National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

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Reply to Attn of: Science Mission Directorate

NASA Response to Planetary Protection Independent Review Board Recommendations

I want to thank Chair Alan Stern and the knowledgeable and hardworking board he pulled together for their quick and comprehensive work to produce this report of the Planetary Protection Independent Review Board (PPIRB).

This report represents an important step forward in a very complex area. It helps inform how we at NASA modernize our approach to the wide range of issues and work with the commercial and international partners who will be involved with us in planetary exploration throughout the solar system in the coming years. The report reaffirms the direction of NASA's thinking and changing practice in this area. We appreciate the PPIRB's assessment that recent changes in the Planetary Protection Office (PPO) and its relocation to the Office of Safety and Mission Assurance (OSMA) have improved communication, clarity, and responsiveness to community needs and concerns.

This is a first step, and there is much important work left to do. Our intent is always to encourage exploration and to be responsible stewards of the amazing places we have the opportunity to visit and to do the very best science while also protecting our home planet.

The report highlights changes in planetary science and planetary protection techniques in recent years. In light of the current pace of change, and the likelihood that it will accelerate in the future, NASA agrees that planetary protection policies need to be updated regularly and expeditiously to be effective. Moreover, and consistent with guidance from a recent report of the National Academies of Sciences, Engineering and Medicine, the way planetary missions are implemented must adapt to the combination of scientific advances and the changing reality of space exploration. NASA is best served with a revised policy regime that enables exploration — both public and private — while also complying with the relevant articles of the Outer Space Treaty and protecting opportunities for scientific discoveries to be made in the future.

We now move toward the internal and external coordination that will enhance this discussion and inform NASA's next steps.

Following the Agency's initial review of the PPIRB's report, I have asked Dr. Lisa Pratt, NASA's Planetary Protection Officer, and Dr. Lori Glaze, the Planetary Science Division Director, to lead the Agency's implementation of the PPIRB's findings and recommendations. Dr. Pratt and Dr. Glaze will coordinate with offices across NASA and the commercial sector, as needed, to carry out this task. Several of the recommendations in this report will require interagency and international coordination; NASA will engage with our interagency and international partners to pursue the implementation of those recommendations as required.

Actively listening to our broader community of experts will be even more critical as we move forward. NASA will work to engage the National Academies and the NASA Advisory Council (NAC), both of which recommended that NASA establish an expert group to explore the changing landscape of planetary exploration. The feedback received from the National Academies and the NAC will be essential in formulating NASA's recommendations to the Committee on Space Research's international planetary protection guidelines.

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Associate Administrator,
Science Mission Directorate

2019

NASA Planetary Protection Independent Review Board (PPIRB)

REPORT TO NASA/SMD

--FINAL REPORT--

Table of Contents

List of Acronyms Used

AA	Associate Administrator
BSL-4	Biosafety Level 4
COSPAR	Committee on Space Research
COPUOS	Committee on the Peaceful Uses of Outer Space
COR	Contracting Officer's Representative
CSA	Canadian Space Agency
CTS	Cornell Technical Services
ESA	European Space Agency
ISECG	International Space Exploration Coordination Group
IAU	International Astronautical Union
ICS	International Council for Science
ICSU	International Council of Scientific Unions
IRB	Independent Review Board
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
MMX	Martian Moons eXploration
MSR	Mars Sample Return
MSRF	Mars Sample Receiving Facility
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering and Medicine
NPR	NASA Procedural Requirement
NPD	NASA Policy Directive
OSMA	Office of Safety and Mission Assurance
OST	Outer Space Treaty
PP	Planetary Protection
PPIRB	Planetary Protection Independent Review Board
PPO	Planetary Protection Office
SMD	Science Mission Directorate
SWRI	Southwest Research Institute
UN	United Nations
UV	Ultraviolet

Executive Summary

In mid-2019, NASA chartered this Planetary Protection Independent Review Board (PPIRB) to assess how its Planetary Protection (PP) policies can be improved and streamlined, and how those policies should adapt to the entry of new planetary mission opportunities and new players, particularly in the private sector. The PPIRB was charged to complete its work in an approximately 90-day timeframe spanning July to September 2019. The chair and members offer to continue their work, if desired by NASA, to delve into specific details, to brief stakeholders, or as otherwise deemed necessary by the Agency.

This report and an associated briefing package to NASA constitute the deliverables from the PPIRB's work. This report provides a brief background on PP, summarizes the meetings and other work the PPIRB performed, and makes a wide-ranging series of findings and recommendations to NASA regarding extant and future PP policy. Those findings and recommendations, which concern both PP processes and policy, are organized into topical categories; within each topical category, findings and recommendations have been categorized as either major or supporting.

This report also contains a set of appendices that provide ancillary information. Outside of this report, NASA, through its PPIRB Review Manager, Dr. T. Jens Feeley, has collected all of the presentations made to the PPIRB during the span of its work.

The chair and members of the PPIRB note that many stakeholders who presented to the PPIRB applauded NASA for its foresight in recognizing the changing PP landscape and soliciting the input of a review to help chart a path forward. The PPIRB also applauds SMD's and OSMA's recent revamping of the Planetary Protection Office (PPO) and the work of the new PP Officer, which has increased communication, clarity, and responsiveness to community needs and concerns.

Key among the overarching recommendations that the PPIRB makes here is to regularly reconstitute a similar activity every few years as the PP landscape evolves. Such regular reviews should again independently assess how NASA's PP policies can be improved and streamlined, and how those policies should further adapt.

Numerous other major findings and recommendations, along with numerous supporting findings and recommendations, are detailed below.

1.0 Background

Planetary Protection Background. In its essence, Planetary Protection (PP) refers to (i) managing contact between terrestrial life forms and organic material from celestial bodies as it relates to adversely affecting the scientific study of these bodies, called forward contamination; and (ii) mitigating harmful contact between pathogens or biology from other celestial bodies and terrestrial biology, called backward contamination.

PP policy originated in the late 1950s. In 1967, the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," commonly referred to as the Outer Space Treaty (OST), was signed and ratified by the United States. Article IX of the OST addresses harmful contamination of the Earth and other celestial bodies. Over time, the Committee on Space Research (COSPAR), NASA, and others have developed PP guidelines to clarify how State Parties to the OST could address the harmful contamination aspects of Article IX. The COSPAR voluntary international guidelines and the NASA PP guidance stemmed from procedures and techniques originally developed for the Viking program, NASA's first Mars lander mission. More than two dozen U.S. National Academy of Sciences reports have previously reviewed and evaluated planetary protection.

NASA's PP activities are centered in its Planetary Protection Office (PPO), which resides within the Office of Safety and Mission Assurance (OSMA). The PPO categorizes missions NASA is involved in based on estimated threats they may pose to undesirable forward or backward contamination. NASA planetary protection policy then requires implementation of mitigation strategies to reduce the risk of forward or backward contamination. Neither COSPAR PP guidelines nor PP as implemented by NASA directly addresses or attempts to mitigate the ethical issues of forward contamination that could threaten the biota of other celestial bodies. Nor does PP address historical site preservation or the implications of the human modification of bodies in the Solar System, for example for resource recovery.

Current NASA and COSPAR PP regimes were developed prior to the emergence of recent stakeholders, including the growing capability for private sector entities to engage in planetary missions, although NASA and COSPAR PP guidelines are being updated to reflect these emerging missions.

In some parts of the private sector and within some NASA mission circles (particularly for missions in study or very early stages of formulation), there is significant confusion over many aspects of NASA PP policy and how it applies to increasingly diverse space activities.

