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Towards the Development of a National Planetary Protection Policy

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Executive Summary

Humanity's activities in space are on the verge of a transformation. Human missions to Mars are under consideration not only by governments around the world but also by private companies. Both public and private entities, some of which have never before conducted space missions, are proposing sample return activities from the Moon as well as Mars. With new efforts to explore and use the solar system, the challenges associated with "planetary protection" continue to grow. There are concerns that planetary protection requirements today are excessive and therefore needlessly expensive, and the technology used both for cleaning spacecraft and life detection may be outdated.

The White House Office of Science and Technology Policy (OSTP) requested that the IDA Science and Technology Policy Institute (STPI) review current planetary protection policies and approaches; summarize current U.S. and international law, regulation, standards, policies, and practices governing planetary protection; assess relevant authorities, challenges, and opportunities for change; and provide policy options to inform OSTP in reviewing and updating, as necessary, national planetary protection policies.

As part of its data collection, STPI held non-attributional discussions with over 50 stakeholders in relevant fields from various parts of NASA, other U.S. Government agencies, academia, for-profit firms, non-profits, and domestic and international subject matter experts. STPI also reviewed the literature on planetary protection and relevant topics, including relevant laws/regulations, biology, biosafety, and risk assessment.

Origin and Evolution of Current Planetary Protection Policy

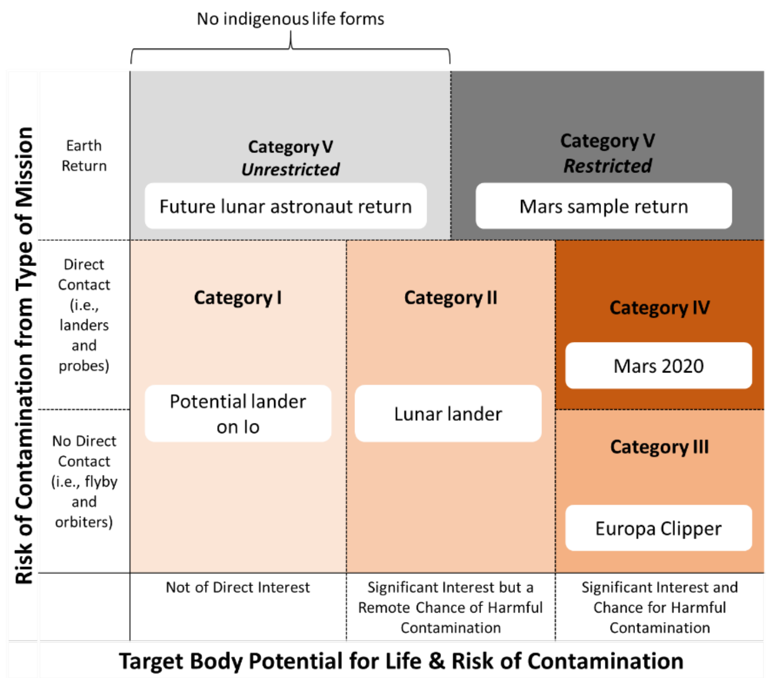
Planetary protection is a term that generally refers to the practice of avoiding contamination of other celestial bodies by terrestrial lifeforms or organic compounds (forward contamination), and avoiding contamination of the Earth by extra-terrestrial biological organisms (backward contamination). Planetary protection policy, as practiced today, is rooted in the late 1950s, when scientists became concerned that improperly supervised space exploration could affect the integrity of scientific investigations—i.e., microbes or organic constituents carried on spacecraft from Earth could contaminate and thus jeopardize current and future experiments. At the behest of several scientific organizations, including the U.S. National Academy of Sciences, the Committee on Space Research (COSPAR) and its predecessors created international standards and guidelines to protect the biological and environmental integrity of other solar system bodies for future science missions.

In parallel, the Outer Space Treaty (OST), rooted in concerns related to nuclear weapons contamination and physical interference, was being crafted in the late 1960s. Article IX of the OST, concerned with "avoiding harmful contamination" (a term not defined in the Treaty) of celestial bodies and adverse changes to the environment of Earth, afforded a legal foundation for COSPAR's planetary protection policy.

While abiding by COSPAR policy is an accepted way of complying with Article IX obligations, there is no international legal requirement to do so. In 2017, the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS), the organization that oversees the implementation of UN treaties and agreements relating to activities in outer space, "noted the long-standing role of COSPAR in maintaining the planetary protection policy as a reference standard for spacefaring nations and in guiding compliance with Article IX" (COPUOS 2017), but did not make it a legal requirement.

Policy as Implemented Today

Planetary protection policy attempts to meet two goals: (1) preserve the integrity of Earth's biosphere from "backward contamination," and (2) protect the biological and environmental integrity of other solar system bodies from "forward contamination" for future science missions. In the United States, NASA implements planetary protection policy through its Office of Planetary Protection, as well as planetary protection offices at its field centers. NASA categorizes missions based on the threat that they may pose to the integrity of science or Earth's biosphere (see figure below). Based on this categorization, NASA planetary protection policy requires implementation procedures to mitigate the risk of contamination.



NASA's Planetary Protection Policy with Mission Examples

The policy has been reviewed extensively by national scientific organizations, and over 27 National Academy of Science reports have evaluated various dimensions of the policy, but several outstanding challenges remain. Principal among these are that the NASA policy, as currently formulated, focuses solely on robotic exploration and does not provide solutions for allowing human exploration.

The implementation of NASA's planetary protection policy is complicated by the entrance of private entities aiming to conduct human and robotic missions to Mars and the icy moons, as well as upcoming sample return missions from Mars. NASA does not have a legal mandate to ensure that the private sector follows its policy.

The United States has not provided clear in-space authority, nor has it clarified (via legislation, executive action, or regulation) how private entities should ensure planetary protection. Unlike previous government missions, some of these new missions do not have science as their central or sole focus. Not surprisingly, the existing planetary protection framework—developed in a time when there were only government-led, science-focused missions—does not provide guidance specifically for private missions that involve sending machinery or humans to settle or use portions of a celestial body.

Benefits and Costs of Implementing Planetary Protection

Planetary protection policy provides benefits in mitigating risk to scientific integrity and the Earth's biosphere. Avoiding forward contamination diminishes two threats to the future of science: that microorganisms or their remnants could be the source of a false positive in the search for life, and that terrestrial organisms could extinguish extraterrestrial life or adversely affect its environment (and compromise later search for life). Avoiding backward contamination mitigates the risk of harm from the introduction of harmful extraterrestrial material to Earth's biosphere; the probability of such adverse outcomes is very low, but it cannot be entirely discounted.

The cost of implementing planetary protection is difficult to estimate because the process is so embedded in mission development. For missions to Mars, numbers cited in interviews and in the literature varied from 3 to 14 percent of a project's budget. Some interviewees cited a rule of thumb that the cost of planetary protection is about equal to the cost of an instrument on a spacecraft. One private sector interviewee noted planetary protection costs could be as high as 40% of their mission. Actual cost of planetary protection may be unknowable.

Critics of the current policy indicated that it is not the direct cost of planetary protection that is of concern; it is the indirect cost such as the science that does not get conducted because of requirements that they believe are excessive. For example, such requirements may compel or incentivize mission planners to choose a less interesting scientific site to avoid higher planetary protection costs, especially if there is no established ability or willingness to sufficiently clean spacecraft to enable missions to these regions.

The cost of protecting against backward contamination is also high, with no reliable estimates of the actual cost. Sample return is already an expensive mission concept; engineering the return spacecraft to contain materials, sterilize samples, or survive impact with the ground at high velocity introduces weight and engineering complexity—increasing launch, reentry, and design costs. Furthermore, once returned to Earth, authorities must retrieve, house, and analyze unsterilized samples in a controlled environment.

Stakeholders disagree on whether the benefits provided by the current planetary protection policy warrant the associated monetary and opportunity costs. Opinions range from support of planetary protection goals, approach, and implementation as-is, to arguing for the elimination of planetary protection implementation procedures for all outbound missions. There appears to be greater consensus for controlling backward contamination, although disagreement on the prudent level of caution. At a minimum, it seems clear that the United States can improve aspects of its planetary protection practices, and might consider alternatives to the current goals, approach, and implementation procedures.

Summary of Findings and Challenges

Our research revealed findings and challenges in five areas. The first two relate to disagreements in the community regarding the goals, approaches, and implementation procedures; the third relates to challenges related to backward contamination; the fourth relates to a lack of clarity for the private sector; and the last one to a lack of transparency in the system.

- **Stakeholders disagree regarding the appropriate level of stringency in planetary protection.** Some stakeholders acknowledge that the goal of planetary protection (i.e., protecting science from biological contamination) is worthwhile, but think the current approach is flawed and overly burdensome, especially for Mars, or the implementation procedures are excessive. Another group believes that the goal of protecting future science exceeds the "harmful contamination" provision of the OST, is not sufficiently compelling, and that any policy to reduce an already small risk of harming future science is overly burdensome. Finally, a minority maintain that planetary protection should not be changed without assurance of protecting scientific investigations, and in fact, that NASA is already insufficiently conservative.
- **Stakeholders disagree on the types of harm that should be considered by planetary protection.** Some stakeholders agree with the goals of the policy—that it is an appropriately narrow interpretation of Article IX of the OST. Others argue that the goals are too narrow, and that the scope of planetary protection policy should be expanded to "avoid harmful contamination" of the Moon and other celestial bodies and protect more of the space environment, for both environmental and ethical reasons.
- **There are varying opinions among stakeholders regarding efforts to prepare for sample returns from celestial bodies that may harbor life.** Some interviewees argue that no materials (neither samples originating on those bodies nor returning humans/spacecraft sent from Earth) should be returned from celestial bodies until it is demonstrated either that the likelihood of that body containing life is sufficiently low, or that the life that would be brought back will not cause adverse changes to Earth. Others maintain that samples should be returned, but governments are not taking adequate measures to prepare for a sample return mission; this includes a lack of comprehensive implementation procedures, sample containment capabilities, and clear approval processes.
- **Expected growth of participation by the private sector introduces complications into a previously government and science-led system.** Planetary protection experts expressed concern that if private sector entities do not follow planetary protection policy as it currently stands, it could cause irrevocable harm to future science. Some representatives of private entities are in philosophical disagreement with the goals of planetary protection, noting that the current planetary protection policy restricts the search for life today. They also contend that meeting unnecessary implementation requirements would be

cost prohibitive. Lastly, they do not believe the NASA policy does or should apply to them.

In general, it is not clear how the U.S. Government's OST obligations related to Article VI (calling for State "authorization and continuing supervision" of non-governmental entities) and Article IX will be met or addressed, with respect to future in-space private sector activities involving other celestial bodies. It is also unclear whether the Department of Transportation's authority over launch approval includes, or should include, the ability to specifically require that private entities follow NASA planetary protection policy on an ongoing basis. Lastly, regardless of the agency that provides oversight, the process the private sector must follow to obtain planetary protection-related government approval is unknown.

- **There is concern that NASA's planetary protection policy and updating process lacks transparency,** and does not include adequate decision-making authority by scientists from disciplines outside astrobiology, technologists, biosafety and biosecurity experts, and private sector entities.

Policy Levers

Several actions can be taken to address the challenges above. Each action has its pros and cons, as itemized in the table on the following pages. Depending on the challenge the government chooses to address as well as the specific action, policy levers are available at the agency, Presidential, and congressional levels, and each has its pros and cons as well.

To some observers, planetary protection may seem to be a topic for the distant future. However, a confluence of factors suggests that focused U.S. policy leadership is called for now. Ambitious interplanetary space missions are moving toward reality. Advances in diverse technical disciplines are proceeding rapidly, including space technology, biological understanding, and planetary protection techniques. While this research was conducted prior to the outbreak of COVID-19, experiences with its spread and effects illustrate the potential danger of backward contamination. Finally, new governmental and private sector actors are fast emerging within the planetary space community. Addressing the issue of planetary protection policy now will help ensure the United States will continue to lead in the future.

Summary of Challenges and Options to Address Them

Challenge	Actions	Pros	Cons
Challenge 1: Stringency of Forward Planetary Protection	Leave planetary protection goals and approach as is, but improve implementation to take advantage of progress in biology, engineering, and planetary science	Would continue to protect celestial bodies while leveraging previous experience and up-to-date practices	• May be limited, failing to address issues in the underlying goals or approach • Implementing new procedures may take time • Would likely not satisfy stakeholders who believe the issue is more rooted in the applicable policy
	Leave planetary protection goals as is, but improve approach and implementation	Would facilitate easier science and exploration of some celestial bodies while maintaining the fundamental policy	• Effect will be limited to only a subset of missions (i.e., certain missions to Mars) • Would be less than satisfactory to stakeholders who believe the issue is more fundamental (i.e., in the goals)
	Re-interpret the goals of planetary protection, e.g., directly interpret the clauses of *harmful contamination* and *interference* in Article IX of the OST	A blank slate approach could better account for new actors and types of missions	• Novel legal work would be required to create and defend a definition of harmful contamination • May expand types of contamination considered by planetary protection, adding cost to space activities • Would likely adversely affect international relations and cooperation for space missions

Challenge	Actions	Pros	Cons
Challenge 2: Types of Harm Considered	Expand the goals of planetary protection policy (e.g., by defining harmful contamination) to go beyond protecting scientific integrity; this could include a number of further protections up to the full preservation of celestial bodies	May offer a more comprehensive interpretation of possible OST obligations Would consider and work to avoid more threats to celestial bodies	• Would require substantial policy change • Would likely add cost and may further limit space activities
Challenge 3: Preparedness for Sample Return	Prohibit missions currently classified as “restricted Earth-return” until the acceptable risk of backward contamination is established	Would ensure extreme precaution regarding adverse change to Earth and it may lead to increased emphasis on and innovation related to *in situ* research and life detection	• Could delay high-profile missions (Mars Sample Return and humans to Mars), resulting in political ramifications and presumed loss of science
	Allow restricted Earth missions to continue but increase investment and effort to ensure that entities conducting these missions have established safe and effective return processes	Mission planning can continue, and protocol design efforts would build on previous international work to protect against backward contamination	• Would likely be cost-intensive and assume there are implementation procedures that would sufficiently ensure the prevention of extraterrestrial contamination
Challenge 4A: Lack of Clarity of Rules for the Private Sector	Require private entities to follow the same planetary protection goals, approach, and implementation requirements as those followed by NASA missions	Aligns the requirements for public and private efforts, assigning the same amount of contamination risk to both sectors	• Would add cost to some private activities, potentially prohibiting private plans or encouraging efforts to cut corners on implementation efforts
	Require private entities to follow the same planetary protection goals but not the same approach or implementation procedures	Aligns the requirements for public and private efforts, assigning the same amount of contamination risk to both sectors; allows the private sector to interpret the expected outcomes but develop their own procedures	• The science-focused goals may not be meant for private activities • Following the goals could still lead to prohibitive requirements • Regulatory agencies may not have the expertise to determine adherence to novel implementation procedures

Challenge	Actions	Pros	Cons
Challenge 4B: Regulatory Framework for the Private Sector	Require private entities to follow different planetary protection goals (i.e., entire framework) than that followed by NASA missions—e.g., direct interpretation of Article IX	Could remove implicit bias against and allow more neutral consideration of private equities, while still meeting Treaty obligations and avoiding contamination.	• Could increase risk to future science • May face political opposition from proponents of the current planetary protection framework • Implicitly holds the government to a higher standard than non-government actors • May face international opposition
	Clarify through rulemaking how a regulatory agency would regulate planetary protection	Would address the challenge at the lowest level possible	• Agencies may require direction or guidance from EOP or Congress • Rulemaking can be a lengthy process
	Clarify the regulatory regime for planetary protection through EOP guidance (e.g., Presidential Directive)	• Provides executive guidance to regulatory agencies • Would facilitate the interagency consultation process	Presidential action is uncertain and limited by both the legislative authority over agencies and its lack of Constitutional authority over commerce
	Clarify the regulatory regime for planetary protection through legislation (e.g., by providing an agency with clear in-space authority)	• Would streamline regulatory processes • Would provide clear authority on how to regulate planetary protection • Would provide specific direction to entities while meeting Treaty obligations	Congressional action may be time-consuming and difficult to initiate, especially since such a mandate would require funding

Challenge	Actions	Pros	Cons
Challenge 5: Stakeholder Engagement	Change the nature of NASA/COSPAR engagement with stakeholders to include those outside of astrobiology/science equities	Encourages broader participation without interrupting the conventional roles in planetary protection	NASA/COSPAR may not be able to engage a sufficiently broad range of stakeholders independently, either because they cannot attract participants or are limited in soliciting wide participation by their scientific focus
	Create a new forum (e.g., a National Science and Technology Council (NSTC) subcommittee) to formulate/update planetary protection policy for the United States	• Would provide a neutral (i.e., non-science focused) starting point to develop or update policy and take equities other than science under better consideration; • Would provide a whole-of-government approach • Would raise the profile of planetary protection, potentially encouraging improved participation	• Would require EOP effort • May not be necessary to address engagement challenges • May be viewed as encroachment upon traditional NASA and COSPAR equities

Contents

1. Introduction to the Study

A. Background

Planetary protection is a term that generally refers to the practice of avoiding contamination of other celestial bodies by terrestrial lifeforms or organic compounds (forward contamination), and avoiding contamination of the Earth by extra-terrestrial biological organisms (backward contamination).

U.S. planetary protection policy derives from a diverse set of international agreements and standards, Federal statutes, Presidential directives, and best practices or protocols.[1] These policies and practices have profound implications for our quest to explore and study the solar system, as they affect critical decisions involving space mission objectives, requirements, technologies, schedules, costs, and potential partnerships.

Over the last few decades, most of the U.S. activities in space have been science missions from Earth to and in the neighborhood of other celestial bodies; planetary protection has focused on the attendant issues surrounding potential forward contamination that can be caused by these science missions. However, new developments in mission types have raised additional issues—including backward contamination of the Earth—and involve a wider set of stakeholders. These developments include:

- Possible human missions to new destinations within the solar system
- Sample return missions from celestial bodies that may harbor life (e.g., Mars)
- New technologies and approaches for sterilizing instruments and spacecraft
- Improved techniques and tools for more accurate and precise life detection
- Revolution in the understanding of terrestrial life, including the discovery of unexpected extremophiles and the abundance of Earth organisms that cannot be grown in the lab
- Expanded private involvement in science and human exploration missions

[1] While there are no Federal laws specifically addressing planetary protection, NASA's policy references the Space Act of 1958 (as amended) as its authority for its planetary protection policy. Also, a number of federal statutes are indirectly applicable to governmental oversight and decision-making involving planetary protection; these are discussed in Chapter 5.

B. Study Goals and Objectives

National leaders will benefit by understanding the underpinnings of planetary protection, including current U.S. obligations—both legal and normative—and policy options for addressing various future developments and scenarios. The Office of Science and Technology Policy (OSTP) accordingly asked the IDA Science and Technology Policy Institute (STPI) to review current planetary protection policies and approaches. The goals and objectives of this study are to (1) describe current U.S. and international law, regulation, standards, policies, and practices governing planetary protection (forward and backward); (2) to the extent feasible, assess the impacts of this regime on the cost, quality, and timeliness of space exploration and science missions; (3) conduct an assessment of the relevant authorities, challenges, and opportunities for change; and (4) provide policy options to inform OSTP in reviewing and updating, as necessary, national planetary protection policies.

While we ensured awareness, the analysis in this report does not focus on international planetary protection related activities.

C. Study Methodology

To understand the past and current status and future plans related to planetary protection, STPI held non-attributional discussions with over 50 stakeholders in relevant fields including mission planners/operators (both government and private), planetary protection policymakers or experts, policy/legal scholars, and biosecurity/ biology experts. Those contacted included representatives from various parts of NASA, other U.S. Government agencies, academia, for-profit firms, non-profits and both domestic and international subject matter experts. STPI interviewed members of a number of NASA mission teams, including Mars 2020, Europa Clipper, Europa Lander, Insight, Cassini, and Mars Sample Return (MSR), as well as mission teams in the private sector. Interviewees who agreed to be identified in the study are listed in Appendix A.

STPI representatives also engaged in targeted field research. Team members attended the Explore Mars' Humans to Mars Summit, the COSPAR Meeting on Refining Planetary Protection Requirements for Human Missions to Mars, and other symposia and seminars where planetary protection was addressed. They also attended a NASA planetary protection training session to gain experience in the current practices and procedures involved in planetary protection.

STPI also reviewed the planetary protection literature, as well as relevant laws/regulations, literature in legal analysis, biology, biosafety, and risk assessment. All reviewed documents are listed in the Reference section of this report.

D. Organization of Report

Chapter 2 provides an introduction to planetary protection, including an overview of the policy, its legal status, and how the United States implements it. Chapters 3, 4, and 5 provide an assessment of planetary protection policy, requirements, and implementation as they relate to forward contamination, backward contamination, and private actors, respectively. Chapter 6 summarizes the report's key findings and challenges, and provides options to address them.

Appendix A lists all interviewees. Appendices B and C summarize the origin and evolution of PP and key documents. Appendix D lists recent and upcoming missions with planetary protection implications. Appendix E a case study on the Apollo planetary protection experience. Finally, Appendix F summarizes an investigation into principles of risk utilized in planetary protection.

2. Introduction to Planetary Protection

In this chapter, we provide a brief overview of planetary protection policy (PPP), its legal grounding, and how it is implemented in the United States. Appendix B provides a brief overview of the origin and evolution of planetary protection policy. Appendix C lists key historical and current documents and guidelines.

A. Planetary Protection Policy

NASA's website defines planetary protection as "the practice of protecting solar system bodies from contamination by Earth life and protecting Earth from possible life forms that may be returned from other solar system bodies" (NASA 2019b). NASA's policy is to comply with the provisions described in the following policy statement:

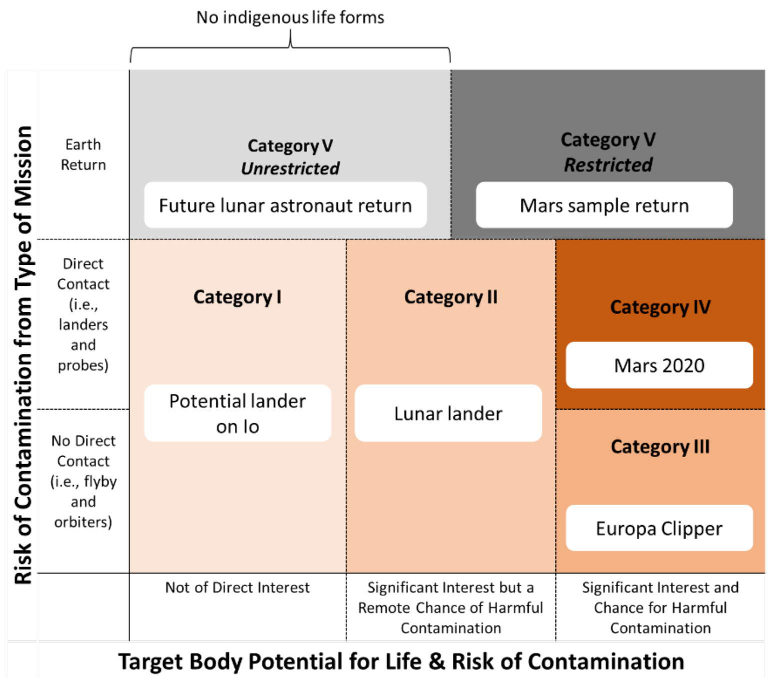
> The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet or other extraterrestrial sources. Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy. (NASA Policy Directive [NPD] 8020.7G)

This policy statement includes both the current goals of planetary protection along with the primary method of meeting them. Those two goals are to (1) preserve the integrity of Earth's biosphere, and (2) protect the biological and environmental integrity of other solar system bodies for future science missions (NRC 2018).[2] To meet these goals, planetary protection implements a method of avoiding organic and biological contamination, or avoiding the forward contamination of other celestial bodies by terrestrial lifeforms or organic compounds and backward contamination of the Earth by extra-terrestrial organisms.

To mitigate the risk of forward and backward contamination (i.e., probability and consequence), NASA flags space missions that pose a threat to the above goals for mitigating efforts. At the time of this writing, the core of the policy's approach is a system

[2] The National Research Council (NRC) called these the rationales of planetary protection instead of goals.

of categories, [3] which are defined by mission type (e.g., sample return, landers, or orbiters) and target body characteristics (e.g., ability to harbor life, scientific interest, etc.). Figure 1 provides a visual representation of these categories.



Note: The placement within a particular category does not matter. The 2D space is not continuous but a category space. Two categories are plotted together to be placed to a category. This is a result of the prescriptive categorization requirements.

Figure 1. Illustration of Planetary Protection Categorizations with Mission Examples

These categories include all mission types, both outbound and inbound. Each category has its own implementation procedures, or the mitigating actions that a mission must take to reduce the risk of harm to science or Earth's biosphere. In general, a higher category number requires more stringent implementation procedures.

B. The Legal Status of Planetary Protection

Planetary protection is based on a complicated and, at times, unclear legal obligation. The desire to practice planetary protection extends beyond legal obligations. Protecting future science and Earth's biosphere has not in the past required legal compulsion; however, as new entities and mission types challenge the status quo of planetary protection, it is important to understand the legal limits underlying such protection. For the United

[3] This report will refer to the portions of planetary protection policy detailing how to meet the above goals as the *approach* of the policy.

States, these legal questions are based on three entities or sources: international law, international standards, and NASA's legal authority.[4]

1. International Law: The Outer Space Treaty

NASA's policy cites what is typically considered the legal grounding of planetary protection: the Outer Space Treaty (OST).[5] The OST, signed and ratified by 109 nations (UNOOSA 2019b), provides the core international principles in space policy, including planetary protection. OST obligations apply to the U.S. Government as a whole (unlike the Space Act, which only affects NASA), which sponsored, signed, and ratified that Treaty. Under the Constitution, ratified treaties are part of the supreme law of the land (Congressional Research Service 2001).[6]

The OST is rooted in the principles laid out in Article I of the Treaty, that outer space "be free for exploration and use by all States" and that "there shall be freedom of scientific investigation in outer space." This applies to protecting the future search for life, for not only future U.S. activities but also international ones. Within the OST, Articles VI, VII, II, and—most especially—IX apply to planetary protection.

Articles VI and VII lay out the responsibilities of States party to the Treaty over non-governmental actors and the responsibility of launching States, respectively. Article II prohibits the appropriation of outer space, which is relevant when considering spacecraft can be prohibited from visiting certain regions or even entire celestial bodies unless they are cleaned sufficiently.

Article IX specifies that State Parties conduct space activities with "due regard to the corresponding interests of all other State Parties to the Treaty." Particularly,

> States Parties to the Treaty shall pursue studies of outer space…so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.[7]

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[4] Because the only missions with planetary protection implications beyond documentation are to or from celestial bodies with the potential to harbor life, we only consider NASA missions for the U.S. Government (e.g., not the Department of Defense) in this report.

[5] The Treaty on Principles Governing the Activities in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UNOOSA 1967).

[6] There is some controversy over whether all parts of the OST are self-executing, meaning that is becomes effective as domestic law even without implementing legislation. For example, see Montgomery 2018.

[7] This sentence is significant because it was not included in the precursor document to the OST, General Assembly Resolution 1962 (XVIII).

Article IX also specifies that a State may undertake or request “appropriate international consultations” if its activities, or those of its nationals or another State, might cause harmful interference in the activities and use of outer space.[8]

Article IX is often cited as the legal force behind planetary protection. For example, NASA states that “[i]t is NASA’s policy to comply with planetary protection provisions in support of U.S. obligations under the 1967 Outer Space Treaty” (NPD 8020.7G). However, the OST does not explicitly name planetary protection, nor does it state that parties should protect the future of science. Instead, the language in Article IX, and the OST as a whole, is ambiguous, likely intentionally so as to allow flexibility in future interpretation (Cypser 1993). This ambiguity raises potential issues in defining how the Treaty relates to planetary protection (see Table 1).

Table 1. Ambiguous Terms in Article IX

Terms, in order of appearance in Article IX	Potential Issue
States Parties to the Treaty	It is unclear if Article IX applies to private sector entities because they are not States Parties (i.e., governments). At least one legal scholar has noted that the drafters of the OST were clear when they distinguished between what applies to government and non-government actors (Montgomery 2019).
Pursue studies, conduct exploration	These two phrases limit the scope of this sentence, and, arguably, Article IX as a whole. They do not reference the “use” of outer space described in Article I.*
Avoid	The OST does not ban forward contamination; it just says that parties must avoid it. There is ambiguity as to what constitutes avoidance and what legal consequences arise from this term.
Harmful contamination	This definition is key to understanding planetary protection. There is no legal consensus on what constitutes harmful contamination, or the object of the harm. Planetary protection uses it to refer to biological contamination, but some consider this scope too limited.
Adverse changes	What constitutes an adverse change is not clarified, and the authority to determine that such a change has occurred is not specified. This also implies that changes to Earth’s environment deemed not adverse are acceptable.
Environment of Earth	In different national planetary protection policies, some nations restrict planetary protection to their national boundaries.

[8] Such consultations are undefined, have never been invoked, and pose potential challenges to enforcing planetary protection policy (interviews). It is possible that they could just refer to the use of normal diplomatic channels; however, the processes and procedures for Article IX consultations remain ambiguous.

Terms, in order of appearance in Article IX	Potential Issue
Appropriate measures	It is not clear what constitutes appropriate measures, and the authority to determine what measures are appropriate is not specified.

Note: Some legal scholars would not advocate for such a close reading of Treaty language as in this table, citing instead that nations should meet their obligations in good faith. While that may be the case, the ambiguity of the wording of the Treaty could still cast doubt on what such good faith might entail.

* Article I of the OST states, "Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States."

Particularly important for understanding the Treaty requirements for forward planetary protection is understanding the meaning of *harmful contamination*. Harmful contamination is ambiguous because it does not define the varying degrees of harm, whom it is harming, and what is considered contamination (e.g., physical, chemical, biological). No definition is given in the OST, and even when the Treaty was being drafted, there were debates about what type of contamination would be considered harmful under Article IX (Williams 1995). Combining the ordinary definitions of both harmful and contamination would lead one to define harmful contamination as "the introduction of elements that make outer space unfit for use or are likely to be injurious to users of outer space" (Mineiro 2008). At least one legal scholar has stated that harm must refer back, not to the celestial bodies, but to the interests of the States Parties to the Treaty (Cypser 1993). However, there is to this day no consensus on the definition of harmful contamination (Sterns and Tennen 2019; Gorove 1972; Roberts 1992).

The historical development of the term *harmful contamination* does not clarify its intended meaning or whether it is meant to apply to planetary protection. Concerns over the contamination of the space environment became especially prominent based on fears of space-based nuclear tests (Mineiro 2008). These concerns increased when the United States launched Project West Ford in 1961, during which U.S. researchers sought to create an artificial ionosphere by releasing hundreds of millions of copper needles into medium earth orbit (MEO) (NASA 2013). The activity prompted an outcry from radio astronomers, both domestically and internationally because this physical contamination interfered with their scientific experiments (Reuters 1961). This response to Project West Ford also raised global awareness to avoid harmful contamination of the space environment and to undertake consultations with other nations when such activities are to be conducted.

It is unclear why and how the meaning of the threat of contamination for planetary protection shifted from a fear of physical interference, like copper needles and nuclear waste, to biological contamination, which is the major concern addressed in planetary protection policy today. One explanation is that an existing concern regarding biological contamination became a greater issue as U.S. missions successfully approached the Moon. Indeed, research on the biological contamination of space began in the mid-1950s

(Barengoltz and Stabekis 1983). As early as 1958, the scientific community expressed its concerns over the lack of protections for scientific investigations:

> [W]e are in the awkward situation of being able to spoil certain possibilities for scientific investigations for a considerable interval before we can constructively realize them…we urgently need to give some thought to the conservative measures needed to protect future scientific objectives on the moon and the planets (Lederberg and Cowie 1958).

Despite the fact that planetary protection policies existed prior to the writing of the OST (including at NASA), explicit reference to protecting the future of science is not included in the Treaty.[9]

The exact meaning of Article IX and how it relates to planetary protection remain open to interpretation. The Article can be seen to clearly support protecting the Earth against backward contamination as well as avoiding biological and organic contamination of other celestial bodies to the extent that such contamination is harmful to human activities (i.e., to future science) or to the celestial bodies themselves. It is not clear to everyone interviewed for this report, however, that Article IX obligations were meant to, or should now, apply to planetary protection as it is implemented today (e.g., cleaning spacecraft in an attempt to keep planets biologically pristine for future science). That being said, the planetary protection community uses the OST as the legal grounding for its policy and practice.

2. International Standards: COSPAR

The Committee on Space Research (COSPAR), established by the International Council of Scientific Unions (ICSU), maintains an international policy and guidelines on planetary protection, and has done so since 1964. Today, the COSPAR policy on planetary protection intends to "guide compliance with the wording of this UN Space Treaty" but focuses on avoiding "organic-constituent and biological contamination in space exploration" (COSPAR 2017).

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9 In 1963, a Canadian delegation to COPUOS raised the issue of planetary protection. They feared that without explicitly calling out harmful contamination, States would not be required to consult "in the event an experiment were being planned which might have the effect of influencing the Earth's environment" (UN General Assembly, 1963), but no mention was made to the importance of protecting scientific experiments. However, the following year, the COPUOS Scientific and Technical Sub-Committee fully considered scientific planetary quarantine requirements, and emphasized their significance by including the full COSPAR resolution with these requirements in their official report (Tennen 2004). Before the process of writing the OST began, President Johnson sent a proposal to the United Nations (UN) on May 7, 1966, containing "essential elements" that should be included in an outer space treaty, one of which was "Studies should be made to avoid harmful contamination" (Vlasic 1967), and the initial U.S. draft of the OST further connected the avoidance of harmful contamination with the freedom to conduct scientific experiments (Tennen 2004).

COSPAR guidelines are not legally binding (NRC 2018). Instead, COSPAR is an observer organization[10] of the United Nations (UN) Committee On the Peaceful Uses of Outer Space (COPUOS) (UNOOSA 2019a) and provides a forum for scientific bodies to discuss, create, and maintain a voluntary international standard for planetary protection. COSPAR has provided a forum for forming international scientific consensus on avoiding forward and backward contamination. In 2017, COPUOS "noted the long-standing role of COSPAR in maintaining the planetary protection policy as a reference standard for spacefaring nations and in guiding compliance with Article IX" (COPUOS 2017). This reference by COPUOS is a critical yet unclear point in the legality of COSPAR policy; while COPUOS does affirm the role of COSPAR, it does not explicitly call out the legitimacy or necessity of that policy. According to interviews with a representative of the Department of State, State parties themselves must make such an interpretation.

While the United States is obligated to follow the OST, it is not legally bound to implement COSPAR policy and guidelines (NRC 2018; interviews). COSPAR's standards, however, offer soft regulations that produce the actual technical requirements for regulated activities. Legal experts interviewed for this report described these standards as sufficient guidelines for complying with the OST; while sovereign nations do not need to adopt them to comply with the OST, doing so is sufficient to demonstrate compliance. Nations that do not comply with COSPAR standards may be called upon by the international community to prove that they are still complying with the Treaty.

3. NASA's Legal Authority

NASA cites the OST as the grounding for its policy, but its authority for maintaining a planetary protection policy and implementing it for its missions comes from U.S. law, specifically the Space Act of 1958 (as amended). The Act (as amended) not only gives NASA the authority to make rules and regulations over its operations (45 U.S.C. §2473), but also affirms the search for life as a priority of the agency. Planetary protection aims to ensure the integrity and success of this search for life.

C. Key Stakeholders in Implementing Planetary Protection in the United States

The United States has been involved in planetary protection policy since it was first raised as an issue in the 1950s. In 1957, the U.S. National Academy of Sciences urged ICSU to develop planetary protection guidelines—a task that was eventually passed to

[10] Observer organizations can participate in sessions and meetings of a UN committee, but do not participate in decision-making (Negoda and Hedman 2014). COSPAR is one of many observer organizations to COPUOS, a full list of which is provided at http://www.unoosa.org/oosa/en/ourwork/copuos/members/copuos-observers.html.

