future crewed and crew-related missions. The impact that these already transported organisms have had on any global Mars ecosystem is unknown but is likely to be minimal.* [51]

The PPIRB and 2018 reports are not comparable on the issue considered in Supporting Finding [51]. The 2018 report did not address what impact the transport of terrestrial organisms to Mars by robotic missions has had on the martian ecosystem. Spacecraft since the dawn of planetary exploration have been cleaned according to the standards in place at the time. The overarching concept was that, even with a crash landing, the chance that an Earth organism would be released on Mars was less than 1/10,000. As the 2018 report described, the history of the U.S. space program is one of diligence and, in the case of the Viking missions to Mars, significant expenditure to assure planetary protection integrity.

The 2018 report also documented what is known about other spacecraft that have landed or crashed on the Red Planet. Although available records indicate that the Soviets followed planetary protection guidelines in their missions to Mars,[44] no process to verify Soviet claims of compliance existed. Thus, “dirtier” spacecraft could have created some contamination. Indeed, several studies cited in the PPIRB report indicate that normal Earth organisms would not survive for any significant length of time on the martian surface.[45] However, as described above, the type of studies, experiments, and analysis recommended for human exploration will help answer questions about the transport and survival of Earth organisms on Mars.

PRIVATE-SECTOR INITIATIVES AND MISSIONS

This section of the PPIRB report includes eight findings and recommendations,[46] beginning with a statement about expanding private-industry interests in planetary missions:

> *Major Finding: In addition to NASA’s world-leading civil space exploration capabilities, the United States now has a vibrant, highly capable private space sector. Through rapid innovation and cutting-edge technology, this space sector is expanding access to space for both private and government users, unleashing new robotic and crewed exploration opportunities in the Solar System.* [52]

The 2018 report also noted “the emergence of private-sector interest in new types of space activities,” which fall within what is variously called “space entrepreneurship” and “new space,” and added:[47]

> These new activities include delivering crew and cargo to the International Space Station, launching and operating remote sensing technologies, plans for asteroid mining, interest in space tourism, transport to the lunar surface, and missions to Mars. The only ‘new space ’areas that implicate serious planetary protection concerns are missions to Mars.

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[44] See NASEM, 2018, pp. 28-31.

[45] See PPIRB report, Supporting Finding [40] and associated citations.

[46] A number of the PPIRB report’s other findings and recommendations are also relevant to private sector missions, specifically, the following findings or recommendations: [1, 6, 7, 10-12, 16, 17, 25, 27, 30, 31, 33]. In developing policy for private-sector actors, the combined set of findings and recommendations from the PPIRB report should be considered.

[47] See NASEM, 2018, p. 85.

Thus, both the PPIRB and 2018 reports recognize the importance for planetary protection policy of the entry of private industry into planetary exploration and other uses of space. Private-sector interest in missions to the Moon and Mars, including human missions, has developed over the last decade and has become more pressing as companies pursue such missions. Lunar and martian missions planned or proposed by private-sector entities underscore the needs to undertake the following:

1. Involve space companies in planetary protection policy discussions;
2. Consider private-sector interests that go beyond science; and
3. Clarify the legal and regulatory framework for private-sector space missions that do not involve NASA participation or use NASA resources.

In terms of the legal and regulatory framework, the PPIRB report stated:

> *Major Finding: Through existing authorization mechanisms under current Federal regulatory frameworks, the U.S. Government licenses the launch and re-entry of private space vehicles, including those for beyond Earth orbit activities. Regarding PP, these licensing mechanisms could be improved to relieve administrative burdens and address misperceptions of legal uncertainty for private sector space activities, including private sector robotic and human planetary missions that do not have significant NASA involvement.* [53]

By contrast, the 2018 report found that the legal problems facing planetary protection in connection with private-sector space activities having no NASA involvement went beyond "misperceptions of legal uncertainty" about federal "regulatory frameworks." The 2018 report noted that the FAA questioned whether its legal authority to approve launches and review launch payloads encompassed the ability to regulate planetary protection issues. The 2018 report also observed that:[48]

> No federal regulatory agency has the jurisdiction to authorize and continually supervise on-orbit activities undertaken by private-sector entities, including activities that could raise planetary protection issues. The committee heard from numerous experts that this regulatory gap is a serious problem in U.S. space law.

However, the PPIRB report also included a recommendation that more closely tracked the conclusions of the 2018 report on legal and regulatory issues:

> *Supporting Recommendation: For space activities without significant NASA involvement (including private sector robotic and human planetary missions), NASA should work with the Administration, the Congress, and private sector space stakeholders to identify the appropriate U.S. Government agency to implement a PP regulatory framework.* [58]

The 2018 report raised similar points:[49]

> Finding: A regulatory gap exists in U.S. federal law and poses a problem for U.S. compliance with the OST's obligations on planetary protection with regard to private sector enterprises. The OST requires states parties, including the United States, to authorize and continually supervise nongovernmental entities, including private sector enterprises, for any space activity that implicates the treaty, including its planetary protection requirements.
>
> Recommendation 6.2: Congress should address the regulatory gap by promulgating legislation that grants jurisdiction to an appropriate federal regulatory agency to authorize and supervise private-

[48] See NASEM, 2018, pp. 86-87.
[49] See NASEM, 2018, Recommendation 6.2.

sector space activities that raise planetary protection issues. The legislation should also ensure that the authority granted be exercised in a way that is based upon the most relevant scientific information and best practices on planetary protection.

The persistence of uncertainty concerning, questions about, and problems with the legal and regulatory framework that applies to private-sector space activities not involving NASA participation elevates this issue as a strategic need for the next phase of planetary protection policy. The committee returns to this issue in Chapter 3.

The PPIRB report also recommends minimizing costs and burdens of planetary protection on private-sector activities:

Major Recommendation: PP–related authorization and supervision across the U.S. government should be implemented in a transparent, timely, and predictable manner, minimizing costs and burdens on private sector activities where possible. [55]

The 2018 report's focus on legal issues arose, in part, from the uncertainty, transparency problems, and potential delays and additional costs that lack of clarity about federal regulation of private-sector activities for planetary protection purposes can create. The 2018 report emphasized the importance for all space missions that planetary protection requirements be set early and implemented according to established project management and engineering protocols. The 2018 report also stressed that appropriate planetary protection policies apply equally to relevant government-sponsored and private-sector space missions.

Thus, the two reports are consistent in stressing that the federal legal power to authorize and continually supervise non-governmental entities for planetary protection purposes be exercised in a clear and transparent manner and in ways that permit timely, predictable, and cost-efficient outcomes.

Two PPIRB report recommendations recognize that different players have diverse objectives for planetary missions and that national space policy supports both scientific exploration and commercial uses of space:

Major Recommendation: In addition to balancing the needs of science and exploration, PP policy should also recognize that it is both a NASA and a national objective to encourage private sector space initiatives and commercial robotic and human planetary missions. [54]

Major Recommendation: Regarding PP, NASA should work in support of the Administration's efforts, and as appropriate with the Congress and private sector stakeholders, to enable private sector space initiatives that do not have significant NASA involvement. [56]

The 2018 report does not have comparable conclusions, but the report is not inconsistent with the PPIRB's recommendations. The 2018 report underscored that the purpose of planetary protection policy is "to enable, not inhibit, space exploration and the search for life."[50] The committee adds that the space community need not think of having to *balance* planetary protection and various mission objectives as if they were competing aims. Rather, the aim is to devise ways to permit exploration and other uses of space to go forward in light of planetary protection rationales.

The PPIRB report identified the growing importance of private-sector interest in space activities and the planetary protection implications of that interest:

Supporting Finding: Several private space companies are rapidly advancing technologies and plans for robotic and human planetary missions, including plans to land cargo and humans on the surface of the Moon and Mars. These developments provide important considerations for updating NASA and other U.S. government PP policy. [57]

[50] See NASEM, 2018, p. 9.

Supporting Recommendation: The U.S. should continue to encourage international PP forums to include private sector stakeholder participation. [59]

Similarly, the 2018 report concluded that engaging the private sector in discussions and advisory activities regarding formulation and implementation of planetary protection policy was needed:[51]

Finding: To date, planetary protection policy development at national and international levels has not involved significant participation from the private sector. The lack of private sector participation creates potential challenges for policy development, because private-sector actors need to be able to understand and embrace appropriate planetary protection measures.

Recommendation 6.3: NASA should ensure that its policy-development processes, including new mechanisms (e.g., a revitalized external advisory committee focused on planetary protection), make appropriate efforts to take into account the views of the private sector in the development of planetary protection policy. NASA should support the efforts of COSPAR officials to increase private-sector participation in the COSPAR process on planetary protection.

In the international context, the 2018 report highlighted efforts that COSPAR officials are making to increase the participation of the private sector in the organization's planetary protection processes. The PPIRB report's apparent interest in using COPUOS rather than COSPAR for international cooperation on planetary protection (see Supporting Finding [18] and Supporting Recommendation [34] above) would shift such cooperation into an intergovernmental body within the United Nations. Typically, intergovernmental bodies do not allow non-governmental entities to participate directly in their meetings or have a say in their decisions. If increasing private-sector participation in international cooperation on planetary protection is a policy objective, then COPUOS would not be an optimal forum in which to pursue that objective. For more on the relative roles of COSPAR and COPUOS see "Areas of Inconsistency and Concern" in Chapter 3.

ROBOTIC MARS SAMPLE RETURN

The findings and recommendations of the PPIRB report are broadly consistent with the 2018 report and previous NASA reports on Mars sample return. Planning for the 2020 Mars sample collection mission is well advanced, and NASA is already implementing some of the PPIRB's recommendations on Mars sample return.

This part of the PPIRB report begins with a finding and recommendation about materials the Earth has already received from Mars over the history of the solar system:

Major Finding: Martian material has been naturally transported to Earth for billions of years. [60]

Major Recommendation: NASA's MSR PP approach should take into account the findings of the recent National Academies' Consensus Study Report on sample return from the Martian moons. [61]

The 2018 report did not focus on the transport of material from Mars to Earth, so these findings are not comparable to the 2018 report. This topic is addressed in previous National Academies' reports and other studies.[52] The committee finds that the naturally occurring transport of martian materials to

[51] See NASEM, 2018, Recommendation 6.3.

[52] See, for example, NASEM, *Assessment of Planetary Protection Requirements for Mars Sample Return Missions*, The National Academies Press, Washington, D.C., 2009, and references therein.

Earth is not a scientifically compelling reason to alter planetary protection policies for returned samples from Mars. The committee notes that, while the Earth regularly receives meteorites from Mars (estimated to be about 1 ton per year of rock fragments 10 cm or more in diameter), the meteorites are mostly igneous, basaltic rocks that are tough enough to survive ejection from Mars and transport to Earth, which makes them a biased sample. Martian meteorite collections contains few or no examples of significantly aqueously altered rocks of sedimentary or altered igneous types that might provide,[53] or might have provided, habitats for living organisms. Samples that might yield signs of life would come from subsurface rock formations affected by water.

Although theoretical models suggest that martian meteorites originate close to the surface (within about 10 m for craters about 10 km in diameter),[54] there is currently no evidence that they accumulated cosmogenic isotopes before launch from the surface of Mars,[55] so they were unlikely to have been sterilized by cosmic radiation before launch. However, natural transfer from Mars to Earth usually requires hundreds of thousands to millions of years of exposure to the severe space radiation environment, although more rapid transfers are possible, but much less likely. [56] Nevertheless, until it is clear that martian material poses no threat to the Earth's environment, strenuous efforts will be required to quarantine martian samples, especially those from the subsurface, from contact with Earth's biosphere by effective barriers in both the return spacecraft and in the sample receiving facility.

The joint report of the National Academies and the European Science Foundation on sample return from the martian moons (mentioned in the PPIRB report's Major Recommendation [61]) concluded that "after considering the body of work conducted by the SterLim and JAXA teams, the effect of desiccation on the surfaces of the martian moons, and the relative flux of meteorite-to-spacecraft-mediated transfer to Earth, the committee recommends that samples returned from the martian moons be designated unrestricted Earth return."[57] This conclusion was specifically based on the following factors:

1. The random, impact-based sampling of the martian surface that contributes material to the martian moons;
2. The inhospitable conditions at the martian surface, during impact, during collision with Phobos, and on Phobos; and
3. The bias inherent in samples that survive impact ejection.

For these reasons, the U.S.-European martian moons report found that "the content of this report and, specifically, the recommendations presented in it do not apply to future sample return missions from Mars itself."[58] Therefore, the committee does not agree with the PPIRB report that compelling scientific evidence exists to change the planetary protection requirements for Mars sample return based on martian meteorites.

The next PPIRB finding on Mars sample return states as follows:

> *Major Finding: As the first restricted Earth return since Apollo, MSR will be a uniquely high profile mission.* [62]

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[53] Out of approximately 220 Martian meteorites catalogued as of 9 January 2019, there is only one example, so far, of a sedimentary rock, NWA 7034 (a basaltic breccia).

[54] J.N. Head, H.J. Melosh, and B.A. Ivanov B. A. 2002. Martian Meteorite Launch: High-speed Ejecta from Small Craters. *Science* 298: pp. 1752-1756, 2002.

[55] O. Eugster, D.F. Herzog, K. Marti, and M.W. Caffee, Irradiation Records, Cosmic-ray Exposure Ages, and Transfer Times of Meteorites,. *Meteorites and the Early Solar System II* 1: pp. 829–851, 2006.

[56] B. Gladman and J.A. Burns, Martian Meteorite Transfer. Simulation. *Science* 274: pp. 161–162, 1996.

[57] NASEM and European Science Foundation, *Planetary Protection Classification of Sample Return Missions from the Martian Moons*, The National Academies Press, Washington, D.C., 2019, pp. 3 and 41.

[58] NASEM and European Science Foundation, *Planetary Protection Classification of Sample Return Missions from the Martian Moons*, The National Academies Press, Washington, D.C., 2019, pp. 5 and 44-45.

The 2018 report likewise recognized the importance of the Mars sample return mission for planetary protection policy by including a case study on Mars 2020.[59] This case study highlighted the significance of the Mars sample return project for planetary protection policy on back contamination. The two reports are consistent in identifying the importance of the Mars sample return mission for planetary protection policy on back contamination.

The PPIRB report next addressed the Mars Sample Receiving Facility:

> *Major Recommendation: Planning for a Mars Sample Receiving Facility (MSRF) should be accelerated, or at least maintained on schedule, and should also be kept as pragmatic and streamlined as possible so that it does not unduly drive the schedule or cost of MSR.* [63]

> *Supporting Finding: Significant work is being done to study the MSRF and whether an entirely new facility should be built, and where, or whether the MSRF should be an add-on to an existing Biosafety Level 4 (BSL-4) facility.* [65]

The 2018 report identified the lack of planetary protection requirements for the Mars Sample Receiving Facility and activities that will take place in it. In particular, the 2018 report noted that "planetary protection requirements for the sample containment, verification of containment, return vehicle, and sample receiving facility are not yet in place" and that the need to develop such requirements as a key part of the overall Mars sample return mission.[60] The two reports are, thus, consistent in emphasizing the need for further work on planetary protection policy planning and implementation for the Mars Sample Receiving Facility. The 2018 report did not address the specific plans or details concerning the building of the Mars Sample Return Facility, but other reports from the National Academies have done so, albeit not recently.[61]

The PPIRB report also focused on the need for a public outreach strategy in connection with the Mars sample return mission:

> *Major Recommendation: NASA should begin work with other government agencies to develop a MSR PP public outreach, communications, and engagement plan.* [64]

The 2018 report focused attention on the need to adapt planetary protection policy and its implementation for Mars sample return within NASA and across the federal government in order to assure that bringing samples back from Mars proceeds as smoothly as possible politically, diplomatically, and scientifically. Therefore, the two reports are consistent in recommending the development of interagency and diplomatic plans to address the challenges of returning samples from Mars, including public outreach, communications, and engagement.

