FINAL REPORT

Prepared for the Committee on Space Research. Panel on Planetary Protection (PPP)
International Council for Science (ICS)

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Final Report

2nd COSPAR <u>Workshop</u> on Refining Planetary Protection Requirements for Human Missions

May 15-16, 2018

and

COSPAR <u>Work Meeting</u> on Developing Payload Requirements for Addressing Planetary Protection Gaps on Natural Transport of Contaminants on Mars

May 17-18, 2018

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Prepared for the COSPAR Panel on Planetary Protection (PPP)

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2nd COSPAR Workshop on

Refining Planetary Protection Requirements for Human Missions

and

COSPAR Work Meeting on

Developing Payload Requirements for Addressing PP Gaps on the Natural Transport of Contamination on Mars 2018

Executive Summary

NASA and COSPAR are engaged in a multi-year stepwise process to identify, prioritize and plan the focused research and technology development (R&TD) activities necessary to address planetary protection (PP) requirements for human missions beyond Earth orbit. The overall objective has been to move incrementally from the current *qualitative* COSPAR PP Principles and Operating Guidelines[1] toward development of *quantitative* PP requirements for future human missions to locations like Mars. The workshops and meetings in this collaborative series have involved participants representing NASA, COSPAR, international space agencies, the scientific/technical community, and commercial/private stakeholders.

This report provides detailed information on the findings of *two* efforts in this series that took place in May 2018 at the Lunar and Planetary Institute (LPI) in Houston, TX: 1) the **2nd COSPAR Workshop** focused on Refining Planetary Protection Requirements for Human Missions, and 2) a *separate* **COSPAR Work Meeting** for Developing Payload Requirements to Address PP Gaps on Natural Transport of Contamination on Mars.

Building on earlier Workshops in the series (held in 2015 and 2016)[2] the 2018 **2nd COSPAR Workshop** advanced understanding in three thematic areas to determine how to meet PP-related R&TD needs for human exploration missions. The three study areas are:

- Microbiology and Human Health Monitoring[3]
- Technology and Operations for Contamination Control[4]
- Natural Transport of Contamination on Mars[5]

The 2nd COSPAR Workshop re-examined all the knowledge gaps (KGs) identified and prioritized during earlier workshops, and assessed whether and how these gaps could be filled

[1] COSPAR 2008 Principles and Guidelines for Human Missions to Mars; see Box 1, p 6.

[2] NASA, 2015. https://planetaryprotection.nasa.gov/humanworkshop2015 and the 1st COSPAR Workshop, (2016) https://planetaryprotection.nasa.gov/humanworkshop2016 (see Conference Doc. link for both reports)

[3] Developing capabilities to comprehensively monitor the microbial communitIes associated with human systems and evaluate changes over time. (referred to as MHHM—Microbial and Human Health Monitoring

[4] Developing technologies for minimizing and mitigating contamination reléase,including, but not limited t: closed-loop systems; cleaning/re-cleaning capabilities; support systems that minimize huyman contact with the Mars environment and other solar system destinations

[5] Understanding environmental processes on Mars and other Solar System destinations that would contribute to dissemination /transport and sterilization/survival of terrestrial organisms released by human activities.

using different mission opportunities and/or varied locations across the solar system. The KGs in each study area were considered across four distinct time periods spanning from the present/near-term (2018) to the mid 2030s. Working in breakout groups, participants at the 2nd COSPAR Workshop evaluated combinations of robotic and human missions and/or analogue research that could be used to address the R&TD needs for the three study areas. Findings were recorded on Excel spread sheets indicating whether, and to what extent, a particular combination of location, mission opportunity and time frame would be useful for addressing specific KGs: fully, partially or not at all. Breakout groups also identified those measurements, instruments and flight opportunities that could be most helpful by virtue of having few or nonexistent PP constraints of their own (e.g. on ISS, Moon, cislunar space, martian moons, asteroids, Earth analogues, and simulations). Final discussions concentrated on findings for the near-term time frame, and considered how upcoming mission and location opportunities of space agencies and partners could aid in addressing specific R&TD activities necessary for human missions and PP compliance.

In order to develop quantitative PP requirements on human missions, the compiled information will need to be analyzed further to generate a roadmap for closing the KGs in each of the three study areas - Microbial and Human Health Monitoring; Technology/ Operations for Contamination Control; and Natural Transport of Contamination. The collective information will contribute to addressing PP issues across a range of upcoming challenges including; sample return, landing zone planning, design of contaminant mitigation, Extra-vehicular Activity (EVA) and technologies for Environmental Control and Life Support System (ECLSS), In-situ Resource Utilization (ISRU), habitat and spacecraft operations, and in-situ science-focused payloads.

The findings of the 2018 Workshop will serve as introductory input for three follow-on COSPAR work meetings planned for 2018, 2019, and 2020. Each of these work meetings will focus on a single study area and its associated KGs, to provide detailed information on measurements, instruments and research that can be addressed during future mission and test opportunities.

The first Work Meeting was held immediately following the end of the 2nd COSPAR Workshop. Participants in the Natural Transport of Contamination study group reassembled to focus on the just-completed Excel spreadsheet data with the aim of addressing the lack of knowledge on what Mars does with released viable biological containment. Their deliberations centered on what measurements and instruments would be needed to gather data on natural transport of contaminants using different missions, locations and time opportunities. The decision to have the first Work Meeting focus on this issue was deliberate: answers to questions about microbial dispersal and survival are particularly urgent for establishing an informed partitioning of the Martian surface (i.e. operation zones for exploration and commercial activities) as well as for defining requirements for flight systems and operations. None of these measurements have been collected at the necessary frequency, duration or location on any Mars surface missions in the past, nor are these types of measurements planned for any approved missions currently under preparation. Moreover, the majority of these questions can only be addressed on Mars.

The main finding of the COSPAR Work Meeting on Natural Transport of Contaminants on Mars is that **a dedicated meteorology mission** in the area of the planned human landing site is needed. New measurements over at least a full Martian year at multiple fixed locations on the surface of Mars are necessary to acquire high-frequency meteorological data needed to develop, test and validate contamination transport models.

Details of the Natural Transport of Contamination Work Meeting output are summarized in Chapter 4 and will also be published in a separate journal article (Patel and Clark, in preparation for publication, (2019)). A combined summary of the findings of Study Group 3 was presented at the 42nd COSPAR Assembly in 2018, and is included in Appendix D.

Following the Workshop and Work Meeting, the findings of all three study groups were consolidated by the organizing panel into a **notional timeline for closing PP KGs.** The timeline included in this report (Fig. 18) represents *one* solution for closing PP KGs in the available time between the present and the notional first crewed mission to the Martian surface.

The sequences shown in this timeline highlight the need for early starts for activities to address certain KGs and ensure our ability to create an end-to-end PP solution. Although the budget was not considered in any of the meeting discussions, the timeline is considered useful for identifying missing elements in current mission planning and highlighting linkages among the KGs and future mission plans.

1. COSPAR 2018 Workshop - Introduction

1.1 Early Steps in Considering PP and Human Missions

After the conclusion of NASA's Apollo Program, which succeeded in landing astronauts on the Moon from 1969 to 1972, human presence in space has been exclusively associated with activities on space stations in low-Earth orbit (LEO). These efforts did not raise any concerns about PP, i.e. avoiding "harmful contamination" of celestial bodies and adverse changes to the environment of the Earth (as stipulated by Article IX of the United Nations Outer Space Treaty).[6] Thus, in the decades since Apollo, PP policy development and implementation concerns have focused primarily on robotic missions to the Moon and other solar system bodies. Many of those discussions on policy and regulatory needs have involved robotic mission to Mars, and particularly what would be required to mitigate forward contamination concerns. Detailed discussions of quantitative requirements for round-trip missions and backward contamination concerns must still be undertaken—particularly for human missions.

As discussions in the space community were drawn again to the idea of sending humans beyond Earth orbit, it was necessary to reconsider how PP controls would apply to missions with crews. Clearly, the numerous changes in technology, science understanding and international policies since the 1960s must be addressed to ensure that appropriate controls and safeguards are incorporated into missions in ways that avoid harmful contamination and preserve opportunities for science exploration; protect human health and safety during all mission phases; and avoid adverse changes in the environment of the Earth upon return.

The first steps toward addressing those objectives were undertaken nearly two decades ago, through a series of international studies and workshops that examined the PP issues associated with post-Apollo missions to Mars (e.g. Criswell et al, 2005; Hogan et al., 2006; National Research Council/Space Studies Board 2002; Kminek et al., 2005). These deliberations about PP and human missions eventually led to COSPAR's development of a set of qualitative Principles and Implementation Guidelines for Human Extraterrestrial Missions (summarized in Box 1, p.6), which even today remain part of the COSPAR official PP policy. When COSPAR adopted the current, *qualitative* human PP principles and guidelines in 2008, it was recognized that additional work would be needed to move towards *quantitative* requirements for human missions to Mars.

NASA and the international space community have acknowledged that many questions lie ahead, particularly how PP concerns will be accommodated in technical solutions applicable to human-rated flight systems on long-duration, round-trip missions to other planetary surfaces. Based on the COSPAR PP Principles and Implementation Guidelines for Human Missions, NASA established a NASA Policy Instruction (NPI) 8020.7, *Planetary Protection Requirements for Extraterrestrial Missions* (NASA, 2014) outlining the need for the agency to translate the COSPAR 2008 principles and guidelines into implementable requirements. This NPI and NASA

[6] UN Outer Space Treaty of 1967—Article IX

policy requirement (NPR) (NPI-NPR) process began with a systematic literature review that identified approximately 100 references providing preliminary technical analyses and reviews related to PP and human missions (see Johnson et al., 2013; Spry et al., 2014). Subsequently, plans were outlined for a series of workshops to identify the current state of knowledge about PP and human mission systems; develop a list of studies and information needed to inform future requirements; and identify specific R&TD studies that can iteratively lead to the development of draft requirements. Based on NPI 8020.7, the workshops and activities would focus on three key study areas:

- Developing capabilities to comprehensively monitor the microbial communities associated with human systems and evaluate changes over time,
- 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
- Understanding environmental processes on Mars and other solar system destinations that would contribute to transport and sterilization of organisms released by human activities.

Figure 1: Photo of Mars. Credit NASA

BOX 1: COSPAR Planetary Protection Principles and Implementation Guidelines for Human Missions to Mars

The intent of this planetary protection policy is the same whether a mission to Mars is conducted robotically or with human explorers. Accordingly, planetary protection goals should not be relaxed to accommodate a human mission to Mars. Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ. **General principles include**:

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- For a landed mission conducting surface operations, it will not be possible for all human associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars, or their support systems, will inevitably be exposed to martian materials.

In accordance with these principles**, specific implementation guidelines for human missions to Mars include**:

- Human missions will carry microbial populations that will vary in both kind and quantity, and it will not be practicable to specify all aspects of an allowable microbial population or potential contaminants at launch. Once any baseline conditions for launch are established and met, continued monitoring and evaluation of microbes carried by human missions will be required toaddress both forward and backward contamination concerns.
- A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a martian life-form occurs.
- A comprehensive planetary protection protocol for human missions should be developed that encompasses both forward and backward contamination concerns, and addresses the combined human and robotic aspects of the mission, including subsurface exploration, sample handling, and the return of the samples and crew to Earth.
- Neither robotic systems nor human activities should contaminate "Special Regions" on Mars, as defined by this COSPAR policy.
- Any uncharacterized martian site should be evaluated by robotic precursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission.
- Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.
- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.
- Planetary protection requirements for initial human missions should be based on a conservative approach consistent with a lack of knowledge of martian environments and possible life, as well as the performance of human support systems in those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus

1.2 Context Leading to 2018 COSPAR Workshop

Considerable progress has been made in recent years on the incremental path toward development of more detailed COSPAR PP Policy for human missions, with the ultimate goal of sending humans to Mars. Figure 2 provides a conceptual overview of the step-wise process that began with the NPI-NPR process earlier in this decade. The checkmarks in Figure 2 indicate workshops and meetings that have occurred to date—with at least two additional COSPAR work meetings planned (2019 and 2020) to complete the examination of all three study areas and develop detailed plans for R&TD to fill remaining KGs.

NASA-COSPAR Conceptual Approach for Development

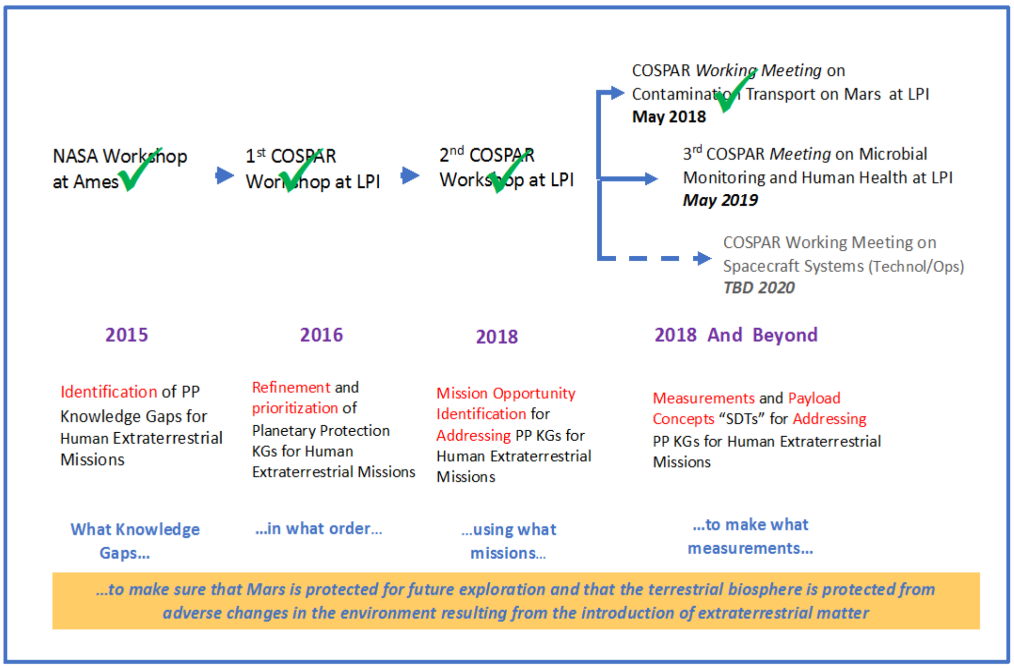

Figure 2: NASA-COSPAR Conceptual Approach for Development

The 1st COSPAR Workshop (2016) began by reviewing the 2015 NASA Workshop findings, and determining whether other gaps or topics should be added. Then, working in groups based on the three study areas, participants used their expert judgements to develop rankings by location, time priority and mission criticality (high/medium/low) for filling each of the specific KGs. During their deliberations, participants considered the KGs in the context of specific questions related to technologies, where/how the R&TD can be conducted, and remaining open issues that must be addressed. Based on their deliberations, the total number of KGs was reassessed and compiled in a table that highlighted those gaps identified as High Priority items. **Table I** provides a summary of the 1st COSPAR Workshop (2016) rankings of all KGs in the three group theme areas. Detailed information on the deliberations of the 1st COSPAR Workshop on PP Knowledge Gaps for Human Extraterrestrial Missions are available online at: https://planetaryprotection.nasa.gov/humanworkshop2016 . (see Conference Documents link)

Based on additional analyses, the 2016 workshop organizers subsequently identified the *Highest Priority Knowledge Gap Areas* *(broader in scope than the specific individual KGs considered by the breakout groups)* and potential ways to address them. In this context, Highest Priority KG Areas were defined as time-critical to establish PP requirements and to design hardware and operations in compliance with requirements. The identified *Highest Priority KG Areas* were:

- Natural transport of terrestrial biological contamination on Mars,
- Status and evolution of microbiome on robotic and human flight systems,
- Synergistic biocidal effects of the Martian environment on the survival and growth of spacecraft associated microbiomes, and
- Determination of the acceptable levels for biological and organic contamination release from human support systems.

Because not all places on Mars are equal in terms of providing the right conditions for microbial growth, KGs in Study Area 3, *"Natural transport of terrestrial biological contamination on Mars"*, were considered the highest priority for an informed partitioning of the Martian surface. Moreover, establishing quantitative PP requirements requires increased understanding of the natural transport of biological contamination on Mars, which in term is dependent on new measurements at Mars. Accordingly, the following actions were also identified as necessary to close the highest priority KG areas:

- Measurements on the surface of Mars to acquire high frequency meteorological data over at least a full Martian year at multiple fixed locations for each proposed Exploration Zone (EZ) to develop, test and validate contamination transport models. These measurements need to include, at a minimum, turbulent fluxes of heat and momentum, basic measurements of air temperature, pressure, humidity and wind velocity, the dust concentration and atmospheric column abundance, and deposition and erosion rates of dust;
- Development of microbiota and microbiome monitoring capabilities and systematic assessment of the microbial diversity and its evolution over time for robotic Mars spacecraft (ground-based during hardware assembly, test and launch operations) and human spacecraft (ground-based during hardware assembly, test and launch operations and in-flight e.g., on the International Space Station or successor vehicles;
- Ground based measurements of the synergistic biocidal effects on the microbial survival and growth of spacecraft associated microorganisms; and
- Measurements to characterize the release of biological and organic contamination from human support systems (e.g., EVA suit, air locks, habitat).

