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NASA's Planetary Protection Program to Assure Mission Safety and Success

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Abstract

NASA's planetary protection program seeks to understand and control harmful contamination of solar systems targets of exploration by terrestrial contamination and prevent harmful biological contamination of the Earth-Moon system by extraterrestrial life, should it exist. To accomplish these objective's NASA has developed a balanced safety and mission assurance strategy that leverages COSPAR Policy guidelines, workshops, scientific consensus, partnerships and international working groups to develop policy and implementation guidelines. Upcoming crewed missions to the Moon and Mars, as well as robotic missions to small solar system bodies, Europa, Titan and Mars are some of the driving activities of astrobiological interest that continue to emphasize the importance of planetary protection throughout the project life cycle.

Development of a responsive and updated agency planetary protection policy has been a focus area in supporting upcoming mission opportunities for exploration to include Mars sample return and crewed mission concepts. An extensive update of this policy is underway which encompasses crewed and robotic procedural polices, a general technical requirements standard, and an implementation handbook. During this timeframe NASA has been working with the international community to develop scientific consensus, and to identify and fill in knowledge gaps for developing balanced policy guidelines, incorporation of risk informed decision making and quantitative technical standards. NASA has developed a planetary protection roadmap as a technology management strategy to track and monitor the development of each knowledge gaps. The Committee of Space Research (COSPAR) Policy on Planetary Protection and the National Academies of Science, Engineering, and Medicine's Committee of Planetary Protection are used to inform updates to the planetary protection polices and guidelines. This integrated strategy for planetary protection seeks to provide a transparent, structured approach for enabling missions, providing guidance for NASA and NASA partnered missions, and being responsive to the increased interest and activities in space exploration whilst maintaining an understanding and control of harmful contamination.
Keywords: planetary protection, Moon, Mars, Europa

Acronyms/Abbreviations

Committee on Planetary Protection (CoPP)
Committee of Space Research (COSPAR)
Federal Aviation Administration (FAA)
International Space Station (ISS)
National Academies of Science Engineering and Medicines (NASEM)
NASA Charter (NC)
NASA Interim Directive (NID)
NASA Policy Directive (NPD)
NASA Procedural Requirement (NPR)
Office of Planetary Protection (OPP)
Office of Safety and Mission Assurance (OSMA)
Planetary Protection (PP)
Planetary Protection Panel (PPP)

1. Introduction

The main objective for planetary protection (PP) is 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. Responsive to Article IX of the Outer Space Treaty to "*conduct exploration of them [the Moon and other celestial bodies] so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter*" NASA continues to pursue an integrative and active PP policy [1]. NASA's policy and implementation approach is centred around a strategy for the prevention of harmful forward (addressing harmful contamination from Earth to other planets) and backward contamination (addressing harmful contamination from extraterrestial material to Earth's biosphere). The main strategy to address forward planetary protection is to understand and control harmful contamination of other worlds by terrestrial organisms, organic materials, and organic volatile materials carried or released by spacecraft in order to assure integrity in the search for evidence of extraterrestrial life and the study of prebiotic chemistry in the solar system for the appropriate period of biological exploration. The main strategy to address backward planetary protection is to prevent harmful biological contamination of the Earth-Moon system by potential extraterrestrial life and bioactive molecules in returned samples and spacecraft from a sensitive solar system body.

With the increase in mission complexity, frequency, and the expansion in the diversity of private sector spacecraft operators the demand for preventing harmful contamination is at an all-time high. For example, the National Academies of Science Engineering and Medicines (NASEM) Decadal Strategy for Planetary Science and Astrobiology 2023-2032 is recommending missions to target the highest biological bodies of interest to include Mars and Enceladus [2]. Post Apollo 14, PP has focused its efforts on robotic exploration, but recently the Artemis Moon to Mars program has reinvigorated the need for PP policies and implementation for crewed missions [3]. An increase in mission frequency is also being proposed to include low-cost Mars concepts to utilize smaller, affordable missions in performing high-priority science investigations to Mars [4]. In addition to the potential of NASA lead and partnered missions, commercial space is also expanding their capabilities for payloads headed to the Lunar surface and Mars. Thus, given this increase in missions and interest to bodies of high PP interest an agile PP strategy is being accomplished by NASA to enable commercial, NASA partnered and NASA missions.