The PPIRB report next addressed sterilization techniques in connection with the Mars sample return mission:

> *Supporting Finding: Some types of sterilization of Mars samples are antagonistic to many important types of scientific measurements.* [66]

> *Supporting Recommendation: NASA should carefully trade the implications of the degree and types of PP sterilization techniques for Mars samples with the implications for various types of science measurements.* [67]

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[59] See NASEM, 2018, pp. 46-52.

[60] See NASEM, 2018, p. 52.

[61] See, for example, NASEM, *The Quarantine and Certification of Martian Samples*, National Academy Press, Washington, D.C., 2002.

Supporting Recommendation: NASA should continue to engage experts from the medical, pharmaceutical, and personal care industries to advise on effective sterilization protocols. [68]

The 2018 report did not discuss sterilization of Mars samples. The 2018 report is also silent on the effect of such sterilization on the science conducted on the samples and on the appropriate expertise required to advise NASA on sample sterilization protocols. However, PPIRB Supporting Recommendation [68] does follow from one in the 2018 report, which reads:

Recommendation 3.7: NASA should engage the full range of relevant scientific disciplines in the formulation of its planetary protection policies. This requires that scientific leaders outside of the standard planetary protection community in NASA participate in revisions to NASA and COSPAR planetary protection policies and requirements.

OCEAN WORLDS EXPLORATION

The PPIRB report had one major finding, one major recommendation, and one supporting finding and recommendation regarding the exploration of Europa, Enceladus, Titan, and the other ocean worlds. The major finding and major recommendation state as follows:

Major Finding: The fraction of terrestrial microorganisms in spacecraft bioburdens that has potential to survive and amplify in ocean worlds is likely to be extremely small.62 Further, any putative indigenous life in subsurface oceans on Europa, Enceladus, or Titan is highly unlikely to have a common origin with terrestrial life. [69]

Major Recommendation: The PP requirements for ocean worlds exploration should be reassessed in light of this finding. [70]

Although the 2018 report included a case study of the planetary protection policy and implementation issues associated with the Europa Clipper mission,[63] it did not address or reach scientific conclusions about the following topics:

1. The potential of terrestrial organisms on spacecraft to survive and amplify in the oceans of icy bodies;
2. Whether any indigenous life in the subsurface oceans of Europa, Enceladus, or Titan is unlikely to share a common origin with terrestrial organisms; or
3. Whether the current bioburden requirements for missions to Europa, Enceladus, or other ocean worlds are appropriate.

Subsequent to publication of the 2018 report, the Europa Clipper project and the NASA PPO reached agreement on a realistic approach to achieving a responsible thousand-fold reduction in the spacecraft's bioburden, with an understanding that flexibility will be granted for hardware that cannot withstand the protocol. By concentrating on being able to estimate that less than one *viable* microorganism could reach the ocean (after accounting for impact survivability, likelihood of landing on an active region of the surface, ocean transport processes, and probability of hitting Europa in the first

[62] M.T. La Duc, A.E. Dekas, S. Osman, C. Moissl, D. Newcombe, and K. Venkateswaran, Isolation and characterization of bacteria capable of tolerating the extreme conditions of clean-room environments, *Applied Environmental Microbiology* 73:2600-2611, 2007; and National Research Council. 2012. *Assessment of Planetary Protection Requirements for Spacecraft Missions to Icy Solar System Bodies*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13401.

[63] For more about the Europa Clipper see, for example https://www.jpl.nasa.gov/missions/europa-clipper.

place), the project devised the means to ensure a very low probability of contamination of a Europan ocean.[64]

The PPIRB report's supporting finding and recommendation on ocean worlds are as follows:

> *Supporting Finding: Category IV is currently assigned to landed ocean world missions when there is a significant probability of contamination of the liquid interior oceans. However, the situation for each ocean world environment is very different and limited information exists for each of these worlds regarding ice shell composition and thickness, ocean composition and habitability, interfaces/communication between the surface and ocean, and any transport of material across the surface.* [71]
>
> *Supporting Recommendation: NASA should study transport, survival and amplification mechanisms of contamination individually for each ocean world.* [72]

The 2018 report did not address the use of Category IV (see Appendix E) for missions that land spacecraft on the surface of icy bodies with subsurface oceans. The 2018 report identified the need for more research to inform missions to such icy bodies that come after Europa Clipper:

> The formulation of planetary protection policies for such missions will need to be informed by new research. In particular the scientific question of whether a single organism, deposited on the surface, could contaminate Europa's entire ocean within a reasonable period of biological exploration needs to be revisited.[65]

The committee agrees that mission categorization be based on the best available scientific knowledge and supports the PPIRB report's recommendation for further study of transport, survival, and amplification potential of terrestrial microorganisms within the oceans of icy bodies. The committee notes that the available scientific knowledge is incomplete with regard to the following: the ability of introduced microorganisms to survive and propagate in an ocean world environment (despite temperatures and pressures comparable to those found in Earth's deep ocean) and whether or not such life forms would be readily distinguishable from indigenous life. Further, as the OST requires that states parties avoid "harmful contamination" of celestial bodies, the committee does not agree with the contention in Major Finding [69] that any potential ability to distinguish terrestrial contaminants from indigenous life negates concerns over potential contamination of ocean worlds with replicating terrestrial microorganisms.

COSPAR

The final five PPIRB findings and recommendations address topics related to the OST, the role of COSPAR, and the semantics of planetary protection—all grouped under the heading of "COSPAR."

> *Major Finding: There is a lack of consensus as to how and when the Outer Space Treaty has legal relevance to non-governmental entities.* [73]

In contrast to the PPIRB report, the 2018 report did not identify confusion about how, under the OST, states parties make Article IX legally relevant for non-governmental entities by fulfilling their Article VI obligation to authorize and supervise the space activities of such entities. The 2018 report's analysis of the OST focused on the treaty's obligations on states parties (governments) to do the following:

[64] January 6, 2020, email from Europa Clipper Project Scientist to committee.
[65] See NASEM, 2018, pp. 56-57.

1. Conduct space exploration so as to avoid harmful contamination of the Moon and other celestial bodies and adverse changes in Earth's environment and to adopt appropriate measures for these purposes,[66] and
2. Authorize and continually supervise space activities of non-governmental entities (private companies).[67]

Under international law, the OST is clear that it becomes legally relevant for non-governmental entities when OST states parties fulfill their treaty obligations to authorize and supervise the space activities of non-governmental entities, including activities that have planetary protection implications.

On the other hand, the two reports are consistent in that both highlight the need to identify, in domestic law, a federal agency to regulate non-governmental entities on planetary protection (or, in OST terms, the agency that will authorize and supervise the space activities of non-governmental entities for planetary protection purposes). The question whether the OST directly applies to non-governmental entities, without the need for domestic legislation implementing the treaty, is a question of national law. Put differently, the U.S. government is required to make Article IX legally relevant for non-governmental entities by fulfilling its Article VI obligation to authorize and supervise such entities. The 2018 report concluded that, at the level of domestic law, the United States has a "regulatory gap" because no federal agency has the explicit authority to regulate planetary protection issues. The PPIRB report also noted the need to identify an appropriate federal agency to regulate the private sector in the planetary protection domain (see Supporting Recommendation [58] in the discussion of private-sector initiatives above).

Major Finding: The process for incorporating recommendations from this report that NASA accepts into COSPAR guidelines is not well defined. [74]

The two reports are not consistent on this point. The 2018 report described the long-established process through which NASA has taken proposed planetary protection policy changes to COSPAR, how COSPAR considers and adopts changed or new policies, and how the restructured COSPAR Panel on Planetary Protection will deal with changes in the future.[68] The committee agrees, however, that while the process may actually be well defined, it is not well understood outside the community of planetary protection experts.

Supporting Finding: The term "Planetary Protection" has been used by different communities to include a variety of topics. This has caused confusion with respect to the primary responsibility of governmental PP oversight and the intent of past practices. [75]

Supporting Recommendation: NASA should broadly communicate that its PP policy is consistent with COSPAR history, and is specifically focused on reducing biological forward contamination that could interfere with future astrobiological investigations and backward contamination that might have adverse impacts on Earth's biosphere. [76]

If the intent of the PPIRB finding was to suggest replacing the term "planetary protection," then the two reports are not consistent because the 2018 report provided nothing to indicate that use of "planetary protection" has produced confusion. Replacing "planetary protection" after many decades of

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[66] From Article IX of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, opened for signature January 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205. Hereafter OST.

[67] From Article VI of the OST.

[68] See NASEM, 2018, pp. 72-76.

successful international use could very probably lead to confusion that the PPIRB may have wished to avoid. The 2018 committee identified the following:[69]

> Two goals for planetary protection that NASA, international, and Space Studies Board documents have reflected for decades:
>
> 1. The control of forward contamination, defined by NASA as "the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, fly-by, or otherwise encounter extraterrestrial solar system bodies; and
> 2. The control of back contamination, defined by NASA as "the control of contamination of the Earth and the Moon by extraterrestrial material collected and returned by robotic missions.

On the other hand, the PPIRB recommendation for communicating COSPAR's long-established role and relationship to NASA is consistent with the 2018 report's description of the history of planetary protection policy. The 2018 report observed that "NASA science and policy have, to date, provided the basis for practically all substantive COSPAR guidelines."[70] Put differently, history of the development of COSPAR's planetary protection policies is the story of the international adoption of Space Studies Board science and NASA policy.[71] As noted above, NASA has consistently defined planetary protection policy to focus on forward contamination to protect astrobiological science's search for extraterrestrial life and prebiotic chemical evolution and backward contamination to protect Earth's environment from potential harm by replicating extraterrestrial organisms.

> *Supporting Recommendation: To reduce confusion, NASA should develop and then use a standard glossary of PP related terminology, including for example "spacecraft cleanliness," "forward biological transport," and "backward biological transport."* [77]

The 2018 report did not identify any serious planetary protection policy problems that arose from confusion about what "planetary protection" means or from the lack of standardized terminology. Nevertheless, having a NASA document that presents a standard glossary could be helpful for new entrants (e.g., human and private-sector missions) as they become part of the solar system exploration milieu.

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[69] See NASEM, 2018, p. 9.
[70] See NASEM, 2018, p. 17.
[71] See NASEM, 2018, pp. 76-78.

3

Conclusions and Recommendations

Chapter 2 contains the committee's detailed comparison of the Planetary Protection Independent Review Board (PPIRB) report[1] findings and recommendations against the 2018 report of the National Academies of Sciences, Engineering, and Medicine, *Review and Assessment of Planetary Protection Policy Development Processes*[2] (hereinafter the "2018 report"). This chapter presents the committee's overall conclusions and recommendations to NASA that emerge from this comparison. The chapter begins by identifying three items:

1. The main areas of consistency between the PPIRB and 2018 reports;
2. The main areas of inconsistency and concern; and
3. Issues raised in the PPRIB report, but not in the 2018 report, that deserve attention.

Then, the committee highlights three priorities in planetary protection that require action and makes recommendations for how NASA and its partners in the federal government can address these urgent needs. The chapter concludes by recommending that NASA implement, as soon as possible, new approaches to planetary protection in an initiative on small satellites, such as CubeSats.

AREAS OF CONSISTENCY

The majority of findings and recommendations in the PPIRB report are consistent with the 2018 report. The consistencies highlight issues in planetary protection policy that many stakeholders recognize as important, and the committee commends the authors of both reports for reinforcing these important aspects of planetary protection.

Both reports recognized that consideration of forward and back contamination is essential for protecting Earth's biosphere and enabling future astrobiology studies and is integral for government and private-sector missions undertaken by all spacefaring nations. Achieving this objective, both reports emphasized, requires U.S. leadership and international cooperation. The reports highlighted the important role COSPAR has played in fostering international cooperation on planetary protection, with the PPIRB noting, for example, that "COSPAR [planetary protection] guidelines have evolved to be an internationally recognized, voluntary standard for protection of scientific interests in celestial bodies" that all spacefaring nations have used to inform compliance with the Outer Space Treaty.[3]

The PPIRB and 2018 reports agreed that developments in science, technology, and private-sector space activities are changing the environment for the development and implementation of planetary protection policy. These developments include progress on a robotic Mars sample return mission, growing interest in low-cost, small satellite capabilities, accelerating plans to put humans on the Moon

[1] Planetary Protection Independent Review Board (PPIRB), *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf.

[2] National Academies of Sciences, Engineering, and Medicine (NASEM), *Review and Assessment of Planetary Protection Policy Development Processes*, The National Academies Press, Washington, D.C., 2018.

[3] See PPIRB, 2019, Supporting Finding [18].

and Mars, and advanced mission planning for exploring ocean worlds, such as Europa, Titan, and Enceladus, with a variety of missions including orbiters and landers.

In light of this changing environment, both reports emphasized the need for NASA to reassess planetary protection policy frequently in light of new scientific information, technological developments, and government or private-sector space activities. The reports supported NASA's decision to relocate the Office of Planetary Protection (OPP) from the Science Mission Directorate (SMD) to the Office of Safety and Mission Assurance (OSMA), and the PPIRB report praised NASA's efforts to improve the OPP's "communication, clarity, and responsiveness."[4] Looking ahead, the reports identified needs to undertake the following actions:

1. Conduct biological and genomic research to explore better ways to characterize bioburdens on spacecraft;
2. Develop new technologies for reducing the bioburden on spacecraft and evaluating samples returned from solar system bodies;
3. Engage in more research on the probability of the survival and transport of terrestrial organisms in extreme space environments; and
4. Develop better methodologies for awarding planetary protection credits for time spent in harsh space environments.

The PPIRB and 2018 reports also aligned in advocating for the expeditious development of new planetary protection policy specifically applicable for human missions. Both reports agree that existing planetary protection policy does not provide appropriate guidance for human missions. Developing planetary protection for human missions requires funding research to produce the scientific and technological information needed to formulate planetary protection policy applicable to human missions. For example, developing the idea of "exploration zones" on Mars into a more serious concept for human missions requires research on, among other things, the likelihood that biological contaminants released in the course of human activities would be transported to other areas of Mars.

The PPIRB and 2018 reports emphasized that mission success depends on developing and applying clear and complete planetary protection requirements early in mission development in order to reduce costs, inefficiencies, and delays—whether NASA or a private entity operates the mission. These requirements, the reports agreed, cannot prescribe how missions achieve compliance. Rather, mission designers are encouraged to innovate and use systems-engineering approaches to meet the necessary requirements.

Finally, the PPIRB and 2018 reports both stressed the need to develop a formal advisory process that provides the broad community of stakeholders with the opportunity to advise NASA on emerging scientific, technological, commercial, legal, and international issues. All such inputs are important for ensuring that planetary protection policy continues to support robust exploration and other uses of space in a rapidly changing context for space activities.

AREAS OF INCONSISTENCY AND CONCERN

In comparing the PPIRB and 2018 reports, the committee identified two major issues on which the reports diverge and one issue where the two reports highlight in different ways contexts in which government and private-sector stakeholders confront a lack of clarity about the development, application, and implementation of planetary protection policy.

