Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions
Workshop Report

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Acknowledgments

EXECUTIVE SUMMARY

Planetary Protection Knowledge Gaps for
Human Extraterrestrial Missions

This report on *Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions* summarizes the presentations, deliberations and findings of a workshop at NASA Ames Research Center, March 24-26, 2015, which was attended by more than 100 participants representing a diverse mix of science, engineering, technology, and policy areas. The main objective of the three-day workshop was to identify specific knowledge gaps that need to be addressed to make incremental progress towards the development of NASA Procedural Requirements (NPRs) for Planetary Protection during human missions to Mars.

While planetary protection requirements are in place for robotic missions to the Moon, Mars and other celestial bodies, current Committee on Space Research (COSPAR) international policy for human missions to Mars includes only qualitative principles and guidelines. It is recognized that there is insufficient scientific and technological knowledge currently to establish the needed detailed quantitative requirements for the planning and development of crewed spacecraft and systems for missions beyond low-Earth orbit. However, quantitative requirements are essential for developing compliant capabilities to support future human missions. *NASA Policy Instruction on Planetary Protection Requirements for Human Extraterrestrial Missions* (NPI 8020.7)[1] outlines the need for the agency to translate the COSPAR international Principles and Guidelines into detailed requirements through a stepwise process. The multi-year, multi-element NPI plan calls for a systematic survey and review of relevant information and studies; a workshop to identify the current state of knowledge in planetary protection and human mission systems; development of a prioritized list of studies needed to inform requirements; and future Research and Technology Development (R&TD) studies that will iteratively lead to development of draft requirements. This workshop was one of the key steps in the NPI process.

A key to the effective and cost-efficient implementation of planetary protection controls is early consideration and frequent coordination on cross-cutting science and technology needs during the earliest stages of mission design and hardware development. Based on NASA Policy Instruction NPI 8020.7, the workshop focused on three main themes:

    a. Developing capabilities to comprehensively monitor the microbial communities associated with human systems and evaluate changes over time,

    b. Develop technologies for minimizing and mitigating contamination release, including, but not limited to: closed-loop systems; cleaning and re-cleaning capabilities; support systems that minimize contact human contact with the environment of Mars and other solar system destinations; and

    c. Understanding environmental processes on Mars and other solar system destinations that would contribute to transport and sterilization of organisms released by human activities.

Accordingly, the workshop agenda and organization gave special attention to knowledge gaps and needs in three study areas of importance to planetary protection: 1) Microbial and Human Health

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[1] See http://planetaryprotection.nasa.gov/documents, NASA Policy Instruction NPI 8020.7

Monitoring; 2) Technology and Operations for Contamination Control; and 3) Natural Transport of Contaminants on Mars.

Because the NPI process recognizes that the path forward will be built upon incremental, collaborative research studies and technology development across assorted disciplines and expertise, it is important to determine what is known, what may be applicable and what is needed. Thus, the goal of the workshop was to capture the current state of knowledge in the aforementioned areas and identify additional research to appropriately inform planetary protection requirements development for the future human exploration of Mars. The information presented and discussed at the workshop, supplemented with information from comprehensive reviews of previous literature and planetary protection workshops, will enable NASA to identify and conduct additional studies that will help define the initial set of planetary protection requirements for human mission to Mars.

The format of the three-day workshop included a combination of invited presentations, submitted papers, and break-out group discussions. The invited talks set the context for the workshop and provided background reviews of information relevant to human missions and planetary protection. A series of submitted paper sessions contributed additional information across the three key areas of the workshop, and provided experts' perspectives about technology, mitigation options, and critical research needs ahead. Subsequently, study group discussions in separate sessions helped focus participants' deliberations on the three study areas and identify specific knowledge gaps of importance for developing future NPRs for planetary protection on human missions. The workshop concluded with out-briefing presentations summarizing the findings of the three separate study groups. The detailed workshop agenda is provided in the Appendix of the full report, and also on the workshop repository site, which includes abstracts and videos of the various presentations:
http://planetaryprotection.nasa.gov/humanworkshop2015/

Overall, the three study groups identified 25 specific knowledge gaps across the three pre-identified areas of importance as summarized below. Additionally, each of the sub-groups indicated how their knowledge gaps related to current COSPAR Implementation Guidelines. A compilation of all identified knowledge gaps from the workshop is presented in Table 6.1 in the Report and briefly summarized below.

Study Group 1: Microbial and Human Health Monitoring

Study Group 1 identified nine specific knowledge gaps related to microbial and human health monitoring that need to be addressed in order to make progress towards developing quantitative verifiable NPRs. The nine gaps were:

> **Knowledge Gap 1.1:** What are the technologies and procedures that should be used for microbial sampling and collection?
>
> **Knowledge Gap 1.2:** What are the appropriate technologies for microbial monitoring to mitigate risk to crew, ensure planetary protection, and preserve scientific integrity?
>
> **Knowledge Gap 1.3:** What technologies and procedures should be used for sample processing and analysis to reduce crew time and mitigate contamination concerns?
>
> **Knowledge Gap 1.4:** What technologies and procedures should be used for data collection, storage, and interpretation during missions?

Knowledge Gap 1.5: What is needed to understand spaceflight-specific microbial responses and heritable changes during extended spaceflight and relocation to a different planetary body?

Knowledge Gap 1.6: What is needed to monitor astronaut, vehicle, and external environmental microbial populations effectively?

Knowledge Gap 1.7: What novel approaches can be developed for:

(a) Effective, low toxicity disinfectants, and

(b) Prevention/recovery from biofilms/microbial-induced corrosion, fouling, etc.

Knowledge Gap 1.8: What studies are needed to understand crew health and biomedicine related to microbial and contamination exposures?

Knowledge Gap 1.9: What information is needed to develop acceptable and appropriate ethical and operational guidelines for human missions to Mars?

Six of the nine identified knowledge gaps in Study Group 1 focused on questions typically associated with microbial research *per se*—such as understanding the microbes themselves and the diverse populations to be monitored; as well as how to monitor, collect and process data about them during the missions (Gaps 1.1 through 1.6). Another gap focused on developing novel approaches for low-toxicity microbial disinfectants and addressing problems associated with microbial biofilms, such as induced corrosion and fouling of equipment. (Gap 1.7 a and b). The two final gaps relate to biomedical considerations associated with microbes. There is a need to develop diagnostic treatment options for crew microbial and health exposures, and to develop operational guidelines for how to integrate data with ethical and operational considerations during Mars missions. (Gaps 1.8, 1.9)

Study Group 2: Technology & Operations for Contamination Control

Study Group 2 focused on technologies needed for cleaning, sterilization and prevention of recontamination; mitigation of spacecraft and system effluents; contamination control associated with surface mobility systems and spacesuits; contamination avoidance in Special Regions[2] and in-situ resource utilization (ISRU) areas; operational strategies to mitigate contamination; and sample containment technologies. They identified the following eight knowledge gaps:

Knowledge Gap 2.1: Does the Duration of human surface stay (30 v. 500 days) matter? Does it change objectives of planetary protection during mission? What is the relationship between duration of human exploration time and the overall density and spread of contamination?

Knowledge Gap 2.2: What level of non-viable bioburden escape is acceptable? I non-viability can be demonstrated, does this significantly address human microbial bioburden concerns? Does it address concerns about external dissemination of microbial contamination? How should differences of opinion between the science and planetary protection communities be addressed regarding acceptable levels?

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[2] Special Regions, as defined by the Mars Exploration Program Analysis Group are places on Mars where terrestrial organisms might replicate. http://mepag.nasa.gov/reports/Rummel_et_al_Astrobiology_14-SR-SAG2.pdf

Knowledge Gap 2.3: Is there a need for decontamination and verification procedures & protocols after releases (nominal or otherwise). Are decontamination procedures needed for both inside/outside the spacecraft as well?

Knowledge Gap 2.4: What considerations should go into the design of quarantine facilities and methods (for uses on the way to-, on Mars , or returning from Mars)?

Knowledge Gap 2.5: How can contamination concerns during human missions be addressed, given that the parameters defining Mars Special Regions vary in space and time (e.g. over diurnal and seasonal cycles) ?

Knowledge Gap 2.6: What research is needed to address gaps in assorted questions about ISRU, habitation, and testing? What related research is needed in advance of planning and design of technologies, systems, and operations?

Knowledge Gap 2.7: What is "acceptable containment" (type; location; duration) of wastes intentionally left behind? Similarly, what are acceptable constraints and procedures on vented materials?

Knowledge Gap 2.8: What microbial contaminants would vent from an extravehicular activity (EVA) suit, and at what concentrations? What are the implications for suit materials and cleaning tools, designated for Mars?

Knowledge gaps in Study Group 2 focused mainly on technology and operations for mitigating and controlling contamination—both microbial and organic. Six of eight identified knowledge gaps applied to mission-related questions, including the implications of mission duration; the escape of viable microbes; understanding what vents from different hardware; containment needs for both planetary protection and science considerations; and developing procedures for decontamination and verification (Gaps 2.1 through 2.6). The other two gaps centered on questions about operations and microbial vulnerability—specifically on acceptable containment of wastes and constraints on vented materials near infrastructural elements (Gap 2.7); and on similar considerations related to EVA systems (2.8).

Study Group 3: Natural Transport of Contamination on Mars

Study Group 3 discussed transport mechanisms on the Mars surface; potential natural sterilization by Martian conditions; and environmental cleanup of inadvertent releases of terrestrial materials. The group identified the following eight knowledge gaps:

Knowledge Gap 3.1: How do interactions of biocidal factors affect microbial survival, growth, and evolution in Mars-type environments? And what is the potential for survivability and replication of very hardy microbes--in dust environments, across Mars, and in biofilms?

Knowledge Gap 3.2: What data or models are needed to determine what happens to windblown dust on the Martian surface, and where it might go? What research is needed to understand meteorological conditions spanning several Martian years at particular site(s)

Knowledge Gap 3.3: What is the probability of transporting hardy terrestrial microbes to Mars via different pathways on a human mission?

Knowledge Gap 3.4: What will leak and/or vent out of pressurized containers or human facilities? What modeling might be possible to understand venting and leaking materials from pressurized systems?What leak rate, size, biological diversity, organic molecules, cells etc. are vented during nominal operations? After significant degradation of materials? And during off nominal situations? What are differences between active designed venting vs. leaking?

Knowledge Gap 3.5: How will we study yet-uncultivable microorganisms? What methods and tools will we use? What proportion of the entire community do they represent? How can we assess and monitor their viability?

Knowledge Gap 3.6: What research is needed to understand and establish acceptable contamination generation rates and thresholds for human landing sites – considering these sites as point contaminant sources (of microbes or organic particles)? Can terrestrial mechanisms be used to model the minimum aeolian contamination spread (over time and distance)?

Knowledge Gap 3.7: What research is needed to understand and establish acceptable contamination generation rates and thresholds for a mobile crewed system (pressurized vehicle or EVA suits)? How can we study mobile systems as point sources of contamination (of microbes and organic particles), or model minimum contamination spread (over distance and time)?

Knowledge Gap 3.8: What research is needed to understand and establish acceptable contamination generation rates and thresholds for Special Regions near human landing sites in context of sub-surface contamination & ISRU of local water/ice?

Study Group 3 had the greatest variation in types of questions identified for further research and development. Four of their eight identified knowledge gaps centered on the need for better modeling and understanding of Martian aeolian processes and their role as potential dispersal mechanisms for dissemination of microbial and other contaminants (Gaps 3.2, and 3.6 through 3.8). Overall, there is a need to understand long-term dust dissemination via natural transport mechanisms—regionally and planet-wide—as well as to gather information about meteorological conditions over several Martian years. Considering that future planetary protection approaches may be based upon a surface categorization system using pre-designated zones with different cleanliness or access restrictions, the group also indicated the need to gather data applicable to determining "acceptable" contamination generation and threshold rates for different mission phases and their associated contamination concerns—specifically for microbial dispersion from landing sites and mobile crew systems, and contamination of sub-surface locations when accessing ISRU resources and ices.

Study Group 3 also identified three knowledge gaps dealing with questions about hardy terrestrial microbes and their monitoring (Gaps 3.1, 3.3, and 3.5). In particular, there is a need to understand the probability of transport of hardy terrestrial microbes via different mission pathways (forward contamination) and to understand potential biocidal factors on Mars and their impacts on very hardy microbes that may be transported during human missions. They also identified the need for better monitoring and assessment methods to study yet-uncultivable microbes—which may represent a large part of the microbial community transported along with humans and their hardware. Finally, Study

Group 3 focused on the need to better understand what is leaking or deliberately venting from pressurized containers or infrastructure elements—through time, and for both nominal and off-nominal operations. (Gap 3.4)

Overall, in addition to identifying key knowledge gaps of importance for development of formal NPRs for planetary protection and human missions, the workshop was useful in gathering experts of diverse disciplines, facilitating collaborative discussions of needs, and enhancing cross-communication about the diverse tasks already underway or ahead

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1. INTRODUCTION

1.1. Context of Planetary Protection and Human Extraterrestrial Missions Workshop

During the course of planetary exploration, internationally recognized planetary protection measures have been developed and are in place to prevent confounding the search for life on the Moon, Mars and other celestial locations, and to safeguard Earth from the return of potentially hazardous material. Since the close of the Apollo program, planetary protection practices have not been necessary for crewed missions, which currently occur only in low-Earth orbit (LEO). Consequently, little consideration has been given to planetary protection in crewed spacecraft system design and development over the past decades. With preparations underway for exploration beyond LEO, including NASA's development of the Space Launch System (SLS) and Orion crewed spacecraft, planetary protection must once again be considered and incorporated in overall system designs. Space suits, habitat modules, rovers, and in-situ resource utilization (ISRU) equipment are just a handful of the systems that will need to address planetary protection requirements and guidelines in their design, development and operations.

While planetary protection requirements are in place for robotic missions to the Moon, Mars and other celestial bodies, current Committee on Space Research (COSPAR) policy for human missions to Mars includes only qualitative principles and guidelines outlining the need and rationale for continued implementation of planetary protection on crewed missions[3]. However, it is recognized that there is insufficient scientific and technological knowledge at this time to establish the needed detailed quantitative requirements for the planning and development of crewed spacecraft and missions. In anticipation of such future missions, NASA created the *NASA Policy Instruction on Planetary Protection Requirements for Human Extraterrestrial Missions* (NPI 8020.7)[4], which outlines the need for the agency to translate the COSPAR principles and guidelines into detailed requirements. A key to the effective and cost-efficient implementation of planetary protection controls is early consideration and frequent discussion of science and technology needs during the earliest stages of mission design and hardware development. This will require further communication and deliberation across many areas. Already, there is a recognized need to increase knowledge in the several study areas, which were the focus of NASA's 2015 Planetary Protection Knowledge Gaps for Human Extraterrestrial Mission(s) Workshop:

Study Area 1: Microbial and human health monitoring. Developing capabilities to comprehensively monitor the microbial communities associated with human systems and evaluate changes over time;

Study Area 2: Technology and operations for contamination control. Developing technologies to minimize and mitigate contamination release, including, but not limited to, closed-loop systems; cleaning and re-cleaning capabilities; support systems that minimize contact of humans with the Martian environment and other solar system destinations; and

Study Area 3: Natural transport of contamination on Mars. Understanding environmental processes on Mars and other solar system destinations that would contribute to transport and sterilization of organisms released by human activities.

In May 2012, the Planetary Protection Subcommittee of the NASA Advisory Council (NAC) Science Committee formulated a recommendation that NASA Procedural Requirements (NPR) be developed

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[3] For Complete COSPAR planetary protection policy, see: https://cosparhq.cnes.fr/sites/default/files/pppolicy.pdf
[4] see: http://planetaryprotection.nasa.gov/documents   NASA Policy Instruction NPI 8020.7

for planetary protection on human missions under NASA Policy Directive (NPD) 8020.7, "Biological Contamination Control for Outbound and Inbound Planetary Spacecraft," as a parallel document to NPR 8020.12, "Planetary Protection Provisions for Robotic Extraterrestrial Missions." This recommendation was endorsed by the full NAC and forwarded to the Administrator in November 2012, and was agreed upon by the NASA Administrator in a letter dated March 8, 2013.

The NPI process acknowledges that the path forward to implementable NASA Procedural Requirements (NPRs) will be built upon incremental research, studies, and technology development involving assorted disciplines and expertise, working in crosscutting collaboration. A first step in the process is to determine what is known, what may be applicable, and what is needed. Thus, the goal of this workshop was to capture the current state of knowledge in the aforementioned areas and identify additional research to appropriately inform planetary protection requirements development for the future human exploration of Mars. The information presented and discussed at the workshop, supplemented with information from comprehensive reviews of previous literature and planetary protection workshops, will enable NASA to efficiently identify and conduct additional studies that will help define the initial set of planetary protection requirements for human missions beyond LEO.

In addition to advancing the path toward development of formal NPRs for planetary protection on human extraterrestrial missions the workshop itself was useful in gathering professionals of diverse disciplinary expertise, facilitating collaborative discussions of common science and technological needs, and enhancing communication and awareness of the diverse tasks underway and ahead.

1.2. Workshop Logistics

1.2.1. Format and Organization

The workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions was conducted at NASA Ames Research Center, March 24-26, 2015. More than 100 attendees represented a diverse mix of science, engineering, technology and policy disciplines relevant to the announced meeting objectives (see workshop Announcement and list of Participants in Appendix C).

The format of the 3-day workshop included a combination of invited presentations, submitted papers, and break-out group discussions. The invited talks set the context for the workshop and provided background reviews of information relevant to human missions and planetary protection. A series of submitted paper sessions contributed additional information across the three key areas of the workshop, and provided experts' perspectives about technology, mitigation options, and critical research needs ahead. Subsequently, study group discussions in separate sessions helped focus participants' deliberations on the three study areas and identify specific knowledge gaps of importance for developing future NPRs for planetary protection on human missions. The workshop concluded with out-briefing presentations summarizing the findings of the three separate study groups. The detailed workshop agenda is provided in Appendix B and also on the workshop repository site, which includes abstracts and videos of the various presentations:
http://planetaryprotection.nasa.gov/humanworkshop2015/

After the workshop, the scribes and study group leaders from each study area submitted more complete written reports on their deliberations and findings, which have been compiled into this workshop report. The sections below provide detailed information and summaries of the key parts of the workshop, including the various presentations, study group deliberations and overall findings.

1.2.2. Workshop Background Information

The first day of the workshop began in plenary session with a series of invited talks designed to set the context and framework for the meeting and provide background information on COSPAR Planetary Protection Policy, NASA plans and activities, and overviews of previous workshops and literature of relevance to human missions and planetary protection. The session began by first outlining the specific goals, objectives, assumptions and scope for the workshop.

1.2.3. Goals, Objectives, Assumptions, Scope

In setting the stage for the meeting, the goals, assumptions and scope of the workshop were reviewed, with emphasis on the main objective—that of identifying specific knowledge gaps that need to be addressed in order to make incremental progress toward developing NPRs for human missions to Mars and other extraterrestrial locations. To identify knowledge gaps with respect to human missions, the workshop attendees were told that the goals were to:

1. Gather and discuss information needed to help move closer to definitive (procedural/implementation) requirements for future human missions NPRs;

2. Assess the types and levels of research underway and/or needed to identify knowledge gaps in areas consistent with fulfilling COSPAR Principles and Guidelines for Human Missions to Mars; and

3. Build a network of expertise to help address planetary protection for human exploration.

For the purposes of the workshop, *knowledge gaps* were described as questions that cannot be definitively answered at this time, or concerns that cannot be addressed until further research, study, and/or testing is completed.

Because specific planetary protection requirements have not yet been developed for human missions, participants were advised to use *assumptions consistent with current COSPAR principles* for human missions to Mars. Specifically, they should recognize that:

- Safeguarding Earth from back contamination is the highest planetary protection priority;
- There is need to understand and control human-associated contamination if human missions are to contribute to the astrobiological exploration of Mars;
- It will not be possible for all human-associated processes and mission operations to be conducted in entirely closed systems; and
- Crew members and their support systems will be exposed to Martian materials.

