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Planetary protection: an international concern and responsibility

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Planetary protection is a set of measures agreed upon at an international level to ensure the protection of scientific investigation during space exploration. As space becomes more accessible with traditional and new actors launching complex and innovative projects that involve robotics (including sample return) and human exploration, we have the responsibility to protect the pristine environments that we explore and our own biosphere. In this sense, the Committee on Space Research (COSPAR) provides the international standard for planetary protection as well as a forum for international consultation. COSPAR has formulated a Planetary Protection Policy with associated requirements for responsible space exploration. Although not legally binding under international law, the standard offered by the Policy with its associated requirements is internationally endorsed along with implementation guidelines supplied for reference in support States' compliance with Article IX of the United Nations Outer Space Treaty of 1967. Indeed, States parties to the Outer Space Treaty (under Article VI) are responsible for any space activities in their countries, governmental and non-governmental.

The main goal of this Policy is to avoid compromising the search for any lifeforms on other celestial bodies and to protect the Earth from a potential threat posed by extraterrestrial samples returned by an interplanetary mission. The COSPAR Planetary Protection Policy has defined five categories, depending on the target and objective of the specific space mission. Associated to these categories are requirements are various degrees of rigor in the contamination control applied. The Policy is assessed regularly and updated with input from new scientific findings and in conjunction with the fast-evolving space exploration milieu. The COSPAR Panel on Planetary Protection (PPP) is a designated international committee composed of scientists, agency representatives and space experts. Its role is to support and revise the COSPAR Policy and its related requirements (https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/). The Panel's activities deal with the individual needs of a space mission while exercising swift care and expertise to ensure sustainable exploration of the Solar System.

KEYWORDS

Planetary protection, COSPAR, space exploration, contamination control, sterilization, space mission, outer space treaty, bioburden (reduction)

1 Introduction: planetary protection and the safe and sustainable exploration of our solar system

As space becomes more accessible and we explore farther across our Solar System, continuing to land robotic missions and humans on our neighbouring planetary bodies, we need to ensure that we do this in a "safe" manner, meaning that we do not harm the target bodies or our own planet. Indeed, we need to protect the pristine environments that could be potentially habitable or offer an opportunity to understand the origin and evolution of the Universe and of the Earth. For this, we need to ensure that we do not compromise scientific investigations that could provide answers to fundamental questions about how life emerged on Earth and whether extinct or extant life exists on other celestial bodies. *In-situ* and observational data have suggested the habitable conditions may exist in our Solar System exist, e.g., Mars and the sub-surface oceans of the icy moons and conditions may have been conducive for life to emerge. To address these key questions careful studies of the environments that harbor such evidence are needed. Indeed, as J. Lederberg and D. B. Cowie (1958) note "*…we are in the awkward situation of being able to spoil certain possibilities for scientific investigations for a considerable interval before we can constructively realize them…we urgently need to give some thought to the conservative measures needed to protect future scientific objectives on the Moon and the planets…*" At the same time, we obviously take care not to affect with what we bring back, the only inhabited planet that we know of today, Earth.

Therefore, planetary protection was identified as an international concern over 60 years ago and the responsibility was raised by the International Astronautical Federation (IAF) and the United States National Academy of Science (NAS), which lead to the establishment in 1958 of the Committee on Contamination by Extraterrestrial Exploration (CETEX) by the International Council of Scientific Unions (ICSU). The ICSU adopted the CETEX Code-of-Conduct ["Development of International Efforts to Avoid Contamination of Extraterrestrial Bodies," Science 128 (3,329), 887–891, 1958] and instituted the Committee on Space Research (COSPAR). COSPAR in turn put in place the Consultative Group on Potentially Harmful Effects of Space Experiments. The Ranger missions to the Moon in 1961 were the first missions to use this Code-of-Conduct. Since then, all planetary missions have implemented different degrees of planetary protection measures, grading from simple documentation to full-scale sterilization of whole flight systems, depending on the level of concern regarding the probability of contaminating the target body of a mission. In the case of Mars, even more elaborate and quantitative regulations, were put in place by COSPAR in 1964 (e.g., Sagan and Coleman, 1965; Sagan et al., 1968).

Planetary protection has recently received renewed attention both within the science community and from the wider publics, due to the emergence of new spacefaring countries or entities and the growing involvement of private/commercial actors, which has led to an increasing number of missions currently in operation or being planned to explore celestial bodies across our Solar System. Indeed, in the current era, many national space agencies exist, such as the European Space Agency (ESA), the United States National Aeronautics and Space Administration (NASA), the Japanese Aerospace Exploration Agency (JAXA), the Russian Roscosmos, the China National Space Administration (CNSA), and the Indian Space Research Organisation (ISRO), the Canadian Space Agency (CSA), the United Arab Emirates Space Agency (UAESA) among others., as well as national space agencies such as the UK Space Agency, the Centre National d'Etudes Spatiales (CNES) in France, the Italian Space Agency (ASI), the Deutsches Zentrum für Luft-und Raumfahrt e.V. (DLR) in Germany and more. These governmental agencies are involved is space missions to increase our scientific knowledge, and in the future, to expand the human presence on neighboring bodies. Many countries also host non-governmental or private sector entities within their respective jurisdictions that have on-going, or upcoming activities planned, in space, including to the Moon and near-by planets. In this context, international collaborations, consultations, and fundamental care about space-related activities is based on some principles and guidance from organizations that have set up expert committees to discuss and recommend best practices and to distil information to interested stakeholders, with COSPAR assisting in coordinating international space research activities in space research, contamination avoidance leading to the establishment of planetary protection guidelines, which is one of its principal responsibilities.

2 COSPAR policy on planetary protection and the outer space treaty

The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the Outer Space Treaty) was established in 1967 (see: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html) and provides an internationally recognised legal basis for the adoption of planetary protection policies and their implementation under its Article IX, which requires that "*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 extra terrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.*" (extract from the resolution adopted at the General Assembly 2222 (XXI): Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies). It is therefore an obligation of States to ensure national mechanisms are in place to ensure space exploration complies with this provision. It should be noted that the Outer Space Treaty does not provide a clear definition of the term "harmful contamination".

Under Article VI of the Outer Space Treaty, States Parties bear international responsibility for their national activities and for assuring that they are carried out in conformity with the provisions of the Treaty (e.g., Coustenis et al., 2019a). National activities include the activities of both governmental agencies and non-governmental entities and that activities of non-governmental entities require authorization and continuing oversight by the appropriate State Party. Essentially, Article VI means that when a State authorizes and supervises the activities of a private sector entity over which it exercises jurisdiction, the State Party must ensure that the activities comply with that State's obligations under the Treaty.

According to Article VI and Article IX, States Parties are responsible for their national activities in outer space. This includes activities, whether performed by governmental agencies or by private sector entities, avoid harmful contamination of explored Solar System objects, as well as hostile changes to the environment of the Earth.

