Final Report of the COSPAR Planetary Protection Knowledge Gaps for Human Mars Missions Workshop Series and Paths to Knowledge Gap Closure

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Overview

- Introduction to Planetary Protection for Crewed Mars Missions
- Review of the Workshop Process and Findings on Knowledge Gaps
- Updates Strategy for Addressing Knowledge Gaps
- Contamination Threat Assessment for a Crewed Mission Concept
- Summary

International Planetary Protection Process

The Outer Space Treaty of 1967

International Responsibility

Article VI:

States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty

Planetary Protection

Article IX:

States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose

Committee on Space Research (COSPAR)

- Panel on Planetary Protection forms international consensus guidelines
- Defines PP Categories I – V based on target body and mission type

NASA

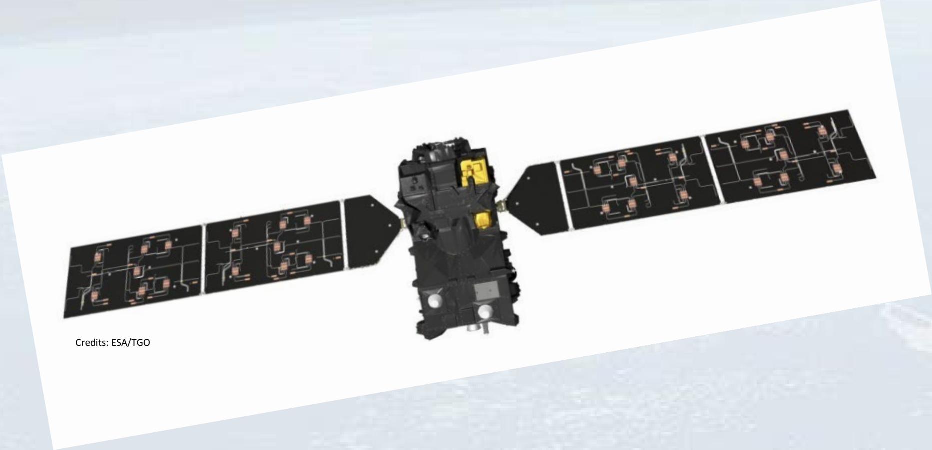
- Implements Planetary Protection Policy to achieve compliance for NASA Missions
- Supports FAA in planetary protection compliance evaluation for Non-NASA Missions
- Maintains US conformity with the provisions in the OS Treaty

- Supports the science-based international consensus process
- Develops new guidelines and provides significant input to COSPAR

Planetary Protection Categorization

Types of Planetary Bodies	Mission Type	Misson Category
Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
Of significant interest relative to the process of chemical evolution, but only a remote chance that contamination by spacecraft could jeopardize future exploration. Documentation is required.	Any	II IIa, IIb (Moon)
Of significant interest relative to the process of chemical evolution, and/or the origin of life or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment. Substantial documentation and mitigation is required.	Flyby, Orbiter Mars, Europa, Enceladus	III
As above	Lander, Probe Mars, Europa, Enceladus	IV IVa, IVb, IVc (Mars)
Any solar system body. Unrestricted applies only to bodies deemed by scientific opinion to have no indigenous life forms.	Earth Return Restricted or Unrestricted	V

Planetary Protection Implementation for Robotic Missions



Typical implementation - Orbiter:

- Probability of Mars impact assessment for launcher upper stage and spacecraft
- Launch, cruise to Mars, MOI and orbital mission phases
- Hardware, software and operational reliability
- Micrometeoroid impact and effect analysis

Alternative approach is bioburden control of spacecraft, including break-up/burn-up analysis, to meet and impacted numeric bioburden limit

Typical implementation - Lander:

- Bioburden reduction of flight hardware using solvent cleaning, dry heat, ionizing radiation and gases
- Recontamination prevention using flight and non-flight filters and barrier systems
- Bioburden control of assembly, test and launch operations
- Bioburden verification with assays

Intent is to meet numeric bioburden limit (with the limit being more stringent for IVb/c missions)

NASA's Planetary Protection General Paradigm

a. "Safeguarding the Earth from potential back[ward] contamination is the highest planetary protection priority in Mars exploration."

b. "The greater capability that human explorers can contribute to the astrobiological exploration of Mars is only valid if human-associated contamination is controlled and understood."

c. "For a landed [human] mission conducting surface operations, it will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems."

d. "[Humans] exploring Mars, and/or their support systems, will inevitably be exposed to Martian materials."