COSPAR—while NASA scientists concurrently raised concerns regarding biological contamination (Meltzer 2011). NASA has continued to play an international role in maintaining planetary protection policy and guidelines, often developing the procedures that COSPAR then adopts (NRC 2018).[11]

While NASA's policies do not need to be identical to COSPAR's, the COSPAR policies often reflect those of NASA, and vice versa. For missions in which NASA does not have a role (i.e., non-government activities), there are no clear or direct planetary protection requirements. Policies applicable to private sector activities are discussed in Chapter 5.

A number of other U.S. entities play a role in planetary protection. The U.S. National Academies, often through the Space Studies Board, continue to support NASA in developing and assessing best practices for avoiding forward and backward contamination. The Department of State interprets the U.S. Government's obligations with regard to OST compliance, specifically for private missions, in consultation with NASA. Missions with a high risk of backward contamination (e.g., those from so-called *restricted* bodies, solar system bodies that could have indigenous life forms) will likely include other government agencies. NASA's Interagency Committee on Back Contamination (ICBC), used during the Apollo missions, included representatives from the Department of Agriculture, the Department of the Interior, the National Academy of Sciences, and the Centers for Disease Control and Prevention (CDC).[12]

In addition to its Constitutional role in directing actions of the executive branch, the Executive Office of the President (EOP) is involved in planetary protection through Presidential Directive/National Security Council Memorandum 25 (PD/NSC-25), under which some Earth-return missions require the approval of the President.[13] The EOP does not currently have a direct role (approval or otherwise) in forward contamination other than its ability to direct executive branch agencies such as NASA, FAA, State, among others.

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[11] The history of planetary protection is summarized in Appendix B. For more on the role of NASA in the development of COSPAR planetary protection policy, refer to NRC 2018.

[12] Then known as the National Communicable Disease Center.

[13] In 1963, National Security Action Memorandum (NSAM)-235 was issued during the Kennedy administration to regulate with "the conduct of large-scale scientific or technological experiments that might have significant or protracted effects on the physical or biological environment," (Kennedy 1963) and was invoked during the Apollo missions regarding the return of astronauts and lunar samples (Pugel 2017). The Presidential Directive/National Security Council Memorandum 25 (PD/NSC-25) replaced NSAM-235.

No legislation explicitly directs to planetary protection, leaving the executive branch to act as it sees fit within designated authorities.[14]

D. Policy Drivers in Planetary Protection

Limited budgets, ambitious missions, and new space actors have all challenged the traditional planetary protection practices. As the United States considers these changes and its planetary protection policy and practices, a number of policy priorities become relevant, beyond those in the NASA planetary protection policy. Considering all of these drivers and how they might conflict will be critical for forming an effective national understanding and policy for planetary protection.

1. Relevant Policy Themes

The research for this report was informed by interviews and a literature review, and yielded eight major themes that warrant consideration for their implications regarding planetary protection practices and stakeholders.

Protect U.S. Citizens and Their Environment

A fundamental responsibility, if not the primary responsibility (Heyman 1984), of the U.S. Government is to protect its citizens and their environment. This protection especially refers to the government not causing harm (e.g., bringing back harmful extraterrestrial material) or allowing nongovernment or international entities to harm U.S. citizens.[15] Planetary protection, first and foremost, should protect the Earth.

Expand Frontiers of Knowledge through Scientific Discovery

The Federal Government seeks to advance scientific understanding and technological development through efforts including executive branch entities (e.g., OSTP and the National Science and Technology Council [NSTC], as well as NASA). NASA's first strategic goal is to *discover*: "Expand human knowledge through new scientific

[14] The National Environmental Policy Act (NEPA) does apply and may require environmental assessment or impact statements for Earth-return missions. NEPA states that all U.S. government agencies should share with other relevant agencies a detailed statement for any major Federal action (e.g., a recommendation, report, proposal, or legislation) that is "significantly affecting the quality of the human environment" (42 U.S.C. §4332(C)).

[15] In addition to protecting U.S. citizens on Earth, the government also has an interest in protecting its citizens in space. The value on protecting each of these individuals may be different, and may not always be aligned: e.g., what if astronaut falls ill on the return journey from Mars?

discoveries" (NASA 2018). Planetary protection policy safeguards the conduct of scientific investigations,[16] but could also limit current scientific effectiveness.

Enable Human Missions to Celestial Bodies

NASA's authorizing legislation, as recent as in 2017, continues to direct NASA "to expand permanent human presence beyond low-Earth orbit" (P.L.115-10). Recent Presidential Directives (e.g., Space Policy Directive 1) emphasize the importance of reinvigorating a sustainable human exploration regime (EOP 2018). Any policy for planetary protection must grapple with the implications of human exploration on celestial bodies, protecting Earth and other celestial bodies while enabling human exploration and expansion.

Support Commercial and Private Sector Activities in Space

In the 1985 amendments to the National Aeronautics and Space Act, Congress directed NASA to "seek and encourage, to the maximum extent possible, the fullest commercial use of space" (42 U.S.C. §2451). Supporting non-government activities has been a hallmark of U.S. space policy; this includes both actively enabling non-government endeavors as well as limiting burdensome Federal regulations (EOP 2018). [17] National policy would require planetary protection policy to consider its effects on private industry, even while managing the contamination risks of potential private sector activities.

Ensure that National Space Activities and Regulations are Cost-Effective

U.S. taxpayers fund national activities in space, activities that should not only be beneficial but also cost-effective, especially given that it is "the policy of the executive branch to be prudent and responsible when spending taxpayer funds" (EOP 2018). A policy of considering cost-benefit also extends to regulatory planning (EO No. 12866; EO No. 13563). This includes government expenditures and regulations for planetary protection.

Abide by Ratified International Treaties and Obligations

The United States has a legal obligation to abide by its international treaties ratified by Congress (Congressional Research Service 2001). The United States has a foreign

[16] A primary goal of planetary protection is that the "the conduct of scientific investigations of possible life forms, precursors, and remnants must not be jeopardized" (COSPAR 2017). Through the priority of science, we get to the fundamental equity of planetary protection: to protect the conduct of science, current and future.

[17] In recent years the United States has endeavored to increase the rate of space commercialization through efforts such as procuring commercial launch for government activities (e.g., delivery of cargo and crew to the International Space Station), increasing the number of commercial activities on the station itself, and funding entrepreneurial experiments such as small satellites, moon landers, and even 3D-printed space nuclear reactors.

policy interest in working with the international community and upholding the legitimacy of international agreements. The Federal Government should be cognizant of the foreign policy implications of following or changing planetary protection policy and practice, to the extent that it relates to treaty obligations.

Demonstrate American Leadership

The Federal Government has an interest in demonstrating and promoting American leadership around the world. Space is characterized by competition for scientific, technological, and commercial pre-eminence. This dynamic will continue as more nations launch ambitious space programs. Planetary protection policy helps decide how humanity will explore and use celestial bodies, and how the Earth will be protected; critical decisions on these issues present opportunities both for establishing national leadership and protecting American interests.

Protect Equities on Other Celestial Bodies

As a ratified signatory to the Outer Space Treaty, the United States has an obligation to avoid the harmful contamination of celestial bodies (UNOOSA 1967). Beyond Treaty obligations, the United States has an inherent interest in protecting other celestial bodies—for scientific discovery, exploration, commercial use, and even potentially aesthetic, ethical, or historical enjoyment—both now and for future generations.[18] Understanding the importance of protecting celestial bodies will be critical for considering the role of planetary protection within and beyond international treaty obligations.

2. Balancing Interests

The eight themes of national interest outlined in the previous section do not always align, and some of them are actually in tension with one another. Any policymaking or assessment process must balance different equities. This work will continually contend with a harmonizing of different national equities affecting planetary protection, especially several of the more pervasive tensions listed below.

- **Protecting celestial bodies *versus* exploring and using them.** The surest way to protect another celestial body from human activities is to not contact it. Anything less than that must balance protection, exploration, and exploitation.
- **Protecting Earth and other celestial bodies *versus* being cost-effective and expanding space commerce.** Burdensome regulations could impede space

[18] For an example of this sentiment, see the National Environmental and Policy Act (NEPA), 42 U.S.C. §4331(b)(1).

commerce, but unregulated commercial activities could introduce higher threats of forward and backward contamination.

- **Reducing the risk of an adverse outcome occurring *versus* the cost of addressing risk.** Policies often take precaution in protection against both forward and backward contamination, which reduces the risk of an adverse outcome but also increases the burden on missions.
- **Seeking life while threatening irreversible harm to the search.** To find life, we must send missions to search for it, which may contaminate or destroy it or its traces. Furthermore, increasing efforts for scientific discovery (e.g., by sending humans) may accelerate discovery but increase the risk of destroying it.

Tensions between scientific and commercial space goals are not unique to other celestial bodies. For example, the recent launch of SpaceX's constellation of satellites to provide broadband service has alarmed astronomers, who are concerned about the physical and electromagnetic interference created when there may be thousands—and potentially tens of thousands—of satellites in LEO (IAU 2019). Contemporary planetary protection policy has addressed these tensions essentially by not explicitly addressing them, focusing only on scientific discovery on celestial bodies. To date, the United States has avoided the more challenging conflict that would pit both human exploration and commercial exploitation against protecting planets.

E. Framework for Assessment

To analyze the domain, STPI used a three-part framework. In our view, planetary protection policy and practice consists of three distinct parts: (1) the *goals* of planetary protection; (2) the *approaches* with which the policy attempts to meet these goals; and (3) the *implementation procedures* by which the goals are achieved.

As currently written and practiced by both NASA and COSPAR, the *goals* of planetary protection are protecting Earth and scientific integrity. These goals are clearly stated in the policy statement above mentioned earlier, and have been reiterated by an ad hoc committee of the National Academy of Sciences and COSPAR (NRC 2018; Coustenis et al. 2019). Planetary protection could have other goals as well, such as conserving the space environment regardless of scientific interest or protecting potential extant organisms for intrinsic reasons (i.e., not just because we want to study them).

The approach refers to the portions of the policy that connect the goals to required actions. To protect science and the Earth, the policy currently takes the sole approach of reducing the probability of biological or organic-constituent contamination with the implicit assumption that such contamination will harm the search for life.[19] Reducing the probability of contamination is only one potential approach to protect science and the Earth. Others include methods to disambiguate between extraterrestrial and terrestrial life. The end result of the approach is identifying steps to meets the policy's goals, which it currently does either through prescription (e.g., for Mars, the approach is to require certain implementation procedures) or setting a requirement (e.g., for the icy moons, the approach is to require that the mission reduce the probability of contamination below 1 in 10,000).

Lastly, the implementation procedures (e.g., ways to reduce the probability of contamination) are the methods by which each approach is implemented. Implementation procedures are required by the approach, but have set requirements and practices. For example, when actively reducing spacecraft bioburden,[20] NASA can use its bioburden goals (based on mission categorization), select bioburden reduction methods, and implement the cleaning along with assaying to verify cleanliness. For some celestial bodies, the implementation procedures have become prescriptive: e.g., the approach for Mars does not set an explicit goal (for example, one predicated on reducing the probability of contamination to a certain level), instead choosing to prescribe that a mission follows certain implementation procedures. This may not be an effective approach (as discussed in Chapter 3), but the planetary protection community has been following it since the 1980s.

The following example illustrates the framework. Take two landers, one going to Mars and one to Europa. The planetary protection goal for these missions is the same as any other mission to a celestial body: to avoid jeopardizing conduct of scientific investigations of possible extraterrestrial life. Both are placed in Category IV because they pose a significant threat to that search for life, and both must reduce their probability of biological and organic-constituent contamination to mitigate this threat. For the lander to Europa, NASA's approach is to require that the probability of contamination be reduced below to 1 in 10,000. For the Martian lander, NASA has no specific requirement to reducing the probability of contamination, but the approach prescribes steps that will (implicitly) reduce the probability of contamination. Thus, the Europa lander can select and modulate implementation procedures (e.g., assembling the spacecraft in a cleanroom) as needed to meet their risk goal, while the Martian lander simply follows prescriptive implementation procedures (including the bioburden goals that are included in the suggested procedures). This is visualized in Figure 2.

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[19] Note that this approach is not explicit in the current policy. Previously, it was captured in a risk goal across all missions (i.e., the probability of contamination of a celestial body must be less than 1 in 1,000 for the period of biological exploration), but it has been relegated to guidance and replaced by the current approach.

[20] NASA defines bioburden as the number of aerobic microorganisms that survive a heat shock of 80°C for 15 minutes (hereinafter "spores") and are cultured on Trypticase-Soy-Agar (TSA) at 32°C for 72 hours.

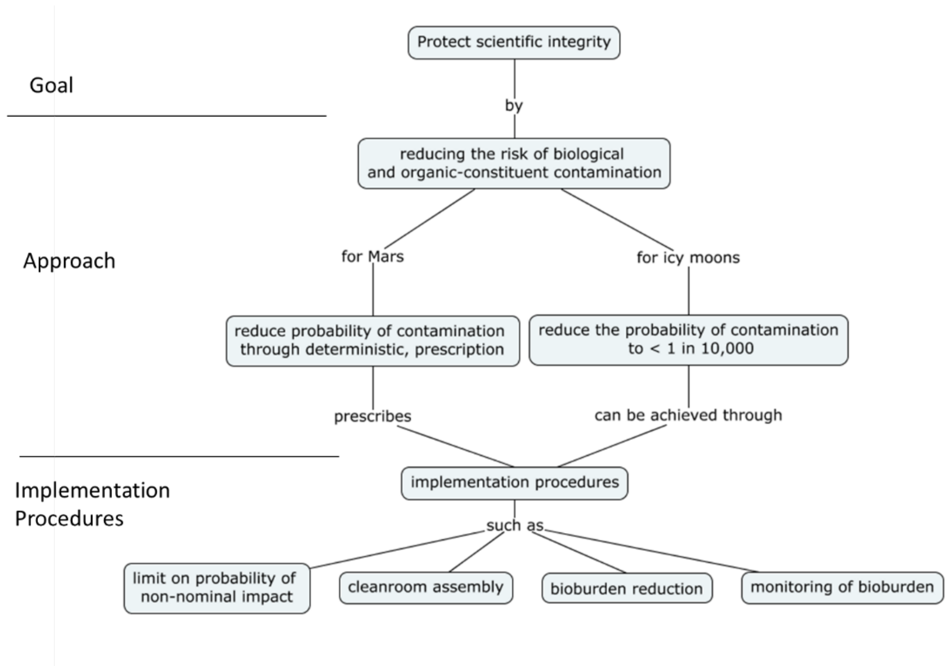

Figure 2. Illustration of STPI's Framework to Assess Planetary Protection

This report uses this goals-approach-implementation framework throughout to clarify and distinguish between levels of the policy. It is feasible, for example, for some stakeholders to accept the goals of planetary protection, but differ in how they approach the goal. Others may agree (as our interviews revealed) to both the goals and approach, but have different implementation mechanisms.

3. Assessment of Forward Contamination Policy and Implementation

As both NASA and new entities launch interplanetary missions, the U.S. Government will consider how the policy and practice affects its activities, objectives, international interests, and national priorities—i.e., the benefits and costs. Forward contamination is a probabilistic threat: failure to actively avoid contamination does not guarantee that terrestrial organisms will survive, proliferate, and spread on other celestial bodies. However, life may still survive on even those bodies expected to be inhospitable to life. Planetary protection processes aim to decrease the probability of this survival and thus the probability of contamination.

A. NASA's Forward Contamination Framework

Both the NASA and COSPAR policies seek to mitigate forward contamination in order to avoid jeopardizing the conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants. It is important to reiterate that the goal of NASA's planetary protection policy is *not to avoid forward contamination* but *to protect science*. Avoiding biological and organic contamination is the method by which this goal is reached. This is a common point of confusion, even within the planetary protection community. This is not to say that the goal might change or expand to avoiding forward contamination for intrinsic reasons, but that is not the current policy of NASA or COSPAR. To protect the future of science, the policy requires that missions avoid organic-constituent and biological contamination (COSPAR 2017); to do so, the policy mandates an approach of categorization, documentation, and implementation procedures. This process begins with categorizing missions based on their relative risk to science; four of these five categories apply to outbound missions, as described in Table 2.

Table 2. Planetary Protection Categorizations

Category	Mission-Body Types	Degree of Concern
I	Any mission to a planetary body not of direct interest for understanding the process of chemical evolution	None

Category	Mission-Body Types	Degree of Concern
II	Any mission to a planetary body 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	Record of planned impact probability and contamination control measures
III	Flybys or orbiters to 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	Limit on impact probability Cleanroom assembly and testing Bioburden control and assays (if necessary)
IV	Landers or probes to 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	Limit on probability of unintended impact Cleanroom assembly Active limit on bioburden Monitoring of bioburden via bioassay

Note: Information taken from NASA NID 8020.109A.

Higher categorizations are reserved for missions of greater concern to future science, specifically target bodies for which missions may pose a "significant[21] chance of contamination which could compromise future investigations." Missions categorized as III or IV must follow mitigation efforts based on the level of concern with the specific mission (e.g., whether or not it is planning to contact the body). The concern is restrained to a period of biological exploration, a length of time over which a body needs to be protected from contamination in order to permit unimpaired study. Mars' period of exploration is currently rolling, extending 50 years after the last Category III or IV mission arrives at the planet, while the icy moons have a period lasting 1,000 years.[22] These mitigation efforts (i.e., implementation procedures) intend to reduce the risk of contamination.[23]

The implementation procedures for reducing the risk of contamination differ even within a single category. One clear example is procedures for missions to Mars or the icy moons. While the international scientific community has developed an extensive set of implementation procedures for missions to Mars (reviewed in Table 3), requirements for

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[21] COSPAR (2017) contextualizes *significant* as "the presence of environments where terrestrial organisms could survive and replicate, and some likelihood of transfer to those places by a plausible mechanism."

[22] Previous COSPAR policy in the 1960s set the period of exploration at 20 years (COSPAR 1968), and an NRC report suggested that the period of exploration should be the time required to establish whether or not a planet has indigenous life (NRC 2006).

[23] The implementation mechanisms are not always directly tied to a probability or risk, as will be discussed in more depth later.

the icy moons are undefined except for the need to reduce the probability of inadvertent contamination to less than 1 in 10,000.[24]

Table 3. Mars-Specific Implementation Requirements

Applicability	Requirements for Implementation Procedures
All Mars Missions (Category III and IV)	The probability of impact on Mars by any part of the launch vehicle shall be $\leq 1x10^{-4}$ for a time period of 50 years after launch If an unintended condition (such as a hard landing) would cause a high probability of inadvertent biological contamination of the special region by the spacecraft, the entire landed system must be sterilized to a surface bioburden level of ≤ 30 spores and a total (surface, mated, and encapsulated) bioburden level of ≤ 30 + (2 x 10^5) spores
Category III	Mars orbiters will not be required to meet orbital lifetime requirements (defined as 20 years after launch at greater than or equal to 99% probability, and 50 years after launch at greater than or equal to 95% probability) if they achieve total (surface, mated, encapsulated) bioburden levels of $\leq 5x10^5$ spores
Category IVa—Lander systems <u>not</u> carrying instruments for the investigations of extant Martian life	Surface bioburden level $\leq 3x10^5$ spores Average of ≤ 300 spores per square meter
Category IVb—Lander systems designed to investigate extant Martian life	Requirements of Category IVa plus: • Entire landed system surface bioburden level must be ≤ 30 spores; OR • The subsystems involved in the acquisition, delivery, and analysis of samples must be sterilized to these levels*
Category IVc—Lander systems which investigate Mars special regions even if they do not include life detection requirements	Requirements of Category IVa plus: • Case 1: If the landing site is within the special region, then the entire system surface bioburden level must be ≤ 30 spores. • Case 2: If the special region is accessed through horizontal or vertical mobility, then only the subsystems that contact the special region must be sterilized to these levels*

Source: NASA NID 8020.109A.

* Bioburden constraints are defined with respect to the number of aerobic microorganisms that survive a heat shock of 80°C for 15 minutes (hereinafter "spores") and are cultured on Trypticase-Soy-Agar (TSA) at 32°C for 72 hours.

[24] This has been explained as a consequence of the lack of knowledge of basic processes on bodies like Europa and Enceladus.

NPD 8020.7G requires that NASA missions follow planetary protection policy and its procedures. The Mars InSight lander and Europa Clipper provide two recent examples of NASA missions with planetary protection implications.

InSight was a Category IVa mission launched in May 2018. As per the top-level requirement, the landed system had to meet the bioburden requirement outlined in Table 3. The lander was assembled in clean rooms (specifically, clean rooms that met the International Organization for Standardization's [ISO] class 8 standards) and the microbial bioburden was reduced by a combination of dry heat microbial reduction (DHMR), precision cleaning, and alcohol wipes on component- and subsystem-level hardware. The planetary protection team continually assayed the spacecraft (using NASA Standard Assays along with some Total-Adenosine Triphosphate (T-ATP) rapid indicators); at least 10 percent of the surface area was sampled, resulting in counting the spores on over 39,000 petri dishes. The rover met its bioburden goal with a 55 percent margin (i.e., a total landed bioburden of $1.38x10^5$ spores) (Benardini 2019). Spacecraft hardware bioburden values were verified by the NASA Planetary Protection Officer (PPO) via audit assays of hardware.

NASA is working towards a reconnaissance orbiter (category III) of Jupiter's moon Europa to be launched in the 2020s. The top-level planetary protection requirement for the mission is the same as in COSPAR policy, that the probability of contamination of the ocean must be less than $1x10^{-4}$. To meet this goal, the project team indicated that they are assembling the spacecraft in ISO Class 8 cleanrooms, reducing bioburden on a component and subsystem level, and proving compliance with the top-level probability goal verified through quantitative modeling.

B. Benefits and Costs of Avoiding Forward Contamination

1. Benefits

Organic-constituent and biological contamination pose two major threats to the search for extraterrestrial life. First, microorganisms or their remnants could be the source of a false positive in the search for life; this potential for false positives casts doubt on later discoveries. (For example, imagine an instance if the ExoMars 2020 rover discovers an extant organism on Mars in five years. How can scientists be sure that the organism is Martian, not contamination from a previous mission?) Second, terrestrial organisms could extinguish or adversely affect extant extraterrestrial life. Planetary protection policy takes steps to mitigate the risk of these threats, attempting to protect the future of science.

Avoiding forward contamination also benefits science for individual missions, as each mission must control contamination to protect the integrity of the mission's science. The goals of planetary protection exist outside of and beyond each mission, but can have positive effects on the mission level. Even though the primary motivation is to protect future science, these efforts will also help maintain celestial bodies in general.

2. Costs

Assigning a cost to meeting planetary protection requirements is nuanced: most interviewees noted that because the planetary protection process is thoroughly integrated throughout the mission, estimating an exact cost is very difficult. Planetary protection activities for NASA missions are often spread across multiple centers, contractors, and manufacturers, and some decisions for planetary protection (e.g., selection of materials that can survive heat treatment) are interspersed among different portions of the project budgets and are therefore categorized as costs other than planetary protection. Additionally, several decisions within a mission (that can affect materials, mission structure and destination, and science goals) are determined based on planetary protection requirements; these may not have a financial cost in the near term, but present a cost to exploration nonetheless. The following sections summarize aspects that contribute to the cost of ensuring forward planetary protection.

a. Direct Costs

Planetary protection, like any other system-level requirement, imposes direct costs on missions (e.g., the budgets required for personnel, consumables, facilities, and mission-funded research). Personnel are required to implement these policies at all stages of the mission: to draft the planetary protection plan, work with project staff to design the spacecraft to maintain adequate bioburden levels, and assay the spacecraft.[25] Direct costs also include the facilities needed to implement planetary protection, including the cleanrooms for assembly and testing,[26] laboratories to handle samples and calculate bioburden, and facilities to reduce the bioburden of the spacecraft if needed.[27] Finally, most missions require original planetary protection research to support their efforts, such as

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25 Existing planetary protection processes are labor-intensive; for example, the Mars 2020 mission currently has about six full-time equivalent team members working solely to address planetary protection requirements.

26 Each facility or supplier contributing to a system, subsystem, or component requires a sufficiently clean facility, the development, certification, and maintenance of which contribute to the mission's overall cost.

27 Microbial reduction processes for full spacecraft require specialized facilities that NASA currently does not have; the research, design, and construction of these facilities will be a significant aspect of cost for future missions that may require such cleaning. Without methods or facilities to sterilize entire spacecraft, NASA may never be able to meet its own requirements for returning to Mars special regions.

sampling novel materials, building quantitative models, or demonstrating new technologies.

The most commonly cited estimate for the cost of planetary protection is 10 percent of mission cost, a number suggested for the Viking landers (Bearden 2017; Rummel and Conley 2017); the Viking landers cost about $4.4 billion in 2019 dollars, so the total cost of planetary protection in today's dollars would be approximately $400 million (NRC 2018).[28] This cost included the construction of a chamber (which no longer exists) to reduce the bioburden of the entire spacecraft, as well as the research that led to the planetary protection requirements used in these and subsequent missions. Because the Viking missions were the first to conduct planetary protection-related research on a life detection mission, and the first mission to land successfully on another planet, the baseline mission cost was likely higher than for any following planetary mission.

Two interviewees cited internal NASA studies that estimated the cost of full system sterilization, including building and operating the sterilization facility, of a modern Mars rover at $80–120 million. Interviewees estimate that the cost of these processes for Mars 2020, a modern rover, would require about 3–5 percent of the mission's total budget.[29] However, another study estimated the recurring costs (i.e., those that do not include principal facility costs) of an Mars Exploration Rover (MER)-class rover sterilized to the level of the Viking missions to require about a 14 percent increase in costs over a mission with Category IVa planetary protection requirements (Rummel and Conley 2017; Gavit et al. 2006). If the relevant costs to Mars 2020 increased by 14 percent, this would have cost the mission about $345 million in additional planetary protection costs.[30]

With the exception of the Viking missions, published cost estimates for previous U.S. planetary missions are not available. While the estimate of 10 percent of mission costs may provide a useful benchmark, it does not necessarily apply to future missions. The cost of planetary protection would likely vary based widely on the mission categorization, novelty of techniques, size of the mission, availability of applicable research and facilities, and the implementation of planetary protection. Additionally, these costs may not always scale for smaller missions, as many costs are unavoidable regardless of spacecraft size and mission

[28] The $4 billion is an after-the-fact estimated cost for Viking's two orbiters as well as the two landers, as well as for the ground-based infrastructure to heat treat the entire encapsulated lander spacecraft (i.e., a large oven).

[29] The Mars 2020 mission is estimated to cost $2.46 billion (Voosen 2019). Mars 2020 did not undergo full system sterilization because it is not going to a special region on Mars; thus, the cost incurred by the mission for planetary protection is likely less than the potential cost of future missions with different destinations.

[30] Interviewees noted that many of the new measures specified on the MER-class rover study have more recently been solved, and/or have been implemented by Mars 2020 as part of their baseline science requirements.

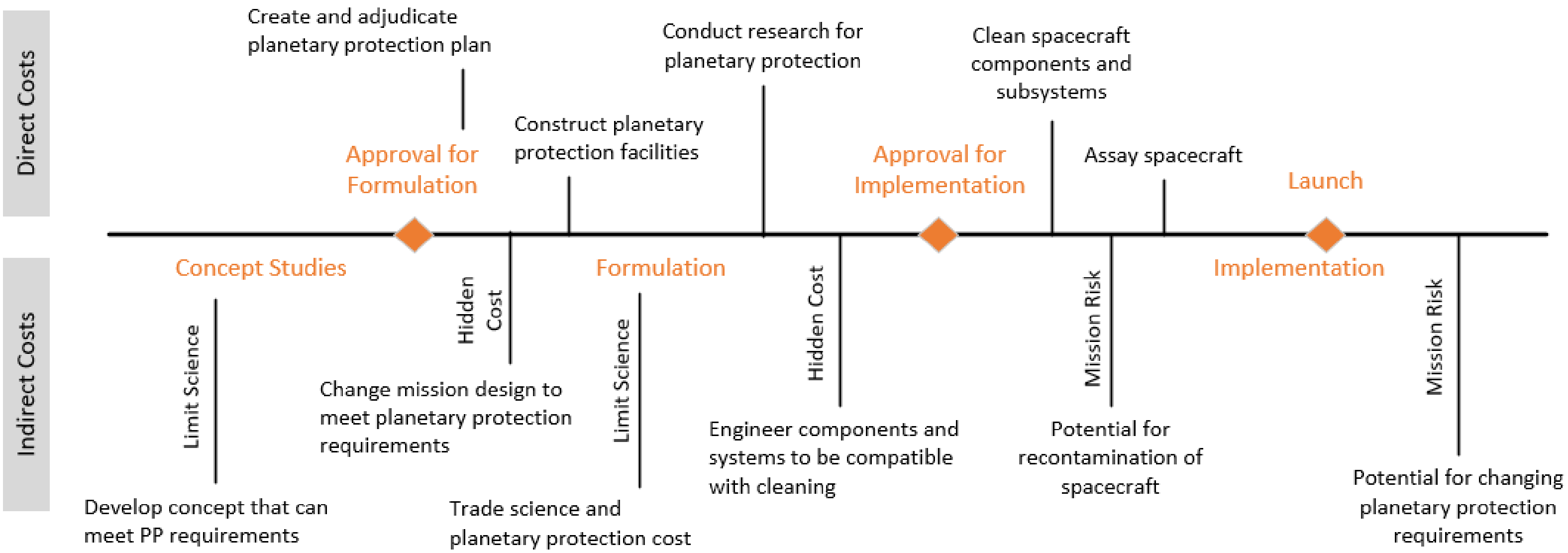
duration. According to a number of experts interviewed, these fixed costs may lead to planetary protection costs that are a large and potentially prohibitive portion of the budget for smaller or newer missions.

A number of interviewees suggested that the NASA PPO does not sufficiently track the cost of planetary protection for both flagship and smaller missions.[31] Monitoring and publishing these costs and the requirements along with the processes that contribute to them will support the Office and its advisory bodies (the National Academy of Sciences or the NASA Advisory Council [NAC]) in holistically evaluating and improving planetary protection policy.

b. Indirect Costs

Even more than the direct costs, planetary protection requirements place non-financial burdens on missions, influencing mission design and scientific opportunity and contributing to mission risk. Figure 3 reviews common sources of hidden or non-monetary costs to missions over their lifecycle. According to some interviewees, these are the real costs of planetary protection.

31 Although monitoring these costs would in turn add to overall costs, this effort might be worthwhile, given the significance of these costs in evaluating the policy and associated procedures.



Notes:

Hidden Cost: Planetary protection requirements levy work on engineers, the launch supplier, and subcontractors. These costs are not often captured in the planetary protection budget, but require time and resources to meet. It is important to note that the reason that these costs are not often captured has somewhat to do with the training of flight project management to include estimates of cost or, in some cases, an organizational resistance to value planetary protection can manifest itself in the degree to which resources are consciously allocated.

Mission Risk: Choosing components or systems to meet planetary protection requirements may reduce the quality of the engineering systems. Like any system-level requirement, not meeting planetary protection will result in cancellation or postponement of a mission.

Limit Science: Strict (difficult to meet) planetary protection requirements restrict potential science destinations, as necessary processes to meet requirements (such as those for reaching Mars Special Regions) would add to mission risk, cost, and time, such that the team chooses an alternate destination.

Figure 3. Cost of Planetary Protection over a Typical Mission Lifecycle

Resources allocated to meeting the planetary protection requirements may come at the expense of scientific capacity and instrumentation. In some situations, a major indirect cost of planetary protection could be the loss of science, if planetary protection provisions were not applied appropriately. Certain locations, such as gullies and subsurface cavities on Mars, have greater scientific value, and may require more stringent planetary protection processes, thereby contributing to mission cost.[32] Mission planners may choose, or be forced, to go to a less interesting scientific site (e.g., a non-special region) to avoid higher planetary protection costs, especially if there is no established ability to reduce the bioburden to satisfactory levels. Critics of planetary protection noted in interviews and in the literature that planetary protection requirements are therefore prohibitive to missions going to the most interesting scientific areas (Fairén and Shulze-Makuch 2013; Fairén et al. 2017; Zubrin 2019; interviews). We note that NASA has never gone to a Mars special region, and has not provided a spacecraft capable of going to one, cleanly, since the Viking era likely because the novelty of special regions, a lack of appetite for the cost of meeting sufficient bioburden levels, and challenges in cleaning Mars landers. Mars Science Laboratory was originally meant to go to a Mars Special Region (i.e., categorized as IVc); however, deviations from the planetary protection plan led the PPO to re-categorize the mission two weeks before launch (Stabekis 2012). The mission was still able to proceed because the landing site was not a Special Region, but a combination of challenging environmental terrain and planetary protection concerns led to at least one high profile prohibition on the rover approaching a special region (Starr 2015).

C. Challenges with Implementation Procedures

Our discussion of challenges is organized from the bottom up, starting with current implementation procedures and ending with the goals, as any challenges with the approach or goals implicitly include or affect the current implementation procedures. Planetary protection requires a variety of implementation procedures, including trajectory biasing, cleanroom, bioburden reduction, and bioassays. Our analysis primarily identified challenges with the last two procedures, which (according to some of our interviewees) are often not implemented effectively or with the latest technology. Furthermore, the current implementation procedures are also limited, not applying to future missions such as human explorers.

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[32] Some researchers have noted that special regions are indicative of those that might harbor terrestrial life, but that features such as recurrent slope lineae may not be special, and thus would not necessarily host the most interesting science (Rummel and Conley 2017). However, interviewees noted that there is likely a wide overlap between these two groups.

1. Cleaning Spacecraft

For spacecraft that will contact a celestial body of scientific interest, missions must take steps to clean the landed systems. The only NASA-certified method for surface, mated, and embedded bioburden reduction is dry heat microbial reduction (DHMR): the application of dry heat for an extended period of time. Additionally, NASA and the European Space Agency (ESA) have jointly certified a method for surface bioburden reduction using Vapor Hydrogen Peroxide (VHP), which was issued in an international standard and is scheduled for integration into a new version of NASA's requirements documentation (ECSS-Q-ST-70-57C). Until this revision is complete, NASA-approved project-level planetary protection plans contain explicit reference and approval of VHP for use on projects such as Europa Clipper and Mars 2020. DHMR was used on the entire integrated Viking lander, allowing it to reach a very low bioburden level. Since that use, DHMR has not been used at spacecraft level due to its potential to damage materials or electronics. [33]

Previous reports have suggested the need for new techniques to clean spacecraft (NRC 2006). Experts interviewed for this report echoed this need. DHMR's incompatibility with some materials and components has limited the ability of missions to thoroughly clean spacecraft. Furthermore, DHMR (along with other penetrating techniques) leaves residual dead bodies, the biochemical traces of which could still be the source of a false positive. Other techniques, such as gamma radiation, nitrous oxide, etc., may provide effective microbial reduction without the same risk to materials. However, these methods require further research and development (Pugel et al. 2017).

To enter a Mars special region, current implementation procedures require that the entire spacecraft surface (or the surface contacting the special regions) must be reduced to less than 30 aerobic spores total. For comparison, the InSight lander had a total of $1.51x10^5$ spores on its surface, or 135 per square foot (Benardini 2019). Reducing bioburden to the level required for a special region requires high levels of microbial reduction, such as the application of DHMR to the entire spacecraft used for the Viking landers. NASA currently does not practice the capability to meet such stringent standards. New cleaning capabilities need to be developed to visit some of the more interesting scientific locations on Mars.