Based on the NASA Policy Instruction, NPI 8020.7 on planetary protection requirements for human extraterrestrial missions, participants were also told that NASA intends to take a phased approach to developing NPRs by focusing on three main areas:

1. Developing capabilities to comprehensively monitor the microbial communities associated with human systems and evaluate changes over time,

2. Developing technologies to minimize and mitigate contamination release, including, but not limited to, closed-loop systems; cleaning/re-cleaning capabilities; support systems that minimize contact of humans with the environment of Mars and other solar system destinations; and

3. Understanding environmental processes on Mars and other solar system destinations that would contribute to transport and sterilization of organisms released by human activities.

Because future Mars surface missions with astronaut crews will introduce levels and types of biological contaminants unlike those of exclusively robotic missions, there is a need to include consideration of the risks associated with both human and sample returns as they fit with currently accepted planetary protection policy—especially regarding the need to break the chain of contact with Mars in appropriate ways prior to returning to the Earth-Moon system.

Participants were also told that the workshop was intended primarily as a wide-open brainstorming session. Thus, in addressing their assigned tasks, they were advised to focus on collecting and identifying lists of knowledge gaps and important research and testing areas, *without* any attempts to rank, prioritize or seek consensus recommendations.

Finally, the workshop was intended to specifically focus on identifying gaps for science exploration missions undertaken by public sector agencies in the near-term, and *not* for addressing future challenges that may arise in the context of private or commercial sector missions, long-term human settlement or terraforming, or associated planetary resource exploitation or preservation concerns. Participants were also told that deliberations should center on identification of the data and information needed, rather than on any particular mission(s) or plans to obtain the information.

2. PLENARY TUTORIALS AND SUBMITTED PAPERS

2.1 Workshop Tutorial Presentations

After presentation of the information about workshop goals, objectives, assumptions and scope, a plenary session of invited speakers provided details about NASA's ongoing exploration plans, current COSPAR planetary protection policy, and overviews of perceived knowledge gaps gleaned from prior reports, papers, and workshops. Six invited presentations outlined: NASA's Evolvable Mars Campaign; the current status of COSPAR planetary protection policy and plans for human spaceflight; NASA's incremental plan proceeding from NPI to NPRs for human missions to Mars; and informational reviews of prior workshops, studies and published papers of relevance to the deliberations ahead. The invited speakers and their presentations topics are briefly summarized below.

In the first background presentation, Douglas A. Craig (NASA HQ, HEOMD) shared an overview of NASA's Evolvable Mars Campaign (EMC), which provided a context for workshop deliberations. The EMC's goals are to "define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s." The EMC's assorted mission scenarios aim for human-robotic advances in exploration, science, innovation, benefits to humanity, and international collaboration. The Campaign involves a three-step approach to planetary exploration, combining activities and missions at different distances and locations—referred to as Earth Reliant (in Earth orbit), Proving Ground (the Moon and interplanetary space, including robotic and human operations conducted during the Asteroid Redirect Mission), and Earth Independent (beyond the Earth-Moon system, including the Mars orbital and surface missions and those to its moons, Phobos and Deimos). In addition to being flexible to policy changes, the EMC seeks to build upon current hardware and technology development investments, leverage new science findings, and emphasize prepositioning, reuse and repurposing of systems.

Next, Dr. Cassie Conley (NASA HQ, PPO) provided an overview of current COSPAR international planetary protection policy for both robotic and human spaceflight, and its translation and implementation under NASA's Planetary Protection Policy NPD 8020.7G. While current planetary protection categories and implementation constraints are well established for robotic missions and based upon the latest scientific knowledge, we are in the early stages of developing detailed planetary protection implementation requirements for human missions beyond Earth orbit. While current COSPAR principles and guidelines provide a useful conceptual approach for human missions, the development of detailed, implementable requirements and controls will require a phased approach that integrates the latest multi-disciplinary input of information and understanding about microbial and organic contaminants, mitigation and control options, and Mars and spacecraft environments.

The third talk, presented by Dr. Bette Siegel (NASA HQ, HEOMD) explained the development of the NASA's NPI 8020.7 and the agency's adoption of a step-wise process leading to development of standards and procedures for implementing human spaceflight missions in compliance with COSPAR planetary protection policy. Siegel recounted how a core team with expertise from various NASA offices and directorates[5] drafted a NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions (NPI 8020.7), a multi-year, multi-element plan including a literature survey of relevant information and studies; a workshop to identify the current state of knowledge in planetary

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[5] The core team included experts from NASA's Human Exploration and Operations Directorate (HEOMD); Planetary Protection (PPO); Science Mission Directorate (SMD); Medical and Health Office; Chief Scientist, Office of General Counsel, Space Technology Mission Directorate; and the Office of International & Interagency Relations.

protection & human mission systems; development of a prioritized list of studies needed to inform requirements, and future R&TD studies that will iteratively lead to development of draft requirements. This workshop is one of the key steps in the process toward those requirements.

A fourth background presentation by James E. Johnson (NASA JSC) summarized an extensive literature review of notional studies and reports that provided important input to the workshop itself. Information from published studies was gathered and analyzed systematically to identify key functions and systems that either exist or need to be further developed for long-duration human spaceflight. Three areas are of critical importance included:

1. Capabilities that will be needed to monitor microbial communities;

2. Technologies and operational developments that will be needed to minimize contamination release; and

3. Environmental processes or conditions on Mars that could contribute to transport and sterilization of forward contamination (including microbes)?

Using the aforementioned analyses as input to workshop deliberations is intended to help assess "state of knowledge" and identify actionable areas of future study as intended by NPI 8020.7.[6] The full literature review and analysis will be published separately. [7]

John Rummel, (Chair, COSPAR Planetary Protection Panel) reviewed the historical context and approaches to planetary protection and human missions, reviewing early concerns about biological contamination in the Sputnik era, the appointment of a NASA "Planetary Quarantine Officer" in the early 1960s, and the implementation of lunar quarantine activities during the Apollo program. Rummel then summarized the various workshops and studies undertaken by various institutions and organizations over the past several decades[8] that have contributed extensive information on forward and back contamination, crew protection, waste disposal, ISRU, Special Regions[9] and zonation, and other considerations for human missions. This collective information has contributed in a stepwise fashion towards the current planetary protection provisions for human missions to Mars in the form of COSPAR principles and guidelines.

The sixth and final background presentation by John Hogan (NASA ARC) summarized details of a 2005 NASA workshop on Life Support & Habitation and Planetary Protection that focused on planetary protection policy development and implementation requirements for future human missions, particularly involving ALS, AEVA, AEMC[10] and planetary protection communities which were beginning to once again re-examine human missions. The workshop examined top-level planetary protection issues associated with both forward and backward contamination, and explored their likely effects on key hardware and operations for the first human mission to Mars. Participants in the 2005 workshop aimed to identify planetary protection requirements needed to guide future technology development and also initiated examination of approaches that might manage the risks prior to full definition of planetary protection policies and requirements. They also identified important areas with

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[6] For the workshop, step one is to learn (gather the knowledge presented throughout the main workshop sessions); Step 2 is to discuss (assess research currently underway, compare to notionally identified studies); and Step 3 is to identify knowledge gaps (via group deliberations).

[7] Johnson, J. E. (2016) A Path to Planetary Protection Requirements for Human Exploration: A Literature Review and Systems Engineering Approach. *In preparation for submittal to Advances in Space Research.*

[8] For example, COSPAR; NASA and ESA's PPOs; NRC Space Studies Board; ESTEC; MEPAG-SAG

[9] Special Regions, as defined by the Mars Exploration Program Analysis Group are places on Mars where terrestrial organisms might replicate. http://mepag.nasa.gov/reports/Rummel_et_al_Astrobiology_14-SR-SAG2.pdf

[10] Advanced Life Support; Advanced Extravehicular Activity, and Advanced Environmental Monitoring and Control

apparent gaps in science or technology capabilities likely to have significant impacts on mission architecture, technology trade options, operations, and development costs. The critical open issues identified at that time included: the establishment of detailed planetary protection requirements (biosignature definition and allowable releases); definition of control approaches for forward and backward contamination ("breaking chain of contact," is impossible, thus minimization will be sought); characterization of the potential nature of backward contamination (determine monitoring and control technologies); the need to define and identify Martian zones of minimum and maximum biological risk; details on allowable waste management practices (waste disposal on Mars, waste state, and containment); need to establish required quarantining of crew and returning vessels (could affect mission architecture); and consideration of contamination events, detection and remediation. Without a doubt, planetary protection constraints are likely to have significant impacts on mission architecture, technology trade options, operations and development costs; and will require serious attention within diverse topic areas starting early in the mission and systems development cycles.

2.2 Overview of Submitted Presentations

Following the introductory session and tutorials, the workshop proceeded to plenary sessions comprising accepted abstracts relevant to the three main study areas and their corresponding concerns. Prior to the workshop, specific input was solicited to cover the information in the three study areas, which established the three workshop study groups as follows:

- **Study Group 1: Microbial and human health monitoring**
  - Monitoring growth and survivability of human and habitat-associated microbial populations in space environments
  - Minimal waste mass and volume, and low consumable/waste product biological assay techniques
  - Microbiome research and ability to detect extraterrestrial perturbations
  - Crew quarantine measures for preventing backward contamination
  - Impacts on crew health and habitat microbiome caused by Mars material
- **Study Group 2: Technology and operations for contamination control**
  - Cleaning, sterilization, re-contamination prevention, and associated verification technologies for in-situ application
  - Environmental Control and Life Support Systems (ECLSS) loop closure and mitigation of spacecraft effluents
  - Technologies for contamination control of human surface mobility systems and spacesuits
  - Contamination control and preventing creation of localized Special Regions for support systems (ISRU, power, etc.)
  - Human surface exploration operational strategies for mitigating contamination
  - Sample containment and breaking-the-chain of contact technologies
  - Environmental cleanup of inadvertent release of unsterilized terrestrial material
- **Study Group 3: Natural transport of contamination on Mars**
  - Transport of biological contamination
  - Transport of organic contamination (particulates and molecular)

In all, five sessions with a total of 30 papers were dedicated to oral presentations submitted by participants from varied backgrounds. Each speaker provided information on research findings, capabilities, trends and technologies in their specific area. Prior to the meeting, speakers had been asked to help identify gaps in research and technology development by highlighting what knowledge

they felt needed to be collected in order to inform future planetary protection requirements. In addition to identifying important knowledge gaps, the groups were also asked to identify the specific COSPAR Implementation Guideline(s) that would be addressed by the identified research or technology areas — see Table A.[11]. To varying degrees, speakers included answers to the following specific questions in their presentations:

1. What planetary protection research activities or technical developments are critical for inclusion in your study area?
2. What work or research is already underway?
3. Is special information or technology needed to plan for nominal vs. off-nominal situations?
4. Are existing options of terrestrial contamination mitigation adaptable for planetary protection needs on the Martian surface?
5. Are there any significant stumbling blocks ahead that are evident?
6. In your opinion, what still needs to be accomplished?

For all research areas, the information from presentations became input for the respective breakout groups later in the workshop. Abstracts of all submitted papers are included on the workshop repository site: *http://planetaryprotection.nasa.gov/humanworkshop2015/*

Table A: Summary of COSPAR Implementation Guidelines

A. **Continued monitoring and evaluation of terrestrial microbes will be needed to address forward and backward contamination concerns**

B. **A quarantine capability (for individuals & entire crew) is needed during and after the mission**

C. **Need to develop comprehensive planetary protection protocols for combined human and robotic aspects of mission**

D. **Neither robotic systems nor human activities should contaminate "Special Regions"**

E. **Uncharacterized sites should be evaluated by robotic precursors prior to crew access**

F. **Pristine samples or sampling components from uncharacterized sites or Special Regions should be treated as Planetary Protection Category V, restricted Earth return**

G. **An onboard crewmember should be designated as responsible for implementing planetary protection measures during the mission**

H. **Planetary protection requirements will be based on conservative approach and not relaxed without scientific review, justification, and consensus**

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[11] For purposes of this task, each study group used an annotated list of COSPAR Implementation Guidelines, listing individual guidelines using letters A through H.

2.2.1 Study Group 1 - Microbial and Human Health Monitoring

Submitted talks on the topic of *Microbial and Human Health Monitoring* were divided into two sessions, with the first chaired by Craig Kundrot (NASA JSC) and the second by Lee Bebout (NASA ARC). A total of twelve speakers addressed various aspects of the topic.

NASA Flight Surgeon Dr. Jennifer Law (NASA JSC) delivered the keynote presentation for Study Group 1, providing background information based on her experiences as both a planetary protection engineer and as a physician supporting astronauts aboard the International Space Station. She discussed the challenges of implementing planetary protection for future long-duration human exploration missions, focusing on what is known about biomedical needs of astronauts on ISS missions in LEO, how those experiences compare to the biomedical risks of future missions to planetary surfaces, and the need for a collaborative approach between the space medical and planetary protection communities to address the challenges ahead. Future human missions will be orders of magnitude more complex than robotic missions, and significantly different from those undertaken during the Apollo era with its Lunar Quarantine Program conducted upon return to Earth. Put simply, there exists a significant experience gap in the implementation of planetary protection requirements and practices for both robotic and human aspects of crewed missions. The Apollo era practices are long outdated, and human support practices and guidelines in LEO do not address key elements of planetary protection concern.

Because humans will inevitably carry diverse quantities and types of microbes, and it will not be practicable to specify all aspects of microbial populations or contaminants at launch, future human Mars missions must instead emphasize preventive, protective, and mitigative measures. Rather than emphasizing the typical approach to robotic planetary protection control using bioburden accounting and microbial reduction, a paradigm shift will be needed. Moreover, assorted human factors must also be taken into account along with planetary protection to keep the crew healthy and functional throughout the missions. This means special attention for air, water, and food systems; waste containment and disposal; effects of microgravity and hypogravity on human physiological systems; and preparedness for medical emergencies, off-nominal situations and more. The combination of planetary protection constraints with diverse biomedical concerns will undoubtedly have significant implications for designs of future systems, operations, and technologies. The planetary protection and space medicine communities must work collaboratively to develop effective guidelines, protocols and research information, and to communicate details to the many stakeholder groups responsible for developing systems in support of future deep space human exploration missions.

Other speakers in the session on microbial and health monitoring presented information on specific topics related to human missions including overviews of the capabilities needed for planetary protection to safeguard both crew and engineering systems. Clearly, detection and monitoring systems will be needed to maintain acceptable microbial bioburden levels, to avoid false positives during life-detection experiments and to prevent inadvertent human exposure to Martian materials. Speakers reviewed the considerable information known about microbial biocontamination control from both robotic and human space missions and habitats, and also identified opportunities for using ISS as a testbed for planetary protection protocol development and data gathering. Information was also presented about the utility of adapting new methods for planetary protection monitoring, including high-throughput "omics" technologies, and other real time testing and quantitation methods using DNA detection microarrays. Presentations also focused on potentially adaptable examples and information from non-space situations, including automated microbial monitoring systems for confined spaces, cleanrooms, health care settings and the indoor built environment.

2.2.2 Study Group 2 - Technology and Operations for Contamination Control

Ten presentations on *Technology and Operations for Contamination Control* were presented in two sessions, both chaired by Molly Anderson (NASA JSC).

Amy Ross (NASA JSC) and Dr. Dean Eppler (NASA JSC) provided the keynote presentation, which was focused on exploration space suit architecture and its critical importance for science operations, particularly for geology sampling activities and other extravehicular work anticipated on planetary surfaces. Drawing from Apollo and other space exploration experiences, it is obvious that spacesuits must allow astronaut crews to collect information at both macro and micro scales during their forays, and return collected materials in acceptable conditions for subsequent laboratory investigations. In considering potential contamination concerns, they noted that an EVA suit is essentially like a small spacecraft in that it that must serve three basic functions: a portable life support system providing physiological well being; a mobility joint system enabling an astronaut to perform EVA tasks under pressurized conditions; and a protective suit that safeguards against the various hazards on the external environment. Undoubtedly, the architecture and operations of space suits—and their cleaning, maintenance and repair—present many important planetary protection considerations that must be addressed to control both forward and backward contamination during a variety of mission phases.

Other speakers in the sessions focused on how planetary protection guidelines will affect operations, processes and functions of various ECLS systems during Mars missions. In addition, speakers identified and addressed planetary protection concerns relevant to specific situations, such as during use of pressurized crew vehicles; implementation of soil-based ISRU concepts; devising technology for sample containment, handling and return; addressing inadvertent contamination of tools and samples during subsurface drilling; and planning for coordinated robotic-human operations on the Martian surface.

2.2.3 Study Group 3 - Natural Transport of Contamination on Mars

The topic of *Natural Transport of Contamination on Mars* was addressed in two sessions of eight presentations, chaired by Drs. John Rummel (East Carolina University) and Andy Spry (NASA JPL), respectively. Dr. Rocco Mancinelli (NASA ARC) provided the keynote presentation, which focused on the prospect of anthropogenic biological contamination on Mars using comparative empirical and modeling studies of diverse locations having extremes of dryness, temperature, and UV radiation. Studies of model systems have included terrestrial analogues (Antarctic dry valleys and the Atacama Desert), orbital space platforms with different exposure conditions and durations, and more recently, ground-based simulations of the Martian environment, including its wind-blown dusts and spacecraft landing conditions. Combining research findings with current understanding of Mars conditions indicate that while the probability of microbial growth on Mars is low, there remains a probability for microbial survival on Mars, and a finite probability of global contamination by dust storms. Continuing studies of extremophiles on Earth and simulations or exposures to various conditions in space indicate that human-caused biological contamination on Mars clearly remains a planetary protection concern for both robotic and human missions to Mars.

Other presentations in the sessions summarized key issues and concerns related to planning for protection of Mars from forward contamination during human exploration, and encouraged taking a "systems view" based on identification of critical driving factors to pro-actively determine the best path forward for requirements development early in the NPI-NPR process. Another paper indicated that recent studies of Earth-based analogues are suggestive that the high solar UV irradiation environment

on Mars will assist in the inactivation of spacecraft, spacesuit and hardware contamination during EVA activities; moreover, evidence of low microbial dispersal rates from crewed rovers in the Arctic, are suggestive that there may be minimal risks to forward microbial contamination during EVA activities, particularly considering the harsh Martian surface condition. Further experiments using ultra low-cost, near-space probes launched by weather balloons were suggested for gathering additional data on how cells can survive extreme environments and for testing species-specific inactivation models of relevance to Mars surface conditions. Clearly, there is a need for gathering considerably more data on microbial survival and Martian conditions to feed into the NPI-NPR process

2.3   Breakout Study Groups - Format and Instructions

After completion of all plenary invited talks, plans for the deliberative part of the workshop were presented. Participants self-divided into three separate study groups for detailed discussions about the specific gaps and needs in their respective study areas. Each group used a common format set of questions as guides during the approximately four hours of study group breakout discussions. Subsequently, all participants reconvened in a final plenary session to hear summary findings and suggestions from the three study groups, followed by open discussion with panelists and participants about suggested science and technology gaps of importance. The workshop concluded with a review of the planned path forward toward the anticipated NPR for planetary protection and human missions. Following the workshop, the chairs and scribes from each study group also submitted written drafts summarizing their discussions. These also served as input for this workshop report. Details of the deliberations and findings of the three study groups are presented in the sections that follow.