(Originally excerpted as "guidance" from COSPAR 2008 policy language)

COSPAR guidelines for crewed missions

Current guidelines, in place since 2008, address:

- Forward contamination
  - *Orders of magnitude greater threat than robotic missions – crew as "biogenerators"*
  - *Crewed spacecraft systems are not sealed*
- Backward contamination
  - *Want the crew to return home*
  - *Earth's biosphere must be protected*

… But do not yet provide enough detail for engineering design requirements

Assessment of Knowledge Gaps for future crewed missions

2015	2016	2018	2018 & beyond
NASA Workshop at Ames	1st COSPAR Meeting at LPI	2nd COSPAR Meeting at LPI	COSPAR Working Meeting on Contamination Transport on Mars at LPI, May 2018 COSPAR Working Meeting on Microbial Monitoring & Health at LPI, May 2019 COSPAR Virtual Working Meeting on Spacecraft Systems, May 2020 COSPAR Virtual Working Meeting on Spacecraft Systems, Dec 2022
Identification of Planetary Protection Knowledge Gaps for human missions to Mars	Refinement and prioritization of Planetary Protection Knowledge Gaps for human missions to Mars	Mission Opportunity identification for addressing Planetary Protection Knowledge Gaps for human missions to Mars	Measurements and Payload/Operation Concepts for addressing Planetary Protection Knowledge Gaps for human missions to Mars
What Knowledge Gaps…	…in what order…	…using what missions…	…to make what measurements…

…to establish the <u>right</u> quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Assessment of Knowledge Gaps for future crewed missions

2015	2016	2018	2018 & beyond
NASA Workshop at Ames	1st COSPAR Meeting at LPI	2nd COSPAR Meeting at LPI	COSPAR Working Meeting on Contamination Transport on Mars at LPI, May 2018 COSPAR Working Meeting on Microbial Monitoring & Health at LPI, May 2019 COSPAR Virtual Working Meeting on Spacecraft Systems, May 2020 COSPAR Virtual Working Meeting on Spacecraft Systems, Dec 2022
Identification of Planetary Protection Knowledge Gaps for human missions to Mars	Refinement and prioritization of Planetary Protection Knowledge Gaps for human missions to Mars	Mission Opportunity identification for addressing Planetary Protection Knowledge Gaps for human missions to Mars	Measurements and Payload/Operation Concepts for addressing Planetary Protection Knowledge Gaps for human missions to Mars
What Knowledge Gaps…	…in what order…	…using what missions…	…to make what measurements…

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…to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Knowledge-Based Robotic to Crewed Transition Assumptions*

- Human spaceflight hardware leaks (in nominal and off-nominal operation), so the old robotic paradigm of managing a fixed bioload is inappropriate.
- The introduction of a maintained temperate terrestrial environment at the Martian surface affords the opportunity for many more organisms (in type and quantity) to escape into the Martian environment.
- This exploration is taking place in a post-Mars Sample Return (MSR) context where Martian life was NOT (yet?) discovered at the Martian surface/shallow subsurface in returned Mars material, but we know a lot more about Mars from those samples.
- Knowledge gaps need to be understood and preferably closed before launch to protect science return and the Earth.

* Developed as ground rules for the 2020 COSPAR "4th Workshop on Refining Planetary Protection Requirements for Human Missions" – see the Conference Documents section at https://sma.nasa.gov/sma-disciplines/planetary-protection