2.1 COSPAR

COSPAR is part of the International Council for Science (ICS), which was established in 1958 as ICSU (https://cosparhq.cnes.fr/). The main objectives of COSPAR are "*to promote scientific research in space at an international level, with emphasis on the exchange of results, information and opinions.*" (https://cosparhq.cnes.fr/about/). COSPAR organizes scientific assemblies, symposia and publications in order to provide a forum open to all parties interested in space activities, scientists, engineers and other stakeholders, encouraging discussions and exchanges on issues related to scientific space research. COSPAR also develops scientific roadmaps on important matters in order to inform decision-makers and help develop collaborative efforts within the international context based on available state-of-the-art space research results.

COSPAR has had a close working relationship with the intergovernmental body the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) since the early 1960s. This is particularly evident in the field of planetary protection, as demonstrated by the COSPAR Consultative Group on Potentially Harmful Effects of Space Experiments, including the Panel on Standards for Probe Sterilization (succeeded by the panel on Planetary Quarantine and the present Panel on Planetary Protection) reporting to COPUOS. The COSPAR Executive Council resolution of 20 May 1964 and its appendices were annexed to the 1964 COPUOS report (see A/5785).

COSPAR comprises of eight Scientific Commissions (https://cosparhq.cnes.fr/scientific-structure/scientific-commissions/) and several Panels (https://cosparhq.cnes.fr/scientific-structure/panels/) all related to space science activities. One of the core activities of COSPAR since the earliest days of space exploration has been to develop, maintain, and promote an international Policy on Planetary Protection (referred to as "the Policy" hereafter) with its associated requirements (Coustenis et al., 2021e; 2022f). This Policy constitutes the primary scientifically authoritative international reference standard to guide compliance with Article IX of the Outer Space Treaty and is the only internationally agreed planetary protection standard available for reference and use by all States and is based on the latest available scientific data. This role of COSPAR was noted by COPUOS in its report of 2017 (A/72/20, para. 332). The Policy therefore represents the current state of the art of scientific knowledge regarding the potential harmful introduction of organic and biological contamination in space exploration activities of the Moon and other celestial bodies (Hedman et al., 2022). Within COSPAR, the Panel on Planetary Protection (hereafter referred at as "the Panel" or "PPP") is responsible for the Policy.

Among the COSPAR Panels, there are some specific ones dealing with topics more relevant to space exploration and planetary protection, as for instance:

- Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS).
- Panel on Space Weather (PSW).
- Panel on Planetary Protection (PPP).
- Panel on Exploration (PEX).
- Panel on Social Sciences and Humanities (PSSH).

However, the role of dealing with planetary protection issues specifically lies within the mandate of the COSPAR Panel on Planetary Protection.

2.2 COSPAR policy on planetary protection

The concept behind the current planetary protection Policy, its challenges and the requirements have been described in various previous publications (Kminek et al., 2017; Coustenis et al., 2019a), with updates published in COSPAR's bulletin *Space Research Today* (e.g., COSPAR PPP, 2020 and, 2021). The Policy is always based on the most recent, peer-reviewed scientific literature and is intended to enable exploration and ensure it is safe (Worms et al., 2020;

FIGURE 1
All Mars spacecraft are assembled and tested under planetary protection constraints. The image shows technicians assembling the spacecraft and preparing it for launch. *Credit: NASA/JPL.*

Coustenis et al., 2022b; d). Planetary protection requirements are not carved in stone but can evolve when new information is presented (Hedman & Coustenis, 2022).

Space exploration involves missions built and launched by private entities and from national or international space agencies that send a variety of craft into outer space to enhance our understanding of its processes and the origin and evolution of the Universe. Some missions are designed as orbiters and others, such as those targeting the Moon, Mars, comets or giant planet icy Moon, comprise landers to explore their surfaces and interiors. They will then analyze the external, surface, and subsurface environments. Some of them have objectives to do with the search for extant or extinct life and employ sophisticated devices for that, others try to determine the habitable conditions or the astrobiological potential of the targets.

The core objective of the COSPAR Policy is the integrity of scientific investigations of possible extra-terrestrial life forms, precursors, and remnants that must not be jeopardized by the introduction of terrestrial biological material into the environments of those bodies (Figure 1). The introduction of such terrestrial biological material would contaminate those bodies, thereby potentially irreparably harming critical scientific investigations and knowledge acquisition. Ensuring that scientific investigations to improve our understanding of the emergence and distribution of life are not compromised entails that we protect our investment in space science and exploration, and we preserve unique opportunities to gain knowledge about the origin of life in a way that is no longer possible on Earth (e.g., Coustenis et al., 2022g).

At the same time, the Earth must also be protected from any risk presented by alien matter carried by spacecraft returning from an interplanetary mission. This is certainly prudent, but also in line with the precautionary principle of environmental protection (Coustenis et al., 2021d; Figure 2).

Therefore, for certain combinations of space mission architectures and targets, controls on contamination and safety measures need to be put in place by operating agencies or national regulatory authorities in accordance with issuances implementing this policy (e.g., Kminek et al., 2017; report of ESA's PPWG 2008; Figure 3). The Policy and associated guidelines constitutes a voluntary non-legally binding standard through which the engineering solutions are to be determined at the discretion of either the governmental organization responsible for undertaking the planetary mission or the regulatory authority tasked with approving and supervising the planetary mission undertaken by a private sector entity within that State's jurisdiction.

3 The COSPAR panel on planetary protection

A special case among the Commissions and Panels in the COSPAR structure is the Panel of Planetary Protection (PPP) which serves an essential function for space agencies pursuing the exploration of the bodies in our Solar System. The primary objective of the COSPAR PPP is to maintain, develop and promulgate the COSPAR Policy and its associated requirements for the reference of spacefaring nations and to provide guidance upon request with compliance with the Outer Space Treaty, specifically with respect to protecting against the harmful effects of forward and backward contamination (Coustenis et al., 2019b; 2021c; Figures 1–3).

In its principal role, the COSPAR PPP ensures that the COSPAR Policy and its associated requirements are up-to-date and represent the actual needs for space exploration (Hedman & Coustenis, 2022). The structure and composition of the Panel, as well as recent documents related to the Panel's activities, are published at

FIGURE 2
The Italian Thales Alenia Space planetary protection team, photographed inside the cleanroom tent at Baikonur. *Credit: Thales Alenia Space*.

FIGURE 3
This picture shows glove boxes in the bioburden-controlled cleanroom at Thales Alenia Space Italy for the assembly of the hardware destined to process and analyze martian samples under aseptic and ultra-clean conditions. *Credit: ESA/Thales Alenia Space*.

https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/. The Panel was restructured in 2018 to comprise a formally appointed membership that includes a number of scientists/experts as well as representatives from space agencies. Since then, members have met regularly in open and closed sessions several times a year. The Terms of Reference ensure a balance between space agency representatives and scientists. In 2022, additional members joined the Panel, this included representatives from space agencies, e.g., UEA and science experts (see: https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/). The COSPAR Bureau formally appoints the Panel leadership and members. The COSPAR PPP currently has 25 members representing space agencies and experts from the scientific community, as well as an ex-officio member from the US' National Academy of Sciences, Engineering and Medicine (NASEM), another from UNOOSA and the representative of the COSPAR Committee on Industrial Relations (CIR). At their meetings, during the open sessions, the Panel welcomes scientists, industry and private sector representatives, interested parties and observers (Fisk et al., 2021; Coustenis et al., 2022e).