Report Background. On April 23, 2019, NASA announced the establishment of a Planetary Protection Independent Review Board (PPIRB).[1] The PPIRB was set up in response to a National Academies of Sciences, Engineering and Medicine (NASEM) report entitled "Review and Assessment of Planetary Protection Policy Development Processes,"[2] and a recommendation from the NASA Advisory Council

[1] https://solarsystem.nasa.gov/news/915/new-planetary-protection-board-to-review-guidelines-for-future-solar-system-and-beyond-exploration/ and included in the Appendices.
[2] https://www.nap.edu/download/25172

(NAC).[3] NASA concurred on the NAC recommendation and agreed to implement both that and recommendations from the NASEM report through the following statement:

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

The complete PPIRB Review Outline is provided as Appendix A to this report. This document constitutes the PPIRB's report to NASA in response to NASA's charge to the PPIRB. A summary overview of the IRB process itself is provided next.

Review Overview. The PPIRB was tasked by the SMD Associate Administrator, Dr. Thomas Zurbuchen, on behalf of NASA, to conduct a quick-turnaround, 3-month, independent look at updating biological contamination guidelines developed by COSPAR in light of current plans for Mars sample return, emerging capabilities for private sector robotic missions, eventual human missions to Mars, and the exploration of the icy moons of the outer planets. This review was conducted between late June and late September of 2019.

The PPIRB explored various aspects of the scientific, engineering, industrial, legal, and program management aspects of planetary protection. Among many relevant documents, the PPIRB members read the NAC recommendation and the NASEM report as part of their review of previous work on this subject. As described below, the PPIRB also met four times in person, comprising 10 days of meetings and held 11 telecons to hear from PP experts and stakeholders and to make deliberations on findings and recommendations.

The PPIRB membership, recruited by NASA, has experience in program and project management, engineering, planetary and astrobiological science, the commercial spaceflight sector, industry and legal matters relevant to planetary protection.

The PPIRB membership consists of the following expert consultants:

Dr. Alan Stern, PPIRB Chair	Southwest Research Institute
Dr. Edward (Beau) Bierhaus	Lockheed Martin
Dr. Wendy Calvin	University of Nevada, Reno
Dr. Amanda Hendrix	Planetary Science Institute
Dr. Christopher H. House	Pennsylvania State University

[3] https://www.nasa.gov/sites/default/files/atoms/files/nasa_response_to_nac_rec_2018-03-03-cospar_tagged.pdf and included in the Appendices.

Dr. Hernan Lorenzi	J. Craig Venter Institute
Mr. Tommy Sanford	Commercial Spaceflight Federation
Dr. Erika Wagner	Blue Origin
Dr. Andrew Westphal	University of California at Berkeley
Mr. Charles Whetsel	Jet Propulsion Laboratory
Mr. Paul Wooster	SpaceX
Dr. T. Jens Feeley, Review Manager	NASA Headquarters (*Ex Officio*)

The PPIRB members were vetted through Cornell Technical Services (CTS) and the PPIRB held an initial organizational telecon on June 28, 2019. The PPIRB then held weekly planning telecons when not meeting in person and received additional input from presenters at some of those weekly telecons.

The PPIRB also met in person at NASA Headquarters in Washington, DC, on July 10-11, at the Jet Propulsion Laboratory (JPL) in Pasadena, CA, on July 30-31, at the Southwest Research Institute (SWRI) in Boulder, CO, on August 5-7, and again at NASA Headquarters in Washington, DC, on September 4-5, to receive input from a variety of government, university and private sector individuals and to deliberate on the findings and recommendations presented in this report.

The deliverables of the PPIRB, as described in the Review Outline in Appendix A, are as follows:

1. A presentation to the Associate Administrator for the Science Mission Directorate, Dr. Thomas Zurbuchen, and other NASA stakeholders summarizing the review results, held on October 8, 2019, at NASA Headquarters in Washington DC; and,

2. This final report, which we note has no non-consensus elements.

Additionally, the PPIRB Chair has agreed to support future briefings to other stakeholders, including to a joint meeting of committees or the full NASA Advisory Council and to COSPAR's PP panel.

The agendas of the four PPIRB in-person meetings comprise Appendix B to this report. Appendix C contains recent NAC recommendations and NASA's response that led to this PPIRB. Appendix D summarizes current COSPAR PP guidelines. Appendix E contains references cited in this report.

This report was reviewed by NASA in advance of its release to ensure that the scope of this report meets the intent of the PPIRB's charge and that this report's findings and recommendations are clear. NASA did not review or provide feedback on the desirability or implementability of the findings and recommendations herein.

2.0 Glossary of Terms

Planetary Protection. The practices of reducing biological forward contamination that could affect astrobiological investigations on other celestial bodies and backward contamination that might have adverse impacts on Earth's biosphere.

Forward Contamination. The delivery of terrestrial biology from Earth to other celestial bodies, and specifically, as it relates to adversely affecting the scientific study of these bodies.

Backward Contamination. Harmful contact between terrestrial biology and pathogens or biology arriving on Earth from other celestial bodies, generally in the context of a mission returning materials from such a body to the Earth.

Contamination Control. The practice of controlling the introduction and removal of unwanted materials that could impede the proper function of a system or component (e.g., clean rooms, visual inspection, offgassing minimization, flushing of fluid lines). While contamination control measures often serve to reduce the risk of forward contamination for planetary production, their ultimate goal is to improve system function.

Biota. In this report, "biota" is a generic term for all life forms, microorganisms, viruses, and prions that have the ability to take in energy from the environment and transform it for growth and reproduction. For the purposes of planetary protection, this is assumed to include all putative forms of exobiology, regardless of their composition or form.

Private Sector. In this report, the term "private sector" refers to products, services, or activities that have significant private capital at risk and their primary financial and management responsibility is within the private sector. The PPIRB intentionally utilizes the term "private sector" to capture the broad nature of private entities seeking to conduct space activities, ranging from privately funded non-profits to for-profit commercial space companies. The PPIRB intends for the term "private sector" as used in this report be consistent with the term "commercial" as defined in the 2010 National Space Policy and the amended National Aeronautics and Space Act of 1958.

Robotic Missions. When used in this report, robotic missions are considered to be untended flights of autonomous systems intended primarily for the conduct of science. This classification does not include missions which are neither crewed nor of this sort, but which could support future crew or crew-support vehicles (e.g., habitat placement, pre-staged cargo emplacement, test flights of human vehicles).

3.0 Findings and Recommendations

The output of the PPIRB consists of a series of Planetary Protection (PP) findings and recommendations pertinent to the next 3-5 years. These findings and recommendations are grouped into the following topic categories:

- General/Overarching
- Planetary Protection Categorization
- Human Spaceflight
- Private Sector Initiatives and Missions
- Robotic Mars Sample Return
- Ocean Worlds Exploration
- COSPAR

As further described below, the longer-term evolution of technology and science will influence PP in ways this PPIRB could not predict and will warrant future PP reviews.

The PPIRB findings and recommendations now follow, in turn, by category. The text of each finding and recommendation is bolded; supporting text, where given, is provided without being bolded. No indication of priority should be assumed by the order that findings and recommendations are presented within a topic category, or by the order of the topic categories themselves.

However, within each topic category, the PPIRB findings and recommendations have been classified as either Major or Supporting to indicate to stakeholders and Agency executives the PPIRB's sense of urgency and impact regarding each finding and recommendation. Major findings and recommendations are further indicated by grey backgrounds.

General/Overarching Findings and Recommendations

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

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

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

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

> **<u>Major Recommendation:</u> Because of advances in knowledge and technologies since the Viking era, NASA's PP policies and implementation procedures should be reassessed.** PP technology and relevant science disciplines are progressing rapidly; thus, the PPO should refresh its knowledge of the state of the art in PP science and technology, and apply this knowledge to advance, and where feasible, simplify PP implementation. This likely requires additional PPO funding to be effective.
>
> **<u>Major Recommendation:</u> Owing to the changing PP context and the rapid advancement of scientific, technological, and private sector planetary mission capabilities, NASA should reassess its PP guidelines at least twice per decade with an IRB-like body that includes representatives of all major stakeholder communities.** The PPIRB findings and recommendations presented in this report apply to the current era and generally are made with a 3-5 year horizon in mind.
>
> **<u>Major Recommendation:</u> NASA should establish a standing forum for the discussion and resolution of emergent PP issues that includes input from government, private sector, and perhaps even non-U.S. private sector enterprises.**

<u>Major Finding:</u> The PPIRB applauds SMD’s and OSMA’s recent revamping of the PPO and the work of the new PP Officer, which has increased communication, clarity, and responsiveness to community needs and concerns.