Findings/Rankings of All Groups from 1st COSPAR Workshop (2016)

TABLE 1: Overview of All Splinter Group Findings	**Priority/Criticality**			**Possible Locations?**				
GROUP 1: Microbial & Human Health Monitoring	**TIME**	**MISSION**		**Mars**	**Moon**	**asteroids**	**Earth**	**ISS**
1A. Microbial Monitoring of Environment	**H**	**H**			M?	M?	**H**	
1B. Microbial Monitoring of Humans	**H**	**H**					**H**	**H**
1C. Mitigation of Microbial Growth in Spacecraft Systems	**H**	**H**			M/**H**?	M/**H**?	**H**	**H ?**
1D. Operational Guidelines for PP and Crew Health	L	L						
GROUP 2: Technol. & Operations For Contam Control								
2A. Bioburden/Transport /Ops during Short v. Long Stays	M	M					M,M	
2B. Microbial/Organic Releases from humans and support systems	**H**	**H**					**H,H**	H
2C. Protocols (Decontamination/Verification/Monitoring) to Remediate Releases	M	**H**					M,**H**	H
2D. Design of Quarantine Facilities/Methods -- for different phases	L	L					L,L	
2E. How do Mars Env Conditions vary over time with respect to growth of Earth microbes?	L	**H**		L, **H**				
2F. Res. needed to make ISRU & PP goals compatible	M	M		M,M			M,M	
2G. "acceptable contamination" of wastes left behind? Constraints on vented materials?	L	L					L,L	
FORMER 2H. DELETED								
2 I. Approach to Achieve 'Break the Chain" Requirements?	L	L					L,L	
2J. Global Distribution/Depth of subsurface. Ice-- and evidence of Extant life?	**H**	**H**		**H,H**				
2K. Evolution of PP Requirements/goals from robotic to Human Missions & zones?	**H**	M		**H**,M			**H**, M	
GROUP 3: Natural Transport of Contamination on Mars	**Time/Mission**							
3A. Measurements/Models for Mars atmospheric transport of contaminants	**H**			**H**				
3B. Measurements/Models for subsurface transport of contaminants	M			M	M	M		
3C. Effect of Biocidal Factors on survival/growth/adapt of microbes on Mars	**H**			**H**	M	M		
3D. Determine Acceptable Contam. Rates & Thresholds	**H**			**H**	**H**	M	**H**	
3E. Protection Mechanisms for organisms on Mars	M			M	M	M		
3F. Degradation of Landed Materials by martian environment?	M			M	M	M		
3G. Induced Environmental Conditions around Structure?	M			M	M	M		
3H. Sensitivity of non-culturable species to biocidal factors	M			M	M	L	M	

Figure 3: Findings/Rankings of All Groups from 1st COSPAR Workshop (2016)

2. The 2018 Workshop – Objectives and Goals

As the next step in the process, the 2nd COSPAR Workshop on *Refining Planetary Protection Requirements for Human Missions* was held at LPI in Houston, Texas on May 15-16, 2018. Organized by COSPAR and co-hosted by NASA, the 2018 workshop, aimed to align the previously identified PP KGs with mission opportunities and locations in specific timeframes, between now and the first crewed flight to the Martian surface. Each of the three study groups concentrated on the specific KGs in their area needing R&TD in order to develop quantitative requirements consistent with COSPAR PP policies for human missions.[7] Study Group 1 (Microbial and Human Health Monitoring) had four KGs; Study Group 2 (Technology and Operations for Contamination Control) had 10 KGs; and Study Group 3 (Natural Transport of Contamination on Mars) had 8 KGs.

2.1 Workshop Format and Plenary Information

The agenda for this 2nd COSPAR Workshop (2018) *(See Appendix A)* was organized to evaluate recent efforts, activities and the state of the art related to COSPAR PP policy. The objective of the collaborative forum was to identify future R&TD efforts from multiple disciplines needed to generate a roadmap that will facilitate timely closure of KGs across all three study areas.

The first day of the workshop began with plenary presentations about COSPAR PP policy, with background details on how the human PP guidelines for missions beyond Earth were developed. Additionally, details from earlier NASA and COSPAR workshops were provided to update attendees on the KGs identified and prioritized to date. Subsequently, short presentations by speakers from NASA, the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA) and commercial entities discussed campaigns and missions that could become important elements in the overall feed-forward opportunities for filling R&TD gaps. In addition to Earth-based analogue studies, research attention was given to the Lunar Exploration Campaign (2018-2030) and Mars mission opportunities (through 2030).

The second day of the workshop began with a plenary review of the 2016 COSPAR Workshop, summarizing the specific time-priorities, mission criticalities and locations that had been determined, as well as the rankings for each KG in the three study areas.

[7] To keep terminology consistent: *Groups 1, 2, and 3* respectively are linked with the three study areas described above The specific *Knowledge Gaps (KGs)* for each Group are referred to by Upper Case letters (e.g., KG 1A-D; KG 2 A- K etc.); with additional recommendations/comments *(if any)* listed as sub-items associated with specific KG's. Thus, KG 1B = Microbial Monitoring of Humans/ Crew, and includes 3 bulleted item(s) listed below it: (e.g., take samples from current astronauts at higher frequency; study changes in human microbiome; and monitor astronauts after missions).

2.2 Group Assignments and Task Overviews

During the deliberative part of the workshop, participants separated into breakout groups representing the three study areas. Each breakout group was tasked with reviewing the evaluations on criticality, priorities and locations from the 2016 Workshop (see Table 1), and then populating an Excel template indicating the location/mission and timeframe that the respective KG could be addressed during four distinct time periods: Near-Term (2018-19), 2020-2024, 2025-2030, and 2031-onward (see Excel format: Table 2). In making their recommendations, each group proceeded through instructions summarized below:

1. Review the matrix in Table 1 and indicate in the cell **YES/NO** to question "Does the Location/ Mission Opportunity help address the KG?"
    a. For each "Yes" above, provide details of measurements/info needed to address the KG (either expand cells– or provide descriptions that correspond to the appropriate cell). Add columns as needed.
        - Capture any assumptions/input needed to enable the KG to be filled.
        - Are there any concerns about the validity of assumptions?
        - Create a rough framework (phase 1, phase 2 etc.) for filling KGs.
2. Indicate any concerns about, or potential problems with, acquiring information with adequate time to incorporate into mission development. For example
    - Are there mission sequence concerns?
    - What if the KG is not addressed with the right level of confidence, are there major issues that could arise?

Although each group developed its own approach to addressing the tasks, all groups focused on possible payload requirements and ground-based test concepts, and aligned previously identified KGs with mission opportunities in the timeframe between now and the first crewed flight to the Martian surface. The Excel spreadsheet product of each subgroup was intended to identify whether a specific combination of location, mission opportunity and time period would be useful to address specific KGs and productively feed forward toward developing human mission requirements. In addition to populating the Excel spreadsheet and assessing the feed-forward opportunities represented by various combinations/categories, each group was asked to record comments and information about the following topics:

- Overview (Group focus)
- Key Assumptions
- Recommendations for Specific Experiments
- Observation and recommendation details?
- Locations (space, missions, Earth etc. and time frame)
- Remaining Questions

General Template Format Used by all Groups

Used to consider KGs using different locations & mission opportunities – across four time periods.

4 Time Periods	**Near Term (2018-19)**	**2020- 24**	**2025- 29**	**2030 Onward**										
Locations	Moon Orbit	Moon surface	Mars orbit					Mars surface		ISS		Ground/ Analogue		Other
Mission Opportunities			Ody	MEx	MRO	TGO	Maven	Opportunity	Curiosity	Study A	Study B	Study X	Study Y	balloons, cubesats etc.
GROUP 1 Microbial & Human Health Monitoring														
4 GAPS A-D														
GROUP 2 Technol. & Ops for Contam. Control														
10 Gaps A-K														
GROUP 3 Natural Transport of Contamination on Mars														
8 Gaps A-H														

Figure 4:General Template Format Used by all Groups

3. Deliberations and Summary Findings by Group

Details on each group's deliberations are provided below, along with their summary recommendations, and Excel data for all four time periods. These Excel charts are intended to serve as introductory data for the three follow-on work meetings that aim to identify specific measurements, and payloads/ instruments to address the KGs for each of the groups. The chair and scribe are listed for each group. Workshop participants are listed in Appendix B.

3.1 Group 1: Microbiology and Human Health Monitoring

Led by Mark Ott and David Pearce

3.1.1 Deliberations and Notes

The KGs related to microbiology and human health monitoring (MHHM) are relevant to all missions, as they apply to both forward contamination of the system under study and back contamination related to human participants or sample returns to Earth. Specific opportunities for research on particular missions to help close the KG are outlined in the Excel spreadsheet. It should be noted that there were no concerns raised about the KGs as originally listed.

Key Assumptions of Group 1

Continued advances in both microbiology and molecular biology will be made over time and improve our ability to resolve the microbial populations present on humans, spacecraft and samples, and more importantly, in mapping the effect of the presence and absence of particular groups to human health and ecological outcomes. This assumption about microbial populations applies to high throughput sequencing to assist culture-based studies, understanding the composition and stability of the human microbiome, and recording the nature of both short- and long-term perturbations in microbial communities over time.

What is Required to Close Particular Group 1 Knowledge Gaps?

The group began by first considering issues or concerns relevant to the four KGs in their area, as follows:

1A. Microbial monitoring of the environment

- Determine what systematic microbial monitoring is required
- Determine what monitoring is required on human missions
- Determine the mutation rate in flight

1B. Microbial monitoring of humans/crew

- From an ecosystem perspective, determine the signals that would indicate the introduction of an unknown

1C. Mitigation of microbial growth in spacecraft systems

- Work to design and improve materials that inhibit microbial growth on Earth and test final candidates in a space environment. (NOTE: this is unlikely to take place on a mission)

1D. Operational guidelines for PP and crew health

- This applies to all human missions, but will follow from closing KGs in Groups 1 and 2 as well. Hence, it was originally classified as low priority.

3.1.2 Group 1: Specific Needs Identified by KGs

Subsequently, Group 1 developed a **list of more detailed suggestions about their four KGs:**

1A. Microbial monitoring of the environment

- Take samples from spacecraft facilities and systems at higher frequency than currently taken (including air filters within the International Space Station)
- Take contained microorganisms on missions to determine the mutation rate in the space environment (through comparative genomics)
- Improve the understanding of microbial persistence in the space environment using targeted simulations (on Earth and on future missions)

1B. Microbial monitoring of humans

- Take samples from current astronauts at higher frequency than are currently taken, and store as a biobank to generate a timeline for analysis
- Study the specific changes in the human microbiome for humans contained within artificial environments for long time periods
- Monitor astronauts after missions to determine whether changes to the microbiome are transient or permanent

1C. Mitigation of microbial growth in spacecraft systems

- This work, although important, is unlikely to take place during missions

1D. Operational guidelines for PP and crew health

- These can only be properly developed with a better understanding of the science underpinning human space travel

3.1.3 Group 1: Other Comments and Considerations

The KGs outlined above are applicable to all missions as they apply to both forward contamination of the system under study, as well as back contamination of human participants (in terms of human missions) and any Mars samples returned to Earth. Additional detailed comments were noted for each KG.

Additional Comments re: KG 1A Monitoring the environment (sampling, processing, measurement, analysis, data storage etc.)

Point 1: *Further research is still needed to define what are the hazards of introducing new organisms into a system, particularly in terms of human health.*

- The community aspires to have 'clean' systems, but what does this really mean? When it comes to human exploration, sterility is not an option, so at what point does bioburden reduction actually become ecologically significant or relevant?
- Indeed, attempts at sterilization and bioburden reduction may actually induce a selection pressure for or promote species that could be detrimental. Furthermore, in promoting the wrong type of activities, we could inadvertently be creating a selection pressure for "superbugs" that might better survive spaceflight or harsh extraterrestrial conditions. This applies to existing processes such as using high salt or perchlorate to clean spacecraft systems and also to indigenous biocidal factors that already exist on Mars.
- So a decision needs to be taken whether we should aspire to creating a sterile environment for PP or, rather maintain some form of acceptable "steady state" or "constrained" environment? In this regard, the rare biosphere is particularly important, as an organism that might grow optimally in a Mars-like environment may be comparatively rare on Earth (or within the human microbiome). These are precisely the groups that our current methods detect ineffectively and emphasizes the need to detect uncultivable microbes.

Point 2: *We urgently need to start sampling all of our exploration subsystems currently in place.*

- Environmental monitoring is currently taking place on the ISS and it occurs quarterly. A minimal number of samples (three) are taken to characterize a room when sampled. Samples are currently analyzed using culture-based methodologies (TSA plate, Sab-Dex+ Chlor) and data have shown that monitoring is sufficient to identify when a new species is introduced. While such procedures are considered suitable for monitoring crew health, they are deemed suboptimal for PP. To this end, the potential exists to use the ISS as a model and starting point in the development of a more comprehensive strategy.
- We need to develop a systematic sampling approach, to define what information is needed to determine that we are monitoring an environment adequately, and to assess whether cultivable isolates are a valid method for assessing whether contamination exists.

Point 3: *What are sufficient sampling processes for PP?*

- Current sampling routinely uses swabs, which raise a number of questions that need to be addressed. Is the swab itself good enough? Are we sampling the right locations (and are these truly representative)? What influence does temporal variability have on measurements?
- In particular, is the frequency of sampling and coverage adequate for PP purposes? Some argue that current sampling is demonstrably insufficient. Hence, we still need to define what is sufficient.
- Currently, this is a moving target that changes as technology advances. Robotic missions require sampling 10% of available surfaces. Do we know whether that is a relevant

requirement for PP purposes? The group believes that this is almost certainly not the case, although the technology will soon be able to achieve this**.**

Point 4: *What types of compounds should be measured?*

- It was suggested that organic materials could be measured as indicators of microbiological contamination. Indeed, it might be possible to measure more general compounds including: high molecular weight polymers or insoluble organic material. However, mass spectrometry may be insufficient on Mars itself. There is certainly the potential for some sort of organic chemistry suite on Mars, e.g. the laser desorption suite of MOMA. This approach might also be used to analyze pieces of the spacecraft. In this regard, we might learn by sampling the planned Gateway. However, we need to properly characterize the organic profile of dead bacteria, fungi, archaea for a variety of different species and over appropriate time scales. An experiment is certainly needed to learn more about this type of monitoring.

Other Points

- Critically, to close the KG in environmental monitoring, we urgently need to know how many samples to collect in order to adequately cover both spatial and temporal variability.
- What we need to do in addition to current monitoring is almost certainly to increase sampling frequency and to take a wider diversity of sample types. Much of this work can be tested on the ground.
- We need to do more work in monitoring closed systems, such as submarines and Antarctic bases, and especially crewed exploration missions. Earth-based laboratory experiments should focus on how to effectively monitor closed systems.
- The group noted that *we currently do not have a systematic microbial monitoring protocol***.** There is a need for automated sampling to reduce crew time for sampling. Certainly, humans are moving the microbes around, but maybe airflow, less so. Thus, we need to determine if it is effective to only monitor air or air filters? We would advocate more experiments on microbial survivability in Mars chambers under different conditions. Looking ahead, they suggested there *should certainly be monitoring on all future crewed missions and upcoming analog missions***.**

Additional Comments re: KG 1B How do we systematically monitor humans for infection markers and exposure to the Mars environment?

Point 1: *The issue of crew health was raised and in particular, the question as to why it was a low priority?*

- It could be that during a mission, a latent infection might emerge that had nothing to do with the environment or space travel. Because this is a concern, the panel felt that it should advocate higher priority. However, there was an expectation that crew health requirements would be developed on earlier mission locations that do not have PP regulations such as moon or orbital flights.

Point 2: *For human health monitoring, a key need is to determine what exactly we are concerned about?*

- There is a need for event detection, not event identification in the first instance. Testing should be done on Earth to look for markers that can be used to identify events.
- For example, what might change ecologically that is detectable and that will help identify a perturbation due to the introduction of a new organism?
- Are there things we can identify that are unique? Essentially, we need to look for deviations from a specific baseline for human health (yet to be established). How do we avoid assuming that any illness acquired in flight is Martian derived? There is a concern about false negatives, and co-infections as well. Can we calculate diversity statistics (e.g. alpha diversity) for existing ISS data to establish such a baseline? Is the current data granular enough? How do we control for confounding variables, (e.g. changes in airflow)? For example, we should be looking for viruses, (e.g., viral reactivation –such as shingles that lead to disease symptoms) which may have been present at the start of a mission.
- Whatever the profile, we certainly need increased sampling frequency, otherwise it will be challenging to determine causation or even correlation with sufficient statistical rigor. Currently the sampling frequency is low and there are a low number of organisms detected.
- Questions still remain about how populations change over time and what causes that change (for example, in biofilm formation, virulence and other gene expression patterns.) Pattern recognition could be used to identify diseases on the ISS, however, it is still difficult because diagnoses are based on reported symptoms. Is there an archive of Apollo samples that could be explored from times when crew reported symptoms like diarrhea?
- Whatever is decided, it is likely that new technology applications such as Raman based autonomous monitoring or near IR and proteomics / antibody-based approach for crew health monitoring will be developed.

Other Points for KG 1B_:

Another important issue that was raised concerns cleanliness itself.

- Is there a problem for human health that may be caused by keeping things too clean? Is beneficial microbiology being destroyed? Do we need to reintroduce it? Perhaps the approach in the first instance would be to look at microbes, then conduct animal exposure studies.
- In addition, there is certainly an argument for talking to other about experiences in analogous environments (e.g. how the ecology of Navy submarines evolves? Or what has the Air Force learned from monitoring air force cadets? We might look to microbial consortia in nuclear environments and commercial companies as well.)
- CubeSats and balloon satellites were suggested for microcosm experiments, but they noted that recovery is difficult. Microcosm experiments might be conducted on NASA's Gateway – which could largely be untended. It was also suggested that witness coupons be developed that could be deployed on the ISS and on new structures (Gateway) as they are being built.

Additional Comments re: KG 1C. How do we design spaceflight systems to mitigate microbial growth**?**

- Opportunities exist for more ground-based research, although lots of work is already happening in this area. PP is a stakeholder but may not be driving the research. One key suggestion raised was whether radiation exposure experiments can be conducted on Earth?