3.1 Role and purpose of the COSPAR PPP

The purpose of COSPAR's PPP is twofold. The first is to provide guidance to States to ensure that any of the space missions sent by their national space agencies, or private sector entities within their jurisdiction, to possible habitable environments do not contaminate the target body (planet/satellite) with biological material brought from the Earth. By the same token, a role of the Panel (and of the COSPAR Planetary Protection Policy) is to assist with guidelines on how to prevent any contamination of our biosphere from returned extra-terrestrial material, e.g., if the mission is designed to acquire samples to return to Earth (Coustenis et al., 2019b; 2021c). COSPAR PPP's main function is then to prevent space missions from transporting terrestrial microorganisms to their destinations (forward contamination) as well as to ensure that no contamination from extra-terrestrial material is released to Earth (backward contamination). For this, the Panel regularly reviews available scientific knowledge through existing or commissioned studies performed by external groups or by Panel subcommittees of experts. Based on this information, recommendations are made to the whole Panel on whether a change to the policy is warranted (e.g., Fisk et al., 2020; 2021; Coustenis et al., 2021a; b, 2022e). In addition, consultations of the scientific community via the COSPAR Commissions can be conducted to provide the Panel with additional expertise (as was done for the lunar requirements in 2020–2021).

The Panel is thus concerned with possible biological interchange during the exploration of the Solar System and aims to secure scientific research at celestial bodies without compromise by terrestrial contaminants. As said above, this serves to safeguard our investment in space investigations, while also protecting the Earth's biosphere from any potential hazards from a sample return mission which is destined to laboratory analysis. The technical aspects of the COSPAR Policy have been developed through exchanges between different stakeholders (scientists, engineers and others) and to date, there are five categories of recommended requirements, which are defined based on the mission's type, its destinations, and the scientific rationale (Coustenis et al., 2019a).

Categories I and II concern all kinds of missions (gravity assist, orbiter, lander) to a target body where there is no direct interest or no significant interest for understanding processes of chemical evolution, of the origin of life, but where there can be only a remote chance that contamination carried by a spacecraft could compromise future investigations. "Remote chance" in this case means that the body does not comprise any environments where terrestrial organisms could survive and replicate, or a very low likelihood of transfer of contaminants to environments where terrestrial organisms could survive and replicate.

In contrast Categories III, IV and V are concerned with missions to target bodies of chemical evolution and/or origin of life interest and for which there exists a significant chance of contamination which could compromise future investigations. "Significant chance" implies the presence of environments where terrestrial organisms could survive and replicate, and some likelihood of transfer to those places by a plausible mechanism. For more information on the different categories see latest Policy update (COSPAR PPP, 2021; Fisk et al., 2021) and https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/.

The PPP regularly reviews the latest scientific research to adapt its planetary protection policy and category assignation of Solar System bodies based upon the most current, peer-reviewed scientific knowledge that is compiled and judged for pertinence by the scientists in the Panel and should enable the exploration of the Solar System, not prohibit it (Coustenis et al., 2022d, g; Coustenis et al., 2023). The Panel has several meetings to which it invites all stakeholders including the private sector and industries. Information and minutes of the open sessions during the PPP meetings can be found at https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/in Section 4.

The Panel also stands ready to support States, upon their request on a voluntary basis, by conducting a thorough review and assessment of mission-specific planetary protection requirements with the aim of fostering harmonized and interoperable approaches and encouraging cooperation at the international level.

3.2 Modus operandi of the PPP and reporting to COSPAR

The Panel works to develop and promulgate a clearly delineated policy and associated requirements to protect against the harmful effects of forward and backward contamination, as explained in the previous sections. It is not the purpose of the Panel to specify how to adhere to the COSPAR Policy and its associated guidelines. This is left to the engineering judgment and effective means of the organization responsible for the space mission, under the condition of certification of compliance with the Policy requirements by the national or international authority responsible vis a vis the UN Outer Space Treaty.

The Panel endeavors, by organising different kinds of meetings, including workshops, topical meetings and sessions at COSPAR General Assemblies, to provide an international forum for the exchange of information on the best practices for adhering to the requirements (e.g., Coustenis et al., 2019b; 2021c; Worms et al., 2020) and for improving or updating the Policy as necessary. The international nature of the Panel allows for discussion (including encouraging an active dialogue with the private sector) and decisions to be made during the Panel's meetings and to arrive at recommendations to be submitted to the COSPAR Bureau for validation prior to publication. Once an update is made the Panel informs the international community through publications and presentations at international meetings (e.g., Coustenis et al., 2021d; 2022a, e; Hedman et al., 2022; Olsson-Francis et al., 2022a; b), the Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations, as well as various other bilateral and multilateral organizations. Some of the more recent updates to the Policy were approved in June 2020 (Fisk et al., 2020), while another one concerning the Moon requirements was published in June 2021 (Fisk et al., 2021) and presented at the 2022 COSPAR General Assembly (e.g., Hedman & Coustenis, 2022; Coustenis et al., 2022a-g).

The Policy recommends that members inform COSPAR when they are establishing planetary protection requirements at the national level. This open and transparent approach facilitates the sharing of information. The Policy also recommends that COSPAR members provide information about the procedures and computations used for planetary protection for each flight. Reports should include, but not be limited to, the following information (from Fisk et al., 2021: COSPAR Policy on Planetary Protection):

- The estimated bioburden at launch (bioburden is defined as the number of bacteria living on an unsterilized surface), the methods used to obtain the estimate (e.g., assay techniques applied to spacecraft or a proxy), and the statistical uncertainty in the estimate.
- The probable composition (identification) of the bioburden for Category IV missions, and for Category V "restricted Earth return" missions.
- Methods used to control the bioburden, decontaminate and/or sterilize the space flight hardware.
- The organic inventory of all impacting or landed spacecraft or spacecraft-components, for quantities exceeding 1 kg.
- Intended minimum distance from the surface of the target body for launched components, for those vehicles not intended to land on the body.
- Approximate orbital parameters, expected or realized, for any vehicle which is intended to be placed in orbit around a Solar System body.
- 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) on a planetary surface.

These reports include: a short planetary protection plan outlining the intentional or unintentional impact targets; brief Pre- and Post-launch analyses detailing impact strategies; a Post-encounter; and an End-of-Mission Report, which should determine the location of any impact.

COSPAR strives to keep a members-only accessible repository of the information received and anything that can be shared with the public will be either published or placed in an accessible location of the Panel's web site (or both).