2. Integrated Planetary Protection Strategy

2.1 Organization of PP with NASA

Planetary protection is a technical discipline housed within the NASA Office of Safety and Mission Assurance (OSMA). Within NASA the OSMA's roles and responsibilities as a technical authority enables PP to work independently of the programmatic structure of the mission directorates responsible for missions, programs and technology development [5,6]. This positions PP to work with multiple key stakeholders across the Agency to include technology development efforts with the Space Technology Mission Directorate, robotic exploration and mission interfacing with the Science Mission Directorate, and crewed Lunar and Mars mission interfacing with the Exploration Systems Development and Space Operations Missions Directorates. In addition to the day-to-day mission operations the Office of PP (OPP) coordinates policy and implementation approaches with the Chief Medical Officer, Chief Scientist, and Chief Engineer.

Within OSMA PP has a safety forward focus of protecting terrestrial, orbital and planetary environments [7]. As per the NASA Policy Directive NPD 8700.1F entitled, NASA Policy for Safety and Mission Assurance, complying with external obligations, adopting effective and responsible safety standards and industry best practices, prioritizing performance-based approaches and engaging on the subject matter experts when strategies are necessary to ensure an acceptable risk posture have been the focus areas for PP within OSMA.

For Agency coordination PP utilizes a NASA Cross-Directorate Federated Board to coordinate, review, advise and advocate on PP topics to include budget, technology needs, and integrated roadmap development and management. As per NC 1000-52, "*The purpose of the FB is to ensure that Agency priorities and general architectural direction are tightly and efficiently integrated for Artemis/Moon-to-Mars (M2M) and other activities that require coordination across the Mission Directorates (MD)*" [8]. To-date, the OPP has been able to establish an integrated technology roadmap (Refer to Section 2.2) and a dedicated budget through this process. Updates are provided to the Cross-Directorate Federated Board on an annual update or as needed.

2.1 NASA's Planetary Protection Role with Commercial Space

Being that NASA is not a regulatory Agency within the United States Government the role for NASA supporting commercial space is solely a technical interface as requested through the formal interagency processes. NASA currently consults with the Federal Aviation Administration (FAA) when asked by the FAA to review a commercial provider's voluntary launch license. During this process a technical assessment is conducted based on the voluntary information provided. The recommended guidance for technical consultation typically includes the following information for both the launch elements and payloads: A. a description of the energetic potential of the proposal systems on the primary launch vehicle, launch vehicle second stage, cruise stage and any independent propulsion systems on the primary or secondary payloads, B. a description of the trajectory including flybys and gravity assists of celestial objects and orbital insertion or landing at the destination, C. an assessment of biological contamination risk and associated mitigation strategy for the avoidance of celestial objects during operations, and D. for spacecraft destined for the Moon an inventory of propulsion products and if the spacecraft are going to permanently shadowed regions (PSRs) or the lunar poles they should also provide a spacecraft organic inventory [9].