Additional Comments re: KG 1D. What operational guidelines are needed to understand PP concerns and crew health?

Point 1: *The group raised concerns about the validity of assumptions*.

- Again, PP is a stakeholder, but not a driver in this area. The fundamental assumption that microorganisms launched into space would not survive the journey, simply does not apply when sending humans. In order to create conditions in which humans can survive, microorganisms might not just survive, but could potentially thrive. Worse, the microbes would be subjected to selection pressures present in space, which could drive their evolution towards an organism that is better able to survive and tolerate a space environment.
- In addition, the group noted that issues of cleanliness and sterility may need to be reconsidered in the light of future ecological experiments. We simply do not yet know if bioburden reduction is sufficient, or whether it just alters the statistical chances of contamination. The use of culture-based assays (e.g. CFU/m^2) to determine biodurden is known to have its limitations. Viable, but as yet uncultivable, microorganisms in the environment may well have a significant role to play in the ecology of complex microbial communities and we are only starting to investigate the potential of this 'rare biosphere'
- Finally, the group noted two additional concerns/potential problems related to getting information early enough to feed into mission development.
- If we do not thoroughly understand the baseline microbiology before sending humans to Mars, we will never be able to know whether we have forward/reverse contaminated either Mars or Earth.
- What if the KG is not addressed with the right level of confidence? -- Are there major issues that could arise? They noted that a fractional assessment would lead to recommendations based upon an incomplete data set. This would give confidence which would be based upon the balance of probability and not scientific fact (effectively, the compromise with which we currently are working).

<u>Additional Group 1 Comments</u> re: *Locations where KGs might be addressed:*

Location 1*: Ground Based Studies*

Considering recommendations for further work, certainly ground based studies are likely to be primary. In terms of PP, crewed missions are likely to be a higher priority than uncrewed missions (although we can still learn a great deal from uncrewed missions). In the first instance, we need to develop automated collection and monitoring methods, effective witness coupons that can be put on every crewed mission and an integrated database. Here, it is possible to leverage miniaturization of biomedical monitoring equipment. It is essential to have some form of biological contamination sensor on future robotic missions. Through ground-based studies, it should be possible to develop improved methods of automated sample collection, to optimize representative sample collections and explore alternative technologies for the detection of contamination such as via volatile organic compounds, the miniaturization of non-DNA based ID technology for example MALDI-TOF[8] and deep UV sensors. We should be able to look at the issue of sample size and sample coverage, to identify and catalog microbes on surfaces and in the air. Ultimately, the first goal is effective ecological characterization as there is an urgent need to define the baseline.

- Routine sampling/microbial monitoring should be undertaken on all analog missions such as Human Exploration Research Analog (HERA), NASA Extreme Environment Mission Operations (NEEMO), and ESA Caves, with the goal of producing a high density spatial and temporal map with genomic profiles. Such an activity would assist standardization of collection protocols, and lock down collection protocols, test kits and methods.
- The community might also draw upon data from the gut microbiome, the cosmonaut microbiome, the Antarctic microbiome, the built environment, and DNA extraction from Mars simulants. From this information, it would then be possible to develop recommendations for common monitoring protocols. Researchers should also consult public health organizations, the Sloan Foundation, the White House microbiome initiative and the military for "ruggedization" (strengthening to resist wear or abuse).
- The potential also exists to leverage existing datasets by reanalyzing utilizing modern statistical and computational techniques. It is advisable to continue doing some culturing for comparison, however the focus should be on culture independent technologies. We should certainly be monitoring biological systems in space craft, waste recycling, life support and suit leakage experiments -and then try to grow those microbes under Mars conditions.

Location 2**:** *Space Studies*

- The 2025-2030 era will probably involve a focus on data, for example, data transmission rates, data processing protocols, for example, perhaps conducting base calling in orbit and only transmitting processed data, exploring the use of artificial intelligence for monitoring. From a

[8] Matrix-Assisted by Laser Desorption Ionization – Time of Flight Analysis – a mass spectroscopy technique

practical experimentation perspective, the potential exists to use **CubeSat experiments for** collecting information on **bacterial evolution,** especially in terms of pathogenicity expression. We might recommend an extension to the MISSE[9] experiments – essentially a suitcase that one could open up outside and expose to the local environment. Such an approach can benefit from a larger number of samples than EXPOSE-E[10], and also could look at radiation and other effects on microbiota.

Location 3: *The International Space Station*

- There is an **urgent need to expand the sampling potential of astronauts currently in space.** For example, if weekly or daily collection of fecal, skin, blood and swab samples were conducted, we could start building a specimen bank and begin the analysis of already collected samples, using high throughput sample collections and processing. (This is low hanging fruit; pick a swab (not cotton) and start collecting now.) Another opportunity is to collect dust samples and determine whether dust ecology reflects the surface ecology inside the ISS. Dust will also contain food, however, so there might be a need to focus on areas where astronauts don't eat (i.e. not Node 1). There is also need to broaden this activity to get the Russians involved, as they have a different air handling system, different housekeeping, different purification, and different construction materials. Other suggestions include: Take all of the 0.22 µm filters out of the PWD [11]and put it in the freezer every time. Perhaps use deep UV or a handheld UV to identify colonized surfaces. Potentially use Class 1E flight hardware process for COTS (commercial off the shelf) monitors. Investigate the utility of Volatile Organic Compounds. Also start daily or weekly sampling of current astronaut corps.

Additional Considerations:

- *Studies of Astronaut Microbiome* - Refine sampling methods. Improve processing technologies. Focus on crew changeovers (which represent a good starting point for historical data too). Curate samples so that you always have a few in reserve to test on new technologies. Collect a large mass of samples (~hundreds of grams?). Chemostat experiments for long term growth and under simulated space conditions. Flight studies with complex, unknown microbial communities.
- *Mars Surface* - Methods that will identify Earth based contamination are needed. Sample Analysis at Mars (SAM) on the Mars Science Laboratory (MSL) is making measurements that would be relevant. In addition, from 2020-24, Mars2020 could acquire samples to increase contamination knowledge and test contamination control measurements. Use the fetch vehicle for Mars2020 and compare with a blank on ExoMars. Could also perform BioContamination identification for MMX returned samples.

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[9] MISSE: Materials **International Space Station Experiments**

[10] EXPOSE: EXPOSE-E. Experiment carried out on the European Technology Exposure Facility

[11] PWD: ISS Potable Water Dispenser

- *Microbial and Human Health Monitoring* – Like experiments for KG 1, it is essential to have a negative control that is never exposed to the Martian surface, (keep it in the orbiter). This would preclude open cabin processing. There is need for careful confirmation that we have picked up something from Mars and not just perturbed the system by changing the environmental conditions. Take microbes to Mars and purposefully expose them there to understand changes induced in a known system. There is also a need to identify changes in the microbiome due to long term confinement.

Remaining Key Questions Compiled by Group 1:

- Where is the right spot to monitor?
- How clean is clean enough?
- Can one be too clean?
- Is iodine still the right sterilization chemical?
- Have we overlooked back contamination?
- How much knowledge is enough? 95%? 98%? How does one decide?
- How does one characterize the material that the crew is bringing back?
- How long do we need to treat returned samples as a biohazard?
- What if mutated Earth microbes are more dangerous than anything we find on Mars?
- Is there potential to use the Deep Space Gateway as a stopover point for Mars Sample Return and returning astronauts?

3.1.4 Group 1: Overview and Near Term Findings

To summarize, Group 1 focused its discussions on exposure of human explorers to potential Mars life that may/will occur in the context of their ongoing exchange with Earth-sourced commensal organisms. They noted that there are significant synergisms between the Earth safety (PP) interests and issues relevant to assessing the health status of astronauts on a mission to Mars. At this time, ISS is the only useful test bed to get long term and statistically relevant data and trends without the effect of planetary surface operations. Moreover, this knowledge is essential for evaluating health effects (symptoms) of crews returning from Mars as compared with Earth safety (PP).

Overall, Group 1 emphasized the opportunity to *focus on ISS initially* for microbial monitoring relevant to both the crew and space environment, and noted the need to *begin gathering important information related to their 4 KGs, and store data as a biobank to generate a timeline for analysis linked to PP issues.*

Regarding ISS, they suggested the need to; *implement a routine and systematic microbial monitoring of the ISS environment*--both inside and outside -- to fully understand the survival and dispersal of microbes and potential contaminants.

Such monitoring should be

- Routine: weekly (TBD) - but certainly more often than currently done
- Systematic: include monitoring of all ISS modules, surfaces and air (including used filters)

Finally, in implementing a routine and systematic *microbiome monitoring of ISS Crews*, Group 1 indicated that monitoring should be:

- Routine: pre-flight, during flight (weekly, TBD), and post flight
- Systematic: include all ISS crews, and be part of pre- and post-flight medical exams

Group 1: Near Term (thru 2019)

TIME PERIOD	In Flight/Near Term (now thru 2019)													
LOCATIONS	Moon Cis Lunar	Moon surface	Mars orbit		Mars surface			ISS			Ground			Other (e.g, CubeSats, balloons)
TEST/MISSION OPPORTUNITIES			Ody	Maven	Opportunity	InSight	Curiosity	Study A	Study B	Study C	Study X	Study Y	Study Z	MMX
Group 1 Microbial and Human Health Monitoring														
1A. Microbial Monitoring of Environment							SAM on MSL	High throughput processing; high numbers; ADD to standard measures;	Start flying technology		Concurrent tech devel. for monitoring; VOC; Focus on ISS dust, filters, etc,; other nonculture based	Focus workshop to determine advanced capabilities	Standardize processes; low biomass; reanalysis of previous data sets with enhanced technology; polymicrobial experiments; EVA microbial analysis; watch plate tech for later flights (cislunar)	Organic info important
1B. Microbial Monitoring of Humans											Begin analysis of ecosystem monitoring to determine parameters that allow distinguishing of potential changes	ID of changes in the microbiome that would impact overall environment	Research into how an indirect measurement would be conclusive enough to be actionable	
1C. Mitigation of Microbial Growth in Spacecraft Systems											Disinfectant testing			
1D. Operational Guidelines for PP & Crew Health														

Figure 5: Group 1: Near Term

Group 1: 2020-2024

TIME PERIOD	2020-2024											
LOCATIONS	Moon Cis lunar	Moon surface	Mars orbit	Mars surface			ISS		Ground			Other (e.g. CubeSats, balloons)
TEST/MISSION OPPORTUNITIES		CLPS	Hope*/ others	M2020	ExoMars	New Mars lander/rover prior to 2024	Study A	Study B	Study X	Study Y	Study Z	MMX
Group 1 Microbial & Human Health Monitoring												
1A. Microbial Monitoring of Environment				Organic info. important	Organic info . important		Continue BioBank; Address changeovers; large amounts of sample mass; chemostat; quorem sensing	EVA suits after 2024	Increased sampling and sampling opportunities; synthetic genomes in combination; include life support and regenerative systems. Consider international laws on synthetics	Limits of what can go when we are monitoring; Effects of lighting, etc. on microbiota	Updated market survey Report deliverabl e	Organic info impt.
1B. Microbial Monitoring of Humans												
1C. Mitigation of Microbial Growth in Spacecraft Systems							Disinfectant testing					
1D. Operational Guidelines for PP and Crew Health									Yes-TBD			

Figure 6: Group 1: 2020-2024

* *Hope is a Mars mission proposed by the United Arab Emirates*

Group 1: 2025-2030

Time Period	2025-2030								
Location	Moon cis lunar	Moon surface	Mars orbit	Mars surface		ISS	Ground		Other (e.g. CubeSat, balloons)
Mission & Test Opportunities			MACO	MSR (NASA-ESA)	Any future landing elements	Study A	Lab based survival expts	Lab based/ model wind tunnel measurements	Mars lower atm vehicles
Group 1 Microbial & Human Health Monitoring									
a. Microbial Monitoring of Environment								Integration of Earth databases w/Mars missions & how much we carry with us.	
b. Microbial Monitoring of Humans									
c. Mitigation of Microbial Growth in Spacecraft Systems	Disinfectant testing								
d. Operational Guidelines for PP & Crew Health	Y	Y							

Figure 7: Group 1: 2025-2029

Group 1: 2030 and Beyond

TIME PERIOD	2031 Onward									
LOCATIONS	Moon & cis lunar	Moon surface	Mars orbit		Mars surface		ISS	Ground		Other (e.g. CubeSats, balloons)
TEST/MISSION OPPORTUNITIES					Any landing element			Lab based survival exps	Lab based /models /wind tunnel measmts.	
Group 1 Microbial and Human Health Monitoring										
1A. Microbial Monitoring of Environment										
1B. Microbial Monitoring of Humans										
1C. Mitigation of Microbial Growth in Spacecraft Systems										
1D. Operational Guidelines for PP and Crew Health										

Figure 8: Group 1: 2030 and Beyond

3.2 Group 2: Technology and Operations for Contamination Control

Led by Michelle Rucker and Julie Mitchell

3.2.1 Initial Information & Assumptions

Group 2 assumed that technological advances in regards to contamination monitoring and operations will continue to be made in the coming years. They also assumed that the International Space Station will continue to be operated and available for PP research until the mid-2020s. [NOTE: Due to time limitations, and the lengthy list of KGs, not all KGs were discussed to the same level of detail.]

3.2.2 Group 2: Observations and Suggestions

The group reviewed each of the KGs and recorded observations and suggestions as follows:

<u>KG 2A. Bioburden/Transport/Ops during Short v. Long Stays</u>

The requirements for contamination transportation on Mars with respect to crew operations depend highly on the expected survivability of microorganisms on the Martian surface. Therefore, a series of laboratory tests to understand the persistence of bioburden under Mars conditions will be necessary in the coming years, though this task falls under the Group 3 category.

In addition, any suite of Mars-tolerant organisms must be coupled with the expectation that such organisms would actually be carried by the spacecraft or crew. For example, some radiation-tolerant bacteria are only found in specific natural environments on Earth and are not expected to live in, on, or near a habitat/space suit. Therefore, while such an organism could survive on Mars, its likelihood of its presence on the spacecraft is low.

The likelihood of bioburden transfer to the Mars environment must be studied as a function of time. Short stays on the Martian surface may not necessitate large waste disposal; however, longer stays would require such a capability which would pose a forward contamination risk. The prevalence of certain species will likely change with time, and could reach a steady state for long-duration stays. Therefore, *we recommend bioburden assessments of existing spacecraft, such as ISS*. Such studies will be critical to understanding how bioburden – both in terms of species present and their relative abundances – changes over time within and outside of a spacecraft.

Additionally, after the bioburden has been sufficiently characterized on existing spacecraft/analogs (such as ISS or NEEMO), *microbial cleanliness operations should be assessed to determine the best practices for preventing forward and backward contamination.* Such a study would also need to include the microbial monitoring of consumables and assessment for both intravehicular activity (IVA) and EVA operations. New spacecraft, such as NASA's proposed Gateway, would be ideal targets for microbial monitoring for both initial short- and long-term operations.

In lieu of empirical observations on Mars or detailed modeling efforts, bioburden assessments of existing Mars analog locations should be conducted, including for example Antarctic field sites and Haughton Crater near the North Pole. The distribution of microbial burden at and near human camps, along with measurements of transport from those locations, would provide useful data for developing models of biological transport on Mars and requirements for human missions in regards to habitat design and spacecraft operations. They also noted that modeling efforts by Group 3 will likely provide critical insights. In addition, dust mitigation strategies developed for lunar operations can be adapted for Mars operations.

KG 2B. Acceptable levels of microbial/Organic Releases from humans and support systems

Several issues were raised in regards to this KG, and a consensus quickly was reached that this KG represents a high-level requirement that applies to and impacts all three study Groups. By defining the acceptable microbial and organic releases from the spacecraft, detection limits and target organisms/compounds for microbial monitoring equipment can be defined. Allowable release of materials from the habitat and space suits (air, liquids, waste, heat, etc.) can also be defined once the allowable microbial limits are determined. Modeling efforts can illustrate how far microbes can be transported at threshold/allowable levels. *Therefore, the group recommends that this KG is elevated to apply to all groups and microbial survival studies (outlined in KG 2A above) are conducted as soon as possible to provide the necessary inputs for such a requirement.*

After the acceptable levels of microbial release on Mars have been defined, specific spacecraft requirements can be developed. For example, estimates can be made of the bioburden in the spacecraft atmosphere, and those estimates can inform spacecraft leak requirements. Leak and vent rates on ISS are well known and have been tracked extensively; therefore, we recommend an assessment of ISS leak microbial leak rates based on existing knowledge of interior bioburden and empirical measurements of bioburden detected on the spacecraft exterior.

An important component of microbial leak rate requirements is estimates of duration and distance that bioburden could be transported on the Martian surface. In addition, the transport of other organic compounds/anthropogenic gases should be incorporated into a Martian global climate model, under the purview of Group 3.

As discussed above, laboratory experiments on viability of certain species that could survive on Mars surface/near-surface should be conducted. This includes thermodynamic modeling of the near-habitat environment and how that environment will be altered by the presence of humans, hardware, equipment, etc. Some microbial species may be more viable in environments local to the habitat than farther away, and that relative viability should be well-defined and better understood. Once these levels of viability have been assessed, acceptable dispersion levels from the habitat as a function of distance can be developed.

The idea was presented that Mars robotic PP requirements can be used as a starting point. By measuring the allowable bioburden for a robotic mission, transport of microorganisms and the persistence of certain robust species can be assessed. Then, the likelihood of transport into special regions can be determined. This understanding of robotic impacts on Mars can be used as a point of comparison for expected bioburden transport levels from a human habitat. The degree of variation between the two values could provide useful insights for understanding the degree to which allowable bioburden requirements will need to be adjusted for human missions.