3   OUTBRIEFING STUDY GROUP 1: Microbial and Human Health Monitoring

Leads

> Moderators: Jennifer Law, Monsi Roman, Aaron Mills, Terry Taddeo
> Scribes: Craig Kundrot, Steve Davison
> Outbrief Presenters: Mark Ott/Lee Bebout

Study Group 1 Participants

> Crystal Jaing, Lawrence Livermore National Laboratory
> Fathi Karouia, NASA (ARC)/ University of California, San Francisco
> Craig Kundrot, NASA (JSC)
> Jenna Lang, University of California, Davis
> Jennifer Law, NASA (JSC)
> Aaron Mills, NASA (KSC)
> Paula Olsiewski, Alfred P. Sloan Foundation
> Mark Ott, NASA (JSC)
> Victor Panchenko, NASA (ARC)
> Jim Polarine, Steris
> Margaret Race, SETI Institute
> Laura Rose, Centers for Disease Control and Prevention
> Bette Siegel, NASA (HQ)
> Terry Taddeo, NASA (JSC)
> Tamas Torok, Lawrence Berkeley National Laboratory
> Kasthuri Venkateswaran, NASA (JPL)
> Robert Zimmerman, Symbiotek Systems

3.1   Group Charge and Pre-Identified Issues

Study Group 1 focused on microbial and human health monitoring associated with forward and backward biological contamination and crew health throughout future long-duration missions to Mars. Their discussions began by considering the range of research and technology development questions related to the understanding, detection, monitoring, and use of assessment techniques that will be important for:

- Monitoring growth and survival of microbial populations that could be associated with humans or human-rated systems in space environments (including populations in or on the human body; inside habitation areas; and external in Martian environments);
- Developing biological assay techniques—adaptable or new—with minimal mass and volume, and low resource consumption and waste production;
- Microbiome research and the ability to detect extraterrestrial perturbations, including impacts from Mars material exposure on astronaut health and human and habitation microbiomes;
- Crew quarantine measures for preventing backward contamination;
- Developing indicator tests and warning and screening systems for planetary protection relevant contaminants; and
- In-Situ Resource Utilization (ISRU) considerations.

Much of the Study Group 1 discussion focused on the detection of microorganisms as it applies to planetary protection, human health, and the impact of microorganisms on scientific findings. Because

humans will carry a large percentage of the microorganisms that will be taken to another planet, the astronaut microbiome is a major area of interest. One recurring theme in the discussions centered on how it will be possible to identify an organism of extraterrestrial origin and its potential health and science impacts to the crew and mission. Summary information from the group deliberations is provided below, with a video of the out briefing report available at https://ac.arc.nasa.gov/p5mehtbsb13/

3.2 Study Area 1: Study Group Answers to Guiding Workshop Questions

The sections below provide a summary of the Study Group 1 deliberations, beginning with the answers to the series of guiding questions used by all groups to focus their discussions. Information from the initial discussions was combined with subsequent deliberations to identify strategic knowledge gaps related to areas of microbial and human health monitoring.

3.2.1 Question 1:

What planetary protection related <u>research activities or technical developments do you believe are critical for inclusion</u> in your study area?

Study Group 1 participants first noted the importance of identifying the various stakeholders and their specific requirements and needs because of the varied perspectives they have (e.g., forward contamination concerns related to science and associated technology are likely to differ from the concerns related to crew health monitoring). Overall the study group identified four general areas deemed critical for future attention: microbial monitoring, crew health, microbial-specific responses, and other general research topics.

In the broad category of *Microbial Monitoring*, there is a need for research on sampling methodology in low biomass environments, with special attention on determining the spatial and temporal granularity and detection limits that will be required. Clearly, there is need for technology to track what is vented from human systems (space suits, habitats, rovers, etc.) into the extraterrestrial environment. For microbe identification and enumeration, there is an obvious concern about the use of traditional, culture-based methods vs. state-of-the-art molecular techniques, each of which has advantages and disadvantages. Considering the clear need for a technology development roadmap for adapting terrestrial molecular methods to use in space, the group questioned whether it would be appropriate to use existing methods to establish a baseline mission plan and then upgrade technology and methods later as advances become available.

Study Group 1 also focused on the possible discovery of life on a mission. The ability to distinguish false positives and false negatives will be critical. If morphological and/or chemical evidence of cells is found in returned samples, will it be possible to determine whether they are truly Martian versus Earth cells that have been dramatically altered by Martian conditions? Moreover, will we have methods to recognize life that may be a new branch off the terrestrial 16S rRNA tree of life?

Study Group 1 identified a number of key questions about microbes and their relationship to *Human Health* during different phases of the mission. Questions about health centered on whether there may be new modalities of pathogenicity that could manifest in crew with possibly suppressed immune systems. Are there techniques that can be used to determine the ability of the immune system to respond to an immunological challenge? Does the human microbiome change on ISS over 6 months? Over 12

months? Over longer periods of time? Could useful data be derived from such understanding and the distinction between changes during different mission durations? Can the microbiome of all astronauts be tracked pre-, in-, and post-flight to develop a comprehensive database (e.g., using a GeneLab[12] type approach)? Additional questions were raised about what standards of cleanliness should be applied to the spacecraft, and what numbers and species would provide a healthy and resilient microbial environment for the crew? What treatments will be needed to make ISRU generated resources safe, and how do we assess the safety of ISRU generated resources such as water?

Other questions about human health and well being focused on the return portion of the mission. How do we prevent astronauts from becoming ill upon re-introduction to terrestrial life (backward contamination)? Will living in a sanitized environment for an extended period of time (months to years) influence the immune system, and in what ways?

Regarding backward contamination concerns, will it be possible to recognize microbial life that has a different underlying chemistry that could still pose a threat to human health through chemical rather than terrestrial biological processes? If we find life on Mars, how do we determine if it is safe or pathogenic? What measurements will crewmembers need to take during the return transit to determine whether they are safe to return to Earth? Will the concept of "the plague ship returns to its port of origin" apply to a crew made ill due to a Martian agent? What should be done if there is uncertainty about crew infectivity as assessed during the return transit? Are there containment and quarantine mitigations that would address these concerns and allow the crew to return?

An assortment of questions also related to research on *Microbial Specific Responses* during long-duration spaceflight. What is the risk of a development of mutations that could generate a pathogenic strain of microbe? Similarly, are there possible microbiological adaptations to spaceflight that may be deleterious to humans? Is there a need to understand the plasmid population of the microbiome (e.g., drug resistance)? Can food be used to maintain a healthy microbiome? How can prebiotics or probiotics be used to maintain health or treat microbiome dysfunction?

The group also focused on questions about the elevated radiation exposure in deep space, and whether and how it might raise the mutation rate of microbes. Clearly there is a need for high fidelity simulation in a high radiation environment (e.g., lunar surface, or in cislunar space) to characterize changes in microbial populations.

Finally, the group also identified a list of assorted other *General Research* topics. For example, what microbial transport occurs between humans in a closed environment, and what changes in human microbiome could be deleterious to crew upon return to Earth? How can the ISS be used to characterize forward contamination into the destination environment? Would it be possible to develop a reasonably accessible database containing sequence data of microbes, both human microbiome and environmental? Can there be a comprehensive database to capture all sequence data from non-culture methods that permits analysis with future analysis tools? Would it be beneficial to develop a communication forum to learn about and exchange planetary protection related information being done by varied groups (space biology, human research programs, other government organizations, private entities, other governments, etc.)? Such interactions would help address other mission considerations such as what type of sample quarantine and containment is needed during transit. Can simulated Martian conditions

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[12] GeneLab is an open-access database with spaceflight genomic data, RNA and protein expression, and metabolic profiles. It includes tools to conduct data analysis, and creates a place online where scientists, researchers, teachers and students can connect with their peers, share their results, and communicate with NASA. http://genelab.nasa.gov/

help assess possible morphological and other microbial changes over long times, and would a shared integrated facility including a closed system be useful for needed planetary protection related work?

3.2.2 Question 2:

What <u>work/research is already underway</u>?

The group was able to compile an impressive list of activities and research already underway in addressing both Martian and human related microbial questions. The list includes various NASA supported activities (e.g., ISS, JPL, NAI, academic and commercial sponsored work on monitoring, crew health, etc.) as well as field analogue research activities (e.g., Haughton-Mars, Mars 500, NEEMO, NAI research), groups with longitudinal studies and bioinformatics data base experience, and international partners (e.g., ISLSWG, ESA, European Commission).[13]

3.2.3 Question 3:

Is special information or technology needed to plan for <u>nominal vs. off-nominal situations?</u>

In discussing the needs of nominal vs. off-nominal situations, the group identified a list of questions that addressed varied research needs, including those related to biocontainment and biosafety labs; sterilization and quarantine needs and scenarios; availability of medical, astrobiological and environmental control expertise; autonomous monitoring and surveillance systems; and approaches for various decision-making situations and emergencies, including timeliness considerations. Although not directly scientific or technical, the group also identified questions about the ethical and operational ground rules for fatalities or contagion during missions.

3.2.4 Question 4:

Are <u>existing mitigation options and approaches adaptable</u> for planetary protection needs on the Martian surface?

The identified mitigation options and approaches fall roughly into three areas—environmental systems, training, and decontamination. Specifically, Study Group 1 focused on the need for developing closed system(s) that minimizes leakage. The group also suggested examining materials composition and degradation in the habitable volume to assess whether they put a detrimental load on environmental systems (e.g., filters) or change the ability to support or inhibit microbial life (e.g., loss of bacteriocide in construction materials). They noted that the designation and understanding of special areas (e.g., Special Regions and Zones of Minimum Biological Risks) can support risk management; and human factors research and training can support continuity and proficiency with planetary protection procedures throughout the missions. Finally, to prepare for potential leaks or accidents, it will be important to consider how to design a habitat and habitable spaces so that contaminated compartments can be decontaminated. Moreover, there is need for research on effective decontamination and validation methods for use on long-duration missions.

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[13] International Space Station (ISS), Jet Propulsion Laboratory (JPL), NASA Astrobiology Institute (NA), NASA Extreme Environment Mission Operations (NEEMO), International Space Life Sciences Working Group (ISLSWG), European Space Agency (ESA)

3.2.5 Question 5:

Are there any significant <u>stumbling blocks</u> ahead that are evident (including coordination across planetary protection, science exploration, engineering, operation and medical communities)?

The identified stumbling blocks are a reflection of the complexity of the overall mission as well as the need for coordination across varied expert communities that don't typically work together. Mission planning will require many disparate efforts that are without standardized conditions or approaches. In addition, there is no overarching structure around which to organize the planetary protection efforts, and only limited communication exists amongst the varied experts within NASA, as well as the community external to NASA. In the long run, international coordination among spacefaring nations will be important for agreeing to the same planetary protection protocols.

Due to the unusual nature of long-duration planetary missions, there is need for discussions about what ethical guidelines and operational ground rules are needed. These will require consensus from a number of stakeholders. While ethical guidelines and operational ground rules may be unlike other R&TD areas, they nonetheless represent a significant knowledge gap that will take special attention of multiple experts to address all the considerations, including planetary protection.

3.3 Identification of Knowledge Gaps for Study Group 1

Using information identified in deliberations over questions 1-5 above, the subgroup then focused on the ultimate workshop question: "What still needs to be accomplished?" In particular, what do we need to focus upon incrementally to answer the questions and fill key knowledge gaps, and based upon what rationale? The study group identified nine specific knowledge gaps in areas related to microbial and human health monitoring. These gaps are summarized in Table 3.1, and explained in the following sections.

Knowledge Gap #1: What are the technologies and procedures that should be used for effective sampling and collection?

* **Rationale:** Samples need to be collected properly to preserve biomarkers and indicators of life as well as to prevent contamination.

* **COSPAR Implementation Guideline(s) involved:** A and C. Identification and development of collection methods and comprehensive protocols for robotic and human aspects of missions are stipulated by COSPAR guidelines.

Knowledge Gap #2: What are appropriate technologies for microbial monitoring to mitigate risk to crew, ensure planetary protection, and preserve scientific integrity?

* **Rationale:** Development of microbial monitoring technologies needs to be guided by requirements (that will include detection limits) of multiple stakeholders, to ensure that primary goals are achieved. Commonality should be a goal for the purpose of minimizing mass and logistics, however it should not preclude logical options.

* **COSPAR Implementation Guideline(s) involved:** A and C. Identification and development of monitoring methods and comprehensive protocols for robotic and human aspects of missions are stipulated by COSPAR guidelines.

Knowledge Gap #3: What sample processing and analysis technologies and procedures should be used to reduce crew time and mitigate contamination concerns?

- **Rationale:** Sample processing (if needed) and analysis should be automated and combined, when appropriate, to reduce crew time and contamination of sample and destination environment.
- **COSPAR Implementation Guideline(s) involved:** A and C. Identification and development of sample processing technologies will be critical for use in association with comprehensive protocols for robotic and human aspects of missions, as stipulated by COSPAR guidelines.

Knowledge Gap #4: What technologies and procedures should be used to develop organized data collection, storage, and interpretation procedures for use during missions?

- **Rationale:** Data collected from microbial monitoring should be stored in an organized way that could be retrieved by the crew when needed. The data should by stored in a manner that will allow the crew to quickly obtain assessments (like trends) or in-depth analysis when needed.

- **COSPAR Implementation Guideline(s) involved:** A and C. Identification and development of data storage and organization requirements will be important for use in association with comprehensive protocols for robotic and human aspects of missions as stipulated by COSPAR guidelines.

Knowledge Gap #5: What is needed to understand spaceflight-specific microbial responses and heritable changes during extended missions and relocation to different planetary bodies?

- **Rationale:** Multiple spaceflight experiments have demonstrated transient changes in microbial molecular genetic and phenotypic responses to culture in the spaceflight environment. This selective pressure, as well as possible increased mutation from radiation damage, creates the potential for both transient and heritable changes in microbial characteristics, including alterations in virulence and virulence characteristics.

- **COSPAR Implementation Guideline(s) involved:** A. Understanding and documenting spaceflight associated responses and heritable changes in terrestrial microbiota will be important elements of addressing COSPAR Guideline A—continued monitoring and evaluation of terrestrial microbiota.

Knowledge Gap #6: What is needed to monitor microbial populations (e.g., astronaut, vehicle, and external environment)?

- **Rationale:** The microbiome of the crew and habitat will dictate the types of microorganisms that will be associated with human exploration of other planets. Likewise, the dissemination of these organisms from the crew and vehicle to the surrounding environment could influence crew health, planetary protection and scientific integrity.

- **COSPAR Implementation Guideline(s) involved:** A, C, D, and E. In order to address COSPAR guidelines A, C, D and E, clear understanding will be needed of all relevant microbial populations.

Knowledge Gap #7: What novel approaches can be developed for effective, low-toxicity disinfectants and prevention and recovery from contamination.

- **Rationale:** Long-duration missions will require novel approaches to microbial control that may be different from those used during missions in LEO.
  The new concerns include:
     a) Development of effective disinfectants with very low toxicity and microbial resistance.

     b) Support of vehicle systems such as prevention of microbial induced corrosion and recovery from systems fouling.

- **COSPAR Implementation Guideline(s) involved:** C, E. Knowledge Gap 7(a), effective contamination controls and methods, will play a part in eventual planetary protection protocols (Guideline C) and be import for avoiding contamination of Special Regions during either robotic or human missions (Guideline E). Knowledge gap 7(b), microbial associated corrosion and fouling of systems, will provide important information for development of eventual protocols (Guideline C)

Knowledge Gap #8: What studies are needed to develop diagnostic and treatment options specifically related to crew exposure to microbes and contaminants?

- **Rationale:** Long-duration missions will require special monitoring to screen for unusual crew health effects and symptoms that may be caused by exposure to microbes or contaminants—either terrestrial or extraterrestrial. Understanding, diagnosing, and treating symptoms may require different or supplemental approaches compared to those used during the comparatively shorter mission experiences in LEO. While the considerable experiences in LEO will be useful for monitoring and addressing crew health, additional information is needed to address potential complications from extended duration missions beyond LEO.

- **COSPAR Implementation Guideline(s) involved:** A, B, C, and G. Continued monitoring and evaluation of terrestrial microbes will be needed to address forward and backward contamination concerns. Likewise, detecting, understanding (and distinguishing) possible health effects and symptoms that may be associated with exposure to Martian materials will be important (A). Such information will be critical for developing comprehensive planetary protection protocols (C) and determining whether or not quarantine may be required during the mission (B, G).

Knowledge Gap #9: What information is needed to develop acceptable and appropriate ethical and operational guidelines for long-duration human missions to Mars?

- **Rationale:** Due to Mars' astrobiological uncertainties and the imperative to safeguard Earth from backward contamination, the well being of Earth may come into conflict with the well being of a Mars crew if extraterrestrial infection cannot be ruled out. Ethical and operational guidelines will need to be developed for long-duration human missions to Mars, requiring input from a variety of stakeholders to reach a consensus on acceptable guidelines. Such collaborative deliberations will involve multidisciplinary expert groups, including NASA Headquarters, the Crew Office, flight surgeons, microbiologists, technologists, and bioethicists. Discussions should be initiated at the outset of mission planning and integrate relevant new information generated by the three study group topical areas.

- **COSPAR Implementation Guideline(s) involved:** B, C, G, and H. Because crew health and well being are essential for mission success, it will be critical to develop comprehensive, appropriate planetary protection protocols (C) and have clear, consistent and scientifically justified rationale for monitoring and evaluating situations that may require quarantine (A and B) throughout the mission. Obviously, there will be considerable need to integrate and apply information from diverse disciplines, and make decisions well in advance about how and when it will be used and implemented (G, H)

TABLE 3.1 : Key Knowledge Gaps Identified by Study Group 1 Microbial & Human Health Monitoring
Knowledge Gap 1.1: What are the technologies and procedures that should be used for microbial sampling and collection?
Knowledge Gap 1.2: What are the appropriate technologies for microbial monitoring to mitigate risk to crew, ensure planetary protection, and preserve scientific integrity?
Knowledge Gap 1.3: What technologies and procedures should be used for sample processing and analysis to reduce crew time and mitigate contamination concerns?
Knowledge Gap 1.4: What technologies and procedures should be used for data collection, storage, and interpretation during missions?
Knowledge Gap 1.5: What is needed to understand spaceflight-specific microbial responses and heritable changes during extended spaceflight and relocation to a different planetary body?
Knowledge Gap 1.6: What is needed to monitor astronaut, vehicle, and external environmental microbial populations effectively?
Knowledge Gap 1.7: What novel approaches can be developed for (a) Effective, low toxicity disinfectants, and (b) Prevention/recovery from biofilms/microbial-induced corrosion, fouling etc.
Knowledge Gap 1.8: What studies are needed to understand crew health and biomedicine related to microbial and contamination exposures?
Knowledge Gap 1.9: What information is needed to develop acceptable and appropriate ethical and operational guidelines for human missions to Mars?

4. OUTBRIEFING STUDY GROUP 2: Technology and Operations for Contamination Control

Leads:

Moderator(s): John Hogan[14]
Scribe(s): Jesse Buffington and Natalie Mary
Outbrief Presenters: Jesse Buffington and John Hogan

Study Area 2 Participants:

Molly Anderson	Margaret Abraham
Dan Barta	Rosalba Bonaccorsi
Jesse Buffington	Marc Cohen
Bob Gershman	Brian Glass
John Hogan	James Johnson
John Karcz	Sanjay Lak
Erin Lalime	Pascal Lee
Mark Lupisella	Rob Manning
Natalie Mary	Amy Ross
Michelle Rucker	Jerry Sanders
Norm Wainwright	Jennie Ward
David Wilson	Larry Zanko

4.1 Group Charge and Pre-Identified Issues

Study Group 2 focused on issues related to cleaning, sterilization, re-contamination prevention, and associated verification technologies for in-situ application during human missions. Their range of research and technology development questions related to:

- Environmental Control and Life Support Systems (ECLSS) loop closure and mitigation of spacecraft effluents of varied types
- Technologies for contamination control of human surface mobility systems and spacesuits
- Contamination control and preventing creation of localized [microbially] habitable environments by support systems (In-situ Resource Utilization (ISRU), induced Special Regions from power systems, etc.)
- Human surface exploration operational strategies for mitigating contamination
- Sample acquisition, containment and technologies for breaking-the-chain of contact Environmental cleanup of inadvertent release of unsterilized terrestrial material

Study Group 2 participants noted that the first human mission to Mars will represent the farthest distance that humans have traveled from Earth. Human missions will include such assets as robotic rovers, habitats, pressurized rovers, ISRU equipment, and Exploration EVA Suits. Crewmembers will perform autonomous and robotically assisted extravehicular exploration; science and research activities both inside and outside; construction, servicing, and repair operations on the exterior of the vehicle(s); and operations and activities in hazardous external conditions of the Mars environment. Study Group 2 discussed the open questions, effects, and dependencies of technology and operations in the Mars environment and the associated planetary protection concerns. Eventual operational concepts and requirements are dependent on the mission profile, surface assets, and the Mars environment, but planetary protection considerations clearly will impact many systems, operations and activities.

