Incorporation of Planetary Protection Knowledge Gaps into Agency Capability Development Planning

J. Andy Spry[1]
SETI Institute, Mountain View CA 94043 USA

Bette Siegel[2] and Lisa M. Pratt[3]
NASA HQ, Washington, DC 20456 USA

and

Gerhard Kminek[4]
ESA, Noordwijk, 2201 AZ, Netherlands

Since its start in 2016, the COSPAR workshop series on "Planetary protection requirements for human extraterrestrial missions" has generated and refined a set of planetary protection (PP) knowledge gaps (KGs) which, if addressed, would represent one path to a successful PP implementation strategy for the first crewed Mars mission. The KGs fall into three topic areas: microbial and human health monitoring (in habitat and in crew); microbial contamination control and mitigation in spacecraft systems, and; transport and survival of terrestrial life at Mars. The 2018 workshop led to a timeline that for the first time described a path to a tractable end-to-end PP solution for a crewed mission to Mars. In the time since the workshop, NASA and ESA have been incorporating elements of the KG set into forward plans for capability developments in human spaceflight architecture.

While the microbial and human health monitoring and transport and survival of terrestrial life at Mars KGs focus primarily on knowledge needed to inform the definition of usable "top down" requirements for spacecraft hardware providers, the KG's for microbial contamination control and mitigation in spacecraft system represent an engineering-driven "bottom-up" requirements set, based on technical performance of needed hardware systems.

The integration of all three topic areas into capability-development planning by space agencies offers the promise that the KGs will be addressed in a timeframe aligned with opportunities for new data acquisition by ISS and Gateway experiments, robotic science missions and ground analog studies on the one hand, as well as the future launch of the first crewed Mars mission to Mars. This paper provides an update on the current status.

Nomenclature

ALARA	As low as reasonably achievable
ATP	Adenosine triphosphate
Con Ops	Concept of Operations
COSPAR	Committee on Space Research; part of the International Council for Science
DNA	Deoxyribonucleic acid
ECLSS	Environmental Control & Life Support Systems
EPA	Environmental Protection Agency

[1] Senior Scientist, SETI Institute, aspry@seti.org
[2] Program Executive, NASA HEOMD, bette.siegel@nasa.gov
[3] Planetary Protection Officer, NASA OSMA, lisa.m.pratt@nasa.gov
[4] Planetary Protection Officer, ESA TEC/Q, gerhard.kminek@esa.int

ESA	European Space Agency
EVA	Extra-Vehicular Activity
HEOMD	Human Exploration and Operations Mission Directorate
HEPA	High Efficiency Particulate Air (filter)
ICES	International Conference on Environmental Systems
ISS	International Space Station
KG	Knowledge Gap
MHHM	Microbial and Human Health Monitoring
NASA	National Aeronautics and Space Administration
NID	NASA Interim Directive
OSHA	Occupational Safety and Health Administration
PP	Planetary Protection
SETI	Search for Extraterrestrial Intelligence
SMD	Science Mission Directorate
Uv	Ultraviolet (light)

I. Introduction

COSPAR (the Committee on Space Research) maintains the international consensus policy on planetary protection[1] that is widely accepted[2] as the methodology for how spacefaring nations should address the "avoidance of harmful contamination" as described in Article IX of the Outer Space Treaty.[3] The COSPAR planetary protection policy has two principal concepts: 1) that the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission, and 2) that the conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized.

While approaches to achieve these goals are well refined for robotic exploration missions, and previously the Apollo Program had developed strategies for addressing planetary protection for crewed lunar missions, currently we do not have the know-how for doing this on a crewed mission to Mars. Indeed, it would be prefereable to ensure some of the shortcomings of the Apollo implementations[4] are addressed as part of this process.

As part of planning for future crewed space exploration, COSPAR, together with participating space agencies, has supported a series of interdisciplinary meetings to consider next steps in addressing knowledge gaps (KGs) in the planetary protection discipline, in advance of future human missions beyond low Earth orbit.