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

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

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

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

<u>Major Finding:</u> The late addition of PP requirements to some projects has been costly and inefficient to implement.

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

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

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

> **<u>Supporting Recommendation</u>: Policy regarding such application of Agency authority to affect PP implementation should be carefully reviewed above the PPO level.**

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

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

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

<u>Supporting Finding</u>: The PPIRB applauds and encourages flexible ways to address PP intent using novel methods.

<u>Supporting Recommendation</u>: The PPO should exploit new discoveries and new technologies to better categorize exploration targets, create better forward and backward PP implementation protocols, and lower PP cost and schedule impacts on projects.

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

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

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

<u>Supporting Recommendation</u>: The PPO should implement both well-documented and transparent PP requirements and requirements waiver processes for all missions with NASA involvement.

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

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

<u>Supporting Recommendation</u>: NASA should assess how to streamline PP implementation for ultra-low cost planetary missions.

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

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

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

<u>Supporting Recommendation</u>: These contractual requirements should be reviewed by NASA to simplify compliance where possible and to avoid overconstraining the means of meeting NASA intent.

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

Planetary Protection Categorization:

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

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

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

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

<u>Supporting Recommendation</u>: In cases of missions to Solar System destinations where there is a large population of similar Category I and II objects (e.g., comets, asteroids, Kuiper Belt Objects), NASA should allow classification of individual objects as Category I to simplify missions to them. Just as the lunar and Martian surfaces in their entirety do not need to bear the same PP classification, in the case of small bodies where there are numerous potential targets, the contamination of any individual does not cause significant contamination to the class as a whole. If chemical evolution or origin of life experiments are planned for such objects, there are myriad to choose from that will not have been previously visited by robotic probes.

<u>Supporting Finding</u>: Various scientific studies[4,5,6,7] suggest that the survival and amplification of terrestrial biota are unlikely on the Martian surface, which would support classification of much of the Martian surface as Category II.

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

Human Spaceflight

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

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

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

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

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

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

> **Major Recommendation: Regarding the return of humans and equipment from Mars, NASA should invest in developing more informed, backward contamination PP criteria, considering protection of Earth’s biosphere, the feasibility of mission implementation, and the potential for *in situ* hazard characterization on Mars.** As discussed for robotic Mars sample return below, these policies should take into consideration current understanding of the ongoing natural transport of material from Mars to Earth since the formation of the planets ~4.5 billion years ago.

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

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

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

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

Private Sector Initiatives and Missions

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

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

> **Major Recommendation: In addition to balancing the needs of science and exploration, PP policy should also recognize that it is both a NASA and a national objective to encourage private sector space initiatives and commercial robotic and human planetary missions.** The National Aeronautics and Space Act of 1958, as amended, explicitly states that one of NASA's functions is to "seek and encourage, to the maximum extent possible, the fullest commercial use of space."[8] Additionally, the 2010 National Space Policy expressly directs Federal agencies to "minimize, as much as possible, the regulatory burden for commercial space activities" and to "refrain from conducting United States Government space activities that preclude, discourage, or compete with U.S. commercial space activities."[9]

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

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

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

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8 See https://history.nasa.gov/spaceact-legishistory.pdf

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

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

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

Robotic Mars Sample Return

<u>Major Finding</u>: Martian material has been naturally transported to Earth for billions of years.[10,11] Current Mars Sample Return (MSR) requirements do not take the natural transport and survival of Mars material into account. Further, quantitative PP risk requirements, which are based on engineering requirements, lack a fully rational basis considering this history. In contrast, the National Academies' Consensus Study Report on Planetary Protection Classification of Sample Return Missions from the Martian Moons eXploration (MMX) took into account the natural flux of Martian material to Earth in their recommendation that MMX samples returned from the Martian moons be designated as unrestricted. That report noted that the natural flux of material from Mars to Earth is orders of magnitude greater than the flux from any conceivable robotic sample return.

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

<u>Major Finding</u>: As the first restricted Earth return since Apollo, MSR will be a uniquely high profile mission. Significant effort is being put into the MSR architectures to ensure there will be no harmful interference with Earth's biosphere. This includes NASA work (alongside international partners) to "break the chain of contact" with the Mars environment during sample collection procedures on Mars 2020, the Sample Retrieval Lander and return procedures with the Earth Return Orbiter.

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

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

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

<u>Supporting Finding</u>: Some types of sterilization of Mars samples are antagonistic to many important types of scientific measurements.

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[10] National Academies of Sciences, Engineering, and Medicine. 2019. Planetary Protection Classification of Sample Return Missions from the Martian Moons. Washington, DC: The National Academies Press. https://doi.org/10.17226/25357 .
[11] Mileikowsky, C. et al., Icarus. 2000 June;145(2):391-427.

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

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

Ocean Worlds Exploration

<u>Major Finding</u>: The fraction of terrestrial microorganisms in spacecraft bioburdens that has the potential to survive and amplify in ocean worlds is likely to be extremely small.[12,13] Further, any putative indigenous life in subsurface oceans on Europa, Enceladus, or Titan is highly unlikely to have a common origin with terrestrial life. Any such life would be readily distinguishable from terrestrial microorganisms using modern biochemical techniques. As a consequence of these findings, the current bioburden requirements for Europa and Enceladus missions (i.e., <1 viable microorganism) appear to be unnecessarily conservative.

> **<u>Major Recommendation</u>: The PP requirements for ocean worlds exploration should be reassessed in light of this finding.**

<u>Supporting Finding</u>: Category IV is currently assigned to landed ocean world missions when there is a significant probability of contamination of the liquid interior oceans. However, the situation for each ocean world environment is very different and limited information exists for each of these worlds regarding ice shell composition and thickness, ocean composition and habitability, interfaces/communication between the surface and ocean, and any transport of material across the surface. For example, the differences between the environments of Enceladus, Europa and Titan are significant. The subsurface ocean within Enceladus is considered by many scientists to be habitable, and fractures at its South Pole provide direct access to its ocean. In contrast, Europa's ice shell is thought to vary from a few km to ~tens of km thick; in some regions, liquid lenses may be present within the ice shell, produced by local heating and melting. Titan's ocean, by contrast, lies below an organic-covered ice shell ~100 km thick and is thus largely inaccessible. Impacts into Titan's icy crust can generate melt, creating a transient liquid water environment in which the liquid water can mix with Titan's surface organics; previously melted deposits are expected near Dragonfly's ultimate target, Selk Crater.

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

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

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

COSPAR

<u>Major Finding</u>: There is a lack of consensus as to how and when the Outer Space Treaty has legal relevance to non-governmental entities.

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

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

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

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

4.0 Appendices

A. PPIRB Review Outline
B. PPIRB In-Person Meeting Agendas
C. NAC Recommendation and NASA Response
D. Current COSPAR PP Guidelines Summary
E. Cited References

Appendix A: PPIRB Review Outline

Planetary Protection Independent Review Board (PPIRB)
Review Outline

I. Background

Planetary Protection is the practice of protecting solar system bodies from contamination by Earth life and protecting Earth from possible life forms and otherwise harmful materials that may be returned from bodies in space. NASA's Office of Planetary Protection promotes the responsible exploration of the solar system by implementing and developing efforts that protect the science, explored environments and Earth.

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

Recent reviews by the NASA Advisory Council (NAC) committee and the National Academies raised concerns about whether advancements in science and engineering are outpacing those COSPAR guidelines, and these reviews also raised concerns about whether the guidelines are outdated in regard to the growing interest from commercial and private groups in exploration and utilization of Mars and other bodies in space.