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[14] Dr. Jitendra Joshi, NASA HQ, a member of the Science Organizing Committee for the Workshop, was also a designated Lead for Study Group 2. However, he was unable to attend the workshop.

Summary information from the group deliberations is provided below, with a video of the out briefing available at https://ac.arc.nasa.gov/p7tsxzsa22b/

4.2 Study Group 2 Answers to Guiding Workshop Questions

The sections below provide a summary of Study Group 2 deliberations, beginning with their answers to the series of guiding questions used by all groups to focus their discussions. Information from these initial discussions were combined with subsequent deliberations to identify strategic knowledge gaps related to areas of technology and operations for contamination control during all phases of the mission.

4.2.1 Question 1:

What planetary protection related <u>research activities or technical developments do you believe are critical for inclusion</u> in your study area?

Study Group 2 noted the importance of ground and on-orbit testing of methods and technologies for dust mitigation prior to human missions to the Mars surface. Varied extraterrestrial opportunities for such testing can be found, such as on missions on and around the moon (particularly in the Proving Ground of cislunar space), and on surfaces of Mars' moons. Because of the many systems likely to be impacted by dusts, coordination on the "best" combination of layered controls and technology concepts is highly desired. While the design and procedural use definitions of cleaning tools are unknown at this time, many factors merit consideration, such as nominal contamination prevention and cleaning, contamination detection technology, and detailed contamination control and removal/cleaning technology.

Other areas of critical research include environment characterization and definition (properties of dust and dirt, dust storms, etc.) as well as efforts to develop suitable Mars simulants based on scientific understanding of regolith conditions (even if there is no Mars sample return in advance of a human mission). Attention should also focus on the use of additives to trace possible backward contamination, as well as chemical additives to understand materials degradation due to toxicity and corrosion.

Programmatic requirements should establish testing protocols for acceptable levels of dust within the habitable volumes. In addition, planetary protection perspectives should be incorporated as work proceeds in development of ingress and egress methods with suits on the other side of a bulkhead. Suit materials testing should be conducted as part of EVA research to understand chemical interactions, because cleaning and sterilization tools and protocols must be compatible with the suit material limitations.

4.2.2 Question 2:

What <u>work/research is already underway</u>?

There is considerable work underway on both operational and vehicle concepts (e.g., pressurized rovers, habitats, ingress and egress method concepts, etc.) that will need input and support on architecture and zoning concepts for overall air quality control. In particular, the working group for landing-site selection will need information on Special Region locations. Planetary surface EVA Suit design is ongoing, with requirements development and potential ISS EMU replacements under

discussion. Likewise, suit materials testing on the Mars 2020 rover is being pursued, although by itself will not likely answer all questions associated with chemical compatibility.

On a positive note, Study Group 2 added that interactions during this workshop contributed to increased communication among engineers and microbiologists who will collaborate on future suit testing aimed at determining and characterizing what is leaked and vented from planetary EVA suits.

4.2.3   Question 3:

Is special information or technology needed to plan for nominal vs. off-nominal situations?

Considering the long-duration missions ahead, operational responses to possible off-nominal situations must be pre-planned (e.g., suit failure; incapacitated crewmembers; breaches of different types; even crew fatalities, etc.). A thorough dialogue is needed to evaluate how contingency operations would be conducted and still fulfill the intent of Planetary Protection guidelines. Such deliberations are yet to be conducted. The group also discussed the need to consider possible ethical and non-science information in the deliberations.

4.2.4   Question 4:

Are existing mitigation options and approaches adaptable for planetary protection needs on the Martian surface?

In general, Personal Protective Equipment for suit servicing is historically quite limited, as is airflow control in flight. Study Group 2 suggested that Vaporized Hydrogen Peroxide (VHP) could possibly be used for decontamination purposes, with possible reclamation of associated by-products. Further testing would be necessary to determine instrumentation, equipment, and materials compatibility. In addition, there would be need for separate area(s) for use during times of decontamination operations.

4.2.5   Question 5:

Are there any significant stumbling blocks ahead that are evident (including coordination across planetary protection, science, exploration, engineering, operations and medical communities)?

Coordination across communities must be increased so that knowledge gained from past, current, and future programs on Mars can be documented and applied to surface exploration and EVA development. Areas of interest and importance include information on environmental documentation and suggested directions about use of simulants for terrestrial testing. Concurrence on testing and validation of ingress and egress methods is particularly important prior to use for the first time on missions to ensure both mission success and adequate planetary protection. Attention should focus on both nominal and off-nominal situations.

4.2.6   Other Questions and Deliberations Relevant to Technology and Operations:

Prior to identifying the knowledge gaps associated with their area of Technology and Operations, Study Group 2 noted that it was impossible to discuss their topic without also bringing up questions and gaps in the other two study group areas. They also generated a long list of mission-related questions and

concerns from presentations earlier in the workshop and grouped them into broad categories associated with different mission phases and activities.

4.2.7   Other Considerations:

In the Study Group 1 area of **Microbial and Human Health Monitoring,** they noted relevant questions and concerns of two types: a) those associated with mission and overall systems design, and b) those related to the need for continued monitoring and evaluation of terrestrial microbes as indicated in the COSPAR Implementation Guidelines. Specific technology and operations questions that were raised in the area of microbial and health monitoring are listed below.[15]

A. Mission and Overall Systems Design
- o What long term monitoring around the human presence do we conduct? How do we sample what we release?
- o What is the discrepancy between what we measure vs. what is actually present?
- o How do we combine the engineering specifications with sampling methods?
- o If microbes mutate, how will that be detected?
- o How do we detect backward/forward contamination? What are the instrument sensitivity requirements for quantitation and characterization for detection of both forward and backward contamination? What is the necessary quality and efficacy of sampling and how do we avoid false results?

B. Continued Monitoring and Evaluation of Terrestrial Microbes
- o What is considered Mars life, and what does it look like? These must be defined before we can measure it.
- o Should the following questions be two different questions? Are terrestrial microbes inherently classified as forward contaminants and are Mars microbes inherently classified as backward contaminants? How do you differentiate between terrestrial and Mars life?
- o How complete does the monitoring need to be? What standards will be used to determine the metrics?
- o What are the procedures? Do you need to meet the same requirements as robotic requirements for return? (Because crew will likely be an interface for microbes, it is acknowledged that there will likely be need for some changes.)
- o How does the presence of human crew change what can be achieved in monitoring and evaluation? How will crew presence impact acceptable levels of baseline cleanliness?
- o What actions and data are needed to demonstrate acceptable contamination mitigation?
- o What is the interplay between detection instruments and Martian geologic features and environment?

The group also noted relevant questions in the Study Group 2 topic of **Natural Transport of Contaminants on Mars.** Specifically, they noted a series of questions and concerns related to (microbial) transport methods and kill times as follows[16]:

- o Does the local Martian environment kill microbes that may be vented as a viable bioburden along with intentionally vented gaseous products?
- o What is the time-scale of transport from a source (even in an acceptable region) to regions of greater concern?

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[15] Not surprisingly, many of these questions overlap with details also discussed in Study Group 1 (Section Section 6 of this report.
[16] Many of these questions also overlap with details discussed in Study Group 3 (Section 5 of this report)

- What is released from suits—and from what part of the suit?   How far away will released microbial contaminants be transported and how quickly will they die? Will there be direct contamination (forward or backward) by physical contact?
- What are the predictions, timelines and implications of various releases? What precursor science is necessary to understand?
- What if microbes in biofilms leak or vent during suited testing or activities? How long will biofilms last in the Martian environment, and what science can be done to generate useful kill time data?

Finally, the group reviewed the list of assorted questions generated from earlier plenary session presentation slides. The information was organized into broad categorical lists of questions corresponding to key mission technologies, systems, and operations. The detailed list of questions were grouped roughly into the following categories:

- Crew Selection
- EVA
- Waste Disposal
- Advanced Life Support
- Life Detection
- ISRU

- Sample Handling
- Contingency Scenarios
- General Forward Contamination
- General Back Contamination
- Logistics, Cargo, Robotics

4.3   Identification of Knowledge Gaps for Study Group 2

Following group deliberations across assorted topics of relevance to *Technology and Operations*, Study Group 2 identified seven knowledge gaps, which are summarized in Table 4.1, and described below:

Knowledge Gap #1: Does the duration of a Mars surface stay affect implementation of planetary protection during the mission?

- **Rationale:** It is possible that the duration of a Mars surface mission (~30 day v. ~500 day stay options) could alter the design of many systems, including ECLSS? Depending on mission design, there could be impacts on different classes and types of operations and technologies for contamination control used on or in the vicinity of Mars. (e.g., low Mars orbit or Phobos and Deimos surface operations, vs. Mars surface, etc.). How does mission duration affect the objective of planetary protection during the mission?

- **COSPAR Implementation Guideline(s) involved:** C, E, G, H. The group indicated that questions and details related to Knowledge Gap #1 (about mission duration and impact on mission and systems design) could touch upon four different COSPAR Guideline areas:

    COSPAR GUIDELINE C: Different mission durations would not only impact overall systems designs, they also could possibly imply different planetary protection control levels and requirements. Current COSPAR planetary protection controls for robotic missions are designed based on using a period of biological isolation set at "launch plus 50 years" for forward contamination control. What does it mean to integrate the known, deliberate presence of microbes and human life into appropriate planetary protection protocols for future human-robotic missions, particularly when there is no post-Apollo heritage for returns from other celestial bodies? Just because humans (and their

commensal microbes) will go to new locations on or near Mars doesn't mean that opportunities for astrobiological science will be lost. Similarly, different mission designs, locations and durations do not readily translate to clear planetary protection controls beyond LEO. Most importantly, current COSPAR principles indicate that protecting Earth upon return is the highest priority for planetary protection controls. Discussions about microbes associated with different systems, mission designs and mission durations clearly will have significant implications for development of the updated planetary protection protocols for round trip human missions beyond LEO.

COSPAR GUIDELINE E: COSPAR Implementation Guidelines stipulate that uncharacterized sites should be evaluated by robotic precursors prior to crew access. How are we going to "adequately characterize" remote or questionable areas prior to crew incursion? If any area is designated a "safe zone,"[17] what does it actually mean to satisfy the expectation of "adequately characterizing the site"? For example, what are the criteria for having "sufficiently characterized" a particular area (e.g., what are the densities of testing points and over what regional extent or radius? What life detection sampling density is required per unit area or per unit volume?)? What types of verification(s) are needed for determining whether indigenous life is there? (e.g., Viability? Sequencing? Culturability? What is acceptable residual uncertainty?)?

Finally, are terrestrial analogs sufficient to address the viability and contamination questions in Pre-landing mission phases; and what precursor science is necessary to understand sites prior to landing?

COSPAR GUIDELINES G and H. Clearly, the above uncertainties regarding protocols and determinations about areas to be explored will also impact implementation of planetary protection measures during the mission as assigned to a designated crew member (Guideline G). In addition, it is unclear how the uncertainties will feed into "conservative" decision-making about planetary protection requirements and changes or relaxation of them (Guideline H).

Knowledge Gap #2: What level of non-viable bioburden escape is acceptable?

- **Rationale:** The current permissible COSPAR bioburden level for *robotic* spacecraft is 3.5×10^5 spores pre-launch (or approximately 10^{-7} grams of spores) on the exterior of the landed hardware. Because crewed missions would by nature include many orders of magnitude more microbes, entirely new approaches and standards will need to be developed for human missions (presumably for both exterior and interior of the spacecraft). However, if a significant portion of microbial load can be demonstrated as non-viable when exposed to Martian conditions, it is possible that this understanding would significantly alter how bioburden concerns are addressed on human missions.

Associated Knowledge Gap 2a. Another gap and concern was identified as part of the acceptable contamination category. The group focused on a specific question: *Will the likely Science Requirements*

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[17] "Safe Zones" and "Zones of Minimum Biological Risk" (ZMBR) were not specifically defined—but are conceptually discussed in earlier documents related to human missions to Mars (e.g., NRC Safe on Mars (2002); NASA (2005): Planetary Protection Issues in the Human Exploration of Mars NASA CP 2005-213461; and ESA-NASA(2007): Workshop on Planetary Protection and Human System Research and Technology.) Full reports downloadable from: https://planetaryprotection.arc.nasa.gov/documents

(beyond Planetary Protection's concern of escape of viable organisms) exceed the constraints of what is acceptable to vent under planetary protection requirements per se? The group assumed that the answer to the question is "Yes." [18]

> **Rationale for 2a: Clearly** there is the possibility for a difference between the control levels that may be set by the planetary protection vs. the scientific communities for what may be considered "acceptable" releases of microbes or contaminants via venting. How do the design and mission communities determine the umbrella constraints that must be fulfilled, i.e., how will the communities resolve differences that may exist between planetary protection vs. science needs that will impact venting considerations?
>
> This also raises an associated concern for possible long-duration missions. Is there anywhere on Mars where both the planetary protection and scientific community would deem it acceptable to deposit many kilograms of exposed biomass on the surface with the presumption that the Martian environment would naturally degrade or "deal with it"?[19] In other words, is there anywhere on Mars where is it permissible to contaminate with deliberately deposited wastes? This concern also may link to other questions about waste disposal and possible containment needs.

- **COSPAR Implementation Guideline(s) involved:** A, C. The group did not specifically indicate what guidelines were involved with Knowledge Gaps 2 and 2a. Because the knowledge gaps about contamination relate to evaluation of microbial concerns and eventual development of planetary protection protocols for robotic and human aspects of surface missions, the gaps will likely involve COSPAR Guidelines A and C, at least initially.

Knowledge Gap #3: Is there need for decontamination and verification procedures after releases (nominal or otherwise)?

- **Rationale:** In the development of eventual protocols, to what extent will the off-nominal or contingency scenarios be driving requirements? For example, how will protocols for decontamination processing of hardware (such as equipment needing maintenance) differ from potential off-nominal situations? Overall how do we handle decontamination of various materials… of what, where, when? What chemicals should be used for decontamination and how much (e.g., VHP)? What cleaning tools and chemicals would be involved? How do these interact with suit materials? Because off-nominal events may also occur, there will likely be the need for a system of addressing and understanding their impacts compared to nominal situations.

> While it is premature to develop detailed protocols, the group noted a number of associated questions and concerns about contamination that could be problematic:
>
> o **Crew Fatality:** If there is a fatality, how will the body be handled or disposed of on the surface (which is different from quarantine). What containment and sanitation strategy

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[18] NOTE: With the current level of knowledge, the answer is no (especially when there are so many low impact options for containing biomass, and/or processing it so that it is chemically decomposed or otherwise sterilized). This question is likely relevant only in off-nominal scenarios. Part of what the planetary protection community has to do is to document what criteria and data will be used to determine acceptability (or not) of specific waste management strategies.

[19] COSPAR policy already addresses spacecraft induced Special Regions, which are assessed on a case-by-case basis, with results potentially impacting future design, but probably as "normal work" rather than requiring new knowledge.

(mitigation) measures should be used? A related non-science question also arose – what ethical considerations or guidelines would be integrated along with scientific input to develop operational and implementation protocols regarding fatalities and emergencies?

- o **Materials Selection & Contamination:** From a Materials and Processes perspective, how will planetary protection considerations be integrated into the materials selection process? How will we make decisions about the best materials while minimizing initial contamination and maximizing decontamination effectiveness? [20]

- o **Secondary Contamination:** While collected samples will be contained, what will be done about the exterior of Earth entry vehicles or elements of the transit vehicle that do not need to be landed? What will it mean for human missions to "break the contact chain" with Mars? Secondary contamination obviously has significant implications for "closed systems".

- o **COSPAR Implementation Guideline(s) involved:** Questions about Knowledge Gap 3 relate to COSPAR Implementation Guideline C—the need for planetary protection Protocols for both human and robotic aspects of mission(s).

Knowledge Gap #4: What considerations should go into design of quarantine facilities and methods (for use to/from or on Mars)?

- **Rationale:** The group raised a variety of questions about quarantine regulations and protocols, both during surface operations and flight phases, all of which represent knowledge gaps of importance for future mission plans and designs. For example:

  - o What is meant by quarantine? Who or what will be protected? For how long? Can the Earth return spacecraft be used as a quarantine facility for the crew? If decontamination is not possible with humans directly present, what are the appropriate separation methods in lieu of highly controlled clean rooms?

  - o On the surface, how will quarantine be maintained between different assets? What does a quarantine ECLSS system look like? For how long must it function? Is it truly possible to isolate one crewmember from others?

  - o During flight phases: from Earth to surface (outbound) or from surface to Earth (return), will it be possible to quarantine one person from the rest? What are the different quarantine procedures for each phase and how do they differ?

  - o From a return-to-earth perspective, how do we create "adequate quarantine" wherein a limit of time or some other criterion is identified prior to "free release" from quarantine or containment?

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[20] For robotic missions, planetary protection is incorporated as a requirement on the hardware, including the design and M&P decisions—so that requirements are met. How would these considerations be integrated for human missions?

o Under what conditions are quarantine protocols initiated? (e.g., symptoms or suspected exposure) What are the crew psychological implications of quarantine? [21]

- **COSPAR Implementation Guideline(s) involved:** B, C. Concerns about Knowledge Gaps 4 relate to COSPAR Implementation Guidelines B and C which indicate that a quarantine capability (for individuals and the entire crew) as well as planetary protection protocols are needed during and after the mission.

Knowledge Gap #5: How will increased understanding over time about the Martian surface and subsurface modify the definition of Special Regions and associated contamination concerns for human missions?

- **Rationale:** It is clear that the notion of Special Regions has implications for future mission activities and operations for both planetary protection and science purposes. What requirements will be used for contamination avoidance and in what regions will they apply? Is the concept of Special Regions an artifact that must be reconsidered in the context of more mobile (less finite) human missions? With human-associated contamination in mind, is all of Mars "special"? The group considered a list of related concerns about both nominal and off-nominal scenarios involving Special Regions:

  o Can material be exchanged between separate and different Special Regions (e.g., by use of tools or instruments, transfers between zones, crew movements etc.) without cleaning in between?

  o What heat transfer requirements will be set for equipment for both long term and short-term use in Special Regions? Because mission-associated heat could contribute to the creation of induced Special Regions, waste heat handling should be considered. [22]

  o What will the requirements be for robots and robotic equipment going between clean and special regions and dirty regions? What decontamination methods and protocols will be used?

  o What are the procedures for maintaining and containing "pristine" samples from special or uncharacterized sites for eventual return to Earth?

  o What are the implications of the mission inadvertently landing off target in a designated Special Region?

- **COSPAR Implementation Guideline(s) involved:** D, F. Both COSPAR Implementation Guidelines D and F are relevant to questions raised about contamination of Special Regions and strict containment of "pristine" samples and sampling components from uncharacterized or special areas. In addition, if materials are returned to Earth, Guideline F about Planetary Protection Categorization for pristine samples or sample components will apply.

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[21] All of these are questions that need to be answered, but may not require new research. Many are issues that can be resolved by applying knowledge from other fields, by a design/architecture trade, or by decisions of an expert committee (and then included as requirements for mission hardware or operations).

[22] COSPAR policy already addresses spacecraft induced special regions, which are assessed on a case-by-case basis, with results potentially impacting future designs, but probably as "normal work" rather than requiring new knowledge.

Knowledge Gap(s) #6: What research is needed to address assorted questions about testing, ISRU, and habitation?

- **Rationale:** The group raised questions about a variety of different aspects of the mission that will require more research and information in advance of planning or designing the technology, systems, and operations. These included: ISRU, Habitation and testing simulants and topics related to astronaut health. While crew health is not directly a planetary protection issue, the inability to discern illness resulting from infection by a terrestrial organism vs a Martian one, or illness due to a non-infective cause (e.g. a chemical poison) *is* a planetary protection concern in the context of allowing an (sickened) astronaut return to Earth. The assorted questions are briefly discussed below:

    - ISRU
        - How do we verify ISRU recovered items are safe for human consumption or exposure?
        - What are the specific planetary protection implications of intentionally using ISRU recovered materials such as water or sand-bagged material (regolith) in close proximity to human elements (e.g., as radiation shielding; use in greenhouses, in water supplies, etc.).