KG 2C. Protocols (Decontamination/Verification/Monitoring) to Remediate Releases

The group quickly determined that *this KG should be split into two distinct scenarios: nominal operations and off-nominal operations in terms of microbial/organic releases from humans and support systems.* Numerous points of reference exist for both operational regimes, including terrestrial containment protocols and ISS flight rules/emergency operations planning. For example, the Centers for Disease Control (CDC) and World Health Organization (WHO) have protocols for both low-risk (low Biosafety Level or BSL) and high-risk (i.e. BSL 4/highly contagious/high mortality rate) terrestrial outbreak scenarios. These protocols should be reviewed to understand the existing effective strategies, along with difficulties yet to be overcome. Additionally, ISS waste and/or chemical release procedures should be reviewed to understand how off-nominal scenarios are handled on existing spacecraft, what consumables are needed for cleanup activities, and the effectiveness of various crew personal protective equipment during in-flight operations.

A comprehensive survey of nominal and off-nominal release scenarios should be generated for a Mars mission. Coupled with this survey, modeling of potential releases should be conducted to understand best- and worst-case bioburden levels in/near/around the habitat, and how that bioburden could be transported across Mars.

KG 2D. Design of Quarantine Facilities/Methods

The mission phases during which quarantine facilities will be needed must be identified. For example, EVA egress and ingress are clear portions of the mission for quarantine—however, crew return to an orbiting vehicle (if used) should also be addressed in addition to the return of the crew to Earth. Additionally, a survey of existing quarantine experience/protocols should be assessed, including the Apollo missions (both EVA ingress/egress and return to Earth), ISS operations, CDC/WHO operations for low and high-risk microbial exposure, etc. These protocols can then be linked to the relevant mission phases and further studies completed to understand what technologies are needed for future quarantine efforts.

KG 2E. How do Mars Environmental Conditions vary over time with respect to growth of Earth microbes?

Group 2 recommends a reassessment of this Knowledge Gap to allow for more specific investigations. As it is written, this KG does not address technology or operations impacts, nor does it directly allow for requirements to be developed for those subjects. In addition, naturally-occurring Mars conditions (e.g. Special Regions produced due to warming from diurnal/annual solar insolation) should be distinguished from anthropogenic conditions (e.g. localized warming in proximity to the habitat and the potential for induced Special Regions).

KG 2F. Requirements needed to make ISRU & PP goals compatible.

The group noted that the current mission paradigm does not rely on in-situ materials for crew water, building materials, or other resources. Therefore, the initial crew will only characterize the potential for, not use the resources in the region of the habitat . In this context, the first mission(s) will likely only include O_2 production from Martian atmosphere. After this initial mission, ISRU activities can be considered on a more detailed level.

KG 2G. "Acceptable Contamination” levels of wastes left behind?

Acceptable levels of microbial release, both in terms of allowable species and their relative abundances, need to be defined before this KG can be completed. Per the recommendation in KG 2B above, a group-wide requirement for allowable microbial levels must be produced first. Only then, can requirements be determined for such issues as constraints on vented materials, levels of sterilization of wastes, and the actual ‘disposal’ of wastes.

FORMER KG 2H. DELETED

KG 2I. Approach to Achieve “Break the Chain” Requirements?

First, the existing requirements for robotic Mars Sample Return should be reviewed and understood, and as well as the hardware used by the mission. The logic behind the robotic sample return requirements and protocols should be carried over for human Mars exploration as well. Such protocols can be applied in a lunar environment, and their effectiveness in a partial-g/crewed scenario explored.

KG 2J. Global Distribution/Depth of subsurface Ice – and evidence of Extant life?

Existing remote sensing and rover-based datasets should be combined for concept studies to understand the depth and distribution of subsurface ice on Mars. A future Mars orbiter with synthetic aperture radar (SAR) will be needed to quantify the distribution/abundance of ice and its changes over time. Existing studies in Antarctica have numerous applications for PP. Drill testing in Antarctica, including its lessons learned, along with assessments of life from previously unexplored habitats, provide an excellent framework by which to begin Mars-relevant PP planning.

KG 2K. Evolution of PP Requirements/goals from robotic to Human Missions & zones?

In addition to the studies proposed in 2J, which the group decided were also relevant to 2K, we need a pragmatic, but well-described working transport model. As described in KG 2B above, we can begin with the robotic requirements and compare those to expected bioburden release rates from the habitat. Quantifying the differences between human output and existing robotic requirements will help to constrain the degree to which human requirements will diverge from their robotic equivalents.

3.2.3 Group 2: Comments on Additional Test Opportunities

The group also identified opportunities for research and testing that could be realized both in space and ground based analogues.

Ground-Based Studies

Numerous laboratories, modeling, and analog efforts can and should be conducted on Earth to support future PP requirements development for human missions. To assess allowable bioburden levels, their levels of transport, and operational scenarios for stays of varying lengths, we recommend laboratory tests relevant to: a) which species could survive on the Martian surface and subsurface, and b) which of those species are likely to be present on a human-rated spacecraft. Bioburden assessments of existing Mars analog locations, such as Antarctic field study sites, NEEMO, Haughton Crater, Iceland, and others can and should be conducted. Existing field studies of new/extremophile organisms, such as in Antarctica, should be studied to determine what microbial monitoring, technologies, and field operations have been both successful and unsuccessful in preventing bioburden release from humans in/near the study site. Existing CDC/WHO/etc. protocols for biological releases, and how they are managed, what hardware and consumables are used, and what technologies have been effective or ineffective in preventing microbial release should be studied as well.

Modeling of bioburden and organic transport/dispersion levels from the habitat to the rest of Mars using a GCM should be conducted. Thermodynamic modeling of the near-habitat environment should be conducted to assess the presence and number of induced special regions (if any), and which species would be viable in those locations. This modeling should also include the natural diurnal and annual/seasonal cycles and the temperature/compositional changes that accompany those cycles. Potential nominal and catastrophic releases of bioburden should also be modeled to assess the nominal and worst-case delivery/transport of bioburden and organic compounds from the habitat to the rest of Mars.

Space Studies

The International Space Station provides an excellent opportunity for characterizing the microbial presence in a human-rated environment and for testing technologies/operations protocols that are effective in space. Bioburden assessments of the ISS, using both existing (Petri-dish-based) and modern (DNA sequencing, etc.) should be compiled into a long-term microbial characterization. Additionally, previous experience in understanding what microbial cleanliness operations work, and don't work, should be assessed along with the consumables impact for microbial monitoring. Microbial monitoring for EVA operations should be conducted as soon as possible to assess effective technologies and operations protocols, and to characterize the degree of contamination to the exterior of the vehicle (if any). Leak rates of air, liquids, wastes, heat, and other relevant parameters must be compiled for ISS to serve as a baseline for a future Martian habitat. This will allow (actual vs. estimated) leak rates on Mars to be characterized and integrated into modeling efforts. ISS protocols for nominal and off-nominal waste and chemical clean-ups should be reviewed and lessons-learned integrated into PP requirements development efforts.

Bioburden assessments of new spacecraft, including Gateway, must be conducted when those vehicles are operational. When crews conduct lunar operations, operations management should use an iterative approach – building on and adapting from one mission to the next - for mitigation of crew to dust exposure. This information will translate well to Mars EVA operations and the prevention of backwards contamination of the crew. PP and microbial mitigation technologies and operations can and should be tested in a lunar environment to assess their effectiveness in relevant space environments. Additionally, waste disposal during lunar operations can be studied and relevant lessons-learned in waste containment applied to Mars.

On Mars, dust characterization and modeling, including particle size distribution and composition of dust, should be conducted to understand transport levels and mechanisms on Mars. A new Mars orbiter for year-round weather monitoring will be necessary to assess the accuracy of models and provide relevant weather pattern data. This orbiter should also have SAR capability to quantify the distribution and abundance of ice, both on the Martian surface and subsurface. Additionally, a next-generation weather station network, or multiple stations operational on Mars should be established as soon as possible. Mars Sample Return break-the-chain requirements, protocols, hardware, and technologies should be reviewed and lessons-learned applied to human Mars exploration. Drilling operations on Mars, either by a human crew or robotically (i.e. controlled from orbit) can help to verify/support remote sensing observations. Similar to lunar operations, Mars operations should be conducted in an iterative approach, where lessons-learned for one mission are integrated and applied to future missions.

3.2.4 Group 2: Key Questions Remaining

i. What is/are the allowable microbial levels on the Martian surface? This includes species-specific requirements for distance from the habitat, time of year, and depth within the subsurface (zero to varying meters deep, etc.).
ii. How do allowable microbial levels translate into allowable leak rates from the vehicle? For air? For liquids? For waste? For heat? For other parameters?
iii. Should leaked materials be actively sterilized prior to release on Mars? To what level, and how?
iv. To what level of accuracy should acceptable microbial levels be characterized and constrained?
v. How far from the habitat can a microbe be transported?
vi. What microbes could survive on the surface of Mars? For how long? Are they likely to be transported by a human crew?
vii. What previous experience with terrestrial, lunar, or orbital operations can help with assessing the technology gaps needed to address KGs?
viii. What previous experience can help with developing protocols/procedures/operations paradigms for Mars operations by a human crew?
ix. How do we integrate PP assessments with lunar orbit or lunar surface exploration activities? How to we integrate lessons learned from lunar operations to Mars surface operations?
x. What lessons-learned, technologies, operations and/or protocols enacted by the CDC/WHO for terrestrial outbreaks can be applied to PP requirements development? What hardware and/or consumables are required for those operations?

3.2.5 Group 2: Recommended Activities

The knowledge gaps for Technology and Operations for Contamination Control began with deliberations of initial suggestions for experiments and data gathering that could be conducted in the immediate future, using existing technology. Deliberations then led to more Specific Recommendations included indications of which KGs were considered **Mandatory** and of high **Priority**.

<u>KG 2A. Bioburden/Transport/Ops during Short v. Long Stays</u>

The group noted the importance of measuring species and conditions of microbes that could survive under Mars conditions. In addition, they indicated that bioburden assessments should be conducted in available relevant environments, along with assessment of the efficacy of existing bioburden control operations. The following list of ten specific recommendations were made, six of which were considered **Mandatory**.

i. Laboratory tests of bioburden persistence (species and persistence) under Mars conditions (though this likely falls under Group 3 purview) - **Mandatory**
ii. Conduct bioburden assessments of existing relevant spacecraft environments, such as ISS, including assessments of existing bioburden and changes over time, what microbial cleanliness operations work/ don't work (efficacy of bioburden control measures), microbial monitoring/assessment of consumables, EVA operations, and impacts for microbial monitoring and degree of contamination to the exterior of the vehicle (if any) - **Mandatory**
iii. Bioburden assessments of existing Mars analog locations, including Antarctic field sites and Haughton Crater near north pole, and the distribution of microbial burden near human camps
iv. Bioburden assessments of new spacecraft, including Gateway - **Mandatory**
v. Assessments of contamination at Apollo landing sites, including chemical and particulate
vi. Iterative operations management during lunar operations for mitigation of crew to dust exposure
vii. Mars dust characterization and modeling, including particle size distribution and composition
viii. Mars orbiter for year-round weather monitoring - **Mandatory**
ix. Next-generation weather station network, or multiple stations operational on Mars (needs to be done soon) - **Mandatory**
x. Use an iterative approach for lessons learned for Mars surface operations, and adapt lessons learned to subsequent activities– **Mandatory** *(after humans on Mars)*

<u>KG 2B. Acceptable levels of microbial/organic releases from humans and support systems</u>

The Group noted that a number of KGs from other groups also feed from this KG, and thus recommended *moving KG 2B up in priority* for all Groups, on the basis that early decisions are needed to maintain hardware design and delivery schedules. In particular, leak rates of previous, existing, and future vehicles should be studied. This should include GCM of relevant gases and lab experiments on viability of certain species that could survive on Mars surface/near-surface. In addition, leak rates should be studied with GCM to determine acceptable dispersion levels of microorganisms. The specific recommended experiments and data gathering include:

i. Leak and vent rates on ISS vehicle and the probability of that leak mass for being transported to a special region and exceeding existing robotic mission requirements
ii. GCM of methane, other relevant anthropogenic gases (group 3 purview)
iii. Lab experiments on viability of certain species that could survive on Mars surface/near-surface
iv. Thermodynamic modeling (using GCM and focusing on leak rates) of near-habitat environment-- and determine whether/ how some species may be more viable local to habitat than further away. Need to assess acceptable dispersion levels of microorganisms depending on distance from the habitat. Need to assess robotic requirements for Mars and whether we can/should carry those over to Mars operations. We have to ensure robotic levels at the sites of high preservation priority (i.e. Special Regions). Need to work forward with existing leak rates on ISS and see how that information matches with robotic requirements on Mars. Do they match? If not, we need to reassess the technology requirements

KG 2C. Protocols (Decontamination/Verification/Monitoring) to Remediate Releases - both *nominal and off-nominal*.

In their discussions, the group highlighted the need to review current ISS protocols for waste/chemicals/etc. and consider how clean-up is handled in space situations They noted the need for modelling of potential releases and understanding CDC/WHO/etc. protocols for biological releases—with a focus on how they are managed under different conditions. Specific rcommendations include the following, four of which were identified as Mandatory:

i. Review ISS protocols for waste/chemical/etc. – with clean-up as a frame of reference
ii. Modeling of potential releases and testing. Need a comprehensive survey of what could go wrong, looking at physics differences between Earth and Mars- **Mandatory in the coming decade**
iii. Understanding CDC/WHO/etc. protocols for biological releases, how they are managed
iv. Testing procedures, protocols, monitoring, on the lunar surface with a human crew **– Mandatory**
v. Implementation of previous monitoring and remediation protocols, iteratively adapting based on lessons learned. - **Mandatory**
vi. After mission is complete, how are residual wastes contained, and do we care? (if yes, we need to assess mitigation) - **Mandatory**

<u>KG 2D. Design of Quarantine Facilities/Methods</u>

Looking ahead, there is need to analyze in advance what facilities, containment methods etc. are appropriate for different mission phases. Before formal recommendations are made, the Group indicated that there is a

i. Need to delineate what methods are appropriate for different mission phases

KG 2E. How do Mars Environmental Conditions vary over time with respect to the growth of Earth microbes?

Before specific recommendations can be made about this Knowledge Gap, considerable new data must be gathered about both Mars and Earth microbes. The Group suggested the need to:

i. Gather new data – either at analogue sites or on Mars-- with a focus on mission related environmental scenarios, including natural, nominal and off nominal situations. For example the possible production of localized, induced Special Regions near infrastructure could result from habitat-associated heat and the production of water ice. It will be important to understand the relevance of how Mars conditions and terrestrial microbial scenarios may be linked with technology/infrastructure/and operations development

KG 2F. Research is needed to make ISRU & PP goals compatible.

i. They noted that current mission paradigm does not rely on local resources for crew water or other resources. Therefore, the initial crew can survey and characterize the potential of resources in the region of the habitat. In this context, the first mission is assumed to depend on only O_2 production from Mars atmosphere.
ii. There will be need to consider other ISRU activities on Mars as they arise.

KG 2G. What is "Acceptable Contamination' of wastes left behind?

i. There is need to establish constraints on vented materials – but this needs to be defined by Group 3 at a later time.

FORMER KG 2H. DELETED

KG 2I. Approach to Achieve 'Break the Chain" Requirements?

i. There is need to assess existing requirements for Mars Sample Return missions as they are refined.
ii. There is also need to test break-the-chain protocols in partial-g environment during lunar operations
iii. There is need to test “breaking the chain” protocols on Mars for Mars Sample Return

KG 2J. Need to develop information on Global Distribution/Depth of subsurface ice-- and possible evidence of Extant life? To address this KG, the group recommended combination of analogue and space mission activities/ :

i. Concept studies and implementation analyses for radar, neutron, etc., combining datasets
ii. Terrestrial life detection studies, such as Antarctic studies for indications of life in the ice,

iii. Mars orbiter with SAR to quantify the distribution/abundance of ice and its changes over time – **Mandatory**
iv. Drill testing in Antarctica with the objective of integrating lessons learned from previous exploration drilling
v. Surface drilling and testing at locations where radar indicates ice
vi. On-site drilling by human crew – **Mandatory**
vii. Remote operations from orbit or surface; with tests of drilling capabilities

KG 2K. Need to study the Evolution of PP Requirements and goals from robotic to Human Missions & varied environmental zones?

i. Need some concept studies for radar, neutron, etc., combining datasets
ii. Use Antarctic studies for indications of life in the ice
iii. Need some kind of pragmatic, but well-described working model, -- which can continue to be refined as a working model over the coming years

3.2.6 Group 2: Specific Recommendations

Addressing the 10 KGs related to *Technology and Operations for Contamination Control* will depend on integrating information and findings from the other two groups (Microbial Monitoring as well as Natural Transport) along with a combination of R&TD activities that occur over time (from near term opportunities available in three locations and eventually feed forward to future robotic and human missions on Mars. Building on their deliberations and KGs they identified specific near term opportunities in three locations

ISS

- Studies during normal operations to understand bioburden production/degree of contamination; Assess cleanliness levels, leak rates/transport; Protocols for waste/clean up; & Microbial contamination during EVA operations.