2. Indicator Organisms

Planetary protection implementation procedures are based on reducing or assaying the bioburden of the spacecraft. That bioburden is defined very specifically in COSPAR policy as "the number of aerobic microorganisms that survive a heat shock of 80°C for 15

[33] We note that MIL-SPEC electronics are generally burned in at 125℃ for 24 hours prior to acceptance. Modern "off the shelf" electronics are capable of DHMR if the right shelf is used to supply them.

minutes (hereinafter "spores") and are cultured on TSA at 32°C for 72 hours" (COSPAR 2017). Spores provide a proxy count, measuring the number of hardy organisms on a representative surface on the spacecraft to indicate the entire microbial population on the spacecraft.

Assaying bioburden is a labor- and time-intensive process. The NASA Standard Assay follows conventional biological assaying methods, including sampling the spacecraft surface (either with swabs or wipes) and then culturing the sample based on the parameters defined above for bioburden.[34] The number of colonies are then manually counted and added to a spreadsheet that tracks the entire bioburden for the spacecraft. This process can take multiple full-time equivalent personnel over the lifecycle of assembly and testing, counting the spores on up to thousands of petri dishes.

The process of assaying for or requiring the elimination of spores yields a limited amount of information. Spore assays provide only a quantitative estimate of the number of spores on a spacecraft; they offer no information on the microorganisms themselves. Reducing the number of spores may provide a rough estimation of the microbial load, but it does not provide certainty that the most relevant organism (i.e., extremophile that could survive on the celestial body) has been removed. Counting colony-forming units does not provide any phylogenetic[35] information on the spores that could be used to understand vectors of contamination, to better eliminate them, or to even understand if they pose a threat of contamination to the celestial body. Furthermore, colony-forming bacteria account for less than 1 percent of a microbial population—a problem commonly referred to as the great uncultured major (Pace 1997); the spore-assay does not detect the majority of biocidal-resistant bacteria on the spacecraft. Using any proxy measurement, especially colony-forming bacteria, does not accurately indicate the bioburden of the spacecraft (NRC 2006).

Most interviewees suggested that NASA could take advantage of advances in biology and, in particular, genetics to improve the identification of specific organisms that pose the greatest risk of contamination. NASA has funded some research on advanced techniques for assaying spacecraft (e.g., using T-ATP analysis, which allows for quick assays of the spacecraft bioburden, rather than waiting 72 hours for results), but these techniques have not been certified by the PPO nor have they received adequate funding to replace the spore-assay, according to interviewees. Advanced methods could more precisely and efficiently identify microorganisms that may proliferate on other celestial bodies, reducing costs of

[34] The NASA procedures for measuring bioburden via the standard assay are codified in NASA standards document HDBK 6022.

[35] Phylogenetics is the study of evolutionary relationships between species. Phylogenetic measures or techniques attempt to classify an organism in relation to other known species

implementing planetary protection.[36] The lack of current viable alternatives is a serious limitation to improving implementation procedures. [37]

Discovering what microorganisms are growing on the spacecraft (e.g., through physiology and genetic assays) would better inform planetary protection efforts: for example, information regarding the constitution of the bioburden would allow for targeted reduction of the organisms that may best survive on the target body. It could also allow for tracking of microbial types to identify Earth organisms in the case that a celestial body is contaminated.[38] In its 2006 report *Preventing the Forward Contamination of Mars,* the NRC recommended that NASA "transition toward a new approach to assessing bioburden on spacecraft." This new approach would include, for example, the use of molecular assay techniques for rapid detection, combined with phylogenetic techniques for precise targeting of microbes that could survive on other celestial bodies.[39]

3. Limitations of Implementation Procedures

It is impossible that the bioburdens of humans will be sufficiently low to meet planetary protection requirements set in place for robotic missions: humans carry orders of magnitude more microbes than a cleaned spacecraft, and continually generate microorganisms.[40] Furthermore, it is impossible that any engineering system will be completely closed, meaning that human-generated microbes will inevitably escape into the Martian environment—and that humans will be exposed to Martian materials (McKay 2009; COSPAR 2017). In other words, unless NASA develops alternative methods to its current robotic policy, humans will not be able to visit the surface of Mars.

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36 That is, assuming that the identified organisms would be relatively easy to kill.

37 Some methods have been suggested, such as genetic assays combined with environmental testing, but no methods have yet been identified for spacecraft cleanroom-specific extremophiles on a timescale or accuracy that is comparable in the low biomass limit that is typical of the spacecraft build environment. Unfortunately, current molecular assay techniques may show relatedness between organisms or groups of organisms, but they do not establish the sort of functionality most important to extraterrestrial survival. A simple translation from aerobic spore counting to quantitative molecular techniques has so far eluded the research community.

38 NASA already does keep some samples of sampled microorganisms to supplement current planetary protection requirements.

39 The panel recommended that these methods be implemented for missions being launched in 2016 and beyond (NRC 2006). At the time of this writing, NASA planetary protection still relies primarily on spore-assays, in spite of these recommendations.

40 A human body harbors trillions of microbes; indeed, an adult human body has more bacterial cells than it does human cells (Sender, Fuchs, and Milo 2016).

As recently as 2017, COSPAR stated that the

> intent of this planetary protection policy is the same whether a mission to Mars is conducted robotically or with human explorers. Accordingly, *planetary protection goals should not be relaxed to accommodate a human mission to Mars* (emphasis added). Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ (COSPAR 2017).

However, this assurance of being able to meet the same goals casts doubt on the current implementation procedures for robotics: if humans with far more numerous spores can visit Mars, than why do space agencies spend so much time and money reducing the bioburden of robotic spacecraft? Although information regarding the Martian environment and the engineering systems that will support a human mission are currently limited, the United States must address the potential impact of human exploration.

Some in the scientific community are concerned regarding impending human missions and their potential irreversible consequences to the search for life. This concern is furthered by the lack of established requirements for human missions; in fact, humans would not be allowed to touch the Martian surface if robotic implementation procedures were applied. NASA has a skeleton policy for human missions (NPI 8020.7) and is working with COSPAR to develop quantitative requirements,[41] but has no procedures (nor any funded plans) to send humans to Mars in the 2030s. The NAC stated in 2012 that this lack of requirements would mean that NASA's plans are out of compliance with its own requirements. Further, the "lack of clearly defined and implemented standards for planetary back-contamination protection will reduce NASA's ability to retire the certain risks, and weaken the Agency's ability to respond to important drivers of Mars exploration from both scientific and public interest perspectives" (NPI 8020.7).

Enabling the human exploration of space is central to both national and scientific goals. It is well documented that humans have capabilities unmatched by current robotics for conducting exploration of celestial bodies. The Apollo 17 astronauts over three days to travel 22 miles on the Moon, while the Opportunity rover took eight years to travel the same distance on Mars (Mann 2012). While Rovers may be well suited to performing simple tasks in known environments, humans are much more capable of navigating

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[41] Over the past several years, COSPAR has hosted a series of workshops on "Refining Planetary Protection Requirements for Human Missions" (Race et al. 2015; Kminek et al. 2018). These workshops have sought to turn the current policy statements regarding human planetary protection (COSPAR 2017) into quantitative requirements that missions can use to design human missions to Mars. To create quantitative requirements, a number of experts told us that the planetary protection community must fill knowledge gaps regarding microbiology of crewed spacecraft, mitigation/ contamination control technology and operations, and the potential dissemination and survival of terrestrial microorganisms under Martian conditions. Current COSPAR efforts focus on filling these knowledge gaps (Race et al. 2018).

complex environments and making real-time decisions, which adds scientific value to a mission (Squyres 2009). Humans may pose a large risk to the current planetary protection implementation procedures and approach, but they also may be a major boon to the ultimate foundation of the policy: to advance science. Accommodating both planetary protection and human activities will be a critical challenge in the next decades of planetary protection.

In addition to challenges with humans, current implementation procedures for Mars are designed for robotic missions with relatively small surface areas. Experts suggested that these requirements are expected to present prohibitive restrictions and cost burdens on larger spacecraft, and especially on missions involving humans. For a mission landing on Mars but not going to a special region or searching for life, the bioburden level is based on the surface area of the spacecraft only up to a surface area of 1,000 ft^2; above that surface area, spacecraft are required to meet a sum bioburden level, meaning that the bioburden per square foot must decrease with the square root of the area.[42] As spacecraft get larger the planetary protection requirements will become more difficult to meet.[43]

The size implications are especially relevant for new classes of small- and cube-satellite missions, of which the NASA Mars Cube One (MarCO) mission is the pathfinder example. If such missions have a significant probability of incidence with certain celestial bodies (e.g., for MarCO a greater than 1 in 10,000 chance of hitting Mars) current NASA requirements demand that the missions either take expensive modelling steps to show that the spacecraft will burn up upon reentry (assuming an atmosphere) or ensure the spacecraft meets a certain level of cleanliness at launch. The price and time for these efforts, while relatively small for large missions, could be prohibitive to the novel approaches of inexpensive, fast, and innovative space missions. NASA is hoping to regularize the burnup assessment so that such missions do not need a dedicated planetary protection specialist, but doing so requires research and research funding.[44]

D. Challenges with the Approach for Protecting Future Science

Beyond the implementation procedures, stakeholders identified challenges in the approach for protecting scientific integrity. This includes lack of clarity for when certain

[42] "Lander systems not carrying instruments for the investigations of extant Martian life are restricted to a surface bioburden level of $\leq 3 \times 10^5$ spores, and an average of ≤ 300 spores per square meter" (COSPAR 2017).

[43] For example, one solar panel on the International Space Station (ISS) has about the same surface area as Viking (NASA 2019a); sending all eight to even a non-special region would require reducing bioburden to 4.3 spores/ft^2, or 3 percent of the level allowed on the InSight mission.

[44] Source: Personal communication with NASA office of planetary protection

implementation procedures are required, potentially over-estimating the risk to science, and not taking advantage of alternative methods to protect future science.

1. Triggering Implementation Procedures

Planetary protection has taken two approaches to avoiding goals for the risk of biological contamination and deterministic implementation procedures. This is represented by the icy moon and Mars requirements: the first requires missions to limit the risk of biological contamination, while the second requires missions to follow determined procedures.[45] Both may be flawed, especially as currently implemented.

All of planetary protection was previously based on a risk goal, that the probability of contamination for a celestial body should be less than 1 in 1,000 over the period of exploration. This approach was replaced in 1983 with the current method based on categories because it was too difficult to estimate the probability of biological contamination (NRC 1992). Although missions to the icy moons will still rely on limiting the probability of contamination, a 2012 study suggested that this method was not defensible given the lack of a method to accurately estimate this probability; as an alternative, the study suggested a decision-tree-based approach (NRC 2012), but NASA and COSPAR have not adopted these recommendations, claiming that the decision tree was itself probabilistic.[46]

For Mars, and for the rest of the solar system, the probability-based approach has been replaced with implementation measures based on the categorization of the mission. One challenge with the current implementation measures is that they are still implicitly based on estimations of probability: current bioburden requirements are based on Viking levels of cleanliness, which are coupled with the assumption of probability of growth/contamination for which those requirements were set (NRC 2006). Even if this Viking estimate were not based on probability, it is not clear why meeting a historical level of cleanliness adequately protects future science.[47]

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[45] The result of the deterministic measures is still probabilistic. Reducing the bioburden of the spacecraft only reduces the probability of contamination.

[46] Members involved with this decision have offered explanations as to why these recommendations have not been adopted; namely, that without research into the hardiness of microbes in the icy moon environments' low temperatures and high radiation, it has not been possible to verify or ground in experimental reality the probabilistic approaches that are under consideration. Without this, requirements cannot be developed, so the existing requirement set persists.

[47] A rationale was provided by the NRC (1992) when the requirements were implemented—namely, that life-detection missions should reduce missions to the greatest extent feasible; for other missions, the group saw little utility in further reducing bioburden further than pre-sterilization, including attempts to further determine a different standard.

A more fundamental challenge with the current method for mitigating biological contamination is the reliance on prescription without clear goal setting.[48] The COSPAR policy requires that missions in categories III and IV undertake implementation procedures, but it does not describe what goals these implementation procedures are meant to reach (other than the implied policy goal to avoid jeopardizing scientific integrity). In lieu of such a specified goal, the recommended implementation procedures become implicitly required; although other implementation procedures could be proposed, the only standard with which to compare them are the conventional implementation procedures. Interviewees noted that COSPAR and NASA in the past have been open to flexible and innovative decisions if they can be shown to achieve the stated goals of their implementation. Proving that alternative measures are sufficient may become especially challenging if a regulatory agency is trying to create requirements for private entities.

An alternative to the current approach might include being more explicit about the goal of the implementation procedures. This does not have to be probability-based, and likely could not be unless understanding progresses sufficiently to enable probabilistic calculations. Instead, the policy could specify qualitative statements that implementation measures should reach. This could be a qualitative assessment of reduced risk of contamination, or a new precautionary approach such as best available technology (BAT), where the best available cleanliness and assaying technology should be used to reduce the probability of harming science. Creating this intermediary goal could enable flexible and innovative solutions to protecting future science,[49] rather than prescriptive implementation procedures.

2. Significance of a Threat to Science

Some scientists believe that the probability of organisms surviving on Mars is too low to warrant the current level of cleaning and requirements of planetary protection (Fairén et al. 2017).[50] Several scientific studies in the mid-20th century attempted to approximate the probability of terrestrial microorganism surviving and reproducing on the surface of Mars, citing the probability of growth of Earth organisms on Mars as low as 10^{-10} (NRC 1978). More recent studies have found that new knowledge about the ability of organisms to survive in extreme environments on Earth found that this probability may be higher (especially for certain extremophiles) and warned against a false sense of confidence from

[48] Clear goal setting is not a simple task without a better understanding of Mars and how terrestrial life would operate there.

[49] This assumes that protecting the scientific investigations into extraterrestrial life remains the goal of forward planetary protection.

[50] For some examples of research in the biocidal factors on Mars, see Nicholson et al. (2013) and Khodadad et al. (2017).

these small probabilities (NRC 2006). Some interviewees for this report, however, reiterated the low probability of growth and that the threat from growth and reproduction of microbes may be overstated.

The implication of this argument would be that the survival and replication of microorganisms might not pose a large threat to science (on Mars). This is especially true if any potential growth is localized, limiting consequences of contamination.[51] Instead, organic contamination, single cell organisms, and biochemical traces are likely more important for science missions and missions operating in close proximity of science missions. This distance is likely small, however, meaning that this contamination mainly has implications for science carried on their own mission. Control of this contamination may be important to planetary protection (NRC 2006), but is more akin to contamination control than planetary protection. Therefore, independent of mission-specific requirements, protecting future science may not require strict, if any, implementation procedures.

A minority of interviewees for this report suggested that forward planetary protection could be entirely abandoned, in that even from a solely science-based perspective, the risk of forward contamination harming science is too low to warrant planetary protection costs on missions. In their opinion, this seems especially true on Mars, where even if an organism found an environment to replicate, the assumed biocidal nature of the surface would make small initial amounts of biological contamination unlikely to continue to spread.

3. Alternative Methods to Protecting Science

To avoid jeopardizing the search for life, planetary protection policy focuses solely on mitigating the probability of biological and organic-constituent contamination. However, this addresses only one aspect of risk and ignores the other—consequence. Another method to protect the future of science is not only to mitigate the probability of contamination but the consequences if a celestial body were to become contaminated, specifically the consequences to science.[52]

The first step in doing so would be to address the potential that the proliferation of terrestrial organisms and organic matter could be the source of false positives, casting doubt on future discoveries. One such method would be to carefully track what we send to Mars so that it can be identified as coming from Earth or not. Planetary protection already

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[51] NRC (2006) assessed that any contamination from previous spacecraft would be localized and unlikely to contaminate distant parts of Mars.

[52] At this point, there may be other consequences outside of science that only limiting the probability of contamination can address; however, for meeting the goals of planetary protection, these methods may suffice.

requires this with organic materials, but the same could be done for the genetic code of microorganisms. If a life form can be clearly identified as having come from Earth, extraterrestrial organisms could then be disambiguated.

Advances in modern genomics may be able to disambiguate Earth life from extraterrestrial life. Several interviewees suggested that, regardless of the character of Martian life, we should be able to identify it.[53] These interviewees argued that even if we suppose that life developed independently on other celestial bodies, that life will most likely have no relationship to Earth DNA and biochemicals, making it simple to differentiate alien life; conversely, if life on other celestial bodies is related to Earth life, that life would likely have developed independently for centuries, genetically drifting to a distinguishable form. Modern biologists have shown the ability to isolate certain DNA sequences even if it a sample is heavily contaminated by other, known Earth life. This has allowed for the identification of the Neanderthal genome (Sankararaman 2012), for example. Although some in the planetary protection community expressed skepticism about the ability to identify non-terrestrial life forms (Rummel and Conley 2017),[54] if we are able to find extraterrestrial life and its precursors in spite of terrestrial contamination, it may weaken the main rationale for avoiding biological contamination.

E. Challenges with the Goals of Forward Planetary Protection

1. Arguments against Protecting Science

The OST requires its signatories to avoid harmful contamination, while the goal of planetary protection is to not jeopardize the search for life. Some interviewees argued that this goal oversteps the obligations in the Treaty—that harmful contamination was not meant to be biological—and that if the United States were to re-interpret Article IX obligations today, they would not choose to attempt to avoid biological contamination for the protection of science. Other interviewees argued that such a position is speculative, and that the historical record may contradict the assertion that harmful contamination does not support today's planetary protection (Meltzer 2011).

For missions to Mars, it is possible that terrestrial microbes and organic constituents do not pose a significant probability of harm to science. Such an argument is based on two proposals: (1) that the probability of a terrestrial organism interfering with science (e.g., surviving, replicating, and providing a false positive for a later mission) is insignificant;

[53] For a published opinion and explanation on this topic, see Fairén et al. (2017).

[54] The core of this argument is the ambiguity of organisms from Mars or organisms "missed" in the pre-mission identification process. In a realistic scenario, unknown organisms might not all be from Mars. Of course, current planetary protection policy does not preclude this scenario currently, as the goal is to limit forward contamination to a low level, not to eliminate it completely.

and (2) that even if a mission comes across a terrestrial organism, modern genetics reduce to insignificance the probability of its being falsely identified as extraterrestrial. Of course, there will always be some risk to science, but reducing the bioburden of landers may not sufficiently reduce the risk of harm to justify its expense. A stronger version of this argument would be that, for Mars, biological contamination does not pose a sufficient threat to be classified as harmful, thus protecting science by mitigating the risk of biological contamination does not fall under OST obligations. This logic only applies to the Martian surface (as opposed to an Europan ocean where terrestrial organisms may have a higher probability of survival) and if one is only focused on protecting the identification of extraterrestrial organisms (and not on environmental effects or the potential harm to extant life).

Accordingly, some stakeholders argue for returning to the term and concept of harmful contamination, in the process abandoning what has come to be known as planetary protection. They argue that this would essentially reset the current framework—which is not working effectively—allowing the United States and its international partners to redefine what to protect and how. One important counterpoint to this is that NASA's authorities to implement planetary protection are not derived directly from the OST, but from the Space Act of 1958 (as amended), of which recent amendments have introduced a search for life as one of NASA's major goals. In other words, adhering to some form of planetary protection may still be necessary for NASA in order to meet these goals, even if the OST obligation was not relevant.

Other interviewees took issue with the absolute and negative language that frames the current planetary protection goals. They argued that instead of avoiding the contamination of future scientific results, planetary protection goals could be framed to better encourage and promote scientific experimentation. By focusing solely on protecting future science, planetary protection policies might inadvertently inhibit other goals of space exploration, such as the exploration of Martian special regions or the development of human mission capabilities. A successful human mission to Mars, as opposed to a robotic one, might exponentially increase scientific output from Martian missions—a benefit that should be weighed against a higher risk of contamination. Allowing for more relativistic framing of planetary protection goals would enable them to be compared to human or national goals in space. This would, in turn, allow for more effective policymaking.

2. Expanding Scope of Protection

By exclusively focusing on the protecting the search for extraterrestrial life, planetary protection omits a number of threats to celestial bodies, protecting only a small portion of what could be considered harmful contamination, as can been in Figure 4.

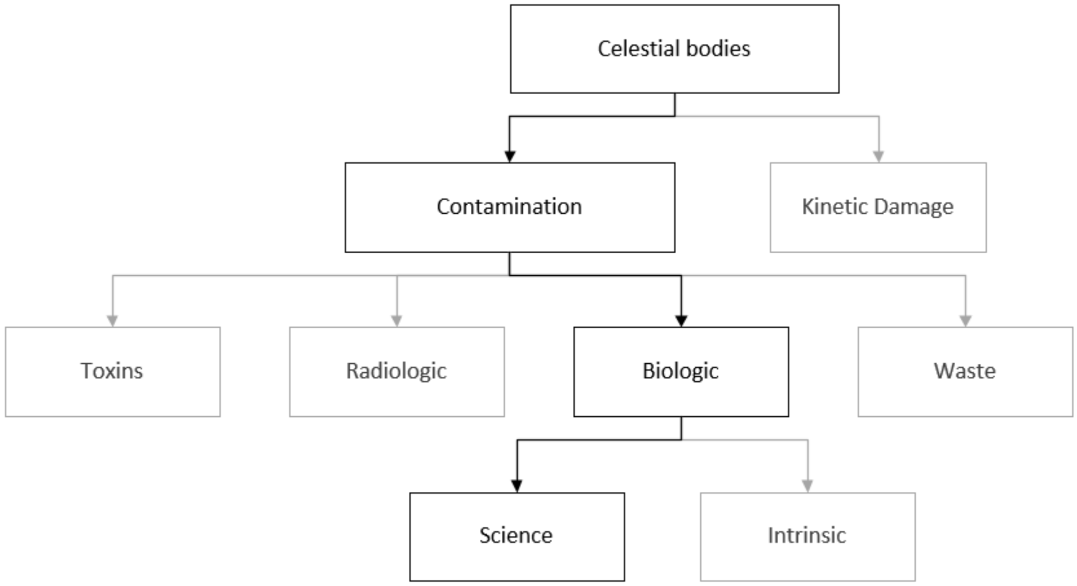

Figure 4. Representation of Current Scope of Planetary Protection Regarding Forward Contamination

Other types of harmful contamination are not covered under planetary protection policy. At the time of this writing, the policy protects only the conduct of scientific investigations (current and future), and any further protection is secondary. For example:

- The policy excludes non-biological contaminates, such as waste or propellants. Indeed, in 2006 the NRC recommended that NASA research the potential harm from contamination by nonliving contaminates (NRC 2006), although planetary protection policy to date has not included such contaminates.
- The explicit goal of the policy is to only protect against biological contamination if it affects the future of science; this does not cover biological contamination that could affect other human activities (such as sending a disease ahead to Mars) or protecting extraterrestrial life unless there is scientific interest (Cockell 2005; Huebert and Block 2007).
- The policy only applies to the contamination of celestial bodies that may harbor life and where terrestrial life may pose a risk to scientific exploration, not the entirety of the space environment. For example, planetary protection does not address the proliferation of space debris, the light pollution of the contamination of astronomical field of view by reflective satellites (IAU 2019).

These stakeholders would prefer to see nations expand protections to the broader space environment (Rummel et al. 2012b; Ehrenfreund, Hertzfeld, and Howells 2013; Galli 2019). Protecting all celestial bodies from a wider range of threats may be a closer reading of OST obligations (Tennen 2004). Expanding the scope of planetary protection may allow for greater protection of the space environment, but it also may restrict activities in space even more than the current policy does. These protections could be implemented through a supplementary protection, instead of an expansion of planetary protection, but the results would be the same.

F. Summary of Forward Contamination Considerations

Based on interviews for this report, it is not clear that the costs and benefits are balanced with regard to protecting future scientific investigations from biological contamination. The costs of implementing planetary protection requirements for a limited number of planetary bodies (e.g., Mars, Europa, Enceladus) are high, especially given inefficient and potentially outdated implementation procedures. In principle, the question of whether life exists in our solar system is clearly important, as is the policy and practice of the search for the answer to it. However, it is not clear how much value current planetary protection methods and practices add to answering this question, especially given advances in understanding of the low probability of microbial survival on Mars, and modern techniques that may allow us to disambiguate extraterrestrial life from terrestrial life. According to a number of experts with whom we spoke, alternative methods to avoiding biological contamination may be more effective in the protection of future science.

It is clear that planetary protection can be improved, but to what extent is still open to debate. Stakeholders fall into three broad camps:

- The benefits still outweigh the costs; implementation procedures can be improved but the goals and approach are is still valid
- The costs outweigh the benefits but the goals are still valid; this can be addressed by updating the implementation procedures (e.g., using genetic measurements) and approach (e.g., relaxing mitigation efforts where the probability of harm is exceedingly low)
- The costs outweigh the benefits (especially because of an insignificant threat to science or because of overstepping the OST) and no planetary protection requirements are warranted for outbound missions, i.e., re-examine the goals of NASA’s planetary protection policy

At a minimum, all parties agree that the technologies and techniques of the implementation measures are outdated and should be updated regularly. Addressing this challenge will require greater dedicated research. Any further changes are an open question, and may require consideration of broader policy themes.

Another outstanding challenge is whether or how to address other types of harmful contamination. This includes deciding the extent to which planetary protection should protect other celestial bodies and the broader space environment.

4. Assessment of Backward Contamination Policy

The protection of Earth is uncontroversial. This high-level verdict, however, does not address the extent of that protection or how it should be prioritized in relation to other interests. Answering these questions requires an understanding of how best to protect Earth from potentially harmful microbes from outer space, and the role of this issue within the context of other national (e.g., exploration and science) and international (e.g., cooperation and leadership) interests.

A. Backward Contamination Framework

Planetary protection includes defense against the potential hazard "posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission." To do so, it adds a fifth category of missions to the first four dealing with forward contamination: Earth-return.[55] Within this category, it divides missions that do or do not pose any biological threat to Earth. Those missions that could pose a threat (i.e., those from solar system bodies that could have indigenous life forms), are classified as *restricted* Earth-return and are to be treated with the "highest degree of concern." There have been three *unrestricted* sample return missions, and several others are planned from asteroids; the novel challenge to planetary protection comes with sample returns from Mars or other restricted celestial bodies.

There are two types of inbound missions: sample return and the return of human astronauts.[56] Most efforts developing restricted Earth-return requirements have focused on robotic sample return missions; these efforts have proposed two ways to mitigate the threat of backward contamination: (1) sterilize the sample with an approved process, or (2) contain the sample to and on Earth. NASA sets out a few policies, including the following (although these policies are target body-specific, they are generalized here):

- The outbound leg of the mission should meet stringent requirements to avoid false positives on the return trip

[55] Earth return includes the return of extraterrestrial materials to the Moon. COSPAR (2017) policy states that "The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel."

[56] Samples have been returned with humans, such as during the Apollo missions.

- Unless the samples are sterilized, contain them, with appropriate verification, through all mission phases up to a sample containment facility on Earth
- No uncontained hardware from the solar system body shall be returned to Earth. The mission and spacecraft must “break the chain of contact”
- Reviews and approval of the mission shall be required at three stages: (1) prior to launch from Earth, (2) prior to leaving the celestial body for Earth, and (3) prior to commitment to Earth reentry
- For unsterilized samples returned to Earth, a program of life detection and biohazard testing must be undertaken before the sample can be distributed

Thus, the planetary protection implementation for a sample return mission has at least three components: (1) meeting forward planetary protection requirements to avoid false positives, (2) containing or sterilizing the sample on the return trip to Earth, and (3) capturing and containing the sample capsule upon return to Earth.

For humans returning to Earth (specifically from Mars), COSPAR policy (affirmed by NASA in NPI 8020.7) currently provides only a few principles or guidelines related to backward contamination:

- Safeguarding Earth from potential backward contamination is the highest priority
- A comprehensive protocol (including backward contamination) should be developed
- A quarantine capability shall be provided during and after the mission.

An important part of an Earth-return process is how the mitigation procedures are reviewed and approved. The Apollo missions received feedback from the ICBC and had to procure approval under NSAM-235 (see more information in Appendix C). Today, there is no standing equivalent of the ICBC, but NSAM-235 has been replaced by PD/NSC-25, which pertains to “scientific or technological experiments with possible large-scale adverse environmental effects and the launch of nuclear systems into space;” an example of an experiment that would likely fall under this PD is MSR.[57] It is noteworthy that none of the prior sample return missions invoked PD/NSC-25. NASA determined that because they were from unrestricted celestial bodies, they did not meet the bar set for PD/NSC-25.

PD/NSC-25 requires the EOP to review and approve some government experiments that “significantly affect the quality of the human environment.” This analysis would build on the environmental review from NEPA, specifically the Environmental Impact Statement (EIS). If the mission were undertaken by the government, the government entity (e.g.,

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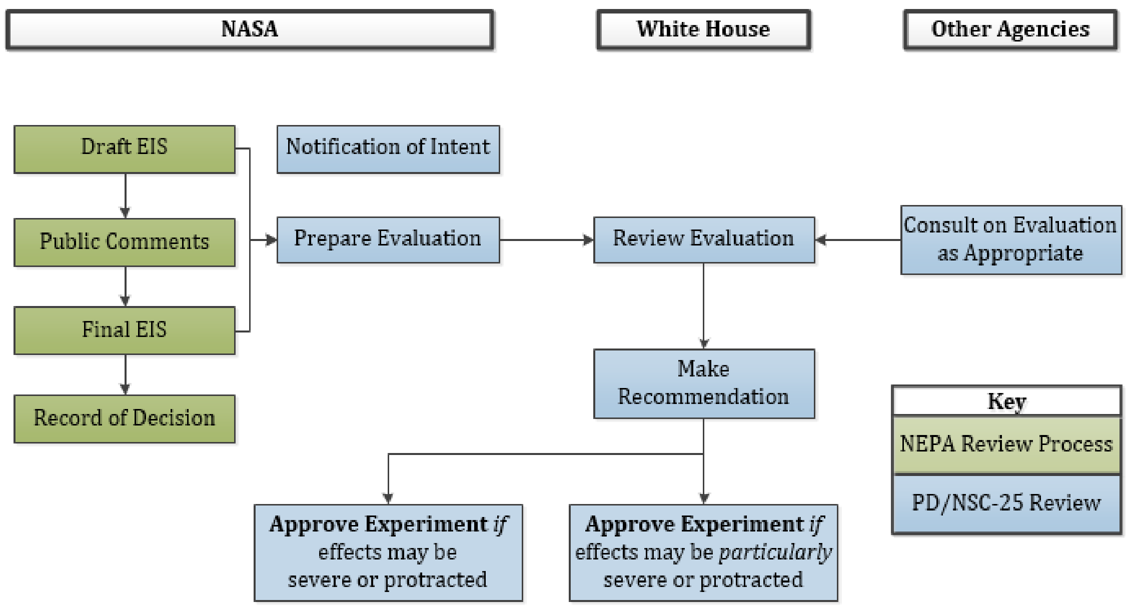
[57] There is some uncertainty in the scope of the document, as it only applies to experiments.

NASA) would provide the basis for the Director of OSTP to consult with the Chairman of the Council on Environmental Quality (CEQ), and offer a recommendation to the President. PD/NSC-25 then gives further detail for the process of national review, consultation, and approval for experiments with potential environmental consequences, as shown in Figure 5. Either the President or the head of the agency must approve some missions with potential for serious adverse consequences.



Note: Based on the potential effects of the experiment, the entity required to approve the experiment changes.

Figure 5. Depiction of PD/NSC-25 Process for Experiments

B. Benefits and Costs of Avoiding Backward Contamination

1. Benefits

Planetary protection mitigates the risk of harm from the introduction of harmful extraterrestrial material to Earth's biosphere. The probability of such adverse outcomes is very low, but it cannot be discounted (ESF and ESSC 2012; NRC 2009; NRC 1997; interviews).

Much of the potential danger of extraterrestrial life lies in the unknown. Experts interviewed for this report stated that if extraterrestrial life is like or related to Earth life it would likely not pose a threat, as it would not have evolved to outcompete Earth organisms or to be pathogenic to animals. However, if that life is completely different from terrestrial life, we cannot predict how it might interact with humans or their environment, including the potential for large adverse consequences (e.g., producing achiral toxins, giving them an ecological advantage).

Scientific consensus suggests that the probability of harm is exceedingly low (ESF and ESSC 2012; NRC 2009; NRC 1997; interviews). For example, for a returned sample to cause biological harm, extant life would need to exist on the target body; the mission would need to collect that life; and it would need to survive the return journey including reentry, escape from any mandated contamination protocol, harm or outcompete terrestrial organisms, and then transmit or proliferate.

Despite the low probability, the consequences of a harmful extraterrestrial organism could be so high that planetary protection takes caution, treating restricted Earth-returns as highly dangerous until proven otherwise. In general, it makes sense to use a basic precautionary approach instead of a probabilistic one due to the impossibility of defining the risk of potential backward contamination.[58] Avoiding backward contamination increases the probabilistic safety of both humanity and the environment, and could also provide insurance against the liability of the United States in the case a return mission causes damage.

Planetary protection provisions can also help meet science goals. Although the current MSR architecture is not designed for life detection (iMars WG 2018), planetary protection provides minimum life detection measures, and also requires contamination control (to avoid false positives) that may ultimately benefit the search for life. Some research has found that implementing planetary protection requirements would also inform scientific goals in the search for life (Allwood et al. 2013; Kminek et al. 2014; Summons et al. 2014).

2. Costs

Protecting the Earth from backward contamination requires adding cost and risk to the mission. Sample return is already an expensive mission concept; International Mars Architecture for the Return of Samples (iMARS) working group (WG) in 2008 estimated the cost of MSR ranging from $4.5 billion to more than $8 billion (iMars WG 2008). Engineering the return spacecraft to contain materials, sterilize samples, or survive impact with the ground at terminal velocity introduces weight and engineering complexity—increasing launch, reentry, and design costs. Furthermore, once returned to Earth, authorities must retrieve, house, and analyze the samples in a controlled environment. This will likely require the construction of a new biosafety facility (e.g., an enhanced BSL-4

[58] A probabilistic standard can still be precautionary. Instead of attempting to define a probability limit for adverse effects, ESF and ESSC (2012) attempted to prevent release of the sample to a certain probability. This is a precautionary approach implemented through a quantitative, probabilistic requirement. For more information, see Appendix G.

facility),[59] which could costs tens or hundreds of millions of dollars, and the facility must be staffed for the duration of the experiments. NASA studies in the early 2000s estimated the cost of building such a facility at about $120 million, with an annual operating cost of $7 million (Beaty 2009).

Adding engineering complexity and additional approval layers also contributes to mission risk. In general, adding approval points for planetary protection (e.g., to receive Presidential approval) increases mission cost and schedule. The current approach requires that a sample is effectively contained or sterilized, and the mission team must verify each necessary step during mission operations. If at any point the team cannot confirm that the required and appropriate containment or sterilization processes are being fully conducted, the sample cannot be returned, with loss of both the samples and the investment in the mission. Finally, it is not currently possible to eliminate the risk of harm to Earth's biosphere. That remaining risk (and the uncertainty of this risk) should be considered a cost of the mission.

C. Challenges with Current Approach and Implementation Procedures

The planetary protection and scientific communities have expended considerable effort into constructing the current sample return policy, regarding both Mars and other celestial bodies. Table 4 lists several of the major efforts to set and review the requirements.

Table 4. Sample List of Reports on Sample Return Requirements

Reports
NRC. 1988. Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies
NRC. 1997. Mars Sample Return: Issues and Recommendations
NASA. 1999. Mars Sample Quarantine Protocol Workshop
NASA. 2002. A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth
iMars WG. 2008. Preliminary Planning for an International Mars Sample Return Mission. Phase 1 Report
NRC. 2009. Assessment of Planetary Protection Requirements for Mars Sample Return Missions
ESF and ESSC. 2012. Mars Sample Return Backward Contamination – Strategic Advice and Requirements

[59] To prevent the contamination of the sample, the facility will require the control of outflow and inflow for organic contamination control, something that current biosafety facilities do not do.