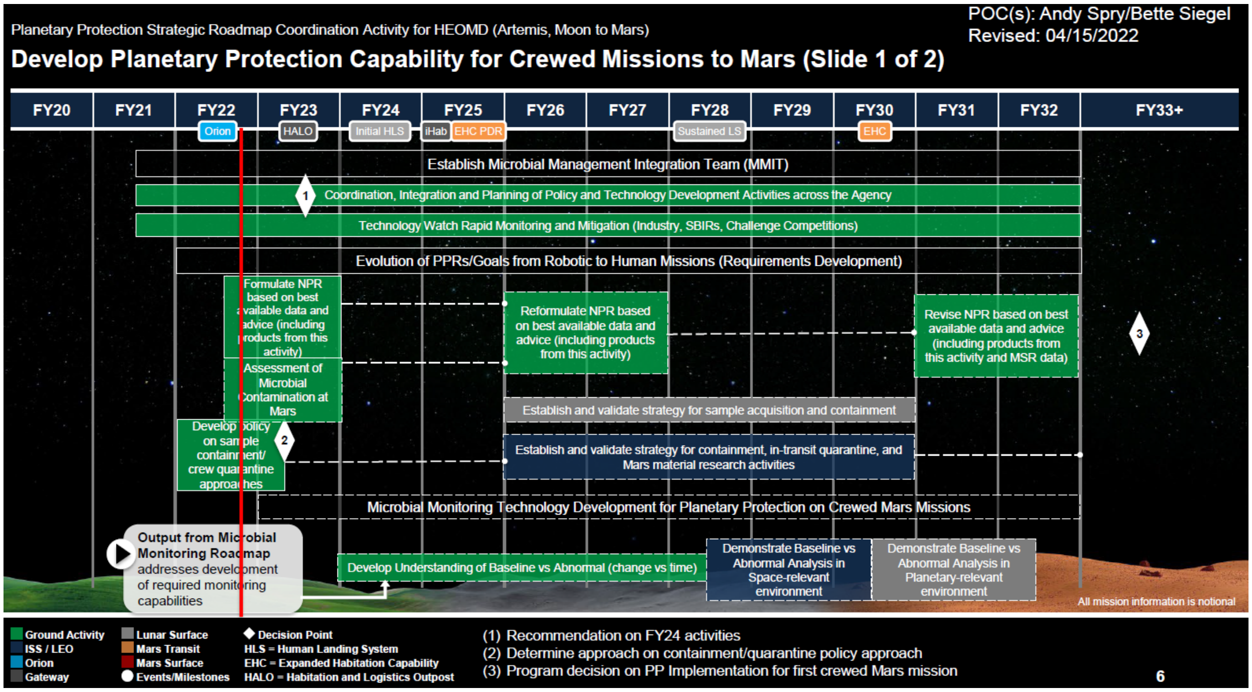

Figure 1. An example of the integrated Agency Planetary Protection Technology Roadmap.

2.2 Roadmap and Knowledge Gap Identification

To enable crewed Mars missions a total of six workshops were held (one NASA and five NASA, European Space Agency and COSPAR jointly sponsored workshops) with the international science, engineering, and industry stakeholders from 2015-2022. These workshops helped to establish what knowledge gaps exist, refined the prioritization of the knowledge gaps, identified the mission opportunities needed to address each gap, defined the measurement of the payload and operational concepts for closure to establish a balanced quantitative and provide an implementable PP requirement for the safe and sustainable exploration and utilization of Mars. These workshops have been leveraged to identify and fill in knowledge gaps for developing balanced policy guidelines, incorporation of risk informed decision making and formulation of technical standards for crewed flight. Based on the initial NASA workshop report from 2015, the COSPAR Policy was updated, and NASA adopted the research structure as part of its basis for the research structure to further develop policy on biological PP for crewed missions to Mars [10,11]. The knowledge gaps identified were based on microbial and human health monitoring, spacecraft technology and operations, and natural transport of contamination at Mars [12]. These workshops have also help to develop an Agency level technology roadmap for planetary protection (Figure 1) which are integrated and managed alongside other engineering and science discipline technology roadmaps. An example, of this is illustrated in the bottom left-hand side of Figure 1 where outputs from the microbial monitoring roadmap are needed to address what monitoring capabilities are before developing a baseline microbial understanding of the crewed environment for PP purposes. This is to ensure that a synergy between disciplines is present to coordinate crewed resources.

For microbial and human health monitoring there was a significant synergy between Earth safety for PP and issues relevant to assess the health status of the astronauts on a mission to Mars and back. Systemic monitoring of the International Space Station (ISS) flight system and crew onboard was identified as a useful testbed to get long-term and statistically relevant baseline data and trends to help close this gap [13, 14]. To close this gap, the currently leveraged MinION (Oxford Nanopore Technologies) is planned to be used given the demonstrated flight capability, necessary consumables, and crew-time already characterized and in use onboard the ISS [15]. Technical data mining is necessary to understand the existing, limited microbial monitoring in scope (i.e., number of crew and locations) and depth (i.e., details of the microbial population) alongside a standardized sampling and analysis procedure for an in-depth monitoring study.