II. Scope

The Planetary Protection Independent Review Board (PPIRB) will look at updating biological contamination guidelines developed by the international Committee on Space Research (COSPAR). We anticipate engagement on a weekly or biweekly basis over a period of about 3 months and estimate the level of effort to be 3 to 4 hours per week plus the possibility of travel.

III. Study Management

The convening authority for the PPIRB is NASA's Science Mission Directorate (SMD) Associate Administrator (AA). As such, the PPIRB will report to the SMD AA. This Independent Review shall be organized by Cornell Technical Services (CTS) and will be comprised of members with considerable current experience in program and project management, engineering, science, industry and legal matters relevant to planetary protection.

The SMD AA will assure the necessary support for the PPIRB. The PPIRB Chair and the SMD Contracting Officer's Representative (COR) will support all activities of the PPIRB and coordinate production and ensure the quality of review deliverables. The SMD COR will ensure that the information needs of the review members are met. The non-consensus final report will be verbally presented to the SMD AA and other NASA stakeholders, followed by the provision of a non-consensus final written report.

IV. Notional Schedule

The review panel will conduct the assessment over a 12-week period from initial meeting to completion of the non-consensus final report. The final schedule will be determined following discussions between the PPIRB, SMD AA and other NASA stakeholders.

Pre-Work	Select and appoint panel members; PPIRB members will attend all meetings from week 1 to week 12
#1: Jun 24-28	Organizational Telecon (2-hour); review background materials; June 28@11am-1pm EASTERN
#2: Jul 1-5	
#3: Jul 8-12	Face-to-face Meeting at NASA HQ in DC: July 10-11 (half-day on 7/11)
#4: Jul 15-19	
#5: Jul 22-26	
#6: Jul 29-Aug 2	Fact-finding trip (Los Angeles and Pasadena, CA): July 30-31
#7: Aug 5-9	Fact-finding trip (Denver and Boulder, CO): August 5-7 Develop and discuss draft findings for report; decide on writing assignments
#8: Aug 12-16	Draft any final questions for further discussion
#9: Aug 19-23	Work on writing assignments and internal review; submit draft report to NASA and NASA review of draft report
#10: Aug 26-30	Review NASA comments on draft report; close out remaining questions and revise draft report; and NASA reviews revised draft report and submits final comments
#11: Sept 2-6	Complete draft report
#12: Sept 9-13	Brief non-consensus final report to SMD AA and other NASA stakeholders in Washington, DC
#13: Sept 16-20	Prepare non-consensus final report; print & deliver to SMD AA

V. Deliverables

- Presentation to SMD AA and other NASA stakeholders summarizing the review results.
- Non-consensus final report with observations, findings, concerns, and Recommendations consistent with Section II above.

VI. Personnel

The PPIRB membership includes:

Dr. Alan	Stern	SWRI, Chair
Dr. Edward (Beau)	Bierhaus	Lockheed Martin
Dr. Wendy	Calvin	University of Nevada-Reno
Dr. Amanda	Hendrix	Planetary Science Institute
Dr. Chris	House	Pennsylvania State University
Dr. Hernan	Lorenzi	J. Craig Venter Institute
Mr. Tommy	Sanford	Commercial Spaceflight Federation
Dr. Erika	Wagner	Blue Origin
Dr. Andrew	Westphal	University of California at Berkeley
Mr. Charles	Whetsel	Jet Propulsion Laboratory
Mr. Paul	Wooster	SpaceX

Ex Officio (Review Manager): Dr. T. Jens Feeley

Approved:

Thomas Zurbuchen
Associate Administrator
Science Mission Directorate

Appendix B: PPIRB Meeting Agendas

Agenda: July 10, 2019 (NASA Headquarters)

Time	Presenter(s)	Affiliation	Topic(s)
9:00-10am	Thomas Zurbuchen & Alan Stern	NASA, SWRI	Introductions/Overview of the PPIRB
10-10:30	Members	---	Administrative discussion
10:30-11	Michael Gold	Maxar	NASA Advisory Council Recommendation:
11-Noon	Joe Alexander & David Smith	Consultant, NASEM	NASEM Report on PP Policy Development
Noon to 1pm	Members	---	Lunch
1-2	Lori Glaze	NASA	NASA Planetary Science Plans
2-3	Marc Neveu		Habitable Zones Overview
3-4	Jim Green	NASA	COSPAR Planetary Protection Panel
4-5	Members		Discussion

Agenda: July 11, 2019 (NASA Headquarters)

Time	Presenter(s)	Affiliation	Topic(s)
8:30-11:00am	Lisa Pratt	NASA	Current State of Planetary Protection at NASA
11-Noon	Marshall Smith	NASA	Plans for Human Exploration of Mars
Noon-12:30pm	Members	---	Discussion/Plans for Site Visits

Agenda: July 30, 2019 (JPL and LASP)

Time	Presenter(s)	Affiliation	Topic(s)
8-8:15am	Charles Whetsel	JPL	Intro, Logistics, Agenda Review
8:15-9:00	Charles Whetsel	JPL	View Mars 2020 Integration & Test
9-9:30	Scott Hubbard	Stanford University	Perspectives on science and non-governmental aspects of PP
9:30-10	Alvin Smith, John Logar	JPL, Johnson & Johnson	NASA Sterilization Working Group
10-10:30	Barry Goldstein, et. al.	JPL	Europa Clipper Project
10:30-11	Members	---	Break & Discussion

11-11:30	James 'Nick' Benardini, et. al.	JPL	InSight/PI mission perspective
11:30-Noon	James 'Nick' Benardini	JPL	Metagenomics Inventory Research
Noon-12:45pm	John McNamee, et al.	JPL	Mars 2020 experience with PP
12:45-1:30	Lunch	----	----
1:30-2:30	Dave Beaty	JPL	Special Topic
2:30-3	Adam Schilffarth	Xplore	Private sector experience and views
3-3:30	Members	----	Break & Discussion
3:30-4	Dianne Newman	CalTech	Ongoing research including identifying meaningful biomarkers
4-4:30	Kris Zacny	Honeybee Robotics	Drilling, containment, Europa Lander sampling
4:30-5	Members		Discussion

Agenda: July 31, 2019 (JPL & SpaceX)

Time	Presenter(s)	Affiliation	Topic(s)
8-8:30am	Pete Worden	Breakthrough Foundation	Enceladus or Europa mission plans
8:30-9:30	Margarita Marinova	SpaceX	SpaceX plans for future missions; Red Dragon experience
9:30-10	Members	---	Break & Discussion
10-10:30	Carol Stoker & Penny Boston	NASA	the requirements and payload design for robotic life detection in advance of human exploration
10:30-11	Kevin Hand, et al.	JPL	Europa Lander sampling, technologies for ocean worlds
11-Noon	Jen Eigenbrode, Alfonso Davila (and Chris McKay)	NASA	Proposed missions to special regions on Mars and to Enceladus
Noon-1:00pm	Rob Manning	JPL	Working Lunch: discuss followup from yesterday
1-2:00	Brian Muirhead, et al.	JPL	MSR Overview
2-2:30	Discussion	---	Findings and Recommendations; plans for Colorado trip
2:30-3:30	Members	---	Travel to SpaceX
3:30-5	Members	---	Tour SpaceX

Agenda: August 6, 2109 (SWRI & Lockheed Martin)

Time	Presenter(s)	Affiliation	Topic(s)
8-10:45am	Members	---	Discuss potential findings, Recommendations, writing assignments
10:45-12:15pm	Members	---	Travel to Lockheed Martin
12:15-1:30	Members	---	Lunch
1:00-1:10	Stu Spath	Lockheed Martin (LM)	Welcome and introductions
1:10-1:30	Dave Murrow	LM	LM experience with missions that require planetary protection, and future plans
1:30-2:15	Joe Witte	LM	mechanics of planetary protection
2:15-2:30	Cat Riegle	LM	Contamination control
2:30-3:00	Members	LM	Discussion
2:55-3:00	n/a	LM	Break before tour
3:00-4:30	various	LM	tour of facilities used for spacecraft build, test, and operation
4:30-5:45	Travel to Boulder		