As a follow-on to the 2015 NASA[5], and 2016, 2018 and 2019 COSPAR workshops[6] on planetary protection for human missions to Mars, two COSPAR-supported meetings were held (virtually) in 2020. The earlier meetings had first, identified, and then prioritized important knowledge gaps in science and technology areas related to planetary protection for crewed missions. Their reports describe much of the basis for 2020's meetings and also include a timeline, developed to assist in ensuring timely closure of the knowledge gaps. Later meetings considered implementation of strategies to close knowledge gaps in the areas of "Microbial and human health monitoring" and in the "Natural transport of contamination on Mars". The remaining subject of the 2020 virtual meetings described in this paper was the topic of "Technology and operations for contamination control", which aimed to determine potential strategies in managing the contamination associated with in- and outflow of crewed systems at the surface of Mars.

The first of the two meetings (May 2020) functioned as a briefing to the interdisciplinary community, and the later (Dec 2020) meeting was partitioned into virtual breakout groups to discuss and generate responses on the following knowledge gaps brought forward from earlier meetings:

KG 2B: What level of microbiological and organic release from humans and their support systems is acceptable?

KG 2C: What decontamination, verification, & monitoring protocols (inside & outside pressurized systems) are required for remediation after potential releases from humans and their support systems?

KG 2G: What is considered acceptable regarding waste handling and disposal?

Each KG was addressed in turn, in a series of breakout group sessions as described below. Groups were organized so that each had a spectrum of scientists, engineers, planetary protection specialists and program folk. The sub-questions around each KG topic were provided to the breakout groups for consideration. Summary responses from each breakout group are provided in tables for easy cross-comparison, with additional explanation in the text. Verbatim responses provided by the individual breakout groups are preserved in the appendices of the COSPAR meeting report[7].

II. Knowledge Gap "2G" What is considered acceptable regarding waste handling and disposal?

A. Is surface or subsurface disposal preferred or required?

This question addresses whether (and how) trash and waste should be buried, stored or otherwise contained. In general, the breakout groups indicated that burying risked undetected leakage over time, particularly when the regolith at Mars may have oxidative properties. Also burying wastes would require work, which (unless done robotically) would deplete one of the key mission resources (crew time) in essentially a non-productive task. For the first mission at least, surface storage was preferred. This could be at grade, in a depression (to further reduce exposure to wind), or even raised on a platform (which would allow access for a future mission, with potentially more capability to process and recycle the waste). Note that this finding applies to all waste streams (e.g., fecal waste, urine/condensate, wet trash, dry trash) but may be optimized for each.

B. How long should any container be expected to provide its containment?

The consensus was that waste containment should be designed to be effective for 50+yr. This assessment was reached based on a number of factors, including subjective assessment of what might be possible for a containment system in a mass-limited environment, some notion of the cadence of crewed exploration, consideration of estimates of decay of the biological threat, and anticipation about the trajectory of our knowledge about the Mars environment and the need for planetary protection constraints to protect future science.

C. Should trash etc. be "sterilized" prior to disposal?

For this question, there was no clear single answer. Although an active sterilization process is an effective approach to achieving planetary protection goals, this is potentially a mass and power overhead for the mission. In addition, the mission would have to be able to accommodate a failure of the sterilization process, due to e.g. equipment malfunction. Effective containment of unsterilized waste, potentially taking into account passive sterilization processes at Mars, may be sufficient. An engineering trade study is needed to evaluate this issue in more detail.

D. Should bulk containment be used to surround trash to prevent interaction with wind?

There was broad agreement that multiple layers of containment (at least two, potentially three) should be used, with the outer layer being a larger container that was resistant to the Mars environment.

E. What degree of containment is required?

Here, two more detailed sub-questions were considered: First, is use of a sealed container (for pressure), but with no special microbial mitigation applied to the trash, a viable option? And second, is a sealed container with specific microbial mitigation to contents and container exterior required? In some groups, sealing was preferred. In others, closure but with venting through a HEPA filter (and potentially also a molecular scrubber) was the preferred solution. In particular, the issue was identified that a sealed vessel will leak eventually. Given the absence of a clear answer, an engineering trade study is needed to address this issue.

F. What degree of contents (microbial) tracking is required?

The groups concurred that some degree of microbial tracking of the waste is required, in the sense of understanding the initial bioload so that the risk can be assessed. There was no a consensus that monitoring the bioload over time was necessary.

G. Is a single dedicated disposal site near the habit preferred or can disposal occur along the path of a rover?

Groups 3 and 4 that considered this trash management question recommended that a single site adjacent to the landing site be used for waste disposal. The rationale was pragmatic in the sense that, for the short duration mission planned, there is no need to dispose of waste material en route, and returning the waste to the landing site location makes it easier for tracking, allows for potential resource recovery by processing at the landing site by later missions, and potentially allows for sterilization at the landing site, e.g. by exposure to irradiation from the "Kilopower" surface power elements that may be present[7].