- External and internal swabbing identified as *high priotity* to assess bioburden production & spread from vents and habitat areas. **Mandatory**

Ground & Analogue Studies

- Determine Bioburden levels/releases from Arctic & Antarctic field camp; Microbial levels inside-, outside- & far from habitats; Studies for indications of life in ices
- Lab expts. on viability of microbes under extreme conditions; Modelling to asses/compare leak rates with ISS and Mars tech designs; Modelling/testing releases of Anthropogenic gasses; Testing with regolith & water ice for relevant data.
- Understand CDS/WHO protocols for biocontainment; consider MSR containment (break the chain)

Mars

- Collect relevant data on Martian environmental conditions & partitioning etc.; modelling & weather testing

Group 2: Group agreed that closing all the knowledge gaps in a timely way for the first "boots on Mars" mission in 2037 is a challenging schedule, given the need for information to feed-forward into engineering design. Based on the Excel sheets, GROUP 2 recommended an iterative approach to addressing KGs, starting with NEAR TERM and 2020-24 actions in different locations, with indications of what was considered both important (**Priority**) and/or **Mandatory** for addressing their various KGs (and time periods)

KG 2A. Study the Effect of Biocidal Factors on survival/growth/adaptation of microbes on Mars

Mars:

i. 2020 pre-mission modelling **Mandatory**
ii. MSL weather data **Mandatory**

ISS:

i. Assess microbial cleanliness operations, (swabbing) **Mandatory**
ii. Assess EVA operations & degree of contamination **Mandatory**

Ground:

i. Study Bioburden levels @ Antarctic and Arctic human field camps **Mandatory**

KG 2B. Microbial Monitoring of Humans (recommend moving 2B up in priority for all groups)

ISS- Study Leak & vent rates;

i. Determine the Probability of leak mass being transported to a special region (this was identified as a near term **Priority**)

Ground:

i. GCM of methane, other anthropogenic gases (group 3)
ii. Lab experiments on viability of microbes able to survive on & near the Mars surface and in the shallow sub-surface
iii. Thermodynamic modeling

KG 2C. Assess Protocols (Decontamination/Verification/Monitoring) to Remediate Releases under both nominal & off-nominal situations

- **ISS:**
  i. Review ISS protocols for waste/chemical clean-up as frame of reference.
- **Ground:**
  i. Modelling/ testing of potential releases - compare Earth & Mars differences and comparative survey of what could go wrong .
  ii. Understanding CDC/WHO and similar protocols for biological releases and how they are managed.

KG 2D. Consider Design of Quarantine Facilities/Methods -for different phases

- **Ground:**
  i. Field Operations

KG 2E. How do Mars Environmental Conditions vary over time with respect to growth of Earth microbes

Mars:

i. Subsurface thermal/heat flow measurements on InSight?

Ground:

i. Assess implications of local Spec. Regions from heat sources; Consider design implication for Mars Special Region requirements, and
ii. Ground Testing with regolith, water ice, etc. to get relevant data.

KG 2F. Research needed to make ISRU & PP goals compatible

Mars

(Initially ISRU on Mars missions will only be for oxygen production - but need to characterize other potential resources in region of habitat as well.)

KG 2G. Determine "Acceptable Contamination" by wastes left behind? What Constraints should there be on vented materials? . *(No Comments listed for near term or 2020-2025*)

KG 2I. Develop an Approach to Achieve 'Break the Chain' Requirements

Ground:

i. In context of MSR

KG 2J. Study how to assess Global Distribution and/Depth of subsurface Ice, and evidence of Extant life?

Mars

ii. Data from MRO, ODY

Ground

i. Concept studies for radar, neutron, etc.; combining data sets.
ii. Antarctic studies for indications of life in ice

KG 2K. Evolution of PP Requirements/ goals include shift from robotic to Human Missions & different zones**?**

Ground:

i. Need pragmatic, well described working transport model.

Group 2: Near Term (thru 2019)

TIME PERIOD											In Flight/Near Term (now thru 2019)						
LOCATION	Moon cis lunar		Moon surface	Mars orbit					Mars surface		ISS			Ground			Other (e.g. CubeSats, balloons)
GROUP 2 Technology & Operations for Contamination Control																	
2A. Bioburden/Transport /Ops during Short vs. Long Stays	N		N	N	N	N	N	N	Y, 2020 (pre-mission modeling), Y - MSL weather data	Y, PHX (dust characterization)	Y (swabs to assess bioburden production external to vehicle). Considered **MANDATORY**	Y - microbial cleanliness operations - what works, what doesn't, consumables for cleanliness	Y - EVA operations and degree of contamination	Y - Antarctic field operations, distribution of microbial burden near human camps	Y - Haughton Crater near north pole		
2B. Acceptable levels of microbial/Organic Releases from humans and support systems (NOTE: other KGs feed into this KG, along with inputs from other Groups). Recommend moving this up in priority for all Groups											Y - leak and vent rates on ISS vehicle and the probability of that leak mass for being transported to a special mission and exceeding existing robotic mission requirements			Y - GCM of methane, other anthropogenic gases (group 3)	Y - lab experiments on viability of certain species that could survive on Mars surface/near-surface	Y - thermodynamic modeling of near-habitat env. (some spp may be more viable local to hab than further away). Need assess acceptable dispersion levels by distance from the habitat.) ***SEE NOTE BELOW****	
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases - both nominal and off-nominal NOTE: need to separate these into nominal vs. off-nominal drivers											Y - review ISS protocols for waste/chemical/ etc. clean-up as a frame of reference			Y - modeling of potential releases and testing. Need a comprehensive survey of what could go wrong, looking at physics differences between Earth and Mars	Y - understanding CDC/WHO/etc. protocols for biological releases, how they are managed		
2D. Design of Quarantine Facilities/Methods -for different phases																	
2E. How do MarsEnv Conditions vary over time wrt growth of Earth microbes. Includes localized production of Special Regions near hab due to heat and possible production of water ice. Need to make this clearer to show relevance for technology/infrastructure/ops development. Recommend splitting induced special regions from natural ones.									Y - InSight will provide subsurface thermal/heat flow measuremts					Y - Need to assess implications of localized special regions due to heating from any heat source. Need to consider design implications for meeting special regions requirements.	Y - ground testing with regolith simulants, water ice, etc. to get relevant data.		

Group 2: Near Term (cont'd)

TIME PERIOD											In Flight/Near Term (now thru 2019)						
LOCATION	Moon cis lunar		Moon surface	Mars orbit					Mars surface		ISS			Ground			Other (e.g. CubeSats, balloons)
2F. Res. needed to make ISRU & PP goals compatible. NOTE: current mission paradigm does not rely on local resources for crew water, resources. Therefore, the initial crew can characterize potential of resources in the region of the habitat. In this context, the first mission is only O2 production from Mars atmosphere. Will need to consider other ISRU activities on Mars as they arise.																	
2G. "acceptable contam' of wastes left behind? Constraints on vented matls.																	
FORMER 2H. DELETED																	
2 I. Approach to Achieve 'Break the Chain" Requirements?																	
2J. Global Distrib/Depth of subsurf. Ice-- and evidence of Extant life?				**	N	N	N	N	N	N	N	N	N	Y - some concept studies for radar, neutron, etc., combining datasets	Y - Antarctic studies for indications of life in the ice		
2K. Evolution of PP Reqmets/goals from robotic to Human Missions & zones?																	

*NOTE: **2B Ground**: Need assess robotic requirements for Mars & whether can/should carry over to Mars operations. Must ensure robotic PP levels at high-priority sites (i.e. special regions). Work forward with existing leak rates on ISS to determine robotic reqmts on Mars--& reassess the technology requirements

**** 2J:** Global Distribution /Depth of Ice --MRO, ODY

Figure 9: Group 2: Near Term

Group 2: 2020-2025

Time Period	2020-2025										
Location	Moon surface	Mars orbit	Mars surface			ISS		Ground			Other (e.g. CubeSa
Mission/Test Opportunity	CLPS	Hope/others	M2020	ExoMars	New Mars lander/rover arriving prior to 2024	Study A	Study B	Study X	Study Y	Study Z	MMX
GROUP 2 Tech & Ops for Contamination Control											
2A. Bioburden/Transport /Ops during Short v. Long Stays	Y - Gateway-based sampling of Apollo sites to assess previous bioburden	Y - next Mars orbiter (weather measuremts) **CONSIDERED MANDATORY**	Y - Mars 2020 (weather measurements, particle size distribution, ISRU), AES future Mars studies	Y - ExoMars (organic molecule analyzer, weather/dust), InSight (weather station)		Y - ISS, bioburden swabbing **CONSIDERED MANDATORY**		Y - Antarctic field operations, distribution of microbial burden near human camps	Y - Haughton Crater near north pole	Y - lab tests of bioburden persistence under Mars conditions (group 3) **CONSIDERED MANDATORY**	No lunar Cube Sats on EM1?
2B. <u>Acceptable levels</u> of microbial/Organic Releases from humans &support systems (NOTE: other KGs feed into this KG, along with inputs from other Groups). Recommend moving this up in priority for all Groups	Y - Gateway-based sampling of Apollo sites to assess previous bioburden										
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases - both nominal and off-nominal NOTE: need to separate these into nominal vs. off-nominal drivers						Y - review ISS protocols for waste/chemical/etc. clean-up as a frame of reference		Y - modeling of potential releases & testing. Need comprehensive survey of what could go wrong; look at physics differences between Earth & Mars	Y - understanding CDC/WHO/etc. protocols for biological releases, & how managed		
2D. Design of Quarantine Facilities/ Methods for different phases						Yes-		Yes- TBD			
2E. How do Mars Environmental Conditions vary over time wrt growth of Earth microbes? Includes localized production of Special Region due to heat from hab & possible production of water ice. **2E** continued			Y - Need characterize geotechnical properties of Mars regolith & subsurface to allow prediction where induced Special Regions could be formed on Mars surface. Monitor salts & hydrated minerals in proximity to habitat **to** understand potential for forming								

Group 2: 2020-2025 (cont'd)

Time Period	**2020-2025**										
Location	Moon surface	Mars orbit	Mars surface			ISS		Ground			Other (e.g. CubeSa
Mission/Test Opportunity	CLPS	Hope/others	M2020	ExoMars	New Mars lander/rover arriving prior to 2024	Study A	Study B	Study X	Study Y	Study Z	MMX
			a Special Region. (study both natural and induced Special Regfions)								
2F. Res.needed to make ISRU & PP goals compatible . NOTE: current mission paradigm does not rely on local resources for crew water, etc. Thus, initial crew can characterize potential of resources in the region of the habitat. In this context, the first mission is only O2 production from Mars atm. Will need consider other ISRU activities on Mars as they arise.											
2G. "acceptable contam' of wastes left behind? Constraints on vented materials.											
2 I. Approach to Achieve 'Break the Chain" Requirements?								Y - in context of MSR			
2J. Global Distrib/Depth of subsurf. Ice-- Evidence of Extant life?		Y - Mars orbiter with SAR to quantify distribution/ abundance of ice and changes over time (**MANDATORY**)						Y - Drill testing in Antarctica, Lessons learned from previous drilling			
2K. Evolution of PP Reqmts/goals from robotic to Human Missions & zones?								Y - proceeding with refinements to working model			

Figure 10: Group 2: 2020-2024

Group 2: 2025-2030

Time Period	2025-2030								
LOCATION	Moon cis lunar	Moon surface	Mars orbit	Mars surface		ISS	Ground		Other (e.g. CubeSats
Mission/ Test Opportunities			MACO	MSR (NASA-ESA)	Any future landing elements	Study A	Lab based survival exps	Lab based/model wind tunnel measure ments	Mars lower atmosph
GROUP 2 Technology & Operations for Contamination Control									
2A. Bioburden/Transport /and Ops during Short v. Long Stays	Y - Gateway bioburden assessmnts continuing- **MANDATORY**	Y - sample prioritization for Apollo sites, return to Earth, Human lander/ activities/EVA on lunar surface adding to bioburden, how well do bioburden mitigation technologies work? EVA distance & freq. may increase w/ longer stays on surface, short vs long operations for bioburden mitigation, iterative operations - changing ops based on previous lessons learned	Y - next Mars orbiter (weather measurmts) **MANDATORY**	Y - next-gen weather station network/multiple stations operational on Mars (should be done sooner) **MANDATORY**		Y - but depends on status/ availability for NASA	Y - more advanced modeling based on previous lunar, Mars, and laboratory data (group 3)	Y - Continued surface ops in Antarctica, north pole, etc.	
2B. <u>Acceptable levels</u> of microbial/Organic Releases from humans and support systems (NOTE: a lot of other KGs info feed into this KG,)Recommend moving 2B up in priority for all Groups									
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases - both nominal and off-nominal NOTE: need to separate these into nominal vs. off-nominal drivers		Y - testing procedures, protocols, monitoring, on the lunar surface with a human crew **MANDATORY**					Y - modeling / testing of potential releases. Need comprehensive survey of what could go wrong, looking at physics differences between Earth & Mars. **MANDATORY**	Y - understanding CDC/WHO/etc. protocols for biological releases, how they are managed	
2D. Design of Quarantine Facilities/Methods -for different phases	Y	Y				?			
2E. How do MarsEnv Conditions vary over time wrt growth of Earth microbes. Includes localized production of special region near hab due to heat from hab and possible production of water ice. Need to make this clearer to show relevance for technology/infrastructure/ops development. Recommend splitting induced special regions from natural ones .				Y - design surface systems to mitigate formation of special regions based on previous testing/characterization of Mars regolith/ice properties			Y - ground testing w/ regolith simulants, water ice, etc. to get relevant data. For high-fidelity simulants; ground tests of flight hardware to determine they aren't inducing special regions.		

Group 2: 2025-2030 cont'd

Time Period	2025-2030								
LOCATION	Moon cis lunar	Moon surface	Mars orbit	Mars surface		ISS	Ground		Other (e.g. CubeSats
Mission/ Test Opportunities			MACO	MSR (NASA-ESA)	Any future landing elements	Study A	Lab based survival exps	Lab based/model wind tunnel measure ments	Mars lower atmosph
2F. Res. needed to make ISRU & PP goals compatible . NOTE: , first mission is only O2 production from Mars atm.									
2G. "Acceptable Contam' of wastes left behind? Constraints on vented matls?.							Y - OK as a ground activity—need inputs from Gp3		
2 I. Approach to Achieve 'Break the Chain" Requirements?		? - First opportunity to test in partial G		? - Opportunity to test robotically					
2J. Global Distrib/Depth of subsurf. Ice--and evidence of Extant life?			Y - continued operation of radar instrument	Y - surface drilling & testing at locations where radar indicates ice. **MANDATORY**					
2K. Evolution of PP Reqmets/goals from robotic to Human Missions & zones?							Y - OK as a ground activity. - Need inputs from Gp 3		

Figure 11: Group 2: 2025-2030

Group 2: 2030 and Beyond

Time Period	2031 Onward									
LOCATION	Moon cis lunar	Moon surface	Mars orbit		Mars surface		ISS	Ground		Other (e.g. CubeSats, balloons)
Mission/ Test Opportunities					Any landing elemen t			Lab based survival exps	Lab based/ model wind tunnel measur emts	
GROUP 2 Technology & Operations for Contamin Control										
2A. Bioburden/Transport /Ops during Short v. Long Stays		Y - iterative operations management	Y - next Mars orbiter (weather measurements)	Y - crew in Mars orbital mission, teleoperations	Y - surface ops on Mars by humans, iterative ops; adapt ops to lessons learned **MANDATORY**	Y - teleoperations investigations (transport)	N			
2B. Acceptable levels of microbial/Organic Releases from humans & support systems (NOTE: other Groups & their KGs feed into this, item). Recommend moving up in priority for all Groups :								Y - modeling of potential releases & testing. Need comprehensive survey of what could go wrong, looking at physics differences between Earth & Mars	Y - understanding CDC/WHO/etc. protocols for biological releases, how they are managed	
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases - both nominal and off-nominal NOTE: need to separate these into nominal vs. off-nominal drivers		Y - testing procedures, protocols, monitoring, on the lunar surface with a human crew	Y- monitoring gas (i.e. CH4) release from hab/storage container		Y - implementation of previous monitoring and remediation protocols, iteratively adapting based on lessons learned. **MANDATORY**	Y - after mission complete, how are residual wastes contained; do we care? (if yes. Need to assess mitigation) **MANDATORY**				
2D. Design of Quarantine Facilities/Methods -for different phases								Y - ground testing with regolith simulants, water ice, etc. to get relevant data.	Y - implementation of previous monitoring and remediation protocols, iteratively adapting based on lessons learned. **MANDATORY**	
2E. How do MarsEnv Conditions vary over time wrt growth of Earth microbes. Includes localized production of special region near hab due to heat from hab and possible production of water ice. Need to make this clearer to show relevance for technology/ infrastructure/ops development. Recommend splitting induced special regions from natural ones.					Y - monitoring of liquid water, salinity, heat flux/temperature, etc. at and in proximity to the habitat and in the subsurface to ensure that special regions are not being induced in proximity to the hab. Collect samples to assess risk.					

Group 2: 2030 and Beyond cont'd

Time Period	2031 Onward									
LOCATION	Moon cis lunar	Moon surface	Mars orbit		Mars surface		ISS	Ground		Other (e.g. CubeSats, balloons)
Mission/ Test Opportunities					Any landing element			Lab based survival exps	Lab based/ model wind tunnel measurements	
2F. Res. needed to make ISRU & PP goals compatible . NOTE: current mission paradigm does not rely on local resources for crew water, resources. (first mission is O2 prodiuction from Mars atm. only.) Initial crew can characterize resources in region of habitat.. Consider other ISRU activities on Mars as they arise.			**Y**		**Y**			**Y**		
2G. "acceptable contam' of wastes left behind? Constraints on vented matls.										
2 I. Approach to Achieve 'Break the Chain" Requirements?					? - Opportunity to test robotically?					
2J. Global Distrib/Depth of subsurf. Ice--and evidence of Extant life?					Y - on-site drilling by human crew **MANDATORY**	Y - remote ops from orbit or surface, drilling				
2K. Evolution of PP Reqmets/goals from robotic to Human Missions & zones?								**Y**		

Figure 12: Group 2: 2030 and Beyond

3.3. Group 3: Natural Transport and Dispersal of Contamination on Mars

Led by Benton Clark and Manish Patel

3.3.1 Initial Assumptions

Group 3 began by noting that planning human missions to Mars consistent with the PP goals requires a more refined partitioning of the Martian surface. In addition, knowledge about the natural transport of terrestrial biological contamination on Mars is essential to inform such partitioning of Mars' surface (i.e., need to distinguish operation zones designated for exploration and commercial activities –versus Special Regions or other areas designated for extra protection)

3.3.2 Group 3: Observations and Notes

Group 3 noted that new measurements on the surface of Mars are necessary to acquire high frequency meteorologcal data over at least a full Martian year at multiple fixed locations to develop, test and validate contamination transport models. None of thse measuremnts have been done at the necessary fidelity, frequency, duraton or location on any of the Mars surface missions in the past, nor are they on any approved mission under preparation.