Agenda: August 7, 2019 (SWRI)

Time	Presenter(s)	Affiliation	Topic(s)
8am-2pm	Members		Discussion

Agenda: September 4, 2019 (NASA Headquarters)

Time	Presenter(s)	Affiliation	Topic(s)
8-8:15am	Stern & Feeley	SWRI & NASA	Overview and Agenda
8:15-9:15	Lal & Watson	STPI & OSTP	OSTP-STPI report on Planetary Protection-related interviews
9:15-9:45	Members		Discussion
9:45-10:15	Diane Howard	NOAA	NOAA's role in interagency process
10:15-10:55	Patricia M. Beauchamp	JPL	Technology for Europa missions
10:50-11	Members	---	Break

11-11:45	Alison Murray	DSI	utilizing molecular biological and genomic approaches to describe the diversity of life
11:45-1:00pm	Members	---	Lunch
1-1:30	Phil Brinkman	FAA	FAA role and perspectives
1:30-2	Anne Sweet	NASA	NASA-internal process
2-2:30	Marc Timm	NASA	Red Dragon and Moon Express experience
2:30-3	Gabriel Swiney	DOS	International Law and Outer Space Treaty
3-3:30	Members	---	Break / Discussion / Contingency
3:30-4	Ann M. Zulkosky	Lockheed Martin	Perspectives on congressional interest (prior job) and Lockheed experience
4-5:15	Tom Hammond	HSCI	Congressional perspective (House Science Minority staff)
5:15-5:30	Members		Discussion

Agenda: September 5, 2019 (NASA Headquarters)

Time	Presenter(s)	Affiliation	Topic(s)
8am-Noon	Members		Discussion

Appendix C: NAC Recommendation and NASA Response

NASA Advisory Council Recommendation

COSPAR
2018-03-03 (RPC-03)

Recommendation:
NASA should establish a multi-disciplinary task force of experts from industry, the scientific community, and relevant government agencies, to develop U.S. policies that properly balance the legitimate need to protect against the harmful contamination of the Earth or other celestial bodies with the scientific, social, and economic benefits of public and private space missions. The recommended multi-disciplinary task force should be tasked with producing a detailed policy, provided to a joint session of the NAC Regulatory and Policy Committee, the Science Committee, and the Human Exploration and Operations Committee, that will describe best practices for the Administration, the science and research community, and private sector, to protect against harmful contamination and adverse changes in the environment of the Earth. The multi-disciplinary task force should also explore the use of the term 'Planetary Protection' relative to other terms utilized in the Outer Space Treaty.

Major Reasons for the Recommendation:
The COSPAR regulations are becoming obsolete and do not properly account for the possibilities of human spaceflight and private sector missions. Creating a multi-disciplinary team to craft a balanced policy that can be implemented by NASA (and eventually COSPAR itself) will help to encourage new, innovative, human spaceflight, robotic, and private sector missions to Mars and other celestial bodies. The more of these missions that take place the more science, exploration, and commerce can be conducted.

Consequences of No Action on the Recommendation:
If NASA adopts the COSPAR guidelines without any review or revisions they will have a chilling effect on robotic, human spaceflight, and private sector missions. The costs and complexity of conducting space missions will not be moderated and could become problematic. The result will be less science, exploration, and commercial activities, harming both national and global interests.

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

Appendix D: Summary of current COSPAR Guidelines (Kremik, et. al.)

COSPAR's Planetary Protection Policy [G. Kminek (ESA), C. Conley (NASA), V. Hipkin (CSA), H. Yano (JAXA)]

Responding to concerns raised in the scientific community that spaceflight missions to the Moon and other celestial bodies might compromise their future scientific exploration, in 1958 the International Council of Scientific Unions (ICSU) established an ad-hoc Committee on Contamination by Extra- terrestrial Exploration (CETEX) to provide advice on these issues. In the next year, this mandate was transferred to the newly founded Committee on Space Research (COSPAR), which as an interdisciplinary scientific committee of the ICSU (now the International Council for Science) was considered to be the appropriate place to continue the work of CETEX. Since that time, COSPAR has provided an international forum to discuss such matters under the terms "planetary quarantine" and later "planetary protection", and has formulated a COSPAR Planetary Protection Policy with associated implementation requirements as an international standard to protect against interplanetary biological and organic contamination, and after 1967 as a guide to compliance with Article IX of the UN Space Treaty in that area (see for reference: UNOOSA 2017, Report of the Committee on the Peaceful Use of Outer Space, 60th Session, A/72/20, United Nations, New York).

Updating the COSPAR Planetary Protection Policy, either as a response to new discoveries or based on specific requests, is a process that involves representatives from the COSPAR Scientific Commissions B (Space Studies of the Earth-Moon System, Planets, and Small Bodies of the Solar System) and F (Life Sciences as Related to Space), national and international scientific organizations and unions and individual scientists (Figure 1). After reaching a consensus among the involved parties, the proposed update is formulated by the COSPAR Panel on Planetary Protection and submitted to the COSPAR Bureau and Council for review and approval.

The COSPAR Planetary Protection Policy described in this paper is the currently approved version (dated March 2017) and based on the COSPAR Panel on Planetary Protection Colloquium (published in Space Research Today, #195, April 2016) and the COSPAR Panel on Planetary Protection Business Meeting (2 August 2016). Updates affect only some requirements for Mars (Mars Special Regions) and for Enceladus (new requirements) with respect to the previous version of the policy published in Space Research Today, #193, August 2015.

Preamble

Noting that COSPAR has concerned itself with questions of biological contamination and spaceflight since its very inception, and

noting that Article IX of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (also known as the UN Space Treaty of 1967) states that [1]:

"States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter, and where necessary, shall adopt appropriate measures for this purpose."

therefore, COSPAR maintains and promulgates this planetary protection policy for the reference of spacefaring nations, both as 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 this UN Space Treaty and other relevant international agreements.

Policy

COSPAR,

Referring to COSPAR Resolutions 26.5 and 26.7 of 1964 [2], the Report of the Consultative Group on Potentially Harmful Effects of Space Experiments of 1966, the Report of the same Group of 1967, and the Report of the COSPAR/IAU Workshop of 2002 [3],

notes with appreciation and interest the extensive work done by the Panel on Standards for Space probe Sterilization and its successors the Panel on Planetary Quarantine and the Panel on Planetary Protection and

accepts that for certain space mission/target body combinations, controls on contamination shall be imposed in accordance with a specified range of requirements, based on 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 an interplanetary mission. Therefore, for certain space mission/target planet combinations, controls on contamination shall be imposed in accordance with issuances implementing this policy. ([4, 5]; ESA PPWG 2008)

The five categories for target body/mission type combinations and their respective suggested ranges of requirements are described as follows, and in Table 1. Assignment of categories for specific mission/body combinations is to be determined by the best multidisciplinary scientific advice. For new determinations not covered by this policy, such advice should be obtained through the auspices of the Member National Scientific Institutions of COSPAR. In case such advice is not available, COSPAR will consider providing such advice through an *ad hoc* multidisciplinary committee formed in consultation with its Member National Scientific Institutions and International Scientific Unions:

Category I includes any mission to a target body which is not of direct interest for understanding the process of chemical evolution or the origin of life. No protection of such bodies is warranted and no planetary protection requirements are imposed by this policy.