Spacecraft systems and operations were discussed in detail over the course of several workshops to include waste management, crew associated gas/liquid/microbial discharge management, crew quarantine for back PP, and sample containment considerations for restricted Earth return [16]. During the waste management discussion surface disposal was preferred by engineering, but there was consensus that the containment of the waste be designed based on the 50-year period of biological exploration using multiple layers, microbial tracking and a single site adjacent to the landing site to minimize the crew footprint. For discharge management both nominal and non-nominal scenarios were detailed where microbes (not chemistry) were of concern during ingress and egress without consensus on how much contamination was too much or what should be monitored. Given the lack of consensus a concepts of operation proposal is being formulated by the Mars Architecture Team for a use case to study this topic further. (Workshop report). The last workshop in June of 2022 focused on sample return and quarantine measures of crew for return. Given the lessons learned with COVID and quarantine there was lots of conversation surrounding the feasibility of quarantining astronauts although the group concluded that since isolation of an astronaut is not deemed practical the entire crew should be quarantined. Also, it was concluded that the crew be quarantined upon return and that the transit back could be used as additional data to further assess quarantine limits (as opposed to the transit time back starting the clock for quarantine). During the last workshop restricted Earth return for Mars material was discussed and it was determined that the Mars samples should be contained irrespective of whether Mars Sample Return Campaign shows no life, and the crew are previously exposed. Additionally, all samples are to be contained until demonstrated to be "safe".

Contamination transport and understanding natural transport phenomena of terrestrial biological contamination (e.g., windblown dust or ground water flow) on Mars is necessary for defining requirements for flight system and operations for establishing operational zones for exploration and commercial activities. Ideally, high fidelity meteorological data over at least a full martian year at multiple fixed locations has been identified to develop, test and validate the necessary contamination transport models. While there have been meteorological measurements collected on Mars to-date these measurements have not been collected at the frequency and duration required to develop such contamination transport models. Notably, the First mArs High-resolution Regional Environmental monitoring Network for Human Exploration-related climate Investigations and dust Transport mission included in ESA's Terrae Novae 2030+ Strategy Roadmap is currently the only mission in design that addresses the need air pressure, air temperature, ground temperature, horizontal and vertical wind speed, dust particle concentration/mass flux, total dust column opacity, humidity, solar flux measurements [17].

These knowledge gaps are being used to inform key areas within policy and in parallel used to architect technology roadmaps. Currently, NASA has developed an integrated cross-Agency technology roadmap to track and monitor the development of each knowledge gaps. Being integrated knowledge gaps, these dovetail together with interfaces to other science and engineering roadmaps.

2.3 Policy Evolution

Over the past 5 years, NASA PP Policy has undergone a significant overhaul to further clarify and restructure the PP policy by updating the technical standards as well as streamlining and aligning the policy to the NASA policy management directives process (Refer to Figure 2). The NPD that described the NASA management structure to prevent harmful contamination of terrestrial and planetary environments was implemented to replace the old structure of PP being within the Science Mission Directorate. NPR 8715.24 was generated to replace the decades standing NPR 8020.12D/NID 8020.109A to update the PP policy with the agency level policy directives standards. This resulted in the NPR focusing on the procedural requirements while pushing the technical requirements to the standard. In addition to this separation, the NPR was expanded to include the ability for leveraging risk informed decision making, standardized the PP process and execution to NASA management process, updated PP gate products and reviews, and expanded the roles and responsibilities to include a programmatic component in addition to the technical authority. The technical standard was then revised to include a performance-based approach in addition to the prescriptive requirement which has increased the flexibility for PP compliance approaches. Additionally, since there is not a standard for the microbiological laboratory for the NASA Standard Spore assay the technical standard also has a chapter dedicated to biological contamination assessments on spacecraft surfaces using swab or wipes. Unlike other standard techniques for planetary protection (e.g., cleanrooms) this specific traditional microbiology standard is not captured in other industrial standards so it cannot be preferably cited.