4 Planetary protection standards

Examples of planetary protection standards are available to provide technical requirements to protect and enable current and future scientific investigations. They inform on means to limit biological and molecular contamination of explored Solar System bodies and to best protect the Earth's environment by refraining from harmful biological contamination carried in samples returned from a space mission. These include the standards published in August 2022 by NASA in their NASA-STD-8719.27 document and standards published by the European Cooperation for Space Standardization (ESA ECSS-Q-ST-70). Both are available on the COSPAR PP website (https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/current-planetary-protection-standards/). These include:

- Planetary protection management requirements.
- Technical planetary protection requirements for robotic and human missions (forward and backward contamination).
- Planetary protection requirements related to procedures.
- Document Requirements Description and relation to the respective reviews.

The NASA standards aim to "*provide technical requirements to protect and enable current and future scientific investigations by limiting biological and relevant molecular contamination of Solar System bodies through exploration activities and protecting the Earth's biosphere by avoiding harmful biological contamination carried on returning spacecraft.*" (NASA-STD-8719.27). The ESA requirements in the ESA ECSS-Q-ST-70 standards define what should be accomplished, and not how to arrange and carry out the necessary work. This creates space for organizational structures and methods to be applied where they are operative but leaves room for evolution and improvement of the structures and methods if necessary without the need to rewrite the standards (Figure 4). Technicians in different agencies preparing spacecraft for launch frequently clean surfaces by wiping them with an alcohol solution. The surfaces are then carefully examined and submitted to microbiology tests to ensure that each spacecraft satisfies the requirements for biological cleanliness. For constituents that tolerate even high temperatures, as is the case for parachute and thermal blanketing, they need to be heated to at least 110°C to extermine the microbes. Requirements call for caution not to transport an excess of a total bacterial spores 300,000e on any surface from which the spores could be inserted into the Martian environment.

The five categories for target body or mission type (orbiter, lander) combinations and their respective recommended requirements described above can also be found on the COSPAR PPP web page and were described in our recent publications (e.g., COSPAR PPP, 2021; Fisk et al., 2021). When the need to assign the right category for a specific mission/target combination presents itself, the Panel bases its decision on the most relevant and up-to-date scientific advice available obtained through the experts in the Panel and by consulting the Member National Scientific Institutions of COSPAR. In case such expertise is missing, COSPAR may envisage setting up one or several *ad hoc* multidisciplinary committees with focused tasks. This has been the case for instance for the Martian Moon Explorer (MMX) JAXA mission (see 7.2.4).

Employing a categorization assignment enables us to effectively determine the level of risk associated with a particular mission. The

FIGURE 4
Bioburden control test on the flight model of the ExoMars Rosalind Franklin Rover using a dry heater sterilizer. Rigorous sterilization is required for Mars and applied here at 125°C for 35 h and 26 min in an oven which is part of the Lab's 35 sqm ISO Class 1 cleanroom, one of the facilities in Europe. *Credit: ESA-M. Cowan.*

five Categories of Planetary Protection outline the recommended measures that an agency should apply to each mission. For more details see: https://cosparhq.cnes.fr/scientific-structure/panels/panel-oplanetary-protection-ppp/.

5 Updated categorization of lunar landed missions

Samples returned to Earth for study by the Apollo manned missions in the 1960s and 1970s indicated that the Moon was too dry for biological activity, or even for prebiotic chemistry, leading to assignment of the Moon as a Category I target for planetary protection considerations. However, more recent findings and discoveries by robotic lunar missions during the early 2000s led to the hypothesis that ice deposits present in the permanently shadowed regions (PSRs) on the Moon could represent a layered record of Solar System history. Consequently, COSPAR re-categorized the Moon in 2008 as a Category II target for which "*there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could compromise future investigations*" (Planetary Protection Policy, e.g., Fisk et al., 2021).

So, until recently, all missions landing on the Moon required full organic inventory to be reported to COSPAR. But new findings and the intensified agency and private mission projects to the Moon warranted a new consideration of planetary protection requirements.

In 2021 the Panel updated the Policy relating to the Moon missions that would land on the surface. This included protecting scientifically interesting regions but recognizing the need for relaxation of the reporting requirements for the rest of the Moon (Fisk et al., 2021; COSPAR PPP, 2021; Coustenis et al., 2021d; Coustenis et al., 2022a; c). This was based on various activities and elements taken into consideration by the Panel such as a thorough examination of all the existing studies and reports (in particular the "Planetary Protection for the Study of Lunar Volatiles" report by NASEM/SSB CoPP issued in 2020), as well as literature findings and a joint NASA/LEAG-COSPAR survey of the community.

An updated Policy was then recommended and published in the Space Research Today issue of August 2021 and can be found on the PPP web site (https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/). The publication included the new categorization for lunar missions. The Moon remains as Category II, which comprises of all types of missions (flyby, orbiter, lander) 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[1] chance that contamination carried by a spacecraft could compromise future investigations." (from COSPAR Planetary Protection Policy, e.g., Fisk et al., 2021). However, now Category II contains two new subcategories specifically for landed missions on the Moon.

The two subcategories for lunar landers (cited from the COSPAR Planetary Protection Policy published in Fisk et al., 2021), state that:

- Cat IIa: requirements are relaxed for missions to almost all places on the Moon with requested material inventory limited

1 "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 (Fisk et al., 2021).

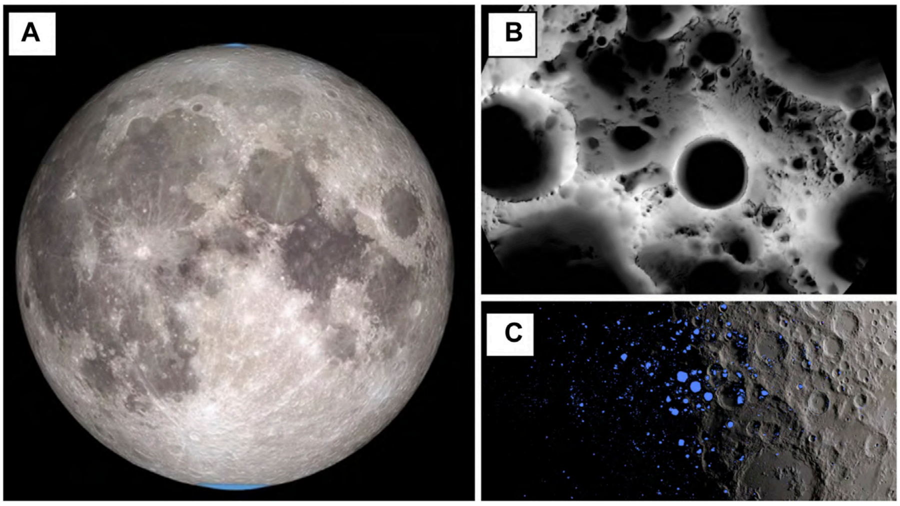

FIGURE 5
(A) COSPAR's new lunar policy concentrates the full inventory requirements at the poles (small blue caps to the left). *Image credit NASA/GSFC/ Arizona State University*. **(B)** Multi-temporal illumination map of the lunar south pole. Shackleton crater (19 km in diameter) is in the center. Darkest areas are permanently shadowed regions (PSRs). *Image credit NASA/GSFC/Arizona State University*. **(C)** Locations of PSRs at the lunar south pole derived from Lunar Orbiter Laser Altimeter data. *Image credit NASA/GSFC*.

to organic products that may be released into the lunar environment by the propulsion system.