    - Habitation
        - How can we design habitation elements around functions associated with life support and contamination control?
        - Can we isolate and/or protect the habitat from dust and other contaminants?
        - What personal protective equipment is needed?
        - What ingress and egress methods should be used and when and how should they be tested in advance of use on the Martian surface?

    - Testing
        - What simulants should be used for ground testing of assumed Martian contaminants? Should anything be added to them?

- **COSPAR Implementation Guideline(s) involved:** Because of the wide range of questions and knowledge gaps in these collected areas that impact technology, operations and systems, it is likely that multiple COSPAR guidelines will be involved, including at least A, B, C, D, and potentially G and H.

Knowledge Gap(s) #7: What is considered acceptable regarding waste handling and disposal?

- **Rationale:** Decisions about waste handling, treatment, and disposal will affect multiple mission phases—during flight (to and from Mars), during operations and activities on the Martian surface, and during end-of mission preparations for departure from Mars. Numerous questions about the planetary protection implications of wastes arose:

o What is considered acceptable containment of intentionally left-behind waste?

o What can be done with flight-generated wastes prior to arrival at Mars, and what is the acceptable disposition for such wastes (e.g., ejection for burn-up in limited Mars atmosphere or ejection into a solar orbit, etc.)? Landing without the out-bound waste would be a significant mass and weight savings during Entry Descent & Landing (EDL) and would also address planetary protection concerns by reducing or avoiding some amount of human-associated contamination during the overall mission.

- **COSPAR Implementation Guideline(s) involved:** C and D are most relevant for waste generated on the surface, and potentially A should it be determined that monitoring of viable organisms is needed. Guideline H also becomes relevant in the context of disposition of wastes generated prior to arrival at Mars, although the available options (and the need to dispose at Mars) are likely quite variable in the context of the mission architecture elements, including availability of SEP, Phobos and Deimos scenarios, Mars orbiter elements (similar to the Apollo command module?), etc.

Knowledge Gap #8: What microbial contaminants would vent from an extravehicular activity (EVA) suit?

- **Rationale:** Extravehicular activities on the Martian surface will present a variety of contamination and planetary protection questions that are likely to be distinct from those associated with habitat and lab-associated infrastructures at the landing zone. Because there is insufficient post-Apollo heritage for EVAs on planetary surfaces and a dearth of applicable data from EVA experiences in Earth orbit, many knowledge gaps arise that will require new research and information. Some of the key questions include:

o What microbial contaminants can be expected to vent from an EVA suit and in what concentrations? Are there *other* contaminants of concern that could also leak?

o What chemicals should be used for decontamination (e.g., VHP) and how much? What cleaning tools are needed? How do these interact with suit materials?

In order to understand the prospects for microbial and other contamination in various possible zones of operation, there is need to quantify and understand what contamination and concentrations are expected from EVAs on Mars.

- **COSPAR Implementation Guideline(s) involved:** A, C, D, H. There is clear linkage here between the EVA systems and aspects of Mars transportation discussed by Study Group 3, where new knowledge is needed in time to inform systems and process designs for EVA operations in the Mars system.

Table 4.1: Key Knowledge Gaps Identified by Study Group 2 Technology & Operations for Contamination Control

Knowledge Gap 2.1: Does the Duration of human surface stay (30 v. 500 days) matter? Does it change objectives of planetary protection during mission? What is the relationship between duration of human exploration time and the overall density and spread of contamination?

Knowledge Gap 2.2: What level of non-viable bioburden escape is acceptable? I non-viability can be demonstrated, does this significantly address human microbial bioburden concerns? Does it address concerns about external dissemination of microbial contamination? How should differences of opinion between the science and planetary protection communities be addressed regarding acceptable levels?

Knowledge Gap 2.3: Is there a need for decontamination and verification procedures & protocols after releases (nominal or otherwise). Are decontamination procedures needed for both inside/outside the spacecraft as well?

Knowledge Gap 2.4: What considerations should go into the design of quarantine facilities and methods (for uses on the way *to-*, on Mars , or returning from Mars)?

Knowledge Gap 2.5: How can contamination concerns during human missions be addressed, given that the parameters defining Mars Special Regions vary in space and time (e.g. over diurnal and seasonal cycles) ?

Knowledge Gap 2.6: What research is needed to address gaps in assorted questions about ISRU, habitation, and testing? What related research is needed in advance of planning and design of technologies, systems, and operations?

Knowledge Gap 2.7: What is "acceptable containment" (type; location; duration) of wastes intentionally left behind? Similarly, what are acceptable constraints and procedures on vented materials?

Knowledge Gap 2.8: What microbial contaminants would vent from an extravehicular activity (EVA) suit, and at what concentrations? What are the implications for suit materials and cleaning tools, designated for Mars?

5. OUTBRIEFING STUDY GROUP 3: Natural Transport of Contamination on Mars

Leads

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Outbrief Presenters: Andy Spry and Lindsay Hays

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5.1 Group Charge and Pre-identified issues

This Study Group was tasked with discerning knowledge gaps in the natural transport of contamination of Mars that would result from a crewed mission to the surface. Specifically, the workshop Science Organizing Committee provided the following topics for discussion:

- Transport of contamination on Mars (biological, particulate, molecular)
- UV effects (on organisms; on EVA; as passive mitigation to contamination)
- Terrestrial analogues for dispersal
- Balloon experiments as Mars environment analogs
- Current knowledge and datasets across a gamut of contamination transport scenarios
- Empirical and modeling studies to help identify unknown or unaddressed issues in context of candidate exploration strategies
- Aerial dispersion and modeling
- Effects of people and habitats in relation to contaminants
- Effects of specific activities (options and trades for activities)
- Sub-surface considerations (drilling, aquifers, ISRU, models, measurements, etc.)
- Robotic precursor measurements of importance
- General Mars environments vs. issues specific to human landing sites
- Special Region considerations

5.2 Discussion Following Plenary Presentations

Rather than using on the organizer-suggested guiding questions from the outset, the Study Group 3 began by compiling a list of questions and concerns from each of the discussion topics that will need to be addressed before eventually determining how and where to put a human habitat and labs on the surface of Mars. In this process, each topic item in the list above was addressed. Acknowledging that humans on Mars would inevitably contaminate the planet to some extent, the group felt that a key question centers on how to determine appropriate quantitative requirements for allowable contamination, and where such contamination would be permitted or tolerated.

The group assumed that some type of zonation concepts will apply on Mars and considered the "zoning" concept image from previous reports (e.g., Safe on Mars 2002 and other references—see

footnote 17), which show "safe" zones (for human habitat and traverses), and "keep out" zones (for identified Special Regions or unexplored areas only accessible to appropriately clean robotic systems. They noted the need for varied cleanliness requirements as well as scale bars on zone dimensions. Importantly, they questioned whether all zones might become contaminated eventually, given the high-velocity winds on Mars, and plans for designated zones where contamination would be allowed. At this time, the balance between microbial distribution by wind and inactivation or death as a result of the natural Mars environment are not known. Thus, these represent important areas for research.

As a challenge, the group also considered two questions: 1) is the plan of sending humans to Mars supportable? 2) Do we care about science investigations (and for how long)? In the context of this workshop, the answer to both questions is clearly "yes". Either way, it is assumed that the existing planetary protection paradigm would be followed. Specifically, the goal of planetary protection constraints does not change if humans are on Mars; the goal is to protect against harmful contamination, protect future science, and subsequently, upon the crew's return home (with or without samples), to protect Earth.

A summary of the specific discussion questions and information related to preliminary gaps is presented below, with details grouped into the indicated categories. A video of the out briefing presentation for Study Group 3 is available at https://ac.arc.nasa.gov/p7tsxzsa22b/

5.2.1 Questions Related to Wind and Other Natural Transport Processes

- What are the processes that transport material on Mars, such as wind, impacts, etc.?
- What are the sizes and transport rates of different aerosols and surface materials (dust, dirt, rocks), and how do they compare to viral or microbial sizes?[23]
- Is it possible to refine models of global transport of materials by global dust storms?
- What is the utility of existing global climate models and can they be applied to these problems?

Very broad circulation models apply to the big picture only and may not provide a full understanding of actual transport. Examples of associated problems include: dust devils transport materials locally, and perhaps may be more important than global circulation models; we cannot predict wind – we can only measure temperature; and there may be differences in places where dust is being cleared and places where it is accumulating.

> **Overall, understanding of natural transport is an important gap:** We do not have enough refined data or models to determine what happens to windblown dust (or an organism entrained in it), and where it might go.

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[23] Although it was not discussed during the session, Martian atmospheric dust was found by the Viking mission to be composed of particles of mode 0.4um and mean 2.5um diameter (Pollack et al. 1979). Also, a description of the clearing of Mars dust from the MER rovers during cleaning events was described by Kinch et al. (2007)

Pollack, J. B., D. S. Colburn, F. M. Flasar, R. Kahn, C. E. Carlston, and D. Pidek (1979), Properties and effects of dust particles suspended in the Martian atmosphere, J. Geophys. Res., 84(B6), 2929–2945, doi:10.1029/JB084iB06p02929.

Kinch, K. M., J. Sohl-Dickstein, J. F. Bell III, J. R. Johnson, W. Goetz, and G. A. Landis (2007), Dust deposition on the Mars Exploration Rover Panoramic Camera (Pancam) calibration targets, J. Geophys. Res., 112, E06S03, doi:10.1029/2006JE002807

5.2.2 Questions about Microbes and Associated Features

- What is the lifetime of microbes on Mars? Under what conditions?
- What is the potential/limit of a very hardy microbe to survive on Mars?
- What is the presumed survival of unattached microbes in dust environments (suspended and after deposition at the surface)?
- What are the different associations that Earth microbes can have with Martian materials (attached to dust, inside rocks, etc.) and what sort of protection might these materials provide for microbial survival?
- Is there a fidelity issue in comparing Earth-based background information with presumed Martian conditions? Do we need to measure more on Mars, or background on Earth?

Obviously, the current understanding of microbe survival in Mars dust environments remains uncertain and represents an important knowledge gap.

5.2.3 Considerations Regarding Mission-Associated Transport Mechanism Concerns

- The initial transport mechanism results from vehicle landing (including dust settling). The next is leakage, followed by wind.
- An important gap is understanding what is venting out of pressurized containers (and at what rate) and knowing whether it is capable of moving microbial cells.
- It will be helpful to study and understand the fate of artificially generated aerosols with distinct sources.
- It will be helpful to understand the effect of human-sourced water and other compounds on Martian materials (e.g., mineralogy, chemistry, bulk quantities such as soil moisture).
- It will be helpful to understand which Mars surface assets will tolerate the surface environment. We don't have models of EVA suits or habitats, rovers or transport vehicles etc. to test in the Mars environment.
- What is the applicability of using analogues?
- We need to understand what will happen to any released microbes when human systems leak. Will the microbes die or disperse short distances (i.e., 100 m), or do global dust storms carry microbes far away? Will particularly hardy microbes be among the ones released from these systems?
- We know that biofilms create much more favorable environments for survival of microbes. Will biofilms be a similar concern on Mars (in contained environments, external, or in ECLSS systems, etc.?)
- The group also had a discussion related to microbial transport, which raised the question of the probability (abundance?) of transporting hardy microbes to Mars on human mission elements.

5.2.4 Planetary Protection and Science Concerns

Clearly, there will be more contamination from a human mission than a robotic mission, which has extensive pre-launch sterilization and bioburden reduction. How do microbial "hitchhikers" on a human mission relate to planetary protection v. science cleanliness and bioburden levels? The group discussed that:

- The primary issue of concern about planetary protection forward contamination is considered to be dispersal of viable microbes (secondary is dispersal of organic contamination that could be mistaken for material of Martian origin -- which is still important for science investigations).

- Does a single organism matter for forward contamination? Does it matter where it goes? What causes the inactivation of microbes?
- It is important to continue to focus on two main paths to understanding: studying microbial association to particles and the lethality effects of the Mars environment; and using physical particle transport models.
- One way to simplify the concerns is to treat the human landing site as point source of contamination—assume some amount of microbes released, and study their transport using variants of established (terrestrial transport) models. It is important to ensure that there is enough Mars data to make this approach accurate and relevant.

To address the lethality issues, quantitative data are needed about what would happen on the surface of Mars by way of microbial reduction for all mission components that could be expected to be brought with human missions. This is a complex question given the multiple factors in the Martian environment that would affect each microorganism, and the plethora of different microorganisms that would be introduced to Mars associated with the human exploration endeavor.

In particular, Study Group 3 discussed how the 17 Mars environmental factors described by Schuerger et al. (2013) [24] might combine, and which of the factors (with 3.6×10^{14} possible combinations) are most pertinent. It was discussed that it is incorrect to do single factor experiments and simply "add the results together". The most significant factors must be studied in combination. Of the 17 factors, the group considered that (for planetary protection purposes) the biocidal (rather than inhibitory) factors are the most important, which include solar UV irradiation, desiccation, low pressure, the anoxic CO_2 atmosphere, galactic cosmic rays, solar particle events, UV-glow discharge from blowing dust, solar UV-induced volatile oxidants [e.g., O_2-, $O-$, H_2O_2, O_3] and toxic components (oxidants, heavy metals) in Martian regolith.

A further issue is how to identify viable microorganisms not able to be grown using classical culture-based methods (so-called "uncultivable" or "not-yet cultivable" organisms) in the context of contamination threat(s), and how to represent or understand the whole environment. The group considered the use of a cultivable species (or several) as proxies for the whole community, as is currently done for robotic missions, but the validity of this approach would have to be confirmed.

5.2.5 Considerations for Dispersion of Microbes During Mission Activities

The issue was also discussed about what will happen when crew and rovers start moving around on the Martian surface contributing localized, short-term and long term contamination. Research indicates that humans generate millions of particles per hour and some of these will have viable organisms associated with them.[25] What will this mean on Mars?
On the other hand, literature also suggests that there is rapid fall-off of contamination as you leave the locale of analogue habitats (Schuerger & Lee 2015).[26] Perhaps concern will likewise be minimal on Mars, but this would need to be demonstrated. Associated questions include:
- What near field and far field effects or models are appropriate for understanding such microbial dispersal on Mars?

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[24] Schuerger et al., 2013, Astrobiology 13, 115-131
[25] Sciple, G. W., D. K. Riemensnider and C. A. J. Schleyer (1967). Recovery of Microorganisms Shed by Humans into a Sterilized Environment. App. Microl., 15, 1388-1392
[26] Schuerger and Lee, 2015. Microbial Ecology of a Crewed Rover Traverse in the Arctic: Low Microbial Dispersal and Implications for Planetary Protection on Human Mars Missions. Astrobiology 15(6) pp 478-91

- There is a dilution effect—but how much? And what does this dilution effect mean in terms of planetary protection (for example, the balance of transport processes against the rate of microbial death)?
- What is the habitability at distant microenvironments or sites? The current assumption is that one microbe that lands in the right place could grow in a habitable environment. Is this correct?
- What is the size and configuration of the contamination zone from a point source? It may not be a circle concentric from origin, depending on local environmental factors. It was suggested that, similar to mapping fall-out, one would find the furthest distance a microbe could reach, add orders of magnitude and use that to scale the contamination zone. At the present time there is no model for survival, dispersal and growth of microorganisms for different distances from a point source of contamination on Mars.
- To reach an understanding of the scale of "survivability" of microbes on Mars, we need to figure out what parameters affect how easily microbes could survive in a Special Region. It can't just be assumed that a microbe in a Special Region would survive and replicate 100% of the time.
- Contamination is an imprecise term. It could be referring to a single microbe into a Special Region or trillions of microbes into other regions. There is need for considering a "sensitivity" scale.
- A particular gap was identified in understanding what is the actual leak-rate of microbes from an EVA suit (during nominal operations - when new, as well as after significant degradation).
- A question was asked; Can we focus any leak in a single place (by creating a path of least resistance? Is it possible (desirable) to vent in a particular path? Leaks are not intended, as anything that comes out has to be replaced, but given that leaks will occur, is there an approach by which this can be minimized/managed?

It was clear that there is significant work to do, in terms of how to maintain systems and keep them clean, and to know what the failure modes and leak (contamination) rates are.

5.2.6 Considerations for Contamination and Science Activities

Finally, because science activities will be an important priority on Mars, there are numerous questions that need to be addressed regarding spatial and temporal aspects of contamination. For example:
- How do we ensure that science measurements etc., will be taken beyond the (any?) localized contamination plumes? These presumably would be the most contaminated areas due to inevitable releases associated with infrastructure and operations.
- How do we address the size and location of contamination zones from an operational approach? What data do we use? How far from various assets can we assume there will be a place for clean sampling? There also is a need to understand meteorological conditions across Mars throughout several years to more fully account for temporal contributions to contaminant spread.
- Do we know whether human associated or terrestrial microbes can metabolize in the Martian atmosphere?
- What kind of location characteristics would maximize lethality effects? For instance, equatorial regions have stronger incident UV; craters have less connection to global atmospheric circulation; globally weathering rates vary and perhaps elevation effects (atmospheric density) would affect survival times for contaminant microorganisms.

5.2.7   Concerns About Special Regions and Landing Locations

A variety of questions were raised about designation of Special Regions and landing sites. Would planetary protection concerns result in vetoes for particular landing sites? This might be expected because there currently are such vetoes for the robotic program, based on the cleanliness (or not) of the robotic spacecraft and the likelihood of Special Regions at the landing site target. Among the questions raised were:

- Can a potential Special Region be sacrificed, and if so, by whom and based upon what criteria? Is it currently acceptable under the Outer Space Treaty to do so deliberately, vs. accidental contamination? For example, if a particular hypothetical Special Region is an isolated single creek in an area with a group of similar creeks, the science can be preserved in the combined group, while a single isolated creek could serve as an unprotected in situ resource. (This is analogous to the approach for asteroids: although they are pristine they are demonstrably isolated). The issue with aquifers is that we cannot demonstrate isolation on Earth so this would be a stretch to conceive of how it would be demonstrated at Mars (Note: Mars is seemingly devoid of "creeks").
- Is there a way of understanding whether there are global aquifers, and if so, are they linked? (Note: Such aquifers are not detected by current radar assets, SHARAD and MARSIS). Is there any connectivity between Special Regions that must be considered?
- It was surmised that if there is only one Special Region, then it would be unacceptable to "sacrifice" it. But what if there are other areas (e.g., north pole, glaciers)? Because it would be inadvisable to make such decisions in the absence of data, it was suggested that wherever humans go, there must be a few remote sensing or robotic surface missions ahead of time.

5.2.8   Other Concerns

The group also discussed some concerns that were not specifically pre-identified in the starting questions. These included:

- **Off-nominal Scenarios:** What should be done if a leak is made up only of gas and not of microbes? What should be done in off-nominal (crisis, emergency) situations? What can be done to put a scale on the range of living things and other contaminants? How close is close (distance, temporal) to establish parameters to constrain contamination? Such scales would need to be based on data, and for all relevant scenarios _including_ credible, off-nominal ones.
- **Drilling:** How will we address deliberately accessing places in the subsurface? Can we access the subsurface and have the robotic drillers or astronauts remain uncontaminated by subsurface materials, including extant Martian life-containing elements? Can this be done while keeping the subsurface portions of a drill string sterile? At what level (depth) would it be required to switch from manual activity to a robotic (sterile) activity (assuming there is access to Special Regions below some depth)? Clearly, testing will need to be done to establish these parameters.
- **Uncertainty**: Once you determined whether or not there is life in a sample, can you then relax? Or panic? Is no detection the same as no presence? Can terrestrial life live (survive) there? Would terrestrial life move (settle) there? How long should things (hardware, people) stay isolated before move to next place? (current planetary protection language is 50years). Policies should be established for each of these scenarios.
- **Low restriction zones** – If low restriction zones are established, then entire areas will be affected, and any internal Special Regions sacrificed. How do you protect "the border" and when, if ever, does it stop?