Reports
Bennett, A., and T. Pottage. 2016. “EURO-CARES: A Plan for European Curation of Returned Extraterrestrial Samples.”
iMars WG. 2018. A Draft Mission Architecture and Science Management Plan for the Return of Samples from Mars. Phase 2 Report

1. High-Level Approach

A number of the high-level criteria and decision points for a restricted Earth-return are included in current planetary protection policy. Figure 6 summarizes the policy for a sample return mission.

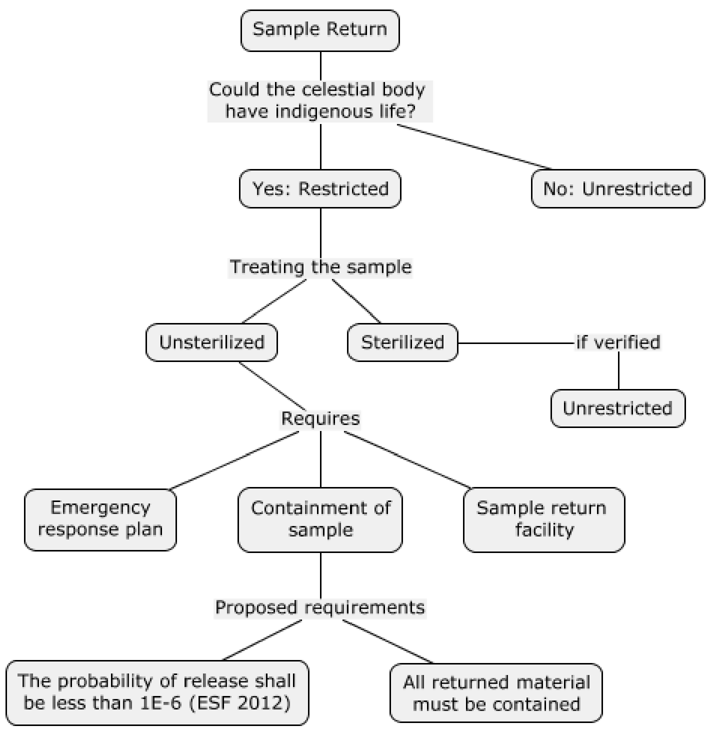


Figure 6. Planetary Protection Requirements for a Sample Return Mission

Overall, these top-level requirements seem to be well thought out and comprehensive. No person interviewed for this report suggested any changes or gaps in the current framework. However, this project did not systematically review or assess the high-level policy, and it would benefit from a review of experts outside of the planetary protection field such as biosafety and biosecurity experts. Such a review would be critical in advance of an MSR mission.

Previous reports have identified points of consideration for future implementation procedures regarding restricted Earth-return. First, the policy currently lacks procedures to mitigate the consequences of potential adverse effects in addition to mitigating its probability; for example, minimizing the population exposed to a potential sample release (ESF and ESSC 2012). Second, there is danger in assuming that conventional biosafety technology (e.g., the biosafety level 4 [BSL-4] used to isolate dangerous biological threats) is an adequate containment technology just because it is the most stringent current standard. If it is the best available technology, there may be no alternative, but some aspects may need to be redesigned—for example, filtering air both in and out of the sample containment facility to prevent escape of life or containment of the sample (Rummel et al. 2002; Bennett and Pottage 2016). Finally, the policy for humans returning from celestial bodies (e.g., Mars) requires additional consideration. The return of humans will introduce risks that are novel compared to sample return. For example, the risk of humans as a vector for backward contamination is not well understood, nor can they be sterilized or contained to the same tolerances as a sample container. In addition, human quarantine and an interest in protecting astronaut health could complicate planetary protection decisions. For example, as Appendix E shows, quarantine procedures were violated in the Apollo program for both technical and public relations reasons, and these issues could occur again. Some questions NASA and international entities must consider are:

- If we do not have adequate knowledge about the nature of life on Mars, should the first humans who visit Mars be allowed to return?
- If so, should returning astronauts returning require additional quarantine beyond their time in transit?
- If a human falls ill on the return journey from Mars, how should their quarantine be handled?

2. Lack of Precise Implementation Procedures

As of this writing, an MSR mission has not yet been funded, yet there have been calls for setting and updating detailed planetary protection requirements (e.g., iMars WG 2018). This includes requirements for engineering the return, retrieving the sample, and handling the sample on Earth. The lack of samples makes it not only challenging to assess the preparedness of NASA for sample return, but interviewees have noted that it affects mission planning, especially as ESA moves further ahead of NASA in designing the sample return orbiter.[60]

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[60] The fact that ESA is progressing faster than NASA is not a planetary protection-specific issue, although it does have implications for planetary protection. If there is no funded project, there is no international agreement. If there is no international agreement, whatever each party is doing is being done at risk and

Several reports in the early 2000s proposed a quantitative requirement for the containment of a sample. The most recent iteration of the requirements states that the probability that the mission releases a single unsterilized particle from Mars, $\geq 10\ nm$ in diameter, should be less than 1 in one million (ESF and ESSC 2012). This requirement covers containment but it does not define limits to other transmission pathways such as microbes that attached to the outside of the spacecraft or capsule (ESF and ESSC 2012). Furthermore, the currently proposed one-in-a-million limit for release of a particle may not be sufficient; the fact that one-in-a-million is a commonly used standard does not make it adequate (Kelly 1991).

A critical aspect of sample return will likely be retrieving, transporting, and handling the samples on Earth, and humans have been the cause of most biosafety breaches in recent history (Piper 2019). NASA worked on procedures for handling extraterrestrial samples in anticipation of an MSR mission in the early 2000s, but these draft protocols have not been updated since. Even as early as 2008, planetary protection experts were calling for these protocols to be updated to match recent understanding (Atlas 2008).

Even the best mitigation efforts cannot account for all risks—there are always "unknown unknowns." Without better understanding of the target body (i.e., whether it harbors extant life, and whether it will be harmful to terrestrial life), the risk of any return mission (sample, spacecraft, or human) will never be zero, even if the probability is likely exceedingly low. This is to be expected with a probabilistic challenge; however, policy and decision makers need to account for this uncertainty throughout the sample return regime.

3. Challenges with Scope of Backward Contamination

For backward contamination, planetary protection only addresses "organic-constituent and biological contamination in space exploration" (COSPAR 2017). Practically, this reduces the scope to space missions that are returning extraterrestrial material (i.e., samples or resources or objects/people) from celestial bodies that have a significant probability of maintaining indigenous life forms. Outside of biological threats, the responsibility for protecting Earth has been distributed among several policy areas, as can be seen in Figure 7.

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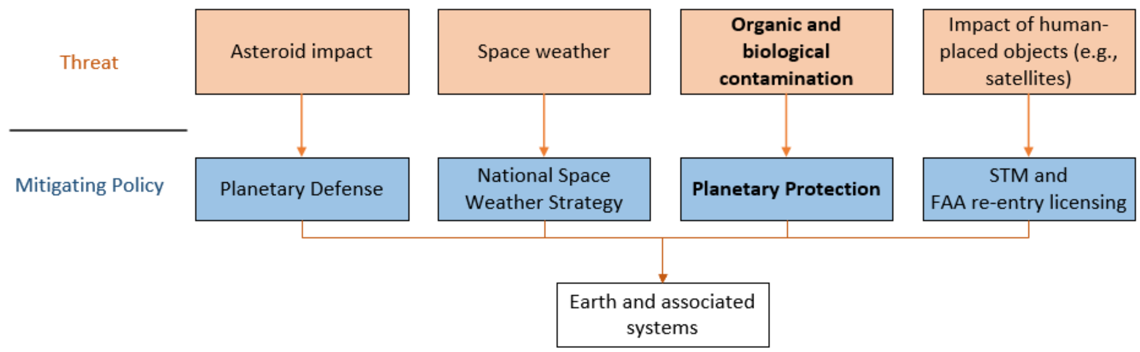
without requirements or a formal agreement. ESA is taking on a much larger risk by proceeding to develop hardware that will require integration with another entity without agreements or formal requirements in place.



Notes: FAA – Federal Aviation Administration; STM – Space Traffic Management.

Figure 7. Representation of Space-Based Threats to Earth and their Associated Policy Areas

Even for biological contamination, planetary protection may be missing some potential vectors. Two sources of biological threats could be lacking in the backward contamination portions of the current planetary protection policy: (1) natural interplanetary transfer that has occurred for millennia without any observed damage, and (2) potential for terrestrial organisms that could be mutated during their time in deep space (e.g., from the radiation environment of deep space). Neither of these threats is large nor warrants immediate consideration, but should be, at a minimum, considered as a part of the thinking on protecting Earth from microbes from outer space.

There is scientific consensus that meteorites from Mars have impacted Earth, and it is possible that these meteorites could have delivered viable Martian organisms (NRC 2009; ESF and ESSC 2012). Currently, backward planetary protection policy applies only to potential biological contamination from spacecraft and other human-made materials returning to Earth, not naturally occurring interplanetary transfer. Expanding the requirements to include meteoritic transfer may be impractical, but planetary protection may be the best forum to, at minimum, consider this additional risk to Earth's biosphere.[61]

Planetary protection only accounts for the "potential hazard posed by extraterrestrial material" (COSPAR 2017). This does not include the risk of Earth-originating organisms that have mutated in the low-gravity, high-radiation space environment. Research has shown that Earth microorganisms have reacted in new ways to the environment on the ISS (Nickerson 2004; Nickerson 2000; Tirumalai et al. 2017). However, no known research has shown that these mutations pose a threat to human health, and some interviewees stated

[61] These threats can be used to contextualize the risks seen from a sample return mission. It should be noted that even if humanity does not conduct return missions, the biological risk from extraterrestrial organisms will never be zero due to the chance of natural interplanetary transfer. The idea that Martian material may have been arriving on Earth for millennia may decrease the probability of adverse consequences (but not eliminate it).

that there is virtually no novel risk from a mutated organism. While scientists do not know if extraterrestrial life exists, we do know that Earth life survives in space and can mutate in unexpected ways. Planetary protection policy may be the appropriate forum to consider this hazard (beyond its implications for astronaut health), especially as the United States plans to send humans and their microbiomes further into space and for longer .

D. Alternatives to Return Missions

1. Presumption of Acceptability

Both mission planners and planetary protection policymakers have assumed that samples or humans will be returned to Earth. While that may be the appropriate decision, it should not be made a priori without fully considering the risks of backward contamination. All of the studies listed in Table 4 were intended to evaluate *how* a sample return mission could be carried out with respect to the goals of planetary protection, not *if* a sample return mission should be undertaken.[62] Through our research and interviews with biosafety experts, this may not be a prudent assumption.[63] Proper containment, verification, and response protocols may reduce the risk to a very low number, but with our current scientific and astrobiology understanding, we cannot be certain. The United States must act in advance of this certainty, not only to assess the mitigation efforts of potential return efforts, but also to determine whether the return itself is properly aligned with risk and reward.

2. Weighing the Cost-Benefit of Return Missions

One approach to determining whether to proceed with a sample return mission is to determine the cost-benefit of the mission itself compared to other relevant alternatives; this can be one of the earliest aspects of the mission design, and can influence mission architecture, materials, timelines, and destinations, among other factors. While the scientific community has already established that assessing samples on Earth will provide greater scientific value than *in situ* research (NRC 2007), this is a purely scientific judgment: it does not include an assessment of the risk of sample return, national policy goals or priorities, views of a broader set of stakeholders, or even an analysis of all alternatives. It is equally important, if not more important, to clarify if humans will be

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[62] At least one article we researched does touch on whether sample return should be allowed: DiGregorio (2001).

[63] The recent ESF and ESSC study on requirements for MSR chose to implement a BAT principle; they did not consider another approach, the prohibitory precautionary principle, on the grounds that it "would simply lead to the cancellation of the MSR mission" (ESF and ESSC 2012, 25). Appendix G summarizes the most common risk methodologies.

allowed to return to Earth from Mars, or what steps need to be taken to allow their return. These decisions have significant implications for national and private missions.

Fully informing such a decision is beyond the scope of this project; it would require convening international biology, biosafety and biosecurity, engineering, ethics, and risk experts. Instead, this section will provide considerations that might inform an OSTP decision-making process regarding sample return. Specifically, this report considers how to "assure that the need for the experiment has been properly weighed against possible adverse effects" (PD/NSC-25). This discussion will touch only on sample return missions, focusing on MSR.[64]

a. The Benefits of Sample Return from Mars and of Planetary Protection

According to a number of space experts, sample return would provide notable benefits to scientific understanding. The 2007 NRC report, *An Astrobiology Strategy for the Exploration of Mars*, stated that "[t]he greatest advance in understanding Mars, both from an astrobiology and a more general scientific perspective, will come about from laboratory studies conducted on samples of Mars returned to Earth." Bringing Martian material back to Earth will allow scientists to carry out multiple analyses, follow discoveries, and use instruments that cannot currently be landed on Mars (NRC 2007). Later NRC reports have affirmed the importance of the investigation of samples on Earth as compared to *in-situ* analysis (NRC 2011; NRC 2019). Mars 2020 is the first step in the process of returning a Martian sample to Earth,[65] to be followed by a return trip currently proposed by NASA and ESA.[66]

Other benefits of sample return include the potential gathering of knowledge to enable human missions to Mars, generating excitement about space and science, sharing samples in the global scientific community, and demonstrating American leadership.

b. Alternatives to Return

Sample return missions are attractive because of the potential for increased scientific discovery. There exist alternative pathways to sample return while still gaining some scientific knowledge. One can conduct the sample return itself in different ways, such as keeping the sample as is and containing it, sterilizing the sample in space, or bringing the

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[64] We consider that the return of humans from another planet to Earth is politically and ethically fraught, and outside of the considerations of this project.

[65] The Mars 2020 mission will collect about a half kg of Martian rock samples to be brought back to Earth for analysis. For more information, see the Mars 2020 official webpage at https://mars.nasa.gov /mars2020/mission/overview/.

[66] See the Jet Propulsion Laboratory (JPL)'s website for details on the mission at https://www.jpl.nasa.gov/missions/mars-sample-return-msr/.

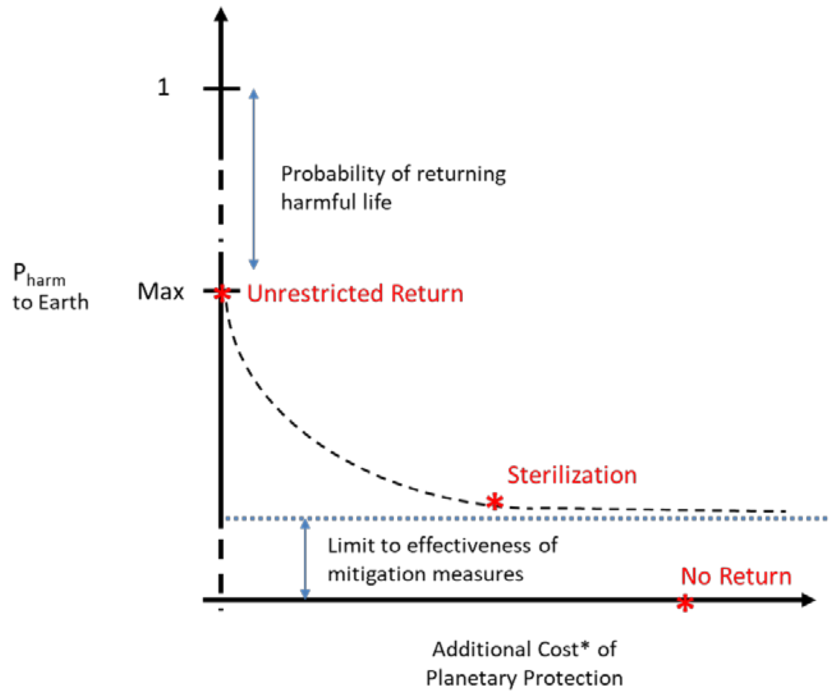
sample back to an off-Earth location (e.g., a Lunar space station),[67] capable of sustained operations and analysis in a high-radiation, low-gravity environment. The major option other than sample return is *in situ* research, sending humans or robotics to the celestial body to conduct the research there. Another alternative is to return samples with no risk mitigation efforts; i.e., assuming the inherent risk from extraterrestrial organisms may be so low that it does not warrant active mitigation. These alternatives can be compared to each other to determine optimal paths onward.

c. Evaluating the Cost-Benefit of Planetary Protection Requirements

A decision to undertake any mission, especially one with potential consequences for Earth's biosphere, must weigh both the cost and risk of the mission against its planned benefit. Completing such an evaluation will be challenging and may not provide a simple answer.

When considering planetary protection alternatives, a decision maker should consider not only the cost of the mission, but also its proposed benefits—specifically the scientific and political value. For example, allowing a mission that is returning to Earth from a celestial body that may harbor indigenous life as an unrestricted Earth-return represents a maximum in a probability of harming Earth's biosphere. At a lower value, sterilizing a sample would reduce the risk its return presents to Earth, but would also reduce its scientific value by destroying any life forms and potentially altering the sample's chemical or geological properties. These evaluations also consider uncertainty in two major parts: (1) the probability that extant life will be returned and that it will be harmful, and (2) the limitation and uncertainty of human factors and engineering systems in addition to our imperfect ability to account for "unknown unknowns." A rough visualization of this approach can be seen in Figure 8.

[67] This alternative has been considered in the past. See, for example, NASA's Anteus report (DeVincenzi and Bagby 1978).



* Efforts to determine the cost of reducing the risk of backward contamination could consider the mission cost, mission risk, and the opportunity cost to science and political leadership.

Figure 8. Notional Representation of the Risk-Cost Relationship for Mitigating Backward Contamination

Decision makers can also attempt to qualitatively understand the effect of planetary protection decisions on the cost and benefit of the mission. For example, one can compare the three options included in Figure 8 to the containment protocols as shown in Table 5. The table compares alternatives to returning a contained sample, and compares the scientific value, risk to Earth, mission cost, and mission risk to that baseline containment. For example, an unrestricted sample return poses greater risk to Earth but less mission cost and risk.

Table 5. Comparison of Cost-Benefit of Sample Return Options

Return Option	Scientific Value	Risk to Earth	Mission Cost	Mission Risk
Baseline: Sample Containment on Earth	-	-	-	-
Unrestricted Return	-	↑	↓	↓
Sample Sterilization and Return to Earth	↓	↓	?	?
In Situ Analysis	↓	↓	?	↓

Note: Arrows estimate the effects of different risk mitigation options on the equities relative to the baseline of sample containment.

Based on the high projected cost of sample return, advances in miniaturizing scientific instruments that could enable *in situ* analysis, and the risk of backward contamination, the U.S. Government and international community should ensure that a sample return is the best allocation of resources. Furthermore, we should consider the role of planetary protection on the forward, *in situ* portion of science. Protecting planets from forward contamination may restrict scientific experimentation and exploration of those planetary bodies, but may also increase the interest in conducting sample return missions, and thereby ultimately increase the risk of backward contamination. Because the restrictions of forward contamination requirements may be making sample return missions of higher relative value, one alternative to increasing scientific output while not risking backward contamination may be to re-assess forward contamination policy, or enhance forward contamination protection capabilities, potentially increasing the value of *in situ* research. Finally, alternatives to *in situ* research or sample return to Earth, such as return to orbital laboratories or unrestricted return, might be viable options.

E. Decision-making for Backward Contamination

The national decision-making process addressing the threat of backward contamination for government missions[68] is guided by two policy documents: Presidential guidance via PD/NSC-25 and public environmental disclosure through NEPA. NEPA requires all Federal agencies to consider environmental impacts in all proposed Federal actions and may give an opportunity for public comment. However, the NEPA process is relatively clear, and does not provide much in the way of approval guidance. While PD/NSC-25 has not been applied to a planetary protection mission, its predecessor, NSAM 235, has. PD/NSC-25 has the greatest implications for deciding on the return of samples from space, as it lays out a process for the review and approval of a mission by the executive branch.

This section will primarily consider the role of PD/NSC-25. Approving the return of samples from an interplanetary mission includes at least four major components: who makes the decision, who is consulted, how the proposal is reviewed, and how the decision is made. This section will review each of these components, assessing the completeness of the process. The process is even less clear for private sector-led missions.

1. Who Makes the Decision

Based on the severity of the potential environmental effects, PD/NSC-25 requires differing levels of notification or approval. Inherently, the mission owner (e.g., NASA)

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[68] NASA policy will have control over the internal decision-making process. This section discusses the interagency and whole-of-government processes. This discussion is relevant to U.S. Government missions. Chapter 6 discusses commercial and international entities.

will approve all of their own missions. However, for experiments with potentially large environmental effects, PD/NSC-25 requires the approval of either an agency principal (e.g., the administrator of NASA) or the President. These requirements are outlined in Table 6.

Table 6. Approval and Notification Requirements for PD/NSC-25

Potential Effects	Required Action
Approval	
Particularly serious or protracted adverse effects (emphasis added)	The President must approve the experiment
Serious or protracted adverse effects	The head of the department or agency involved must approve the experiment
Neither serious or protracted adverse effects	Not specified
Notification	
Might have major and protracted effects on the physical or biological environment, or on other areas of public or private interest	Notify the director of OSTP

Note: None of the sample return missions to-date have involved PD/NSC-25

The effects triggering different levels of approval are currently ambiguous. For example, the memorandum does not clarify what makes a potential effect *particularly* serious or protracted as opposed to only serious or protracted. Without greater clarity, mission planners will likely be uncertain about the length and cost of the approval process, adding risk to the mission.

Similarly, PD/NSC-25 is not explicit about what planetary protection categorization requires the EOP to be notified. In the past, NASA has functionally determined that sample returns deemed to be unrestricted Earth-return did not pose a major environmental threat (interviews). This was the case for missions such as Stardust, Genesis, and OSIRIS-REx. However, current COSPAR policy does not distinguish between unrestricted and restricted return based on the probability of environmental impact, but on whether the target body has indigenous life forms (COSPAR 2017). This distinction has been expanded upon for the review of the Japanese Martian Moons eXploration (MMX) mission, where the question was not necessarily of indigenous life on Phobos or Deimos but on whether Martian life had been transferred to one of its moons. For assessing the categorization of this mission, a joint National Academies and ESF panel took a probabilistic approach that the mission would be unrestricted if the probability that the mission returns a single unsterilized particle from Mars, $\geq 10\,nm$ in diameter, is less than 1 in one million

(National Academies 2019).[69] However, this unrestricted classification does not mean that there *might* not be major or protracted effects on the environment, only that the probability is even lower. Thus, if it were a U.S. mission, it would likely require EOP notification even though it is unrestricted. There have been other evaluations that have not been able to confidently classify restricted vs. unrestricted Earth-return, such as the risk analysis for returning asteroid material from the Japanese-MUSES-C mission, which made no assumption of unrestricted or restricted return.

Furthermore, the EOP may wish to consider whether increased levels of approval are warranted. Presidential approval can provide top-cover and add political awareness, but experiences with Presidential approval for the launch of nuclear systems has shown that it incentivizes over-analysis at the agency level, and that the approval process at the EOP level can be *pro forma* (Buenconsejo et al. 2018).[70]

Finally, for shared missions with international collaborators (such as the planned MSR mission with ESA), the approval process will become more complicated. For MSR, it is likely that both the executive branch and the European Union council of ministers would need to approve the sample return mission or sample distribution. Expanding decision-authority will add time to getting the mission approved, and could reduce the control of the EOP. The shared architecture also introduces potential territorial disputes. For example, under the current architecture, an ESA spacecraft will be returning the samples to American soil. It is unclear how ESA and the United States will make the decision that the package can be released for Earth-return.

2. Who Is Consulted

OSTP may not always have the expertise to independently review an Earth-return mission, and will likely have to rely on the consultation of the interagency community and other experts. PD/NSC-25 directs OSTP and the mission planner to consult with multiple entities regarding the decision to conduct the experiments. Table 7 lists the consultation requirements.

Table 7. Consultation Requirements in PD/NSC-25

Entity	Context
Council on Environmental Quality (CEQ)	The Director of OSTP will consult with the Chairman of CEQ when reviewing proposals

[69] This mission has now been determined to be unrestricted Earth-return (Coustenis et al. 2019).

[70] This and other STPI reports on space nuclear power will be cited to draw lessons from the space nuclear launch approval process. To inquire about obtaining a copy of the report or a briefing, please email Dr. Bhavya Lal, blal@ida.org.

Entity	Context
The National Academy of Sciences and, where appropriate, International scientific bodies or intergovernmental organizations	In the case that experiments might have adverse effects beyond the United States
The Secretary of State	Shall be notified "when experiments are expected to have [adverse] impacts in foreign countries"
Other concerned agencies	In appropriate cases, "any experiment will not be conducted without the advice of other *concerned agencies*"

The 2018 National Academies report on planetary protection found that PD/NSC-25 "does not adequately capture the full range of Federal agencies that, today, would have a legitimate role in reviewing planetary protection plans" (NRC 2018, 69). The memorandum carves out the authority for any concerned agency to give advice where appropriate, but it could be useful to require the mission owner to consult with specific agencies, updated for currency. For example, for nuclear launch approval, PD/NSC-25 requires specific agencies to review the safety application as a part of the Interagency Nuclear Safety Review Panel (INSRP). The portions that affect planetary protection could either specify a committee, such as the ICBC that was set up during Apollo, or individual agencies such as the Department of Agriculture, Department of State, the Centers for Disease Control and Prevention, the Department of Defense, the Environmental Protection Agency, and other relevant agencies. Regardless of the requirements of PD/NSC-25, NASA does not currently have such a standing source of interagency consultation and experts to ensure that backward contamination policy is as up-to-date and effective as possible. Historically, the NAC operated via the Planetary Protection Subcommittee, which existed for nearly two decades until it was disbanded by NASA in 2017.

The Federal Government may also want to consider emphasizing consultations with international entities (as per Article IX provisions in the OST). Other nations are likely to express concern over a mission that could have implications for their environment and citizens, just as the United States would if another nation were conducting a sample return mission. By consulting with the international community, the United States can address these concerns, as well as set a precedent for open communication in case other nations pursue similar missions.[71]

[71] Several countries including China are currently considering a sample return mission from Mars (Mosher 2019).

3. Decision Process

The United States has never put PD/NSC-25 into practice to address the risk of backward contamination. The closest equivalent is the portion of PD/NSC-25 dedicated for approving the launch of nuclear materials, which is reviewed on the next page. Due to this lack of practice and the ambiguity of the document, neither NASA nor the EOP have a clear picture of the approval process for a sample return mission. This uncertainty extends to the timeline for implementing the process, the format of the proposal, and the review mechanism.

PD/NSC-25 Process for the Launch of Nuclear Systems

The government nuclear launch approval process, governed predominantly by PD/NSC-25, includes multiple steps completed by multiple government stakeholders. This process typically includes an environmental analysis resulting in an environmental impact statement (EIS), a Safety Analysis Report (SAR) completed by the Department of Energy, empanelment of an interagency safety review panel (INSRP) resulting in a Safety Evaluation Report (SER), and, eventually, Presidential approval. The process takes x-y years, and costs at least $x0 million. See Figure 9 for a depiction of this process.

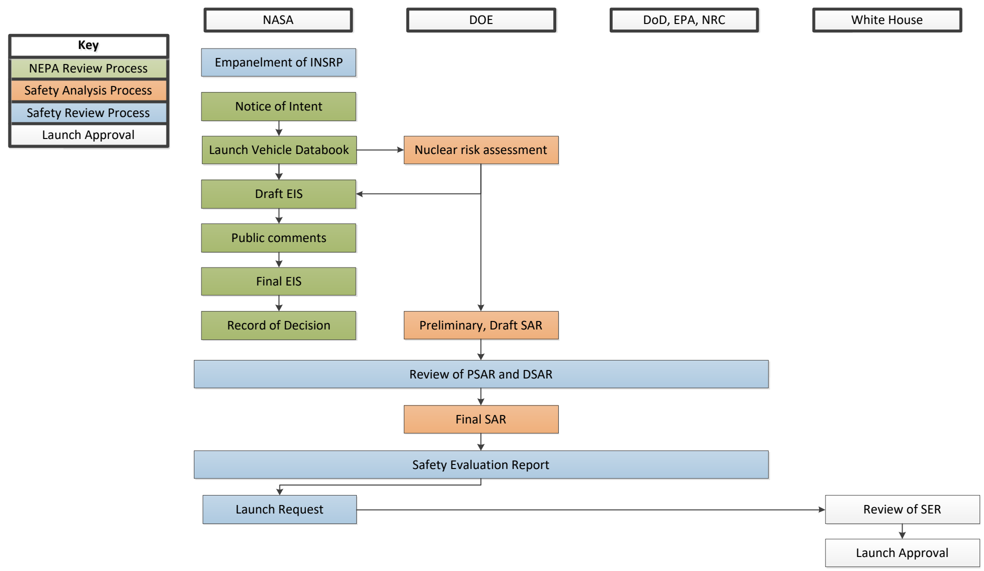

Figure 9. Depiction of the Launch Approval Process for Government Launches

STPI has previously investigated the government space nuclear launch approval process and identified barriers to its effectiveness. Some of the relevant challenges are summarized in Table 8.

Table 8. Challenges Associated with the Government Launch Approval Process

Challenge	Description
Lack of criteria for safety analyses	Few criteria or guidance, beyond precedent set by prior missions, exist to govern the level of safety analyses and reviews necessary to support a launch approval decision.
Duplicative analyses	The analyses required for the SAR and EIS have substantial components that are duplicative.
Practices for satisfying NEPA requirements	Incorrectly choosing to administer an EIS when an EA may suffice; also, the timing of the EIS can be problematic.
Lack of guidance for INSRP	There are no documents related to the space nuclear launch approval process that provide any guidance to the scope and role of INSRP.
Burden of Presidential approval	Launch approval at the Presidential level is unprecedented and seems to result in little meaningful engagement.

Source: Buenconsejo et al. (2018).

The EOP would need to approve a return mission likely before NASA could launch the mission.[72] COSPAR and NASA policy requires several decision points for an Earth-return mission: (1) before the mission can be launched from Earth, (2) before the mission can be launched from the celestial body, and (3) before the spacecraft can commit to Earth-return (COSPAR 2017). PD/NSC-25, however, requires that the mission owner must notify OSTP sufficiently in advance that the experiment may be "modified, postponed, or canceled" [Paragraph 1] and that missions shall not be conducted without the requisite approvals [Paragraph 7]. If launching a mission is part of "conducting it", the EOP must approve a mission prior to its launch.

There is no precedent or exact answer for when a mission owner must begin the PD/NSC-25 review and approval process. The closest analog is the approval process for the launch of nuclear materials, which has taken anywhere from four to nine years (Buenconsejo et al. 2018). That review process has key differences, such as a required interagency review, but the backward contamination approval could take a similar amount of time due to its potential for catastrophic consequences and especially as a first-of-a-kind approval process.

The most conservative answer would be to start the approval process as soon as possible. PD/NSC-25 refers to findings from the NEPA process, so NASA could conduct the EOP proposal concurrently or immediately following the EA or EIS required for NEPA.[73] NASA should also notify OSTP prior to or as soon as a mission is selected. The planetary protection officer and OSTP can then coordinate to formulate an approval process.[74]

The contents of the required proposal are also undefined. PD/NSC-25 states that the sponsoring agency will prepare "a detailed evaluation of the importance of the particular experiment and the possible direct or indirect environmental effects that might be associated with it" [Paragraph 2]. Such an evaluation, while valuable, might be difficult to create, given the uncertain consequences of backward contamination. In addition, a report following only the guidelines above may lack other critical information such as the mitigation efforts of the mission, alternative options to the return mission, and potential effects on humans (i.e., not just environmental effects). NASA is likely assuming that the input to this process would be the Earth Safety Analysis (ESA), as required in NASA

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[72] How a joint ESA and NASA approval process may proceed is currently uncertain. It is likely that since it would be a joint mission, multiple government entities would need to approve the sample return process.

[73] NEPA does apply and requires EA or EISs for Earth-return missions (14 U.S.C. §1216.305(b) 5 and 14 U.S.C. §1216.306(d), respectively).

[74] Given the lack of experience with conducting and approving return missions, it may make sense to conduct the approval process ad hoc instead of prescribing a timeline and process a priori.

Interim Directive NID 8020.12. The ESA is the primary planning document covering Earth-return, to demonstrate to the PPO that the project is meeting planetary protection requirements.[75]

Finally, the report is currently reviewed solely by OSTP in consultation with CEQ; while other agencies may be consulted, they are not a part of the official review process. This in itself is not necessarily a problem; past research has shown that the review panel for the launch of nuclear material may have not been effective or efficient (Buenconsejo et al. 2018).

4. Decision Criteria

OSTP and CEQ are required to review the experimental proposals to "assure that the need for the experiment has been properly weighed against possible adverse effects" [Paragraph 3], and then recommend to the President what action should be taken.[76] This criterion provides the EOP flexibility to assess all aspects of an experiment but may introduce uncertainty into the decision-making process. Determining whether the risk of the proposed mission is acceptable in light of its need is a complex, highly subjective proposition. As noted earlier, the risks are unquantifiable and uncertain. The EOP can leverage some decision-making protocols that account for catastrophic risk to help inform qualitative decision making (Sunstein 2003) or even provide numerical criteria (Ghirardato, Maccheroni, and Marinacci 2004, Farber 2011).

Weighing the need and possible adverse effects of a mission would allow the EOP to consider the equities discussed throughout this report. This decision would be best informed by examining all alternatives to a contained sample return mission. Whatever decision criteria the EOP utilizes, it should prioritize the safety of Earth's biosphere while seeking to maximize the benefits of the mission.

F. Summary of Backward Contamination Considerations

No nation has undertaken a restricted Earth-return mission since the Apollo era (and since then, Moon sample returns are no longer restricted). NASA has undertaken a number of sample return missions and they can help inform an MSR mission (Mangus and Larsen 2004; Allen et al. 2011), but these missions are either over half a century past (Apollo) or

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[75] Important components of the document include potential contaminating sources, decontamination approach, Earth entry plan, and the probability of contamination model.

[76] This assurance should include that other mission alternatives were considered, and that Earth-return was chosen not only because the scientific value is better, but also because it is worth the risk of backward contamination.

were not restricted Earth-return.[77] COSPAR and NASA have promulgated policies for a sample return mission from Mars, but may need to review those policies (see Section C of this chapter) as well as create detailed requirements, protocols, and guidance for carrying them out. Finally, the requirements must be implemented, sometimes far ahead of the return itself.

NASA and its international partners must still establish requirements and protocols for the return of humans, which are currently lacking. The high-level policy for backward contamination has been established, but it has not yet been used to create systems engineering requirements that engineers can use to design the mission, sample return facility, and the emergency response plan. NASA studied potential requirements in the early 2000s (when it was previously considering sample return),[78] but these requirements need to be updated and implemented into official NASA policy. This likely should be an internationally tasked and accepted protocol that should be produced as soon as possible (iMars WG 2018). The details for the implementation procedures require as much, if not more, care than the policy.

All but a small part of this report was completed before the global outbreak of COVID-19, the effects of which have disrupted the world and damaged its economy. This terrestrial outbreak underlines the potential danger posed by extraterrestrial life, its consequences not predictable but now too easily imaginable. In considering the risk of backward contamination, U.S. planetary protection policymakers face the unfortunate and difficult—but necessary—task of addressing these risks amid abundant uncertainty. When responding to the questions raised by planetary protection, the lessons and experience from COVID-19 may prove instructive.

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[77] The iMars WG (2018) report suggested that an MSR can learn from terrestrial examples, specifically the international collaborative deep-sea ocean drilling (Smith et al. 2010). See pp.S-21–S-23 of the iMARS WG report for more information.

[78] See DeVincenzi et al. (1997) and Rummel et al. (2002).