Ahead of the analytical activity, the group discussed how the spreadsheet entries should be managed. It was decided that a simple yes/no (Y/N) was insufficient, and that (at the least) a "P" (for partial addressing of KG) should be added for additional granularity. At the meeting Y was used to mean it closes the gap (to the extent necessary for a crewed mission, recognizing that fully closing it could be an impossible task). P was then used to indicate that the item "substantially addresses" an element of the KG.[12] . The phases of the timeline were also discussed as well as the potential need to cover/add more mission opportunities (e.g., SpaceX, CubeSats) than were presented in the original template.

In their initial reviews of the spreadsheet entries, they refined their thinking on several of the KG's. In particular, they decided to *retire KG 3G* (Induced environmental conditions around structures)—because discussions indicated it is not a major problem and can be avoided with current engineering practices. In addition, *KG 3H* (Sensitivity of non-culturable species to biocidal factors) was re-characterized as a subset of KG 3C—and would also require labwork and other research. Discussions on the possibly of undertaking survival studies of selected microbial species deliberately sent to Mars was also raised, but considered unwise. Additonal comments were made about the fact the chaotropicity or salts could also effect survival rates of microbes. Clearly there is much work to be done to fill gaps related to biocidal effects and microbes—as discussed in KG 3C below.

In considering meteorological measurements, a number of facts were key to the Group's thinking:

- Understanding Mars wind is key to addressing knowledge gaps

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[12] *Post-meeting, it was agreed that blank columns should be indicated as 'N'*

- Variation in transport must be considered several ways: diurnally, seasonally and in location specific terms;
- High frequency, high fidelity measurement of the boundary layer is needed, including
    - Turbulent fluxes of heat and momentum, measurements of air temperature, pressure, humidity and wind velocity;
    - Concentration, deposition and erosion rates, and physical/chemical properties of mobilized grains (biocidal properties)
- Assimilation of long-term, high frequency meteorological measurements is needed at multiple fixed concurrent locations for dispersion models, and
- Measurements made over one or more annual cycles (inter-annual variability, dust storm/clear atmosphere etc)

After re-examining each of their KGs (from 2016) in order to identify potential recommendations and experiments/studies for consideration both on Earth and in space, the group decided to focus on three KGs in particular:

- 3A. Meteorological measures and models to predict Atmospheric Transport of contaminants,
- 3C. Effects of biocidal factors on survival, growth and adaptation of microrganisms on Mars, and
- 3D: Determination of acceptable contamination rates and thresholds.

In their re-examinations, the Group decided that KG 3D is not actually a knowledge gap, but rather a risk acceptance issue. Inevitably, It will be tied to a future PP Office working with others to set requirements for acceptable amounts and rates of contamination. The Group acknowledged that some people may argue that totally new PP requirements will need to be set –because humans represent walking microbiomes and will shed biota at a prodigious rate. However, others could argue that PP Requirements should not be changed just because humans are going to Mars. There is need to show *by analysis of data (from KG research and missions)* whether human activities will violate relevant PP requirements related to contamination. Obviously, if spacecraft and crew are far enough away from Special Regions (or areas treated as Special Regions), human contamination might be of little concern, especially if it is permissible to take credit for sterilization by UV during dispersal/transport of microorganisms by wind. *Accordingly, Gap 3D was not eliminated from consideration, but rather set aside for now*. It will be for future scientists and decision makers to determine what PP Requirements for **KG 3D** are/will be.

The group then decided to go back and address the other two priority KGs, which they felt represent the highest priority issues to be resolved: **KG 3A** and **KG 3C.**

Starting with **KG 3C**, the group felt that Mars orbiters address **KG 3C** only partially, in that they provide optical depth (and therefore incident UV levels), but don't actually address the whole KG (UV, desiccation, volatile oxidants, high salt in soil, acidity, solar energetic particle events, low air pressure etc.). Surface oxidant effects are still a large unknown (and need to be added to the *in-situ* Mars work to be done). Another element of **KG 3C** that was raised is the *identity of the most resistant organisms and the need to understand what/where they can survive*. This gap is recognized as challenging to address in a comprehensive sense. For example, anaerobes are found in cleanrooms but are hard to work with. In addition, because most of the microbes are sourced from humans, it is difficult to determine what their potential might be in the Mars environment. The challenge is to determine what experiment(s) would address **KG 3C**. Is it necessary to bring organisms to Mars? Could this work be done by measuring UV under different conditions, characterizing sterilizing components, and then conducting earth-based research? The group considered that yes, ground-based research is needed (for multiple organisms, and multiple factors as well as UV), but such research would require more detailed input on Mars environmental parameters (desiccation, oxidant, etc.) from a Mars surface mission.

They also recognized that current missions in preparation won't measure oxidants directly, although MOMA (on ExoMars 2020 rover) is expected to be able to derive some relevant information. What is clear is that no foreseeable robotic lander is likely to identify all of the oxidants. Thus, it will be necessary to place constraints on models of lethality that are yet to be developed. They recognized that modeling has to be conservative for PP; however, in the context of a well-understood (**KG 3A**) transport effect, it may be good enough to know that there *is* a biocidal effect. While it is known that the terrestrial biosphere has too many organisms to research the survival limits for them all, they reasoned that if you understand cell biomechanisms for lethality, you can apply that exposure (with margin) to any microbe. And if ubiquitous atmospheric oxidants prove to be more biocidal than directional, obscurable solar UV, then PP compliance may not be a problem for Mars. But a dedicated mission/instrument suite needs to be added to gain this information, similar to the MOx experiment hosted on Mars 96 (McKay et al. 1998). Alternatively MSR might be expected to give insight into the salts present.

In further discussions, it was noted that existing Mars orbital platforms may be used for more monitoring, perhaps even to partly address **KG 3A**. The Group noted that the InSight mission was not included in the Excel template, yet its pressure sensor could address **KG 3A** to some degree. It is clear that ground studies can also be used (including e.g., wind tunnel studies and atmospheric modeling) to inform **KG 3A** parameters applicable at Mars. The concept of a "bear fence" [13] for terrestrial microbes was raised, and while it may be a desirable concept, our knowledge of how to implement such a 'barrier' is insufficient as it stands now.

3.3.3 Group 3: Additional Notations/Observations

In closing their analyses of the priority KGs and potentially useful time periods, locations, and missions to study natural transport and dispersal of contaminants, Group 3 recorded a variety of questions and issues relevant to upcoming deliberations anticipated in their follow-on work-meeting (days 3-4):

- Do any other planetary bodies have relevance towards natural transportation on Mars e.g. the Moon? Mars' UV flux, its atmospheric conditions and its surface soil composition(s) make it simpler at this stage to consider Mars alone.
- What is missing from preexisting rover-based meteorology instruments in order to track or accurately model the natural transport of contaminants on Mars?

[13] A 'bear fence' was used metaphorically to indicate some type of physical or other barrier that would prevent microbial spread from containment—in order to separate human crew from microbial hazards.

- What is missing from preexisting orbiters in order to accurately track the weather around a lander on Mars? Orbiters are problematic in tracking transport from the surface. Moreover, opacity/reflectivity uncertain.

Human vs Laboratory (Spacecraft) Contaminants:

- What is the assumed starting total microbial composition of the lander that would subsequently contaminate the martian surface? (Primary microbiology is important.)
- How do Humans vs Rovers/Landers differ in this primary contaminating microbiology?
- For human missions, can we provide an initial relative content of spacecraft-based microbes/spores to those added by astronauts?

Factors Controlling Natural Transport

- Mechanical (e.g. wind, subsurface transport – pushing by fluids)
  - How do different types of biota adhere to dust grains?
  - What properties of martian dust (e.g. size distributions) affect biocidal rates?
  - Is Subsurface transport sensitive to soil/rock composition and mechanical properties?

- Chemical (soil composition, atmospheric composition)
  - How does soil composition effect the spread of contaminants? Highly oxidizing martian soil should result in a high biocidal rate. Can a working calculation of biocidal rate be made as a function of distance on the surface? E.g. phoenix and SAM measurements for starting soil composition - perchlorate rich, soil rich in free radicals.
  - How will be the biocidal rate vary with different soil compositions?

- Solar Radiation (Solar UV radiation and ions)
  - Can we calculate the UV flux in both the atmosphere and on the surface for varying wind conditions and dust concentrations?

Calculating and Testing Biocidal Rates (rates of destruction of biota)

- Determine precursor biota – Determine how to characterize surrounding location in order to determine evolution

Understand Biocidal rates/probability distributions on different landing sites on Mars.

- Parameterize biocidal rates/probabilities as a function of radial distance from the martian laboratory.
- Produce probability/biocidal rate pictures for an assumed starting contaminating composition for different martian landing sites (e.g. A picture of a particular landing region on Mars overlaid with rate/probability numbers in a ‘bubble’ around the landing site. The shape of the bubble will have larger dimensions in the atmosphere vs the surface/subsurface. Calculate to what extent as a working hypothesis)
- Understand the effects and limits of the Mars oxidation/chaotropic/salt environment on terrestrial organisms.

- Consider *in-situ* experiments on terrestrial organisms at Mars to validate (may need to be genetically crippled to prevent "leakage")

Group 3: Near Term (thru 2019)

TIME PERIOD	In Flight/Near Term (now thru 2019)																
LOCATION	Moon cis lunar	Moon surface	Mars orbit					Mars surface			ISS			Ground			Other (e.g. CubeSats, balloons)
OPPORTUNITIES			Ody	MEx	MRO	TGO	Maven	Opportunity	InSight	Curiosity	Study A	Study B	Study C	General survival experiments	Study Y	Study Z	
GROUP 3: Natural Transport																	
3A. Measurements/Models for Mars atm. transport of contaminants	N	N	N	N	N	N	N	N	N	N				N			
3B. Measurements/Models for subsurf. transport of contaminants	N	N	N	N	N	N	N	N	**Partial**	N				N			
3C. Effect of Biocidal Factors on surv./growth/adapt of microbes on Mars	N	**Partial**	N	N	N	N	N	N	N	N	N	N	N	Y - the testable parameter ranges are currently known for P,T,UV, soil pH etc. Ranges of oxidation rate, salt concentrations not known well. Need inactivation rates for increasing combinations of multi-factorial exposures, for a diversity of PP-relevant organisms.	N	N	N
3D. Determine Acceptable Contam. Rates & Thresholds																	
3E. Protection Mechanisms for organisms on Mars	N	**Partial**	N	N	N	N	N	N	N	N	N	N	N	Partial	N	N	N
3F. Degradation of Landed Materials by Martian envmt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3G. Induced Env Conditions around Structure?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3H. Sensitivity of non-culturable spp to biocidal factors	N	N	N	N	N	N	N	N	N	N	Y TBD	N	N	Partial	N	N	N

Figure 13: Group 2: Near Term

Group 3: 2020-2025

TIME PERIOD	2020-2025									
LOCATION	Moon surface	Mars orbit	Mars surface			ISS		Ground		Other (e.g cubesats, balloons)
MISSION/ TEST OPPPORTUNITY	CLPS	Hope/others	M2020	ExoMars	New Mars lander/rover arriving prior to 2024	Study A	Study B	Lab based survival exp	Lab based/model wind tunnel measurements	MMX
GROUP 3: Natural Transport of Contamination on Mars										
3A. Measurements/Models for Mars atmospheric transport of contaminants	N	N	N	N	Y -TBD			N	Partial	N
3B. Measurements/Models for subsurface transport of contaminants	N	N	N	Partial						
3C. Effect of Biocidal Factors on survival/growth/adaptation of microbes on Mars	N	N	N	N	Y - require a long-term (annual) oxidation rate measurement (e.g. film oxidation), at a single location on either rover or lander. Requirements: clear sky view, one sensor head located close to the surface, one on a probe in order to go just below the surface layer, approx. 1kg (?) mass, low data rate (1 sample/day), low power (TBD), within camera view, operational duration of 1 Mars year. ASSUMPTIONS: Site representative of intended exploration zone; **Phase 1:** Perform multi-factorial lab expts within known parameter ranges for various combinations. **Phase 2:** Flight opportunity for measurement of oxidation rate. **Phase 3**: New lab experiments utlizing oxidation rate knowledge.	N	N	Partial	N	N
3D. Acceptable Contamination Rates & Thresholds										
3E. Protection Mechanisms for organisms on Mars	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
3F. Degradation of Landed Materials by martian environment	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
3G. Induced Env Conditions around Struture?	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
3H. Sensitivity of non-culturable species to biocidal factors	**N**	**N**	**N**	**N**	**N**	**Y TBD**	**N**	**N**	**N**	**N**

Figure 14: Group 3: 2020-2024

Group 3: 2025-2030

TIME PERIOD	2025-2030								
LOCATIONS	Moon cis lunar	Moon surface	Mars orbit	Mars surface		ISS	Ground		Other (e.g. CubeSats,
TEST/MISSION OPPORTUNITY			MACO	MSR (NASA-ESA)	Any future landing elements	Study A	Lab based survival exps	Lab based/model wind tunnel measurements	Mars lower atmosphere vehicles
GROUP 3: Natural Transport of Contamination on Mars									
3A. Measurements/Models for Mars atmospheric transport of contaminants	N	N	N	**Y?**	**Y**	N	N	**Partial**	**Y**
3B. Measurements/Models for subsurface transport of contaminants									
3C. Effect of Biocidal Factors on survival/growth/adaptation of microbes on Mars	N	N	N	N	**Y**	N	**Partial**	N	N
3D. Determine Acceptable Contam. Rates & Thresholds									
3E. Protection Mechanisms for organisms on Mars	N	N	N	N	N	N	N	N	N
3F. Degradation of Landed Materials by Martian envmt	N	N	N	N	N	N	N	N	N
3G. Induced Env Conditions around Structure?	N	N	N	N	N	N	N	N	N
3H. Sensitivity of non-culturable spp to biocidal factors	N	N	N	N	N	N	N	N	N

Figure 15: Group 3: 2025-2030

Group 3: 2030 and Beyond

Time Period	2031 onward									
LOCATION	Moon cis lunar	Moon surface	Mars orbit		Mars surface		ISS	Ground		Other (e.g. CubeSats
Mission / Test Opportunities					Any landing element			Lab based survival exps	Lab based/model wind tunnel measurements	
GROUP 3: Natural Transport of Contamination on Mars										
3A. Measurements/Models for Mars atm. transport of contaminants	N	N	N		**Yes**			N	Partial	**Yes**
3B. Measurements/Models for subsurf. transport of contaminants										
3C. Effect of Biocidal Factors on survival/growth/adaptation of microbes on Mars	N	N	N	N	**Yes**	N	N	Partial	N	N
3D. Determine Acceptable Contam. Rates & Thresholds										
3E. Protection Mechanisms for organisms on Mars	N	N	N	N	N	N	N	N	N	N
3F. Degradation of Landed Materials by Martian envmt	N	N	N	N	N	N	N	N	N	N
3G. Induced Env Conditions around Structure?	N	N	N	N	N	N	N	N	N	N
3H. Sensitivity of non-culturable spp to biocidal factors	N	N	N	N	N	N	N	N	N	N

Figure 16: Group 3: 2030 and Beyond

4. COSPAR Work Meeting on Developing Payload Requirements for Addressing Planetary Protection Gaps on Natural Transport and Dispersal of Contamination on Mars (Group 3)

4.1 Initial Work Meeting Deliberations

After the close of the two-day COSPAR Workshop, Group 3 re-convened for a separate Work Meeting, (May 17-18), the first of three planned meetings to develop payload concepts linked to specific Study Groups (see Figure 2 in this report). In this Work Meeting, Study Group 3 considered specifically what measurements, instruments, and research would be necessary to close KGs, and where these measurements could be obtained, both on the different current mission and locational opportunities ahead, but also on new missions if required. Their findings will also serve as input to the other two study areas for their future work meetings (planned for 2019 and 2020). The results of the Day 3-4 Work Meeting are summarized briefly below.

Building upon their just-completed Excel spreadsheets, Group 3 affirmed that the main need is for a dedicated mission to address KGs about natural transport of contamination in the Near Term and subsequent time period (2020-24),. If such a mission is to be achieved in the relevant timeline in advance of the first crewed mission arriving at the surface (NASA JSC notional timeline is 2037***), it becomes an urgent mission***. With post-arrival data collection, interpretation, and model incorporation to be considered, as well as defining/approval of a new planetary protection policy in time for incorporation in to engineering design ~10 years before the 2037 launch, there is not a lot of slack for timely completion of such a mission.

The Group also noted that commercial un-crewed missions (e.g., SpaceX cargo missions) might provide additional opportunities to get a payload of this type to the Martian surface. Thus, as an alternative to adding an additional mission to the space agencies' manifests, it may be possible to work with commercial groups on this requirement. An alternative concept discussed was the opportunity to eject small weather stations during the descent phase (similar to the ballast ejections systems currently used by surface asset delivery), providing an opportunity to add atmospheric measurement payloads to planned missions, with independent interfaces.