Category II missions comprise all types of missions to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote[14] chance that contamination carried by a spacecraft could compromise future investigations. The requirements are for simple documentation only. Preparation of a short planetary protection plan is required for these flight projects primarily to outline intended or potential impact targets, brief Pre- and Post-launch analyses detailing impact strategies, and a Post- encounter and End-of-Mission Report which will provide the location of impact if such an event occurs. Solar system bodies considered to be classified as Category II are listed in the Appendix to this document.

Category III missions comprise certain types of missions (mostly flyby and orbiter) to a target body of chemical evolution and/or origin of life interest and for which scientific opinion provides a significant chance of contamination which could compromise future investigations. Requirements will consist of documentation (more involved than Category II) and some implementing procedures, including trajectory biasing, the use of cleanrooms during spacecraft assembly and testing, and possibly bioburden reduction. Although no impact is intended for Category III missions, an inventory of bulk constituent organics is required if the probability of impact is significant. Category III specifications for selected solar system bodies are set forth in the Appendix to this document. Solar system bodies

[14] "Remote" here implies the absence of environments where terrestrial organisms could survive and replicate, or a very low likelihood of transfer to environments where terrestrial organisms could survive and replicate.

considered to be classified as Category III also are listed in the Appendix.

Category IV missions comprise certain types of missions (mostly probe and lander) to a target body of chemical evolution and/or origin of life interest and for which scientific opinion provides a significant[15] chance of contamination which could compromise future investigations. Requirements imposed include rather detailed documentation (more involved than Category III), including a bioassay to enumerate the bioburden, a probability of contamination analysis, an inventory of the bulk constituent organics and an increased number of implementing procedures. The implementing procedures required may include trajectory biasing, cleanrooms, bioburden reduction, possible partial sterilization of the direct contact hardware and a bioshield for that hardware. Generally, the requirements and compliance are similar to *Viking*, with the exception of complete lander/probe sterilization. Category IV specifications for selected solar system bodies are set forth in the Appendix to this document. Solar system bodies considered to be classified as Category IV also are listed in the Appendix.

Category V missions comprise all Earth-return missions. The concern for these missions is the protection of the terrestrial system, the Earth and the Moon. (The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel.) For solar system bodies deemed by scientific opinion to have no indigenous life forms, a subcategory "unrestricted Earth return" is defined. Missions in this subcategory have planetary protection requirements on the outbound phase only, corresponding to the category of that phase (typically Category I or II). For all other Category V missions, in a subcategory defined as "restricted Earth return," the highest degree of concern is expressed by the absolute prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body or unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth. Post-mission, there is a need to conduct timely analyses of any unsterilized sample collected and returned to Earth, under strict containment, and using the most sensitive techniques. If any sign of the existence of a nonterrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure. Category V concerns are reflected in requirements that encompass those of Category IV plus a continuing monitoring of project activities, studies and research (i.e., in sterilization procedures and containment techniques).

Further, COSPAR

Recommends that COSPAR members inform COSPAR when establishing planetary protection requirements for planetary missions, and

Recommends that COSPAR members provide information to COSPAR within a reasonable time not to exceed six months after launch about the procedures and computations used for planetary protection for each flight and again within one year after the end of a solar- system exploration mission about the areas of the target(s) which may have been subject to contamination. COSPAR will maintain a repository of these reports, make them available to the public, and annually deliver a record of these reports to the Secretary General of the United Nations. For multinational missions, it is suggested that the lead partner should take the lead in submitting these reports.

Reports should include, but not be limited to, the following information:

1. The estimated bioburden at launch, the methods used to obtain the estimate (e.g., assay techniques applied to spacecraft or a proxy), and the statistical uncertainty in the estimate.

2. The probable composition (identification) of the bioburden for Category IV missions, and for

[15] "Significant" here implies the presence of environments where terrestrial organisms could survive and replicate, and some likelihood of transfer to those places by a plausible mechanism.

Category V "restricted Earth return" missions.

3. Methods used to control the bioburden, decontaminate and/or sterilize the space flight hardware.

4. The organic inventory of all impacting or landed spacecraft or spacecraft-components, for quantities exceeding 1 kg.

5. Intended minimum distance from the surface of the target body for launched components, for those vehicles not intended to land on the body.

6. Approximate orbital parameters, expected or realized, for any vehicle which is intended to be placed in orbit around a solar system body.

7. For the end-of-mission, the disposition of the spacecraft and all of its major components, either in space or for landed components by position (or estimated position) on a planetary surface.

([3, 6, 7, 8])

Appendix: Implementation guidelines and category specifications for individual target bodies

Implementation guidelines on the use of clean-room technology for outer-planet missions

COSPAR,

Noting that in the exploration of the outer planets, the probabilities of growth of contaminating terrestrial micro-organisms are extremely low, reflecting the fact that the environments of these planets appear hostile to all known biological processes,

noting also that these environments do not preclude the possibility of *indigenous* life forms in some of these environments,

recognizing that the search for life is a potentially valid objective in the exploration of the outer solar system,

recognizing that the organic chemistry of these bodies remains of paramount importance to our understanding of the process of chemical evolution and its relationship to the origin of life,

recognizing that study of the processes of the pre-biotic organic syntheses under natural conditions must not be jeopardized,

recommends the use of the best available clean-room technology, comparable with that employed for the *Viking* mission, for all missions to the outer planets and their satellites.

([9])

Numerical implementation guidelines for forward contamination calculations

To the degree that numerical guidelines are required to support the overall policy objectives of this document, and except where numerical requirements are otherwise specified, the guideline to be used is that the probability that a planetary body will be contaminated during the period of exploration should be no more than $1x10^{-3}$. The period of exploration can be assumed to be no less than 50 years after a Category III or IV mission arrives at its protected target. No specific format for probability of contamination calculations is specified.

Guidelines on the implementation of an organic inventory

A spacecraft organic inventory includes a listing of all organic materials carried by a spacecraft which are present in a total mass greater than 1 kg. A complete inventory should include organic products that may be released into the environment of the protected solar system body by propulsion and life support systems (if present), and include a quantitative and qualitative description of major chemical constituents and the integrated quantity of minor chemical constituents present.

Trajectory biasing

The probability of impact on Mars by any part of the launch vehicle shall be ≤ $1x10^{-4}$ for a time period of 50 years after launch.

Implementation guidelines for Category V missions

If during the course of a Category V mission there is a change in the circumstances that led to its classification, or a mission failure, e.g.:

- New data or scientific opinion arise that would lead to the reclassification of a mission classified as “Unrestricted Earth return” to “Restricted Earth return,” and safe return of the sample cannot be assured, OR

- The sample containment system of a mission classified as “Restricted Earth return” is thought to be compromised, and sample sterilization is impossible, then the sample to be returned shall be abandoned, and if already collected the spacecraft carrying the sample must not be allowed to return to the Earth or the Moon.

Category-specific listing of target body/ mission types

Category I: Flyby, Orbiter, Lander Recommendation: Undifferentiated, metamorphosed asteroids; Io; others to-be-defined (TBD)

Category II: Flyby, Orbiter, Lander Recommendation: Venus; Moon (with organic inventory); Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; Ganymede*; Callisto; Titan*; Triton*; Pluto/Charon*; Ceres; Kuiper- Belt Objects > 1/2 the size of Pluto*; Kuiper- Belt Objects < 1/2 the size of Pluto; others TBD

Category III: Flyby, Orbiters: Mars; Europa; Enceladus; others TBD

Category IV: Lander Missions: Mars; Europa; Enceladus; others TBD

Category V: Any Earth-return mission

“Restricted Earth return”: Mars; Europa; others TBD

“Unrestricted Earth return”: Venus, Moon; others TBD

*The mission-specific assignment of these bodies to Category II must be supported by an analysis of the “remote” potential for contamination of the liquid-water environments that may exist beneath their surfaces (a probability of introducing a single viable terrestrial organism of < 1×10^{-4}), addressing both the existence of such environments and the prospects of accessing them.

Category III/IV/V requirements for Mars

<u>Missions to Mars</u>

Note: All 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 (Tryptic-Soy-Agar) TSA at 32°C for 72 hours.