First, the PPIRB found that adherence to COSPAR guidelines constitutes one "mechanism for establishing compliance with Article IX" of the Outer Space Treaty and that "other mechanisms that may

[4] See PPIRB, 2019, Major Finding [8].

be more appropriate also exist."[5] The PPIRB recommended that the U.S. government use the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS) as an alternative mechanism for international cooperation on planetary protection policy.[6] The PPIRB report provided no supporting information or analysis for why the PPIRB recommended that the U.S. government shift its international participation in planetary protection policy development from COSPAR to COPUOS. By contrast, the 2018 report did not discuss any other mechanism other than COSPAR as the main forum for the U.S. government's involvement in international cooperation on planetary protection. The 2018 report focused on ways that NASA and other parts of the U.S. government could support ongoing efforts to improve COSPAR as an international forum for discussing planetary protection issues and developing science-based guidance on planetary protection for spacefaring nations. The 2018 report noted that COPUOS itself, in 2017, identified "COSPAR as the appropriate international authority for creating consensus planetary protection guidelines."[7]

Second, the PPIRB and 2018 reports did not align on how the Outer Space Treaty becomes legally relevant for non-governmental entities. The PPIRB heard briefings on this issue that presented different perspectives, and, based on these presentations, the PPIRB took no position on what it heard, finding instead that "[t]here is a lack of consensus as to how and when the Outer Space Treaty has legal relevance to non-governmental entities."[8] The 2018 report focused on how the Outer Space Treaty clearly requires states parties to make the planetary protection provisions in Article IX legally relevant for non-governmental entities by fulfilling their obligation under Article VI to authorize and continually supervise the space activities of non-governmental entities. The 2018 report located legal problems at the level of national rather than international law in analyzing the "regulatory gap" in U.S. federal law on planetary protection and private-sector space activities. The differences between the two reports on this issue highlight confusion and a lack of clarity about how the U.S. government fulfills its Article VI and IX obligations under the Outer Space Treaty through federal law applicable to the space activities of non-governmental entities.

Third, the PPIRB and 2018 reports focus on the new challenge of implementing science-based planetary protection policy within private-sector space initiatives and missions. In various places, the PPIRB report reflected concerns that implementation of planetary protection policy might constrain private-sector innovation and impede the U.S. government's policy of encouraging commercial exploration and uses of space.[9] The 2018 report described the importance of U.S. leadership in ensuring that planetary protection policy is based, first and foremost, on the best available scientific evidence relevant to forward and back contamination.[10] Both reports stress that the same planetary protection measures apply equally to both government and private-sector space activities. Rather, together, the two reports underscore in different ways that NASA and the U.S. government have not yet constructed a planetary protection policy process that aligns the needs of science and the private sector in ways that appropriately foster space exploration and commercial uses of space.

NEW TOPICS FOR CONSIDERATION

The PPIRB report discussed a number of topics not addressed in the 2018 report, and the committee agrees that these topics deserve attention in planetary protection policy. To begin, the PPIRB offered findings and recommendations focused on the need to re-examine the planetary protection

[5] See PPIRB, 2019, Supporting Finding [18].
[6] See PPIRB, 2019, Supporting Recommendation [34].
[7] See NASEM, 2018, p. 11.
[8] See PPIRB, 2019, Major Finding [73].
[9] See, for example, PPIRB report, Major Recommendation [54].
[10] See, for example, NASEM, 2018, p. 39.

categorization of missions to the Moon, Mars, and small solar system bodies, such as asteroids.[11] The PPIRB also explored whether minimum, base costs of complying with planetary protection requirements would adversely affect the feasibility of missions using small, inexpensive spacecraft.[12] The PPIRB expressed interest in NASA providing technical information or assistance on planetary protection to private-sector entrepreneurs.[13] Further, the PPIRB report identified problems arising from the SpaceIL incident and made recommendations to prevent those problems for impeding commercial space activities.[14]

The PPIRB also reached conclusions on another topic not considered in the 2018 report, but with which the committee does not agree. The PPIRB supported the idea that the presence of martian meteorites on Earth can inform how samples of martian material returned from Mars are handled. As the committee discussed in Chapter 2 with respect to Major Finding [60] and Major Recommendation [61] in the PPIRB report, arguments that NASA can relax planetary protection requirements for Mars samples brought to Earth are not scientifically persuasive to this committee.

STRATEGIC FINDINGS AND RECOMMENDATIONS

From its comparison of the PPIRB and 2018 reports and its examination of the topics considered only in the PPIRB report, the committee has identified three areas of strategic importance for planetary protection policy common to both reports on which it makes specific findings and recommendations:

- The need to establish a new advisory process for the development of planetary protection policy;
- The need to clarify the legal and regulatory framework applicable to private-sector space activities that implicate planetary protection; and
- The need to improve the scientific and technological foundation of planetary protection policies for the human missions to Mars.

Establishing a New Advisory Process for Planetary Protection Policy

As the PPIRB and 2018 reports highlight, the context for planetary protection policy has gained new dimensions and is becoming increasingly complex. These developments create the need to engage new stakeholders in the development and implementation of planetary protection policy in order to ensure that NASA formulates policies with comprehensive input and communicates the policies effectively to all the communities affected.

Seven findings and recommendations in the PPIRB report refer to the importance of engaging the planetary protection stakeholder community by means of a regular, formal advisory process.[15] The 2018 report emphasized that a key means to secure stakeholder engagement is through advisory groups, and it strongly recommended an advisory group that could provide ongoing review of planetary protection policies. As stated in the 2018 report, the advisory body will:

> • Serve as a sounding board and source of input to assist in development of planetary protection requirements for new missions and U.S. input to the deliberations of COSPAR's Panel on Planetary Protection;

[11] See PPIRB, 2019, starting at Major Finding [35] and through to Supporting Finding [40]. Small bodies refers to planetary bodies, including asteroids, comets, Kuiper Belt objects, and dwarf planets.

[12] See PPIRB, 2019, Supporting Finding [28] and Supporting Recommendation [29].

[13] See PPIRB, 2019, Major Recommendation [12].

[14] See PPIRB, 2019, Supporting Finding [30].

[15] Two prominent examples are Major Recommendations [6] and [7].

- Provide advice on opportunities, needs, and priorities for investments in planetary protection research and technology development; and
- Act as a peer review forum to facilitate the effectiveness of NASA's planetary protection activities. [16]

The committee supports the findings and recommendations in both reports that focus on the need for a new advisory process on planetary protection policy. Indeed, the committee agrees that many of the PPIRB's concerns about participation in the policy-making process could be addressed, if not ameliorated, through a stakeholder forum charged to examine the planetary protection issues and make recommendations to decision makers in the U.S. government.

> **Finding**: The PPIRB and 2018 reports, independently and together, make the persuasive case that NASA establish a new process for gathering input from the community of relevant stakeholders to ensure that the planetary protection policy comprehensively reflects the new environment of public and private space activities, contributes to the success of government and private-sector space missions, and reinforces U.S. leadership on planetary protection.

> **Recommendation: NASA should establish a new, permanent, and independent advisory body formally authorized to provide NASA with information and formulate advice from representatives of the full range of stakeholders relevant to, or affected by, planetary protection policy.**

Attributes of a New Approach to Advise and Review

NASA and the National Academies are adept at establishing advisory bodies for various scientific, project review, advanced technology, and related purposes. Even so, creating an advisory body tasked with providing input on all aspects of planetary protection poses a challenge because of the legal, scientific, public policy, commercial, and public health issues involved. Given the very broad scope of potential advisory issues to be considered (ranging, for example, from establishment of Mars exploration zones, to guidelines for quarantine facilities and protocols, to approaches for international policy coordination), an effective advisory process might actually consist of more than a single committee or panel. The following sections deal with key aspects of a new advisory process.

Inclusion of All Stakeholders

In view of the scope of the advice required, NASA will need to ensure that the new advisory process includes representatives from all relevant stakeholder communities, especially given that subsections of the same community may hold opposing views on some topics. In addition, NASA will have to be proactive in keeping the appointed representatives engaged in the advisory process. The 2018 report noted that some past advisory bodies suffered from inadequate participation by stakeholders.[17] To mitigate this problem in the future, the committee suggests that senior levels of the convening authority establish the charter and requirements for the advisory body. Wide circulation of the terms of reference for this new advisory body among relevant stakeholder communities will promote "buy in" by the various constituencies.

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[16] See NASEM, 2018, p. 92.
[17] See NASEM, 2018, p. 63.

Initial Focus of the Advisory Committee

During the committee's review, all three of the major stakeholder communities (science, human exploration, and private-sector space) communicated a sense of urgency, driven by factors such as the following:

- Plans to launch the first element of the Mars sample return campaign in July 2020;
- An administration directive to return to the Moon in 2024 and then go on to Mars; and
- Private entities developing plans for human Mars exploration and demonstrating capabilities for deep space launching.

Given the urgency of this activity, the committee sees advantages for this new advisory body to begin addressing the issues outlined above. While, some, if not all, of them have international ramifications, all have strong implications for near-term activities by NASA and other U.S.-based entities and organizations. Therefore, prompt U.S. action is needed in the near future. Adopting this approach is not only consistent with the United States' traditional role in the development of planetary protection policies, but also addresses the clarity of authority desired by the private sector. The committee does recognize a need for COSPAR participation, and the committee fully anticipates that a new advisory group will share and exchange any relevant decisions, findings, or recommendations with COSPAR. It is in NASA's best interest that international partners are fully aware of U.S. efforts to modernize and improve planetary protection policy.

> **Finding**: The execution of planetary protection policy necessarily requires international coordination. However, the United States has shown leadership in developing planetary protection policy and most, if not all, of these policies have been adopted internationally. However, there are U.S. issues that require immediate attention.

> **Recommendation: The initial focus of the new advisory body should be on the needs of upcoming private sector and government missions.**

To summarize, there are many vexing issues identified by the PPIRB and 2018 reports that can be addressed through a properly constituted and chartered review and advisory process that engages all planetary protection stakeholders. Such an effort will go far toward providing the transparency, which some thought was lacking in previous reviews of planetary protection.

Clarifying Legal and Regulatory Issues Concerning Planetary Protection

A second strategic challenge identified in the PPIRB and 2018 reports involves issues with the international and national legal and regulatory frameworks applicable to the planetary protection aspects of private-sector space activities. More specifically, these issues arise in connection with private-sector activities undertaken without contracts with NASA. When NASA provides support to a private-sector activity, the requisite contract typically includes requirements for the private-sector partner to implement NASA's planetary protection measures. In connection with planetary protection, the committee is concerned that a lack of clarity persists about the obligations of the United States under the Outer Space Treaty and how federal law applies to private-sector space activities implemented independent of NASA involvement. Such uncertainty stands in the way of a clear and authoritative legal and regulatory framework for private-sector space missions that implicate planetary protection requirements.

International Law: The Outer Space Treaty, Planetary Protection, and Private-Sector Space Activities

At the level of international law, the PPIRB and 2018 reports described debates about how the United States, as a state party to the Outer Space Treaty, is required to comply with its obligation to authorize and continually supervise planetary protection aspects of the space activities of non-governmental entities.[18] In its review of the Outer Space Treaty and the debates surrounding it, the 2018 report concluded that "states parties have a clear obligation under Article VI of the OST to authorize and continually supervise the space activities of non-governmental entities," which is an obligation that encompasses authorization and supervision of such activities that implicate a core aspect of Article IX of the treaty—planetary protection.[19] The PPIRB heard conflicting presentations on the Outer Space Treaty and took no position, merely noting that "[t]here is a lack of consensus as to how and when the Outer Space Treaty has legal relevance to non-governmental entities."[20]

The committee agrees with the conclusion reached by the 2018 report. However, based on the views presented to the PPIRB, the committee acknowledges that disagreements continue about how the United States will comply with its obligations under the Outer Space Treaty concerning the planetary protection aspects of private-sector space activities not involving NASA participation.

> **Finding**: The persistence of disagreements about how the United States fulfills its obligations under the Outer Space Treaty in connection with private-sector space activities that implicate planetary protection creates uncertainty for the private sector and potentially harms the objective of the U.S. government to facilitate exploration and uses of space by the private sector.
>
> **Recommendation**: **NASA should work with other agencies of the U.S. government, especially the U.S. Department of State, to provide the private sector with a clear and authoritative explanation of the U.S. government's obligations under the Outer Space Treaty to authorize and continually supervise the space activities of non-governmental entities that raise planetary protection issues.**

Domestic Law: Legal Authority, Substantive Rules, and Enforcement

The PPIRB and 2018 reports identify problems with how U.S. federal law applies to the planetary protection aspects of private-sector space activities undertaken without NASA participation. The 2018 report found that "[a] regulatory gap exists in U.S. federal law and poses a problem for U.S. compliance with the OST's obligations on planetary protection with regard to private-sector enterprises."[21] Although the PPIRB report did not use the term "regulatory gap," the chair of the board confirmed to the committee that the legal and regulatory issues addressed at various points in the PPIRB report were equivalent to the regulatory-gap problem identified by the 2018 report.[22] Uncertainty about how U.S. federal law applies to the planetary protection aspects of private-sector space activities creates unneeded and potentially costly confusion that does not advance the U.S. government's and NASA's strategy of encouraging private-sector exploration and uses of space.

Congress has granted the Federal Aviation Administration (FAA) the legal authority to approve the launch of vehicles and payloads into space from the United States and their re-entry into Earth's atmosphere. With companies developing plans for new types of space activities, such as commercial lunar

[18] Outer Space Treaty, Articles VI and IX.
[19] See NASEM, 2018, p. 15.
[20] See PPIRB, 2019, Major Finding [73].
[21] See NASEM, 2018, p. 88.
[22] Conference call between PPIRB Chair S. Alan Stern and the committee on December 16, 2019.

missions or human missions to Mars, the FAA confronted the question of whether its legal authorities included the power to regulate private-sector activities for planetary protection purposes. The 2018 report noted that "[i]n reviewing private-sector plans for lunar missions," the FAA "tested the scope of its regulatory authority, leading it to conclude that the FAA might need additional authority to evaluate future missions in order to ensure the United States complies with the [Outer Space Treaty]."[23] In addition, the 2018 report stated that "there is no explicit legislative or executive guidance about whether FAA's spacecraft reentry licensing authority extends to review or approval of plans to prevent back contamination from sample return missions."[24] The PPIRB report found that various licensing mechanisms, including the FAA's launch and re-entry approval authorities, "could be improved to relieve administrative burdens and address misperceptions of legal uncertainty for private sector space activities, including private sector robotic and human planetary missions that do not have significant NASA involvement."[25]

In a presentation to the committee, a representative from the FAA stated that the agency had sufficient authority in its launch and re-entry licensing power to evaluate and regulate the planetary protection aspects of private-sector space missions conducted independent of NASA.[26] The statements from the FAA representative appear to clarify the FAA's present position that it has clear and sufficient legal authority to vet the planetary protection aspects of vehicles and payloads under its power to license launch and re-entry activities and conduct payload reviews for private-sector actors. However, in exercising this authority, the FAA apparently can accept or reject NASA advice on planetary protection. This situation leaves an applicant for a license potentially uncertain as to what planetary protection standards the FAA will apply in reviewing the proposed mission. The possibility that the FAA could approve a license under planetary protection standards that do not conform to NASA's measures could create problems for the principle supported by the PPIRB and 2018 reports that government and private-sector missions be held to the same planetary protection standards.

The FAA's representative's statement to the committee about the FAA's legal authority to evaluate planetary protection issues in licensing activities does not address another aspect of the regulatory gap—the lack of clear legal authority concerning the authorization and supervision of post-launch, on-orbit activities undertaken during private-sector space missions. The 2018 report stated that "[n]o federal regulatory agency has the jurisdiction to authorize and continually supervise on-orbit activities undertaken by private-sector entities, including activities that could raise planetary protection issues."[27]

After publication of the 2018 report, an incident involving planetary protection and the private sector occurred that underscored the uncertainties surrounding federal law in this area. As the PPIRB report discussed, the owner of a payload allegedly did not inform the launch provider that the payload contained biological materials.[28] The disclosure of such biological material to the FAA was required, under NASA planetary protection guidance, as part of the launch licensing process. In light of this incident, the PPIRB recommended that "[b]reaches of PP reporting or other requirements should be handled via sanctions that hold the root perpetrator accountable, rather than increasing the verification and regulatory burden on all actors."[29] This recommendation raises a number of questions, including the following:

[23] See NASEM, 2018, p. 87, footnote 6.
[24] See NASEM, 2018, p. 70.
[25] See PPIRB, 2019, Major Finding [53].
[26] Briefing to the committee by C. Philip Brinkman, senior technical advisor, Licensing and Evaluation Division, FAA Office of Commercial Space Transportation, November 21, 2019.
[27] See NASEM, 2018, p. 86.
[28] See PPIRB, 2019, Supporting Finding [30].
[29] See PPIRB, 2019, Supporting Recommendation [31].