Breakout Group 2 – Day 2	Group 1	Group 2	Group 3	Group 4
(December 2, 2020)	Focus Area: Habitats		Focus Area: Suits/Vehicles	
Summary Question (from KGs): What is considered acceptable regarding waste handling and disposal (2G)?				
Q. Is surface or subsurface disposal preferred or required? ***A. Surface***	Depends on how waste is contained -surface disposal has a risk for aerial distribution, subsurface disposal carries the risk for leaching	Sealed container inside the habitat, **triple contained**. No need to relaunch waste.	Bags will be placed in a hard wall/metal container (including filter for emissions)	Should store waste on the surface in a container away from the environment
Q. How long should any container be expected to provide its containment? ***A. 50+yr***	At least 50yr (100 and 250 considered)	40-50yr (after biology is dead)	50yr	At least 50yr cf orbital assets (until we answer life detection question)
Q. Should trash etc. be "sterilized" prior to disposal ***A. (No clear answer – Engineering trade study needed)***	Yes – filter gases, heat/radiation sterilize liquids/solids	Mars will sterilize for us? 50:50 vote to sterilize vs. not (alternative is to use passive Mars processes) Sterilizing waste before disposing them to the sterilizing conditions of Mars is double the work.	Stabilizing prior to containment may be beneficial to stop degradation/gas emission Sterilization not required	Waste should be sterilized to reduce microbial activity and then stored in a leak tight container (complete containment is ideal) that can withstand the Martian environment.
Q. Should bulk containment be used to surround trash to prevent interaction with wind? ***A. Yes***	Containment is preferable (also can containment be an alternative to sterilization?)	Seal them and vent them, from the engineering systems is the optimal design	Yes - Smaller containers would be placed into larger containers	
Q. What degree of contents (microbial) tracking is required? ***A. Microbial Tracking Required***	Characterization may be necessary to verify sterilization Barcode system for waste bags	N/A	Monitoring should be a requirement	We want to identify the microorganisms in our waste before we dispose of it, not track the waste over its lifespan

Table 1: Summary Responses to KG 2G by Breakout Groups

Q. What degree of containment is required?	Heat sealed baggies?	Mission architecture fidelity needed to provide the best approach. Equivalent System Mass (ESM) is the driver. For short missions we might not need to have as strict requirements. A little bit of engineering goes a long way. Preparation is key.	As humans or robots pass smaller waste containers into larger one, could have something like a tunnel/chute that could sterilize	The container needs to be environmentally resistant (e.g. UV, temperature, freeze-thaw, ice deposition, dust deposition, etc.) and last at least until we answer life detection questions
Is a sealed container (for pressure) but with no special microbial mitigation to trash a viable option?	Preference is to sterilize and have fewer requirements for containment but could make the container part of the sterilization method	Contain at equal pressure and vent		
Is a sealed container with specific microbial mitigation to contents and container exterior required? ***(No clear answer – Engineering trade study needed)***	Not if we are sterilizing the waste	N/A	Want it contained, but can find advantages to different ways – will be dependent upon needs	
Q. Is a single dedicated disposal site near the habitat preferred or can disposal occur along the path of a rover? ***A. Single***	N/A	N/A	Leave on rover until get to trash disposal area	For preliminary missions there should only be one waste disposal site to reduce how much we need to bring/build, but if sterilization and containment strategies are sufficient we can develop multiple sites.

Table 1 (contd.): Summary Responses to KG 2G by Breakout Groups

III. KG "2B" What level of microbiological and organic release from humans and their support systems is acceptable?

A. What gas/liquid/microbial discharges are acceptable?

The common presumption was that, by the time of the first crewed Mars mission, non-biological discharges will not be the concern: Only release of viable microbes (potentially attached to particles) would be the concern. The solution for this would be for HEPA filtration of gas releases and for storage of liquids, with the goal of preventing release of viable microbes into the martian environment. One of the groups considered that it may be acceptable for some low biomass gas waste streams to not be filtered, provided that it could be acceptably demonstrated that the martian environment would effectively sterilize that waste stream (e.g. potentially space suit joint leakages).