Category III. Mars orbiters will not be required to meet orbital lifetime requirements* if they achieve total (surface, mated, and encapsulated) bioburden levels of ≤ 5×10^{5} spores. (*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.) ([10])

Category IV for Mars is subdivided into IVa, IVb, and IVc:

Category IVa. Lander systems not carrying instruments for the investigations of extant Martian life are restricted to a surface bioburden level of ≤ 3 x 10^5 spores, and an average of ≤ 300 spores per square meter.

Category IVb. For lander systems designed to investigate extant Martian life, all of the requirements of Category IVa apply, along with the following requirement:

- The entire landed system is restricted to a surface bioburden level of ≤ 30* spores, or to levels of bioburden reduction driven by the nature and sensitivity of the particular life-detection experiments, OR
- The subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection must be sterilized to these levels, and a method of preventing recontamination of the sterilized subsystems and the contamination of the material to be analyzed is in place.

Category IVc. For missions which investigate Martian special regions (see definition below), even if they do not include life detection experiments, all of the requirements of Category IVa apply, along with the following requirement:

- Case 1. If the landing site is within the special region, the entire landed system is restricted to a surface bioburden level of ≤ 30* spores.
- Case 2. If the special region is accessed through horizontal or vertical mobility, either the entire landed system is restricted to a surface bioburden level of ≤ 30* spores, OR the subsystems which directly contact the special region shall be sterilized to these levels, and a method of preventing their recontamination prior to accessing the special region shall be provided.

If an off-nominal 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.

*This figure takes into account the occurrence of hardy organisms with respect to the sterilization modality. This specification assumes attainment of Category IVa surface cleanliness, followed by at least a four order-of- magnitude reduction in viable organisms. Verification of bioburden level is based on pre- sterilization bioburden assessment and knowledge of reduction factor of the sterilization modality.

Planned 3-sigma pre-launch landing ellipses must be evaluated on a case-by-case basis as part of the (landing) site selection process, to determine whether the mission would land or come within contamination range of areas or volumes meeting the parameter definition for Mars Special Regions or would impinge on already described features that must be treated as Mars Special Regions. The evaluation must be based on the latest scientific evidence and in particular include an assessment of the extent to which the temperature and water activity values specified for Mars Special Regions are separated in time. The evaluation must be updated during the mission whenever new evidence indicates that the landing ellipse and/or the operational environment contain or are in contamination range of areas or volumes meeting the parameter definition for Mars Special Regions or already described features that must be treated as Mars Special Regions [11].

Definition of "Special Region"

A Special Region is defined as a region within which terrestrial organisms are likely to replicate. Any region which is interpreted to have a high potential for the existence of extant Martian life forms is also defined as a Special Region.

Given current understanding of terrestrial organisms, Special Regions are defined as areas or volumes within which sufficient water activity AND sufficiently warm temperatures to permit replication of Earth organisms may exist. The physical parameters delineating applicable water activity and temperature thresholds are given below:

- Lower limit for water activity: 0.5; Upper limit: 1.0
- Lower limit for temperature: -28°C [11]; No Upper limit defined
- Timescale within which limits can be identified: 500 years

Spacecraft-induced special regions are to be evaluated, consistent with these limits and features, on a case-by-case basis.

Observed features to be treated as Special Regions until demonstrated otherwise [11]:

- Gullies (taxon 2-4)†, and bright streaks associated with gullies
- Subsurface cavities
- Subsurface below 5 meters
- Confirmed and partially confirmed Recurrent Slope Lineae (RSL)‡

Features, if found, to be treated as a Special Region until demonstrated otherwise [11]:

- Groundwater
- Source of methane
- Geothermal activity
- Modern outflow channel

Observed features that require a case-by-case evaluation before being classified as a Special Region [11]:

- Dark streaks
- Pasted-on terrain
- Candidate RSL‡

†Description for Gully taxon [12]

‡Observational evidence for Recurrent Slope Lineae (RSL), adapted from [13]:

- Confirmed: observed simultaneous incremental growth of flows on a warm slope, fading, and recurrence of this sequence in multiple Mars years
- Partially confirmed: observed either incremental growth or recurrence
- Candidate: slope lineae that resemble RSL but where observations needed for partial confirmation are currently lacking

Spacecraft-induced special regions are to be evaluated, consistent with these limits and features, on a case-by-case basis.

In the absence of specific information, no Special Regions are currently identified on the basis of possible Martian life forms. If and when information becomes available on this subject, Special Regions will be further defined on that basis [14].

<u>Sample Return Missions from Mars</u>

Category V. The Earth return mission is classified, "Restricted Earth return."

- Unless specifically exempted, the outbound leg of the mission shall meet Category IVb requirements. This provision is intended to avoid "false positive" indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned. A “false positive” could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.

- Unless the samples to be returned from Mars are subjected to an accepted and approved sterilization process, the canister(s) holding the samples returned from Mars shall be closed, with an appropriate verification process, and the samples shall remain contained during all mission phases through transport to a receiving facility where it (they) can be opened under containment.
- The mission and the spacecraft design must provide a method to “break the chain of contact” with Mars. No uncontained hardware that contacted Mars, directly or indirectly, shall be returned to Earth. Isolation of such hardware from the Mars environment shall be provided during sample container loading into the containment system, launch from Mars, and any in- flight transfer operations required by the mission.
- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving Mars for return to Earth; and 3) prior to commitment to Earth re-entry.
- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample.

Principles and Guidelines for Human Missions to Mars

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. Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ. General principles include:

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- For a landed mission conducting surface operations, it will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars, or their support systems, will inevitably be exposed to Martian materials.

In accordance with these principles, specific implementation guidelines for human missions to Mars include:

- Human missions will carry microbial populations that will vary in both kind and quantity, and it will not be practicable to specify all aspects of an allowable microbial population or potential contaminants at launch. Once any baseline conditions for launch are established and met, continued monitoring and evaluation of microbes carried by human missions will be required to address both forward and backward contamination concerns.
- A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a Martian life-form occurs.
- A comprehensive planetary protection protocol for human missions should be developed that encompasses both forward and backward contamination concerns, and addresses the combined human and robotic aspects of the mission, including subsurface exploration, sample handling, and the return of the samples and crew to Earth.
- Neither robotic systems nor human activities should contaminate “Special Regions” on Mars, as

defined by this COSPAR policy.

- Any uncharacterized Martian site should be evaluated by robotic pre- cursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission.
- Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.
- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.
- Planetary protection requirements for initial human missions should be based on a conservative approach consistent with a lack of knowledge of Martian environments and possible life, as well as the performance of human support systems in those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

Category III/IV/V requirements for Europa and Enceladus [11]

Missions to Europa and Enceladus

Category III and IV. Requirements for Europa and Enceladus flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of an Europan or Enceladan ocean to less than $1x10^{-4}$ per mission. The probability of inadvertent contamination of a Europan or Enceladan ocean of $1x10^{-4}$ applies to all mission phases including the duration that spacecraft introduced terrestrial organisms remain viable and could reach a sub-surface liquid water environment. These requirements will be refined in future years, but the calculation of this probability should include a conservative estimate of poorly known parameters, and address the following factors, at a minimum:

- Bioburden at launch
- Cruise survival for contaminating organisms
- Organism survival in the radiation environment adjacent to Europa or Enceladus
- Probability of landing on Europa or Enceladus
- The mechanisms and timescales of transport to a Europan or Enceladian subsurface liquid water environment
- Organism survival and proliferation before, during, and after subsurface transfer

Preliminary calculations of the probability of contamination suggest that bioburden reduction will likely be necessary even for Europa and Enceladus orbiters (Category III) as well as for landers, requiring the use of cleanroom technology and the cleanliness of all parts before assembly, and the monitoring of spacecraft assembly facilities to understand the bioburden and its microbial diversity, including specific problematic species. Specific methods should be developed to eradicate problematic species. Methods of bioburden reduction should reflect the type of environments found on Europa or Enceladus, focusing on Earth extremophiles most likely to survive on Europa or Enceladus, such as cold and radiation tolerant organisms [15].