- Cat IIb: full organic inventory (solid and volatiles) is required for missions to the surface of the Moon whose nominal mission profile accesses Permanently Shadowed Regions (PSRs) and the lunar poles, particularly at latitudes southwards of 79°S and northwards of 86°N. (Figure 5).

The scientific concern is not just direct contamination of impact sites, but also the possibility of indirect contamination resulting from the release of volatile compounds that could migrate in the lunar exosphere and be cold-trapped in the PSRs (Figure 5).

We note that neither the previous categorization nor the new one prohibits landing or accessing any region on the Moon. It does not prevent studies of the Moon which can bolster our understanding of the unique satellite and of our own planet, the Earth-Moon system formation, as well as that of the Solar System and its planets. On the contrary, the Policy is put in place to ensure that future robotic and manned missions to the Moon by international multi-component, or by single projects, will be able to conduct investigations securing scientific results (Coustenis et al., 2022b; c).

Requirements for lunar exploration from the COSPAR Policy are for simple documentation but request that be submitted:

1. Preparation of a short planetary protection plan, which outlines flight projects primarily to signify intended or potential impact targets.
2. A brief Pre- and Post-launch analyses detailing impact strategies; and
3. Post-encounter and End-of-Mission Report, which will provide the estimated location of impact if such an event is planned or occurs by chance.

6 Recent considerations regarding the Policy for Venus, Mars and small bodies

6.1 Venus missions' policy

In the past couple of years, there has been an increased interest in the possibility of a habitable environment in the clouds of Venus (e.g., Cordiner et al., 2022 and references therein; Figure 6). Under its remit, the Panel tasked some of its expert members to evaluate the current understanding within the specific framework of the planetary protection Policy.

They considered the environmental conditions within the clouds, for example, the amount of water in the clouds, the temperature conditions, and the acidity. Based on the reported measurements, even in regions where the temperatures might support terrestrial life, the water activity was low (below 0.60, which is the limit for microbial growth on Earth (Rummel et al., 2014; Hallsworth et al., 2021), even though the temperatures in the clouds would support terrestrial life. Even in the absence of lethal radiation and sulfuric acid, terrestrial-kind life would not be able to replicate there, even if nutrients were available. The PPP subcommittee recommended that unless there are new measurements that demonstrate water activity > 0.6 (RH> 60%), Venus is not expected to pose any concern for planetary protection because "life as we know it" would not proliferate therein (Zorzano et al., 2023). We, therefore, did not promote any updates to the current COSPAR Policy for Venus missions, which are still assigned Category II.

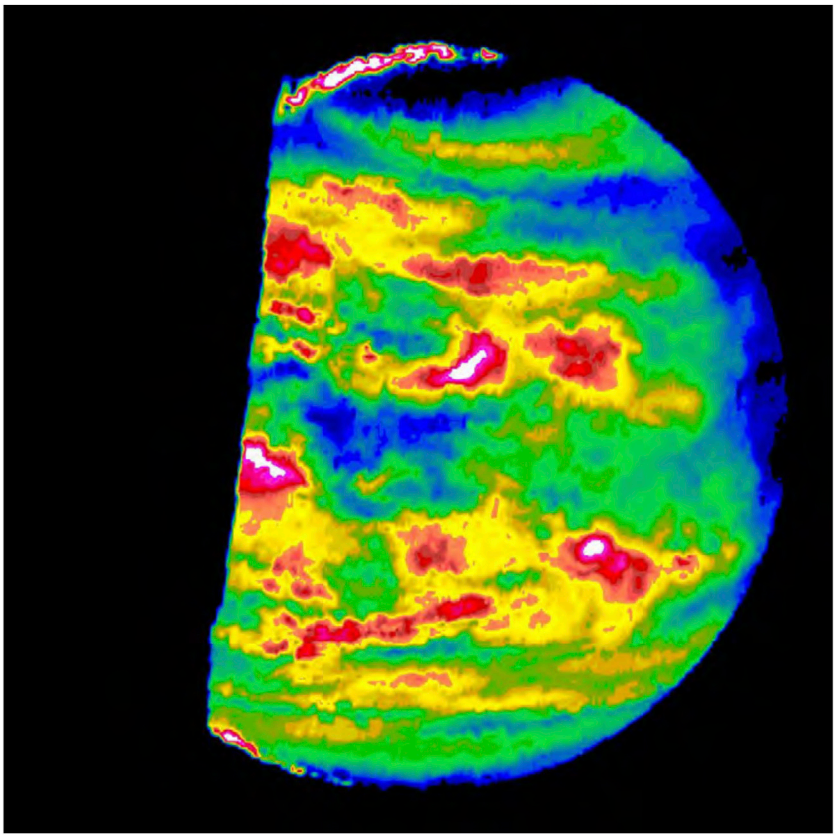

FIGURE 6
False color image of night-side Venus lower-level clouds in the near-IR, taken by the Near Infrared Mapping Spectrometer on the Galileo spacecraft in February 1990. *Credit: NASA.*

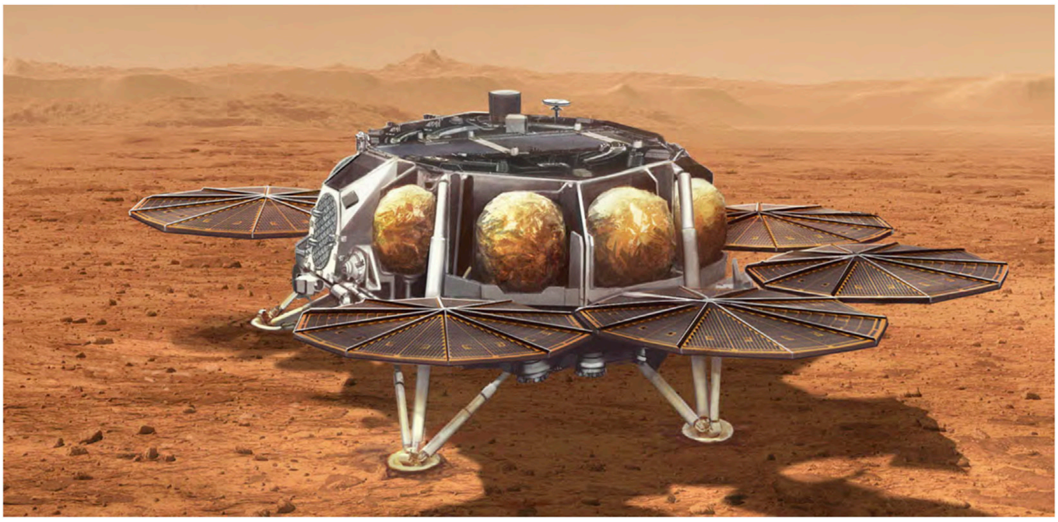

FIGURE 7
An artist's concept of a Mars Sample Retrieval Lander. *Credit: NASA and ESA.*