5. Assessment of Planetary Protection Associated with Private-Sector Missions

Since COSPAR and NASA first developed planetary protection policy in the 1950s and 1960s, the major actors in space have changed and expanded. Our research found that not only has the number of countries with interest in sending missions to Mars or sample returns increased,[79] there are also new private sector entities aiming to conduct human and robotic missions to Mars and the icy moons, as well as sample return missions. Unlike previous government missions, some of these new missions do not have science as their central or sole focus. Not surprisingly, the existing planetary protection framework, developed in a time when there were only government-led missions, does not provide rules and guidance specifically for private missions that involve sending machinery or humans to settle or use a celestial body. These private entities also operate under different constraints compared to traditional players. For example, private entities are typically focused on achieving business objectives that translate into highly constrained technical, cost, and schedule parameters designed to achieve a financial return on investment. This

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[79] See Appendix F for case studies on planetary protection in other nations. International State actors are seeking to initiate or expand their efforts to explore the solar system, especially Mars. The following efforts were identified during STPI's research on global activities with planetary protection implications:

- China is planning to send rover missions to Mars during the 2020 launch window (Jones 2017). As of May 2019, the Chinese Mars lander mission is on schedule and undergoing integration (Jones 2019). The Chinese have also indicated that a Mars sample return mission is being planned for the future, which would entail addressing both forward and backward contamination (Jones 2017).
- Europe has plans to send rover missions to Mars during the 2020 launch window (ESA 2016). The European ExoMars mission has a 2-meter drill and an organics detection instrument.
- India and France are planning on collaborating to send a lander to Mars, with India's government approving the budget in 2017 (Bagla 2017).
- United Arab Emirates is planning the Emirates Mars Mission (EMM), and is planning to send the Hope probe to study the Martian atmosphere by 2021 (Sharaf et al. 2017). Although not a lander, this probe will also necessitate planetary protection considerations under the current COSPAR guidelines.
- Russia has indicated plans for a Mars sample return mission called Mars-Grunt (Roscomos 2010), but these plans have been pushed back after their involvement in the ExoMars 2020 landing platform has been completed and it has done a sample return mission to the Martian moon, Phobos.
- JAXA, the Japanese space agency, has plans to explore Phobos and Deimos, in a mission named MMX (Martian Moons eXploration) and plans to return samples from one of the Martian moons (JAXA 2019).

profit-making goal is a key attribute that differentiates these missions from government-led space programs.

A. The Private and Planetary Protection Communities

The entrance of private actors poses challenges to planetary protection, and planetary protection poses challenges to private activities. These challenges are heightened by a lack of a neutral forum to discuss and deliberate the future of planetary protection.

1. Challenges to Planetary Protection

Under the current guidelines, more missions means a higher probability of contamination, and thus a greater risk of harming future science or Earth's biosphere. Now that planetary protection requirements are the same across missions to a given celestial body (i.e., not a probability apportioned amongst actors as was the case when the policy was first developed), the more missions to Mars, the more microbes that could potentially contaminate it.

Concern about contamination is heightened by the perception that private entities will be more careless or engage in activities that will make contamination more likely. This is part of a greater concern that heightened commercialization and private activity in space will lead to harm to the space environment (Mann 2013; David 2017). This is especially concerning for the risk of backward contamination, where the consequences could be especially large.

These concerns are accentuated by the lack of direct control over private activities from the current planetary protection community. Other than missions for which NASA has a role, authority over private activities could reside in agencies that have not had extensive (or any) planetary protection experience, such as DOT or the Department of Commerce (DOC).[80] Rather than following a NASA planetary policy, private missions would be required to adhere to whatever policy other agencies might agree would meet U.S. obligations under the OST, which might be the COSPAR planetary protection policy—itself a voluntary standard, not particularly well adjusted for private entities who are unlikely to wish to add costs for protecting future science.

2. Challenges to Private Sector

Very few current or planned private activities have planetary protection implications, and, of those that do, few have requirements beyond basic documentation, as they involve travel to celestial bodies that are not likely to harbor extraterrestrial life, such as the Moon. However, there are some entities that aspire to send spacecraft to celestial bodies such as

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[80] DOT has consistently called upon NASA to play a consulting role in the review of applications.

Mars or the icy moons, planetary bodies that are more likely than others to harbor extraterrestrial life. These entities consist of both for-profit companies and non-profit organizations interested in sponsoring and sending private science missions.[81]

While government missions may be able to withstand cost and schedule challenges that derive from planetary protection requirements, private entities are more fiscally limited, and in most cases, need to generate a return on invested capital. A private entity interested in sending an orbiter to Mars estimated a 25–40 percent increase in cost of the assembly, integration, and test for the mission if they had to follow COSPAR planetary protection policy and guidelines.[82] Implementation costs might be quite high, but it is challenging for private entities to understand that without clear cost information and estimates for similar missions from NASA. The indirect costs of planetary protection can also be too high for private entities, limiting what regions of Mars they can easily access, whether or how they can send humans to Mars or precursor robotic missions, and adding risk that their mission might not be approved for planetary protection reasons. Private entities argue that these costs would be prohibitive.

More challenging are the core disagreements some private entities have with the current goals of planetary protection. Most of these companies have a scientific interest, but, along with some scientists, are looking for new and innovative ways to conduct science rather than to protect the biological pristineness of the target bodies. As stated in Chapter 3, some scientists have argued that the human capability to explore complex environments would further scientific advancements in space. At least one company echoed this view, indicating that it did not seem logical to limit the search for life in the interest of avoiding a small probability of false positives or harming that life, but rather, humans should be sent to do the research, drawing inspiration from terrestrial exploration where human explorers search for life in extreme environments. A more productive approach would be to prioritize human exploration rather than viewing it as a threat to science.

When private entities start becoming interested in non-scientific goals, such as tourism, mining, or colonization, protecting the future of science will no longer be directly

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[81] The BoldlyGo Institute is proposing a Martian dust sample return mission called SCIM (Sample Collection to Investigate Mars). The scientific goal of this mission is to study the chemical, isotopic, and mineralogical composition of the samples, not to search for signs of life (BoldlyGo 2019). Additionally, the Planetary Society also has two Mars projects that would require forward contamination considerations. The first is PlanetVac, a low-cost concept for sampling planetary surfaces, and the second is the Planetary Deep Drill, which they are developing and testing with Honeybee Robotics (Planetary Society 2019). While most of the private-sector missions that would require planetary protection are headed to Mars, at least one plans on going to the icy moons. The private foundation Breakthrough Initiative has proposed a mission to either Enceladus or Europa (Anderson 2018 and interviews).

[82] A planetary protection expert notes that this estimate could be ill informed, as the policy offers choices between spacecraft cleanliness and operational limitations.

aligned with their goals. At that point, planetary protection is a cost that will not benefit their long-term missions, especially as the current goals of the policy and its standards are explicitly science-focused. Originally, the period of biological exploration was meant to free worlds for private access, but the original 50-year period of biological exploration has gone by without any change.

If the costs of implementing planetary protection requirements become prohibitive, they could affect private plans and activities. If planetary protection makes a mission unaffordable to a private entity, they would be forced to cancel or change the mission, move to a nation with different interpretation of planetary protection, or attempt to cut corners. One entity interviewed for this report stated that if planetary protection dramatically increases the costs of the mission, they would likely stop pursuing it.

3. Communication and Representation

When COSPAR and NASA first established planetary protection requirements, there were no private actors that could launch planetary missions. Therefore, much of the discussion about planetary protection policy occurred among a small subset of interested scientists who were focused only on government missions. Planetary protection policy development at national and international levels has not involved significant participation by the private sector (NRC 2018).

Despite the emergence of new actors, however, this dynamic has remained largely unchanged today. Beginning in January 2019, COSPAR now holds open discussion during meetings of the Panel on Planetary Protection, which private entities can attend, but only appointed space agency and COSPAR Scientific Commission representatives are allowed to attend closed meetings or vote (Coustenis et al. 2019). NASA has included more private views through its recently announced review process through the NAC (Foust 2019). However, companies interviewed for this report still indicated that they felt excluded from decision-making roles in the deliberations affecting planetary protection.

It may be difficult for the private and planetary protection communities to effectively communicate, especially under the current framework. At present, there is no explicit forum where private entities can contribute to discussions of planetary protection, especially on par with the scientific community (NRC 2018). The NAC provided an attempt at such an open and public forum via the Planetary Protection Subcommittee, which existed for nearly two decades until it was disbanded by NASA in 2017. COSPAR is an explicitly scientific-focused organization, the goals of which will not change regardless of private sector representation. NASA has direction to support private activities, but again it is scientifically focused on the "expansion of human knowledge of phenomena in the atmosphere and space" (Space Act 1958). Furthermore, many of the disagreements between the two communities are value driven, namely that the two groups place different levels of value on the search for extraterrestrial life and thus on the benefits on planetary protection. Considering these fundamental differences, planetary protection and the private community may benefit from a new, more neutral forum for considering the future of planetary protection.

B. Private Sector Obligations and Authorities

In the United States, authority over space activity is currently delegated to several different agencies. DOT has authority over launch and reentry (21 U.S.C. §50904), the Federal Communications Commission (FCC) has authority over the transmission of energy including communications with spacecraft (47 U.S.C. §152), and DOC via the National Oceanic and Atmospheric Administration (NOAA) has authority over Earth-sensing space systems (51 U.S.C. §60121).[83] Most non-government space activities have historically fallen under the authority of one of these agencies, but as private entities pursue new activities in space that might cause planetary protection concerns, government regulation is no longer so clear.

The OST is clear about the responsibility of the United States in regard to its non-governmental actors. Article VI states that signatories to the Treaty "bear international responsibility for national activities in outer space…whether such activities are carried on by governmental agencies or by non-governmental entities." Furthermore, non-governmental activities require "authorization and continuing supervision by the appropriate State Party." Whether the United States is meeting these Treaty obligations is a complex question and still up for debate (Egan 2016).

The United States has not provided clear in-space authority, nor has it clarified (via legislation, executive action, or regulation) how private entities should abide by OST Article IX stipulations about harmful contamination or adverse changes to Earth. A majority of legal scholars interviewed for this report believe that private entities should be required to follow Article IX obligations regarding harmful contamination (e.g., when applying for a DOT license). According to at least one expert we spoke to, however, OST obligations are not self-executing—meaning that, without legislation, DOT would not have the authority to deny access to space based on OST articles that apply to State parties (Montgomery 2018; Montgomery 2016). Furthermore, other interviewees have contended that Congress does not intend for DOT to have any authority on activities in space. That being said, it seems likely that OST obligations will be passed on to private entities, especially as DOT has authority related to decisions based on the foreign policy interests of the United States (49 U.S.C. §70104).

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[83] The Commercial Space Launch Act of 1984, as amended, addresses the licensing of private sector space launches by DOT as delegated to the FAA Office of Commercial Space Transportation. Separate statutory authorities govern other Federal agencies, such as DOC, State, and NASA, all of which are involved in civil space policymaking that will affect future U.S. planetary protection oversight.

Meant to provide "an international standard on procedures to avoid organic-constituent and biological contamination in space exploration, and to provide accepted guidelines in this area to guide compliance with the wording of th[e] UN Space Treaty," COSPAR policy is not legally binding to the United States (COSPAR 2017). As discussed previously, it is a type of soft-regulation that may be within the best interests of nations to follow (either because it is beneficial for them or for diplomatic reasons). NASA has provided the leadership to establish the current COSPAR policy, and maintains a roughly similar policy and suggested practices for their own missions, but outside of NASA, the U.S. Government does not explicitly require adherence to either policy for private missions. In fact, Congress has previously considered legislation explicitly clarifying that COSPAR guidelines "may not be considered international obligations of the United States" (HR 8209).

NASA policy does affect what might typically be considered a private mission. NASA policy dictates that NASA may only participate in non-NASA missions if activities are performed consistent with the OST, and may provide

> hardware, services, data, funding, and other resources to non-NASA missions (including but not limited to resource 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 (NASA NPR 8020.12D Chapter 2.2).

Thus, the policy states that any missions that rely on NASA funding or even use its capabilities—such as its Deep Space Network—must follow planetary protection procedures as approved by NASA. For example, to develop plans for its mission to Enceladus, the Breakthrough Foundation signed a Space Act Agreement with NASA that included the requirement for Breakthrough to request mission categorization from NASA (NASA and Breakthrough 2018). However, NASA can maintain flexibility for private entities by waiving this requirement in contractual agreements.

For private missions not associated with NASA, it is not clear that they must follow procedures generally consistent with COSPAR. Currently, responsibility for making that determination would fall to DOT. It has some extending authority to authorize payloads or missions, such as it gave Moon Express for the MX-1E spacecraft in 2016, the SpaceX Tesla launch in 2018, or the Israeli Beresheet launch in 2019. This process worked through interagency consultation between the FAA, State, and the EOP, resulting in a determination that "the launch of the payload does not jeopardize public health and safety, safety of property, U.S. national security or foreign policy interests, or international obligations of the United States" (FAA 2016). DOT is obligated to consult with the Department of Defense for matters affecting national security and with State for matters affecting national policy. It shall consult with other agencies: (1) to provide consistent application of licensing requirements, (2) to ensure fair treatment of all license applications, and (3) when appropriate (51 U.S.C. § 50918).

This is a process that interviewees expected future missions with planetary protection implications to follow. DOT receives an application for a launch, including information on the payload (i.e., the mission). DOT can then consult with State to ensure compliance with foreign policy considerations, as well as potentially consulting with NASA for technical expertise on planetary protection.[84] This was generally the process followed with the review for the February 2018 SpaceX launch of a Tesla roadster, although NASA expressed concern regarding a lack of access to technical details for analysis of planetary protection compliance and to assess impact risk of the roadster to existing Federal scientific assets. SpaceX stated that consistent with the launch license application, the Tesla roadster would not be encountering any celestial body as a flyby, lander, or orbiter—specific terms to both COSPAR and NASA policies. If there was no encounter with a celestial body, they argued that there could be no planetary protection categorization. NASA assessed probability of impact risk to existing Federal scientific assets and conducted trajectory analyses prior to providing a final opinion to DOT. NASA did not confirm that the roadster would not encounter a celestial body. NASA did state for the record that SpaceX showed some basic consistency with international guidelines (NRC 2018).

It is not clear how planetary protection will be regulated in the future, especially if it involves a mission with more serious planetary protection implications, such as SpaceX's aspirations to send humans to Mars in 2024 (SpaceX 2019). Should DOT decide to not issue a launch license for a commercial mission because of planetary protection, complications arise because of DOT's other mandates to encourage, facilitate, and promote private activities and economic growth (51 U.S.C. § 50901). Which mandate should DOT prioritize? This question cannot be answered by understanding current authorities and obligations, but will require making new decisions. These decisions will include not only how to regulate private activities, but also what aspects of those activities will require regulation.

C. Deciding How to Treat Private Entities

There is limited direction for how the U.S. Government should regulate private entities regarding planetary protection, and the obligations that do apply are uncertain and often even contentious. Given this uncertainty, the Federal Government must currently not only decide how to implement authority over private entities but also what that authority should be. This requires a balancing of multiple national interests.

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[84] Some interviewees argued that this is not a clear application of DOT's obligation to consult with other agencies as listed in 51 U.S.C. § 50918

1. Backward Contamination

Avoiding backward contamination is the clearer regulatory case, given the importance of protecting U.S. citizens and their environment. It seems reasonable that private entities should be held to the same standard as the government, and be forced to prove that they are taking the appropriate amount of caution. No private entities interviewed for this report argued against this assumption.[85]

DOT has clear authority when it comes to protecting against backward contamination. Any U.S. person reentering a reentry vehicle or any person reentering a reentry vehicle in the United States must procure a license from DOT (51 U.S.C. §50904). DOT will issue a "favorable payload reentry determination unless it determines that reentry of the proposed payload would adversely affect U.S. national security or foreign policy interests, would jeopardize public health and safety or the safety of property, or would not be consistent with international obligations of the United States" (14 CFR §431.59). Such a hazard of harm from extraterrestrial materials would fall under such a threat, and current regulations require entities requesting a payload reentry license to provide the "type, amount, and container of hazardous materials" (14 CFR §431.57). That does not mean that planetary protection would explicitly be considered, but it does give DOT authority to prohibit reentry based on a threat arising from biological contamination or international obligations derived from the OST.

While DOT would have to review any reentry mission, whether it has the expertise to execute that review effectively is uncertain. It would likely have to rely on ad hoc interagency expertise. One challenge is that the national approval process, PD/NSC-25, which has authority over NASA return missions from restricted bodies, currently does not include or direct DOT over private missions. The EOP may be limited in what influence it has over DOT,[86] but it could ensure that DOT is prepared to review any such mission and consults with the proper agencies and entities.

2. Forward Contamination

Deciding how to avoid forward contamination is the more complex case, both normatively and practically. Private entities offer advantages to space commerce, international leadership, and enabling science and human missions. Planetary protection could inhibit these activities, but the United States does have an obligation to abide by the

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[85] It is likely that a number of private companies will want to minimize the costs of avoiding backward contamination to the extent possible, especially given how expensive it might be.

[86] The Constitution delegates authority over commerce to Congress, not the President. Without legislative action, the options for implementation through Presidential action are limited by the Constitution. Typically, the President may not grant himself approval authority over a commercial activity, although the President may be able to require the above steps under his national security authority as Commander-in-Chief.

OST (both Articles IX and VI), along with an interest in protecting equities on other celestial bodies, protecting science, and concern over diplomatic ramifications. Deciding how to regulate private entities requires balancing these equities and obligations.

Beyond keeping with international obligations, deciding how to regulate private entities may reduce to a question of cost-benefit. The U.S. Government is required to consider benefits and costs, both quantitative and qualitative when considering regulation (EO 13563), and it is the position of the current administration to streamline regulations for the non-governmental use of space (EOP 2018). Following the analysis in this report, planetary protection policy and guidelines may not effectively balance benefit and cost, especially when including the potential benefits of private activities.

The extent to which, then, private entities must follow planetary protection relies on (1) the interpretation of Treaty obligations under the OST, and (2) the extent to which the regulations would meet regulatory goals while promoting economic growth. Neither of these questions can be answered within the confines of this project.

Once these questions are addressed, the next consideration is the practical question of how to regulate private activities. DOT may be legislatively limited in its ability to address forward contamination. The root of its authority is provided in 49 U.S.C. §70104, "the Secretary may *prevent* the launch if the Secretary decides the launch would jeopardize the public health and safety, safety of property, or national security or foreign policy interest of the United States" (emphasis added).[87] Similarly, 51 U.S.C. §50909 gives the Secretary of Transportation the ability to "prohibit, suspend, or end immediately the launch of a launch vehicle or the operation of a launch site or reentry site, or reentry of a reentry vehicle" for the same reasons. Following the OST would likely be considered a foreign policy interest of the United States. Thus, under this statute, the Secretary has the ability to decide whether the launch would jeopardize the obligation to avoid harmful contamination.[88] However, this legal authority extends only the Secretary's ability to prevent launch, and leaves unclear the authority that the secretary has for review activities. If planetary protection, or a portion of it, is considered beyond the obligation in Article IX (as some have argued in interviews for this report), DOT may not have the legislative authority to deny issuance of a launch license. Furthermore, DOT has jurisdictional restrictions to its authority; namely, it cannot influence a U.S. person placing a payload on

[87] This is echoed in the regulations. For example, 14 CFR 415.1 states: "If not otherwise exempt, the FAA reviews a payload proposed for launch to determine whether its launch would jeopardize public health and safety, safety of property, U.S. national security of foreign policy interests, or international obligations of the United States."

[88] Note that a legal view mentioned earlier would argue that DOT does not have the authority to restrict access to space based on Article IX or any other non-self-executing treaties without legislation passed by Congress (Montgomery 2018).

a foreign rocket, such as the Living Interplanetary Flight experiment on the Russian Phobos Grunt mission (Minkel 2009).

Like DOT, the FCC also plays a role in the licensing of space missions. The FCC issues licenses for spectrum use and communication between spacecraft and the Earth. Recently, however, the Commission has used its authority to make licensing decisions for reasons beyond this. The FCC Charter states that the FCC must determine if new technologies or services are "in the public interest" (47 U.S.C. §151). This mandate affected a private space entity for the first time when, in 2018, the FCC fined Swarm Technologies $900,000 for launching and communicating with unlicensed picosatellites (Henry 2018). The FCC had rejected Swarm Technologies' initial license application because their satellites were too small to be reliably tracked in orbit, and therefore could not "conclude that a grant of this application is in the public interest" (Koren 2018). Swarm Technologies decided to launch their satellites without the license, and thus faced punitive action from the Federal Government. The FCC's decision to fine them was unprecedented, but shows the influence that the Commission can have on a private space entity. It is possible, therefore, that the FCC could similarly reject the license of a spacecraft on the grounds that its planetary protection measures (or lack thereof) are also not in the public interest.

D. Summary of Considerations for Private Entities

At present, the private and planetary protection communities may seem to be at odds with each other. Private sector missions operate on tight budgets and timelines, and see planetary protection requirements as a deterrent to their ambitious goals. More fundamentally, they disagree with planetary protection policy, both from philosophical and legal perspectives. A majority of the planetary protection community see private entities as a contamination risk without experience in the sector.

This inherent disconnect is worsened by a lack of communication, both historically and currently. Private entities have neither been organized to provide a clear voice to planetary protection policy, nor are the current forums of planetary protection fit for a non-scientific voice. Likewise, private entities may not fully appreciate how planetary protection policies, if properly applied, could assist them.[89]

The U.S. Government has two outstanding decisions to make regarding planetary protection and private activities. The first is what policy, approach, and implementation

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[89] As an example, not contaminating a future Mars greenhouse with introduced microbes might be an essential requirement to protect a Mars life support system and food supply, while a previous planetary protection clearance of a tourist landing site on Mars might be important for allowing a "sick passenger" tourist (and all other passengers) to return to Earth, rather than to an expensive off-Earth quarantine facility. It should be noted, however, that the first of these examples is not captured within the current scientific-focused planetary protection goals.

approaches to require of private activities. The second is equally important: how to regulate these activities; there may not be an easily available mechanism.

Regardless of the decisions with regard to the previous two questions, all parties need clearer expectations and communication. Both private entities and planetary protection offices should know clearly what to expect with private missions with respect to planetary protection.

6. Findings and Challenges, and Options for Change

Chapters 3–5 reviewed each of three areas—forward contamination, backward contamination, and private sector participation—and identified several systemic challenges. In this chapter, we summarize the cross-cutting and conceptual challenges as related to planetary protection, and then propose policy alternatives to address these challenges. We close the chapter with potential paths forward for OSTP.

A. Summary of Findings and Challenges

1. Stringency of Forward Planetary Protection

Stakeholders disagree regarding the effectiveness with which planetary protection both protects and enables present and future science, as well as if that goal warrants such protection at all. On a fundamental level, they disagree on the extent to which the benefits justify the costs.

Most scientists and planetary protection experts argue that the goals of planetary protection are valid, but the approach and/or implementation procedures could be improved. One subgroup contends that the approach is well founded, but the implementation procedures are outdated (e.g., cleaning and assaying methods) and need to be cheaper and more efficient. Another subgroup argues that the approach itself is flawed, including that more care needs to be taken to identify which missions require implementation procedures, that the approach should set clear goals for implementation procedures, and that the community should consider other approaches to forwarding science (such as disambiguating terrestrial organisms). Both groups believe that current planetary protection policy and practice is overly burdensome, but the second believes that this challenge is inherent in the policy while the first argues that the stringency can be addressed predominantly through modernizing the implementation procedures.

Another group (consisting of both scientists and private entities) argues that the challenge is not simply in the approach or implementation of planetary protection policy but rather that the goals do not apply, or are not sufficiently compelling. In their view, the policy exceeds the OST's mandate of "avoiding harmful contamination," and that nearly any policy to reduce an already small risk of harming future science is overly burdensome. Some interviewees suggested that current practice of actively mitigating forward contamination be abandoned entirely.

On the other side, not all stakeholders believe that planetary protection is overly stringent. While implementation procedures could always be improved, they should not be changed without assurance of equal or greater mitigation of contamination. At least one interviewee stated that planetary protection, especially as currently implemented at NASA, does not sufficiently protect science. This is coupled with concern that any changes would further put future science at risk and therefore should be avoided.

2. Types of Harm Considered

There is disagreement in the community regarding what should be considered in the goals of planetary protection. Currently, the goals solely focus on protecting future scientific investigations and harm to Earth's biosphere from extraterrestrial organisms on return spacecraft, not any other types or vectors of harm.

Some stakeholders maintain that COSPAR has assumed an appropriately narrow interpretation of Article IX of the OST, and that planetary protection should continue to solely focus on organics and biological contamination that could harm future scientific research. Others suggested that the goals of planetary protection policy should be expanded to protect the celestial bodies themselves, for both environmental and ethical reasons.

A few stakeholders argue that current or planned activities specifically regarding Mars do not warrant any protection or avoidance of contamination, given the ability to reliably detect indigenous life using emerging technologies notwithstanding any contamination.

3. Preparedness for Sample Return

There are varying opinions among interviewees regarding potential efforts to prepare for sample returns from celestial bodies that may harbor life.

Some interviewees argue that no materials (including both samples originating on those bodies as well as humans or spacecraft sent on a roundtrip from Earth) should be returned from celestial bodies until it is demonstrated that (a) the likelihood of that body containing life is sufficiently low; or (b) we have greater certainty, perhaps through *in situ* experiments, that any life that would be brought back will not cause adverse changes to Earth.

Other stakeholders maintain that, while samples should be brought back, neither governments nor private actors are currently adequately prepared for a sample return mission; this includes a lack of comprehensive implementation procedures, sample containment capabilities, and clear approval processes.

4. Growing Participation by the Private Sector

Some stakeholders are concerned that private entities may cause harm to future science, that if private sector entities do not follow planetary protection goals, approach, or implementation procedures, there could be irrevocable harm to future science.

Some private entities are in philosophical disagreement with the goals of planetary protection, noting that in the interest of future science, planetary protection restricts the search for life today; one example is restricting human exploration, which effectively places science and humans at odds when private entities believe humans could forward science on the whole. They also contend that implementing the policy—unnecessary to begin with—would be cost prohibitive. They do not believe that the NASA policy either does or should apply to them. They argue that the phrase "avoiding harmful contamination" has not been appropriately interpreted. Lastly, private entities are uncertain regarding the steps they should take to comply with the OST, and how these efforts might affect the financial viability of their future endeavors.

It is unclear whether DOT's authority over launch approval includes, or should include, the ability to specifically require that private entities follow COSPAR or NASA planetary protection policy for all future in-space activities. There is lack of clarity as to how the U.S. Government's Article VI and IX obligations will be met or addressed with respect to ongoing, in-space private sector activities involving other celestial bodies. It is specifically unclear (1) which agency would authorize and continually supervise missions with planetary protection implications, following initial launch licensing; (2) what guidelines and policies private entities will be required to follow; and (3) how the application review process will proceed. These challenges are complicated by the potential for the creation of new authorities governing in-space activities and current disagreement over (1) whether such authorities should be established, and (2) the resulting implementation details, including who would maintain these authorities.

5. Stakeholder Engagement

As the number of stakeholders with interest in other interplanetary exploration and sample return increases (to include both non-U.S. and non-governmental entities), interviewees expressed concern that COSPAR's planetary protection policy and updating process lacks transparency and does not include adequate decision-making authority by scientists from other disciplines, technologists, biosafety and biosecurity experts, and private sector entities. They do not believe that simply increasing access to and participation in COSPAR and NASA forums would adequately address their equities, and would like a seat at the decision-making table.

B. Principal Policy Levers and Options to Address Each Challenge

There are several different ways to address these challenges, ranging from updates to NASA policy to legislative action. Agency-level actions can affect the policies and regulations of agencies relevant to planetary protection (e.g., NASA) and regulatory agencies (e.g., DOT, DOC).[90] Because of voluntary compliance with COSPAR and a lack of legislation specifically on planetary protection, agencies currently have the freedom to change planetary protection policy and requirements; however, they may shy away from more extreme changes without EOP or congressional direction. The EOP's authority and influence over planetary protection is currently implemented through the review and approval requirements laid out in PD/NSC-25. While PD/NSC-25 solely related to backward contamination, the EOP's influence and direction can extend to all aspects of planetary protection. The EOP can effectively engage all stakeholders, including the private sector, and account for multiple national priorities. It also can provide executive-level political support or accelerate activity, although agencies may resist such actions. Lastly, Congress can pass legislation directing the Federal Government and the private sector to follow certain planetary protection policies or requirements. Legislation can also provide a more permanent policy change. However, legislative action may take a long time.

This section provides options for addressing each of the challenges reviewed in Section A of this chapter. Since the government always has the option of doing nothing, ways to retain status quo are not explicitly discussed.

1. Addressing Challenge 1: Stringency of Forward Planetary Protection

There are three potential actions the government can take to address this challenge. First, the government could leave planetary protection goals and approach as is, but improve its implementation procedures to take advantage of progress in biology, engineering, and planetary science. An advantage of this approach is that it would continue to protect celestial bodies while leveraging previous experience and up-to-date practices. The disadvantages are that this option may be limited, failing to address issues in the underlying goals or approach; if the policy aims at protecting the wrong things or the approach triggers implementation procedures incorrectly, implementation procedures, no matter how effective, will be aimed at the wrong things and thus ineffective. Additionally, implementing new procedures (e.g., proving new technology) may take time, especially given the historical lack of updates in this area. Lastly, the approach would likely not satisfy stakeholders who believe the issue is more rooted in the applicable policy, rather than in the current implementation procedures.

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[90] NASA policy on planetary protection affects NASA missions and other missions that must follow NASA policy due to Space Act Agreements (SAA) or other use agreements. DOT or DOC policies (or regulations) affect entities receiving a license for launch or reentry.

Second, the government could change the approach and implementation of planetary protection (e.g., by protecting science through tracking contamination or eliminating planetary protection requirements when the probability of contamination is deemed sufficiently low). An advantage of this approach is that it would facilitate easier science and exploration of some celestial bodies while maintaining the fundamental goals. The disadvantage is that its effect may be limited to only a subset of missions (e.g., certain missions to Mars), while potentially taking less caution. The approach would also be less than satisfactory to those who believe the issue is more fundamental (i.e., in the goals).

Finally, the government could move away from the current goals (and thus approach and implementation procedures) of current planetary protection policy, and directly interpret the clauses of harmful contamination and interference in Article IX of the OST. The advantage of proceeding with this option is that it would reset the policy "baseline," allowing the United States (and its international partners) to directly determine obligations under the OST; the blank slate approach could also better account for the views of new actors and types of missions. The disadvantages are that (1) novel legal work would be required to create and defend a definition of harmful contamination; (2) it may expand the types of contamination to be avoided, adding cost to space activities; this would be counterproductive to starting the process; and (3) it would likely adversely affect international relations and cooperation for space missions.[91] The global implications of the United States withdrawing from the use of COSPAR policy are unknowable (for example, other countries could also withdraw from it, which may be more detrimental to all interests).

2. Addressing Challenge 2: Types of Harm

To address this challenge, the government could engage in appropriate consultations with stakeholders, and expand the goals of planetary protection policy to go beyond protecting scientific integrity; this could include a number of further protections up to the full preservation of celestial bodies. An advantage of this action is that it may offer a more comprehensive interpretation of OST obligations, and would consider and work to avoid more threats to celestial bodies. A disadvantage is that the effort would require substantial policy change, which would likely add cost and may further limit space activities.[92] Few entities in power are likely to support this action.

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[91] For example, it could restrict the ease of working with international partners in space (e.g., ESA and JAXA) and give other nations precedent to ignore planetary protection.

[92] Some current mission categories (e.g., infrequent robotic missions) might not pose large risks of non-biological harm to celestial bodies; therefore, extensive work to address other types of harm, which may not be huge threats (given the frequency and types of these missions), offer limited benefit.

3. Addressing Challenge 3: Preparedness for Sample Return

First, the government could prohibit missions currently classified as restricted Earth-return until the acceptable risk of backward contamination is established.[93] An advantage of this approach is that it would ensure extreme precaution regarding adverse change to Earth. It may also lead to increased emphasis on and innovation related to *in situ* research and life detection. A disadvantage of this decision is that it could delay high-profile missions (MSR and humans to Mars), resulting in political ramifications and presumed loss of science.

Second, the government could allow restricted Earth missions to continue but increase investment and effort to ensure that entities conducting these missions have established safe and effective return processes including detailed protocols, containment facilities, interagency and interdisciplinary consultation, and clear approval processes.[94] An advantage of this action is that mission planning can continue, and protocol design efforts can build on previous international work to protect against backward contamination. A disadvantage is that these efforts would likely be cost-intensive, and assume that there are protocols, processes, and technologies that would sufficiently ensure the prevention of extraterrestrial contamination.

4. Addressing Challenge 4: Private Sector Involvement

Addressing private sector missions requires two levels of action. The first is related to determining what planetary protection requirements private entities should follow. For this level of action, there are three alternatives.

First, the government could require private entities to follow the same planetary protection goals, approach, and implementation requirements as those followed by NASA missions.[95] An advantage of this action is that it aligns the requirements for public and private efforts, assigning the same amount of contamination risk to both sectors. The disadvantage is that some private actors claim that NASA implementation procedures would be cost-prohibitive to their activities, which would add cost to some private activities, potentially prohibiting private plans or encouraging efforts to cut corners on implementation efforts.

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[93] Action to delay restricted Earth-return missions would likely need to take place at the Presidential or congressional level. The government could attempt to establish acceptable risk through an interagency committee or by sponsoring more life detection research on the target celestial body.

[94] Action to develop implementation procedures would likely need to take place at the agency level (in conjunction with international partners), but could be directed by Congress or the President.

[95] This approach has extreme interdependencies with how Challenges 1–3 are addressed. If private missions are subject to the same policies as government missions, any changes to the government framework are relevant.

Alternatively, the government could require private entities to follow the same planetary protection goals as those followed by NASA missions, but not the same approach and/or implementation procedures. An advantage this option is that it aligns the policy for public and private efforts, assigning the same amount of contamination risk to both sectors. It also allows the private sector to interpret the expected outcomes based on a performance-based method but develop tailored and innovative methods and implementation procedures. A disadvantage is that some private actors claim that the planetary protection goals (i.e., protecting science) should not be imposed upon private (especially non-science-based) entities, and that following the goals could still lead to prohibitive requirements; furthermore, regulatory agencies may not have the expertise to determine adherence to novel implementation procedures.

Lastly, the government could require private entities to follow a different planetary protection framework than that followed by NASA missions—e.g., by establishing new goals through direct interpretation of the language (such as *harmful contamination* in Article IX) of the OST. An advantage of this pathway is that it would remove implicit bias against and allow more neutral consideration of private equities, while still meeting Treaty obligations and avoiding contamination. A disadvantage is that it could raise concerns that any divergence from the established framework increases the risk of contamination, and would implicitly hold the government to a higher standard than non-government actors. This may face opposition from proponents of the current planetary protection framework, along with other nations.

The second level of action is to clarify how private entities will be regulated. Here also, there are three possible actions.

First, relevant agencies (e.g., DOT, State, or DOC) could clarify, through rulemaking for instance, how they will regulate planetary protection. An advantage of this approach is that it would address the challenge at the lowest level possible. A disadvantage is that agencies may not be able to do so without better direction or guidance from the EOP or Congress, and that rulemaking can be a lengthy process.

Second, the government (e.g., the EOP) could provide guidance or policy on how to implement planetary protection for private missions. An advantage of this approach is that it provides guidance to regulatory agencies, and could facilitate the interagency consultation process. A disadvantage is that some Presidential action is limited by both the current legislative authority given to agencies and its lack of Constitutional authority over interstate commerce.

Lastly, Congress could pass legislation clarifying the regulatory regime for planetary protection (e.g., by providing an agency with clear in-space authority). An advantage of this action is that this could streamline regulatory processes, provide clear authority on how to regulate planetary protection, and provide specific direction to entities while still meeting Treaty obligations. A disadvantage is that congressional action may be time-consuming and difficult to initiate, especially since such a mandate would require funding.