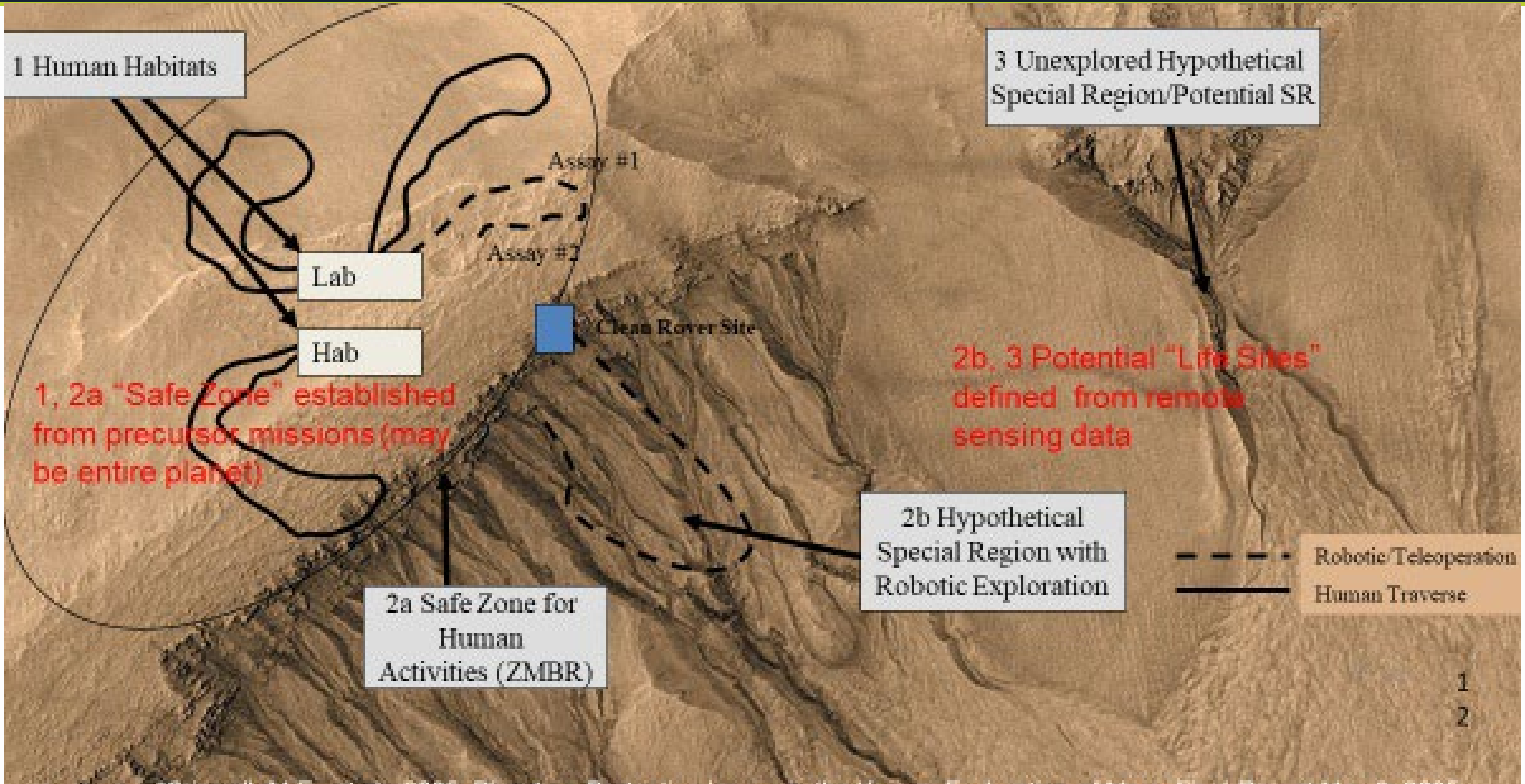
Knowledge Gap Areas

- **Microbial and human health monitoring**
  - *Evaluation and monitoring of microbial communities associated with human systems, both for their initial state and changes over time*
- **Technology and operations for contamination control**
  - *Designs, methods and procedures for controlling contamination release of human spacecraft systems*
- **Natural transport of contamination on Mars**
  - *Understanding the environmental processes on Mars that contribute to transport, survival and replication of microbes released by human activities*