A handbook for implementing planetary protection is currently under draft to expand on the NASA Handbook 6022 [18]. The draft in planning will serve to update and modernize the biological contamination assessments for spacecraft and spacecraft associated environments (e.g., use of molecular biological techniques). An expansion of this handbook will include organic inventory and archiving, burn up and break up analysis, and impact avoidance topics to be more inclusive of standard practices for meeting compliance with PP standards.

A NASA Interim Directive (NID) 8715.129, entitled "Biological Planetary Protection for Human Missions to Mars" was introduced 9 July 2020 to assist in the planning phases for crewed missions to Mars [19]. The intent of this NID was to introduce a set of international consensuses guidelines and objectives for mission planning and designing. As an interim directive this is a temporary set of requirements that should be assessed on a yearly basis as a follow-on NPR is being drafted. The working objectives for this NID include safeguarding Earth's biosphere from Mars material as the highest safety priority and understanding and controlling the human-associated contamination to preserve future exploration. It is assumed that that for both objectives the crew and/or their support systems will be exposed to the Mars environment and that all operations will not occur within an entirely closed loop system. To continue to develop technical standards the NID also details the technology gaps of microbial and human health monitoring, spacecraft technology and operations, and natural transport of contamination at Mars as further reinforced in the road mapping effort detailed in Section 2.2.

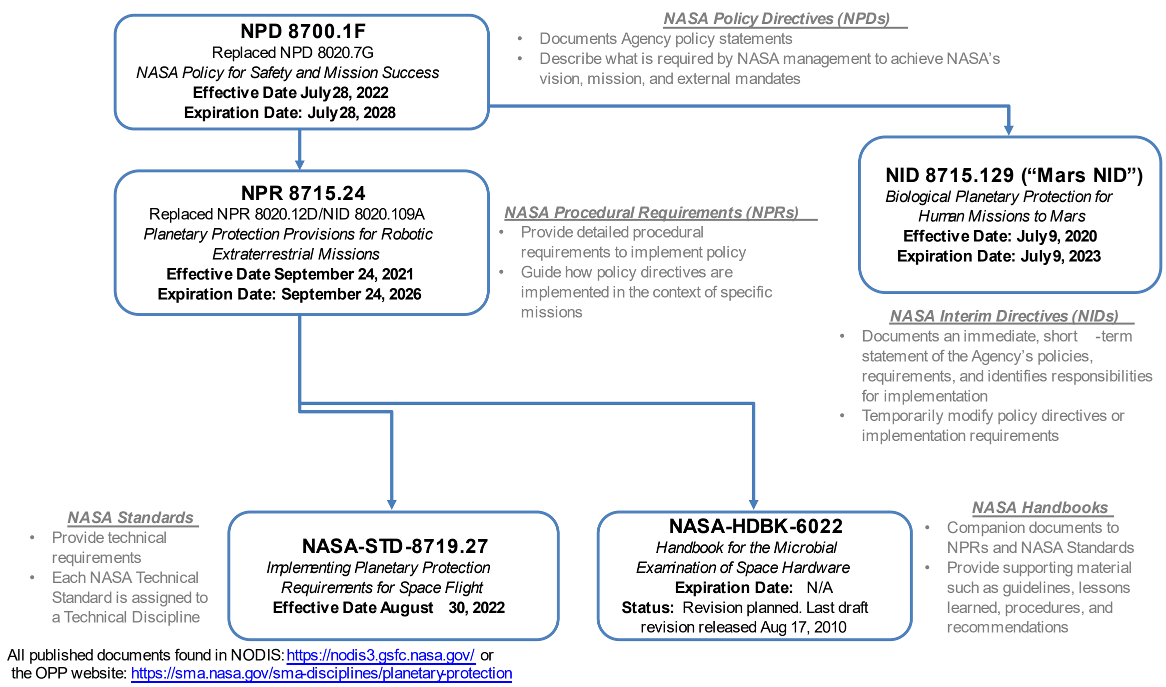

Figure 2. NASA's planetary protection policy relationship with detailed background into NASA policy objectives.

