Planetary Protection Knowledge Gaps and Enabling Science for Crewed Mars Missions

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Dec 21, 2021

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# 1. Introduction

In the coming decade, as we prepare for the first mission to Mars with a human crew, we have a continuing obligation to protect the integrity of scientific investigations at Mars. In particular, it is unlikely that the search for life on Mars will be completed by the time the first crew-rated systems arrive at the martian surface.

Indeed, some consider the presence of astronauts to be an essential augmentation to the robotic search for evidence of life on the red planet. In addition, the environment of the Earth needs to be protected from the threat posed by the uncontrolled release of a putative martian life form into the terrestrial biosphere. Prevention of such harmful cross-contaminations between Mars and the Earth is the practice of planetary protection.

At present, the knowledge of how to achieve these two goals (prevention of forward contamination from Earth and backward contamination from Mars) is well described for robotic systems. In contrast, for crewed missions there are only guidelines (COSPAR, 2021) but no engineering requirements. This is, in part, because our knowledge of the environments of Mars (and of how terrestrial contamination from crewed systems will interact with those environments) is incomplete. These gaps in our knowledge (as described in 2020 NASA NID8715.129) need to be addressed through acquisition of new data during the next decade, if planetary protection measures are to be implemented successfully by future crewed missions.

This white paper focuses on the planetary protection-relevant research elements of the Space Biology and Physical Sciences Programs being addressed by the current Decadal Survey on Biological and Physical Sciences Research, describing the need for a **campaign-level crosscutting approach** to acquire the needed new data, drawing on the earlier and more detailed 2020 Planetary Science and Astrobiology Decadal Survey submission with the same authorship (Spry et al., 2021).

# 2. Background

Since 2015, the topic of planetary protection knowledge gaps (KGs) for crewed missions has been systematically addressed during a series of workshops (e.g., Race et al., 2019), currently being held under the COSPAR banner. The international multidisciplinary group of scientists and engineers participating in this activity have generated and refined a set of KGs, and grouped them into three study areas: 1) natural transport of contamination on Mars; 2) microbial and human health monitoring, and; 3) technology and operations for contamination control. The concept is that closure of KGs in these study areas would make feasible an end-to-end knowledge-based solution for setting planetary protection requirements and developing implementation procedures for crewed missions. Knowledge gaps in all three study areas fall under the scope of activities supported by NASA under the Space Biology and Physical Sciences Programs.

# 3. Planetary Protection Knowledge Gaps related to the Space Biology and Physical Sciences Programs

The Space Biology Program supports research to understand how biological systems respond to spaceflight environments. The Physical Sciences Program supports research to understand how physical systems respond to spaceflight environments. Overlaps to the planetary protection KG data needs are as follows:

## 3.1 Microbial survival in the space environment

A key aspect of KG closure is to understand the combinations of environmental factors under conditions relevant to the journey to Mars, and at the martian surface, that affect the survival of cultivable and non-cultivable bacteria, archaea, fungi, and other eukarya associated with crewed spacecraft environments as a risk factor for contamination at Mars (Nicholson et al., 2010; Schuerger et al. 2012, 2013; Rabbow et al., 2017).

## 3.2 Microbial survival in the spacecraft environment

New advancements in genomics and DNA sequencing technology have deepened our understanding of microbial populations and their interactions to the point where diagnostic monitoring of the microbiome of the built environment is achievable (e.g. Lax et al., 2014). Likewise, these advancements have been applied to isolate and characterize microbes from spacecraft-associated environments (e.g., Singh et al.,

2019), and provide the potential for a data-rich cost- and mass-effective tool for long term monitoring of the health and functional performance of the spacecraft environment and its systems, as well as the threat posed to Mars by the spacecraft microbiome. The ability to sample for genomic data broadly, then use software tools to focus on relevant microorganisms, is key to the unique utility of the method in closing KGs. For example, using metagenomics data generated from a spacecraft assembly facility and the International Space Station (ISS), environmental samples were analyzed for radiation-resistant non-spore forming microorganisms (Be et al. 2017).

## 3.3 Microbial monitoring and crew health

A critical component of a crewed mission to the surface of Mars is monitoring astronaut responses to exposure to the martian environment, particularly if the presence of a martian biosphere is suspected or detected. Evaluation of human health requires the monitoring of the crew themselves, as well as all the

microbial communities associated with spacecraft systems described in 3.2 previously (Voorhies et al. 2019). These microbial florae need to be monitored and tracked not only at their initial state against an established baseline, but also for changes over time.

NASA is pursuing DNA-sequencing methods for microbial monitoring based around the MinION platform. While sample preparation aboard the ISS has been demonstrated, significant optimization will be required to support extended mission duration in deep space environments to close this KG.

## 3.4 Biological contamination mitigation

Crewed spacecraft systems are not designed to be “sterilizable” in their entirety, nor should they be, since the presence of the crew means that the substantial microbial community (microbiome) that is travelling with the humans in the spacecraft would almost immediately begin to recontaminate any sterilized environment. However, wherever humans have unmitigated direct contact with an environment, their microbes are transferred, so mitigations will be required if microbial release into the martian environment is to be controlled. Microbial surveillance and tracking studies on the ISS have demonstrated that the microbiology of its built environment changes to include the microbes of each successive crew who lives on the ISS (Voorhies et al 2019, Avila-Herrera et al 2020). Testing of hardware and protocols would need to be conducted using ISS and/or terrestrial analog closed system habitat facilities, to determine the most efficient (and sufficient) habitat/operations mitigation approaches and protocols to allow effective crewed exploration on the martian surface while mitigating both forward and backward contamination risk.