Knowledge Gap List from COSPAR Workshop Series

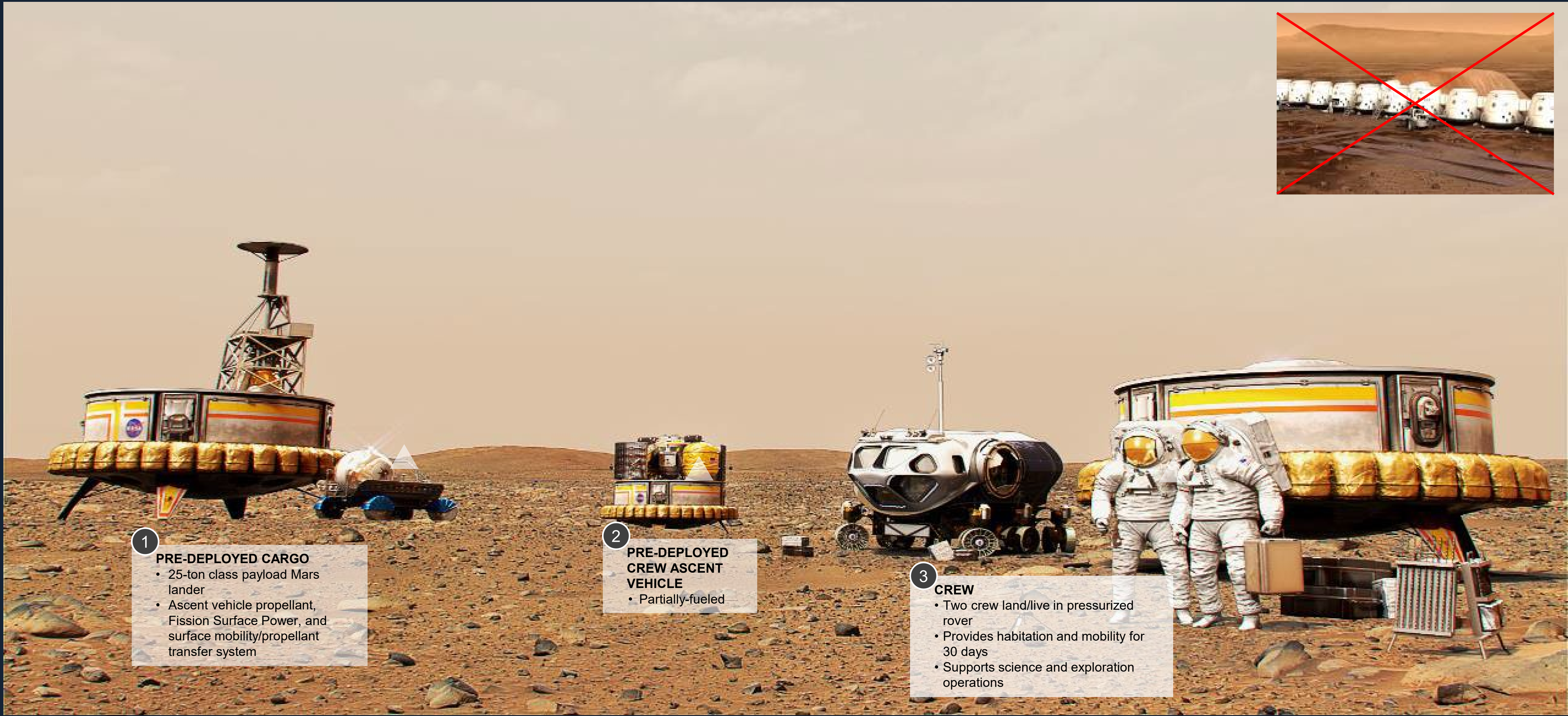
Microbial & Human Health Monitoring	
1A. Microbial monitoring of the environment	
1B. Microbial monitoring of humans	
1C. Mitigation of microbial growth in spacecraft systems	
1D. Operational guidelines for planetary protection and crew health	
Technology & Operations for Contamination Control	
2A. Bioburden/transport/operations during short vs. long stays	
2B. Microbial/organic releases from humans and support systems	
2C. Protocols for decontamination & verification procedures	
2D. Design of quarantine facilities/methodologies at different mission phases	
2E. Martian environmental conditions variation over time with respect to growth of Earth microorganisms	
2F. Research needed to make ISRU & planetary protection goals compatible	
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	
ORIGINAL 2H. DELETED (merged with 2B.)	
2I. Approaches to achieve 'Break the chain" requirements	
2J. Global distribution/depth of subsurface ice and evidence of extant life	
2K. Evolution of planetary protection requirements/goals from robotic precursor through to human missions & exploration zones	
Natural Transport of Contamination on Mars	
3A. Measurements/models needed to determine atmospheric transport of contaminants	
3B. Measurements/models for subsurface transport of contaminants	
3C. Effect of biocidal factors on survival/growth/adaptation of microorganisms	
3D. Determination of acceptable contamination rates & thresholds	
3E. Protection mechanisms for organisms on Mars	
3F. Degradation of landed materials by Martian environment	
3G. Induced environmental conditions around structures	
3H. Sensitivity of non-culturable species to biocidal factors	

Planetary Protection Concept* for a Crewed Mission to Mars



*Criswell, M.E., et al., 2005. Planetary Protection Issues in the Human Exploration of Mars, Final Report May 9, 2005 (workshop held June 2001), NASA, Ames Research Center, Moffett Field CA, NASA/CP – 2005-213461