Is it possible to create a surface "band" for the whole planet, so rather than having raisins in the pudding, there is a broad zone with "unspecial" regions? Such a scenario can only be considered if new data becomes available to assert that human activities in such a "band" would not result in harmful contamination scenarios.

5.2.9 *Identification of Specific Knowledge Gaps*

Using information identified in the deliberations above, the subgroup then focused on the ultimate workshop question: "What still needs to be accomplished?" In particular, what do we need to do incrementally to answer the questions and fill important knowledge gaps—either through research or technology development? In the study area on Natural Transport of Contamination on Mars, eight specific gap were identified, which are summarized in Table 5.1, and described below:

Knowledge Gap #1: How do interactions of biocidal factors affect microbial survival, growth and evolution in Mars-type environments?

We do not have sufficient information regarding quantitative measurements of interactions of biocidal factors on microbial survival, growth, and evolution (and how these factors combine) to understand the survivability of microbes in environments like the Martian surface. Additionally it is unknown how association with a biofilm may change the effectiveness of these biocidal processes.

- **Rationale**: This is needed to address the potential for any terrestrial microbe to survive and replicate on the surface of Mars.

- Affected systems and activities: All spacecraft systems and operational activities would be affected by the ability (or lack thereof) of terrestrial organisms to survive, grow, or evolve in the Martian environment.

- This is a critical area for understanding in developing a quantitative planetary protection implementation strategy for crewed missions to the Martian surface and will be needed to address both nominal and off-nominal mission scenarios. Current work in this area is piecemeal, with data on microbial survival robustness being generated both by the astrobiology and planetary protection research community and the broader environmental and medical microbiology communities. The only mitigation for not having the necessary data would be to prevent the release of any terrestrial microbes into the Martian environment at all. As discussed previously, this is considered impracticable by most, if not all, informed parties from both the spacecraft engineering and microbial containment communities. The current main stumbling block for generation of the needed data is the absence of a plan, scope and schedule to get the needed work done.

- **COSPAR Implementation Guideline(s) involved:** C,D,E,H. Better understanding of microbial survival, growth, evolution and mortality will be needed for the eventual development of planetary protection protocols (C), and plans for working in or near Special Regions or uncharacterized areas (D, E). Planetary protection requirements and systems designs will inevitably be based upon a conservative approach until there is greater understanding of microbes and biocidal factors on Mars (H)

Knowledge Gap #2: What data or models are needed to determine what happens to windblown dust on the Martian surface?

There is not enough data or data refined well enough, or models addressing meteorological conditions throughout several years of a particular site, to determine what happens to windblown dust, and where or how far it might travel.

- **Rationale:** This is needed to address the spread of contamination on the surface of Mars.

- Affected systems and activities: Habitat and EVA systems and scientific activities are impacted by uncertainty in knowing where and how far contamination entrained in dust would travel in the Martian environment.

- This is a critical aspect of preventing the contamination of, for example, areas identified as Special Regions. However, because of the complexity of the system, it will likely not be possible by data analysis and modeling alone to make deterministic assessments about which regions will or will not be contaminated. Any work in this area will address both nominal and off-nominal mission scenarios. Current work in this area is limited to planetary scientists and is not being performed for planetary protection purposes. The only mitigations for not having the necessary data would be to demonstrate (based on addressing Knowledge Gap #1 above) that all terrestrial organisms would be killed by exposure to the Martian environment before they reached the zone that needs to be protected. The current main stumbling block for generation of the needed data is the absence of a plan to acquire the needed data (e.g., by a precursor robotic mission), together with the uncertainty that the work done will actually allow prediction of where contamination would travel, with the needed degree of certainty.

- **COSPAR Implementation Guideline(s) involved:** C, D, E, H. Similar to the findings of Study Group 3 Knowledge Gap #8 below, an understanding of microbial survival, growth, transport, mortality, and evolution, is needed for the eventual development of planetary protection protocols, as well as plans for working in or near Special Regions (C,D, E). Planetary protection requirements and systems designs will inevitably be based upon a conservative approach until there is greater understanding of microbes, dispersal, and biocidal factors on Mars (H).

Knowledge Gap #3: What is the probability of transporting hardy terrestrial microbes to Mars via different pathways on a human mission?

We are not able to predict with sufficient confidence the threat of transporting very hardy terrestrial microbes via a human mission to Mars. NOTE: Probability is taken to be 1.0: We just don't know how many, or their survival potential.

- **Rationale:** Understanding how likely it would be to bring contamination via different pathways is important to understand what types of contamination are most likely to accompany a human mission and how these may then be affected by natural transport.

- Affected systems/activities: Habitat systems and scientific/EVA activities are impacted by uncertainty in knowing how long contamination entrained in dust would remain viable in the Martian environment. This would also affect how far it could travel and still remain a contamination threat

- The group noted that this is a critical area for understanding in developing a quantitative planetary protection implementation strategy for crewed missions to the Martian surface and will be needed to address both nominal and off-nominal mission scenarios. Current work in this area is piecemeal, with data on microbial survival robustness being generated by the astrobiology and planetary

protection research community and the broader environmental and medical microbiology communities. The only mitigation for not having the necessary data would be to make conservative assumptions about the abundance of hardy organisms in the overall microbial population introduced into the Mars environment. This would likely (as is the case for bioburden reduction on robotic missions) mean that abundance of hardy organisms would become the driving factor for planetary protection implementations. The current main stumbling block for generation of the needed data is the absence of a plan, scope and schedule to get the needed work done. This work would likely be done as part of work to address Study Group 3 Knowledge Gap #1.

- **COSPAR Implementation Guideline(s) involved:** A, C, H. Because the mission and crew may inadvertently transport very hardy terrestrial microbes via diverse ways, it will be important to address those concerns in the protocols that are developed (C). Clearly, continued monitoring and evaluation to detect such microbes will be needed (A) unless demonstrated otherwise (H).

Knowledge Gap #4: What will leak or vent out of pressurized containers? What modeling might be possible to understand venting and leaking materials from pressurized systems?

We do not understand in sufficient detail, nor do we have models for exactly what would be leaking and/or venting out of pressurized containers and human facilities (e.g., the rate, size, biological diversity) and how this would differ between intentional (by design) venting and unintentional leakage. It is unknown what the actual leak rate would be of these materials out of containment during nominal operation, and after significant degradation or during off-nominal events. (Note, this was the topic of Study Group 2)

- **Rationale:** Understanding what and how much is leaking is important to understanding how the material would behave (and the threat it presents) after it has been released from the enclosed areas.

- Affected systems and activities: Habitat and EVA system designs contribute to (and are affected by rules governing) the amount of biological material released into the Martian environment.

- This is a critical area for understanding the limits and trades in developing a quantitative planetary protection implementation strategy for crewed missions to the Martian surface and will be needed to address both nominal and off-nominal mission scenarios. Study Group 2 addresses current work in this area. The current main stumbling block for generation of the needed information is the maturity of the system designs.

- **COSPAR Implementation Guideline(s) involved**: A, C, D, H. Thorough understanding of all vented or leaked microbial materials (A), along with protocols for dealing with them (C), will be important, particularly because they could inadvertently contaminate Special Regions (D). Like other planetary protection requirements, designs of technologies, systems and activities must take a conservative approach until scientific review determines otherwise (H).

Knowledge Gap #5: What methods and analysis can be employed for "uncultivable" microbes?

We currently do not have adequate methods to routinely analyze the function or capabilities of microorganisms that are "uncultivable". In that case, we cannot gauge how representative cultivable microorganisms are of the whole community. Planetary protection is mainly concerned with viable organisms. At present, it is difficult to assess viability without the ability to culture cells from that community (we can detect viability, but not of individual cells which can be identified) and therefore we cannot accurately assess planetary protection risk.

- **Rationale:** Microbes that are no longer viable are not considered contaminants from a planetary protection perspective. However, without a reliable way to measure viability, it is unclear how to confirm this.

- This is another critical area for developing a quantitative planetary protection implementation strategy for crewed missions to the Martian surface, and will be needed to address both nominal and off-nominal mission scenarios. All spacecraft systems and operational activities would be affected by the lack of understanding of the threat posed by currently uncultivable terrestrial organisms to survive, grow, and evolve in the Martian environment.

- Current work in the area of comparing cultivable vs. uncultivable communities is limited, although some work is being done. Ideally, it should be possible through microbiome work to compare cultivable and uncultivable organisms in a community to establish panels of representative cultivable organisms as indicators. The only conservative mitigation for not having the necessary data would be to presume that all uncultivable terrestrial microbes are highly resistant. This is considered undesirable due to the impact on spacecraft engineering design and microbial containment requirements. The current main stumbling block for generation of the needed data is the absence of a plan and scope for the work.

- **COSPAR Implementation Guideline(s) involved**: A, C, H. Understanding what microbes are present and where and how far they disperse (A) is a difficult task for a human mission—particularly because the microbial community of the spacecraft and crew will likely include uncultivable microbes. It will be important to consider their presence and implications in future planetary protection protocols (C), and take a conservative approach to planetary protection requirements until more is known about them (H).

Knowledge Gap #6: What research is needed to understand acceptable contamination rate and threshold levels at human landing sites?

Currently, there is insufficient information to establish acceptable contamination generation rates and thresholds for a human landing area or habitat site as a point source of contaminants (of microbes and organic particles) or to model the minimum aeolian contamination that could spread over some distance and at a particular rate.

- **Rationale:** Understanding the generation of contamination, and modeling its spread, is a key component of understanding the natural transport of contamination. There is a need to understand the specific threat of a point source of contamination (landing site and habitat) at a particular location, relative to the particular research area(s) and Mars as a whole. The gap, which focuses on the threat to the Martian environment posed by landing spacecraft and a static habitat, clearly involves information about many systems and activities.

- Critical in developing a quantitative planetary protection implementation strategy for a specific mission to the Martian surface, it will be necessary to address both nominal and off-nominal mission scenarios. Current work on the topic for Mars is limited, although substantial work has been done to analyze and model terrestrial contamination from point sources. The only conservative mitigation for not having the necessary data would be to presume uniform high levels of local contaminants radiating from the site, which would adversely affect operational strategies (e.g., landing further away from "interesting" sites; needing to do long traverses to get "pristine" samples, etc.). The current main stumbling block for generation of the needed data is the absence of a plan, scope, and schedule to get the needed work done. Because field test data from Mars are not available, R&TD work would need to be based on terrestrial models.

- **COSPAR Implementation Guideline(s) involved:** A, C, D. Understanding what microbes are present and where and how far they disperse (A) will be a consideration the development of future Planetary Protection Protocols (C), particularly because the habitat/landing site could become a point source responsible for dissemination of microbes into Special Regions (D) over time.

Specific Knowledge Gap #7: What research is needed to understand acceptable contamination rates and thresholds for mobile crewed systems?

There is insufficient information to establish acceptable contamination generation rates and thresholds for a mobile crewed system (e.g., pressurized vehicle or suited astronaut) as point contaminants (of microbes and organic particles) or to model the minimum contamination that could spread over some distance and at a particular rate when such systems are used.

- **Rationale:** Understanding the generation of contamination and modeling its spread is a key component of understanding the natural transport of contamination.

- Affected systems and activities: This knowledge gap is specific to the threat that mobile crewed systems pose to the Martian environment.

- Similar to Study Group 3 Knowledge Gap #6, this gap focuses on understanding the specific threat(s) of a point source of contamination (mobile system) at a particular location, for a particular timeframe, relative to the research area in particular, but generally to Mars as a whole as well. Also critical in developing a quantitative planetary protection implementation strategy for a specific mission to the Martian surface, it will be necessary to address both nominal and off-nominal mission scenarios. Current work on the topic for Mars is limited, although substantial work has been done to analyze and model terrestrial contamination from point sources, including the recent work of Schuerger and Lee (2015)[27] to measure contamination of "pristine" environments on Earth. The only conservative mitigation for not having the necessary data would be to presume uniform high levels of local contaminants radiating from the mobile source(s), which could adversely affect operational strategies (longer distance of minimum approach to "interesting" sites; requiring longer robotic traverses to get "pristine" samples, etc.). The current main stumbling block for generation of the needed data is the absence of a plan, scope, and schedule to get the needed work done. Currently, acquisition of field test data from Mars is not planned, meaning that work to address the gap will need to be based on terrestrial models.

- **COSPAR Implementation Guideline(s) involved:** A, C, D, H. Understanding what microbes are present and where/how far they disperse (A) from mobile crewed systems will be a consideration in the development of future planetary protection protocols (C), particularly because crew activities facilitated by mobile systems could become point sources responsible for dissemination of contaminants of Special Regions (D) over time. Accordingly, conservative approach to allowable venting and leakage from crewed mobility systems should be considered (H).

Knowledge Gap #8: What research to needed to establish acceptable contamination generation rates and thresholds on Special Regions near human landing sites?

There is insufficient information to establish acceptable contamination generation rates and thresholds for a human landing site in the context of sub-surface contamination and the use of local water (ice).

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[27] Schuerger and Lee, 2015. Astrobiology 15(6) pp 478-91

- **Rationale:** Understanding the "connectedness" of subsurface hydrology systems is another important element for understanding the natural transport of contamination and for establishing "safe" use of water ice in ISRU systems and/or pristine sampling.

- Affected systems/activities involve many aspects of a mission, including ISRU systems, advanced life support systems, and science operations.

- This is a critical area for development of any mission concept where ISRU is envisaged for water or fuel generation. There is no known current work in this area (measurements from orbit do not have the requisite resolution), although NASA's Mars 2020 mission is anticipated to have the RIMFAX radar system to allow of detection of subsurface ice. The only conservative mitigation for not having the necessary data would be to only permit access to subsurface water and ice deposits using sterile processes. This is considered undesirable due to the impact on spacecraft design and operations. The current main stumbling block for generation of the needed data is the absence of precursor missions to generate needed data, however it is uncertain whether data of sufficient integrity for decision making could be generated with the likely available resources. In the minds of the group members, this issue remains unresolved, although terrestrial analog studies, to examine contamination avoidance down boreholes, could be undertaken.

- **COSPAR Implementation Guideline(s) involved:** A, C, D, H. Understanding what microbes are present and where and how far they disperse (A) from various systems will be crucial information for decisions about ISRU systems and associated future Planetary Protection Protocols (C). Because such contamination could impact Special Regions (D) over time, a conservative approach to planetary protection requirements related to ISRU should be considered (H).

Table 5.1: Key Knowledge Gaps Identified by Study Group 3 Natural Transport of Contaminants on Mars
Knowledge Gap 3.1: How do interactions of biocidal factors affect microbial survival, growth, and evolution in Mars-type environments? And what is the potential for survivability and replication of very hardy microbes--in dust environments, across Mars, and in biofilms?
Knowledge Gap 3.2: What data or models are needed to determine what happens to windblown dust on the Martian surface, and where it might go? What research is needed to understand meteorological conditions spanning several Martian years at particular site(s)
Knowledge Gap 3.3: What is the probability of transporting hardy terrestrial microbes to Mars via different pathways on a human mission?
Knowledge Gap 3.4: What will leak and/or vent out of pressurized containers or human facilities? What modeling might be possible to understand venting and leaking materials from pressurized systems? What leak rate, size, biological diversity, organic molecules, cells etc. are vented during nominal operations? After significant degradation of materials? And during off nominal situations? What are differences between active designed venting vs. leaking?
Knowledge Gap 3.5: How will we study yet-uncultivable microorganisms? What methods and tools will we use? What proportion of the entire community do they represent? How can we assess and monitor their viability?
Knowledge Gap 3.6: What research is needed to understand and establish acceptable contamination generation rates and thresholds for human landing sites – considering these sites as point contaminant sources (of microbes or organic particles)? Can terrestrial mechanisms be used to model the minimum aeolian contamination spread (over time and distance)?

Knowledge Gap 3.7: What research is needed to understand and establish acceptable contamination generation rates and thresholds for a *mobile crewed system* (pressurized vehicle or EVA suits)? How can we study mobile systems as point sources of contamination (of microbes and organic particles), or model minimum contamination spread (over distance and time)?

Knowledge Gap 3.8: What research is needed to understand and establish acceptable contamination generation rates and thresholds for Special Regions near human landing sites in context of sub-surface contamination & ISRU of local water/ice?

6. SUMMARY OF WORKSHOP - OVERVIEW

In the concluding plenary session, representatives from each study group summarized their deliberative processes and overall findings, identifying important science and technology knowledge gaps for the areas they covered. In each case, they presented the information *without* prioritizing the knowledge gaps or making consensus recommendations for needed studies, research or testing. Each presentation was followed by a brief time for questions.

The workshop output, combined with information from a pre-workshop literature review and previous planetary protection workshop findings, was deemed useful for capturing the current state of knowledge in the three key areas: [28]

- Monitoring and understanding microbes and human health;
- Technology and operations for contamination control and planetary protection during the overall mission; and
- Natural transport processes on Mars and effects on dissemination and mortality/survival of microbes in the Martian environment.

While there was general acknowledgement that more deliberation time at the workshop would have been helpful, the participants generally agreed that the overall findings are important updates on the incremental path forward toward human exploration of Mars, and indicate areas of future research and development that should be considered in developing planetary protection requirements in the context of the NPI-NPR process.

6.1 Specific Identified Gaps and Findings

Based on information from the reports and out-briefings of the three study groups, Table 6.1 provides a summary of the 25 knowledge gaps identified during workshop deliberations.

In Study Group 1, six of the nine identified knowledge gaps focused on questions typically associated with microbial research *per se*—such as understanding the microbes themselves and the diverse populations to be monitored, as well as how to monitor, collect and process data about them during the missions (Gaps 1.1 – 1.6). Another gap focused on developing novel approaches for low-toxicity microbial disinfectants and addressing problems associated with microbial biofilms, such as induced corrosion and fouling of equipment. (Gap 1.7 a and b). The two final gaps related to biomedical considerations associated with microbes. There is a need to develop diagnostic treatment options for crew microbial and health exposures, and to develop operational guidelines for how to integrate data with ethical and operational considerations during Mars missions. (Gaps 1.8, 1.9)

Knowledge Gaps in Study Group 2 focused mainly on technology and operations for mitigating and controlling contamination—both microbial and organic. Six of seven identified knowledge gaps

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[28] While other topics are also recognized as important for future human missions to Mars, they were beyond the scope and time availability of this workshop and will need future attention. Among the topics specifically *not* included in detail in this workshop were the following:
- Planetary protection related to quarantine, containment, handling, and testing of samples and crew upon return to Earth;
- Guidelines or regulations for commercial human missions or other space endeavors beyond LEO;
- Microbial issues related to possible increase in virulence, modifications, or mutation of symbiotic human terrestrial organisms during long-duration missions;
- The necessity of precursor missions prior to human missions; and
- Long-term Mars settlement and/or terraforming.

applied to mission-related questions, including the implications of mission duration; the escape of viable microbes; understanding what vents from different hardware; containment needs for both planetary protection and science considerations; and developing procedures for decontamination and verification (Gaps 2.1 – 2.6). An additional gap centered on questions about microbial vulnerability—specifically the impacts of local Martian environmental conditions upon survival or mortality of microbes released in vented gaseous products under various scenarios (Gap 2.7).

Study Group 3 had the greatest variation in types of questions identified for further research and development. Four of their eight identified knowledge gaps centered on the need for better modeling and understanding of Martian aeolian processes and their role as potential dispersal mechanisms for dissemination of microbial and other contaminants (Gaps 3.2, and 3.6 to 3.8). Overall, there is a need to understand long-term dust dissemination via natural transport mechanisms—regionally and planet-wide—as well as to gather information about meteorological conditions over several Martian years. Considering that future planetary protection approaches may be based upon a surface categorization system using pre-designated zones with different cleanliness or access restrictions, the group also indicated the need to gather data applicable to determining "acceptable" contamination generation and threshold rates for different mission phases and their associated contamination concerns—specifically for microbial dispersion from landing sites and mobile crewed systems, and contamination of sub-surface locations when accessing ISRU resources and ices.