5. Addressing Challenge 5: Stakeholder Engagement

First, NASA and COSPAR could change the nature of their association to include those outside of astrobiology equities.[96] These would include private sector entities that intend to conduct both scientific and commercial activities on other celestial bodies. An advantage of this change would be that it encourages broader participation without interrupting the conventional roles in planetary protection. A disadvantage is that despite efforts, NASA or COSPAR may not be able to engage a sufficiently broad range of stakeholders independently, because by virtue of their charter they cannot adequately incorporate nonscientific equities.

Alternatively, the government (e.g., the EOP) could create a new forum (such as a National Science and Technology Committee (NSTC) subcommittee or an interagency working group) to discuss planetary protection policy for the United States.[97] Advantages of this approach are that the new forum could (1) provide a neutral (i.e., not exclusively science-focused) starting point to develop or update policy and take equities other than science under better consideration; (2) provide a whole-of-government approach that ensures that non-NASA equities are evenly represented; and (3) raise the profile of planetary protection outside NASA, potentially encouraging improved participation. The disadvantages are that the new forum (1) would require EOP effort; (2) may not be necessary to address engagement challenges if NASA and COSPAR can effectively integrate non-scientific entities; and (3) could face resistance from NASA and COSPAR for encroaching upon their traditional roles.

6. Policy Levers for Addressing Challenges

Table 9 specifies which government entity can fully address all components of each challenge. As the tables show, depending on the specific action, policy levers are available at the Agency, EOP, and congressional levels. Which lever is used depends on actions that are determined to be the right steps. It is worth noting that there are many commonalities between EOP and congressional action, with the difference that congressional action may take longer (but on the other hand, provide more stability). In some cases, EOP action is not feasible without congressional concurrence.

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[96] NASA and COSPAR are already attempting to interface with a wider set of stakeholders. For example, NASA has established an independent Planetary Protection Review Board to review established guidelines for planetary protection and recommend any updates that are required. The committee includes members from the private sector (NASA 2019c).

[97] This could also be an international forum outside of the United States, but we are not fully exploring that alternative within the scope of this initial study.

Table 9. Mapping Challenges to Policy Levers that Can Fully Address Them

	Challenge 1: Stringency of Forward PP	Challenge 2: Types of Harm Considered	Challenge 3: Preparedness for Sample Return	Challenge 4A: Lack of Clarity for the Private Sector	Challenge 4B: Regulatory Framework	Challenge 5: Stakeholder Engagement
NASA Policy	X					X
Regulatory Agency					X	
EOP Action	X	X	X	X	X	X
Congressional Action	X	X	X	X	X	X

There are several different ways to implement the action steps identified above. Each lever has its pros and cons, and multiple levers can be used to address a challenge to varying degrees. One consideration in examining implementation options is that the lowest-level lever should be applied to address challenges: e.g., there is no need for congressional action if an objective can be achieved with guidance from the NASA PPO. These challenges may be addressed by a variety of the policy levers outlined at the beginning of the last section, including potential EOP action. Some of the challenges can be addressed simply by providing the PPO more authority and funding. For example, integration of new science and technology in both bioburden reduction and life detection can be accelerated through research that the Office should fund. With more funding and/or authority, the PPO could also do a better job of tracking the cost of planetary protection for both flagship and smaller missions; this will help the private sector better account for planetary protection in their missions. Other challenges are fundamental and may require more than an allocation of funding and authority to a NASA office.

C. EOP Options

A fundamental objective of this report is to provide policy options to OSTP in reviewing and updating, as necessary, national planetary protection policies. The EOP has the authority to affect change on each of the challenges facing U.S. planetary protection policy. Executive action may not be needed to address each of these challenges, nor may it be the best mechanism to implement each option.

Considering all of the policy options mentioned previously provides a range of options to changing U.S. policy and practice for planetary protection. These options range in terms of the effort they would require and the impact they would have on planetary protection. Figure 10 reviews all of the options for EOP action (direct or indirect) along an effort-impact matrix.

Challenges

1. Stringency of forward planetary protection
2. Types of harm considered
3. Preparedness for sample return
4a. Lack of clarity of rules for the private sector
4b. Regulatory framework for the private sector
5. Stakeholder engagement

Impact \ Effort	Low	Medium	High
Unknown			1. Re-interpret the goals of planetary protection, e.g., directly interpret the clauses of harmful contamination and interference in Article IX of the OST 2. Expand the goals of planetary protection policy (e.g., by defining harmful contamination) to go beyond protecting scientific integrity; this could include a number of further protections up to the full preservation of celestial bodies 4a. Require private entities to follow a different planetary protection goals (i.e., framework) than that followed by NASA missions—e.g., direct interpretation of Article IX
High			3. Prohibit missions currently classified as “restricted Earth-return” until the acceptable risk of backward contamination is established 4b. Clarify the regulatory regime for planetary protection through EOP guidance (e.g., Presidential Directive)
Medium	1. Leave planetary protection goals and approach as is, but improve implementation to take advantage of progress in biology, engineering, and planetary science	1. Leave planetary protection goals as is, but improve approach and implementation 4a. Require private entities to follow the same planetary protection goals but not the same approach or implementation procedures 4b. Clarify through rulemaking how a regulatory agency would regulate planetary protection 5. Create a new forum (e.g., a National Science and Technology Council (NSTC) subcommittee) to formulate/update planetary protection policy for the United States	3. Allow restricted Earth missions to continue but increase investment and effort to ensure that entities conducting these missions have established safe and effective return processes
Low		4a. Require private entities to follow the same planetary protection goals, approach, and implementation requirements as those followed by NASA missions 5. Change the nature of NASA/COSPAR engagement with stakeholders to include those outside of astrobiology/science equities	

Figure 10. Effort-Impact Matrix for Options to Address Planetary Protection Challenges

One way to consider OSTP action is in terms of levels of engagement with planetary protection. OSTP can expend more effort, direct more change, and play a larger role in planetary protection with increasing levels. The reader can picture this as concentric circles, as in Figure 11, with each expanding circle requiring both greater engagement and greater impact.

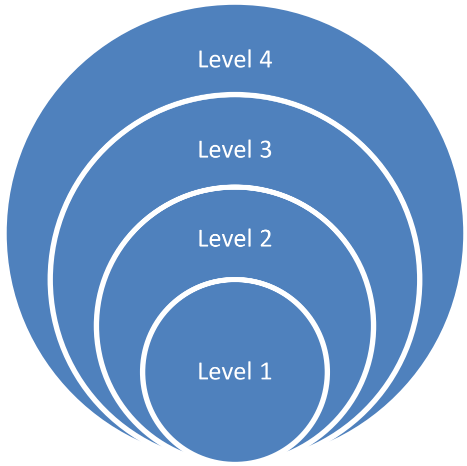

Figure 11. Levels of OSTP Engagement, Effort, and Impact

There are several alternatives for the EOP—in particular, OSTP—to consider:

- Level 0: Take no specific action; leave challenges to be addressed at the agency level
- Level 1: Ensure preparedness for restricted Earth-return missions, such as by updating approval processes (challenge 3)
- Level 2: Level 1 + Clarify how or if private entities will need to comply with planetary protection (challenge 4)
- Level 3: Level 2 + Direct NASA to address challenges related to forward contamination and include a greater range of stakeholders (challenges 1 and 5)
- Level 4: Level 3 + Set national planetary protection policy differentiated from COSPAR, starting from OST obligations with input from a broad set of stakeholders (challenges 1, 2, 3, 4, and 5)

OSTP can expend more effort, direct more change, and play a larger role in planetary protection with increasing levels. While Level 1 may be easiest for OSTP to address, since it is directly relevant to PD/NSC-25, it also has the lowest relative impact. As EOP engagement increases, so does its ability to address challenges.

To implement any selected actions, the EOP could create and lead a working group, co-chaired by OSTP or/and the National Space Council, to address the pros and cons of each action and determine next steps. Another option might be to create a working group or subcommittee under the aegis of the NSTC and make the same decisions. Once the major action steps are finalized (for example, whether planetary protection policy will be updated by revising today's interpretation of harmful contamination), appropriate policy levers can be used to institutionalize them. To identify appropriate action, it would be useful to bring together the widest possible community in a neutral domain.

To some observers, planetary protection may seem to be a topic for the distant future. However, a confluence of factors suggests that focused U.S. policy leadership is called for now. Ambitious interplanetary space missions are moving toward reality. Advances in diverse technical disciplines are proceeding rapidly, including space technology, biological understanding, and planetary protection techniques. Recent experiences with COVID-19 illustrate the potential danger posed by backward contamination. Finally, new governmental and private sector actors are fast emerging within the planetary space community. Addressing the issue of planetary protection policy now will help ensure the United States will continue to lead in the future.

Appendix A.
Interviewee List by Affiliation

Type	Organization	Interviewee Name
Government Agency	DOT	John Sloan
	DOT	Nathaniel Tabelon
	NASA	James Green
	NASA	Catherine (Cassie) Conley
	NASA	Betsy Pugel
	NASA	Lisa Pratt
	NASA	Brandon Eden
	NASA	Margaret Kiefer
	NASA	Frank Groen
	NASA	Erin Lalime
	State	Gabriel Swiney
Academic, FFRDC, Laboratory	Johns Hopkins University Applied Physics Laboratory (APL)	Mihaela Ballarotto
	APL	Morgan Steadham
	APL	Caitlin Shearer
	Georgetown University	David Koplow
	COSPAR	Lennard (Len) Fisk
	Harvard University	George Church
	Harvard University	Gary Ruvkun
	Indiana University	David Fidler
	Johns Hopkins Center for Health Security	Thomas Inglesby
	Johns Hopkins Center for Health Security	Gigi Gronvall
	JPL	Andrew Klesh
	JPL	Barry Goldstein
	JPL	Brian Clement
	JPL	Earl Maize
	JPL	Linda Spilker
	JPL	John Mcnamee
	JPL	Matthew Wallace
	JPL	Fuk Li
	JPL	Moo Stricker
	JPL	James (Nick) Benardini

Type	Organization	Interviewee Name
	National Academies	David Smith
	National Academies	Mia Brown
	Princeton University	Christopher Chyba
	SETI	John Rummel
	SETI/Technical Administrative Services	Amy Baker
	University of Colorado Boulder	Nicolas Ferrington
Industry or NGO	Astrobotic	Dan Hendrickson
	Blue Origin	Erika Wagner
	Boldly Go	Jon Morse
	Breakthrough Prize	Pete Wordon
	Gryphon Scientific	Rocco Casagrande
	Lockheed Martin Space	Joe Witte
	Mars Society	Robert Zubrin
	MAXAR	Michael (Mike) Gold
	Moon Express	Ben Roberts
	SpaceX	Caryn Scenewerk
	SpaceX	Paul Wooster
	SpaceX	Margarita Marinova
	XPlore	Jeff Rich
	XPlore	Lisa Rich
	XPlore	Allie Hannigan
	XPlore	Adam Schilffarth
Consultant	Alexander Space Policy Consultants	Joseph Alexander
	PolySpace	Jim Muncy
	Unaffiliated	Sagi Kfir
	Formerly NASA	Pericles (Perry) Stabekis
International	ESA	Gerhard Kminek
	ESA	Sanjay Vijendran
	COSPAR Planetary Protection Panel	Athena Coustenis
	JAXA	Hajime Yano
	JAXA	Kazuhisa Fujita
	Russian Space Research Institute	Mikhail Gerasimov
	UNCOPUOS	Niklas Hedman

Appendix B.
Origins of Planetary Protection

The origins of planetary protection are resident in two seminal international agreements/organizations. The first is the 1967 Outer Space Treaty, which provides the international legal foundation for current planetary protection requirements, policies, and practices. The second is the Committee on Space Research (COSPAR), an international organization established in 1958 to facilitate international collaboration on space science, which, at the urging of concerned biologists, developed international, non-governmental forward contamination guidelines to protect the integrity of space science experiments. Today COSPAR is the de facto international authority on planetary protection.

Other organizations have also played critical roles in developing international planetary protection standards; one in particular is the U.S. National Academy of Sciences that was instrumental in urging COSPAR to develop planetary protection guidelines in the mid-1950s. Table B-1 lists some major milestones in the development of planetary protection policy.

Table B-1. Select Historical Milestones in Planetary Protection (1957–1984)

Year	Event
1957	U.S. National Academy of Sciences requests that the International Council of Scientific Unions (ICSU) assist in the development of a policy to avoid contamination
1958	United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), Committee on Space Research (COSPAR), and National Aeronautics and Space Administration (NASA) established
1961	The United States launches copper needles into LEO for Project West Ford, causing international calls for increased attention to "harmful interference"
1962	COSPAR joins UNCOPUOS as an observer organization
1964	COSPAR releases Resolution No. 26, first planetary protection recommendations
1967	Outer Space Treaty enters into force
1967	NASA establishes the Interagency Committee on Back Contamination (ICBC) and contracts Baylor University to write back contamination protocol, both for Apollo
1969	Apollo 11 astronauts and lunar samples return successfully to Earth
1975	Viking landers launched
1984	COSPAR revises planetary protection requirements based on mission-type categories

Concerns over planetary protection became prominent during the early Cold War era based on fears of space-based nuclear contamination (Mineiro, 2008). The concerns regarding physical contamination of space increased when the United States launched Project West Ford in 1961, during which U.S. researchers sought to create an artificial ionosphere by releasing hundreds of millions of copper needles into medium earth orbit (MEO) (NASA 2013). The activity prompted an outcry from radio astronomers, both domestically and internationally regarding “harmful contamination” of space (Reuters 1961). This also raised global awareness to avoid harmful contamination of the space environment and to undertake consultations with other nations when such activities are to be conducted.

It is unclear why and how the meaning of the threat of contamination for planetary protection shifted from a fear of *physical* interference, like copper needles and nuclear waste, to *biological* contamination, which is the major concern addressed in planetary protection policy today. One explanation is that an existing concern regarding biological contamination became a greater issue as U.S. missions successfully approached the Moon; indeed, research on the biological contamination of space began in the mid-1950s (Barengoltz et al. 1991) and appeared in *Science* and *Nature* as early as 1958 and 1959, respectively (Lederberg and Cowie 1958; Cleator 1959). These concerns were also spearheaded within the scientific community and at NASA by scientists such as Noble laureate Joshua Lederberg and Carl Sagan (Meltzer 2011). Historical documents reveal that their concern was always the integrity of scientific investigations—ensuring current and future samples are not contaminated with microbes carried on the instruments from Earth.

Whatever the reason, planetary protection has evolved to focus almost exclusively on forms of biological contamination—and with respect to forward contamination, it was not necessarily aimed at avoiding contamination of the celestial body for its own sake, but doing so to preserve the integrity of science (COSPAR 2017). Scoping the definition of planetary protection to focus exclusively on forms of biological contamination implicitly emphasized certain priorities, namely (1) the preservation of celestial bodies for science, specifically the search for extraterrestrial life; and (2) the protection of Earth from an existential threat.

By many accounts, backward and forward contamination protocols were shaped by the United States Apollo and Viking space programs, respectively. The Apollo missions were the first time humans ventured to a celestial body and returned with samples, raising concerns about the astronauts or the moon rocks possibly containing life forms that would harm Earth (Meltzer 2011). To advise the NASA Administrator on backward contamination policies during Apollo, NASA established the Interagency Committee on Back Contamination (ICBC), which included representatives from the Department of Agriculture, the Department of the Interior, the National Academy of Sciences, and the Centers for Disease Control and Prevention (CDC). Although NASA representatives made up the majority of the ICBC, the NASA Administrator was required to consult with all representatives and get unanimous agreement before making any changes to procedures regarding the return of lunar astronauts or samples (Bogart et al. 1967). To detail the technical procedures for backward contamination, NASA contracted scientists from Baylor University to write protocols for astronaut monitoring and return and the testing of lunar samples, which were released in 1967 (Baylor University College of Medicine 1967). Although NASA mission leaders breached the protocol during the Apollo 11 astronaut return (see Appendix C), the protocol was largely followed until NASA determined after Apollo 14 that the Moon posed no threat of backward contamination and relaxed the requirements for avoiding such contamination (Meltzer 2011).

Beginning in the mid-1960s, NASA pursued the Viking lander missions to Mars, which eventually launched in 1975. The planetary protection concerns for Viking focused on forward contamination of the Martian surface. As part of this effort, scientists calculated that microbial heat reduction (i.e., applying dry heat) would offer the best method for sterilizing spacecraft that might interact with other planetary bodies (Meltzer 2011). After Viking, NASA researchers, recognizing the difficulty in both using a probabilistic approach and calculating the potential growth of microbes on Mars, proposed applying a categorization system to celestial bodies and mission types (Barengoltz et al. 1981). They also introduced bioburden requirements for Mars probes and landers based on Viking post-sanitation cleanliness levels (DeVincenzi, et al. 1983). This new approach led to new techniques, both in analysis and laboratory procedures, to demonstrate compliance with the bioburden levels (Barengoltz and Stabekis 1983). The categorization process formed the basis for the international planetary protection guidelines used today.

These two historical examples highlight some key approaches toward planetary protection. First, in both the Apollo and Viking cases, NASA took the most risk-averse position regarding planetary protection. The agency assumed that both bodies were capable of harboring life, and thus took measures to prevent backward contamination during the Apollo return and forward contamination from the Viking landers. However, as understanding increased, NASA decided to rethink—and in some cases, relax—its planetary protection requirements.

Appendix C.
Key Planetary Protection Documents and Guidelines

The Outer Space Treaty (1967)

The Outer Space Treaty (OST) provides the international legal foundation for current planetary protection requirements, policies, and practices. The provisions of the OST most relevant to planetary protection are Article IX, which includes language on avoiding harmful contamination of celestial bodies and adverse changes in the Earth environment, and Article VI, which clarifies the responsibilities of States for their government and non-government actors. While Articles IX and VI are most directly relevant to planetary protection, some experts note that Article II (concerning national appropriation of celestial bodies) and Article VII (addressing damages caused by space objects) also have some applicability. These provisions are discussed in detail in the sections below.

As a ratified signatory to the Treaty, the United States has numerous obligations regarding its space activities, including several that relate to the general topic of planetary protection. However, as will be discussed below, that term is not specifically used in the Treaty.

Article IX

Article IX provides the foundational text for planetary protection, focusing on *harmful contamination* and *harmful interference* of outer space, as well as *adverse changes* to the Earth's environment. The second sentence of Article IX, which specifically calls out *harmful contamination*, forms the primary basis addressing the need and justification for forward planetary protection.

> States Parties to the Treaty shall pursue studies of outer space…*so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose* (italics added).

This sentence is significant because it was not included in the precursor document to the OST, General Assembly Resolution 1962 (XVIII), despite the fact that paragraph six of that General Assembly Resolution is otherwise almost an exact copy of Article IX. During the proceedings leading up to the Treaty the Canadian delegation raised the issue of planetary protection. They feared that without explicitly calling out harmful contamination, States would not be required to consult "in the event an experiment were being planned which might have the effect of influencing the Earth's environment" (UN General Assembly, 1963). References to adverse changes in the Earth's environment resulting from the introduction of extraterrestrial material were added to the OST, along with the mandate to avoid the harmful contamination of other celestial bodies.

The terms *harmful contamination* and *adverse changes* are not defined in the Treaty. According to experts, the language in Article IX, and the OST as a whole, were intentionally ambiguous, so as to allow flexibility in future interpretation (Cypser 1993). Several words and phrases in this article raise potential issues in the context of considering a comprehensive planetary protection policy (see Table C-1).

Table C-1. Ambiguous Terms in Article IX

Terms, in order of appearance in Article IX	Potential Issue
Pursue studies, conduct exploration	These two phrases limit the scope of this sentence, and, arguably, Article IX as a whole. They do not reference the "use" of outer space described in Article I.*
Avoid	The OST does not ban forward contamination; it just says that parties must avoid it. There is ambiguity as to what constitutes avoidance and what legal consequences arise from this term.
Harmful contamination	This definition is key to understanding planetary protection. There is no legal consensus on what constitutes harmful contamination, or the object of the harm. Planetary protection uses it to refer to biological contamination, but some consider this scope too limited.
Adverse changes	What constitutes an adverse change is not clarified, and the authority to determine that such a change has occurred is not specified. This also implies that changes to Earth's environment deemed not adverse are acceptable.
Environment of Earth	In different national planetary protection policies, some nations restrict planetary protection to their national boundaries.
Appropriate measures	It is not clear what constitutes appropriate measures, and the authority to determine what measures are appropriate is not specified.

* Article I of the OST states, "Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States."

Evolution of the Meaning of "Harmful Contamination"

The key to understanding the Treaty requirements for forward planetary protection hinges on the meaning of *harmful contamination*. Harmful contamination is ambiguous because it does not define the varying degrees of harm, whom is it harming, and what is considered contamination (e.g., physical, chemical, biological). No definition is given in the OST, and even when the Treaty was being drafted, there were debates about what type of contamination would be considered harmful under Article IX (Williams 1994). Combining the ordinary definitions of both *harmful* and *contamination* would lead one to define harmful contamination as "the introduction of elements that make outer space unfit for use or are likely to be injurious to users of outer space" (Mineiro 2008). At least one legal scholar has stated that harm must refer back, not to the celestial bodies, but to the interests of the States Parties to the Treaty (Cypser 1993). However, scholars have concluded that there is no consensus on the definition (Sterns and Tennen 2019; Gorove 1972; Roberts 1992).

Appropriate international consultations

The latter half of Article IX specifies that a State may undertake or request "appropriate international consultations" if its activities, or those of its nationals or another State, might harmfully interfere in the activities and use of outer space. Such consultations are undefined, have never been invoked, and pose potential challenges to enforcing planetary protection policy (interviews). It is possible that they could just refer to the use of normal diplomatic channels; however, the processes and procedures for Article IX consultations remain ambiguous.

It should be noted that *harmful interference* is different from *harmful contamination*, although both terms appear in Article IX. The use of the term *interference* predates the use of *contamination* in UN documents relating to space, as it was included in the 1963 precursor Declaration to the 1967 Treaty. While interference relates more to the Cold War concerns of nuclear or physical contaminants impeding space exploration, contamination connotes the introduction of unwanted elements to the space environment.

Article VI and Article VII

Article VI states that signatories to the Treaty "bear international responsibility for national activities in outer space…whether such activities are carried on by governmental agencies or by non-governmental entities." Furthermore, non-governmental activities require "authorization and continuing supervision by the appropriate State Party." This provision is now especially relevant as more private entities are pursuing activities in space.[98] Both private and government missions pose harmful contamination risks; thus, Article VI requires that State parties ensure their private entities avoid them.

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[98] At least one legal scholar has posited that neither Article VI nor Article IX should apply to private entities because the articles are not self-executing (i.e., they cannot be considered Federal law without legislation from Congress) and because Article IX is limited to "States Parties to the Treaty" (Montgomery 2018).

One major challenge is that most countries, including the United States, do not designate an entity specifically responsible for such authorization and continuing supervision. Current U.S. space regulation efforts focus on prelaunch governmental licensing by the Department of Transportation (DOT), which authorizes and licenses commercial launches; the Federal Communications Commission (FCC), which provides licenses for spectrum use; and the National Oceanic and Atmospheric Administration (NOAA), which licenses commercial remote sensing activities. Other than these three, there are no clear authorities for the U.S. Government to license other in-space activities. At best, in the process of executing its statutory authority to authorize and license commercial launches, DOT reviews the applicant's approach to planetary protection policies and practices, and attempts to ensure that the United States is meeting its Treaty obligations by working with NASA and the State Department.

However, there is no entity in the United States specifically authorized to provide "continuing supervision" after a private mission has launched. This has led to questions as to whether private U.S. space entities proposing missions (for example, on the surface of Mars or other celestial bodies capable of harboring life) will be provided continuing supervision as per the United States' international Treaty obligations related to Article VI.

Article VII also deals with the responsibilities of signatories to the Treaty. It says that each Treaty signatory that either procures a launch or launches from its territory "is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons" (UN 1967). Therefore, the United States has an added incentive for regulating the activities of private entities with regard to planetary protection, because it would be liable should a returning spacecraft cause any contamination or harm upon its return.

Article II

Article II contains language relevant to categorizing or restricting use of areas on other planets. Specifically, it prohibits "national appropriation [of celestial bodies] by claim of sovereignty, by means of use or occupation, or by any other means." This is particularly relevant for missions to Mars, where there have been attempts to demarcate special regions, defined as "a region within which terrestrial organisms are likely to replicate" (COSPAR 2017). Current COSPAR guidelines have strict requirements for spacecraft going to a Martian special region.

In the case of a potential human mission to Mars, some experts have suggested restricting human access to these special regions (Rummel et al. 2012a). However, one country cordoning off sections of Mars or imposing a limit on scientific exploration could be considered appropriation under the "by any other means" clause (NRC 2018). Such efforts to restrict contamination might be considered a potential violation of the Treaty if there is not agreement amongst all signatories that declaring a special region does not constitute appropriation by one country.

COSPAR

In 1958, the scientific community expressed its concerns over the lack of protections for scientific investigations:

> [W]e are in the awkward situation of being able to spoil certain possibilities for scientific investigations for a considerable interval before we can constructively realize them…we urgently need to give some thought to the conservative measures needed to protect future scientific objectives on the moon and the planets (Lederberg and Cowie 1958).

In February 1958, at the urging of concerned biologists, the U.S. National Academy of Sciences called on the ICSU to develop international, non-governmental forward contamination guidelines to protect the integrity of space science experiments. In response, the ICSU established the ad hoc Committee on Contamination by Extraterrestrial Exploration (CETEX). CETEX later decided that COSPAR would be a better forum to handle the planetary protection issue, and thus, COSPAR became the de facto international authority on planetary protection.

The International Council of Scientific Unions (ICSU) established the Committee on Space Research (COSPAR) in October 1958 to facilitate international collaboration on space sciences. The objective of COSPAR

> shall be to promote on an international level scientific research in space, with emphasis on the exchange of results, information and opinions, and to provide a forum, open to all scientists, for the discussion of problems that may affect scientific space research. This shall be achieved through the organization of scientific assemblies, publications or any other means (COSPAR 1998).

To establish planetary protection policy, COSPAR adopted Resolution 26 in 1964, which provided the first international standards for planetary protection based on a probabilistic approach. These guidelines instructed that “all practical steps should be taken to ensure that Mars be not biologically contaminated” (COSPAR 1964). Current COSPAR guidelines use the OST as a way to assert their authority. These guidelines reference Article IX, and are meant to “guide compliance with the wording of this UN Space Treaty,” but are solely focused on avoiding “organic-constituent and biological contamination in space exploration” (COSPAR 2017). However, unlike the OST, with which the United States must comply, COSPAR guidelines are simply guidelines, and not the “law of the land” (NRC 2018).

Overview of COSPAR Policy

The COSPAR guidelines rely on a framework of recommended practices to avoid the biological contamination of celestial bodies and Earth for the purpose of ensuring the integrity of scientific investigations related to the origin and distribution of life, not for any environmental or ethical reasons. COSPAR divides celestial bodies and mission types into categories, and recommends maximum limits on the amount of microbes on spacecraft that go to specific celestial bodies. There is a category for sample return as well.

In the 1960s, experts working off best guesses declared that the probability of contamination for a celestial body should be less than $1x10^{-3}$ per mission over the period of exploration[99] (Meltzer 2011). In other words, only one out of 1,000 missions should contaminate the body. In 1969, that probability was apportioned between the major spacefaring nations for Mars: 4.4E-4 for the United States, 4.4E-4 for the USSR, and 2.2E-4 for all others (Meltzer 2011). These target probabilities were defined prior to the Viking mission, based on an assumption of the rate of missions going to celestial bodies. This assumption is now considered to have been overestimated (interviews).

Today, COSPAR-recommended practices are divided into five categories, which are defined by mission type (sample return, landers, or orbiters) and target body characteristics (e.g., ability to harbor life, scientific interest). Each category has its own reporting and documentation requirements. The following graphs and tables illustrate the categories and details regarding the types of missions they cover and the associated requirements for mission operators.

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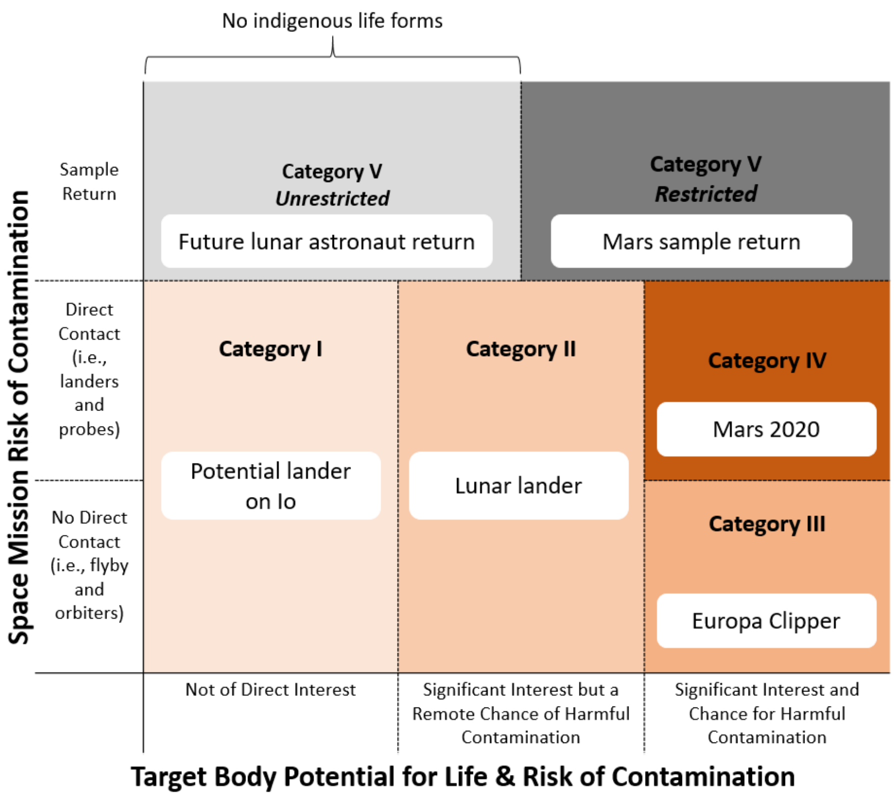
[99] The period of exploration begins when a Category III or IV mission arrives at its target celestial body, and lasts at least 50 years (COSPAR 2017).



Notes:

1. The risk of contamination is not necessarily a continuous variable, as we are considering the risk of contaminating other planets and Earth. The current policy prioritizes protecting the biosphere and (essentially) assigns Earth-return a higher relative risk value.
2. The placement within a particular category does not matter. The 2D space is not continuous but a category space. Two categories are plotted together to be placed to a category. This is a result of the prescriptive categorization requirements.

Figure C-1. Illustration of Planetary Protection Categorizations with Mission Examples

Based on the mission categorization, COSPAR recommends certain practices to mitigate the risk of contamination. These requirements are summarized in Table C-2.

Table C-2. Summary of Requirements Suggested by COSPAR

Category	Requirements
I	None
II	Documentation only
III	Documentation, trajectory biasing, assembly in cleanroom, and (if needed) bioburden reduction
IV	Documentation, trajectory biasing, assembly in cleanroom, bioburden reduction, (if needed) partial sterilization of contacting hardware, bio shield, and monitoring of bioburden

Category	Requirements
V	Same as outbound mission plus requirements for the return trip including: trajectory biasing, sterilized or contained hardware, continual monitoring, extra decision points

The COSPAR guidelines only suggest serious implementation measures for missions in category III and higher. For forward missions in these categories, COSPAR recommends specific requirements based on the celestial body being contacted. For example, for landed systems going to Mars (category IV), COSPAR recommends specific bioburden requirements based on the mission being carried out. These requirements are reviewed in Table C-3.

Table C-3. Requirements for Category IV Missions to Mars

Category	Definition	Requirement(s)	Rationale for Requirement
IVa	Lander systems not carrying instruments for the investigation of extant Martian life	Surface bioburden level $\leq 3x10^5$ spores Average of ≤ 300 spores per square meter	Based on Viking mission
IVb	Lander systems designed to investigate extant Martian life	Requirements of Category IV plus: • Entire landed system surface bioburden level must be ≤ 30 spores; OR • The subsystems involved in the acquisition, delivery, and analysis of samples must be sterilized to these levels*	Based on Viking mission
IVc	Lander systems which investigate Mars special regions even if they do not include life detection requirements	Requirements of Category IV plus: • Case 1: If the landing site is within the special region, then the entire system surface bioburden level must be ≤ 30 spores. • Case 2: If the special region is accessed through horizontal or vertical mobility, then only the subsystems which contact the special region must be sterilized to the surface bioburden level ≤30 spores*	Based on Viking mission

* And a plan to prevent their recontamination must be put into place.

Mars is the only celestial body with such detailed requirements, applicable both to robotic forward contamination missions as well as human and return missions.[100] For other celestial bodies that are less well understood, COSPAR suggests more flexible probabilistic or decision-based guidelines. For example, missions to Europa or Enceladus shall reduce the probability of inadvertent contamination to less than $1x10^{-4}$ per mission. This frequency is derived from the 1E-3 guideline mentioned above, with the assumption that 10 missions will take place to the icy moons[101] during the period of exploration assumed to be 1,000 years.

There are additional requirements for Earth sample return. COSPAR provides qualitative policy statements to mitigate the risk of backward contamination, by either sterilizing a sample or containing it. For example, the policy suggests that samples should be contained with an appropriate verification process, approval should be required at three additional stages, and that no uncontained hardware that contacted Mars should be returned to Earth. Reports have suggested quantitative derivations of this policy—for example, if a return contains a sample, instead of sterilizing it, that "the probability that a single unsterilized particle of 0.1 micron diameter or greater is released into the Earth environment shall be less than $1x10^{-6}$" (ESF and ESSC 2012).

The COSPAR policy at the time of this writing, which is followed by NASA and other international space agencies, includes more detail than is summarized in this report (Kminek 2019).

Legal Status of COSPAR

Although COSPAR is the only international organization that provides guidelines for planetary protection, it does not have actual legal authority. Since 1962, it has been granted the status of an "observer organization" of the United Nations Committee On the Peaceful Uses of Outer Space (UNCOPUOS) (UNOOSA 2019). Observer organizations can participate in sessions and meetings of a UN committee, but are not involved in decision-making (Negoda and Hedman 2014). During the 2017 session of COPUOS, the Committee "noted the long-standing role of COSPAR in maintaining the planetary protection policy as a reference standard for spacefaring nations and in guiding compliance with Article IX." The Committee also specified that COSPAR's involvement in reconstituting and operating the Panel of Planetary Protection "would help ensure that the needs of all States parties

[100] COSPAR suggests policy statements for human missions, but does not offer requirements or suggestions on how to implement them with current requirements.

[101] The COSPAR guidelines only specifically mention Europa and Enceladus, but another planetary body of consideration could be Saturn's moon, Titan. In June 2019, NASA announced that its Dragonfly mission would go to Titan to search for signs of life. Titan has liquid methane and ethane on its surface and carbon compounds in its atmosphere, which could have led to the creation of methane-based life. It is also believed to have a sub-surface liquid water ocean (NASA 2019d).

pursuing the exploration and use of planetary bodies were served satisfactorily" (COPUOS 2017). Although this statement does not confer any legal mandate for States to follow the COSPAR guidelines, it may be useful in any future disputes regarding COSPAR's authority (Conley 2018). While most involved recognize that the COSPAR guidelines are sufficient for complying with OST, an entity could potentially still be in compliance with the OST without necessarily adhering to the COSPAR guidelines. Nevertheless, the COSPAR requirements are foundational for major space agencies' planetary protection policies, including NASA's (see Appendix D for a list of current and upcoming missions with planetary protection considerations). In many cases, COSPAR has simply adopted and promoted requirements developed by NASA. Historically, this process has been facilitated by the National Academies through its Space Studies Board (NRC 2018).