Assessment focused in a “realistic” first crewed mission concept



The “Eye Chart”: Visual of NASA Progress on Closing PP KGs

Microbial & Human Health Monitoring Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
1A. Microbial monitoring of the environment	Detection and monitoring of microorganisms inside the habitat and in the Mars environment	TBD based on data from analog research to establish baseline information and decision-making strategies	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing (Conclusion of the 3rd Meeting)
1B. Microbial monitoring of humans	Detection and monitoring of microorganisms on/in crew	TBD based on data from analog research to establish baseline information and decision-making strategies	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing (Conclusion of the 3rd Meeting)
1C. Mitigation of microbial growth in spacecraft systems	Monitoring of microorganisms inside the habitat and establishment of action limits.	Establish (sub)-system requirements based on (sub)-system design and release limits (2B)	Conclusion of 5th Meeting
1D. Operational guidelines for planetary protection and crew health	Ability to distinguish between benign and hazardous fluctuations in metagenome data	TBD: Outcome dependent on 1A & 1B	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing. Discussion at the 3rd Meeting.
Technology & Operations for Contamination Control Knowledge Gaps	**Parameter**	**Figure of Merit/Current Best Estimate**	**Notes**
2A. Bioburden/transport/ operations during short vs. long stays	N/A	N/A	Since only short stay missions are considered, this KG was left open. (Discussion at 4th Meeting)
2B. Microbial/organic releases from humans and support systems	Is it required for an airlock volume to be sterilized prior to egress.	Yes, degree of filtration/ sterilization processing TBD based on threat of organisms released	Expectation that H_2O_2 vapor and UV technologies might be suitable for this purpose. Conclusion of 5th Meeting
2B. Microbial/organic releases from humans and support systems	Is it required for an airlock volume to be sterilized prior to ingress.	Yes, degree of filtration/ sterilization processing TBD based on threat of organisms released	Expectation that H_2O_2 vapor and UV technologies might be suitable for this purpose. Conclusion of 5th Meeting
2B. Microbial/organic releases from humans and support systems	Is it required for suits/ tools/ instruments/ robots to be sterilized prior to egress	Yes, if required for pristine sample acquisition/processing	Consideration that pass-through glove box technology with hydrogen peroxide technology might be suitable for this purpose. Discussion of 5th & 6th Meetings
2B. Microbial/organic releases from humans and support systems	Is it required for suits/ tools/ instruments/ robots to be sterilized prior to ingress	Yes, if exposed to pristine/pecial Region or unknown Mars environments/materials	Consideration that pass-through glove box technology with hydrogen peroxide technology might be suitable for this purpose. Discussion of 5th & 6th Meetings
2C. Protocols for decontamination & verification procedures	Bioburden reduction technology compatible with spaceflight systems	TBD based on data from analog research to establish performance of candidate technologies	Conclusion of 5th Meeting
2C. Protocols for decontamination & verification procedures	Bioburden reduction technology for Mars	TBD based on data from analog research to establish performance of candidate technologies	Conclusion of 5th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew quarantine considered as a unit (not as individuals)	Conclusion of 6th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew isolated from Mars samples on mission Earth-return leg	Conclusion of 6th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew isolated on return (21 days [tbd] cf. Apollo)	Conclusion of 6th Meeting
2E. Martian environmental conditions variation over time with respect to growth of Earth microorganisms	Understand contemporary discontinuous Special Region conditions at the size and time scale of microbial growth on Mars	Establish temperature and water activity duration limits	Discussion at the 2nd Meeting: Applied from the SR-SAG2 findings (Rummel et al. 2014)
2F. Research needed to make ISRU & planetary protection goals compatible	N/A	N/A	Since only considered as a tech demo for first mission, this item was left open. (Discussion at 4th Meeting)
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	Containment of waste on the Martian surface	50+ year container design life, with sealing or 0.2um HEPA filtered venting	Conclusion at the 5th Meeting. Trade study of sealing vs HEPA filtration needed
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	Should trash be sterilized	No consensus	Conclusion at the 5th Meeting Trade - study needed
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	Should bulk containment be used	Yes, but double layer containment recommended flexible primary (bag), rigid secondary (sealed or with 0.2um filtration TBD)	Conclusion at the 5th Meeting. May take place instead of sterilization.
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	Is a single disposal site needed	Yes a single site is preferred	Conclusion at the 5th Meeting
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials	Does trash need to be buried	No	Surface is better from UV setilization and leak mitigation perspectives. Conclusion at the 5th Meeting
ORIGINAL 2H. DELETED (merged with 2B.)	N/A	N/A	N/A