1. What legal "requirements" for planetary protection did the payload owner allegedly breach? and
2. What legal "sanctions" could the federal government apply to the payload owner for violating such requirements?

The committee takes no position on how the federal government can address the lack of clarity and uncertainties concerning the application of federal law and regulations to the planetary protection aspects of private-sector missions, especially those implemented without NASA participation. The 2018 report recommended congressional action to authorize a federal agency to authorize and continually supervise the space activities of non-governmental entities for planetary protection purposes.[30] Similarly, the PPIRB report recommended that "NASA should work with the Administration, the Congress, and private sector space stakeholders to identify the appropriate U.S. Government agency to implement a [planetary protection] regulatory framework."[31] The federal agency with authority could oversee a legal framework that combines binding regulations, non-binding guidance, and oversight processes in order to achieve planetary protection and the transparency and predictability private-sector actors need. In responses to questions from the committee, the National Space Council noted, for example, that planetary protection objectives can be met through "voluntary, non-binding measures" and "methods such as independent reviews or levying disclosure requirements."[32]

Finding: Problems persist with whether and how U.S. federal law regulates private-sector space activities for planetary protection purposes concerning launch, on-orbit, and re-entry activities. These problems create challenges for U.S. compliance with the Outer Space Treaty's obligations concerning the authorization and continual supervision of activities of non-governmental entities and also undermine the private sector's need for a transparent and efficient legal and regulatory framework to support expanding of private sector exploration and uses of space.

Recommendation: **NASA should work with other agencies of the U.S. government, especially the Federal Aviation Administration, to produce a legal and regulatory guide for private-sector actors planning space activities that implicate planetary protection but that do not involve NASA participation. The guide should clearly identify where legal authority for making decisions about planetary protection issues resides, how the United States translates its obligations under the Outer Space Treaty into planetary protection requirements for non-governmental missions, what legal rules apply to private-sector actors planning missions with planetary protection issues, and what authoritative sources of information are available to private-sector actors that want more guidance on legal and regulatory questions.**

Building the Scientific and Technological Foundation for Planetary Protection Policy on Human Missions to Mars

The PPIRB and 2018 reports took note of planned, proposed, and potential human missions to Mars and for which existing planetary protection policy does not provide adequate guidance. The committee agrees. The reports also contained recommendations designed to help NASA develop planetary protection policy for human missions to Mars. The committee supports those recommendations.

[30] See NASEM, 2018, Recommendation 6.2.
[31] PPIRB, 2019, Supporting Recommendation [58].
[32] Response from National Space Council to questions posed by the committee received from Ryan Whitley, director of Civil Space Policy, National Space Council on January 6, 2020.

In both the PPIRB and 2018 reports, one of the key themes involves developing innovative guidelines that apply to the new types of missions. The 2018 report concludes that "NASA's process for developing a human Mars exploration policy should include examination of alternative planetary protection scenarios."[33] In addition, the latter report also noted that "rather than thinking about forward contamination in terms of an entire body, assessing the effects of human presence on local and regional scales might be more effective."[34] Similarly, the PPIRB report made the following recommendation:[35]

> NASA should consider establishing [zones]…considered to be of high scientific priority for identifying extinct or extant life, and [zones] where the larger amounts of biological contamination inevitably associated with human exploration missions, as compared to robotic scientific missions, will be acceptable.

Both reports went on to call for research to enable mission planners to define exploration zones on Mars. There are important questions about atmospheric transport of dust and gases, the likely range of biological materials released from a hypothetical accident at an occupied site, the survivability of terrestrial microbes on Mars, and the applicability of modern genomic techniques for measuring and monitoring contamination. Both reports also urged NASA to invest in research and technology pertaining to methods to detect life and its components, noting that using the latest information and approaches in life detection, contaminant reduction, and characterization of contaminants will ensure that the planetary protection requirements levied on future missions are sufficiently streamlined and effective.

The necessary research program requires bringing the appropriate resources to the problem. However, the low level of funding for NASA OPP over the period 2005-2019 has only been able to support an average two to three research grants per year.[36] However, in the last couple of years, this number has more than doubled (see Figure 3.1). In describing its recommendation for new research, the PPIRB report says, "This likely requires additional PPO funding to be effective."[37] Similarly, the 2018 report contained the following finding:[38]

> NASA has not adequately funded the research necessary to advance approaches to implementing planetary protection protocols and verifying that those protocols satisfy NASA's increasingly complex planetary protection requirements. For an agency program of solar system exploration and planning for human exploration missions, costing several billion dollars per year, an investment in relevant planetary protection research and technology of less than one tenth of one percent of that total seems inadequate.

Finding: Although NASA recognizes that existing planetary protection policy is inappropriate for human missions to Mars, it has not developed a strategy for producing practical planetary protection measures for such human missions. The lack of a strategy stems, in large measure, from the fact that NASA has not conducted the research and development needed to build the scientific and technological foundation for planetary protection measures designed specifically for human missions to Mars.

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[33] See NASEM, 2018, p. 84.

[34] See NASEM, 2018, pp. 79-80.

[35] See PPIRB, 2019, Major Recommendation [38].

[36] The number of proposals selected for funded by the Planetary Protection Research program offered annually via NASA's Research Opportunity in Space and Earth Science (ROSES) program between 2005 and 2018 is as follows: 2005 (1), 2006 (4), 2007 (6), 2008 (2), 2009 (0), 2010 (1), 2011 (5), 2012 (1), 2013 (not offered), 2014 (7), 2015 (0), 2016 (not offered), 2017 (5), 2018 (7), and 2019 (not offered). Details available at https://nspires.nasaprs.com/external.

[37] See PPIRB, 2019, Major Recommendation [5].

[38] See NASEM, 2018, p. 65.

Recommendation: NASA should make the development and execution of a strategy to guide the adoption of planetary protection policy for human missions to Mars a priority.

The committee has chosen to emphasize the need for a strategy for humans to Mars because of the magnitude of the task and because this topic is emphasized in both the PPIRB and 2018 reports. However, it could be argued that the same kind of effort will be needed to address topics not discussed in the 2018 report and, thus, technically beyond the scope of the current study. Such topics include, for example, relaxing the planetary protection requirements for large areas of the Moon and thus opening them up to private-sector missions and addressing other planetary protection issues associated with the future exploration of the ocean worlds and other astrobiologically significant environments

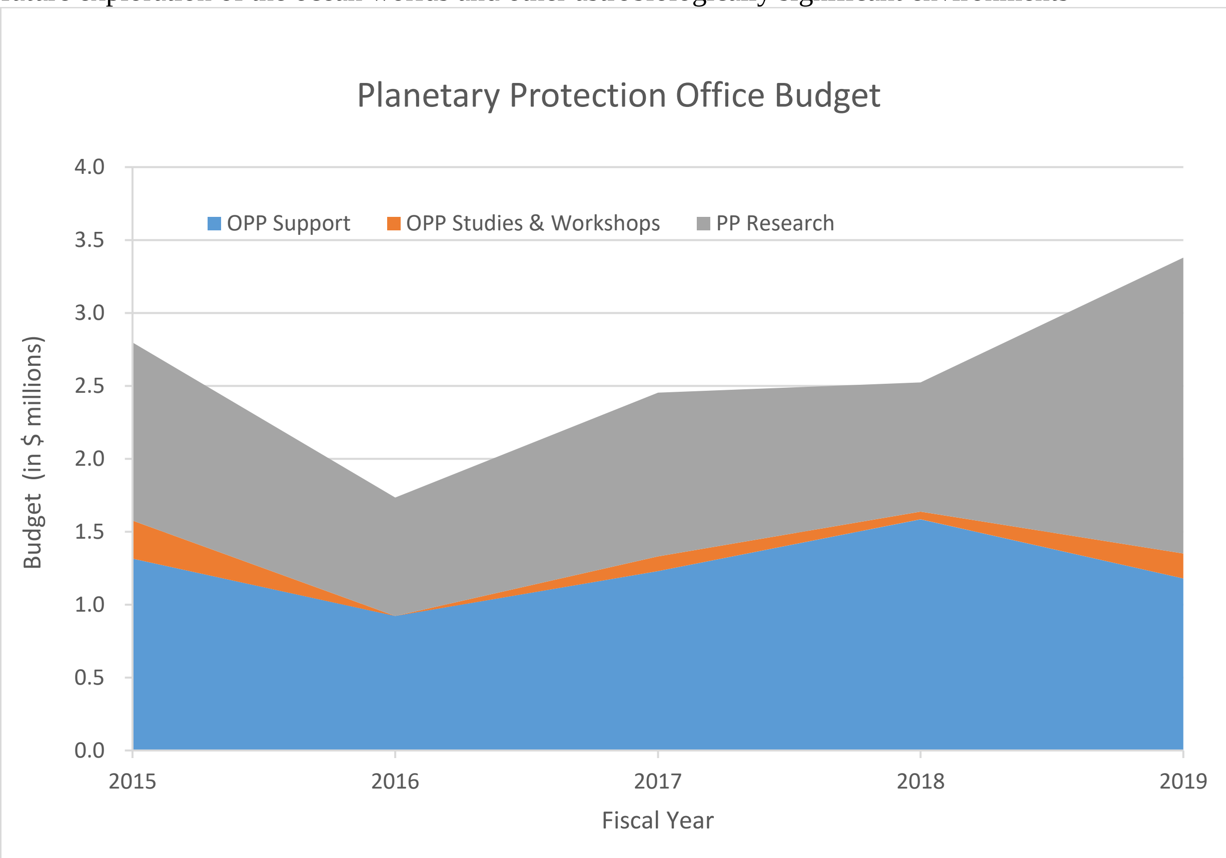

FIGURE 3.1 The budget for NASA's Office of Planetary Protection (OPP) for the last 5 fiscal years. Note the volatility of the budget and relatively small size of the Planetary Protection Research (PPR) program. PPR proposals funded via NASA's recent Research Opportunity in Space and Earth Sciences ROSES solicitations are as follows: 2014 (7 selected), 2015 (0 selected), 2016 (PPR not offered), 2017 (5 selected), 2018 (7 selected), and 2019 (PPR not offered). OPP budgetary data courtesy of Lisa Pratt.

Essential elements of such a Mars-focused strategy could include the following:

- A process to identify the most promising concepts for achieving planetary protection objectives in the context of human missions, such as high-priority astrobiological zones and

human exploration zones building upon the work done to date by COSPAR, NASA, and ESA;[39]
- Establishment of an adequately funded program of research and development to answer questions and address challenges raised by the most promising concepts for integrating planetary protection in human missions, such as the potential for transport of material and the survivability of terrestrial microorganisms on Mars; and
- A plan to develop planetary protection policy for human missions to Mars on a timeline that permits the integration of such research into mission planning and implementation at the earliest possible stages.

Action on the recommendations above will enable the development of science-based guidelines, to be implemented on both government-led and private-sector-led missions. Developing these guidelines in a timely manner would promote an earlier understanding of requirements and would reduce costly system redesign.

EXPEDITING THE DEVELOPMENT OF NEW APPROACHS TO PLANETARY PROTECTION

The committee recognizes that NASA needs time to implement fully the recommendations offered by the PPRIB and 2018 reports, as well as those the committee makes. For example, marshaling the human spaceflight and science communities to conduct the necessary research to further define exploration zones and mission recategorization will not be a trivial exercise. However, NASA can make some rapid progress on important aspects of a new approach to planetary protection policy identified by the PPIRB report, the 2018 report, and this committee. The committee believes that NASA can use the growing importance of small satellites to begin to build its new approach to planetary protection.

The PPIRB report drew attention to the planetary protection challenges that small, low-cost spacecraft missions, present to NASA, private-sector space enterprises, and university researchers. The committee agrees with PPIRB's emphasis on this issue. In so doing, the committee takes note of important developments in this area, including the following:[40]

- NASA's delivery of two small, low-cost communication-relay satellites (MarCO-6U) for Mars missions aboard the 2018 Insight mission;
- The use of SmallSats as part of NASA's Commercial Lunar Payload Services program designed to send small robotic landers and rovers to the Moon;
- The missions selected as part of NASA's Small Innovative Missions for Planetary Exploration (SIMPLEx) program. The Lunar Polar Hydrogen Mapper was selected via the

[39] See, for example: M.S. Race, J.E. Johnson, J.A. Spry, B. Siegel, and C.A. Conley (eds.), *Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions—Final Report*, DAA_TN36403, NASA Human Exploration and Operations Mission Directorate and NASA Planetary Protection Office, Washington,D.C., 2015; G. Kminek, B.C. Clark, C.A. Conley, M.A. Jones, M. Patel, M.S. race, M.A. Rucker, O. Santolik, B. Siegel, and J.A. Spry (eds.), *Report of the COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions*, NASA Science Mission Directorate and Human Exploration and Operations Mission Directorate, Washington, D.C., 2016; and M.S. Race, J.A. Spry, B. Siegel, C.A. Conley, and G. Kminek (eds.), *Final Report of the Second COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions and COSPAR Work Meeting on Developing Payload Requirements Addressing PP Gaps on Natural Transport of Contamination on Mars*, COSPAR, Paris, France, 2019. All three documents are available on line at https://sma.nasa.gov/sma-disciplines/planetary-protection.

[40] For more information about the NASA's small spacecraft programs see, for example, https://www.nasa.gov/mission_pages/smallsats.

first SIMPLEx solicitation. The second SIMPLEx solicitation resulted in the selection of three more missions: Lunar Trailblazer, Janus, and the Escape and Plasma Acceleration and Dynamics Explorers; and

- The submission of 18 SmallSat concepts (all orbiters) by participants in the Mars science community in response from a call for mission concepts by the NASA-chartered Mars Architecture Strategic Working Group.

Each of these executed or proposed missions or payloads required or needs planetary protection attention at the mission development stage and as mission implementation proceeds. The PPIRB report expressed concern that meeting planetary protection objectives might place undue burdens on small, low-cost spacecraft, perhaps limiting their use of for entrepreneurial and scientific research purposes. The potential burden arises because limited budget resources and time require the developers of small spacecraft to adopt a more refined balance between risk and cost than is typically the case for large spacecraft. The chair of the PPIRB told the committee that the PPIRB discussed whether complying with planetary protection measures might produce a base or minimum cost that could be beyond the means of the developers without deep pockets. Similarly, NASA's Planetary Protection Officer, Lisa Pratt, informed that committee that, among other things, completing trajectory calculations required for planetary protection purposes might stress the economic resources of entrepreneurs and university researchers interested in SmallSat capabilities.[41] The committee also learned that the OPP has taken steps to simplify some potentially costly requirements by developing "a single-page organic inventory template to reduce the workload for the CubeSat teams and to standardize the input into the aggregation activity."[42]

Finding: NASA has an opportunity to be proactive in addressing the planetary protection challenges generated by small, low-cost, missions and thereby contribute to the potential that small, low-cost spacecraft offer for scientific, academic, and private-sector exploration and use of space.

The committee believes that effectively addressing the planetary protection challenges presented by small spacecraft missions could allow NASA to begin building its new approach to planetary protection policy. An expedited focus on low-cost missions would let NASA start addressing the three strategic areas for action in planetary protection policy that this committee draws from the recommendations of PPIRB and 2018 reports. An effort targeted on small, low-cost spacecraft would also signal that NASA understands the changing environment for planetary protection and is ready, willing, and able to bring planetary protection policy effectively and efficiently into this new age of space activities.