6.2 Planetary protection policy for Mars exploration

As more and more scientific evidence appears in support the existence of past habitable environments on Mars (e.g., Williford et al., 2018; Wormald et al., 2022), it is important to ensure that future investigations are not hindered due to terrestrial contamination. NASA, ESA, CAS and other agencies have plans for more thorough and extended exploration of the red planet, including drilling rovers and sample return. These investigations will provide an augmented view of our neighboring planet, its origin and evolution, and also potential clues as to the possible emergence of life in the Solar System (Sauterey et al., 2022). In view of these plans, it is important to ensure that future spacecraft landing on Mars comply with the bioburden requirements (Figure 4) established by an up-to-date Policy that considers the most recent scientific findings.

6.2.1 Mars robotic missions

There are several ongoing Mars rover missions with future missions planned (NASA-ESA's Mars Sample Return, MSR, is one of them, planning to return samples to Earth in the early 2030s, Figure 7). Mars robotic missions are of high concern for planetary protection. In 2006 the NRC declaration stated that Mars should be preserved from forward contamination (National Research Council, 2006). In addition, the notion of special regions on Mars has been discussed in meetings and via committees and reports (e.g., Rummel et al., 2014) before being reviewed at COSPAR colloquia in 2007 and 2015 leading to updates in 2008 and 2017 (Kminek et al., 2017). These advances were presented to the NASA Planetary Protection Subcommittee and the ESA PPWG.

More recently, the NASEM Committee on Planetary Protection (CoPP) published a report on the bioburden requirements for Mars missions (National Academies of Sciences, Engineering, and Medicine, 2021). This report reviewed past research on the habitability of the surface of Mars and made recommendations about potential new approaches in planetary protection. The CoPP report was discussed at the PPP meeting on 20 October 2021 and a PPP subcommittee was established to investigate further the current PP policy formulation for robotic missions to Mars and formed a subcommittee in 2021 to review the status based on the existing peer-reviewed literature and the possibility for habitable environments to exist on Mars. The committee focused on elements such as the stability of water, the biocidal effects and the transport of spacecraft bioburden in the Martian environment. These areas were examined in the context of survival of dormant and actively growing cells. Indeed, already harmful contamination is most likely to occur due to proliferation, but furthermore, dormant cells are important since they can be transported to a potential habitable environment, e.g., in Special Regions (Rettberg et al., 2016).

Following a thorough literature review, the subcommittee found that there is neither sufficient new evidence nor scientific community consensus at present to warrant a change or update to the bioburden recommendations for Mars. This finding was based on examples in the literature of Earth life capable of replication in extreme environments similar to Mars' known conditions. There is some ambiguity though due to existing knowledge gaps that will require new targeted research in the hopes that bioburden requirements can be lightened—these include the need for:

(1) Understanding the additive and synergistic biocidal effects of Mars surface conditions. This will require lab experiments on Earth and some new data from the surface of Mars, e.g., the nature of the Mars surface oxidant.
(2) The development of a contaminant transport predictive model with a reasonable confidence level. This will require *in situ* meteorological observations, including upper atmosphere measurements.
(3) Better understanding of the distribution of habitable conditions on the surface or in the sub-surface of Mars. This requires that observations of the surface variations and modelling of meteorological effects be performed continuously to evaluate habitable conditions, such as temperature, water availability and protection from radiation. Laboratory work on Earth could supplement our understanding of the role of salts as a water sink or source.

We therefore encourage and will facilitate additional international community engagement to further refine this list of knowledge gaps and to facilitate additional activities to compensate the information that is lacking. These findings and recommendations were published in detail in Olsson-Francis et al. (2023).

6.2.2 COSPAR sample safety assessment framework (SSAF)

COSPAR strives to perform as a platform for discussions among different space stakeholders and in that vein, co-sponsors several important workshop series that provide insights on various aspects of planetary protection aspects. One such series was concerned with the objective to assess whether samples returned from Mars could be harmful for Earth's systems. Indeed, if life is present in samples from Mars, this may represent a potential source of extraterrestrial biological contamination for Earth.

The COSPAR Sample Safety Assessment Framework (SSAF) was accordingly developed by a COSPAR appointed working group. The purpose of the SSAF was to evaluate if the presence of Martian life can be excluded in samples returned by a mission to the red planet (e; g. Kminek et al., 2014). The SSAF objectives (as described in the report) are: "The objective of the sample safety assessment is to evaluate whether there is Martian life present in samples intentionally returned from Mars that could pose a hazard for Earth's systems."

SSAF scope (as described in the report): "Conducting a comprehensive safety assessment with the required rigor to predict harmful or harmless consequences for Earth is not feasible. Therefore, the scope of the SSAF is limited to evaluating whether the presence of Martian life can be excluded in the samples. Any possible hazard is only considered in the sense that if there is no Martian life, there is no extraterrestrial biological hazard in the samples."

The SSAF therefore started from a positive hypothesis, which is complementary to the science null-hypothesis, and included four elements (Kminek et al., 2022): "1) *Bayesian statistics,* 2) *subsampling strategy,* 3) *test-sequence, and* 4) *decision criteria. The test-sequence capability covered self-replicating and non-self-replicating biology and biologically active molecules. Most or all of the SSAF investigations would need to be carried out within biological containment. The SSAF is described at a level of detail to support planning activities for a Sample Receiving Facility (SRF) and for preparing science announcements, while at the same time acknowledging that further work is required before a detailed Sample Safety Assessment Protocol (SSAP) can be developed.*" Indeed, it is clear that a comprehensive assessment to predict the effects of invasive species is difficult or even impossible (especially for some type of unknown extraterrestrial life).

In order to effectively implement and optimize the SSAF three major open issues it is necessary to: 1) set a level of assurance to exclude the presence of Martian life in the samples, 2) carry out an analogue test program, and 3) acquire relevant contamination knowledge from all future missions (like the Mars Sample Return) flight and ground elements. The SSAF is also considered a sound basis for other COSPAR Planetary Protection Category V, restricted Earth return, missions beyond Mars.

The related COSPAR statements in the Policy are:

- Category V, restricted Earth return description: "*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 non-terrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure.*"
- Specific description for MSR in the implementation chapter: "*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.*"

The SSAF covers the category description element "conduct timely analyses of any unsterilized sample collected and returned to Earth, under strict containment, and using the most sensitive techniques". The SSAF scope also covers the MSR specific implementation description "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".