The desired measurement parameters for addressing **KG 3A** and K**G 3C** were then discussed in more detail. The returned data from Mars would be needed by ~2026 in order for it to be analyzed over a period of at least 1 year, and made available in time (circa 2027) to influence hardware design needed for a crewed mission in 2037 (allowing for analysis, model development and acceptance by regulatory authorities before applying to the hardware design effort). Noting the desire for one complete Mars year of data (which is ~2 Earth years), this would necessitate launch of such a payload during the 2024 opportunity. It would need to be known by 2020 if we could actually do that type of mission, and if so, whether it is necessary to promote the concept now. In considering the programmatics of this type of mission, it was noted that on the NASA side it would likely be a joint mission directed by Human Exploration & Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD), since Discovery and New Frontiers are competed missions. Again, commercial missions were considered as a potential opportunity to gather important data as well. The view in the room was that this work will only be supported if it is recognized as a human precursor mission.

Conceptually, such a mission ‘would be a network lander sent to the specific landing site of human mission. However, the group did not want to comment on or discuss, a likely named site, recognizing that the site selection process is not a PP issue *per se*. However, it might be anticipated that a potential future human landing site might be planned to be close to (subsurface) ice. The Mars2020 Jezero site is not nearknown ice, like the Viking Lander 1 site probably was, and known environments such as *Utopia Planitia's* ice lens might be a possibility as a candidate landing site for human missions. The group agreed that any precursor mission must be able to cope with the worst-case scenario (from a PP constraints point of view), or be able to accurately land within identified bounding areas. Given that human landing sites are likely to be in the km size range, such a bounded landing area may be possible. The important factor for the success of the precursor mission would be to ensure it is able to return the relevant data based on the wind regimes at the site.

The group noted the discrepancy between the NASA timelines for "first boots on Mars" and current commercial timelines, in particular for SpaceX which has described plans for humans arriving at Mars in the mid-2020s. The group felt it was important to flag this discrepancy in this report and indicate that States and the space agencies need to address it. In particular, crew arriving before these phenomena (transport and survival) are understood are unlikely to have hardware and mission operations concepts that will be able to accommodate the whole spectrum of possible outcomes (some potentially critical) of the ability of terrestrial organisms to contaminate Mars and the ability of Mars to transport/disperse and nurture such organisms.

One aspect that was discussed in the context of **KG 3C** was the potential of the Mars environment to actually be a preservative environment rather than a lethal one. There are many individual aspects of the Mars environment that (taken singly, in isolation) will inhibit growth but not be biocidal for some/all terrestrial organisms. This could allow for transport and metabolic recovery by microbes (especially if protected from UV in colonies or attached to larger particles), resulting in contamination at a site remote from the original contamination source. By comparison with another industry, food scientists burn to clean using ethanol to avoid this threat, with a known (lethal) result for all organisms. Is there a Mars equivalent that would be similarly lethal?

The presence of oxidative species known from photochemical equations is one factor that has not been adequately considered (or constrained) in lethality assessments to date (primarily, UV is the main parameter that has been considered, as it is well understood). Oxidative effects in the atmosphere and in the surface/shallow subsurface environment are predicted to have potentially significant biocidal effects, if universally present. However, can enough information be obtained about this effect for it to be permitted as a significant contributor to lethality? If data are unavailable, it's only acceptable (from a PP point of view) to note the range of oxidative possibilities, and their potential to contribute to biocidal effects, but without a specific lethality being accounted. In reality, the oxidative environment is difficult to measure, and while some of this data may come from MSR, another approach may be to account for lethality based on a range of effects seen in the lab in ground-based experiments. It was noted that oxidative effects are not the only other known biocides in the environment if UV fails to kill an organism. However, we don't know the oxidant levels or effects; the salt concentrations ('liked' by some extremophiles), or soil pH and other factors are known to a degree, but are not necessarily biocidal. Much of this work has been spearheaded by the Schuerger lab (see earlier report: https://www.hou.usra.edu/meetings/ppw2015/pdf/1011.pdf), but with so many variables to to consider and so many unknowns, the question was raised: Is pursuit of knowledge in this area useless or potentially useful? Generally, it was considered that Ground-based lab work in this area, using bounding cases and multi-factorial biocidal factors, is useful to constrain growth of organisms on Mars; moreover, it was noted that what matters most is growth and reproduction, not only survival. The group considered that it would be useful to analyze both the most survivable organisms and those most associated with humans/human activities, since these are the ones that are PP-relevant.

Returning to the other knowledge gaps, in particular with reference to the ability to address them using upcoming missions, the group wanted to refine the KG wording, in spite of encouragement to avoid this as a distraction. For **KG 3D** (Determination of Acceptable Contamination Rates & Thresholds), the group considered that this is not really a discrete knowledge gap, but more of a risk acceptance development process informed by the data resulting from work to address KG 3A and KG 3C. The group felt that KG 3D, by itself, does not need extra flight missions to close the knowledge gap, although ground studies may inform the process development task. Data to close KG 3E will be generated as a result of work to address KG 3C (so no new hardware is needed, but it needs to be included in the experimental plan). Similarly, KG 3G can be addressed through work done for KG 3B

KG 3B (Measurements/Models for subsurface transport of contaminants) and **KG 3E** (Protection Mechanisms for organisms on Mars) are two KGs that might be partially addressed at the Moon by revisiting the Apollo sites to determine what (if anything) has survived. It is clear that the lack of atmosphere as part of an experiment to study a 60+ year contamination timeline is relevant and cannot be recreated in a terrestrial laboratory. It is also relevant to the operational cleanliness regimes that may be required for subsurface) operations at Mars (notionally 2 cm below the current exposed layer). Existing surface missions (ExoMars, InSight) might help a little in our understanding of contamination threat in such operations, but the group did not consider that obtaining additional data would necessarily affect hardware design at all. More likely, specific surface operations might be tailored, but could be addressed on a case-by-case basis.

In considering the subsurface transport **KG 3B**, the question was asked whether subsurface transport should be considered generally, or only in SR (Special Regions)? Generally subsurface transport was considered to be much slower, if it occurs at all, so this topic was set as a medium priority activity. Previously (per COSPAR), a Special Region was considered as >5m depth, based on the maximum depth hardware from an impacting spacecraft could penetrate and thermal models of the surface/shallow subsurface. Depending on the landing site's proximity, it could be laterally a long way from a SR. However, was noted that melted brine as a transport mode could happen almost anywhere (although not at all times). It was noted that there are diurnal and seasonal thermal skin depths, and that salts depress freezing points. A way is needed to detect subsurface brine, which may be covered on upcoming missions (2020 landers with

GPR). Also, this KG will be partially addressed by InSight data. However, this data needs to be established as valid for the human landing zone to be applicable to KG closure, but as of today that site is not even selected. It was observed that melting

The question was discussed; how far is transport? The group observed that for subsurfaces, this is difficult to study on Earth and did not reach consensus. Maybe the better question is for how long do we care. Fungal spore travel down fault lines, could move around in dust storms, settling in cracks without UV, could last 100s yrs in viable condition to be reactivated by later human-induced Special Regions.

Of note is that 3A, 3G instrument measurements should also be measured during human missions, not just on the precursor missions, in order to continue compliance. These don't necessarily have to be from the same instruments, but continuity of data would be needed.

4.2 Overall Work Meeting Recommendations

The focus of the COSPAR Work Meeting was to move towards closing the KGs for natural contamination transport on Mars at the Human landing site, based on new data acquisition. The group focused on specific measurements and payload concepts that could be used to address PP KGs. The group analyzed what measurements would allow the development of a high-fidelity predictive model for weather at that site. Based on the COSPAR 2nd Workshop finding that currently no "*measurements have been done at the necessary frequency, duration and location*" to address Group 3 concerns, participants were asked to consider what would be the *minimum* mission (or test opportunity) to obtain data about contaminant dispersal on Mars of the necessary frequency, duration and location, and what instruments would be needed.

The Group discussed extensively the measurement contributions that would be needed to address all the input parameters in a predictive model. The discussions were at two levels: baseline, which would generate data at the sensitivity and frequency for a high fidelity model and; floor, which represented the minimal data set that would be informative in generating any model of the local weather environment. Detailed instrument configurations were discussed, but knowledge in the room was not uniform across all instruments/measurement devices. The group leads were tasked with generating this information off-line, which yielded **Table 4.2** below that describes the instuments and measurements needed to close **KG 3A** for natural transport of contamination on Mars.

For **KG 3A**, the group consensus is that a static meteorological payload package of a few tens of kgs at a single site for one martian year (longer is better) would generate the necessary quality and quantity of data to close the KG. Key to the quality of the data is the avoidance of some of the accommodation compromises experienced by meteorology instruments on previous missions, for example temperature measurements being performed in the thermal shadow of RTGs and wind sensors being affected by the profile of the host lander/rover. The group also noted that concurrent data from a set of dispersed lower fidelity (local, multiple, redundant, shorter lifespan) stations would provide higher value information than a second high-fidelity station. In this case, a single secondary station would ideally be placed upwind of the high fidelity station. If three such secondary stations were available, positioning at 120º relative to the high fidelity stations would give the best data set.

While specific instrument resource needs (mass, power, volume, data rate, accommodation, etc.) were not discussed beyond an approximate total mass estimate, it was noted that some sets of measurements could be put into single instruments as suites, for example ground temp/upwelling surface winds, dust opacity/downwelling surface winds and UV-C flux.

The paucity of high enough quality data from previous missions means that any new high quality martian dataset is valuable in developing understanding of Mars at the level needed for human exploration. It is strongly recommend that in order to close the knowledge gap for natural transport of contamination on Mars, **all future surface assets** have a dedicated **high fidelity meteorology package** to enable the accumulation of sufficient data. The Group considers that it is prudent for meteorological measurements to be given **high priority** in future human **and** robotic exploration of Mars.

Instruments & Measurement Requirements to close **KG 3A** for
Natural Transport of Contamination on Mars.

Sensor	Air pressure	Air temp.	Ground temp.	Upwelling shortwave & IR	Wind (3D)	Humidity	Total dust opacity	Downwelling solar flux	UV-C flux	Dust size and conc.	Dust saltation mass flux
Sampling duration	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline = Floor = each hour per sol	Baseline = Floor = each hour per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline = Floor = each hour per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods a>6 times per sol
Accuracy	MSL	+/- 0.1 K	+/- 1 K	TBD	+/- 0.05 m/s, +/- 5°	+/- 5%	+/- 0.03	TBD	TBD	+/- 0.05 µm	+/-10 um, 1m/s
Range	MSL	150-300 K	150-300 K	TBD	0-50 m/s, 360°	0-100%	0-6	TBD	TBD	>0.2 µm, 1 to 5000 cm^{-3}	>65 µm, 0-30 m/s
Sampling frequency	> 4 Hz	> 4 Hz	Once per hour	Once per hour	>10 Hz	Once per hour	> 4 Hz	> 4 Hz	> 4 Hz	> 4 Hz	> 4 Hz
Heritage	Beagle 2, ExoMars Humboldt, Curiosity, InSight	Beagle 2, ExoMars Humboldt, Curiosity, InSight	Curiosity	Beagle 2, Curiosity	No flight heritage. Development heritage from Beagle 2 and US proposals	Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	No flight heritage. Development heritage fromExoMars Humboldt	Beagle 2, ExoMars Humboldt
TRL	9	9	9	9	4-5	9	9	9	9	4-5	4-5

Figure 17: Instuments & Measurement Requirements

5. Development of a Roadmap/Timeline

To close the PP knowledge gaps identified at the beginning of the workshop series, it is necessary to gain new information to feed forward into setting quantitative guidelines. In this workshop the participants were asked to identify locations/ missions where this information *could* be obtained, using their expertise and perspectives, and the implied timeline of the spreadsheet tools, to suggest a sequence for needed studies to take place.

This study sequence was to be practicable, based on current mission timelines, and given the (then) current NASA goal of launching the first crewed mission to the Mars surface during the 2037 opportunity. Clearly, such timing estimates carry a significant element of uncertainty, particularly for space agency and/or government-funded projects that may slip to the right based on budgetary or other situations. Although perhaps commercially-funded projects will bring this capability forward.

Nonetheless, for these deliberations, the working assumption was that an end-to-end solution must be considered *for each knowledge gap* and that all knowledge gaps need to be addressed (independent of previous prioritizations from the 1st COSPAR Workshop) in the time period ahead of the first crewed launch, in order to create a comprehensive "solution" to the human exploration PP "problem". Additional (notional) milestones (e.g. policy making decisions, engineering design decisions) are also added to inform start/stop timings of activities, based on anticipated project lifecycle and programmatic decision-making ahead of the 2037 launch.

During deliberations at the COSPAR workshop, the three Study Groups worked more-or-less independently from one another. Although each Group was aware of potential dependencies between Knowledge Gaps across groups [for ex. where a design solution in the Group 2 (Technology & Ops) would need input from a KG in Group 3 (Natural Transport of Contamination)], generally it was not possible to accomplish a comprehensive level of integration in the Workshop setting. Thus, the incorporation of KG "solutions" into a timeline or roadmap (see Fig. 18) was performed after the workshop by its organizers.

The timeline was synthesized to consider/demonstrate whether a plausible path to comprehensively addressing the PP knowledge gaps could be envisaged, based on information taken from spreadsheet entries from each Group. However, it is recognized that the timeline as presented represents "a" solution rather than "the" solution. Judgement had to be used in how the collation activity was done, both internal to a single group's data, and between groups (as highlighted above with regard to coordination of start/stop of activities between Group 2 and Group 3). For each Group's spreadsheet, entries sometimes needed to be "down selected" to a single choice from the several possible destinations even though a KG could be closed by data obtained from more than one location (e.g., from LEO (ISS) or Gateway). For the purposes of the timeline, only one choice would be selected if the data were likely to be identical. Also, Group 1 suggested some testing to be done continuously in their spreadsheet entries, even at times working beyond the 'need' date for decisions on parameters to be incorporated into policy or to influence hardware design. Since continued testing implies continued funding (undesirable), the testing activity in this timeline development was stopped once a task had reached the ‘needed’ date for information. (This is not to say such data would not be valuable in informing operational performance, just that it may not be required for PP KG closure).

The tentative timeline is to be presented as part of the 3rd COSPAR Workshop (2019), with a view to gaining acceptance of this or a similar approach for knowledge gap closure within the community of workshop attendees. Should that be achieved it will be available as a resource for advocacy more broadly within space agency, exploration and scientific stakeholders.

Timeline Synthesized from the 2nd COSPAR Workshop on Planetary Protection for Human Missions to Mars—Breakout Group Output

View scalable image at: **https://nsc.nasa.gov/images/default-source/discipline-pages/planetary-protection/cospar-2018-timelinev8_master.jpg**

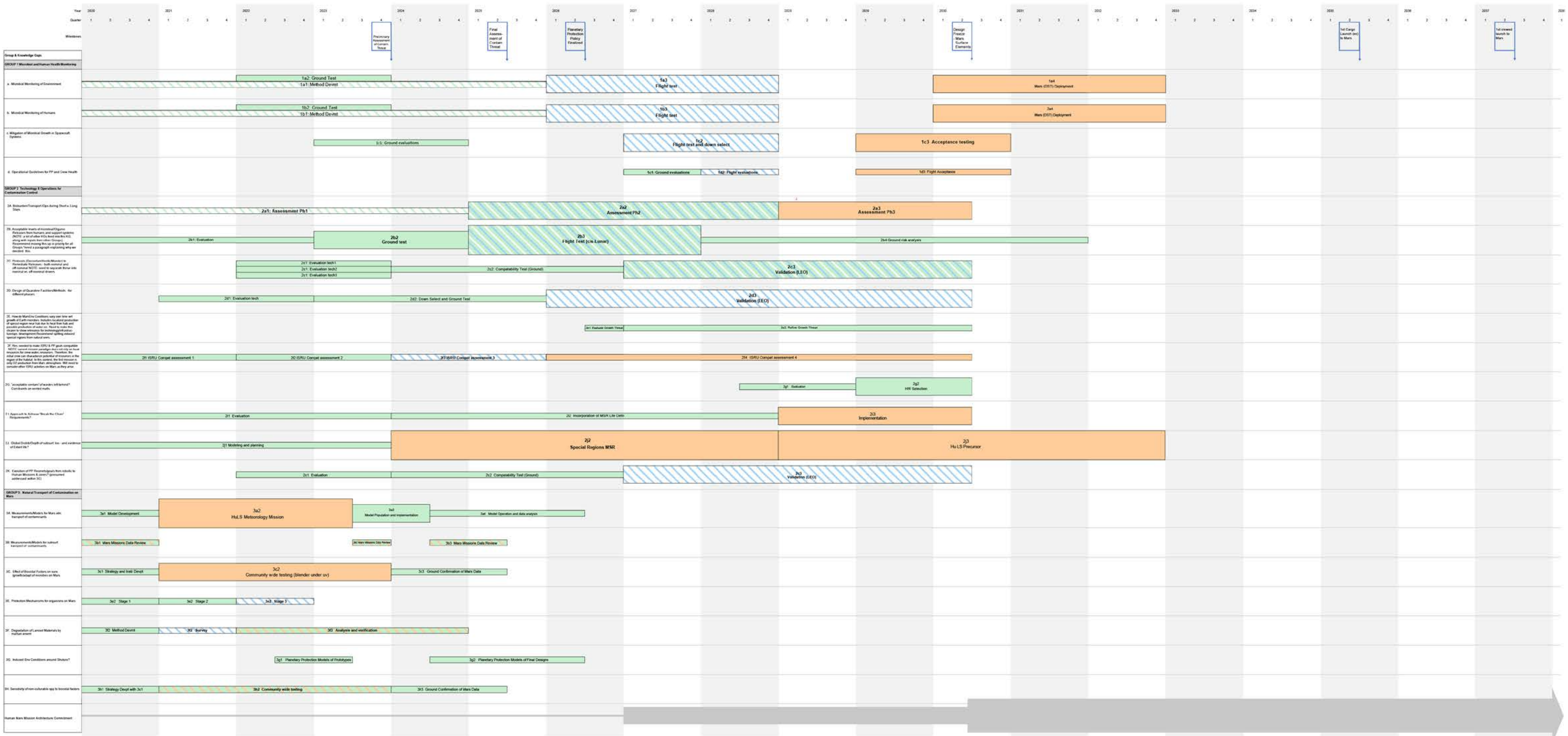

Figure 18: Timeline Synthesized from the 2nd COSPAR Planetary Protection for Human Missions to Mars Workshop Breakout Group

Notes about the Timeline: Each Knowledge Gap represented, in rows, organized as addressed by previous workshops, with inputs from each discussion group considered.Horizontal Scale is time from now to the first crewed mission to the surface (based on 2018 "Journey to Mars" paradigm), and includes key Planetary Protection and Program milestones.Opportunities may be different in the current Moon-focused exploration paradigm.Colored bars used to represent when and where a knowledge gap is addressed across multiple "phases" of an activity to CLOSE the knowledge gap. Color of the bar represents location of activity (green=ground; white=ISS; blue=Moon; orange=Mars – plus combinations). Multiple bars shown in places to reflect e.g., complexity of tasks to address a knowledge gap ahead of consolidation or downselect options."Weight" of the colored bar is depiction of the somewhat subjective scope of the activity.Front-loaded activity relative to any "Humans to Mars" program profile Each row gives the end–to-end activity to close a single COSPAR Knowledge Gap. Could be remade into a project management-style chart, with tasks and interrelationships, critical paths etc. as a plan for real work.