Sample Return Missions from Europa and Enceladus

Category V. The Earth return mission is classified, "Restricted Earth return."

- Unless specifically exempted, the outbound leg of the mission shall meet the contamination control requirements given above. This provision should avoid "false positive" indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned. A "false positive" could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Europa or Enceladus missions.

- Unless the samples to be returned from Europa or Enceladus are subjected to an accepted and approved sterilization process, the canister(s) holding the samples returned from Europa or Enceladus shall be closed, with an appropriate verification process, and the samples shall remain contained during all mission phases through transport to a receiving facility where it (they) can be opened under containment.
- The mission and the spacecraft design must provide a method to "break the chain of contact" with Europa or Enceladus. No uncontained hardware that contacted material from Europa, Enceladus or their plumes, shall be returned to the Earth's biosphere or the Moon. Isolation of such hardware from the Europan or Enceladan environment shall be provided during sample container loading into the containment system, launch from Europa or Enceladus, and any in-flight transfer operations required by the mission.
- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) subsequent to sample collection and prior to a maneuver to enter a biased Earth return trajectory; and 3) prior to commitment to Earth re-entry.
- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample [16].

Category requirements for small solar system bodies

Missions to Small Solar System Bodies

Category I, II, III, or IV. The small bodies of the solar system not elsewhere discussed in this policy represent a very large class of objects. Imposing forward contamination controls on these missions is not warranted except on a case-by-case basis, so most such missions should reflect Categories I or II. Further elaboration of this requirement is anticipated.

Sample Return Missions from Small Solar System Bodies

Category V. Determination as to whether a mission is classified "Restricted Earth return" or not shall be undertaken with respect to the best multidisciplinary scientific advice, using the framework presented in the 1998 report of the U.S. National Research Council's Space Studies Board entitled, *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making* [16]. Specifically, such a determination shall address the following six questions for each body intended to be sampled:

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO_2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)?
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms?
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?

For containment procedures to be necessary ("Restricted Earth return"), an answer of "no" or "uncertain" needs to be returned to all six questions.

For missions determined to be Category V, "Restricted Earth return," the following requirements shall be met:

- Unless specifically exempted, the outbound leg of the mission shall meet contamination control requirements to avoid "false positive" indications in a life-detection and hazard-determination protocol, or in any search for life in the sample after it is returned. A "false positive" could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later missions to that body.
- Unless the samples to be returned are subjected to an accepted and approved sterilization process, the canister(s) holding the samples shall be closed, with an appropriate verification process, and the samples shall remain contained during all mission phases through transport to a receiving facility where it (they) can be opened under containment.
- The mission and the spacecraft design must provide a method to "break the chain of contact" with the small body.

No uncontained hardware that contacted the body, directly or indirectly, shall be returned to Earth. Isolation of such hardware from the body's environment shall be provided during sample container loading into the containment system, launch from the body, and any in-flight transfer operations required by the mission.

- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving the body or its environment for return to Earth; and 3) prior to commitment to Earth re-entry.
- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample [16]

Figure 1: Process to update the COSPAR planetary protection policy

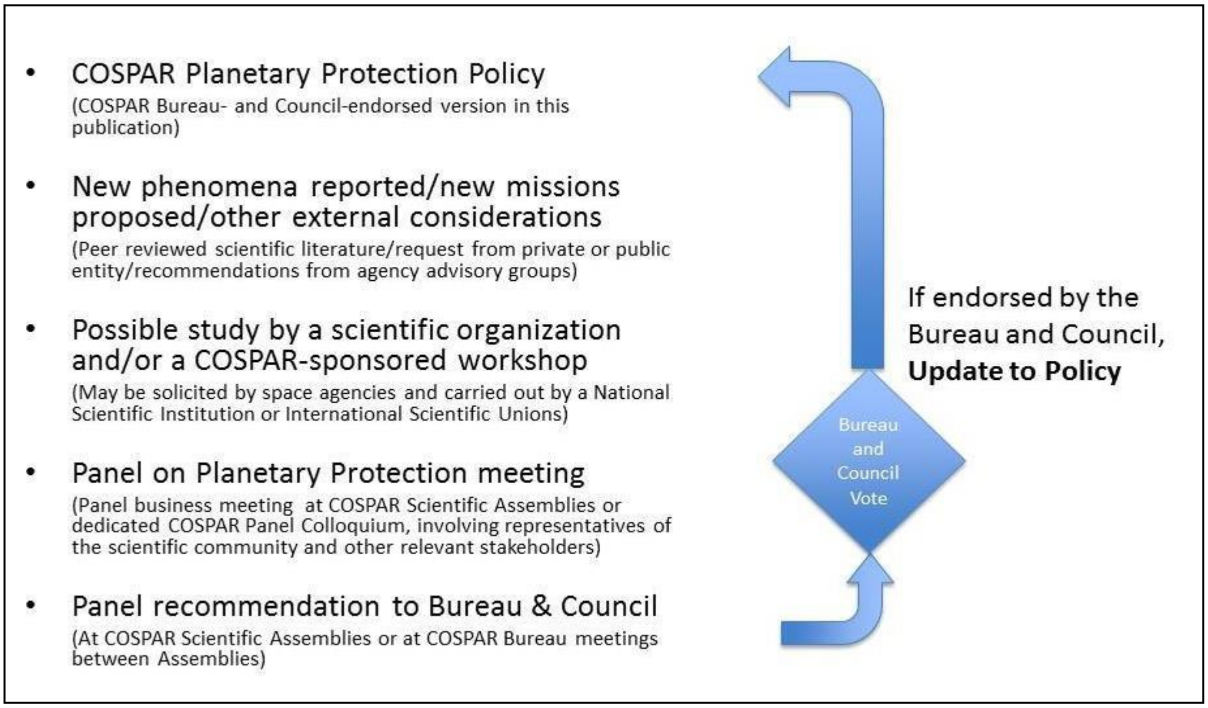

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Table 1: Categories for solar system bodies and types of missions [3, 4, 7, 8, 10]

	Category I	**Category II**	**Category III**	**Category IV**	**Category V**
Type of Mission	Any but Earth Return	Any but Earth Return	No direct contact (flyby, some orbiters)	Direct contact (lander, probe, some orbiters)	Earth Return
Target Body	See Category-specific listing	See Category-specific listing	See Category- specific listing	See Category- specific listing	See Category- specific listing
Degree of Concern	None	Record of planned impact probability and contamination control measures	Limit on impact probability Passive bioburden control	Limit on probability of non-nominal impact Limit on bioburden (active control)	If restricted Earth return: • No impact on Earth or Moon; • Returned hardware sterile; • Containment of any sample.
Representative Range of Requirements	None	Documentation only (all brief): • PP plan • Pre-launch report • Post-launch report • Post- encounter report • End-of- mission report	Documentation (Category II plus): • Contamination control • Organics inventory (as necessary) Implementing procedures such as: • Trajectory biasing • Cleanroom • Bioburden reduction (as necessary)	Documentation (Category II plus): • Pc analysis plan • Microbial reduction plan • Microbial assay plan • Organics inventory Implementing procedures such as: • Trajectory biasing • Cleanroom • Bioburden reduction • Partial sterili-zation of contacting hardware • (as necessary) • Bioshield • Monitoring of bioburden via bioassay	Outbound Same category as target body/ outbound mission Inbound If restricted Earth return: • Documentation (Category II plus): • Pc analysis plan • Microbial reduction plan • Microbial assay plan Implementing procedures such as: • Trajectory • biasing • Sterile or contained returned hardware • Continual monitoring of project activities • Project advanced studies and research If unrestricted Earth return: • None

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