2I. Approaches to achieve 'Break the chain" requirements	Pristine sample containment (defined as a sample that could be used to test for extant and (TBD) extinct Martian life	Consistent with current Special Region containment for “pristine” samples	Conclusion of 6th Meeting
2I. Approaches to achieve 'Break the chain" requirements	“Regular” sample containment	TBD by policy for determining Consistent with current Special Region containment for “pristine” samples	Discussion in 6th Meeting
2J. Global distribution/depth of subsurface ice and evidence of extant life	Local depth of ice (ground truth preferred)	Increased confidence level from SWIM data/future precursor (Icemapper-type) mission data	Needed to inform risk posture. Discussion in the 2nd Meeting
2J. Global distribution/depth of subsurface ice and evidence of extant life	Evidence of extant life	Increased confidence level from MSR data*	Desirable to inform risk posture. MSR will help bound the issue, although “absence of evidence is not evidence of absence”. Discussion in the 2nd Meeting
2K. Evolution of planetary protection requirements/goals from robotic precursor through to human missions & exploration zones	Ongoing knowledge-based transition	Closure of these knowledge gaps	Stability of the knowledge gap set from 2015 to the end of the Meeting series gives confidence that this is addressable
Natural Transport of Contamination on Mars Knowledge Gaps	**Parameter**	**Figure of Merit/Current Best Estimate**	**Notes**
3A. Measurements/models needed to determine atmospheric transport of contaminants	Measurements to establish a mesoscale predictive model (baseline performance levels assuming appropriate instrument suite)	Air Pressure 4Hz cf MSL Air Temp. 4Hz 150-300K +/-0.1K Ground Temp. 1/Hr 150-300K +/-1K Wind (in 3D) 10Hz 0-50m/s +/-0.5m/s: 360deg +/-5deg Humidity 1/Hr 0-100% +/-5% Upwelling shortwave & IR 1/hr w/ TBD Range & Accuracy Downwelling Solar flux 4Hz w/ TBD Range & Accuracy UV-C flux 4Hz with TBD Range & Accuracy Total dust opacity 4Hz 0-6 +/-0.03 Dust size & conc. 4Hz >0.2um +/-0.05um @1-5000/cm^3 Dust saltation mass flux 4Hz >0.65um +/- 10um @1-30m/s	Conclusion at the 2nd Meeting (minimum specs quoted)
3A. Measurements/models needed to determine atmospheric transport of contaminants	Instrument suite to establish a mesoscale predictive model	Few 10s of Kgs high fidelity instrument suite supported by three low fidelity instrument suites	Conclusion at the 2nd Meeting
3A. Measurements/models needed to determine atmospheric transport of contaminants	Application of a mesoscale predictive model	TBD time/distance concern for viable organisms in the Martian atmosphere/surface	Discussion at the 2nd Meeting
3B. Measurements/models for subsurface transport of contaminants	Develop and prove drill sterilization strategies	TBD case-by-case development of planetary protection compatible operational plan	Conclusion at the 2nd Meeting
3B. Measurements/models for subsurface transport of contaminants	Analyze contamination pathways for sterile drilling	TBD time/distance/depth concern for viable organisms in the Martian subsurface	Discussion at the 2nd Meeting
3C. Effect of biocidal factors on survival factors on growth and adaptation of microorganisms	Effect of UV on terrestrial indicator organisms	Survival vs time	Conclusion at the 2nd Meeting
3C. Effect of biocidal factors on survival factors on growth and adaptation of microorganisms	Effect of Martian (electro-) chemical environment on terrestrial indicator organisms	Survival vs time	Conclusion at the 2nd Meeting
3C. Effect of biocidal factors on survival factors on growth and adaptation of microorganisms	Effect of analog environment (combination factors) on indicator organisms	Survival vs time	Conclusion at the 2nd Meeting
3D. Determination of acceptable contamination rates & thresholds	Application of 3A/3B and 3C/3E to 2B and 3G inputs to establish risk posture for crewed missions	Development of an acceptability model for biological contamination	Conclusion at the 2nd Meeting
3E. Protection mechanisms for organisms on Mars	Shielding effects of biologic (eg biofilm, colony) materials on organisms released into Mars environment	Lethality rate decrease compared to the “standard” Mars environment	Conclusion at the 2nd Meeting
3E. Protection mechanisms for organisms on Mars	Shielding effects of abiotic (dust, spacecraft) materials on organisms released into Mars environment	Lethality rate decrease compared to the “standard” Mars environment	Conclusion at the 2nd Meeting
3F. Degradation of landed materials by Martian environment	Use life of general components	Catalog operational performance of materials on Mars rovers	In general, this is addressable from existing robotic mission performance data together with terrestrial testing
3F. Degradation of landed materials by Martian environment	Use life of specific components/materials for needed applications	Earth/precursor mission testing of operational performance of materials on Mars rovers	In general, this is addressable from existing robotic mission performance data together with terrestrial testing
3G. Induced environmental conditions around structures	Growth of contaminant organisms in s/c induced SR	TBD time/distance/depth concern for viable organisms in the Martian subsurface (subset of 3B)	Discussion at the 5th Meeting
3H. Sensitivity of non-culturable species to biocidal factors	Demonstration of equivalent sensitivity compared to cultivable population	Establishment of a factor (if not 1.0 cf 3C data) for lethality to allow assessments under 3D to be made	Discussion at the 2nd Meeting