A couple of points pertaining to the adequation between the SSAF works output and the COSPAR Policy requirements for a restricted return mission pertain to the non-terrestrial replicating entities and the biohazard testing. In the first case COSPAR's Policy contains a more generic formulation of the "replicating entity" which includes viruses and general biologically active molecules like prions as opposed to the SSAF concern of non-terrestrial self-replicating entities. In the case of the biohazard testing process, it become clear that we cannot define a biohazard testing process that would be generic enough and with a high confidence in a result as there are too many variables involved. Therefore, the SSAP working group came to the conclusion described in the scope (see above). Associated to that is one of the SSAF elements: "*If evidence of extinct or extant Martian life is detected, a Hold and Critical Review (HCR) must be established to evaluate the relevant data and the risk management measures before deciding on the next steps.*" In other words, if a protocol is proposed to assess whether Martian life is present that would pose a risk for Earth's systems (e.g., environment, biosphere, geochemical cycles) there could be several reasons why such a protocol could be either incomplete or of very low fidelity. A more realistic approach is to study the life form detected and define a tailored hazard assessment depending on what we find. That is what justifies the scope for the SSAF as it is now. The reports from these proceedings were published (Kminek et al., 2014; 2022).

What is very important to underline again that the SSAF is not a life defection framework (as explained in detail in the 2014 report). A life defection framework starts with a negative hypothesis with the aim to prove it wrong. The SSAF starts with a positive hypothesis with the aim to prove it wrong (within an agreed level of confidence). In the COSPAR Policy, the requirement includes a life-detection examination of the returned samples, while the SSAF specifically states (Kminek et al., 2022) that it is not a life-detection protocol.

In the future, through additional community consultation in particular, these considerations will be taken further into account by the Panel.

6.2.3 Mars human exploration and planetary protection

Human exploration of Mars will require additional planetary protection considerations to those for robotic missions. COSPAR has co-sponsored with NASA a series of workshops on Planetary Protection for Human Missions to Mars. These interdisciplinary meetings are considered the next steps in addressing knowledge gaps for planetary protection in the context of future human missions to Mars. The workshop series identified and prioritized essential knowledge gaps in science and technology areas of human exploration. Reports from these workshops are posted under Conference Documents at https://sma.nasa.gov/sma-disciplines/planetary-protection/.

A report was issued after the 6th COSPAR Meeting on "Planetary Protection Knowledge Gaps for Crewed Mars Missions", which was held in June 2022 (Spry et al., 2021) and represented the completion of the COSPAR series. This report aims to identify, refine, and prioritize the knowledge gaps that are needed to be addressed for planetary protection for crewed missions to Mars, and describes where and how needed data can be obtained.

The knowledge gaps addressed in this meeting series fall into three major themes: "*1. Microbial and human health monitoring; 2. Technology and operations for biological contamination control, and; 3. Natural transport of biological contamination on Mars.*" (Spry et al., 2021).

This approach was consistent with current scientific understanding and COSPAR policy, that the presence of a biological hazard in Martian material cannot be ruled out, and appropriate mitigations need to be in place. The findings will be published in the future in a peer-reviewed journal in order to summarize the COSPAR workshop series for the wider planetary science community and capture the planetary protection KGs and issues we have been discussing. This paper will highlight the scientific measurements and data needed for knowledge gap closure, updating and completing in more detail the material previously presented in the Planetary Science Decadal Survey

FIGURE 8
The Martian Moons Explorer mission to Phobos and Deimos. *Credit: JAXA/NASA*.

white paper (downloadable at https://doi.org/10.3847/25c2cfeb.4a582a02).

The COSPAR PPP has given their support to generate such a summary paper, with a view to using it as a vehicle to establish a path forward for future conversations and development regarding planetary protection for crewed missions.

6.2.4 The special case for the JAXA MMX mission

A particular mission case was brought to our attention by the managers of the JAXA-led Martian Moon Explorer mission (https://www.mmx.jaxa.jp/en/, Figure 8). In this case, the Panel issued a special categorization for an unrestricted Earth return. This resulted from the outcome of the dedicated studies determining that any samples returned from Phobos would not present a risk for Earth provided careful handling and processing is performed.

ESA and JAXA conducted a multi-year study on sample return mission concepts from the Martian moons Phobos and Deimos. For the mission planetary protection categorization, ESA established a science group tasked to evaluate the level of assurance on the Phobos (or Deimos) returned samples not carrying unsterilized Martian material that would have been naturally transferred to the satellites. NASA also supported the activity from the start by providing expert advice and material for testing. Later on, JAXA began their own experimental and modelling activities to assist with the overall assessment. The ESA-JAXA-NASA coordinated but separate activities used different kinds of analysis, modelling, and laboratory work that incorporated current scientific knowledge of the Martian Moons. They were completed with an independent review by the US National Academy of Sciences (NAS) and the European Science Foundation (ESF). COSPAR was also involved during the multi-year-long process.

The result of the coordinated activities between ESA, NASA and JAXA, combined with the outcome of the NAS-ESF review were presented to the ESA Planetary Working Group (PPWG) and to COSPAR. The ESA PPWG gave COSPAR a written assessment of the proposed categorization and in 2019 a planetary protection category specifically for the MMX mission was assigned: outbound Cat III and inbound Cat V (unrestricted Earth return), as recommended by the PPP and validated by the COSPAR Bureau. All these studies and results were published in a special issue (Raulin et al., 2019).

This constitutes an example of how the Panel can operate on a case-by-case process when needed and also how COSPAR is determined to share the information that leads to planetary protection requirements.

6.3 Policy on small bodies

The current COSPAR Policy for small bodies states that "*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*" (COSPAR Policy, e/g., Fisk et al., 2021).

A NASEM/SSB CoPP report titled "Planetary Protection Considerations for Missions to Small Bodies in the Solar System" was released in 2022 and a summary presented to the Panel soon thereafter (https://nap.nationalacademies.org/download/26714). The CoPP report found that it is highly unlikely that small Solar System bodies contain extinct or extant life or that terrestrial life could proliferate there. The Committee concluded that "*given the importance of some relatively primitive, volatile-rich, and organic-bearing small bodies to studies of prebiotic chemistry and the sparsity of current knowledge about them, there is no reason at this time to reduce the current categorizations (from Category II to Category I) for missions to small bodies.*" They did point out that larger objects like Ceres may be an exception. Knowledge about these larger objects is scant, and they should be assessed further before being visited, but for now, Category II is acceptable until further assessment.

PPP took the CoPP report into account at a meeting in 2022 and noted that the findings were compatible with the current policy. After thorough considerations and discussion by the Panel experts, it was decided that there was no need currently to change anything in the Policy as concerns small bodies.