Recommendation: NASA should undertake the following actions:

- **Develop a broad-based, representative advisory process to inform the development of planetary protection policy for small, low-cost spacecraft;**
- **Identify, fund, and complete research and development priorities related to small, low-cost spacecraft (e.g., on analyzing base costs for planetary protection compliance and on crafting a standard planetary protection template);**
- **Clarify the legal and regulatory environment for small, low-cost spacecraft used in missions that are not subject to agreements or contracts with NASA; and**
- **Record, analyze, and communicate the lessons learned from specific small, low-cost spacecraft missions in order to inform the development and implementation of the new approach to planetary protection policy as recommended in NASA's 2019**

[41] Briefing to the committee by Lisa Pratt on November 22, 2019.
[42] Private communication from J. Andy Spry to G. Scott Hubbard, January 22, 2020.

Planetary Protection Independent Review Board report and National Academies of Science, Engineering, and Medicine's 2018 report *Review and Assessment of Planetary Protection Policy Development Processes*.

NASA has the expertise to convene experts to clarify these areas, and the effort can be carried out in a relatively short time at a modest cost. By conducting these actions, the agency can take near-term steps to ameliorate an emerging concern identified by the PPIRB report and with which this committee agrees. The effort can also provide an opportunity for NASA to demonstrate success in addressing the committee's highest priority issues—stakeholder engagement, research to facilitate new planetary protection approaches, and legal and regulatory clarity.

Appendixes

A

Letter Requesting this Study

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

AUG 16 2019

Reply to Attn of: Science Mission Directorate/Deputy Associate Administrator for Research

Dr. Margaret Kivelson
Chair, Space Studies Board
National Academies of Sciences, Engineering, and Medicine
500 5th Street, NW
Washington, DC 20001

Dear Dr. Kivelson,

A report issued in 1958 by a subcommittee of the International Council of Scientific Unions described the first code-of-conduct for Planetary Protection and recommended that the newly-formed Committee on Space Research (COSPAR) should resume responsibility for matters of Planetary Protection; and in 1967 the Outer Space Treaty formalized the legal requirements for Nations to avoid "harmful contamination" of celestial bodies and "adverse changes in the environment of the Earth." The COSPAR guidelines have been updated in the interim and have been used by all spacefaring nations to guide their preparations for encounters with solar system bodies.

Recent reviews by the NASA Advisory Council (NAC) committee and the National Academies of Science (NAS) (*Review and Assessment of Planetary Protection Policy Development Processes*, 2018) have raised concerns about whether advancements in science and engineering are outpacing those COSPAR guidelines. These reviews also raised concerns about whether the guidelines are outdated in regard to the growing interest from commercial and private groups in exploration and utilization of Mars and other bodies in space.

In response to these concerns, NASA's Science Mission Directorate Associate Administrator has convened the Planetary Protection Independent Review Board (PPIRB) that will look at updating COSPAR's guidelines on biological contamination. The PPIRB is planned to complete its work and issue its report (in presentation form) by early September 2019.

Statement of Task: The National Academies of Sciences, Engineering, and Medicine (NASEM) will establish an *ad hoc* committee to review the findings of the PPIRB and comment on their consistency with the recommendations of the recent NASEM report *Review and Assessment of Planetary Protection Policy Development Processes* (2018).

In order for NASA to make optimal use the results of this study, NASA would like to receive the Academy's findings within the first quarter of 2020.

Once agreement with the NASEM on the scope and cost for this study has been achieved, the NASA Contracting Officer will issue a task order for implementation. Dr. Michael New, the Deputy Associate Administrator for Research, will be the technical point of contact for this effort and may be reached at (202) 358-1766 or michael.h.new@nasa.gov.

Sincerely,

Thomas H. Zurbuchen, Ph.D.
Associate Administrator,
Science Mission Directorate

B

Review and Assessment of Planetary Protection Policy Development Processes: Findings and Recommendations

The statement of task for the current study makes specific reference to the National Academies of Sciences, Engineering, and Medicine's 2018 report *Review and Assessment of Planetary Protection Policy Development Processes.* The latter report contains 18 recommendations and a somewhat larger number of findings. While recommendations are numbered sequentially within their respective chapter (e.g., Recommendation 3.2 is the second in Chapter 3), the findings were not. For ease of reference within the current report, all of the findings and recommendations are reproduced verbatim and by chapter below.

CHAPTER 1—INTRODUCTION

Finding: The committee finds no reason to augment these two established rationales for planetary protection with a third one focused on the integrity of the science investigations themselves.

Finding: Creating a more arms-length relationship within NASA between those responsible for the development of planetary protection policies and those responsible for implementing the requirements deriving from the policies would create a greater sense of equity and fairness.

CHAPTER 2—HISTORICAL CONTEXT

Finding: The OST provides the critical and effective international legal framework for countries to identify risks of forward and back contamination, formulate risk management strategies, and implement those strategies in space missions. States parties to the OST have not experienced serious disagreements on the meaning of, or compliance with, the treaty's planetary protection provisions.

Finding: Planetary protection policies and requirements for forward and back contamination apply equally to both government-sponsored and private-sector missions to Mars.

Finding: For five decades, the states parties to the OST have used COSPAR policy as part of complying with their planetary protection obligations under the treaty and, thus, have made COSPAR interdependent with their respective national rules, institutions, and processes on planetary protection.

Finding: All spacefaring nations, including new entrants to space exploration, have declared they will comply with COSPAR guidance on planetary protection. Such commitment highlights the importance of the COSPAR planetary policy development process to the behavior of spacefaring nations, including state party efforts to comply with their planetary policy obligations in the OST.

CHAPTER 3—SUMMARY AND ASSESSMENT OF THE CURRENT PROCESS

Finding: In connection with Mars sample return, planetary protection requirements for the sample containment, verification of containment, return vehicle and sample receiving facility are not yet in place.

Recommendation 3.1: NASA's process for developing planetary protection policy for sample return missions should include early consultation with mission developers and managers, mission and receiving facility science teams, and microbiologists and include providing a means to use the best available biological and technological knowledge about back contamination and containment.

Finding: Because NASA planetary protection policies have been incomplete with respect to unique aspects of new, first-of-a-kind missions, requirements for these spaceflight missions have not always been clearly defined at the beginning of a project or communicated to projects in accordance with NASA's standard protocols for imposing headquarters-level requirements.

Finding: The NASA Office of Planetary Protection and the mission project teams have not been following standard NASA spaceflight program and project management and systems engineering practices. In particular the PPO has been issuing level-1 requirements informally through letters, email, and verbal direction, and the project teams have accepted this practice even though this methodology is inconsistent with normal NASA practices. NASA officials delayed unnecessarily in taking advantage of NASA's established conflict resolution process.

Recommendation 3.2: NASA should assess the completeness of planetary protection policies and initiate a process to formally define the planetary protection requirements that are missing. NASA should ensure that all future headquarters planetary protection requirements imposed on spaceflight missions follow NASA standard project management and systems engineering protocols for review, approval, and flow-down of requirements and, when disagreements occur, ensure that NASA's conflict resolution process is followed. For future new situations such as private sector missions to other bodies or human exploration of Mars, the policies and their potential impacts should be evaluated and examined well in advance of a mission start.

Finding: The COSPAR process can approve international guidance on planetary protection without such guidance being reviewed and agreed upon in advance by the range of NASA stakeholders that participate in making NASA policy on planetary protection.

Recommendation 3.3: NASA should ensure that in assessing changes to COSPAR planetary protection policies and requirements there is a process to engage the full breadth of NASA stakeholders, including the spaceflight mission and science communities. This process should be at least as disciplined as the process NASA uses to review, concur, and approve changes to its own policies.

Finding: NASA has not finalized all issues related to transferring the PPO from SMD to OSMA or revised its policy directives, procedural requirements, and advisory structure to reflect this important change.

Recommendation 3.4: NASA should expeditiously complete the transition of the OPP to OSMA and clarify the remaining issues concerning roles, responsibilities, resources, and locations of OPP functions. The Chief of the Office of Safety and Mission Assurance should complete the Science Mission Directorate's move toward instituting a formal method for imposing planetary protection requirements that are in accordance with standard NASA systems engineering practices.

Recommendation 3.5: NASA should develop an agency-wide strategic plan for managing the planetary protection policy development challenges that sample return and human missions to Mars are creating.

Finding: The development and implementation of planetary protection policy at NASA has benefited in the past from a formally constituted independent advisory process and body. As this report is written, both the advisory body and process are in a state of suspension.

Recommendation 3.6: NASA should reestablish an independent and appropriate advisory body and process to help guide formulation and implementation of planetary protection adequate to serve the best interests of the public, the NASA program, and the variety of new entrants that may become active in deep space operations in the years ahead. The advisory body and process should involve a formal FACA committee and interagency coordination, as well as ad-hoc advisory committees, if and as circumstances dictate. This advisory apparatus should be situated and engage within NASA at a level commensurate with the broad cross-cutting scope of its purview and the potentially broad interests that the involved issues may engender.

Finding: The field of planetary protection science fills a rather small sector of modern science, and it has not been able to engage a substantial number of scientists who have been leading in important areas of modern sciences. For example, while the field of biology has made enormous advances in recent years many of those advances that could be applicable to improving approaches to planetary protection have not yet been fully integrated into the development of planetary protection policy or translated into practical approaches to implement policies.

Recommendation 3.7: NASA should engage the full range of relevant scientific disciplines in the formulation of its planetary protection policies. This requires that scientific leaders outside of the standard planetary protection community in NASA participate in revisions to NASA and COSPAR planetary protection policies and requirements.

Finding: NASA has not adequately funded the research necessary to advance approaches to implementing planetary protection protocols and verifying that those protocols satisfy NASA's increasingly complex planetary protection requirements. For an agency program of solar system exploration and planning for human exploration missions, costing several billion dollars per year, an investment in relevant planetary protection research and technology of less than one tenth of one percent of that total seems inadequate.

Recommendation 3.8: NASA should adequately fund both the Office of Planetary Protection and the research necessary to determine appropriate requirements for planetary bodies and to enable state-of-the-art planetary protection techniques for monitoring and verifying compliance with these requirements. The appropriate investment in this area should be based on a strategic assessment of the scientific advances and technology needs to implement planetary protection for likely future missions.

Finding: ESA's planetary protection process reduces organizational conflicts of interest by separating lines of responsibility for formulating policy, establishing requirements, and implementing requirements and by giving more authority to mission project managers to translate top-level requirements into implementation approaches.

Recommendation 3.9: NASA should evaluate the ESA process for planetary protection implementation and strongly consider incorporating the elements of that process that are effective and appropriate.

Finding: As the exploration of the icy moons rises in priority and plans for piloted missions to Mars emerge, it is necessary to reevaluate and clarify the period of biological exploration.

Recommendation 3.10: Given the implications with respect to the Outer Space Treaty, NASA and COSPAR should facilitate development of an international strategy for establishing periods of biological exploration. Such a strategy should ensure that individual nation states are all using the same values. Specification of this period is vital to the calculations of probability of contaminating a potential habitat on another world.

CHAPTER 4—POLICY DEVELOPMENT PROCESS BEYOND NASA

Finding: NSC-25 is out of date. Plans to send robotic sample-return and human-crewed missions to Mars in the next few decades will, in all likelihood, create planetary protection challenges that current national processes on developing planetary protection policy are not well-equipped to handle.

Recommendation 4.1: The Administration, most probably through the National Space Council, National Security Council, and the Office of Science and Technology Policy, should revisit NSC-25 in light of NASA plans for Mars sample-return missions and human-crewed missions to Mars and revise or replace its provisions for engaging relevant federal agencies in developing back contamination protection policies.

Finding: The effectiveness of COSPAR's development of planetary protection policy guidelines and international compliance with the provisions of the Outer Space Treaty has mitigated the need for significant interventions by the Department of State. However, the planned sample-return and human missions to Mars will raise planetary protection issues that require more diplomatic attention.

Recommendation 4.2: The Department of State, informed by consultations with the appropriate experts and stakeholders, should embark on active international diplomacy to forge consensus on appropriate policies for planetary protection for a broad range of future missions to Mars. The goal should be to maintain and develop international consensus on how best to mutually and cooperatively meet all signatories' obligations under Articles IX and VI of the Outer Space Treaty. Such diplomacy should take into consideration, to the extent possible, the best available science as well as anticipate new missions in space.

Finding: COSPAR has been a crucial forum for furthering international cooperation with respect to planetary protection ever since its creation in 1958.

Finding: The COSPAR policy has historically been incomplete with respect to missions to solar system bodies that have not yet been explored by any nation. These gaps in the current COSPAR policy need to be defined by the nation pursuing a new mission to a previously unexplored body, such as Europa, where the policy has not yet been fully documented. This role has historically been filled by the United States.

Finding: COSPAR's reorganization of its Planetary Protection Panel will help ensure a more structured and formal process for COSPAR planetary protection policy deliberations, however a need remains to ensure that U.S. participation in panel deliberations is appropriately representative of all stakeholder perspectives.

Finding: The SSB's international leadership role in planetary protection has been a reflection of the dominant U.S. role in the robotic exploration of the solar system and NASA's sustained interest in securing and using scientific advice from the SSB, but those factors may are not necessarily guaranteed in the future. The SSB has been reactive to requests from NASA rather than proactive, constrained by the limited pool of planetary protection experts to serve on study committees, unable to provide advice on short time-scales, and focused on issues for robotic scientific missions.

Recommendation 4.3: The SSB and NASA should pursue new mechanisms to anticipate emerging issues in planetary protection, respond more rapidly, and address new dimensions such as private sector missions and human exploration. Future decadal survey committee's should give greater prominence to planetary protection issues and play a more proactive role in their identification and possible resolution.

CHAPTER 5—PLANETARY PROTECTION CHALLENGES FROM THE HUMAN EXPLORATION OF MARS

Finding: Although NASA is planning for human missions to Mars in the 2030's, NASA does not currently have an adequate planetary protection policy for human exploration and activities on Mars. In addition, neither NASA nor the Department of State have crafted strategies for productive international dialog on developing policy for planetary protection and for other issues, such as the relationship between exploration zones on Mars and the OST's prohibition on national appropriation of parts of celestial bodies, associated with human missions to Mars.

Recommendation 5.1: NASA's process for developing a human Mars exploration policy should include examination of alternative planetary protection scenarios and should have access to the necessary research that informs these alternatives. It should also include plans to engage with other nations on the policy and legal implications of missions to Mars.

CHAPTER 6—THE PRIVATE SECTOR AND PLANETARY PROTECTION POLICY DEVELOPMENT

Finding: Current planetary protection policy and requirements do not mandate significant actions beyond documentation and inventory of organic materials for the vast majority of ongoing and planned private-sector space activities.

Recommendation 6.1: Planetary protection policies and requirements for forward and back contamination should apply equally to both government-sponsored and private-sector missions to Mars.

Finding: A regulatory gap exists in U.S. federal law and poses a problem for U.S. compliance with the Outer Space Treaty's obligations on planetary protection with regard to private sector enterprises. The Outer Space Treaty requires states parties, including the United States, to authorize and continually supervise non-governmental entities, including private sector enterprises, for any space activity that implicates the treaty, including its planetary protection provisions.

Recommendation 6.2: Congress should address the regulatory gap by promulgating legislation that grants jurisdiction to an appropriate federal regulatory agency to authorize and supervise private-sector space activities that raise planetary protection issues. The legislation should also ensure that the authority granted be exercised in a way that is based upon the most relevant scientific information and best practices on planetary protection.

Finding: To date, planetary protection policy development at national and international levels has not involved significant participation from the private sector. The lack of private-sector participation creates potential challenges for policy development, because private-sector actors need to be able to understand and embrace appropriate planetary protection measures.

Recommendation 6.3: NASA should ensure that its policy-development processes, including new mechanisms (e.g., a revitalized external advisory committee focused on planetary protection) make appropriate efforts to take into account the views of the private sector in the development of planetary protection policy. NASA should support the efforts of COSPAR officials to increase private-sector participation in the COSPAR process on planetary protection.

CHAPTER 7—A NASA PLANETARY PROTECTION STRATEGIC PLAN

Finding: The issues raised in the committee's assessment of NASA's planetary protection policy development processes comprise appropriate topics for a planetary protection strategic plan, but NASA currently lacks such a plan.