B. Is it required for an airlock (and residual air in it) to be sterilized prior to egress for an EVA? Is it required for an airlock (and residual air in it) to be sterilized prior to ingress from an EVA?

Discussion reflected that, at the very least, for egress (operatons?), the atmosphere/surfaces in the airlock ought to be bioburden reduced (with acceptable levels TBD). A similar bioburden reduction process would be imposed prior to reentry into the pressurized environment from an EVA. However, there was not a clear consensus, so a "use case" needs to be developed, in order that needed requirements can be identified and addressed. One of the groups highlighted that recovered gas (collected during depressurization) should be HEPA filtered.

C. Is it required for e.g. suits and tools to be sterilized prior to egressing for an EVA? Is it required for e.g. suits and tools to be sterilized to ingress from an EVA?

Yes, potentially, for egress, depending on the hardware item and its use. The expectation is not that robotic mission-level bioburden cleanliness levels are maintained (new cleanliness requirement TBD), but that gross contamination is prevented and that pristine Mars samples (free of terrestrial microbial contamination) can be acquired. Discussions reflected that bulkier items such as suits should be bioburden reduced on an ALARA-type basis[8], while tools intended to acquire samples or potentially contact the Mars subsurface could potentially be sterilized prior to use. As long as it has not been determined whether Mars is an abode of current life, steps need to be taken to minimize the opportunity for potential Martian biota to encroach into the interior of crewed systems. Thus, processing of tools, suits etc. would be needed prior to ingress. One of the groups highlighted the need for a separate airlock (or other pathway) for tool egress and ingress from the pressurized volume.

For both the airlock atmospheres and the materials moving in and out of the pressurized volume, a more detailed use case would be needed in developing and optimizing approaches for egress and ingress.

D. What planetary protection constraints are required for using bio-regenerative systems or plants for consumption?

In general, plants and bioregenerative system wastes were considered similarly to other terrestrial contaminated waste, including the need to sterilize and/or contain prior to departure, while minimizing (eliminating?) uncontrolled release into the Mars environment. That said, the breakout groups were informed that a full bioregenerative life support system was unlikely for the first mission to the martian surface. Accordingly, the large biomasses that might be associated with full-scale versions of these systems were not given significant consideration as a threat to the martian environment at this meeting.

Breakout Group	**Group 1**	**Group 2**	**Group 3**	**Group 4**
(Dec 3, 2020)	**Focus Area: Habitats**		**Focus Area: Suits/Vehicles**	
Summary Question (from KGs): What level of microbiological and organic release from humans and their support systems is acceptable (2B)?				
Q. What gas/liquid/microbial discharges are acceptable? ***A. Filter gas Store liquid Prevent micro release***	Filtration: HEPA for gas/0.2um for liquid Store liquid Sterilize on departure Use daylight UV Condition before departure 50-100yr requirement	Filter by HEPA Contain human waste – 3 layer Take advantage of natural conditions Some risks need to be accepted	Low biomass (e.g. suit leaks) – vent and rely on Mars HEPA for others Need risk assessment 1um cutoff for particles Shower space? – trust but verify	Assume concern is microorganisms O2 loss is OK Research needed to ID performance requirement
Q. Is it required for an airlock (and residual air in it) to be sterilized prior to egressing for an EVA? ***A. Reduce bioburden***	Yes – filter (2 layers?)		Bioburden reduction (not sterilization per se)	
Q. Is it required for e.g. suits and tools to be sterilized prior to egressing for an EVA? ***A. Potentially (develop use case to prove)***	Separate airlock for tools	Sterilize/ Sanitize on ALARA basis Reduce Bioburden	Depends on use – life detection instrument vs mechanical fixings Tools: manage by – witness plate use, material selection (cleanable), contamination knowledge, make clean, keep clean.	Minimize cross contamination. Sterilization may be preferred but weigh against ops burden/ cost
Q. Is it required for an airlock (and residual air in it) to be sterilized prior to ingress from an EVA? ***A. No clear consensus – use case needed***	Yes – separate system		Need a mudroom? Visibly clean may be acceptable Ground testing needed	