COSPAR planetary protection KG parameters for a crewed Mars mission all in one table, with progress color-coded in the 3rd column

Key:	
	Knowledge Gap response approach is mature and/or addressable as policy
	Knowledge Gap response is actively being addressed and planetary protection application and outcome is clear
	Knowledge Gap response or path to closure is identified but planetary protection acceptability and/or outcome is not clear
	Knowledge Gap is not being addressed or work to closure is not started or new data acquisition is still needed

Note: not all KGs need to be closed for a viable PP Implementation strategy, but all need to be addressed and dispositioned in a risk-based approach

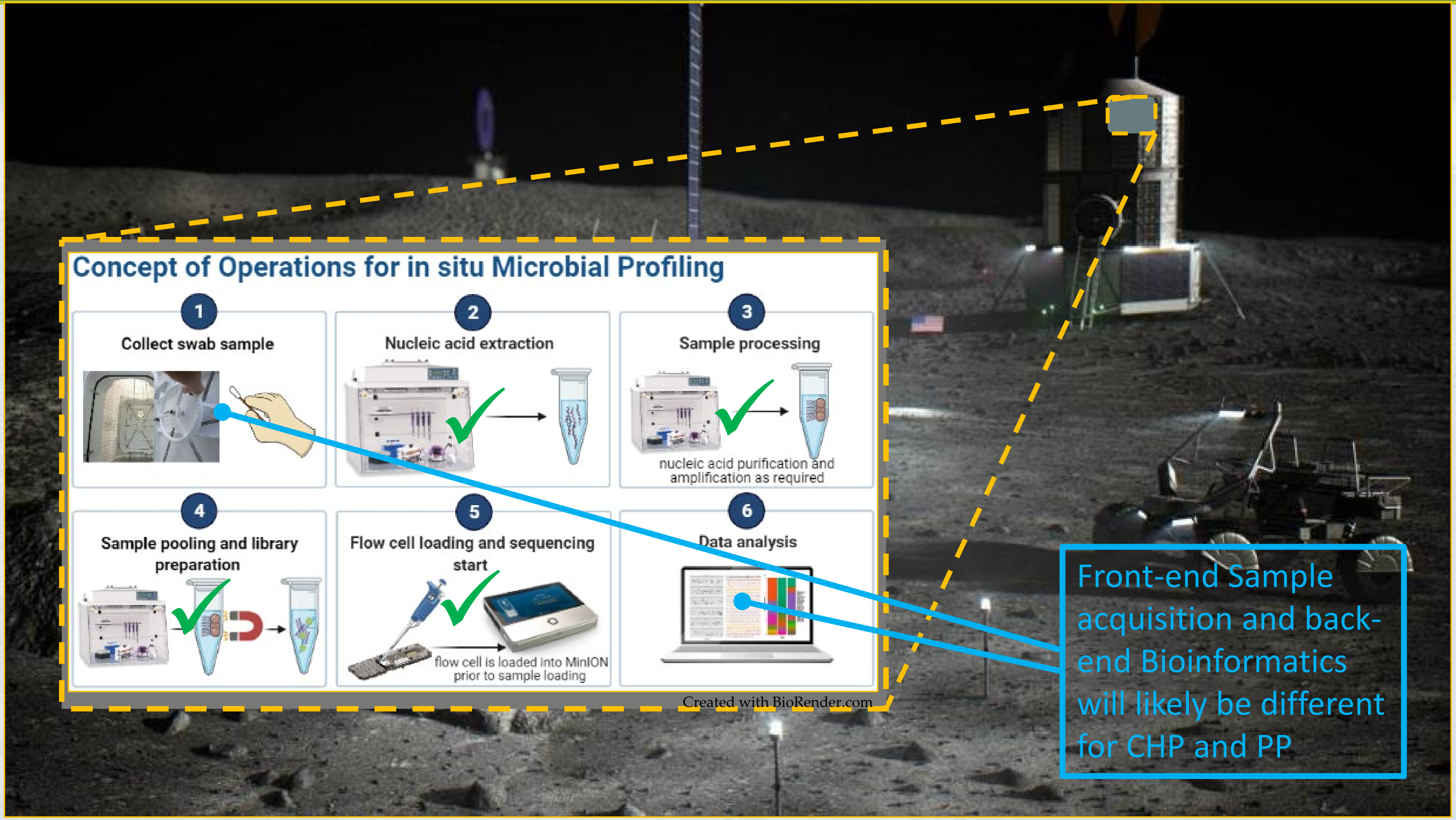
Disposition of Planetary Protection KGs at the end of the COSPAR Meeting Series – 1) Microbial and Human Health Monitoring

Microbial & Human Health Monitoring Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
1A. Microbial monitoring of the environment	Detection and monitoring of microorganisms inside the habitat and in the Mars environment	TBD based on data from analog research to establish baseline information and decision-making strategies	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing (Conclusion of the 3rd Meeting)
1B. Microbial monitoring of humans	Detection and monitoring of microorganisms on/in crew	TBD based on data from analog research to establish baseline information and decision-making strategies	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing (Conclusion of the 3rd Meeting)
1C. Mitigation of microbial growth in spacecraft systems	Monitoring of microorganisms inside the habitat and establishment of action limits.	Establish (sub)-system requirements based on (sub)-system design and release limits (2B)	Conclusion of 5th Meeting
1D. Operational guidelines for planetary protection and crew health	Ability to distinguish between benign and hazardous fluctuations in metagenome data	TBD: Outcome dependent on 1A & 1B	MinION technology with appropriate front-end (sampling) and back-end (bioinformatics) processing. Discussion at the 3rd Meeting.

- Needed technology is identified to be able to address KGs in Microbial & Human Health Monitoring
  - Demonstrated on ISS for crew monitoring
  - Data needs to be generated to create a framework for developing PP decision-making processes

Key:	
(blue)	Knowledge Gap response approach is mature and/or addressable as policy
(green)	Knowledge Gap response is actively being addressed and planetary protection application and outcome is clear
(yellow)	Knowledge Gap response or path to closure is identified but planetary protection acceptability and/or outcome is not clear
(red)	Knowledge Gap is not being addressed or work to closure is not started or new data acquisition is still needed

Microbial Monitoring Technologies for Planetary Protection



Disposition of Planetary Protection KGs at the end of the COSPAR Meeting Series – 3) Natural Transport of Contamination on Mars