2.4 Obtaining Scientific Consensus

Utilization of current scientific consensus throughout the project life cycle is important to ensure that missions maintain an acceptable approach for demonstrating compliance with the Outer Space Treaty. Scientific consensus has potential to impact the overall policy objectives in prevention harmful contamination to impacting the standards for spacecraft cleanliness, operations, and disposal. For example, within NASA the current scientific consensus should be consistent with the missions categorization, identification of applicable requirements, verification and planning activities, execution and oversight of the implementation with the understanding that any new scientific discovery made and accepted as current scientific consensus may change constraints on the project.

Given the important of current scientific consensus in the life cycle of the mission understanding the process in which obtaining scientific consensus is necessary. Scientific consensus implies that a majority of international scientists should accept a current scientific discovery. It should not be reactive towards a new scientific findings, but represent a widespread viewpoint allowing time for peer-reviewed debate and discussion. For large scale and multidisciplinary topics this may require scientific organizations such as the NASEM CoPP or a mission-by-mission tailoring process initiated by The Committee of Space Research (COSPAR) Policy on Planetary Protection. For focused topics such as categorization or implementation topics an independent science review board or the peer-reviewed journal community may suffice with mission report out during the COSPAR PPP meeting. The NASEM CoPP has been used to study key PP topics informing updates to the PP polices and guidelines. Since 2020 the NASEM CoPP has released two study reports to include updated inputs for Lunar and Mars missions [20,21]. For Lunar missions this CoPP report on the assessment of Lunar volatiles recommended language for updating PP guidance. These recommendations were then discussed internally within NASA and a proposal was presented to the COSPAR PPP based on the CoPP report. COSPAR PPP then updated the COSPAR policy with modifications to the proposed Categorizations for orbiting, landed missions to all sites not including permanently shadowed regions, landed missions to the permanently shadowed regions as II, IIa and IIb, respectively in June 2020. After adoption from COSPAR, NASA NPR 8715.24 was updated with the new Lunar categories. In contrast to policy level changes the NASA Chief Scientist's Office has independently reviewed the Europa Clipper disposal target location proposed for Ganymede to conclude that given the spacecraft's energy at impact would not penetrate the ice crust as well as evaluated the Dragonfly categorization proposal of PP Category II to ensure it still has a remote potential of contamination. Both Europa Clipper and Dragonfly mission findings were reported out in the COSPAR General Meeting in July 2022 in Athens during the PPP mission update session.

3. Discussion and Future Work

While PP has started to develop a more streamlined and integrated strategy within NASA more work is planned to prevent harmful contamination while enabling future missions. Alongside technology advancement and policy development the OPP is working to develop a complementary suite of command media with educational videos, online training, establishing an in-person training course, webinars, establishing a NASA Engineering Network Community of Practice for Planetary Protection, generation and updating the OSMA OPP website, and updating the commercial payload voluntary information for request as more clarity comes online. This would support the policy through a series of communication formats to support information disseminated to the broadest community possible.

In addition to the internal work within NASA it is also important to the Agency for continued and transparent relationships with the international PP community. This would include an active role in COSPAR, working with key Agency partners to coordinate policy, training, technology gap identification and development, standard development, and necessary compliance coordination for partnered missions.

From a policy perspective the immediate need for NASA would be to establish both a precedence for the utilization of performance-based approach and development of a crewed mission NPR. With the increased flexibility for leveraging a performance-based approach to meet PP more technical work will be required to implement, develop standards and handbook material to capture best practices for conducting biological assessments on prior to flight, biological assessments in flight for crew and habitats monitoring as well as biological assurance cases within NASA.

4. Conclusions

This integrated strategy for planetary protection seeks to provide a transparent, structured approach for enabling missions, providing guidance for NASA and NASA partnered missions, and being responsive to the increased interest and activities in space exploration whilst maintaining an understanding and control of harmful contamination. The integrated strategy of revising policy to parse out the technical authority responsibility of PP, further documenting and providing clarity for supporting the payload consultation process, identification and planning for technology roadmaps, and codifying a scientific consensus review process has streamlined mission interactions and PP development activities. While not fully implemented NASA PP continues to seek a proactive role in technology and policy development that results in a balanced, safety focused prevention of harmful contamination that supports mission design, integration and execution as further technology gaps are closed and crewed Mars mission policies developed.

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