Table 2: Summary Responses to KG 2B by Breakout Groups

Q. Is it required for e.g. suits and tools to be sterilized to ingress from an EVA? ***A. Potentially (develop use case to demonstrate)***	UV in airlock to sterilize Need to manage dust problem	Reduce risk Likelihood x Consequence type of risk analysis Coveralls - problematic for suits; mobility, logistics		Sterilization may be preferred but assess against operations burden/ cost
Q. What planetary protection constraints are required for using bio-regenerative systems or plants for consumption? ***A. Manage (eliminate?) release into Mars environment***	Not an additional risk in the Hab. Need to destroy on leaving	Inside – no problem Outside – no plant pathogens	Same as human systems and waste Could sterilize seeds, soil Manage bioreactors as a contamination source	Mitigate via sterilization

Table 2 (contd.): Summary Responses to KG 2B by Breakout Groups

IV. KG "2C" What decontamination, verification, & monitoring protocols (inside & outside pressurized systems) are required for remediation after potential releases from humans and their support systems?

A. How can unacceptable discharges be made acceptable?

This question was mainly addressed by Group 2 through considering mitigation of spills. They suggested the need for controls to reduce accidental spillage, and appropriate protocols in the event of situations when spills do occur. Group 3 considered EPA/OSHA-style treatment of spills (control spread and stabilize; collect, minimize and isolate). This group also considered protection of special regions[9] at Mars and the potential for bioburden reduction by whatever means is appropriate and available. Overall there was no clear consensus across the groups, demonstrating the need for integration with ConOps planning and one or more future engineering trade studies.

B. Microbial/chemical monitoring capability is assumed: What microbial detection/monitoring of the habitat environment is required?

For limiting forward contamination, bioburden control and monitoring were baselined as expected implementations for the first crewed Mars mission. DNA sequencing to obtain microbiome information[10] was recommended by three of the four groups, although additional work is needed to develop an appropriate detection end point for such assays. One group suggested that this should be in parallel with classical culturing, although another group pointed out that deliberately culturing terrestrial microorganisms in a mission to another planet would be something that should probably be avoided. One group suggested that other technologies be used alongside sequencing, such as witness plates and/or a direct detection methodology. A use case scenario needs to be developed to evaluate the various options.

C. What microbial detection/monitoring outside the habitat environment is required?

First, it was identified that there needs to be the ability to detect (and potentially to mitigate) a change in the microbial community, which implies the ability to establish a baseline. Again, multiple groups identified DNA sequencing as a desireable methodology, combined with a physico-chemical method such as uv (blacklight) inspection or a chemical detection methodology.

D. What constitutes a biomarker for forward contamination purposes (what do we care or not care about)?

On this issue, no clear consensus was achieved. There was comment that very small particles (close to the size of a microorganism) would be degraded by martian uv, and so can be disregarded. However, use of artificial tracers to track contamination was considered to be a threat to detection of martian biomolecules and should be avoided. Once again, a use case is proposed to evaluate options.

E. How is backward contamination to be detected and measured?

This topic was very much unresolved in the meeting. On the one hand, the bulk sources of the contamination are left behind at Mars, and so crew are being "quarantined" from the Mars environment on the return journey to Earth. However, the astronauts, their equipment and any samples being brought back will have been exposed to Mars. ATP (adenosine triphosphate) was suggested as a detection methodology, but it is recognized that in a crewed mission there may be signal to noise issues. The need for a glove box capability was suggested for analyses en route, but this may be in conflict with quarantining requirements. Another group advocated for simple miniaturized monitoring technologies, but there was no clear consensus, indicating that again, a use case study is needed. How should non-nominal spills/leaks be addressed (in contingency planning and surface operations)?

This final topic was how to treat spills, particularly from vehicles. Some groups had partially addressed this in earlier discussions, but in the this final analysis groups 3 and 4 considered spills occurring during a traverse. Both groups identified that crew safety would be prioritized, but beyond that, the strategy should be based on containment rather than some kind of disinfection treatment: Mars is cold and dry, so spills of liquid will most likely freeze, then sublime, rendering the biologic contamination frozen and dessicated, and therefore be unlikely to cause harmful contamination based on current knowledge[10].