7 Future planetary protection items for consideration

In the past 3 years, the COSPAR PPP has published two updates of the Policy for Outer Solar System bodies and the Moon (COSPAR PPP, 2020; 2021; Fisk et al., 2020; 2021), and also has expressed its current position on other planetary exploration endeavors, always striving to taking into account the most up-to-date scientific findings. The Panel has also published their findings from studies and reviews in scientific articles and special issues. But space exploration continues. New scientific and technological advances and ever increasing interest in space exploration require constant attention and the PPP needs to keep abreast with all such developments.

As explained above, we recently discussed and in the future will address again (among other) as a priority:

- Martian robotic and human exploration.
- Further exploration of the moons of giant planets to determine whether there is any reason to update the Policy in these cases.

Indeed, higher planetary protection categories include missions to bodies that are of interest for scientific research concerned with the origin of life. Category III, IV and V missions are those investigating celestial bodies like Mars, Jupiter's moons and Saturn's moons, in particular Europa and Enceladus), where any kind of forward contamination with terrestrial organisms might compromise future exploration, as well as those returning samples to Earth.

For such missions, the highest degree of contamination control is applied to ensure that a minimum level of "bioburden" is carried on the spacecraft and transported to the target body. Planetary protection technologies are constantly reviewed in order to be updated and improved, in particular for methods of cleaning and sterilizing spacecraft and for handling samples of soil, rock and atmosphere. The Panel is always mindful of all scientific arguments and results so as to azlways make an informed and accurate decision.

7.1 Mars exploration

The COSPAR PPP plans to pursue the investigations into the Mars exploration PP Policy and in particular:

- Determine the best way to investigate regions of high interest for the search of extinct or extant life on the red planet.
- encourage enhanced international community engagement to further refine the current list of knowledge gaps in various aspects (especially manned missions), as well as the way forward for improving our understanding of what is needed to be done.

7.2 Icy moons

The natural satellites of the giant planets offer new tantalizing opportunities to explore dark and cold (far-away from the Sun) undersurface environments that harbor liquid water, organic chemistry and energy sources, so that a new concept of habitable environments could still be considered. This is the case for satellites of Jupiter and Saturn like Europa, Enceladus, Titan and Ganymede for instance.

The COSPAR PPP has already updated the policy requirements and definitions for the icy moons (especially Europa and Enceladus), (see Fisk et al., 2020; Figure 9), and plans to continue work on their exploration.

The 2020 update was based on a project funded by the European Commission and led by the European Science Foundation with DLR/Germany, INAF/Italy, Eurospace, Space Technology/Ireland, Imperial College London (UK), China Academy of Space Technology (partner), and NAS-SSB (as an observer). The Planetary Protection of the Outer Solar System (PPOSS) study led to the revision of the planetary protection requirements for missions to Europa and Enceladus, also considering the NAS-SSB 2012 Icy Bodies Report. The PPOSS study was supported by the European Commission's H2020 Program (2016–2018, under grant agreement 687,373) with several additional contractual partners with a main goal to provide an international platform to review the specificities of Planetary Protection regulations as concerns outer Solar System bodies and to provide related recommendations to COSPAR (see Kminek et al., 2019).

The PPOSS recommendations were presented to the ESA Planetary Protection Working Group (PPWG) and to COSPAR in 2019. The ESA PPWG provided a written assessment of the PPOSS recommendation to COSPAR. Having followed the multi-year-long process, COSPAR's policy and requirements for missions to Europa and Enceladus were adopted in the 2020 updated Policy (Fisk et al., 2020), which read as follows:

- Policy should include a generic definition of the environmental conditions potentially allowing Earth organisms to replicate.
- Implementation guidelines should be more specific on relevant organisms.
- Implementation guidelines should be updated to reflect the period of biological exploration of Europa and Enceladus.
- Implementation guidelines should acknowledge the potential existence of Enhanced Downward Transport Zones at the surface of Europa and Enceladus.

The new COSPAR Policy updated official document was published in the August 2020 SRT issue (Fisk et al., 2020). In the future and in view of the upcoming space missions that agencies are planning for the icy moons (like ESA/JUICE to Ganymede, NASA/Europa Clipper to Europa and NASA/Dragonfly to Titan, among other), the PPP will be gathering community input to acquire

FIGURE 9
New Policy aspects were implemented for icy moons of the giant planets, in particular Europa and Enceladus. This image shows Europa Clipper's vault, with the nadir deck attached, being prepared for transport to the High Bay 1 clean room of the Spacecraft Assembly Facility at JPL. The vault is aimed to protect the spacecraft's electronics, while the nadir deck is destined to provide a stable platform for the science instruments. *Credits: NASA/JPL-Caltech*.

consensus on changes that can be made to the protocols for visiting icy worlds in our Solar System.

7.3 Special cases

COSPAR PPP is operating and open to operating in tailored or specific target body or mission unique perspectives. As for the special categorization that was issued by the PPP for an unrestricted Earth return from Mars' Moon Phobos by the JAXA MMX mission (See 7.2.4), since studies showed that samples would not pose a threat for our biosphere when care is taken in the processing and handling (Raulin et al., 2019, the entire special issue of LSSR volume 23; Figure 9) the Panel is further discussing items related to evaluating via a risk management-based approach, as well as how best to integrate the opportunities and caution represented by the private sector endeavors.

8 Conclusions and prospects

Planetary protection concerns are not new, but, as we move forward in space exploration, they become more immediate. Planetary protection guidelines have been developed to enable safe scientific space exploration and to ensure the protection of our planet. Given the current and future enhanced space exploration by traditional and new entities, securing sustainable robotic and human investigations in space relies upon compliance with the Planetary Protection Policy, which should be consulted at the start of new space projects by all stakeholders, whether space agencies or the private sector.

Technologies are developed in many places for cleaning and sterilizing spacecraft and handling soil, rock, and atmospheric samples. At the same time, more efficient and sophisticated methods and facilities are put in place to protect our home planet upon return of extraterrestrial matter to Earth as more missions aim at returning samples from different Solar System bodies.

The open sessions proposed during the PPP meetings offer the possibility for all interested parties in space exploration to attend and propose issues of concern. Scientists, engineers, as well as space agencies and the private companies representatives participation in these meetings is encouraged and welcomed.

The Panel will continue to tackle any new needs for improvements and updates in the Policy, and any new possibilities of exploration that might entail contamination (forward or backward) and will strive to keep the community informed and aware of these changes.

In the meantime, community input on science findings and research reserves regarding recent reports that COSPAR is always welcome. The Panel will assist in any way—via co-sponsoring a number of new studies, community surveys, Workshops and focused conferences—all projects of exploration that require particular attention in terms of planetary protection.

Author contributions

AC, KO-F, FR, OG, PD, MZ, OP-B, VI, and KX worked on the scientific knowledge as can be applied to the planetary protection requirements and the categorisation of the space missions. NH worked on the issues of space law and compliance with the OST. The other co-authors, while representing space agencies, also added their scientific and engineering expertise to the service of updating and promoting the COSPAR Planetary Protection Policy. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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