Recommendation 7.1: NASA, under the direction of the Office of the Administrator, should develop a planetary protection strategic plan that clearly addresses the agency's approach for

- Managing planetary protection policy implementation,
- Securing relevant outside expert advice,
- Developing a long-range forecast of future solar system exploration missions having planetary protection implications,
- Setting planetary protection research and technology investment priorities, and
- Identifying the agency's strategy for dealing with major policy issues such as sample-return, human missions to Mars, and private sector involvement in solar system exploration missions.

C

Report of NASA's Planetary Protection Independent Review Board: Findings and Recommendations

For ease of reference, the findings and recommendations contained in the report of NASA's Planetary Protection Independent Review Board (PPIRB)[1] have been numbered sequentially and are referred to in brackets throughout the report. Please note that the findings and recommendations are presented in the PPIRB report in bold type and some, but not all, are accompanied by supporting text in normal type. For compactness, the findings and recommendations are shown below in normal type, and the supporting text is in italic.

Reference Number Assigned by Committee	Finding or Recommendation in the PPIRB Report
[1]	***Major Finding:*** With the advent of private sector robotic and human planetary missions, as well as new ultra-low cost (e.g., CubeSat-class) planetary missions, the context in which PP is conducted is profoundly and rapidly changing.
[2]	***Major Finding:*** For planetary missions involving locations of high astrobiological potential, it is essential that forward and backward contamination consideration be integral to mission implementation. This applies to both government and private sector missions.
[3]	***Supporting Finding:*** The PPIRB did not assess planetary exploration historical site preservation or the implications of the human modification of celestial bodies in the Solar System, for example, for resource recovery.
[4]	***Supporting Finding:*** The scope of Planetary Protection landscape is complex, broad, nuanced, and sometimes politically charged. The PPIRB could only evaluate it at a top level in the time and resources allocated for our review.
[5]	***Major Recommendation:*** Because of advances in knowledge and technologies since the Viking era, NASA's PP policies and implementation procedures should be reassessed. *PP technology and relevant science disciplines are progressing rapidly; thus, the PPO should refresh its knowledge of the state of the art in PP science and technology, and apply this knowledge to advance, and where feasible, simplify PP implementation. This likely requires additional PPO funding to be effective.*
[6]	***Major Recommendation:*** Owing to the changing PP context and the rapid advancement of scientific, technological, and private sector planetary mission capabilities, NASA should reassess its PP guidelines at least twice per decade with an IRB-like body that includes representatives of all major stakeholder communities. *The PPIRB findings and recommendations presented in this report apply to the current era and generally are made with a 3-5 year horizon in mind.*

[1] Planetary Protection Independent Review Board, *NASA Planetary Protection Independent Review Board (PPIRB): Report to NASA/SMD: Final Report*, NASA, Washington, D.C., 2019, https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf.

[7] ***Major Recommendation:*** NASA should establish a standing forum for the discussion and resolution of emergent PP issues that includes input from government, private sector, and perhaps even non-U.S. private sector enterprises.

[8] ***Major Finding:*** The PPIRB applauds SMD's and OSMA's recent revamping of the PPO and the work of the new PP Officer, which has increased communication, clarity, and responsiveness to community needs and concerns.

[9] ***Major Recommendation:*** NASA should establish explicit processes such as an ongoing process of independent review to ensure that PPO policies and procedures are consistently applied regardless of specific PPO personnel.

[10] ***Major Finding:*** There is a general lack of clarity concerning PP requirements and implementation processes, particularly for non-NASA missions; this impedes the development of private sector planetary exploration.

[11] ***Major Recommendation:*** NASA should clarify its policy for exercising PP authority over primarily non-NASA space activities that have some level of NASA involvement.

[12] ***Major Recommendation:*** To further encourage the development of private sector planetary activities, NASA should offer a greater degree of PP expertise and tools to new and emerging actors in planetary exploration.

[13] ***Major Finding:*** The late addition of PP requirements to some projects has been costly and inefficient to implement.

[14] ***Major Recommendation:*** To reduce project inefficiencies, PP requirements should be finalized early in mission formulation and should avoid past practices of adding new or unexpected PP requirements, including in categorization letters.

[15] ***Major Recommendation:*** PP requirements on missions should be written to define PP intent, rather than detailed implementation methods, thereby allowing projects to select and/or develop implementations most suitable to meet their PP requirements from a systems standpoint.

[16] ***Major Finding:*** Although NASA is not a regulatory agency, the Agency can likely affect control over non-NASA U.S. missions by linking PP compliance to eligibility for current or future NASA business or NASA support. However, overreaching application of such control could result in reduced opportunities for collaboration with private sector missions.

[17] ***Supporting Recommendation:*** Policy regarding such application of Agency authority to affect PP implementation should be carefully reviewed above the PPO level.

[18] ***Supporting Finding:*** COSPAR PP guidelines have evolved to be an internationally recognized, voluntary standard for protection of scientific interests in celestial bodies. Adherence to the COSPAR guidelines has been considered an acceptable mechanism for establishing a State party's compliance with the harmful contamination aspects in Article IX of the OST. Adherence to COSPAR PP guidelines have constituted one type of mechanism for establishing compliance with Article IX, but this is not the only such compliance mechanism; other mechanisms that may be more appropriate also exist.

[19] ***Supporting Finding:*** For many of NASA's scientifically driven planetary exploration missions to astrobiologically relevant targets, scientific cleanliness requirements often exceed PP bioburden requirements.

[20] ***Supporting Finding:*** Anachronistic, and sometimes unrealistic, PP requirements (e.g., delivery of <1 viable organism to Europan liquid water for Europa Clipper) have driven a great deal of costly and sometimes questionable effort, often involving requirements or implementation waivers.

[21] ***Supporting Finding:*** The PPIRB applauds and encourages flexible ways to address PP intent using novel methods.

[22] ***Supporting Recommendation:*** The PPO should exploit new discoveries and new technologies to better categorize exploration targets, create better forward and backward PP implementation protocols, and lower PP cost and schedule impacts on projects.

[23] ***Supporting Recommendation:*** For forward contamination, NASA PP policy should move beyond exclusive adherence to spore counts, which is an outdated legacy of the 1970s Viking era. PP policy should encourage the use of proven modern techniques and well-established genomic tools for monitoring and characterization of bioburden of cleanroom facilities and flight hardware. NASA should also encourage the broader use of probabilistic models of the risk of "harmful" forward contamination based on likely scenarios and acceptable risk outcomes.

[24] ***Supporting Recommendation:*** For both forward and backward contamination requirements, NASA should continue to allow novel approaches, such as crediting for time spent in the harsh space environment or on harsh planetary surfaces (e.g., UV, radiation, temperature extremes, lack of liquid water). To enable this, NASA should support quantitative laboratory studies of such approaches to demonstrate quantitative PP credits.

[25] ***Supporting Recommendation:*** NASA's PP requirements should be completely specified in NASA Procedural Requirements (NPRs)/NASA Policy Directives (NPDs) so that projects subject to NASA PP requirements know what to expect and can better plan in advance to a known, fixed set of project requirements.

[26] ***Supporting Recommendation:*** The PPO should implement both well-documented and transparent PP requirements and requirements waiver processes for all missions with NASA involvement.

[27] ***Supporting Recommendation:*** NASA should provide external stakeholders with clear information and better insight and outreach on its PP standards and processes. This should include a rollout plan for new PP processes, followed by regular stakeholder engagement opportunities to ensure widespread awareness and understanding of PP standards and processes.

[28] ***Supporting Finding:*** Without further changes to streamline low-cost mission PP implementation, ultra-low cost planetary missions (e.g., CubeSats) will likely have a PP implementation cost burden that is a larger percentage of their total budget than larger missions, which in turn could threaten their low cost, particularly for those missions beyond PP Category II.

[29] ***Supporting Recommendation:*** NASA should assess how to streamline PP implementation for ultra-low cost planetary missions.

[30] ***Supporting Finding:*** It is impractical for launch providers or satellite hosts to definitively determine the biological content of every payload. Biological materials intentionally added by a bad actor are especially challenging for launch providers to monitor or report, as they can be further obscured by falsified verification or inaccurate documentation. *The recent experience in which a launch customer placed tardigrades and other biological samples on the SpaceIL Beresheet lunar lander is illustrative. By the Moon's Category II PP designation, it is likely that a payload license would have been readily granted had the bioload been self-reported; however, the lack of such reporting created new issues relating to launch licensing.*

[31] ***Supporting Recommendation:*** Breaches of PP reporting or other requirements should be handled via sanctions that hold the root perpetrator accountable, rather than increasing the verification and regulatory burden on all actors.

[32] ***Supporting Finding:*** Space Act Agreements and some NASA contracts require NASA 8020.12 PP compliance, which in turn invokes COSPAR policy/guidelines.

[33] ***Supporting Recommendation:*** These contractual requirements should be reviewed by NASA to simplify compliance where possible and to avoid overconstraining the means of meeting NASA intent.

[34] ***Supporting Recommendation:*** Whenever updating U.S. PP policy and implementation practices, the U.S. government should work with the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) to communicate new U.S. PP approaches to the international community, share best practices, and encourage the international community to address such issues.

[35] ***Major Finding:*** As more is learned about each celestial body, more detailed and tailored approaches to forward contamination become advisable. These include variable categorization based on surface/subsurface location, where and how many times past missions have investigated the body, and the survivability and propagation of terrestrial organisms in the body's environments.

[36] ***Major Recommendation:*** NASA should study how much of the Moon's surface and subsurface could be designated PP Category I versus Category II. Establishing different categories for different locations on the Moon could significantly simplify and enhance exploration opportunities for both the civil and private sectors. *An object that has "no direct interest for understanding the process of chemical evolution or the origin of life" is designated Category I. The Moon is currently classified Category II—of "significant" interest to origins of life questions but with "low risk" that contamination will compromise future science. In general, however, scientific interest in the Moon is not focused on the origin of life or its building blocks. Other than locations where ice is known to exist near the lunar poles (which could remain Category II), most locations on and inside the Moon are not relevant to questions of the chemical evolution leading to or the origin of life itself.*

[37] ***Major Recommendation:*** NASA should reconsider how much of the Martian surface and subsurface could be Category II versus IV by revisiting assumptions and performing new analysis of transport, survival and amplification in order to reassess the risk of survival and propagation of terrestrial biota on Mars. *All past U.S. landed missions have been treated as though there is a "significant" chance that terrestrial organisms can survive and be transported to areas where life or biosignature detection experiments would be performed. Rummel et al. (2014) have shown that many areas of the surface are not locations of PP concern. Similarly, although there may be subsurface regions that continue to warrant additional special PP consideration, this need not be the case for all subsurface regions. NASA should revisit the categorization of areas that are not considered to be "Special Regions" and determine limits on terrestrial bioload transport and amplification from current landing sites.*

[38] ***Major Recommendation:*** NASA should consider establishing (i) high priority astrobiology zones, i.e., regions considered to be of high scientific priority for identifying extinct or extant life, and (ii) human exploration zones, i.e., regions where the larger amounts of biological contamination inevitably associated with human exploration missions, as compared to robotic scientific missions, will be acceptable.

[39] ***Supporting Recommendation:*** In cases of missions to Solar System destinations where there is a large population of similar Category I and II objects (e.g., comets, asteroids, Kuiper Belt Objects), NASA should allow classification of individual objects as Category I to simplify missions to them. *Just as the lunar and Martian surfaces in their entirety do not need to bear the same PP classification, in the case of small bodies where there are numerous potential targets, the contamination of any individual does not cause significant contamination to the class as a whole. If chemical evolution or origin of life experiments*

are planned for such objects, there are myriad to choose from that will not have been previously visited by robotic probes.

[40] ***Supporting Finding:*** Various scientific studies[2,3,4,5] suggest that the survival and amplification of terrestrial biota are unlikely on the Martian surface, which would support classification of much of the Martian surface as Category II.

[41] ***Major Finding:*** Human missions to Mars will create new opportunities for science and exploration. *The presence of humans is likely to enable exploration and science on Mars at a pace previously unachievable by robotic missions, and should enable more complex surface activities than have previously been possible robotically.*

[42] ***Major Finding:*** PP planning for human missions to Mars and the communication of those plans to the public are presently immature.

[43] ***Major Recommendation:*** NASA should expeditiously develop PP guidelines for human missions to Mars, whether those missions are conducted by NASA, other international agencies, or private entities. *We note that the title of NPD 8020.12 includes the phrase "For Robotic Extraterrestrial Missions," acknowledging the implicit need for a future PP policy addressing non-robotic missions. A subset of future Mars missions are expected to be neither crewed missions nor traditional scientific robotic missions, but missions of other types that could involve crew or crew-support vehicles (e.g., habitat placement, pre-staged cargo emplacement, test flights of human vehicles). Explicit clarification is needed as to which policies apply to each type of Mars mission, including such un-crewed, non- or not-primarily science-driven activities.*

[44] ***Major Recommendation:*** NASA should begin planning for the public communication of all aspects of PP planning for human missions to Mars sooner rather than later, and should pay special attention to public PP concerns, similarly to NASA's proactive treatment of NASA missions involving radioisotope power systems.

[45] ***Major Finding:*** Human missions to Mars will inevitably introduce orders of magnitude more terrestrial microorganisms to Mars than robotic missions have done or will do. *This is especially true when taking into account highly probable off-nominal events during human exploration (e.g., inadvertent venting or leaks, off-nominal landings).*

[46] ***Major Finding:*** NASA's current policies for robotic Category V Restricted Earth Return from Mars appear to be unachievable for human missions returning from Mars. *Specifically, requirements such as "No uncontained hardware that contacted Mars, directly or indirectly, may be returned to Earth unless sterilized" and "The mission and the spacecraft design shall provide a method to 'break the chain of contact' with Mars" appear to drive towards implementation approaches that are difficult, if not impossible, for human missions and their hardware to achieve.*

[47] ***Major Recommendation:*** Regarding the return of humans and equipment from Mars, NASA should invest in developing more informed, backward contamination PP criteria,

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[2] Pavlov, A.A., Vasilyev, G., Ostryakov, V.M., Pavlov, A.K., Mahaffy, P., 2012. Degradation of the organic molecules in the shallow subsurface of Mars due to irradiation by cosmic rays. *Geophys. Res. Lett*. 39 (13).

[3] Khodadad, C.L., Wong, G.M., James, L.M., Thakrar, P.J., Lane, M.A., Catechis, J.A., Smith, D.J., 2017. Stratosphere conditions inactivate bacterial endospores from a Mars spacecraft assembly facility. *Astrobiology* 17 (4), 337-350.

[4] Shotwell, R.F., Hays, L.E., Beaty, D.W., Goreva, Y., Kieft, T.L., Mellon, M.T., Moridis, G., Peterson, L.D. and Spycher, N., 2019. The potential for an off nominal landing of a multimission radioisotope thermoelectric generator-powered spacecraft on Mars to induce an artificial special region. *Astrobiology* (in press) V. 19, #11, DOI: 10.1089/ast.2017.1688.

[5] 7 Rummel, J.D., Beaty, D.W., Jones, M.A., Bakermans, C., Barlow, N.G., Boston, P.J., Chevrier, V.F., Clark, B.C., de Vera, J.P.P., Gough, R. V., Hallsworth, J.E., et al., 2014. A new analysis of Mars ''special regions'': findings of the second MEPAG Special Regions Science Analysis Group (SR-SAG2). *Astrobiolog*y 14 (11), 887–968.

considering protection of Earth's biosphere, the feasibility of mission implementation, and the potential for in situ hazard characterization on Mars. *As discussed for robotic Mars sample return below, these policies should take into consideration current understanding of the ongoing natural transport of material from Mars to Earth since the formation of the planets ~4.5 billion years ago.*

[48] ***Major Recommendation:*** Special attention should be paid to assess how astrobiological research can be carried out in the presence of human activities. *Lessons can be learned from similar activities conducted in locales such as Antarctica and the Atacama Desert. Examples could include pristine sub-sampling, extracted from within larger samples whose exterior surfaces may be contaminated, and the ability to perform subsurface sampling without introducing contamination. This activity should take into account other findings and recommendations in this report related to the application of different categorizations to different portions of the Martian surface and subsurface and the application of modern PP techniques. NASA should engage appropriate international groups such as COSPAR and the International Space Exploration Coordination Group (ISECG) to engage in similar planning.*

[49] ***Supporting Recommendation:*** In considering crew return from Mars, NASA should assess the acceptability of the multi-month return trajectory as a PP quarantine and evaluation period, potentially simplifying terrestrial quarantine scenarios, requirements, and timescales.