Breakout Group	**Group 1**	**Group 2**	**Group 3**	**Group 4**
(Dec 3, 2020)	**Focus Area: Habitats**		**Focus Area: Suits/Vehicles**	
Summary Question (from KGs): What decontamination, verification, & monitoring protocols (inside & outside pressurized systems) are required for remediation after potential releases from humans and their support systems (2C)?				
Q. How can unacceptable discharges be made acceptable? ***A. No clear consensus -Engineering trade study needed***		Do controls Have protocols ready	Special regions consideration Bioburden reduction	
Q. Micro/chemical monitoring capability is assumed: What microbial detection/ monitoring of the habitat is required? ***A. No clear consensus – use case needed***	Mixed culture and Next Gen Sequencing	Witness plates Materials coatings	Leak checks Sampling Look for step function changes	No culturing – DNA sequencing/ATP

Table 3: Summary Responses to KG 2C by Breakout Groups

Q. What microbial detection/ monitoring outside the habitat environment is required? ***A. Ability to detect (and mitigate?) a change***		Establish the baseline & detect changes UV light inspection MinIon	Monitor Look for step function changes	Chemical signature and DNA analysis is ideal
Q. What constitutes a biomarker for forward contamination purposes (what do we care or not care about)? ***A. No clear consensus – use case needed***		Tracers are false contamination		
Q. How is backward contamination to be detected and measured? ***A. No clear consensus – use case needed***		ATP? (signal to noise problem?) Glove box detection en route for returning mission		Assume not a problem (sources left behind). Use simple miniaturized technologies
Q. How should non-nominal spills/leaks be addressed (in contingency planning and surface operations)? ***A. Basis should be containment rather than treatment (Mars is cold)***			Crew safety prioritized EPA/OSHA approaches: control spread, stabilize, collect, minimize & isolate	"spill kit" (to collect, contain, track is better [easier] than disinfection?)

Table 3 (contd.): Summary Responses to KG 2C by Breakout Groups

V. Agency Considerations

While this COSPAR-led activity has been multi-agency in its support and participation, of the agencies taking part, only NASA currently has a significant level of work in the architecture planning for crewed exploration of Mars, through its Moon to Mars program. Within NASA, the planetary protection discipline is being incorporated into planning and preparation activities for the current 30-day surface mission architecture study[12] for the first crewed mission to Mars. Much of the paradigm created by the COSPAR studies has been adopted (albeit temporarily) in NASA's Interim Directive, NID8715.129[13] that entered into effect on July 9th, 2020. Planning within NASA continues to integrate planetary protection considerations into the work of the HEOMD SE&I (Systems Engineering and

Integration) group, with significant coordination activities ongoing with other organizations engaged in hardware development and knowledge generation. Much of this work is pertinent to developments in the planning for crewed lunar exploration because of the intent to use the Moon as a venue for testing planetary protection approaches before deployment at Mars. Also there are significant cost advantages to redeploying technologies and hardware developed for use at the Moon onto the first crewed Mars mission.

VI. Conclusion and Future Work

The 2020 virtual meetings were successful in addressing the three knowledge gaps highlighted (2B, 2C, 2G). As with many workshops, different breakout groups addressed topics differently from each other, giving the variety shownand agency representatives are considering how best to incorporate these topics into ongoing portfoliios of activity. However, a number of gaps remain unaddressed in the “Technology and operations for contamination control” topic area. In particular, issues around approaches to quarantine and pristine sample handling have not been addressed in the era of the current NASA Mars transit/30 day short-stay mission architecture (KGs 2D. and 2I. from the 2016 workshop). The intention is to convene a further virtual meeting and a final in-person meeting in 2021 to wrap up these topics and provide an opportunity to update previous findings, in order to provide the COSPAR community with a current, comprehensive perspective on planetary protection knowledge gaps for human missions to Mars ahead of the 2022 Athens General Assembly.

As a result, the report series will provide an update from the data set[14-16] used to support generation of the original COSPAR planetary protection guidelines for human missions to Mars[1]. Any update to the COSPAR guidelines would reflect input from a more up to date scientific background[10], technological capability[11] and mission architecture[12]. In particular, updates to the guidelines might reflect changes in scientific opinion and data fidelity about the habitability of different areas of the Mars environment, new opportunities to monitor microbial contamination (using for example, in situ DNA sequencing), constraints imposed by the less capable 30-day architecture[12] that does not provide separate “lab” and “hab” as envisaged previously[16] and the publication in the US of a National Strategy for Planetary Protection[17].

In the work to close the KGs, NASA is currently the only agency maturing a significant program for the crewed exploration of Mars. In doing so, it is aligning progress developing hardware, systems and processes with planetary protection “built in” to the design. A systematic approach to addressing they survival and dispersion of terrestrial organisms at Mars has not yet been adopted. However, it is important that these early (scientific) parameters are well constrained, to minimize the accommodations that spacecraft hardware designers need to make to deal with such uncertainties at a later date.