6. Workshop and Work Meeting Conclusions

At the 2nd COSPAR Workshop (2018), participants built upon findings from previous NASA and COSPAR workshops, and engaged in separate group deliberations about the previously identified KGs that must be filled in order to develop future quantitative PP requirements for Human Missions beyond Earth orbit. Each of the three study groups worked in breakout sessions to consider the rankings, locations, mission criticality, test opportunities and time periods of relevance for addressing R&TD needs —from Near Term to beyond 2031. Based upon their deliberations, each breakout group filled in Excel formatted templates as their work products. The filled in Excel-file information, along with previous workshop reports and findings, are intended to serve as input to three additional follow-on Working Meetings scheduled for 2018, 2019, and 2020. Each Working Meeting is intended to identify detailed measurements and payload instruments as well as ground-based test concepts that may be used to close the KGs across the each of the KG areas related to PP and human missions.

The work to date has recognized that while knowledge gaps exist, they are tractable through activities aimed at developing technical solutions to the KGs that have been identified.

Analysis of task sequencing and end-points are presented as a proof of concept in the Timeline generated after the workshop. Further deliberations in the working meetings will add more detail to an eventual Timeline and path forward in the next several years.

It is clear that there are many ground/analog as well as mission test opportunities available to address the multiple recommendations made in the meetings and studies to date. However, the sequences shown in the timeline highlight the need for early starts for activities to address certain KGs in order to protect the ability to develop a timely end-to-end PP solution.

As a result of the deliberations to date in the workshop and the subsequent Work Meeting, it is apparent that a specific concern is the lack of knowledge about what Mars does with released viable biological contaminants. Addressing this particular KG requires a dedicated (robotic) meteorology mission that (ideally) is landed local to the planned human landing site. Later elements of the PP KGs, particularly those in Group 2 (Technology and Operations) are strongly dependent on this information being available in a fashion that is timely for hardware design closure. The Work Meeting identified meaurements and instrumentation needed for a high fidelity weather station to close this knowledge gap.

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Appendix A: Meeting Agendas

A-1: Workshop Agenda

2nd COSPAR Workshop on Refining Planetary Protection Requirements for Human Missions

Scope: Align previously identified knowledge gaps in planetary protection with mission opportunities in the timeframe between now and the first crewed flight to the Martian surface. This workshop will feed into subsequent working meetings that produce COSPAR reports assessing potential opportunities to address the various knowledge gaps.

Venue/dates: Lunar & Planetary Institute, TX; May 15-16, 2018

Call in number: USA Toll Free #: 1-844-467-4685 or USA Local/Toll #: 1-720-259-7012
Participant Passcode: #: 496180
Remote access: Webex – http:// nasa.webex.com
Meeting number: 995 617 148
Meeting password: May15-16!

Day 1 (15 May) 12:30pm – 6:00pm

Workshop Objectives and Planetary Protection Overview

12:30 "Registration"

1:00 – 1:30 Welcome, objectives of the workshop – Siegel, Introductions

1:30 - 2:00 Review of COSPAR Planetary Protection Policy – Kminek

2:00 – 2:30 How the COSPAR human guidelines for missions beyond Earth Orbit were developed - Spry

2:30 - 2:45 Planetary Protection at NASA - Pratt

2:45 – 3:00 Coffee break

3:00 - 3:20 Update on Knowledge gaps for Human Missions - Siegel

Current Potential Mission Opportunities

3:20 - 6:00 Presentations on Launch Opportunities on different Agencies/ Commercial platforms – Various invited presenters, plus open microphone option for 5min/3slide presentations on missions/technologies

- 3:20 Connolly (NASA) ISS/DSG/DST
- 3:40 Galica (NASA) Cubesats

4:00 Edwards (TBC-JPL) Future Mars robotics
4:20 Patti (TBC-ESA) Precursors/Moon
4:40 Fujita (TBC-JAXA) Precursors
5:00 (TBC) US Precursors
5:20 Open microphone

6:00 – 7:00 Reception
8:00 Dinner (optional)

Day 2 (16 May) 8:30am – 5:30pm

Update on 2016 Meeting Findings

8:00 – 8:30 Coffee/Snacks

8:30 – 8:50 Microbial and Human Health Monitoring - Conley

8:50 – 9:10 Technology and Operations for Contamination Control - Rucker

9:10 – 9:30 Natural Transport of Contamination on Mars – Patel

Mission Opportunities to Address Planetary Protection Knowledge Gaps

9:30 – 10:00 Break-out group resources and products – Race/Kminek

10:00 – 10:20 Coffee break

10:20 - 12:30 Break-out groups: Aligning flight opportunities with KGs

12:30 -12:40 Group Photo

12:40 - 1:40 Lunch

1:40 – 2:10 Plenary report out

2:10 - 5:00 Break-out groups: Concept refinement

(3:10 – 3:30 Coffee break)

5:00 – 5:30 Data capture presentations

A-2: Work Meeting Agenda

COSPAR Work Meeting on Developing Payload Requirements for Addressing Planetary Protection Knowledge Gaps in the Area ofNatural Transport of Contamination on Mars
May 17-18, 2018.

Venue: Lunar & Planetary Institute, TX;
Chairs: Manish Patel, Ben Clark

Scope: Developing payload requirements and ground based test concepts for addressing knowledge gaps in the area of natural transport of contamination on Mars, as described in the the 1st COSPAR Workshop Report (2016) on Refining Planetary Protection Requirements for Human Missions and taking into account mission opportunities identified in the 2nd COSPAR Workshop (2018).

AGENDA (17 and 18 May, 2018)

Day3 (May 17)

8:30am – 11:00am JSC Site Tour

11:15am – 6:30pm

- Review of day 1 and 2 break-out sessions on Contamination Transport and Mission Prioritization and resulting roadmap
- Iterative development of payload requirements and ground based test concepts to address knowledge gaps

Day 4 (May 18)

8:00am – 12:00 noon

- Refinement/finalization of payload requirements and ground based test concepts
- Plenary discussion, gap identification/filling, conclusions, writing assignments and plan forward

Appendix B: Participants and Group Photo

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* Asterisk = Days 3 &4 Participants: Work Mtg on Natural Transport of Contamination

Figure 19: Group Photo

Appendix C: Acronyms/List of Terms

Abbreviations & Acronym	Term
AES	Advanced Exploration Systems
BSL	Biosafety Level
CDC	Centers for Disease Control
CFU/m^2	Colony Forming Unit
CLPS	Commercial Lunar Payload Services
COSPAR	Committee on Space Research
COTS	Commercial off the Shelf
DNA	Deoxyribonucleic Acid
ECLSS	Environmental Control and Life Support System
EM 1	Exploration Mission 1; now Artemis Mission 1
ESA	European Space Agency
EuTEF	European Technology Exposure Facility
EVA	Extra-vehicular Activity
EZ	Exploration Zone
GANTT	Time/activity chart for graphic display
GCM	General Circulation Model
GPR	Ground Penetrating Radar
HEOMD	Human Exploration Mission Directorate
HERA	Human Exploration Research Analog
ICSU	International Council for Science
ID	Identification
IR	Infrared radiation
ISRU	In-situ Resource Utilization
ISS	International Space Station
IVA	Internal Vehicular Activity
JAXA	Japan Aerospace Exploration Agency
KG	Knowledge Gap
LEO	Low-Earth Orbit
LPI	Lunar and Planetary Institute
MALDI-TOF	Matrix-Assisted by Laser Desorption Ionization
MarsEnv	Mars Environmental
MAVEN	Mars Atmosphere & Volatile EvolutioN mission
Mex (Table 2; pg 12)	Mars Express Mission (European mission)
MHHM	Microbial and Human Health Monitoring
MISSE	Materials International Space Station Experiments
MMX	Martian Moons Explorer
MOMA	Mars Organic Molecule Analyzer (on ExoMars rover)
MOx	Mars Oxidant experiment on Mars 96
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NEEMO	NASA Extreme Environment Mission Operations
NPI	NASA Policy Instruction
NPR	NASA Policy Requirements
ODY (Table 2; pg 12)	Odyssey mission

Ops.	Operations
PHX	Mars Phoenix Mission
PP	Planetary Protection
PPP	Panel on Planetary Protection
PWD	Potable Water Dispenser
R&TD	Research and Technology Development
SAM	Sample Analysis at Mars
SAM	Sample Analysis at Mars
SAR	Synthetic Aperture Radar
SETI	Search for Extraterrestrial Intelligence (Institute)
SMD	Science Mission Directorate
TBD	To Be Determined
TGO	Trace Gas Orbiter
TSA	Tryptic Soy Agar
UV	Ultra Violet radiation/light
UV-C	UV wavelengths bet. 200 – 280 nms.
VOC	Volatile Organic Carbon
WHO	World Health Organization
wrt	with respect to

Appendix D: Summary of Overall findings of Subgroup 3: Natural Transport of Contamination on Mars (Workshop and Work Meeting)

Natural transport of (human) contamination on Mars

Summary of findings from the 2018 workshop

Manish Patel[1], Benton Clark[2], Corien Bakermans[3], Esther Beltran[4], Brandi Carrier[5], Hitesh Changela[6], Richard Davis[7], Peter Doran[8], Lori Fenton[9], John E. Hallsworth[10], Gerhard Kminek[11], Vera Kolb[12], Bette Siegel[7], Andrew Spry[7,9]

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The Open University

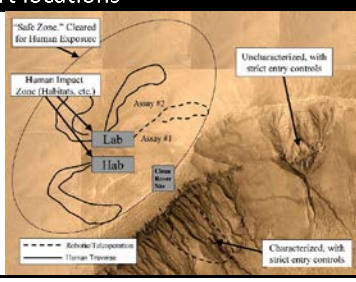
Scope of the study

To consider issues of transport of viable microorganisms and organic contaminants from a human exploration zone into the general Mars environment

- Ultimate emphasis is on the probability of a contaminant release reaching a potential Mars 'special region'

The Open University

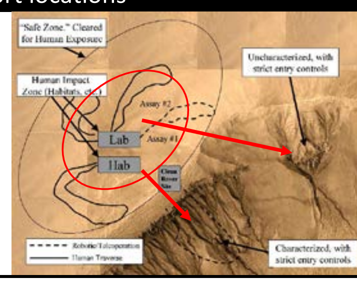
Transport locations



The Open University

Transport locations

How much, and how fast…?



The Open University

Context

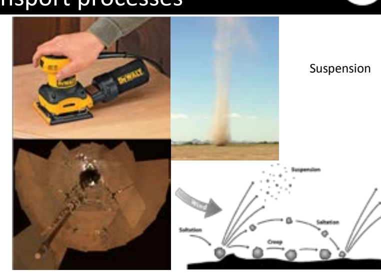
The movement of dust, microorganisms and organic molecules by aeolian processes, including:

The Open University

Aeolian transport processes

Abrasion

Suspension



DepositionSaltation

The Open University

Questions that arise

How close should we get to a special region, and where is the best place to locate an 'exploration zone'?

In the event of a release of contaminants, can we model the transport?

2016 Knowledge gaps summary

Knowledge Gap	Description	Rank
3A	*Measurements and models needed to determine atmospheric transport of contaminants*	High
3B	Measurement and models needed to determine subsurface transport of contaminants	Medium
3C	*Effects of biocidal factors on survival, growth and adaptation of microorganisms*	High
3D	*Determination of acceptable contamination rates and thresholds*	High
3E	Protection mechanisms for organisms	Medium
3F	Degradation of landed materials by the environment	Medium
3G	Induced environmental conditions around structure	Medium
3H	Sensitivity of non-cultivable species to biocidal factors	Medium

- '**High**' priority: time critical to define requirements and design hardware.
- '**Medium**' priority: not immediately critical to define requirements and design hardware but still required.

2016 Knowledge gaps summary

Knowledge Gap	Description	Rank
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- '**High**' priority: time critical to define requirements and design hardware.
- '**Medium**' priority: not immediately critical to define requirements and design hardware but still required.

2018 – Round 2…

2018 Task for Group 3

Review the Knowledge Gaps

Determine requirements

2018 Review of high priority KGs

The three 'high priority' knowledge gaps identified in the 2016 meeting

1) **Meteorological measurements and models are needed to accurately predict atmospheric transport of contaminants**
2) **Effects of biocidal factors on survival, growth and adaptation of microorganisms on Mars**
3) **Determination of acceptable contamination rates and thresholds**

2018 Review of high priority KGs

- The three 'high priority' knowledge gaps identified in the 2016 meeting

1) **Meteorological measurements and models are needed to accurately predict atmospheric transport of contaminants**
2) **Effects of biocidal factors on survival, growth and adaptation of microorganisms on Mars**
3) ~~**Determination of acceptable contamination rates and thresholds**~~

2018 Review of high priority KGs

- The three 'high priority' knowledge gaps identified in the 2016 meeting

1) **Meteorological measurements and models are needed to accurately predict atmospheric transport of contaminants**
2) **Effects of biocidal factors on survival, growth and adaptation of microorganisms on Mars**
3) ~~**Determination of acceptable contamination rates and thresholds**~~

Meteorological measurements

- Wind is key
- Transport varies diurnally, seasonally and is location-specific
- High frequency, **high fidelity** measurement of the boundary layer is needed:
- Turbulent fluxes of heat and momentum, measurements of air temperature, pressure, humidity and wind velocity;
- Concentration, deposition and erosion rates, and physical/chemical properties of mobilized grains (biocidal properties)
- Assimilation of long-term, high frequency meteorological measurements is needed at multiple fixed concurrent locations for dispersion models
- Measurements made over one or more annual cycles (inter-annual variability, dust storm/clear atmosphere etc)

Hold on….

…don't we have meteorological measurements from Mars already?

Mission opportunities analysis

This particular knowledge gap can ONLY be closed by high fidelity *in situ* meteorological measurements on Mars

Analogue or laboratory measurements are of no use – so…

We urgently need a mission to Mars with meteorological measurements as a main priority incorporating a high fidelity weather station

Measurement requirements

Sensor	Air pressure	Air temp.	Ground temp.	Upwelling shortwave & IR	Wind (3D)	Humidity	Total dust opacity	Downwelling solar flux	UV-C flux	Dust size and conc.	Dust saltation mass flux
Sampling duration	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline = Floor = each hour per sol	Baseline = Floor = each hour per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline = Floor = each hour per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr >6 times per sol	Baseline: continuous Floor: 1 hr periods >6 times per sol	Baseline: continuous Floor: 1 hr periods a>6 times per sol
Accuracy	MSL	+/- 0.1 K	+/- 1 K	TBD	+/- 0.05 m/s, +/- 5°	+/- 5%	+/- 0.03	TBD	TBD	+/- 0.05 µm	+/-10 um, 1m/s
Range	MSL	150-300 K	150-300 K	TBD	0-50 m/s, 360°	0-100%	0-6	TBD	TBD	>0.2 µm, 1 to 5000 cm^{-3}	>65 µm, 0-30 m/s
Sampling frequency	> 4 Hz	> 4 Hz	Once per hour	Once per hour	>10 Hz	Once per hour	> 4 Hz	> 4 Hz	> 4 Hz	> 4 Hz	> 4 Hz
Heritage	Beagle 2, ExoMars Humboldt, Curiosity, InSight	Beagle 2, ExoMars Humboldt, Curiosity, InSight	Curiosity	Beagle 2, Curiosity	No flight heritage. Development heritage from Beagle 2 and	Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	Beagle 2, ExoMars Humboldt, Curiosity	No flight heritage. Development heritage from ExoMars	Beagle 2, ExoMars Humboldt

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We urgently need a mission to Mars with meteorological measurements as a main priority incorporating a high fidelity weather station

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When?

- Timeline to a dedicated mission:
  - 2037: Assumed date for a manned mission to Mars in 2037 (assume 10 yr development)
  - 2027: PP requirements to be defined following data analysis
  - 2026: 1 full Mars Year of data collected
  - 2024: Dedicated mission with high priority met package

Concluding remarks

*It is strongly recommend that in order to close the knowledge gap for natural transport of contamination on Mars, **all future surface assets** have a dedicated **high fidelity meteorology package** to enable the accumulation of sufficient data.*

*Meteorological measurements should be given **high priority** in future human *and* robotic exploration of Mars.*