## 3.5 Materials selection and performance

Cleaning and sterilization methods only temporarily reduce the microbial load on a surface, which becomes re-populated with (different) microbes over time. This necessitates a tolerance of recleaning approaches. Spacecraft microbial reduction protocols can be leveraged from earlier NASA robotic missions, separately or in combination, with additional operational cleaning strategies such as anti-microbial wipes, vaporized sterilizing agents, and germicidal lighting. Additionally, surfaces impregnated with anti-microbial agents or naturally antimicrobial materials could be used (Sobisch et al, 2019). However, current spacecraft systems may be incompatible with anti-microbial surface treatments, anti-microbial material choices or aggressive cleaning processes. End-to-end strategies need to be developed to close this KG, including demonstration of physical performance/tolerance of materials used in spacecraft systems to operational conditions imposed by planetary protection constraints.

# 4. Discussion

Robotic missions to Mars have revealed a diverse, active geology, but not all places on Mars are equal in terms of providing the right conditions for microbial growth, resulting in the concept of “Special Regions” (Rummel et al. 2014) which is included in the COSPAR Planetary Protection Policy (COSPAR 2021). In our present state of knowledge, this recognition of differential need of protection will likely continue into the crewed exploration era. Enabling crewed missions to Mars while maintaining the safety of the Earth and the continued scientific exploration of Mars requires establishment of quantitative planetary protection requirements to avoid microbial contamination and develop associated mitigation measures.

The high-priority KG areas that need to be closed before we can actually do this are in understanding of:

* Source terms – microbiological contamination threat of a crewed system
* Distribution terms – dispersal of biological contamination released into or from the martian environment
* Reduction terms – biocidal and inhibitory effects of the martian environment on the biological contamination.

Addressing these KGs requires NASA and other Space Agencies to engage in the following SBP- and PSP-relevant activities:

* Fundamental understanding of survival limits and the effect of the space environment on the survival of terrestrial microorganisms.
* More frequent and systematic microbial monitoring of ISS crews and associated ISS/spacecraft environments to obtain statistically relevant data over long time periods and multiple crew complements. Such systematic microbial monitoring would need to be extended to cis-lunar and lunar environments, i.e. beyond the protective terrestrial magnetic field, in the 2020s.
* Ground-based and destination (lunar/deep space) testing; to model multi-factorial combinations of biocidal/ inhibitory and mitigation factors on biological contamination; and to demonstrate with humans the needed operational concepts for use at Mars (Cockell et al. 2018).

# 5. A Campaign-Level Issue

In order to preserve the integrity of science at Mars and to assure the safety of both returning astronauts and the terrestrial biosphere during crewed exploration, progress must be made in the next decade to obtain the scientific data for timely closure of planetary protection KGs and the definition of appropriate planetary protection requirements for crewed missions to Mars. Much of this essential data would be obtainable from measurements made by instruments already anticipated to be on crewed missions to the ISS, in the cis-lunar and lunar surface environments, and on precursor martian missions. However, a deliberate campaign to obtain the required data is needed, as an extension of the anticipated activities in fundamental and applied space biology and physical sciences. The acquisition during the next decade of this additional data set is essential to ensure that timely data is available to inform policy making and spacecraft hardware design, so that our ability to address the question “Are we alone?” remains answerable during our exploration at our planetary next-door-neighbor.

**References**

Avila-Herrera, A. et al., (2020) PLOS ONE, 15(4) <https://doi.org/10.1371/journal.pone.0231838>

Be N.A. et al., (2017) Microbiome 5:81 <https://doi:10.1038/s41598-019-46303-8>

Cockell, C.S, et al., (2018) Int. J. Astrobiol, <https://doi.org/10.1017/S1473550418000186>

COSPAR (2021) <https://cosparhq.cnes.fr/assets/uploads/2021/07/PPPolicy_2021_3-June.pdf>

Lax S, et al., (2014) Science 345:1048-52 <https://doi.org/10.1126/science.1254529>

NASA (2020) https://nodis-dms.gsfc.nasa.gov/library/OPD\_docs/NID\_8715\_129\_.pdf

Nicholson, W. L. et al., (2010) Appl. Environ. Microbiol. 76, 7559-7565 <https://doi:10.1128/AEM.01126-10>

Rabbow, E et al. (2017) Frontiers in Microbiology 8, 1533 <https://doi:10.3389/fmicb.2017.01533>

Race, M. S. et al., (2019) 2nd (2018) COSPAR Workshop Report

Rummel, J.D. et al., (2014) Astrobiology 14, 887-968 <https://doi.org/10.1089/ast.2014.1227>

Schuerger, A. C. et al., (2012) Planetary Space Sci. 72, 91-101 <https://doi.org/10.1016/j.pss.2012.07.026>

Schuerger, A. C. et al., (2013) Astrobiology 13, 115-131 <https://doi.org/10.1089/ast.2011.0811>

Singh, NK et al., (2019) Appl Microbiol Biotechnol <https://doi:10.1007/s00253-019-09813-z>

Sobisch, Y-L. et al., (2019) Front. Microbiol, <https://doi.org/10.3389/fmicb.2019.00543>

Spry, JA et al. (2021) Bull. of the AAS, 53(4) #205 <https://doi.org/10.3847/25c2cfeb.4a582a02>

Voorhies, A.A. et al., (2019) Sci Rep, 9(1):9911. <https://doi:10.1038/s41598-019-46303-8>