COSPAR serves an important role as an internationally recognized body for scientific research relating to space, not just in the field of planetary protection. While the COSPAR requirements do not carry any legal weight, they are useful in ensuring that nations follow the same standards for planetary protection. COSPAR could also serve as an international forum to resolve any planetary protection disputes, or if international consultations regarding harmful interference, like those laid out in Article IX of the OST, should ever take place.

NASA Planetary Protection Policy and Framework

NASA, for the most part, follows both the overarching COSPAR planetary protection policy and COSPAR-suggested requirements. The basic structure of NASA's policy is the same as COSPAR's, as are the quantitative requirements for reducing the risk of contamination. NASA's policies do not need to be identical to COSPAR's, but as discussed previously, the COSPAR policies often reflect the adoption of NASA policies, as recommended through the National Academies' Space Studies Board reports.

The NASA policies do add implementation details, review requirements, and documentation that are unique to the NASA project management lifecycle. Three major policy documents set the planetary protection policy and requirements for NASA missions. These requirements also apply to missions that are undertaken pursuant to NASA agreements (such as a Space Act Agreement). The three NASA documents are:

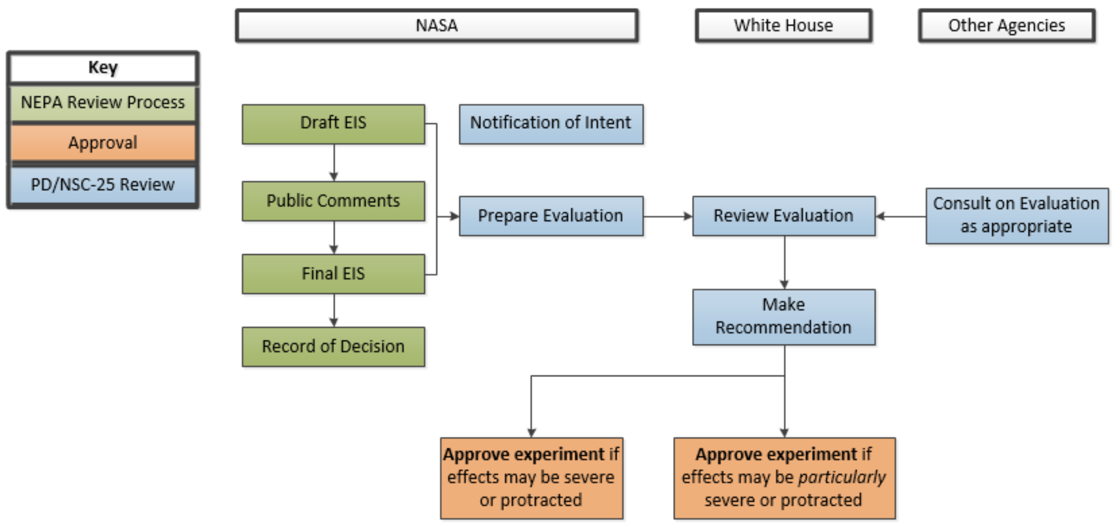
- **NPD 8020.7G: Biological Contamination Control for Outbound and Inbound Planetary Spacecraft.** This NASA Policy Directive (NPD) restates the COSPAR planetary protection policy, with only a few small language changes. The document defers most responsibility to the Planetary Protection Officer. Their responsibilities include prescribing standards; certifying that the mission has met all measures prior to launch, prior to return of the mission, prior to Earth entry, and prior to the approved release of materials; and conducting reviews of materials.

- **NID 8020.109A: Planetary Protection Provisions for Robotic Extraterrestrial Missions.** This NASA Interim Directive (NID) is a temporary replacement for NASA Procedural Requirement (NPR) 8020.12D, which provides requirements to implement NPD 8020.7G. This document is scoped to address only robotic space vehicles, and attempts to specify the categorization of missions, the project management tools to implement planetary protection, and the required reports and reviews.
- **NPI 8020.7: NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions.** This NASA Policy Instruction (NPI) establishes the policy guidelines and describes the approaches for developing research and technologies that will be necessary to eventually draft an NPR for crewed planetary missions. This NPI was created on the recommendation of the NAC Planetary Protection Subcommittee in 2012.

Presidential Directives

National Security Action Memorandum No. 235 (NSAM 235), issued in 1963 during the Kennedy administration, was concerned with "the conduct of large-scale scientific or technological experiments that might have significant or protracted effects on the physical or biological environment," (Kennedy 1963) and was invoked during the Apollo missions regarding the return of astronauts and lunar samples (Pugel 2017); however, since then, neither NSAM 235 nor its successor, Presidential Directive/National Security Council Memorandum 25 (PD/NSC-25), has been applied to any space mission. As with its predecessor, PD/NSC-25 pertains to "scientific or technological experiments with possible large-scale adverse environmental effects and the launch of nuclear systems into space." Its use may be invoked as NASA and private companies consider sample return and human missions that could present potential risks to the Earth environment. Currently, both the threshold to invoke PD/NSC-25 and the processes that would follow are unclear. The scope of PD/NSC-25 is limited to the *human environment*, which is distinctly different from the scope of the OST, which specified the *Earth environment* along with *celestial bodies*. Therefore, at present, PD/NSC-25 can only be applied to missions with backward contamination concerns. However, there is the potential that future settlement of other planetary bodies could be considered human environment, and PD/NSC-25 could then apply to forward contamination as well.

PD/NSC-25 requires the Executive Office of the President (EOP) to review and approve some government experiments that "significantly affect the quality of the human environment." This analysis would build on the environmental review from the National Environmental Policy Act (NEPA), specifically the Environmental Impact Statement (EIS). If a mission were undertaken by the government, the government entity (e.g., NASA) would provide the basis for the Director of OSTP to consult with the Chairman of the Council on Environmental Quality (CEQ), and offer a recommendation to the President. PD/NSC-25 then gives further detail for the process of national review, consultation, and approval for experiments with potential environmental consequences, as shown in Figure C-2. There is no currently provided guidance on backward contamination requirements for missions that are led by the private sector with no government affiliation.



Note: The Federal entity that approves the experiment depends on potential environmental impact.

Figure C-2. Depiction of PD/NSC-25 Process for Experiments

There are definitional issues that would need to be addressed should PD/NSC-25 ever be invoked. The terms *significantly alter* and *human environment* are not clearly defined, and the Directive does not specify who should further define these terms. Additionally, the Directive does not specify how large a *large-scale* scientific experiment is, or what information should be included in the impact statement. Further challenges related to PD/NSC-25 are discussed in Chapter 4.

National Environmental Policy Act

NEPA states that all U.S. Government agencies should share with other relevant agencies a detailed statement for any major Federal action (e.g., a recommendation, report, proposal, or legislation) that is "significantly affecting the quality of the human environment" (42 U.S.C. §4332(C)).[102]

Federal agencies must first implement an Environmental Assessment (EA), and then, if warranted, an EIS about their proposed actions. Because of the significant effort and

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[102] As with PD/NSC-25, the definition of the *human environment* is not explicitly stated, leaving open the possibility that this term could be applied to human missions to celestial bodies.

expenditure required to address back contamination concerns (e.g., constructing a sample return facility in the United States that would neither allow samples to escape nor allow anything from the outside environment to enter the chamber housing the samples), an EIS would likely be required for planetary protection activities. Future efforts will need to determine how these processes would address new government and private missions. For example, it will be important to understand how the processes would compare for a NASA sample return mission versus a private mission.

Appendix D.
Missions with Planetary Protection Considerations

Table D-1. Planned and Upcoming Missions to the Moon (Category II)

Mission	Owner	Mission Type	Launch Date
Chandrayaan-2	ISRO	orbiter, lander, rover	2019?
Chang'e 5	CNSA	orbiter, lander	2019
NASA RP Lander		lander	2018
SELENE-2		orbiter, lander, rover	2020s
ATHLETE	NASA, JPL	rover	
Luna 25		lander	2019
Luna 27		lander	2022
Luna 28		lander	2025
Luna 29		rover	2025?
Scarab	Carnegie Mellon, NASA	rover prototype	
Space Exploration Vehicle (SEV)	NASA		
Smart Lander for Investigating Moon (SLIM)	JAXA	orbiter, lander	2021
Tesla Surveyor	Synergy Moon	rover	2019
Sorato	Hakuto	rover	2020
AngelicvM		rover	
Beresheet-2	Israel Aerospace Industries	lander	
HHK-1	TeamIndus	lander	2018-2019
ECA	TeamIndus	rover	2018-2019
Peregrine	Astrobotic	lander	2020
Griffin	Astrobotic	lander	
Polaris	Astrobotic	rover	2020
CubeRover	Astrobotic	rover	2020
Blue Moon	Blue Origin	lander	2020
MX-1E	Moon Express	lander	2019?
MX-2	Moon Express	lander	2019?
MX-5	Moon Express	lander	
MX-9	Moon Express	lander	2020
Chang'e 6	CNSA		

Table D-2. Planned and Proposed Missions to Other Destinations

Mission	Owner	Target	Mission Type	Launch Date	COSPAR Category
Europa Clipper	NASA	Europa	45 flybys of Europa	2020s	III
Mars 2020	NASA	Mars		Summer 2020	IVb
NEAScout	NASA	Asteroid	Asteroid flyby	2020	
Prospector-1	Deep Space Industries	Asteroid	Lander		
Exomars	ESA/ Roscosmos	Mars	Rover	2020	IV
Hope	Mohammed bin Rashid Space Centre	Mars	Orbiter	2020	III
Mangalyaan 2 (Mars Orbiter Mission 2)	ISRO	Mars	Orbiter (possible lander/rover)	2022	III, IV
Mars Global Remote Sensing Orbiter and Small Rover (HX-1)	CNSA	Mars	Orbiter, rover	2020	III, IV
Lucy	NASA	Jupiter trojans (5)	Orbiter	2021	II, III
JUICE (Jupiter Icy Moons Explorer)	ESA	Ganymede, Callista, Europa		2022	II, III
Laplace-P	Roscosmos	Jupiter moon system, Ganymede	Orbiter, lander	2026	II
MMX (Mars Moons Exploration Mission)		Phobos, Deimos		2024	V
Psyche	NASA	Asteroid Psyche	Orbiter	2023	
Phootprint	ESA	Phobos	Orbiter, lander	2024	V
Dragonfly	NASA	Titan	Lander	2026	III
DePhine (Deimos and Phobos Interior Explorer)	ESA	Phobos, Deimos	Orbiter	2030	III or IV
PADME (Phobos and Deimos & Mars Environment)	NASA	Phobos, Deimos	Orbiter		III or IV
Fobos-Grunt 2	Roscosmos	Phobos	Lander		V
Mercury-P	Roscosmos	Mercury	Orbiter, lander	2030s	I/II
near-Earth asteroid 2016 H03	CNSA	Asteroid 2016 H03, Mars flyby	Orbiter, lander	2022	V
Enceladus	Breakthrough Foundation				
Asteroid Impact Mission	NASA, ESA	Asteroid	Projectile	2020	

Appendix E.
Case Study on Planetary Protection in the Apollo Missions

The Apollo missions provide an important use case for backward contamination protocols in the United States, which can inform efforts to prepare for future and ongoing U.S. missions. The Apollo protocols are especially relevant today, as the United States contemplates sending astronauts to Mars (Bridenstine 2019).

Apollo Protocol Development

The objective of sending humans to a planetary body—the Moon—and bringing them back forced NASA to confront the possibility of back contamination, both to the astronauts and the people with whom they interacted upon their return.

Concerns about back contamination from lunar samples and Apollo astronaut return were raised in the early 1960s by a variety of actors, including Carl Sagan, the National Academies' Space Studies Board, and eventually politicians. In 1963, Senator Margaret Chase Smith asked questions about the threat of back contamination from the return of lunar samples at a budget hearing (Meltzer 2011).

Some of these concerns were addressed when the Kennedy administration issued National Security Action Memorandum No. 235 (NSAM 235) on April 17, 1963. This document addressed "large-scale scientific or technological experiments with possible adverse environmental effects" (Kennedy 1963). It called for Presidential approval via the Special Assistant for Science and Technology of any large-scale scientific experiment that could cause physical or biological harm to the environment. NSAM 235 was applied to both atmospheric nuclear tests and the return of Apollo astronauts and samples (Conley 2018). This document was a precursor to PD/NSC-25, which was later issued during the Carter administration in 1977.

The Baylor University Operating Procedures – 1967

NASA contracted Baylor University to produce a protocol for the quarantine and analysis of the astronauts and the lunar samples. The Baylor researchers laid out a comprehensive protocol for the swabbing and analysis of the Apollo crew microbiology before the lunar mission to establish a baseline, and after their return to search for any sources of contamination. The researchers also detailed the collection, transport, receipt, mixing, and distribution of lunar samples, as well as laboratory management for the Lunar Sample Receiving Lab (LRL). Because the LRL was create to be a "quarantine laboratory," the primary focus of its researchers was to complete "short-term, time-critical analytical procedures and identification of whether or not the lunar sample constitutes a threat to our terrestrial biosphere" (Baylor 1967). The Baylor protocol is composed of three main sections:

1. *Astronaut Analysis:* A comparison of crew microbiology before and after flight to be conducted under quarantine in order to ensure no communicable diseases
2. *Sample Replication In Vitro:* Attempt to culture microorganisms from lunar samples in vitro
3. *Biological System Introduction:* Introduce the lunar samples to biological systems to see if there were any adverse effects (Mogul 2018)

The introduction to the Baylor protocol also stresses the need for collaboration outside of NASA, especially with other Federal agencies, because of the complexity of the task and the expertise needed. The authors of the report specifically highlight the Department of the Interior, the Department of Agriculture, and the Public Health Service as instrumental for defining the needs of the laboratory and for anticipated continued advice on how to run the laboratory successfully (Baylor 1967).

Interagency Committee on Back Contamination (ICBC) – 1967

In order to facilitate interagency agreement on the implementation of back-contamination protocol, NASA established the Interagency Committee on Back Contamination (ICBC) in 1966. This committee was composed of 11 representatives: one each from the Department of Agriculture, The Department of the Interior, and the National Academy of Sciences; two from the Public Service, National Communicable Disease Center; and six from NASA. Although NASA had the majority of the seats on the ICBC, the Interagency Agreement states that they had to get approval from all other representatives before taking any actions to change back contamination protocol (Bogart et al. 1967). The formation of the ICBC coincided with the Outer Space Treaty, in which Article IX gave the legal guidelines for avoiding backwards contamination.

Clashes with Other Mission Priorities

Within the Apollo mission plans, there were three competing goals: sending and returning astronauts to/from the moon, performing sample return of lunar rocks, and avoiding back contamination (Allton et al. 1998). NASA was working under time pressure to successfully complete all three of these goals before the end of the 1960s.

Time Pressure

In 1961, President Kennedy delivered a speech to Congress challenging them to send Americans to the moon and return them safely to Earth by the end of the decade (Kennedy 1961). This time pressure to successfully land on the Moon and return before 1970 was one of the main barriers to the proper implementation of planetary protection (Allton et al. 1998). The protocol breaches discussed above could have been remedied with more time, but in order to stick to mission timeline, NASA officials chose to increase the risk of back contamination and proceed on schedule.

Sample Return

Another source of tension during the Apollo missions was between the scientists who were conducting analysis on the returned samples and the need for planetary protection. A more credible concern to these scientists was not the threat of back contamination or lunar microbes, but rather that the lunar samples would become contaminated with Earth materials after landing (Meltzer 2011). However, these scientists were still required to follow protocol, which included intense cleaning, showering after leaving the lab, and walking through a UV light tunnel before being able to change back into their clothes (Allton et al. 1998). They also had to examine samples using thick leather gloves in a vacuum tube. While examining samples brought back from the Apollo 12 mission, the discovery of a small tear in one of these gloves forced 11 scientists into quarantine (Meltzer 2011). These measures were not only inconvenient, they were also costly. After the injection of lunar samples into a variety of mice, birds, and plants yielded no results of danger, the quarantine procedures were canceled after Apollo 14.

Protocol Breeches and Priorities

Despite the Baylor Report protocols and the efforts made by the ICBC to ensure inter-agency decision-making during planning for Apollo, NASA committed two major breaches in protocol during the return of the Apollo 11 Command Module (CM). First, the engineers had designed the CM vent to expel gas into the ocean during landing. This ventilation system was critical for astronaut safety while they were sealed in the CM. In order to better comply with planetary protection protocol, the option of adding biological filters to the vents was suggested, but ultimately discarded because they would have added an additional 30 pounds of weight to the CM (Meltzer 2011). In balancing mission priorities, NASA chose to keep the vents unfiltered rather than risk having the astronauts overheat inside.

The second protocol breach was the decision to recover the astronauts by opening the CM while it was in the ocean, and airlifting the astronauts to a ship via helicopter. The original plan in the protocol was to lift the entire CM onto the ship using a crane. The breach occurred because it was discovered after launch that the crane on the ship could not lift the CM on board safely. There was a risk that if the CM was lifted in choppy water, it could start swinging and ultimately damage the rescue ship. Therefore, NASA decided instead to take the risk of back contamination by opening the CM and retrieving the astronauts by raft and helicopter. Of the priorities to balance, NASA placed a high value on astronaut safety instead of maintaining a strict adherence to planetary protection protocols.

Lessons Learned from Apollo

The Apollo mission faced some of the same challenges from the implementation of planetary protection that other missions do today. There were doubts about the necessity of the planetary protection requirements and the cost and time needed to properly carry them out. In the end, the Apollo missions exemplified the principle that back contamination risks would never trump the risk of harm to the three astronauts.

One major takeaway from Apollo was the flexibility of the implementation of planetary protection requirements. After scientists completed their experiments and concluded that no harm had come to the astronauts or the terrestrial organisms exposed to lunar material, they decided to cease all back contamination processes. This same scenario could play out during sample return missions from Mars. However, as with Apollo, the certainty of no extraterrestrial biological contamination requires clean samples to be returned to Earth and tested in laboratory conditions. Therefore, perhaps the most effective way to responsibly ease planetary protection requirements on future missions is to have stringent requirements in the beginning.

Appendix F. International Case Studies

The case studies summarized below are intended to inform decisions about whether and how to update U.S. planetary protection policy. They represent a sampling of countries undertaking planetary exploration. Each is planning to send spacecraft to Mars, with some also planning to conduct sample return missions. These five case studies are not exhaustive. For example, India is also planning to send an orbiter to Mars, but there is relatively little information available about its planetary protection policies or practices. The private sector in other countries is also involved in space science and exploration. For example, in 2019, Israel's non-profit company SpaceIL sent a lander to the Moon. Its adherence to The Committee on Space Research (COSPAR) planetary protection policies was unclear—the lander was carrying life without the knowledge of SpaceIL, SpaceX (the launch provider), or even the regulatory authorities in Israel (Johnson et al. 2019).

For purposes of this study, it is helpful to note the difference between planetary protection policies and practices. Policies are generally adopted or prescribed by one or more central decision-making authorities, while practices are the means of implementing those policies. In the case of planetary protection, a national policy might involve the decision whether to adopt COSPAR recommendations for various categories of space exploration missions. The planetary protection practices would include the specific manufacturing processes and sterilization techniques used in the development and launch of those missions. In general, STPI was able to find relevant information on national planetary protection policies for each country, but less information on planetary protection practices in some of the countries studied, most notably, China and Russia.

Europe

Europe provides a unique case study of planetary protection policies and practices because its space exploration capabilities combine those of national space agencies (e.g., France's National Center for Space Studies [CNES], the German Aerospace Center [DLR], and the Italian Space Agency [ASI]) and the international European Space Agency (ESA), with 22 member states.

ESA represents the interests of its member states, all of whom are signatories of the Outer Space Treaty.[103] Therefore, ESA writes its policies to abide by the articles and principles outlined in the treaty, including Article IX and its implications for planetary protection.

Planetary Exploration Plans

ESA has conducted a number of missions that necessitated planetary protection considerations, the most involved of which are the ExoMars robotic exploration missions. In 2016, ESA sent the ExoMars Trace Gas Orbiter into Martian orbit, and had to satisfy the probability impact constraint, showing that the orbiter had a 1 in 100 chance of impacting Mars within the first 20 years. This mission also included the Schiaparelli lander, for which ESA built a new cleanroom in Italy. They conducted microbial heat reduction and completed approximately 3,000 microbiological tests throughout the development of the spacecraft (ESA 2019a). The lander crashed upon impact of the Martian surface. ESA is now planning to continue the ExoMars program with the Rosalind Franklin rover.

Planned Outgoing Missions

ESA has three planned outgoing missions with planetary protection considerations. The first is the ExoMars Rosalind Franklin rover mission to Mars, which is a life-seeking mission (Category IVb). This mission is being completed in collaboration with Roscosmos in Russia, which will provide a Martian surface platform. NASA has also provided expertise for ExoMars—most notably for the development of the Mars Organic Molecule Analyzer (MOMA) instrument, designed to examine organic molecules. On March 12, 2020, ESA delayed the mission to 2022 due to issues with the parachutes and electronics (Jones 2020).

The second relevant mission is the Jupiter Icy Moons Explorer (JUICE) mission. This mission is Category III for Europa and Category II for Ganymede, and is expected to launch in 2022 (ESA 2019). The goal of this mission is to investigate the evolution of the Jovian system, particularly focused on the emergence of potentially habitable worlds (i.e., the icy moons) around a gas giant.

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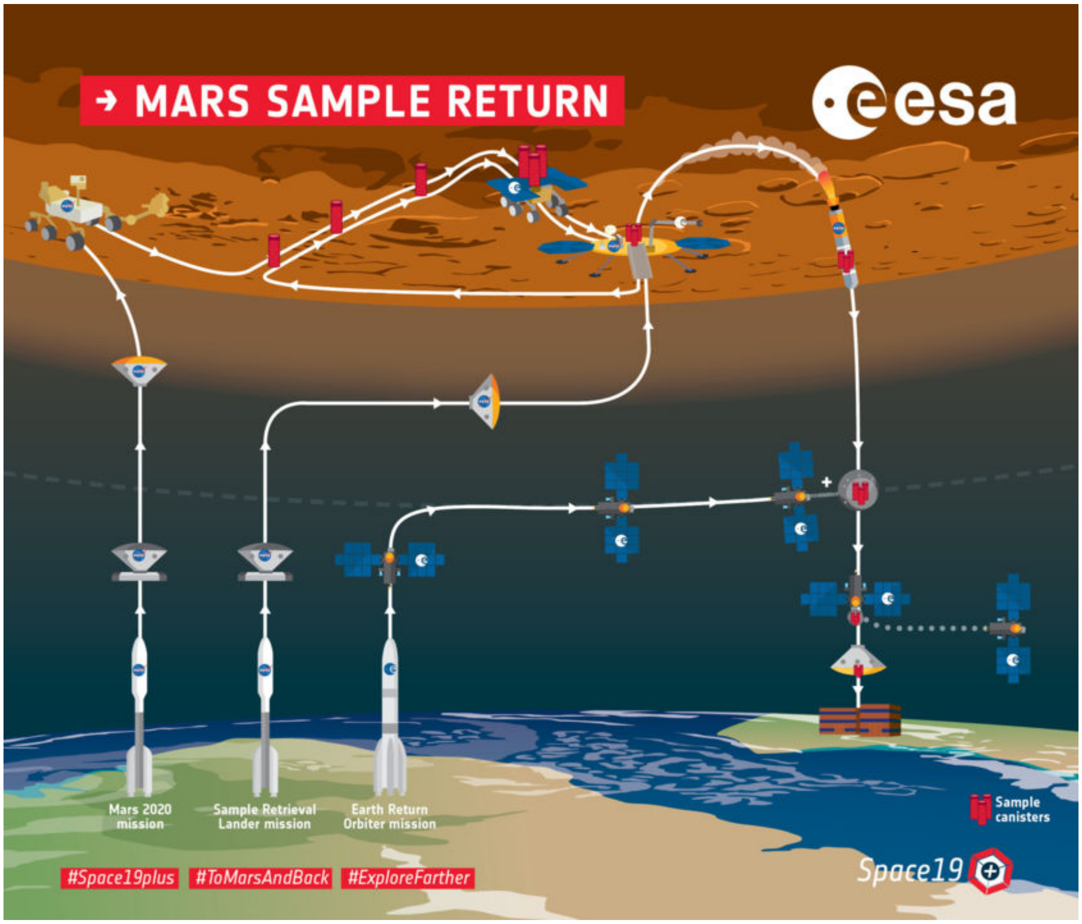
[103] ESA Convention, Article II

The third and final relevant mission is the outgoing leg of the Mars sample return campaign, which will be Category III.

Planned Return Missions

ESA will be collaborating with the United States to plan and execute a Mars sample return mission. The first step of this mission begins with the launch of NASA's Mars 2020 mission, which will send a rover to Mars to select samples for subsequent return to Earth. Then, a NASA Sample Return Lander with an ESA Sample Fetch Rover will retrieve these samples. A Mars Ascent Vehicle (MAV) will launch the container into Mars orbit. In Martian orbit, the ESA Earth Return Orbiter will collect the samples in a biocontainment capsule before returning to Earth and landing in Utah (ESA n.d.). (See Figure F-1 for a depiction of the mission architecture).

Because of the risk of returning extant Martian life, the mission will be a Category V restricted Earth return requiring extensive protections. This joint sample return campaign requires a cohesive policy framework between the United States and the ESA—for example, to facilitate the return of samples from a European spacecraft to the United States' landing site in Utah. A policy framework for such a mission does not currently exist.



Source: ESA

Figure F-1. Architecture of Mars Sample Return

National/Regional Planetary Protection Policy and Practices

The ESA Planetary Protection Policy is based directly on the COSPAR Planetary Protection Policy (European Cooperation for Space Standardization Secretariat 2019). The European Planetary Protection Requirements, both at ESA and European Cooperation for Space Standardization (ECSS) levels, are in line with the COSPAR planetary protection implementation requirements (with some additional elements to ensure that requirements are clear and verifiable). ESA is well represented on the COSPAR Planetary Protection Panel (PPP) and has often played a leadership role. The current chair of the COSPAR PPP is European, as are both vice-chairs, one of whom is the ESA Planetary Protection Officer. Members of the COSPAR panel also include agency representatives from Italy, the United Kingdom, Germany, and France. European scientists are also individual members of the panel (interview with ESA expert). To the best of our knowledge, European countries all follow COSPAR's Planetary Protection Policy.

The European Planetary Protection Requirements, based on the COSPAR Planetary Protection Policy, are reviewed approximately every 2 years, historically during the biannual COSPAR Scientific Assembly (interview with ESA expert). Potential updates to the requirements are discussed between space agencies, and if all agencies agree on the need for updates, it is recorded and discussed at the COSPAR level. The last time they were reviewed was in July 2018 at the 42nd COSPAR Scientific Assembly in Pasadena, California. The requirements will likely be reviewed next at the 43rd Scientific Assembly in in Australia.

ESA does promulgate its own implementation procedures of the COSPAR policy as standards. Changes to these practices are discussed between individual space agencies and their industry partners. According to interviewees, there have been no recent discussions about updating the implementation of the European policies, analogous to the 2019 update to the NASA Planetary Protection Independent Review Board (PPIRB) recommendations in the United States. Internationally, these ESA planetary protection standards are perceived to be the best formulated (interviews).

Russia

In the Russian Federation, the main hub for space activities is the Roscosmos State Corporation for Space Activities (Roscosmos), which is a national state corporation. Roscosmos assumed these responsibilities after the Federal Space Agency Roscosmos merged with the United Rocket and Space Corporation in 2015 to form a nationalized Russian space industry (Pandey 2015; Henry 2015). The Institute on Biomedical Problems (IMBP), which is a part of the Russian Academy of Sciences, addresses most of the biological concerns of the Russian space program.

PAO S.P. Korolev Rocket and Space Corporation Energia (RSC Energia) is the primary manufacturer of spacecraft and space station components for Roscosmos. In addition, there are dozens of subsidiaries and partners who collaborate with Roscosmos on Russian space initiatives. Notable examples include: NPO Lavochkin, a spacecraft developer and manufacturer; the Central Research Institute of Machine Building (TsNIIMash), a space and defense research agency focusing on propulsion and satellite systems; and Proton-PM, a heavy machinery and engine manufacturer. The Russian Academy of Sciences (RAS) also plays a prominent role in space activities by providing proposals, designing instruments, and lending expertise for missions.

Planetary Exploration Plans

Since the dissolution of the Soviet Union, there has only been one attempted Russian mission with planetary protection considerations, Phobos-Grunt. This mission planned to go to Phobos, one of the Martian moons. It intended to be the first spacecraft to return a macroscopic sample from an extraterrestrial body in over 30 years (Kremer 2011). The orbiter portion of this mission was Category III. At the end of assembly, Russian researchers noted that the microbial contamination did not exceed 500 bacterial spores per sq. m and with a bioburden not exceeding $5x10^5$ spores, which is a lower threshold than requested by COSPAR guidelines (Martynov et al. 2011). This was achieved by sterilizing and assembling the craft in a class eight clean room, in accordance with GOST ISO 14644-1-2002 (Martynov et al. 2011). The descent module was Category V for unrestricted Earth return, and again, the procedures for the lander supposedly followed COSPAR guidelines.

Beyond the Russian lander and orbiter, Phobos-Grunt also included a Chinese orbiter, Yinghuo-1, and a payload from the Planetary Society, an American space exploration and advocacy organization.(NASA 2018; Minkel 2009). The Planetary Society's payload, Living Interplanetary Flight Experiment (LIFE), contained samples of Earth-based life meant to fly to Phobos and then return to Earth. These samples included *Deinococcus radiodurians*, an extremely durable bacterium; tardigrades; three species of archaea, single-celled prokaryotic organisms; yeast; plant seeds; and a soil sample from the Negev Desert (Minkel 2009). These samples, most of which were freeze-dried and rendered inert, were placed in individual vials, which were placed into a titanium disc. According to

NASA's Planetary Protection Office at the time, the LIFE payload satisfied planetary protection requirements due to the conditions on Phobos, and under the condition that Roscosmos would provide detailed confirmation that the mission reached its target. However, the planetary protection procedures for this mission were ultimately a moot point, as after launch Phobos-Grunt failed while still in Earth orbit due to a programming error and the spacecraft was destroyed upon re-entry (Clark 2012).

Planned Outgoing Missions

Currently, the ESA and Roscosmos are planning a Martian mission, ExoMars *Rosalind Franklin*, which is slated for launch in 2022 after over a decade of delays (Amos 2020). Roscosmos will be the primary manufacturer for the lander—named *Kazachok* or "Little Cossack"—and ESA will be the primary manufacturer of the rover *Rosalind Franklin.* In a public interview, Gerhard Kminek, ESA's Planetary Protection Officer, noted that the ExoMars mission "has stringent planetary protection requirements" that are being carefully followed (ESA n.d.). However, information could not be gathered on the implementation practices Russia has used to follow these planetary protection requirements.

Roscosmos has three lunar missions planned for the next decade: Luna 25 in 2021, Luna 26 in 2024, and Luna 27 in 2025. Luna 25 and Luna 27 will land on the lunar South Pole to prospect and drill for water ice. Luna 26 is an orbiter that will survey the surface for resources, particularly water ice (Patel 2020). If these missions contain an organic inventory, they fall into Category II and do not have stringent planetary protection requirements. If these missions do not contain organics, they fall into Category I.

In the mid-2020s, Russia is planning to launch an orbiter, lander, and surface station to Venus, called Venera-D (Schulze 2019). The orbiter is intended to operate for at least 3 years, and the lander will operate for just a few hours on the planet's surface (Wall 2017). The orbiter will collect data on the Venusian atmosphere, including composition, dynamics, and structure. The lander will also collect atmospheric information on its descent, but upon landing, will focus on the composition of the surface. There have been some reports that NASA or other international space agencies will collaborate on these missions; however, this has not been confirmed beyond news articles and a single NASA Jet Propulsion Laboratory (JPL) press release from 2017—so the nature and extent of the collaboration are unclear (Levchenko 2019; NASA 2017). This mission falls into Category II and is subject to the planetary protection requirements that correspond to this designation.

Planned Return Missions

Russia has indicated plans for a Mars sample return mission called Mars-Grunt, but these plans have been pushed back until after their involvement in the ExoMars landing (Roscosmos 2010).

National/Regional Planetary Protection Policies and Practices

It is prohibited in Russia to create harmful contamination of outer space that leads to undesirable changes to the environment under Article 4(2) of the Law of the Russian Federation about Space Activities (Boccardo 2018). The text translates to "Space activities are carried out in accordance to the following principles: ensuring the safety of space activities and environmental protection."[104] This article also establishes the licensing regime of Russian space activities. In addition, Article 5(H) of Resolution 104 of the Government of the Russian Federation on the Statute on Licensing Space Operation of February 2, 1996 mandates that licensing applicants must confirm that their mission meets safety standards, including environmental.[105] The direct text, according to the United Nations Office for Outer Space Affairs, is "to obtain a license, the applicant shall submit to the Russian Space Agency [now Roscosmos]…documents confirming the safety of space operations (including ecological, fire and explosion safety) and reliability of space equipment (Russian Federation 1996)."[106]

While these two statutes establish the baseline for planetary protection standards, Russia does not have, in its national space law, a specific planetary protection policy or program (email correspondence with Russian space and planetary protection experts). However, they do report to follow COSPAR regulations, and are long-standing members of the organization (Shustov 2019; Khamidullina 2012). More specifically, the Russian Academy of Science's Council on Space is the primary agency in Russia addressing

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[104] Original text: Космическая деятельность осуществляется в соответствии со следующими принципами:... обеспечения безопасности космической деятельности и охраны окржающей среды.

Закон РФ от 20 августа 1993 г. Н 5663-1 "О Космеческой деятельности" [The Law of the Russian Federation of August 20, 1993 N-5663-I "On Space Activities"]. http://base.garant.ru/1363230020040030030030030030030030030030030030030030030030030030030030030030030030030030036

[105] Ibid.

[106] Постановление от 2 февраля 1996 ф И 104 "Об Утверждении Положения о лицензировании космеческой деятельнотси" [Decree of 2 February 1996 no. 104 "On the Approval of the Regulation on the Licensing of Space Activities."] Russian Federation, February 2, 1996. http://www.consultant.ru/document/cons_doc_LAW_9145/

Original text: "Для получения лицензии заявитель представляет в Российское Космическое агентство:... документы, подтверждающие безопасность космической деятельности (в том числе экологическую безопасность и пожаровзрывобезопасность) и надежность космической техники."

planetary protection, and within the Council on Space, the Experts Working Team on Planetary Protection is charged with the regulation of such activity in Russia (Planetary Protection Activity in Russia n.d; email correspondence with Russian planetary protection expert). The Experts Working Team on Planetary Protection acts as the intermediary between COSPAR, the various Institutes of the Academy of Sciences, Roscosmos, and the Federal Medical Biological Agency. The major players within the Experts Working Team are Institute of Biomedical Problems of the RAS (IMBP); Space Research Institute of RAS (IKI); Vernadsky Institute of the RAS; Federal Medical-Biological Agency; Lavochkin Association; and the Central Research Institute of Machine Building (TsNIIMASH). In particular, an interviewee noted that IMBP focuses on these issues and sends delegates to COSPAR (interview with ESA expert). As far as STPI could ascertain from interviews, Russia has no plans to change their planetary protection policies in the near future.

The Russian Academy of Science's Institute of Biomedical Problems (RAS IBMP) has been conducting "bio-risk" experiments on the International Space Station (ISS) to better understand the effects of spaceflight on certain forms of life—higher order plants, microorganisms, lower crustaceans, etc.—to understand the survival limits and whether such life forms could survive longer-duration missions in space (Orlov et al. 2017). These bio-risk experiments found these organisms could survive and reproduce after 31 months on the exterior of the ISS, which is similar to the expected duration of a voyage to Mars. As to the effect these experiments may have on planetary protection requirements, all that was stated was that the ability of these organisms to survive harsh conditions "must be taken into consideration when developing and validating planetary quarantine methods" Orlov et al. 2017).