[50] ***Supporting Recommendation:*** NASA should review COSPAR's humans to Mars principles and guidelines to assess which should be followed, discarded, or updated for NASA's first human Mars expedition.

[51] ***Supporting Finding:*** Terrestrial biology has been transported to Mars by previous robotic missions at discrete locations, although at low levels as compared to what is likely on future crewed and crew-related missions. The impact that these already transported organisms have had on any global Mars ecosystem is unknown but is likely to be minimal. *Since it is impractical to completely sterilize all spacecraft materials, it is likely that terrestrial biota, in the form of bacteria, spores, etc., survived the transit to Mars on past robotic missions. Further study and experiments would be needed to address whether or not terrestrial biota have been able to survive on Mars, replicate, or be transported beyond the constrained locations where these spacecraft landed or crashed on the surface of Mars.*

[52] ***Major Finding:*** In addition to NASA's world-leading civil space exploration capabilities, the United States now has a vibrant, highly capable private space sector. Through rapid innovation and cutting-edge technology, this space sector is expanding access to space for both private and government users, unleashing new robotic and crewed exploration opportunities in the Solar System.

[53] ***Major Finding:*** Through existing authorization mechanisms under current Federal regulatory frameworks, the U.S. Government licenses the launch and re-entry of private space vehicles, including those for beyond Earth orbit activities. Regarding PP, these licensing mechanisms could be improved to relieve administrative burdens and address misperceptions of legal uncertainty for private sector space activities, including private sector robotic and human planetary missions that do not have significant NASA involvement.

[54] ***Major Recommendation:*** In addition to balancing the needs of science and exploration, PP policy should also recognize that it is both a NASA and a national objective to encourage private sector space initiatives and commercial robotic and human planetary missions. *The National Aeronautics and Space Act of 1958, as amended, explicitly states that one of NASA's functions is to "seek and encourage, to the maximum extent possible,*

the fullest commercial use of space."[6] *Additionally, the 2010 National Space Policy expressly directs Federal agencies to "minimize, as much as possible, the regulatory burden for commercial space activities" and to "refrain from conducting United States Government space activities that preclude, discourage, or compete with U.S. commercial space activities."*[7]

[55] ***Major Recommendation:*** PP–related authorization and supervision across the U.S. government should be implemented in a transparent, timely, and predictable manner, minimizing costs and burdens on private sector activities where possible.

[56] ***Major Recommendation:*** Regarding PP, NASA should work in support of the Administration's efforts, and as appropriate with the Congress and private sector stakeholders, to enable private sector space initiatives that do not have significant NASA involvement.

[57] ***Supporting Finding:*** Several private space companies are rapidly advancing technologies and plans for robotic and human planetary missions, including plans to land cargo and humans on the surface of the Moon and Mars. These developments provide important considerations for updating NASA and other U.S. government PP policy.

[58] ***Supporting Recommendation:*** For space activities without significant NASA involvement (including private sector robotic and human planetary missions), NASA should work with the Administration, the Congress, and private sector space stakeholders to identify the appropriate U.S. Government agency to implement a PP regulatory framework. *This regulatory framework should take into account the nation's exploration, scientific, commercial, and national security interests, and should provide external stakeholders with clear information, including better insight and outreach on PP standards and processes.*

[59] ***Supporting Recommendation:*** The U.S. should continue to encourage international PP forums to include private sector stakeholder participation.

[60] ***Major Finding:*** Martian material has been naturally transported to Earth for billions of years.[8,9] *Current Mars Sample Return (MSR) requirements do not take the natural transport and survival of Mars material into account. Further, quantitative PP risk requirements, which are based on engineering requirements, lack a fully rational basis considering this history. In contrast, the National Academies' Consensus Study Report on Planetary Protection Classification of Sample Return Missions from the Martian Moons eXploration (MMX) took into account the natural flux of Martian material to Earth in their recommendation that MMX samples returned from the Martian moons be designated as unrestricted. That report noted that the natural flux of material from Mars to Earth is orders of magnitude greater than the flux from any conceivable robotic sample return.*

[61] ***Major Recommendation:*** NASA's MSR PP approach should take into account the findings of the recent National Academies' Consensus Study Report on sample return from the Martian moons. *In particular, the risk of adverse effects Martian material poses to the terrestrial biosphere should be re-evaluated in light of the ongoing, established, natural transport of Martian material to Earth.*

[62] ***Major Finding:*** As the first restricted Earth return since Apollo, MSR will be a uniquely high profile mission. *Significant effort is being put into the MSR architectures to ensure there will be no harmful interference with Earth's biosphere. This includes NASA work (alongside international partners) to "break the chain of contact" with the Mars*

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[6] See https://history.nasa.gov/spaceact-legishistory.pdf.

[7] See https://obamawhitehouse.archives.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[8] National Academies of Sciences, Engineering, and Medicine. 2019. *Planetary Protection Classification of Sample Return Missions from the Martian Moons*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25357.

[9] Mileikowsky, C. et al., *Icarus*. 2000 June;145(2):391-427.

environment during sample collection procedures on Mars 2020, the Sample Retrieval Lander and return procedures with the Earth Return Orbiter.

[63] ***Major Recommendation:*** Planning for a Mars Sample Receiving Facility (MSRF) should be accelerated, or at least maintained on schedule, and should also be kept as pragmatic and streamlined as possible so that it does not unduly drive the schedule or cost of MSR.

[64] ***Major Recommendation:*** NASA should begin work with other government agencies to develop a MSR PP public outreach, communications, and engagement plan. *Government agencies such as the National Institutes of Health and the Food and Drug Administration have significant experience in crafting public communications policies that could be beneficial to NASA in educating the public about the realities of MSR missions.*

[65] ***Supporting Finding:*** Significant work is being done to study the MSRF and whether an entirely new facility should be built, and where, or whether the MSRF should be an add-on to an existing Biosafety Level 4 (BSL-4) facility.

[66] ***Supporting Finding:*** Some types of sterilization of Mars samples are antagonistic to many important types of scientific measurements.

[67] ***Supporting Recommendation:*** NASA should carefully trade the implications of the degree and types of PP sterilization techniques for Mars samples with the implications for various types of science measurements.

[68] ***Supporting Recommendation:*** NASA should continue to engage experts from the medical, pharmaceutical, and personal care industries to advise on effective sterilization protocols. *Such engagement provides meaningful insights from adjacent fields, demonstrates NASA's due diligence to the public, and offers lessons on effective communication to non-experts regarding safety for both robotic sample return and for future human missions to Mars.*

[69] ***Major Finding:*** The fraction of terrestrial microorganisms in spacecraft bioburdens that has the potential to survive and amplify in ocean worlds is likely to be extremely small.[10,11] Further, any putative indigenous life in subsurface oceans on Europa, Enceladus, or Titan is highly unlikely to have a common origin with terrestrial life. *Any such life would be readily distinguishable from terrestrial microorganisms using modern biochemical techniques. As a consequence of these findings, the current bioburden requirements for Europa and Enceladus missions (i.e., <1 viable microorganism) appear to be unnecessarily conservative.*

[70] ***Major Recommendation:*** The PP requirements for ocean worlds exploration should be reassessed in light of this finding.

[71] ***Supporting Finding:*** Category IV is currently assigned to landed ocean world missions when there is a significant probability of contamination of the liquid interior oceans. However, the situation for each ocean world environment is very different and limited information exists for each of these worlds regarding ice shell composition and thickness, ocean composition and habitability, interfaces/communication between the surface and ocean, and any transport of material across the surface. *For example, the differences between the environments of Enceladus, Europa and Titan are significant. The subsurface ocean within Enceladus is considered by many scientists to be habitable, and fractures at its South Pole provide direct access to its ocean. In contrast, Europa's ice shell is thought to vary from a few km to ~tens of km thick; in some regions, liquid lenses may be present within the ice shell, produced by local heating and melting. Titan's ocean, by contrast, lies*

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[10] M.T. La Duc, A.E. Dekas, S. Osman, C. Moissl, D. Newcombe, and K. Venkateswaran, Isolation and characterization of bacteria capable of tolerating the extreme conditions of clean-room environments, *Applied Environmental Microbiology* 73:2600-2611, 2007.

[11] National Research Council. 2012. *Assessment of Planetary Protection Requirements for Spacecraft Missions to Icy Solar System Bodies*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13401.

below an organic-covered ice shell ~100 km thick and is thus largely inaccessible. Impacts into Titan's icy crust can generate melt, creating a transient liquid water environment in which the liquid water can mix with Titan's surface organics; previously melted deposits are expected near Dragonfly's ultimate target, Selk Crater.

[72] ***Supporting Recommendation:*** NASA should study transport, survival and amplification mechanisms of contamination individually for each ocean world. *Such studies should include transport both laterally and vertically, through the ice shell and/or cracks into the ocean and/or subsurface pockets of liquid water, to assess the risk that Earth-based biology could be transported to a liquid water zone of an ocean world and reproduce. For example, the current metric guiding Europa Lander PP is the requirement of <1 viable organism delivered to a liquid body. These stringent numerical limits force requirements that can be unattainable, do not use the current best practices in industry of a probabilistic approach to contamination and risk mitigation, and have the potential to drive mission cost and schedule increases. Studies that examine transport, survival and amplification of relevant forward organic contaminants will inform whether contamination at one lander site provides a significant risk to future science conducted at other locations on the surface or sub-surface.*

[73] ***Major Finding:*** There is a lack of consensus as to how and when the Outer Space Treaty has legal relevance to non-governmental entities.

[74] ***Major Finding:*** The process for incorporating recommendations from this report that NASA accepts into COSPAR guidelines is not well defined. *The PPIRB has made a number of recommendations to modernize and clarify PP guidelines. For example, it has recommended a focus on identification of the top-level forward contamination requirements rather than specification of specific engineering implementations to be taken, as well as encouraging the use of modern molecular biological approaches to PP, such as metagenomic analyses of cleanroom samples. We also recommended revision or elimination of obsolete or unnecessarily conservative PP guidelines. Similarly, clarification and streamlining of COSPAR PP guidelines will encourage planetary mission activities by all, including non-traditional entities in other nations.*

[75] ***Supporting Finding:*** The term "Planetary Protection" has been used by different communities to include a variety of topics. This has caused confusion with respect to the primary responsibility of governmental PP oversight and the intent of past practices. *"Planetary Protection" has been used in different contexts including bioload guidelines for spacecraft, the search for life beyond Earth, scientific studies focused on the survivability of microbes in space, philosophical positions related to the implications of the possibility of a separate origin of life within our Solar System and potential harm to putative non-terrestrial life forms or ecosystems, and contamination concerns for specific astrobiological investigations. Misunderstanding about the intent of the past PP guidelines has caused some parties to assume that COSPAR PP is intended to protect possible extraterrestrial life from competition from Earth's microbiota. This has, in turn, resulted in an incorrect assumption by some that future human exploration is at odds with original COSPAR intent.*

[76] ***Supporting Recommendation:*** NASA should broadly communicate that its PP policy is consistent with COSPAR history, and is specifically focused on reducing biological forward contamination that could interfere with future astrobiological investigations and backward contamination that might have adverse impacts on Earth's biosphere.

[77] ***Supporting Recommendation:*** To reduce confusion, NASA should develop and then use a standard glossary of PP related terminology, including for example "spacecraft cleanliness," "forward biological transport," and "backward biological transport."

D

Establishment of the PPIRB

FINDINGS AND RECOMMENDATIONS CONCERNING PLANETARY PROTECTION ISSUED BY THE NASA ADVISORY COUNCIL'S REGULATORY AND POLICY COMMITTEE

The Regulatory and Policy Committee of the NASA Advisory Council (NAC) forwarded the following set of findings and recommendations relating to planetary protection to the NAC for discussion and potential action at its meeting in December 2018.[1]

Committee on Space Research

Finding: It is in NASA's, the nation's, and the world's interest for NASA and non-government entities to contribute to the advancement of science and space exploration by executing missions to celestial bodies, with appropriate oversight and supervision by American authorities.
Finding: Policies and guidelines produced by the Committee on Space Research's ("COSPAR's") Planetary Protection Panel are not legally binding.
Recommendation: NASA should establish a multi-disciplinary team of experts from industry, the scientific community, and relevant government agencies, to develop U.S. policies that properly balance the legitimate need to protect against the harmful contamination of the Earth or other celestial bodies with the scientific, social, and economic benefits of public and private space missions. The recommended multi-disciplinary team should be tasked with producing a detailed policy, provided to a joint session of the Regulatory and Policy Committee and the Science Committee, and (HEO [Human Exploration and Operations Committee]), that will describe best practices for the Administration, the science and research community, and private sector, to protect against harmful contamination and adverse changes in the environment of the Earth.
Recommendation: The term 'Planetary Protection' should not be used by NASA to describe the need to prevent the contamination of the Earth or other celestial bodies through human or robotic exploration. Instead, NASA should more properly refer to conducting space exploration so as to avoid 'harmful contamination' of celestial bodies and 'adverse changes in the environment of the Earth' when referencing concerns regarding contamination through human or robotic exploration. (alter to fit with the previous recommendation to review the term).

NASA ADVISORY COUNCIL RECOMMENDATION CONCERNING COSPAR

The findings and recommendations relating to COSPAR and its planetary protection policy adopted by the NASA Advisory Committee's (NAC's) Regulatory and Policy Committee at its November 16, 2018, meeting were discussed by the NAC at its December 10-11 meeting and the following recommendation was issued.[2]

[1] Available at https://www.nasa.gov/sites/default/files/atoms/files/regulatory_policy_committee_report_dec2018_tagged.pdf.
[2] Available at https://www.nasa.gov/sites/default/files/atoms/files/nac_meeting_recommendations_dec_10-11_2018_signed_tagged.pdf.

Name of Committee: Regulatory and Policy Committee
Chair of Committee: Mr. Michael Gold
Date of Council Public Deliberation: December 10-11, 2018
Short Title of Recommendation: COSPAR

Recommendation: NASA should establish a multi-disciplinary task force of experts from industry, the scientific community, and relevant government agencies, to develop U.S. policies that properly balance the legitimate need to protect against the harmful contamination of the Earth or other celestial bodies with the scientific, social, and economic benefits of public and private space missions. The recommended multi-disciplinary task force should be tasked with producing a detailed policy, provided to a joint session of the NAC Regulatory and Policy Committee, the Science Committee, and the Human Exploration and Operations Committee, that will describe best practices for the Administration, the science and research community, and private sector, to protect against harmful contamination and adverse changes in the environment of the Earth. The multi-disciplinary task force should also explore the use of the term 'Planetary Protection' relative to other terms utilized in the Outer Space Treaty.
Major Reasons for the Recommendation: The COSPAR regulations are becoming obsolete and do not properly account for the possibilities of human spaceflight and private sector missions. Creating a multi-disciplinary team to craft a balanced policy that can be implemented by NASA (and eventually COSPAR itself) will help to encourage new, innovative, human spaceflight, robotic, and private sector missions to Mars and other celestial bodies. The more of these missions that take place the more science, exploration, and commerce can be conducted.
Consequences of No Action on the Recommendation: If NASA adopts the COSP AR guidelines without any review or revisions they will have a chilling effect on robotic, human spaceflight, and private sector missions. The costs and complexity of conducting space missions will not be moderated and could become problematic. The result will be less science, exploration, and commercial activities, harming both national and global interests.