Study Group 3 also identified three knowledge gaps dealing with questions about hardy terrestrial microbes and their monitoring (Gaps 3.1, 3.3, and 3.5). In particular, there is a need to understand the probability of transport of hardy terrestrial microbes via different mission pathways (forward contamination) and to understand potential biocidal factors on Mars and their impacts on very hardy microbes that may be transported during human missions. They also identified the need for better monitoring and assessment methods to study yet-uncultivable microbes—which may represent a large part of the microbial community transported along with humans and their hardware. Finally, Study Group 3 focused on the need to better understand what is leaking or deliberately venting from pressurized containers or infrastructure elements—through time, and for both nominal and off-nominal operations (Gap 3.4).

6.2   Relation of Gaps to COSPAR Implementation Guidelines

As part of the workshop guiding questions, each study group was asked to identify the specific COSPAR Human Planetary Protection Guidelines that would be addressed by the various identified research or technology gaps. Table 6.2 presents an overview of how the identified knowledge gaps relate to current COSPAR Implementation Guidelines. Overall, the gaps relate mainly to guidelines A-E. Not surprisingly, questions about sample returns, oversight of planetary protection implementation, and future changes in planetary protection requirements, represent issues for future attention (Guidelines F-H).

6.3   Knowledge Gaps Grouped by Research Areas

Another way to view the collection of knowledge gaps is to consider what general research and/or technology/operational areas are currently addressed or will be involved during design phases. Table 6.3 shows the cross-cutting nature of the information needed to address planetary protection concerns during mission planning. All three study groups identified one to several knowledge gaps that overlap with or involve activities in other R&TD areas. The knowledge gaps associated with planetary protection touch upon diverse disciplinary areas and mission phases, and involve numerous technologies and operations. Without having considerable interaction across disciplinary groups, it will be impossible to avoid duplicative research and development efforts. Before future NPRs can be

developed for human missions to Mars, there is need for additional coordinated research and study on the planetary protection implications across multiple domains, including EVA-related hardware and operations; habitat and advanced life support; ISRU and science operations; monitoring and control systems; maintenance and repair of equipment; access to Special Regions and various designated zones; waste disposal and containment during various mission phases; biomedical and health concerns; and containment and quarantine issues.

6.4   All Knowledge Gaps Grouped by Research Areas

Table 6.4 is a compilation of all the knowledge gaps identified by the study groups, with shading indicative of the planetary protection knowledge gaps within and across various areas. In general, knowledge gaps shown in *white boxes* are associated with questions about microbial and human health monitoring; those in *blue*, are linked with technology and operations needed for mitigating or controlling contamination; while *green boxes* show gaps related to natural transport of contaminants and microbial survival/mortality in the Mars environment. In examining the combined knowledge gaps, one can see that each group focused mainly on its assigned theme, but also identified one or more gaps that overlap with R&TD topics from other areas—reflecting the cross-cutting nature of planetary protection requirements and implementation.

In particular, there is considerable basic research needed to understand terrestrial microbial survival or mortality in the Martian environment as well as how to monitor venting and dispersal into the Martian environment (Gaps 1.1-1.6). Additional research will need to develop diagnostic and treatment options related to crew exposures to microbes and contaminants during long-duration Mars missions. (Gap 1.8). Microbiologists will also need to work with technology and operations experts as they seek to develop effective, low toxicity disinfectants and practical methods for controlling corrosion, fouling and other problems linked with biofilms in space environments. (Gap 1.7 a and b), a problem that does not occur for robotic missions. Moreover, microbial information and understanding will be needed to develop implementable operational guidelines for long-duration human missions (Gap 1.9). Without more information about the microbes themselves, it will be impossible to set quantitative requirements or to develop effective technology and operational approaches necessary for meeting eventual planetary protection needs.

While Study Group 2 addressed the assorted technology and operations questions aimed at mitigating and controlling microbial contamination (Gaps 2.1 and 2.3-2.8), some of their work will need updated understanding about basic microbial vulnerability (Gap 2.2), specifically the impacts of local environmental conditions upon survival/mortality of microbes released in vented gaseous products under various scenarios. Again, basic microbial research will be needed before tackling questions about engineering designs for controlling the venting and leaking of habitats, EVA suits, and pressurized vehicles on Mars.

Study Group 3 had perhaps the widest variation in types of questions needing further research and development to address planetary protection concerns. While half of their gaps related to combining Martian environmental data with modeling efforts to understanding potential dust dispersal, locally and planet wide, (Gaps 3.2, 3.6-3.8), a number of other concerns also arose. Three identified gaps dealt with questions about microbes and monitoring (Gaps 3.1, 3.3, and 3.5), all of which have considerable overlap with knowledge gaps identified by Study Group 1. In particular, they noted a need to understand the probability of transport of hardy terrestrial microbes via different pathways (forward contamination) and to understand biocidal factors on Mars and their impacts on very hardy microbes. (Gaps 3.1, 3.3) They also identified the need for better monitoring and assessment methods to study yet-uncultivable microbes, which may represent a large part of the microbial community (Gap 3.5).

Finally, the group indicated that a better understanding of what is leaking or deliberately venting from pressurized containers or infrastructure elements is needed, over time for both nominal and off-nominal situations (Gap 3.4).

Clearly, before future NASA Procedural Requirements (NPRs) can be developed for human missions to Mars, there is need for additional research and study on the implications of the end-to-end details of the specific mission concept to ensure that the intent of COSPAR Planetary Protection Principles and Guidelines—to protect Mars and the Earth—are addressed in every mission system and operation.

6.5 The Path Forward Towards NASA Procedural Requirements (NPR)

Earlier workshops on planetary protection and human missions (see Footnote 17) focused on devising a conceptual approach to provide preliminary guidelines for planners and designers of systems for AEVA, ALS and AEMC. In contrast, this workshop began by integrating the earlier conceptual approach with NASA's current long-range planning concepts. The objective of this workshop was to identify key knowledge gaps in three important areas, and to list the diverse R&TD areas needing more work in order to move from the current qualitative, notional guidelines for human missions to eventual detailed requirements and formal a NPR for planetary protection that will be relevant to NASA exploration and pioneering concepts being considered during agency mission planning activities for human missions to Mars.

6.5.1 Path Forward Requires Inter-Disciplinary Work And Collaboration

Clearly any approach to planetary protection requirements development will need updated information about terrestrial microorganisms and Martian environmental conditions, as well as collaboration between technical and operations experts across multiple disciplines to achieve efficiency in these R&TD efforts. There is also a need to include specialists from other Mars science communities and stakeholders not represented at this workshop, such as environmental modelers and those with understanding of global Martian environments and conditions. Researchers in these disciplines may presently have limited awareness about planetary protection, but their information may have significant implications for developing appropriate and acceptable planetary protection requirements in the coming years.

Already some progressive steps have been made. For example, as result of greater communication between the planetary protection and mission/technology communities (in part, due to this workshop), a project proposal was accepted to sample inside and outside vents on ISS. It was perhaps surprising to learn that, while there is considerable research on extremophile survival in space, as yet there is no published information about survival of human associated microbes inside and outside of the ISS. Previous data from crewed systems focused mainly on biomedical concerns related to crew health and microbial-induced corrosion or fouling. Now is the time to begin to strategically identify and address such key knowledge gaps in order to move toward detailed procedural requirements. Getting disparate groups to collaborate and work together will help generate timely responses to the multiple challenges of the planetary protection concerns for human space exploration, and ensure funding is secured to complete the needed work.

6.5.2 Interdisciplinary Communication Needs To Be Maintained

Just as early and regular coordination is important, so too is communication. This workshop should be followed by regular collaborative activities across science, biomedical and technology and engineering communities in coming years. It is important to work together and move toward effective, data-based decision making for future human missions to Mars. Building planetary protection considerations and understanding into planning will help avoid costly, duplicative efforts.

It is anticipated that this report and presentations about the workshop (as well as the online workshop presentations themselves) will be used in spreading information beyond the planetary protection and science communities, specifically linking with human mission designers and others not previously involved with planetary protection. Looking ahead, communication of such information is critically important. Already, information about planetary protection and human missions has been discussed, presented, and submitted to a number of conferences and journals (e.g., AbSciCon, ASR, ICES, IEEE, COSPAR), and the NASA Exploration Zone Workshop, as well as in seminars and newsletters). Additionally, an international COSPAR meeting was planned for late 2016, to enable further discussion of these concepts within a broader international community. Formal discussions/proposals about next steps were also planned for presentation at COSPAR 2016 in Istanbul. [Note: the COSPAR 2016 Assembly was cancelled subsequently due to security concerns]

The continuing integration of planetary protection considerations into broader planning activities for sending humans to Mars can only increase the potential for mission success, both at Mars and when returning safely to Earth.

TABLE 6.1: Overview of All Identified Knowledge Gaps by Study Groups

SG 1: Microbial and Human Health Monitoring	SG 2: Technology & Operations for Contamination Control	SG 3: Natural Transport of Contamination on Mars
1.1: What are the technologies and procedures that should be used for microbial sampling and collection?	**2.1**: Does the duration of human surface stay (30 days v. 500 days) matter? Does it change the objectives of planetary protection during missions? (What is the relationship between human mission duration and the density and spread of contamination?)	**3.1**: How do interactions of biocidal factors affect microbial survival, growth and evolution in Mars-type environments?; and what is the potential for survivability and replication of very hardy microbes—in dust environments, across Mars, and in biofilms?
1.2: What are the appropriate technologies for microbial monitoring to mitigate risk to crew, ensure planetary protection, and preserve scientific integrity**?**	**2.2**: What level of non-viable bioburden escape is acceptable? If non-viability can be demonstrated, does this significantly address human microbial bioburden concerns? Does it address concerns about external dissemination of microbes?	**3.2:** What data or models are needed to understand what happens to windblown dust on the Martian surface, and where it might go? What research is needed to understand meteorological conditions spanning several years at particular site(s)?
1.3: What technologies and procedures should be used for sample processing?	**2.3**: Is there a need for decontamination and verification procedures and protocols after releases— nominal and otherwise? Are decontamination procedures needed for both inside and outside the spacecraft?	**3.3;** What is the probability of transporting hardy terrestrial microbes to Mars via different pathways on a human mission??
1.4: What technologies and procedures should be used for data collection, storage, and interpretation while on Mars?	2.4 What consideration should go into the design of quarantine facilities and methods—for uses on the way to Mars, on Mars, or returning from Mars?	**3.4:** What will leak and/or vent out of pressurized containers or human facilities? What leak rate, size, biological diversity, organic molecules, cells, etc., are vented during nominal operations? After significant degradation of materials? And during off-nominal situations? What are the differences between active venting vs. leaking?
1.5: What is needed to understand spaceflight-specific microbial responses and heritable changes during extended spaceflight and relocation to a different planet?	**2.5**: How can contamination concerns during human missions be addressed, given that the parameters defining Mars Special Regions vary in space and time (e.g., over diurnal and seasonal cycles)?	**3.5:** How will we study yet-uncultivable microorganisms (e.g., what methods and tools will we use)? What proportion of the entire community do they represent? How can we assess and monitor their viability?

SG 1: Microbial and Human Health Monitoring	SG 2: Technology & Operations for Contamination Control	SG 3: Natural Transport of Contamination on Mars
1.6: What is needed to monitor astronaut, vehicle, and external environmental microbial populations effectively?	**2.6:** What research is needed to address gaps in assorted questions about ISRU, habitation, and testing? What related research is need in advance of planning and design of technologies, systems and operations?	**3.6**: What research is needed to understand and establish acceptable contamination generation rates and thresholds for *human landing sites*—considering these sites as point sources of contamination (of microbes or organic particles)? Can terrestrial mechanisms be used to model the minimum aeolian contamination spread over distances, times and particular rates and conditions?
1.7: What novel approaches can be developed for (a) Effective, low toxicity disinfectants, and (b) Prevention/recovery from biofilms/microbial-induced corrosion, fouling etc.	**2.7:** What is "acceptable containment" (type, location, duration) of wastes intentionally left behind? What are acceptable constraints and procedures on vented materials?	**3.7:** What research is needed to understand and establish acceptable contamination generation rates & thresholds for *mobile crew systems* (pressurized vehicle or EVA suits)? How can we study mobile systems as point sources of contamination (of microbes & organic particles), and model minimum contamination spread (over time and distance)?
1.8: What studies are needed to understand crew health and biomedicine related to microbial and contamination exposures?	**2.8**: What microbial contaminants would vent from an extravehicular activity (EVA) suit, and at what concentrations? What are the implications for suit materials and cleaning tools designated for Mars?	**3.8**: What research is needed to understand and establish acceptable contamination generation rates and thresholds for human landing sites in the context of *subsurface contamination and ISRU of local water/ice?*.
1.9: What information is needed to develop acceptable/ appropriate ethical and operational guidelines for human missions to Mars?		

Table 6.2: Knowledge Gaps by COSPAR Implementation Guidelines

	COSPAR Implementation Guidelines	SG 1	SG 2	SG 3
A	**Continued monitoring and evaluation** of terrestrial microbes will be needed to address forward and backward contamination concerns	1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8	2.2a, 2.2b, 2.6, 2.8	3.3, 3.4, 3.6, 3.8
B	A **quarantine capability** (for individuals & entire crew) is needed **during and after the mission**	1.3, 1.4, 1.8, 1.9	2.4, 2.6	3.6
C	**Need to develop** comprehensive planetary protection **protocols for combined human and robotic aspects of mission**	1.1, 1.2, 1.3, 1.4, 1.6, 1.7a, 1.7b, 1.8, 1.9	2.1, 2.2a, 2.2b, 2.3, 2.4, 2.6, 2.7, 2.8	3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7 3.8
D	Neither robotic systems nor human activities should contaminate "**Special Regions**"	1.6	2.5, 2.6, 2.7, 2.8	3.1, 3.2, 3.4, 3.6, 3.7, 3.8
E	**Uncharacterized sites should be evaluated** by robotic precursors prior to crew access	1.6, 1.7a	2.1,	3.1, 3.2
F	**Pristine samples** or sampling components from uncharacterized sites or Special Regions **treated as planetary protection Category V,** Restricted Earth Return		2.5	
G	An onboard **crewmember** should be designated as **responsible for implementing planetary protection** measures during the mission	1.8 ,1.9	2.1	
H	Planetary protection **requirements** will be **based on a conservative approach** and not relaxed without scientific review, justification, and consensus	1.9	2.1, 2.8	3.1, 3.2, 3.3, 3.4, 3.5, 3.7, 3.8

Table 6.3: Knowledge Gaps Grouped by Research Areas

Gaps Assoc. with Microbial Survival & Monitoring	Gaps Assoc. with Technology & Operations	Gaps Assoc. with Dispersal-Transport
1.1. Microbial collection	1.7b. Protect from Biofilms (corrosion, fouling etc.)	
1.2. Microbial processing	1.9 Develop Ethical and Operational Guidelines for crewed Mars missions	
1.3. Microbial monitoring		
1.4. In situ data collection & Interpret		
1.5. Microbial responses in space		
1.6. What microbes to be monitored		
1.7a. Contamination control/ toxicity		
1.8 Crew Health & Biomed. Studies re: Microbial & Contamination Exposures		
2.6. Kill rates from vented microbes	2.1. Mission Duration	
	2.2. Venting of viable / non-viable Microbes; Dissemination	
	2.3. What vents from Suits?	
	2.4. Containment & Waste Technol.	
	2.5. Sci. Concerns & Vented contamination.	
	2.7. Decontamination Procedures upon Release?	
	2.8. What microbial contaminants would vent from EVA suits? Concentrations? Implications?	
3.1. Microbes in dust & biofilms	3.4. What leaks/vents from pressurized facilities; how change over time?	3.2. Models of dust transport; timeframes
3.3. Transport of hardy microbes to Mars via crew and assets		3.6. Understand & model contamination rates /thresholds for human landing sites (as point source)
3.5. How study uncultivable microbes		3.7. Understand & model contamination rates/thresholds for mobile crewed systems
		3.8. Understand acceptable contamination generation rates/ thresholds at human sites in context of sub-surface contamination & water/ice use

Table 6.4: All Identified Gaps and Research Areas

SG 1: Microbial and Human Health Monitoring	SG 2: Technology and Operations for Contamination Control	SG 3: Natural Transport of Contamination on Mars
1.1 ID Sampling collection technology & procedures	2.1. Does Duration of human surface stay (30 v. 500 days) matter? Does it change objectives of planetary protection during mission? (what is relationship between duration of human exploration time & overall density/spread of contamination?)	3.1. Understand interactions of biocidal factors on microbial survival, growth & evolution in Mars-type environments; & potential for survivability & replication of very hardy microbes (in dust environments; across Mars? in biofilms?)
1.2 ID technology for microbial monitoring to mitigate risks to crew, planetary protection & science integrity	2.2. Acceptable Microbial Contamination? What level of non-viable bioburden escape is acceptable? (if non-viability can be demonstrated, does this significantly address human microbial bioburden concerns? does it address concerns about external dissemination of microbial contamination?)	3.2. Need data or models to determine what happens to windblown dust, where it might go, in what timeframes; and understand meteorological conditions throughout several Martian years at particular site(s)
1.3. ID sampling processing tech. and procedures (automated handling and testing in lab?)	2.3 Need for decontamination & verification procedures & protocols after releases (nominal or otherwise). Are decontamination procedures needed for both inside/outside the spacecraft as well?	3.3. What is the probability of transporting hardy terrestrial microbes to Mars via different pathways on a human mission?
1.4. Organize data collection, storage & Interpretation for on-site use	2.4 Quarantine. What considerations should go into the design of quarantine facilities and methods (for use *to*-, from- or on-Mars)?	3.4. What is leaking &/or venting out of pressurized containers or human facilities (rate, size, biol. diversity, cells, organic molecules etc.) during nominal operations, after significant degradation and during off nominal situations? What are differences between active designed venting vs. leaking?
1.5. Understand spaceflight specific microbial responses & heritable changes	2.5 Definitions of Special Regions, changes of understanding over time, and how these related to contamination concerns during human missions.	3.5. How to study yet-uncultivable microorganism? What proportion of the entire community do they represent? How to assess /monitor viability?
1.6. Understand different microbial populations to be monitored (astronaut, vehicle, & external environment.)	2.6 Assorted Questions about Testing, ISRU & Habitation-- research needed in advance of planning/design of technologies, systems, operations.	3.6. Understand/establish acceptable contamination generation rates/thresholds for human landing site -- & consider as point contaminant sources (of microbes/organic particles); Model the minimum aeolian contamination spread over distances and particular rates.

SG 1: Microbial and Human Health Monitoring	SG 2: Technology and Operations for Contamination Control	SG 3: Natural Transport of Contamination on Mars
1.7. Develop novel approaches to: a) effective, low toxicity disinfectants and b.) Prevention/recovery from biofilms/microbially induced corrosion, fouling etc.	2. 7. What is acceptable containment (type; location; duration) of wastes intentionally left behind? Similarly, what are acceptable constraints/procedures on vented materials?	3.7.Understand/establish acceptable contam. generation rates /thresholds for a mobile crewed system (pressurized vehicle or suited crew) & study as point contaminant (of microbes & organic particles), or model minimum contamination spread (over distance & time)
1.8 Crew Health & Biomed Studies related to Microbial & Contamination Exposures	2.8. EVA. What microbial contaminants would vent from a EVA suit? & what concentrations? Implications for suit materials, cleaning tools, designated Mars zones etc.	3.8 Understand/establish acceptable contam. generation rates/thresholds for human landing site in context of sub-surface contamination & use of local water/ice.
1.9 Develop Acceptable/Appropriate Ethical & Operational Guidelines for crewed missions to Mars		

APPENDICES

A. Workshop Announcement
B. Workshop Program & Agenda
C. Participants List
D. Breakout Group Templates and Questions
E. Website Info—Online Resources
      NASA Workshop Repository website—with speaker info, abstracts & videos
      COSPAR Human Principles and Guidelines
      NPI 8020.7 and NPD 8020.7G
F. Acronym List

APPENDIX A: Workshop Announcement

Workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions

NASA's Ames Research Center and the SETI Institute will co-host a workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions on March 24-26, 2015, in Moffett Field, California.