China

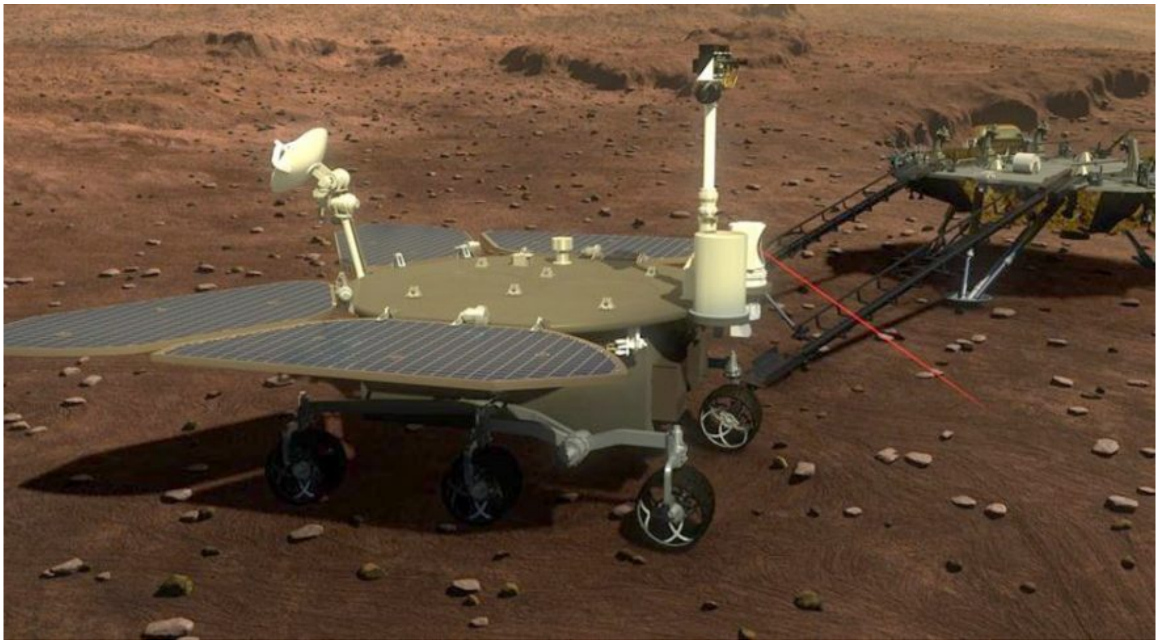
China’s space program began as part of a Cold War defense program, sending its first satellite, *Dong Fang Hong* (The East is Red), into Low Earth Orbit (LEO) in April 1970 (Yu et al. 2019). Since that time, China has launched more than 357 space objects and pursued a number of scientific and exploration missions with planetary protection implications (Wu 2018).

Planetary Exploration Plans

As discussed in the Russia case study, Yinghuo 1 (Category III) was a Chinese orbital satellite for Martian surface surveillance and testing deep space navigation, launched with the Russian Phobos-Grunt mission in 2011 (NASA 2018a). The mission failed in the secondary firing stage, leaving Yinghuo 1 in LEO. One interviewee from another national space agency, who was then involved in COSPAR, indicated that China was not very cooperative on the Yinghuo 1 mission in adopting the categorizations proposed by the international scientific community through COSPAR (interview). Other previous missions include Chang’e missions 3 and 4 (Category II), both of which put landers on the Moon, sampling lunar soils and conducting biological experiments on the surface of the Moon.

Planned Outgoing Missions

China aims to expand its space exploration capabilities by launching a Mars rover in the 2020–2022 timeframe, carrying out orbiting and roving exploration (Lemonick 2019; Information Office of the State Council of the People’s Republic of China 2016). If the rover is launched on schedule (July 2020), a landing module could enter the Martian atmosphere in early 2021 (Clark 2020). The rover would carry high and medium resolution cameras in addition to a spectrometer to analyze Martian geology (Clark 2020). The Mars mission will advance Chinese orbiting, roving, and sample return technical capabilities for future missions (Information Office of the State Council of the People’s Republic of China 2016).



Source: SpaceNews

Figure F-2. 2020 CNSA Mars Rover

Planned Return Missions

Chang'e 5 will be the first Chinese lunar sample return mission, bringing 2 kg of lunar regolith back to Earth (Williams 2019). The return sample will go to the Inner Mongolia Autonomous Region for testing and research, transported in a sealed container (Space Daily Staff Writer 2019). Pending the success of Chang'e 5, China has planned another sample return mission with Chang'e 6 in the late 2020s. Initial plans for Chang'e 6 include 20 kg of payload reserves selected from Chinese colleges, universities, private enterprises, and foreign scientific research institutions for lunar sampling and other lunar research (Xuxin 2019).

China is also conducting technology studies for a Mars sample return but does not expect to return Martian samples until sometime in the 2030s. While on the Martian surface, the mission plans to study soil and atmospheric conditions, searching for water ice and habitability characteristics (Jones 2017). China is working to increase its technological capabilities to be compliant with planetary protection standards for their Mars sample return (Xu et al. 2019).

National/Regional Planetary Protection Policy and Practices

China is a signatory of the OST and joined COSPAR in 1993. China has created CN-COSPAR to "promote the development of China's space science cause and improve the level of Chinese space research (Chinese Academies of Science National Space Science Center 2019)." The Chinese Panel on Planetary Protection is led by General Secretary Wu Ji, director of the National Space Science Center and Vice President of COSPAR. The panel consists of roughly 50 committee members and 12 executive committee members (Chinese Academies of Science National Space Science Center 2019).

China does not appear to have national space laws at the time this case study was written (Hauser Global Law School Program 2018; Wu 2018). International agreements, in order to have legal standing in China, must be passed through statutes from the Standing Committee and the National People's Congress, or reflected in departmental rulings. To our knowledge, there are no departmental regulations concerning planetary protection. However, at the November 2017 CN-COSPAR meeting, Vice President of the Chinese Academies of Sciences and Chairman of CN-COSPAR Xiangli Bin indicated:

> Starting in 2018, space science mission data will be made public through a large number of publications, using the COSPAR stage to carry out good communication and learning, playing a role in COSPAR, the largest international space research academic organization (Office of International Cooperation 2017).

Chinese researchers from government and private entities—including the China Astronaut Training Center, Aerospace Shenzhou Biotechnology Group Co., Ltd., Beijing Space Biotechnology Research Center, China Aerospace Science and Technology Corporation Space Bioengineering Research Center, China Academy of Space Technology, and the Beijing Spacecraft Overall Design Department—have all noted that planetary protection should be a priority for China to become a major spacefaring nation (Xu et al. 2019; Zhang et al. 2019). Online, the CNSA published the NASA PPIRB statements, indicating that state and commercial entities operating in space should "keep up with the times" developing planetary protection policies that reflect the current state of technology (Science Daily 2019). Interviews confirmed that the dynamic between China and COSPAR has changed since the Yinghuo mission, changing for the better (interview). Based on publicly available information and interviews, China does not appear to be considering changes to their planetary protection practices that would be in conflict with COSPAR guidelines.

China's views on space parallel its ambitious economic and political goals on Earth. According to Lt. Gen. Zhang Yulin of the Central Military Commission, China has long-term goals to reach cislunar space for solar power and resource exploitation, among other things, using this space to expand exploration capabilities (Xinhua 2016). The Chinese scientific community understands the value of complying with international standards in order to be seen as a great spacefaring nation; however, it remains to be seen to what extent China will provide timely and complete registration of space objects to adhere to international agreements (Wu 2018).

Japan

The Japan Aerospace Exploration Agency (JAXA) runs Japan's aerospace and space activities. It was founded in 2003, combining several pre-existing space and aerospace agencies. The majority of JAXA's work focuses on Earth-orbiting activities, but Hayabusa 1 and 2 sample return missions have established JAXA as a major player in the international planetary protection community. JAXA sets and implements its own planetary protection policy, follows COSPAR planetary protection policies, and coordinates with the international community.

Exploration Plans

Japan has conducted several missions with planetary protection implications, most notably two sample return missions, Hayabusa I and II. Both missions from small bodies were categorized as unrestricted Earth return, as confirmed by the international community. In addition to the sample return missions, JAXA's first planetary protection activity was a Mars orbiter, NOZOMI, launched in 1998.

Planned Outgoing Missions

JAXA has several planned outgoing robotic, scientific missions. These include several to small solar system bodies such as DESTINY+ (2022) and Comet Interceptor (2028). JAXA is also planning a lunar lander (SLIM) for launch in 2021 to be followed by more lunar exploration activities (Sasaki 2019). Only one planned mission rises above Category II: the sample return missions named the Martian Moons Exploration (MMX), which has an outgoing rating of Category III.

Planned Return Missions

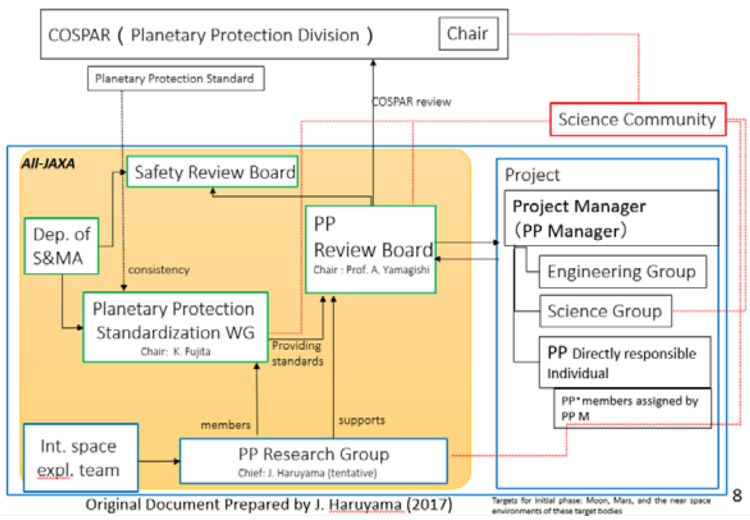
JAXA is planning a Martian Moon observation and sample return mission expected for launch in 2024. MMX will bring back 10 grams of soil from the Martian Moon Phobos, returning it to Earth in 2029. NASA, ESA, and CNES are participating in the project and will provide scientific instruments.

MMX is categorized as an unrestricted Earth return mission and was recently approved by COSPAR (Coustenis 2019). To obtain an unrestricted status as the first mission to Phobos, JAXA had to show that the probability of a viable organism being returned from the celestial body was very low—less than one in a million. To do so, JAXA modeled the probability of a viable organism transferred from Mars to Phobos as the result of a meteorite impact. JAXA concluded the most likely sampling probability value was 10^{-8}, warranting an unrestricted status (Fujita et al. 2019). That conclusion was confirmed by a joint study of the U.S. National Academies and the European Science Foundation (NASEM 2019).

National/Regional Planetary Protection Policy and Practices

Japan is a signatory of the OST but does not have national planetary protection provisions nor any legislation to protect the environment while conducting space activities (Boccardo 2018). JAXA independently directs and implements its planetary protection policies in coordination with COSPAR and the international community.

The JAXA planetary protection organization comprises a standard-setting working group, a research group, and a planetary protection review board (see Figure F-3). The planetary protection organization resides within JAXA's Department of Safety and Mission Assurance (S&MA). COSPAR standards have been implemented as agency policy and standards. In 2018, JAXA established its own planetary protection policy and "organizationally committed to steadily complying with the COSPAR planetary protection policy (JAXA 2019)."



Source: Yano, Hajime. 2018. "Planetary Protection Management at JAXA." Presentation at the PPOS Planetary Protection Tutorial 101, June 12-13, 2018 in Pasadena, CA, USA.

Figure F-3. JAXA Planetary Protection Structure

Prior to 2018, each project organization within JAXA or its predecessor organization handled its own planetary protection implementation. Although several missions required planetary protection consideration (NOZOMI, Hayabusa I & II), small teams within the project independently implemented requirements, namely orbital calculations. As described by a JAXA press brief:

> obligations under the COSPAR planetary protection policy were implemented by individual projects by adopting standards in compliance with the COSPAR planetary protection policy and associated requirements, and by forming an international agreement at the COSPAR planetary protection panel (JAXA 2019).

In the 2017-2018 timeframe, JAXA decided to establish agency-wide planetary protection policy "in consideration of an increase in space-exploration missions and in response to recently implemented space activity laws (Institute of Space and Astronautical Science 2018)." The newly created policy and office were created in time for and to support the MMX mission.

According to interviews, the top-level planetary protection policy is in full compliance with COSPAR planetary protection policy. The underlying standards and thus the underlying practice are based on ESA standards, with small changes to compensate for different organizational and project management structures.[107] ESA's standards were seen as simpler and more up-to-date than those from NASA, as well as more appropriate for a smaller space agency like JAXA.

JAXA's planetary protection policy only applies to JAXA missions, and there is no explicit national policy or law to deal with private sector missions or those sponsored by other components of Japan's government. According to interviews, Japan's cabinet offices have limited knowledge of planetary protection, and typically consult with JAXA to determine mission compliance with treaty obligations. Except for the UAE Hope mission, no non-JAXA missions launched or planned in Japan have had significant planetary protection implications. The Emirates Mars Mission (see Chapter 7) is on schedule to be launched from Japan in July 2020 on the now privatized H-IIA Mitsubishi Heavy Industries launcher. Because the United States participated in the planetary protection review for the UAE mission (Category III) and COSPAR approved it, a JAXA planetary protection review is reportedly not required (interviews with JAXA scientist).

JAXA has remained informed of the changes to planetary protection policy recently proposed by the NASA PPIRB. JAXA does not yet have an official position on any proposed changes, but the personal opinion of one interviewee is that the lower categorizations of the Moon and Mars (especially for commercial entities) are welcome changes so long as more at-risk portions of the celestial bodies are still better protected.[108] However, the interviewee indicated that sending humans to Mars, whether sponsored privately or by a state actor, could pose an unavoidable loss to future science.[109]

An interviewee related that because all outgoing missions have been Category III or less, the cost of planetary protection for each mission has been small. However, they are finding that as JAXA examines missions to Mars, the cost is rising. MMX, as a Category

[107] The policy and standards are currently only available in Japanese.

[108] The interviewee also noted that ESA, on the other hand, will likely want to keep more stringent policies.

[109] The United States, including several of its private companies has planned human missions to Mars." Because you cannot clean humans or keep them fully contained, it is unavoidable that a human on Mars would leave behind microorganisms.

III outgoing mission, may be the first iteration of this increase. As an important example, the interviewee related that JAXA's proposal for a landed mission to Mars was recently not approved due to high cost, in part arising out of planetary protection requirements. JAXA used NASA's experience and data to estimate the cost of cleaning a Martian lander. In spite of this, according to interviewees JAXA has no plans change their planetary protection policy independent of advances made at and through COSPAR.

United Arab Emirates

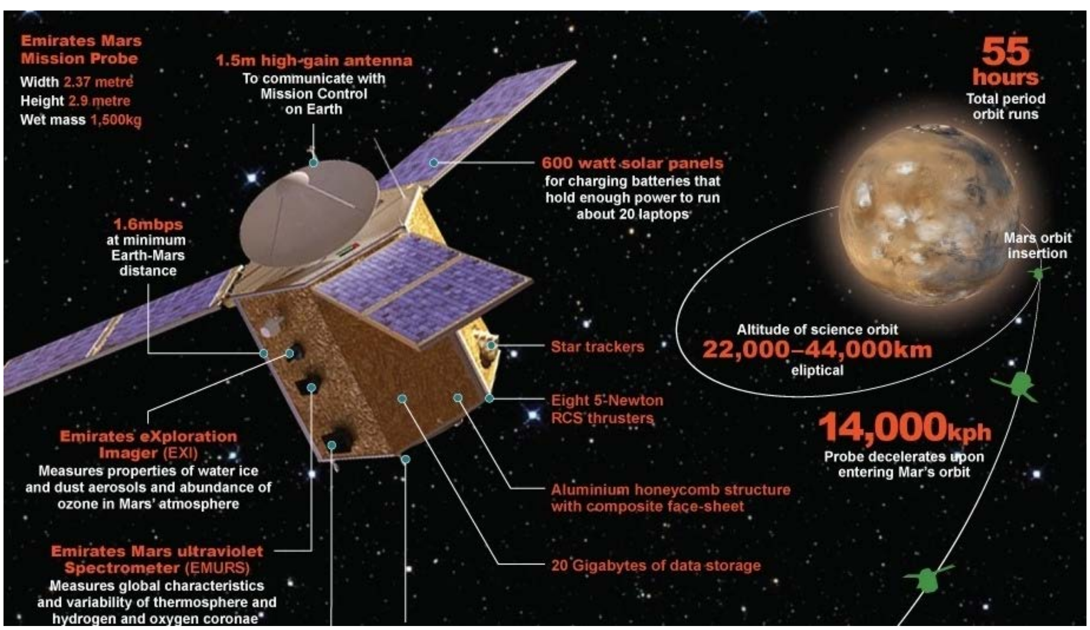
The United Arab Emirates (UAE) is a relative newcomer to the space industry. The country has two space agencies: The United Arab Emirates Space Agency (UAESA), a government agency based in Abu Dhabi, and the Mohammed bin Rashid Space Centre (MBRSC), a government entity of Dubai. These agencies were established in 2014 and 2006, respectively. Since then, the UAE has made quick strides in establishing itself as a major player in space, and in 2019 sent its first astronaut to the International Space Station (Chang 2019). The UAE's upcoming plans include sending a spacecraft into Mars orbit.

Planetary Exploration Plans

The UAE has not yet conducted any space missions with significant planetary protection implications. It has one planned orbiter mission to Mars and its practices are based on the COSPAR planetary protection policies.

Planned Outgoing Missions

The UAE is currently working on the Emirates Mars Mission (EMM), the main component of which is the Hope spacecraft. This mission is funded by the UAESA and is being built and operated by the MBRSC. The Hope spacecraft is on schedule to launch from Japan in July 2020 on a private launch provided by Mitsubishi Heavy Industries. It will stay in Mars orbit and its goal is to collect weather and climate information from the Martian atmosphere (MBRSC 2020). This is a Category III mission.



Source: Sarwat, Nasir. 2020. "UAE's mission to Mars on schedule for launch despite Covid-19." *The National*. https://www.thenational.ae/uae/science/uae-s-mission-to-mars-on-schedule-for-launch-despite-covid-19-1.993686

Figure F-4. Emirates Mars Mission Hope Probe

To successfully execute the mission, the UAE collaborated with teams from U.S. universities, rather than building its own space infrastructure. Its main collaborator is the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, Boulder (Chang 2020).

Planned Return Missions

The UAE currently has no plans for return missions.

National/Regional Planetary Protection Policies and Practices

The UAE has no national or regional planetary protection policies, nor an office of planetary protection. According to interviewees, there are no plans to change this. The UAE has ratified the OST, and their national space policy states that "[a] safe, sustainable, and stable space environment, free from impediments to access and utilization, is a vital national interest (UAE Government 2016)." The UAE does not have a representative on the COSPAR Planetary Protection Panel; however, an interviewee participating in COSPAR indicated that an invitation has been extended or will soon be, and that UAE contributions would be welcome.

When LASP was helping to design EMM, it had to develop its own planetary protection practices. It was the responsibility of the mission designers to ensure that the Hope spacecraft was sufficiently sterilized to meet the treaty obligations under Article IX of the OST. LASP collaborated directly with COSPAR to ensure that its planetary protection practices abided by the COSPAR guidelines, and used the ESA planetary protection policies as a reference (interview with EMM expert). The EMM mission required planetary protection approval from JAXA, the launch provider, and NASA, for use of the Deep Space Network (DSN). Working with COSPAR to determine planetary protection implementation plans gave the mission credibility with the NASA PPO and JAXA.

When asked about challenges implementing the planetary protection requirements, a representative from the Hope mission said that the major challenge was interacting with NASA to get planetary protection approval because the mission plans to use the DSN. For example, during mission planning, the NASA planetary protection officer changed, which precipitated a change in planetary protection requirements. This contributed to delayed mission approval from NASA. The mission did not receive approval until a year after it would have been possible to make any changes. Fortunately, all changes required by the new PPO were addressed through further reporting (interview with EMM expert).

Findings

All countries examined as part of this study appear to adhere to COSPAR guidelines and none is planning major policy changes

In STPI's review of the planetary protection policies of the five countries, we found that all claim and appear to adhere to COSPAR's Planetary Protection Policies. To the best of our knowledge, none of these countries is currently considering any major changes to their national planetary protection policies or practices. A number of the country-level experts we spoke to reported that they are aware of the recommendations of the NASA PPIRB. No analogous study appears to have been conducted elsewhere.

Difficult to ascertain level of adherence of some countries

Nation state space competitors, such as China and Russia, have both ratified the OST and are members of COSPAR. They have therefore signaled their overall willingness to commit to and develop planetary protect policies and practices that conform to the COSPAR Planetary Protection Policy. However, domestic space activities in these countries are more challenging to research and would necessitate additional time to be reviewed. Public information on and evaluations of their programs are not readily available. It is therefore much more difficult to ascertain their level of adherence to and compliance with internationally accepted planetary protection practices.

It is in the interest of the United States to gain more specific information from Russia, China, and other countries to further understand their specific implementation of planetary protection policies and practices. This would build upon the literature review and interviews used as sources for this report and inform any revisions to U.S. planetary protection policies and practices.

This additional information gathering could be done directly by the U.S. Government, or through an intermediary, such as COSPAR. A direct, "official" approach may more likely convey the gravity of the request, while engagement via intermediaries might facilitate a more open initial dialogue.

No relevant policies or regulations for the private sector

None of the countries studied has explicitly developed planetary protection policies or regulations specifically applicable to the emerging private space sector, as is also the case in the United States. Of the countries we examined, only Japan has private sector activities related to planetary protection.

Need to accelerate update of U.S. planetary protection policies

Based upon the case studies conducted, the countries most closely allied with the United States—and those pursuing active space exploration programs (e.g., Europe and Japan)—are most directly and actively involved in cooperative efforts to establish and update international planetary protection policies and practices. These countries, especially those in Europe, are invested in the update of U.S. planetary protection policies. This is especially true for U.S. policies intended to mitigate the risk of backward contamination, as the United States and Europe are planning to collaborate on missions for Mars sample return.

Appendix G.
Risk Methodologies for Planetary Protection

The international community could most effectively prevent biological contamination by prohibiting the introduction of foreign material—i.e., by not going to other celestial bodies or bringing any extraterrestrial material back to Earth. However, not going is an impracticable solution if the United States intends to continue exploring the solar system. Instead, planetary protection requirements seek to avoid contamination by mitigating its probability—allowing us to conduct missions while still "protecting" the planets (risk management as distinct from risk avoidance).

Planetary protection, therefore, becomes an exercise in defining an acceptable level (or probability) of contamination. Defining such a limit is a dauntingly difficult task: at the time of this writing, we know little about what life we might bring back to Earth or how terrestrial life might proliferate on another planetary body. Any planetary protection requirements must be set in a high degree of uncertainty.[110] To assess such requirements, both for forward and backward contamination, we first review common methods to approaching uncertainty and risk, and summarize a few considerations for setting relevant requirements.

Planetary protection requirements typically utilize two methodologies: (1) the precautionary principle; and (2) probabilistic assessments.[111] Neither of the approaches eliminates uncertainty, but they each provide different methods to approach risk. [112] For some suggestions on how to address risk in planetary protection policy, see Appendix E.

Assessing Approaches to Risk

The Precautionary Principle

Scholars and policymakers have advanced several formulations of the precautionary principle (O'Riordan and Cameron 1994), but the fundamental tenet remains: *take caution*

[110] Uncertainty is defined as "where the likelihood of peril is nonquantifiable," compared to risk, "where the likelihood is quantifiable" (Farber 2011).

[111] These are not mutually exclusive categories. For example, you could set a cautious risk requirement that relies on the precautionary principle to set but a probabilistic assessment to reach. However, for simplicity we consider them separately here.

[112] Risk is typically defined as the product of the likelihood and potential consequence of an event, or the sum of the products for a suite of outcomes

in light of uncertainty. In domains of uncertainty, the principle suggests that decision makers should act with caution beyond what is certain; for example, acting "in advance of scientific certainty to protect the environment from incurring harm" (O'Riordan and Jordan 1995).

With regard to planetary protection, the philosophical root of the policy is precautionary. Neither scientists nor policymakers know if life exists on other planets or if such life could be harmful to Earth's biosphere. Planetary protection policies act in advance of certainty by assuming extraterrestrial life is extant and that it could be harmful, then taking the precaution of reducing the probability of contamination to near zero.

Attempting to prevent that contamination often takes a precautionary approach. For example, the requirements circumscribe the microbial bioburden, although those microbes may not survive to proliferate on another celestial body; they also require quarantine procedures for humans after they have returned to Earth, although they may not carry anything dangerous. Policymakers did not implement these requirements as a mitigation to a probabilistic assessment, but as prudent measures to an uncertain risk.

Some scholars have taken issue with the precautionary principle, as it is generally vague on what actions are required beyond "take care." It may understate the potential risks of government intervention, and may also be overused when individuals fail to conceptualize the relevant risks (Bodansky 2004, Cross 1996, Stone 2001, Sunstein 2003). There have been some attempts to further define formulations of the precautionary principle. For instance, one formulation of the precautionary principle—the best available technology approach—advocates implementing the best available technology for planetary protection in light of the uncertainty of contamination (ESF and ESSC 2012).[113] The precautionary principle may also lead to deterministic requirements that are overly conservative, not aligned to actual risk, and therefore not cost effective.

The Probabilistic Approach

Probabilistic approaches include consideration for both the likelihood and the consequences of a potential event. Instead of choosing deterministic steps to avoid or mitigate a potential adverse effect (i.e., the precautionary principle), a mission planner or decision maker assesses the risk. Based on the assessment of risk, a mission planner can implement mitigations to reduce the risk and a decision maker can determine whether the risk is acceptable (contingent on the potential benefit) and whether to approve the mission. A completely probabilistic approach would define a maximum acceptable probability for the end-adverse event. For example, planetary protection policy used to rely on a top-level

[113] Sunstein (2003) argues against the use of the precautionary principle, as the goal to be cautious may be a paralyzing force.

limit to the probability of contamination could specify that the "Probability that a planetary body will be contaminated should be no more than $1x10^{-3}$" (COSPAR 2017). [114]

Policymakers can leverage probabilistic approaches to implement a precautionary approach. For example, limiting the probability of microbial contamination on a celestial body is still precautionary because it assumes that the contamination would be harmful. A fully probabilistic approach would set a risk limit for harming astrobiological research, taking into account not only the probability of contamination, but also the probability that life exists or has existed and that the terrestrial contamination would harm the search for it.

Probabilistic approaches provide a method to compare the risk of a mission with other considerations, such as alternative mission options or the potential benefits of the mission. These methods also require an explicit definition of some assumptions through the specification of modeling parameters such as duration.[115] Probabilistic assessment, however, can provide a false sense of security. Models built upon uncertain phenomena require large assumptions and allow for the manipulation of outcomes by hiding risk in different components of the model. Furthermore, for events with incredibly low probabilities, it is unlikely that the probability of the scientific analysis is sound to that same fidelity. For example, if a report shows that the risk of a sample return introducing a catastrophic pathogen is less than one in a billion, it is very unlikely that the probability of the associated study being wrong is less than one in a billion as well. Such limitations reduce the ability to provide a prediction of the catastrophe occurring (Ord, Hillerbrand, and Sandberg 2008).

Assessment of Methodologies

A key challenge to effective planetary protection is handling uncertainty. Uncertainties will inevitably persist in planetary protection because the life forms that missions could encounter are unknown, and the environments where missions will go are not well understood. Questions over how missions could harm those environments and how return missions could harm the terrestrial environment cannot be fully resolved prior to observation—thus, decisions regarding planetary protection must be made without resolving all uncertainty. For instance, in the case of backward contamination, without knowledge of a microbe's biology—and how similar or different it is from DNA—it is

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[114] This is no longer a top-level requirement for planetary protection but instead exists as guidance. For more information, see details in Chapter 2.

[115] Duration is an important component of how risk guidelines are applied. Period of exploration refers to all missions that will be undertaken during a particular period of time. If risk guidelines are not implemented on a per mission basis, multiple missions must divide up the overall allowable risk over a period of at least 50 years (COSPAR 2017).

difficult, if not impossible, to predict the likelihood of it replicating in or harming the terrestrial environment.

If stakeholders do not clearly address uncertainty, ambiguity aversion may play a dominant role in decision-making. Multiple studies have provided strong empirical evidence for the psychology of ambiguity aversion, where humans avoid making decisions where they lack certainty to avoid a feeling of incompetence, and take actions to increase their certainty regardless of the actual risks (Heath and Tversky 1991; Barberis and Thaler 2003). This fear of uncertainty may cause risk areas, such as nuclear power or planetary protection, to receive outsized investment regardless of the actual risk of a mission.

No approach to setting requirements, whether precautionary or probabilistic, can remove the uncertainty. Probabilistic approaches, however, may be appealing because they attempt to quantify the risk, allowing a comparison with benefits and giving decision makers a sense of certainty—even if that certainty is false. Uncertainty cannot be engineered out of probabilistic models, nor is it often effectively considered or propagated into the final variables. A tendency towards certainty could also lead probabilistic methodologies to underweight the likelihood of a negative outcome (e.g., not including an uncertain vector for backward contamination). There is the potential to assume that scenarios that cannot be quantified have a very small likelihood (Farber 2011) as well as to miss extreme events that are not apparent in a statistical analysis (Taleb 2007).

Precautionary methods by nature address uncertainty by setting requirements ahead of human understanding. By acting in advance of certainty, the decisions are by definition being conservative. For example, Europa Clipper implementation requirements assume that a single microbe will contaminate the entirety of the Moon’s ocean, even though the probability is certainly not unity. Sometimes this precaution may be prudent, especially when the potential consequences are high, but applied too often or to low stakes may result in policy and requirements that are overly conservative (i.e., not aligned with the actual risk).

Setting effective requirements to mitigate forward and backward contamination will require an explicit acknowledgment of uncertainty and a balance of precautionary and probabilistic approaches. Policymakers should seek to encourage the definition of risk but not allow probabilistic approaches to hide uncertainty or heedlessly eliminate the need for caution. Similarly, any new requirements should take prudent precaution, especially where the potential consequences are high, but should also take care to not be unnecessarily conservative or inhibitive. Admittedly, this is a very complex and challenging undertaking for policymakers.

Considerations for Using and Communicating Risk

Approach Uncertainty Separately for Backward Contamination and Forward Contamination

Backward contamination will likely require different methodological approaches to uncertainty compared to forward contamination efforts, given that the terrestrial system warrants greater protection. When the entire tree of life is potentially at stake, a small likelihood could still tip conventional risk assessments to call for massive investments. It may be useful to more fully review how catastrophic uncertainty analyses compare to conventional risk analyses.

Clarify the Rationales and Assumptions of Requirements

While it is difficult to set requirements for planetary protection, the rationales and assumptions upon which the requirements are based should always be clear. Requirements, especially top-level guidelines (such as that a planetary body will be contaminated to no more than $1x10^{-3}$), trickle down and affect multiple requirements and all aspects of a mission. The rationales for current planetary protection requirements are ambiguous and were formulated only as the estimates of experts in 1964 (Meltzer 2011).

Lack of clarity on why a value was chosen is an issue because the number may appear to be set in stone. It is more difficult to adjust values based on new scientific understanding if that understanding cannot be compared to the original rationale.

Sometimes it may not be possible to set a requirement with clear reasoning. If the best option going forward is to still choose a number that seems reasonable to enough people, that rationale should be documented to maximize flexibility. This will enable an update to the probability of contamination limits in the event new knowledge is gained.

Emphasize Communication of Risks and Decision-Making Processes

The methods by which the U.S. Government communicates contamination risks will be critical for building trust with domestic and international entities. Backward contamination will require particular care, given that the safety and security of the public is subject to a greater risk.[116] Communication of the risks of harming the terrestrial environment and the steps missions are taking to mitigate those risks will have several impacts. These include mitigating the potential for lawsuits, meeting mission launch timelines, budgeting for these endeavors, and planning for future exploration efforts.

[116] See the ESF (2012) report on backward contamination from Mars that provides a fuller discussion of the importance of risk perception for planetary protection.

Mission owners and decision makers should broaden discussions to allow the interagency community and experts to provide inputs. Such discussions can identify improvements to probabilistic models or prudent best practices to follow. Although final decisions may not require interagency or Presidential approval, a forum for input will improve decision-making processes. In addition, the nation should provide information to relevant international partners to maintain foreign relations and prepare for scenarios in which a return mission may land in a foreign territory.

Illustrations

Figures

Tables

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Abbreviations

APL	Applied Physics Laboratory
ATP	Adenine Triphosphate
BAT	Best Available Technology
BSL	Biosafety Level
CDC	Centers for Disease Control and Prevention
CEQ	Council on Environmental Quality
CETEX	Committee on Contamination by Extraterrestrial Exploration
CFR	Code of Federal Regulations
CM	Command Module
COPUOS	Committee on the Peaceful Uses of Outer Space
COSPAR	Committee on Space Research
DHMR	Dry Heat Microbial Reduction
DOC	Department of Commerce
DOS	Department of State
DOT	Department of Transportation
EA	Environmental Assessment
EIS	Environmental Impact Statement
EMM	Emirates Mars Mission
EO	Executive Order
EOP	Executive Office of the President
ESA	Earth Safety Analysis
ESA	European Space Agency
ESF	European Science Foundation
ESSC	European Space Studies Committee
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
HR	House Resolution
IAU	International Astronomical Union
ICBC	Interagency Committee on Back Contamination
ICSU	International Council of Scientific Unions
IDA	Institute for Defense Analyses

iMARS	International Mars Architecture for the Return of Samples
INSRP	Interagency Nuclear Safety Review Panel
ISO	International Organization for Standardization
JPL	Jet Propulsion Laboratory
LEO	Low Earth Orbit
LRL	Lunar Sample Receiving Lab
MEO	Medium Earth Orbit
MER	Mars Exploration Rover
MMX	Martian Moons eXploration
MSR	Mars Sample Return
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NID	NASA Interim Directive
NOAA	National Oceanic and Atmospheric Administration
NPD	NASA Policy Directive
NPI	NASA Policy Instruction
NPR	NASA Procedural Requirement
NRC	National Research Council
NSAM 235	National Security Action Memorandum No. 235
NSTC	National Science and Technology Council
OST	Outer Space Treaty
OSTP	Office of Science and Technology Policy
PD/NSC-25	Presidential Directive/National Security Memorandum 25
PPO	Planetary Protection Officer
PPP	Planetary Protection Policy
S&T	Science and Technology
SAA	Space Act Agreement
SAR	Safety Analysis Report
SCIM	Sample Collection to Investigate Mars
SER	Safety Evaluation Report
STM	Space Traffic Management
STPI	Science and Technology Policy Institute
T-ATP	Total-Adenine Triphosphate
TSA	Trypticase-Soy-Agar
U.S.C.	United States Code

UN	United Nations
UNOOSA	United Nations Office of Outer Space Affairs
VHP	Vapor Hydrogen Peroxide
WG	Working Group

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14. ABSTRACT

New mission designs, advances in science and technology, and the entrance of new actors has raised concerns with the applicability of planetary protection to modern space activities. Planetary protection is a term that generally refers to the practice of avoiding contamination of other celestial bodies by terrestrial lifeforms or organic compounds (so-called “forward contamination”) and avoiding contamination of the Earth by extra-terrestrial biological organisms (“backward contamination”). To address these challenges, the White House Office of Science and Technology Policy (OSTP) requested the IDA Science and Technology Policy Institute (STPI) to: review current planetary protection policies and approaches; summarize current U.S. and international law, regulation, standards, policies and practices governing planetary protection; assess relevant authorities, challenges, and opportunities for change; and provide policy options to inform OSTP in reviewing and updating, as necessary, national planetary protection policies.

15. SUBJECT TERMS

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