MEMBERSHIP OF THE PLANETARY PROTECTION INDEPENDENT REVIEW BOARD

NASA's Planetary Protection Independent Review Board (PPIRB) was established by NASA's Science Mission Directorate in mid-2019 in response to a recommendation issued by the NASA Advisory Council (see above). Its membership consisted of the following individuals:

- Alan Stern, Southwest Research Institute, *Chair*
- Edward Bierhaus, Lockheed Martin
- Wendy Calvin, University of Nevada, Reno
- Amanda Hendrix, Planetary Science Institute
- Christopher H. House, Pennsylvania State University
- Hernan Lorenzi, J. Craig Venter Institute
- Tommy Sanford, Commercial Spaceflight Federation
- Erika Wagner, Blue Origin
- Andrew Westphal, University of California, Berkeley
- Charles Whetsel, Jet Propulsion Laboratory
- Paul Wooster, SpaceX
- T. Jens Feeley, NASA Headquarters (Ex Officio), *Review Manager*

E

Planetary Protection Categories

TABLE E.1 Mission Type Categories as Specified in COSPAR's Planetary Protection Policy

Mission Category	Mission Type	Planetary Bodies	Planetary Protection Requirements (Illustrative Examples)
I	Any	Bodies not of direct interest for understanding the process of chemical evolution or the origin of life (e.g., undifferentiated, metamorphosed asteroids, and others [to be determined]).	None
II	Any	Bodies of significant interest relative to the process of chemical evolution and origin of life, but only a remote chance that contamination could compromise future investigations (e.g., comets, carbonaceous chondrite asteroids, outer solar system planets, Venus, the Moon, icy bodies of the outer solar system [note 1] and others [to be determined]).	Brief documentation only (except for missions to the Moon, which also require an inventory of all organic compounds present in excess of 1 kg).
III	Flyby, orbiter (no direct contact)	Bodies of significant interest to the process of chemical evolution and/or origin of life and where scientific opinion provides a significant chance that contamination could compromise future investigations (e.g., Mars [note 2], Europa, Enceladus, and others [to be determined]).	Documentation on contamination control and organics inventory, plus trajectory biasing, cleanroom, bioload reduction.
IV	Lander, probe (direct contact)	Bodies of significant interest to the process of chemical evolution and/or origin of life and where scientific opinion provides a significant chance that contamination could compromise future investigations. (e.g., Mars [note 3], Europa, Enceladus, and others [to be determined]).	Documentation (as for cat. III) plus microbial reduction plan; cat. III procedures plus partial sterilization and bioassay monitoring.
V (unrestricted)	Earth return after contact with another body	Earth-return missions from bodies deemed by scientific opinion to have no indigenous life forms (e.g., Venus, Moon, and others [to be determined]).	None except for requirements for category above for outbound phase.
V (restricted)	Earth return after contact with another body	Earth-return missions from bodies deemed by scientific opinion to be of significant interest to the process of chemical evolution and/or origin of life (Mars, Europa, and others [to be determined]).	Same as for cat. IV plus sterile or contained returned hardware and continual monitoring of project activities.

Note 1 Missions to Ganymede, Titan, Triton, Pluto/Charon, and Kuiper belt objects greater than half the diameter of Pluto can be assigned to Category II if they demonstrate by analysis their "remote potential for contamination of the liquid-water

	environments that may exist beneath their surfaces (a probability of introducing a single viable terrestrial organism of $<1 \times 10^{-4}$) addressing both the existence of such environments and the prospects of accessing them."
Note 2	Mars orbiters are required to meet an orbital lifetime requirement (20 or 50 years after launch with a probability $\geq$0.99 or 0.95, respectively. Lifetime requirements are not required if the orbiter meets a total bioburden level of $\leq$500,000 spores.
Note 3	Category IV missions to Mars are subdivided into IV_a, IV_b, and IV_c. Category IV_a missions—i.e., those not carrying instruments designed to investigate extant martian life—are restricted to a surface bioburden of $\leq$300,000 spores, and an average of $\leq$300 spores m^{-2}. Category IV_b missions—i.e., those carrying instruments designed to investigate extant martian life—must meet Category IV_a requirements plus: "the entire landed system is restricted to a surface bioburden of $\leq$30 spores [note 4] or to levels of bioburden reduction driven by the nature and sensitivity of the particular life-detection system;" or "the subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection must be sterilized to these levels, and a method of preventing recontamination of the sterilized subsystem and the containment of the material to be analyzed is in place." Category IVc missions—i.e., those accessing special regions on Mars, even if not carrying life-detection instrument—must meet Category IV_a requirements plus: "if the landing site is within the special region, the entire landed system is restricted to a surface bioburden level of $\leq$30 spores (note 4);" or "if the special region is accessed through horizontal or vertical mobility, either the entire landed system is restricted to a surface bioburden level of $\leq$30 spores (note 4), or the subsystems which directly contact the special region shall be sterilized to these levels, and a method of preventing their recontamination prior to accessing the special region shall be provided."
Note 4	The 30 spore limit "takes into account the occurrence of hardy organisms with respect to the sterilization modality. This specification assumes attainment of Category IVa surface cleanliness, followed by at least a four order-of-magnitude reduction in viable organisms. Verification of bioburden level is based on pre-sterilization bioburden assessment and knowledge of reduction factor of the sterilization modality."

NOTE: Also shown are examples of the solar system bodies assigned to each category and the corresponding principal planetary protection requirements. Nuances of in the current planetary protection policy for Category III and IV missions to Europa and Enceladus or Category V missions to Mars, Europa, Enceladus or small solar system bodies are not shown.
SOURCE: Adapted from *Review and Assessment of Planetary Protection Policy Development Processes*, The National Academies Press, Washington, D.C., 2018, p. 19 and G. Kminek, C. Conley, V. Hipkin, and H. Yano, "COSPAR Planetary Protection Policy," *Space Research Today*, No. 200, December 2017, pp. 12-24.

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Biographies of Committee Members and Staff

MEMBERS

JOSEPH K. ALEXANDER, *Chair*, is a consultant in science and technology policy at Alexander Space Policy Consultants. He was a senior program officer with the Space Studies Board (SSB) of the National Academies of Sciences, Engineering, and Medicine from 2005 until 2013, and he served as SSB director from 1998 until November 2005. Prior to joining the National Academies, he was deputy assistant administrator for science in EPA's Office of Research and Development. From 1993 to 1994, he was Associate Director of Space Sciences at the NASA Goddard Space Flight Center and served concurrently as acting chief of the Laboratory for Extraterrestrial Physics. From 1987 until 1993, he was assistant associate administrator at NASA's Office of Space Science and Applications where he coordinated planning and provided oversight of all scientific research programs. He also served from 1992 to 1993 as Acting Director of Life Sciences. Prior positions have included deputy NASA chief scientist, senior policy analyst at the White House Office of Science and Technology Policy, and research scientist at the Goddard Space Flight Center. His research interests were in radio astronomy and space physics. He has a B.A. and M.A. in physics from the College of William and Mary. Mr. Alexander's book, Science Advice to NASA: Conflict, Consensus, Partnership, Leadership, was published by the NASA History Division in 2017.

DAVID P. FIDLER is a visiting professor of law at Washington University in St. Louis and an adjunct senior fellow for cybersecurity and for global health at the Council of Foreign Relations. He also served as the chair of the International Law Association's Study Group on Terrorism, Cybersecurity, and International Law; and was the editor of and a contributor to the award-winning book, *The Snowden Reader*. He works on international law and global governance across many policy areas, including cyberspace, global health, trade and investment, environmental protection, weapons of mass destruction, terrorism, and national/international security. His current research focuses on various aspects of national and international cybersecurity. He is the recipient of a Fulbright New Century Scholar Award. He earned his J.D. from Harvard Law School. Mr. Fidler has previously served on National Academies' committees including the Committee to Review Planetary Protection Policy Development Processes.

G. SCOTT HUBBARD is an adjunct professor at Stanford University in the Department of Aeronautics and Astronautics. He is also the director emeritus of the Stanford Center of Excellence for Commercial Space Transportation and the founding editor-in-chief of the peer-reviewed journal New Space. Previous positions include director of NASA's Ames Research Center and NASA's first Mars program director. He also founded NASA's Astrobiology Institute and authored the award-winning book *Exploring Mars: Chronicles from a Decade of Discovery*. His research interests include the study of both human and robotic exploration of space. He has received eight NASA medals, including NASA's highest award, the Distinguished Service Medal and was recently elected honorary fellow of the AIAA. He currently chairs the SpaceX Commercial Crew Safety Advisory Panel. He has received several honorary doctorates, was awarded a Sc.D. by the Polytechnic University of Madrid and earned his B.A. in physics and astronomy at Vanderbilt University.

ROSALY M. LOPES is a senior research scientist at the Jet Propulsion Laboratory, California Institute of Technology (JPL) and principle investigator in the NASA Astrobiology Institute program. Her previous involvements at JPL include the Galileo and Cassini Flight Projects, and she has written more than one hundred and twenty peer-reviewed scientific publications and eight books. Her primary research interest is the geology of Titan, particularly its ice volcanoes. She is a fellow of the American Association for the Advancement of Science, the Geological Society of America, and the American Geophysical Union, and an elected member of the International Academy of Astronautics. She has received several awards, including the American Astronomical Society's Carl Sagan medal, The Explorers Club’s Lowell Thomas award, the Wings Women of Discovery Air and Space award, and two NASA Exceptional Public Service Medals. She obtained a Ph.D. from University College, London, researching volcanism on Earth and Mars. She has previously served on two National Academies’ committees and is a member of the Space Studies Board.

MARGARITA MARINOVA was until recently the senior Mars and vehicle systems development engineer at SpaceX. Before joining SpaceX, she was a planetary scientist at NASA’s Ames Research Center, where she participated in a variety of martian analog studies, and a propulsion engineer at Airbus Safran Launchers. Her main interests include characterizing extreme environments, understanding the surface of Mars, and technical advancement for solar system exploration. She has conducted research in a diverse variety of environments, including the High Arctic, the Sahara Desert in Egypt, the bottom of a lake in British Columbia in Canada, Mount Kilimanjaro in Tanzania, and the Dry Valleys of Antarctica. She earned her Ph.D. in planetary science at the California Institute of Technology.

KIRSTEN SIEBACH is an assistant professor in the Rice University Department of Earth, Environmental, and Planetary Sciences, and a member of the Science and Operations Team for the Mars Science Laboratory. Prior to joining Rice University, she was a postdoctoral research associate at Stony Brook University studying the geochemistry of martian sediments. Her work focuses on understanding the history of water interacting with sediments on Mars and early Earth through analysis of sedimentary rock textures and chemistry; she is also actively engaged in promoting education and outreach related to Earth and planetary sciences. She has received several NASA Group Achievement Awards for her work on the Mars Science Laboratory, Mars Exploration Rovers, and Phoenix missions. She completed her Ph.D. in geology at the California Institute of Technology.

CAROLINE SMITH is the head of Earth Sciences Collections and Principal Curator of Meteorites at the Natural History Museum in London. Prior to joining the Natural History Museum, she was a post-doctoral researcher at the University of Glasgow. She was also the co-principle investigator of the European Commission Horizon2020 project EURO-CARES. Her main research interests are planetary differentiation and extraterrestrial and terrestrial alteration processes. She was a member of the 2011 ESA/NASA Joint Science Working Group for Mars exploration missions, the co-chair of the iMARS Science Team 2014-2015. She is currently a member of ESA’s Human Spaceflight and Exploration Science Advisory Committee. Her experience and expertise in curation and collections has been recognized by the award of an Aurora Fellowship from the U.K. Space Agency and a honorary professorship at the University of Glasgow. Dr. Smith earned her Ph.D. in meteoritics from The Open University.

TRISTA VICK-MAJORS is an assistant professor in the Biological Sciences Department at Michigan Technological University. Prior to joining Michigan Technological University, she was a postdoctoral research scientist at l’Université du Québec à Montréal and at the University of Montana’s Flathead Lake Biological Station. As an Antarctic biogeochemist and microbial ecologist, her research projects focus on microbial communities and carbon cycling under ice. She is best known for her work showing that microorganisms are active in subglacial lakes under the Antarctic ice sheet. She completed her Ph.D. in ecology and environmental sciences from Montana State University.

A. THOMAS YOUNG is the retired executive vice president of Lockheed Martin and chair of the Independent Review Board for the James Webb Space Telescope. Previous positions include director of NASA's Goddard Space Flight Center, president and chief operating officer of Martin Marietta Corporation, and chair of Science Applications International Corporation. Mr. Young received high acclaim for his technical leadership in organizing and directing national space and defense programs, especially the Viking program. He is a fellow of the American Institute of Aeronautics and Astronautics (AIAA) and of the American Astronautical Society (AAS). He has received many awards, including NASA's highest award, the Distinguished Service Medal, as well as the Outstanding Leadership Medal, the Meritorious Executive Presidential Rank Award, and the Distinguished Executive Award. He earned his M.S. in management from the Massachusetts Institute of Technology.

STAFF

DAVID H. SMITH joined the SSB as a senior staff officer in 1991. He has been and is the study director for a variety of National Academies' activities in the general areas of astrobiology, planetary science, and planetary protection. He also organizes the SSB's Lloyd V. Berkner Space Policy Internships and the joint SSB–Chinese Academy of Sciences Forum for New Leaders in Space Science. He received a B.Sc. in mathematical physics from the University of Liverpool in 1976, achieved the honors standard in Part III of the Mathematics Tripos at the University of Cambridge in 1977, and a D.Phil. in theoretical astrophysics from Sussex University in 1981. Following a postdoctoral fellowship at Queen Mary College, University of London, he held the position of associate editor and, later, technical editor of *Sky and Telescope*. Immediately prior to joining the staff of the SSB, Dr. Smith was a Knight Science Journalism Fellow at the Massachusetts Institute of Technology.

MIA BROWN joined the SSB as a research associate in 2016. She comes to SSB with experience in both the civil and military space sectors and has primarily focused on policies surrounding U.S. space programs in the international sector. Some of these organizations include NASA's Office of International and Interagency Relations, Arianespace, the United Nations Office for Disarmament Affairs (Austria), and the U.S. Department of State. From 2014 to 2015, Ms. Brown was the managing editor of the *International Affairs Review*. She received her M.A. in international space policy from the Space Policy Institute at the Elliott School of International Affairs at George Washington University. Prior to entering the Space Policy Institute, Ms. Brown received her M.A. in historical studies from the University of Maryland, Baltimore County, where she concentrated in the history of science, technology, and medicine and defended a thesis on the development of the 1967 Outer Space Treaty.

GAYBRIELLE HOLBERT is a program assistant with the SSB. Prior to joining the National Academies, she was a communication specialist for a non-profit organization that helped inner-city youth by providing after-school programs and resources to engage their needs. Prior to that, she was the social media consultant for the Development Corporation of Columbia Heights and a production assistant for a Startup Multimedia Production Company. She holds a B.A. in mass media communications from the University of the District of Columbia.

JORDAN McKAIG is a recent graduate of the University of Michigan, where she double majored in biology and international studies. There, she developed a rover-based life detection techniques for implementation at the Mars Desert Research Station in Utah, and studied the evolution of antibiotic resistance in hospital pathogens. She spent the last two summers interning at NASA's Ames Research Center with the Space Life Sciences Training Program, where she studied how terrestrial bacteria survive in Mars-like environments, what genetic changes occur in bacteria flown in space, and how high-altitude balloons can be used for astrobiological and atmospheric studies.

OSASE OMORUYI graduated from Yale University with her B.S. in astrophysics and will pursue her Ph.D. in astronomy and astrophysics at Harvard University in the fall of 2020. She has worked on many research projects from bubbles in the interstellar medium to gravitational wave-detected black holes with LIGO. She is also passionate about combating socioeconomic inequality in her field.