While planetary protection requirements are in place for robotic missions, there is presently insufficient scientific and technological knowledge to establish effective quantitative requirements for the development of crewed spacecraft and missions. To prepare for such future missions, NASA created the NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions (NPI 8020.7) that outlines the need to increase knowledge in the following study areas while iteratively developing an appropriate set of requirements:

- Study Area 1: Microbial and human health monitoring
- Study Area 2: Technology and operations for contamination control
- Study Area 3: Natural transport of contamination on Mars

The goal of this workshop is to capture the current state of knowledge in the aforementioned areas and identify additional research to appropriately inform planetary protection requirements development for the human exploration of Mars.

To view the original online program with abstracts, please visit the Lunar Planetary Institute (LPI) website: http://www.hou.usra.edu/meetings/ppw2015

The latest agenda is viewable here: Agenda (as of March 20, 2015) (.pdf, 699 kb)
To virtually participate in the meeting, please go to:
https://ac.arc.nasa.gov/planetaryprotection/

Details of the workshop can be found here: Workshop Announcement (.pdf, 134 kb)

The workshop will take place in Building 152 in the NASA Research Park (NRP). A map of the NRP can be viewed here: NRP map (.pdf, 2 Mb)

APPENDIX B: Workshop Program & Agenda

Tuesday, March 24, 2015
8:00 a.m. Room 171 Planetary Protection and Human Missions: Opening Statements and Background
1:25 p.m. Room 171 Microbial and Human Health Monitoring

Wednesday, March 25, 2015
8:00 a.m. Room 171 Microbial and Human Health Monitoring Continued
10:10 a.m. Room 171 Technology and Operations for Contamination Control
3:25 p.m. Room 171 Natural Transport of Contamination on Mars

Thursday, March 26, 2015
8:00 a.m. Room 171 Natural Transport of Contamination on Mars Continued
10:30 a.m. Room 120 Microbial and Human Health Monitoring Breakout Session
10:30 a.m. Room 116/117 Technology and Operations for Contamination Control Breakout Session
10:30 a.m. Room 112 Natural Transport of Contamination on Mars Breakout Session
2:35 p.m. Room 171 Workshop Conclusion

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PROGRAM DETAIL
**Tuesday, March 24, 2015 PLANETARY PROTECTION AND HUMAN MISSIONS:
OPENING STATEMENTS AND BACKGROUND 8:00 a.m.   Room 171**

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Cassie Conley   Bette Siegel
Conley C. * *Welcome Statement*
Johnson J. * *Statement of Workshop Goals and Scope*
     Craig D./Joshi J. *NASA's Evolvable Mars Campaign Overview*
     Conley C. *Current Planetary Protection Policy and Human Spaceflight*
     Siegel B. * *NPI 8020.7 and Path to Requirements*
     Johnson J. *NASA's Suggested Studies and Status*
     Johnson J. *Workshop Introductions*

Break

Rummel J. D. *   Race M. S. Kminek G.
The Development of Planetary Protection Requirements for Human Mars Missions: A History **[#1010]** The paper will review and highlight the history of the development of planetary protection provisions for human missions to Mars. The role of NASA and ESA's planetary protection offices, and the aegis of COSPAR will be identified and explained.

Hogan J. A. *
Summary of the 2005 Life Support and Habitation and Planetary Protection Workshop **[#1023]**
This presentation provides a summary of the results of the Life Support and Habitation and Planetary Protection Workshop held in 2005 in Houston, TX.
Lunch Break

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**Tuesday, March 24, 2015 MICROBIAL AND HUMAN HEALTH MONITORING I
1:25 p.m.   Room 171**
Steve Davison, Chair

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Law J. *   **[KEYNOTE PRESENTATION]** *Planetary Protection for Human Exploration Missions: A Human Health Monitoring Perspective* **[#1006]** Planetary protection will be a challenge for human exploration missions. A collaborative approach that takes into context all the challenges facing human space exploration will benefit both the space medical and planetary protection communities.

Venkateswaran K. *
Capabilities for Planetary Protection: Safeguarding the Crew and Engineering Systems for Human Missions to Mars **[#1018]** Validated microbial monitoring systems are required to preserve acceptable microbial burden levels, ensure interference of false-positives with life-detection experiments, and prevent the inadvertent exposure of humans to extraterrestrial materials.

Leys N. *   Van Houdt R.
Microbial Biocontamination Control in Manned Space Habitats **[#1028]** A review of knowledge of procedures implemented by space agencies to control bio-contamination in manned spacecraft.

Bell M. S. *   Rucker M. Love S.   Johnson J. Chambliss J.   Pierson D.   Ott M. Mary N. Glass B.Lupisella M.   Scheuger A.   Race M. *NASA's International Space Station: A Testbed for Planetary Protection Protocol Development* **[#1002]**
Toward utilizing NASA's International Space Station to develop an integrated forward contamination test and analysis plan to meet planetary protection standards for human exploration.

Lee P .   *   Lorber   K.
Phobos and Deimos: Planetary Protection Knowledge Gaps for Human Missions **[#1007]** Phobos and Deimos, Mars' two moons, are associated with significant planetary protection knowledge gaps for human missions, that may be filled by a low cost robotic reconnaissance mission focused on elucidating their origin and volatile content.

Roman M. C. *   Ott C. M.
Overview of Microbial Monitoring Technologies Considered for Use Inside Long-duration Spaceflights and Planetary Habitats **[#1016]** NASA has been looking at microbial monitoring technologies that could be used in long-duration missions.This presentation will provide an overview of the microbial monitoring technologies that are been considered for use inside spacecrafts and planetary habitats.

Break

Karouia F. *   Peyvan K. Santos O.   Pohorille A.
Current Trends of High-Throughput Methods for Planetary Protection Requirements Associated with a Human Mission **[#1025]** We will discuss which "omics" technologies are currently amenable to adaptations for space applications and how these adaptations can be achieved to be ready for deployment on-board spacecraft in the next few years.

Wednesday, March 25, 2015 MICROBIAL AND HUMAN HEALTH MONITORING II

Jaing C. * Gardner S. McLoughlin K.
8:00 a.m. Room 171

Allen J.   Thissen J.   Be N.Slezak T.
Comprehensive and Sensitive Microbial Detection Using A Broad Spectrum Detection Microarray **[#1012]** The Lawrence Livermore Microbial Detection Array is a cost-effective and sensitive DNA detection technology to rapidly identify all sequenced microbes from environmental and clinical samples.

Mabilat C. *   Abaibou H.Linder R.   Reffestin S.   Lasseur C.
Current Progresses of Midass: The European Project for an Automated Microbial Identification Instrument **[#1031]** The European Space Agency (ESA) and bioMérieux initiated a co-development of MIDASS, the world's first fully automated system for the monitoring of the environmental microbial load in confined spaces, including clean rooms and hospital wards.

Olsiewski P .   J.   *
The Sloan Foundation Microbiology of the Built Environment Program: What's There? Where Does it Come From? And What Does it Mean? **[#1030]** Sloan began supporting basic research in this area by coaxing prominent life scientists Norman Pace and J. Craig Venter to move from studying natural outdoor environments to indoor built environments.

Rose L. J. *   Coulliette A. D.
Surface Sampling and Detection Investigations at the CDC **[#1027]** The Environmental and Applied Microbiology Team is tasked with investigating disease outbreaks in healthcare settings. We will summarize and discuss applied research endeavors to understand and optimize sampling and detection of microorganisms.

Break
Wednesday, March 25, 2015 TECHNOLOGY AND OPERATIONS FOR CONTAMINATION CONTROL 10:10 a.m.   Room 171
Molly Anderson, Chair

Ross A. * Eppler D. ***[KEYNOTE PRESENTATION]**
Exploration Space Suit Architecture and Critical Science Operations for Mars

Barta D. J. *   Anderson M. S.
Environmental Control and Life Support Systems for Mars Missions — Issues and Concerns for Planetary Protection **[#1024]** Planetary protection (PP) represents additional requirements for Environmental Control & Life Support (ECLSS). planetary protection guidelines will affect operations, processes, and functions that can take place during future human planetary exploration missions.

Leys N. * Janssen P. Monsieurs P.   Mastroleo F.
Human Life Support by Microbes in Space **[#1029]** We discuss how bacteria can be used in closed life support systems to support human life in space, taking the MELISSA system as model.

Buffington J. A. *   Mary N. A.
Extravehicular Activity and Planetary Protection **[#1005]** The extravehicular activity presentation will discuss the effects and dependencies of the EVA system design on the technology & operations for contamination control and planetary protection on surface of Mars.
Lupisella M. L. *Bobskill M.   Rucker M. Glass B.   Gernhardt M.
Low-Latency Teleoperations for Mars Planetary Protection **[#1003]** Low-latency teleoperations has the potential to help address a number of planetary protection concerns associated with human exploration missions to Mars, including landing site evaluation, special region exploration, sample operations, and asset cleaning.
Special Lunch Presentation: Andy Weir and Pascal Lee

Hays L. E. *   Beaty D. W.   Jones M. A.
Mars Sample Return Feedforward of Potential Planetary Protection Technology/Knowledge to Human Exploration **[#1020]** Planetary protection considerations for Mars Sample Return and Human Extraterrestrial Missions clearly have significant overlap. What are some of the ways that considerations for the former may or may not feed forward to the latter?

Sanders   G.   B.   *   Mueller   R.   P .
Mars Soil-Based Resource Processing and Planetary Protection **[#1026]** It is believed that the currently proposed Mars soil-based ISRU concepts will be able to mitigate both forward contamination and creation of Special Region planetary protection concerns.

Glass B. * Paulsen G. Zacny K.   Dave A.
Mitigating Inadvertent Contamination in Subsurface Drilling **[#1014]** Our concept is to develop and test a new method of drill sterilization (embedded bit heater for sterilization) compatible with drilling sample acquisition and transfer.

Wednesday, March 25, 2015
NATURAL TRANSPORT OF CONTAMINATION ON MARS I
3:25 p.m.   Room 171
Andy Spry, Chair

Mancinelli R. * **[KEYNOTE PRESENTATION]** *Human Associated Biological Contamination in the Antarctic and on Mars: Empirical and Modeling Studies*

Jones M. A. *   Beaty D. W.   Hays L. E.
Understanding the Process and Drivers for Developing Human Exploration Planetary Protection Requirements **[#1017]** It is beneficial to take a "system view" approach to determine the best path forward for planetary protection requirements development for future human missions. It is critical to determine driving factors early in the processes for developing an NPR.

BeatyD.W.* DavisR.M. HamiltonV.E. HaysL.E. JonesM.A. LimD.S.S. Rummel J. D.
    Whitley R. *Forward Planetary Protection Issues and Constraints Related to Planning for the Potential Human Exploration of Mars* **[#1022]** This paper summarizes some of the key issues and concerns related to planning for the forward planetary protection of Mars in a potential human exploration environment.

Schuerger A. C. *
Ultraviolet Irradiation on the Surface of Mars: Implications for EVA Activities During Future Human Missions **[#1011]** The solar UV irradiation environment on the surface of Mars is significant, and will assist in the inactivation of spacecraft, spacesuit, and hardware contamination during EVA activities.

Closing Comments

Thursday, March 26, 2015
NATURAL TRANSPORT OF CONTAMINATION ON MAR II   8:00 a.m. Room 171
Chair: Andy Spry

8:00 a.m. Venue Open
8:30 a.m.   J. Johnson   *Opening Comments*

Paulino-Lima I.G. Araujo G. G. Rodrigues F. Silva E. P. Rothschild L.J. Galante D.
Geodermatophilus Sp. Strain MN04-01 Survives High Doses of Simulated Present-Day Martian UV Radiation **[#1008]**   We found that Geodermatophilus sp strain MN04-01 is extremely resistant to present-day Martian UV radiation with LD10 at least 33 times greater than Deinococcus radiodurans.

Smith D. J. *   E-MIST Team
Predicting the Response of Terrestrial Contamination on Mars with Balloon Experiments in Earth's Stratosphere **[#1009]** A species-specific inactivation model that predicts the persistence of terrestrial microbes on the surface of Mars is one of many possible outcomes from high altitude balloon experiments in Earth's stratosphere.

Schuerger A. C.   *   Lee P .
Low Dispersal of Human-Associated Microbes on to Pristine Snow during an Arctic Traverse on Sea Ice by the Moon-1 Planetary Surface Rover **[#1004]** The harsh conditions on the surface of Mars, combined with an anticipated ultra-low rate of microbial dispersal away from crewed rovers, suggests minimal risks to the contamination of the martian surface.

Harrison S. M. *
Near Space Biological Research Using Weather Balloons **[#1015]** This is a short abstract that explains how ultra low cost near space probes launched via weather balloon can be used for biological research into how cells can survive in extreme environments.

Break

Race M. *
Breakout Session Ground Rules and Assumptions

Thursday, March 26, 2015   BREAKOUT SESSIONS

10:30 a.m. Breakout Sessions Commence

1. MICROBIAL AND HUMAN HEALTH MONITORING Room 120
        Moderators: Jennifer Law, Monserrate Roman, Aaron Mills, Terry Taddeo
        Scribes: Craig Kundrot , Steve Davison

2. TECHNOLOGY & OPERATIONS FOR CONTAMINATION CONTROL Room116/117
        Moderators: John Hogan (and Jitendra Joshi)
        Scribe: Jesse Buffington

3. NATURAL TRANSPORT OF CONTAMINATION ON MARS   Room 112
        Moderator: Andy Spry
        Scribe: Lindsay Hays

11:50 a.m. *Lunch Break*
1:20 p.m.   Breakout Session Wrap-Up
2:20 p.m.   Re-Group

Thursday, March 26, 2015
SUB-GROUP OUTBRIEFINGS and WORKSHOP CONCLUSION
2:35 p.m.   Room 171
Chairs: Cassie Conley Bette Siegel

2:35 p.m. *Microbial and Human Health Monitoring - Outbriefing*   Ott M. , Bebout L.
3:05 p.m. *Technology and Operations for Contamination Control- Outbriefing*   J. Hogan
3:35 p.m. *Natural Transport of Contamination on Mars Outbriefing   A.* Spry & J. Rummel
4:05 p.m. *Discussion of Next Steps*   Johnson J.
4:20 p.m. *Wrap-Up/Closing Comments* Conley C.

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APPENDIX D: Template for Breakout Group Preparation & Deliberation[29]

GENERAL INSTRUCTIONS: Please complete the highlighted sections indicated in Sections 1-6. Shorthand bullet points are okay. Sections 2 and 3 are abstract-level summaries and can be filled in post-workshop or kept as bullet points for now.

1. Report of Breakout Group # (1, 2, or 3)
   Topic Area: (fill in title of study area)

- Participants
    - Moderator(s): (fill in information)
    - Scribe(s): (fill in information)
    - Group Participants: (fill in information)

2. Overview of charge to Breakout Group/Study Area: [**Note:** *can be completed post-breakout session(s) or post- workshop if needed*].

- Paraphrase the goal and bounds/considerations set uniquely to your study area. Include any questions/concerns unique to your study group (aside from the guiding workshop questions).

3. Review/summary of Breakout Group breakout session discussions: [**Note:** *can be completed post-breakout session(s) or post-workshop if needed*].

- Summarize key findings of your breakout session – abstract level
- Include any preliminary discussion on background or starting assumptions (if relevant)

4. Breakout Group answers to Guiding Workshop Questions:
*[**Note:** This section serves to capture the answers to the first five of the Guiding Workshop questions outlined below. Either enter bullets here or in the provided Template for Recording Info During Plenary Sessions as they apply to your study area. It also serves to record any issues or concerns specific to forward/backward contamination control for your assigned study area (reference preliminary list in APPENDIX III).]*

Guiding Workshop Questions:

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[29] (the full template handout also included Appendices of useful information for Study Groups)

1. What planetary protection (PP) related research activities or technical developments do you feel are critical for inclusion in your study area?

2. What work/research is already underway?

3. Is special information or technology needed to plan for <u>nominal vs. off-nominal situations?</u>

4. Are existing mitigation options and approaches adaptable for PP needs on the Martian surface?

5. Are there any significant <u>stumbling blocks</u> ahead that are evident? (including coordination across planetary protection, science exploration, engineering, operation and medical communities)

6. In your opinion, what still needs to be accomplished?

5. Identification of Knowledge Gaps:

Considering the background information gathered from Section 4 above, now focus on Guiding Workshop Question #6: "What still needs to be accomplished?" (What do we need to focus on incrementally to answer the questions & fill the knowledge gaps)

Capture <u>each</u> Knowledge Gap in **3 parts:**
- **Identify the Specific Knowledge Gap:** (brief statement or indication of the open question or concerns)
- **Rationale:** Why is this area perceived as an important gap and which group (who) is raising the concern?
- Which COSPAR Implementation Guideline(s) is involved: (e.g., a, c,… none.)

Repeat this listing for each knowledge gap.

6. Grouping of Knowledge Gaps:

Group the knowledge gaps identified from Section 5 above into categories of similarity based on your judgment (e.g., EVA-related; habitat & ALS related; waste disposal; ISRU; science ops; etc.) Explain/indicate why you chose these categories.

OVERALL NOTE: Again, we are *not* looking for prioritized lists or ranked recommendations—but rather important knowledge gaps that identify the R&TD questions/areas that need to be addressed incrementally in order to eventually develop detail for an NPR on Planetary Protection and Human Missions to Mars. **Feel free to include post-scripts if some information doesn't fit easily into the template … for example:**

- If you identified unique or unusual assumptions beyond the COSPAR ones, please explain any important facts or considerations

- **Were there any dissenting opinions that should be noted or understood?** (Again, we are not prioritizing the lists-- but we want to make sure no gaps or ideas are omitted)

Other important info or comments for planning future R&TD areas?

APPENDIX E: Website Information—Online Resources

NASA Workshop Repository website—with speaker information, abstracts & videos
http://planetaryprotection.nasa.gov/humanworkshop2015/

COSPAR Principles and Guidelines for Human Missions to Mars
https://cosparhq.cnes.fr/sites/default/files/pppolicy.pdf

NPI 8020.7 and **NPD 8020.7G:** http://planetaryprotection.nasa.gov/documents
  See Section under: NASA Planetary Protection Policy & Related Documents

  NPI 8020.7: NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions
  NPD 8020.7G: Biological Contamination Control for Outbound and Inbound Planetary Spacecraft

NASA Office of Planetary Protection Website: http://planetaryprotection.nasa.gov/

APPENDIX F: ACRONYM LIST

AEMC	Advanced Environmental Monitoring and Control
AEVA	Advanced Extravehicular Activity
ALS	Advanced Life Support
COSPAR	Committee on Space Research
DNA	Deoxyribonucleic acid
DRO	Distant Retrograde Orbit
ECLS & ECLSS	Environmental control and Life Support (Systems)
EDL	Entry, Descent & Landing
EMC	Evolvable Mars Campaign
EMU	Extravehicular Mobility Unit (space suit)
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
EVA	Extravehicular Activity
ISLSWG	International Space Life Sciences Working Group
ISRU	In-Situ Resource Utilization
ISS	International Space Station
LEO	low-Earth orbit
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding (Instrument on Mars Express Orbiter)
MEPAG-SAG	Mars Exploration Program Analysis Group - Science Analysis Group
MIDASS	Automated system for monitoring environmental load in confined spaces
NAC	NASA Advisory Council
NAI	NASA Astrobiology Institute
NASA	National Aeronautics and Space Administration
NASA ARC	NASA Ames Research Center
NASA HQ	NASA Headquarters
NASA JPL	NASA Jet Propulsion Laboratory
NASA JSC	NASA Johnson Space Center
NEEMO	NASA Extreme Environment Mission Operations
NPD	NASA Policy Directive
NPI	NASA Policy Instruction
NPR	NASA Procedural Requirements
NRC	National Research Council
PPO	Planetary Protection Office/Officer
R&TD	Research & Technology Development
RIMFAX	Radar Imager for Mars' subsurFAce eXperiment
SEP	Solar Electric Propulsion
SETI	Search for Extraterrestrial Intelligence
SHARAD	Shallow Radar (instrument on Mars Reconnaissance Orbiter)

SKG	Strategic Knowledge Gaps
SLS	Space Launch System
SR	Special Region
UV	Ultraviolet (radiation)
VHP	Vaporized Hydrogen Peroxide