Acknowledgments

Work by Spry is supported through the SETI Institute by NASA contract 80HQTR20F0153 for support of all phases of current and future planetary protection missions to ensure compliance with planetary protection standards.

The valuable contribution of J Broyan (NASA) is recognized in the development of discussion topics for the breakout sessions.

References

[1] COSPAR Policy on Planetary Protection (2020) Space Research Today 208 pp10-22

[2] Fisk, L, “Planetary Protection: The COSPAR Perspective” Presentation to the National Academies of Science, Engineering & Medicine (NASEM) Committee on the Goals, Rationales, and Definition of Planetary Protection, Irvine, CA 27-28 June 2017

[3] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty) United Nations (1967) accessible at: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html

[4] Meltzer, M (2012) When Biospheres Collide: A History of NASA's Planetary Protection Programs, NASA Washington DC.

[5] Spry, J. A., J.E. Johnson, M.S. Race, B. Siegel, and C. A. Conley, (2015) Planetary Protection Concepts in the Context of the Evolvable Mars Campaign. Paper ICES-2015-311, 45th International Conf. on Env. Systems, July 2015, Bellevue, WA.

[6] Race, M.S., J. A. Spry, B. Siegel, C. A. Conley and G. Kminek (Eds), (2019) 2nd COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions, COSPAR, Paris accessible at: https://sma.nasa.gov/docs/default-source/sma-

disciplines-and-programs/planetary-protection/cospar-2019-2nd-workshop-on-refining-planetary-protection-requirements-for-human-missions-and-work-meeting-on-developing-payload-requirements-for-addressing-planetary-protection-gaps-on-nat.pdf

[7] Spry, J. A., B. Siegel, L. M. Pratt and G. Kminek (Eds), (2021) 5th COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions, COSPAR, Paris accessible at: https://sma.nasa.gov/sma-disciplines/planetary-protection#planetaryProtection_conferenceDocuments

[8] Patrick R. McClure, David I. Poston, Marc A. Gibson, Lee S. Mason & R. Chris Robinson (2020) Kilopower Project: The KRUSTY Fission Power Experiment and Potential Missions, Nuclear Technology, 206:sup1, S1-S12, DOI: 10.1080/00295450.2020.1722554

[9] CDC recommendations on Radiation and your Health, accessible at: https://www.cdc.gov/nceh/radiation/alara.html#:~:text=ALARA%20stands%20for%20%E2%80%9Cas%20low,time%2C%20distance%2C%20and%20shielding.

[10] Rummel, J.D. et al., (2014) A new analysis of Mars "Special Regions": findings of the second MEPAG Special Regions Science Analysis Group (SR-SAG2) Astrobiology 14, 887-968 DOI: 10.1089/ast.2014.1227

[11] Be N.A. et al., (2017) Whole metagenome profiles of particulates collected from the International Space Station Microbiome 5:81. https://doi.org/10.1186/s40168-017-0292-4

[12] Bleacher, J & Rucker, M (2021) Human Mars Exploration – report to MEPAG 1/27/2021, accessible at: https://mepag.jpl.nasa.gov/meeting/2021-01/07_2021-01-19-MEPAG-SE&I%20FINAL.pdf

[13] National Aeronautics and Space Administration, (2020) NASA Interim Directive on Biological Planetary Protection for Human Missions to Mars (NASA Publication No. NID 8712.129, accessible at: https://nodis3.gsfc.nasa.gov/OPD_docs/NID_8715_129_.pdf).

[14] Criswell, M.E., M.S. Race, J.D. Rummel, and A. Baker, (2005) Planetary Protection Issues in the Human Exploration of Mars. NASA/CP-2005-213461

[15] Hogan, J.A., M.S. Race, J.W. Fisher, J.A. Joshi, and J.D. Rummel, (2006) Life Support and Habitation and Planetary Protection Workshop: Final Report. NASA/TM- 2006-213485, NASA Ames Research Center, Mountain View, CA.

[16] National Research Council, Space Studies Board, (2002) Safe On Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface. National Academy Press, Washington, D.C., www.nap.edu.

[17] National Space Council (2020) National Strategy for Planetary Protection, accessible at: https://fas.org/spp/eprint/protection.pdf