Natural Transport of Contamination on Mars Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
3A. Measurements/models needed to determine atmospheric transport of contaminants	Measurements to establish a mesoscale predictive model (baseline performance levels assuming appropriate instrument suite)	Air Pressure 4Hz cf MSL Air Temp. 4Hz 150-300K +/-0.1K Ground Temp. 1/Hr 150-300K +/-1K Wind (in 3D) 10Hz 0-50m/s +/-0.5m/s: 360deg +/-5deg Humidity 1/Hr 0-100% +/-5% Upwelling shortwave & IR 1/hr w/ TBD Range & Accuracy Downwelling Solar flux 4Hz w/ TBD Range & Accuracy UV-C flux 4Hz with TBD Range & Accuracy Total dust opacity 4Hz 0-6 +/-0.03 Dust size & conc. 4Hz >0.2um +/-0.05um @1-5000/cm^3 Dust saltation mass flux 4Hz >0.65um +/- 10um @1-30m/s	Conclusion at the 2nd Meeting (minimum specs quoted)
3A. Measurements/models needed to determine atmospheric transport of contaminants	Instrument suite to establish a mesoscale predictive model	Few 10s of Kgs high fidelity instrument suite supported by three low fidelity instrument suites	Conclusion at the 2nd Meeting
3A. Measurements/models needed to determine atmospheric transport of contaminants	Application of a mesoscale predictive model	TBD time/distance concern for viable organisms in the Martian atmosphere/surface	Discussion at the 2nd Meeting
3B. Measurements/models for subsurface transport of contaminants	Develop and prove drill sterilization strategies	TBD case-by-case development of planetary protection compatible operational plan	Conclusion at the 2nd Meeting
3B. Measurements/models for subsurface transport of contaminants	Analyze contamination pathways for sterile drilling	TBD time/distance/depth concern for viable organisms in the Martian subsurface	Discussion at the 2nd Meeting
3H. Sensitivity of non-culturable species to biocidal factors	Demonstration of equivalent sensitivity compared to cultivable population	Establishment of a factor (if not 1.0 cf 3C data) for lethality to allow assessments under 3D to be made	Discussion at the 2nd Meeting

- Understanding the Natural Transport of Contamination on Mars allows us to answer the question “How much contamination is too much?”
  - Data needs to be generated to create models of transport at Mars (particularly for the aeolian distribution case)
  - Data is also needed on the ability of contaminant terrestrial microorganisms to survive in the Mars environment

Disposition of Planetary Protection KGs at the end of the COSPAR Meeting Series – 2a) Technology & Ops for Contamination Control

Technology & Operations for Contamination Control Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
2A. Bioburden/transport/ operations during short vs. long stays	N/A	N/A	Since only short stay missions are considered, this KG was left open. (Discussion at 4th Meeting)
2B. Microbial/organic releases from humans and support systems	Is it required for an airlock volume to be sterilized prior to egress.	Yes, degree of filtration/ sterilization processing TBD based on threat of organisms released	Expectation that Hydrogen Peroxide vapor and UV technologies might be suitable for this purpose. Conclusion
2B. Microbial/organic releases from humans and support systems	Is it required for an airlock volume to be sterilized prior to ingress.	Yes, degree of filtration/ sterilization processing TBD based on threat of organisms released	Expectation that Hydrogen Peroxide vapor and UV technologies might be suitable for this purpose. Conclusion
2B. Microbial/organic releases from humans and support systems	Is it required for suits/ tools/ instruments/ robots to be sterilized prior to egress	Yes, if required for pristine sample acquisition/processing	Consideration that pass-through glove box technology with hydrogen peroxide technology might be suitable for this
2B. Microbial/organic releases from humans and support systems	Is it required for suits/ tools/ instruments/ robots to be sterilized prior to ingress	Yes, if exposed to pristine/Special Region or unknown Mars environments/materials	Consideration that pass-through glove box technology with hydrogen peroxide technology might be suitable for this
2C. Protocols for decontamination & verification procedures	Bioburden reduction technology compatible with spaceflight systems	TBD based on data from analog research to establish performance of candidate technologies	Conclusion of 5th Meeting

- The COSPAR meeting series considered Technology and Operations for the first crewed Mars mission, leading to paths forward to address:
  - Contamination from spacecraft systems
  - Mitigation of contamination
  - Waste handling
- The discussions and findings give confidence that these topics are a tractable problem set for an end-to-end planetary protection implementation solution.

Disposition of Planetary Protection KGs at the end of the COSPAR Meeting Series – 2b) Technology & Ops for Contamination Control

Technology & Operations for Contamination Control Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew quarantine considered as a unit (not as individuals)	Conclusion of 6th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew isolated from Mars samples on mission Earth-return leg	Conclusion of 6th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew isolated on return (21 days [tbd] cf. Apollo)	Conclusion of 6th Meeting
2I. Approaches to achieve 'Break the chain" requirements	Pristine sample containment (defined as a sample that could be used to test for extant and (TBD) extinct Martian life	Consistent with current Special Region containment for "pristine" samples	Conclusion of 6th Meeting
2I. Approaches to achieve 'Break the chain" requirements	"Regular" sample containment	TBD by policy for determining Consistent with current Special Region containment for "pristine" samples	Discussion in 6th Meeting

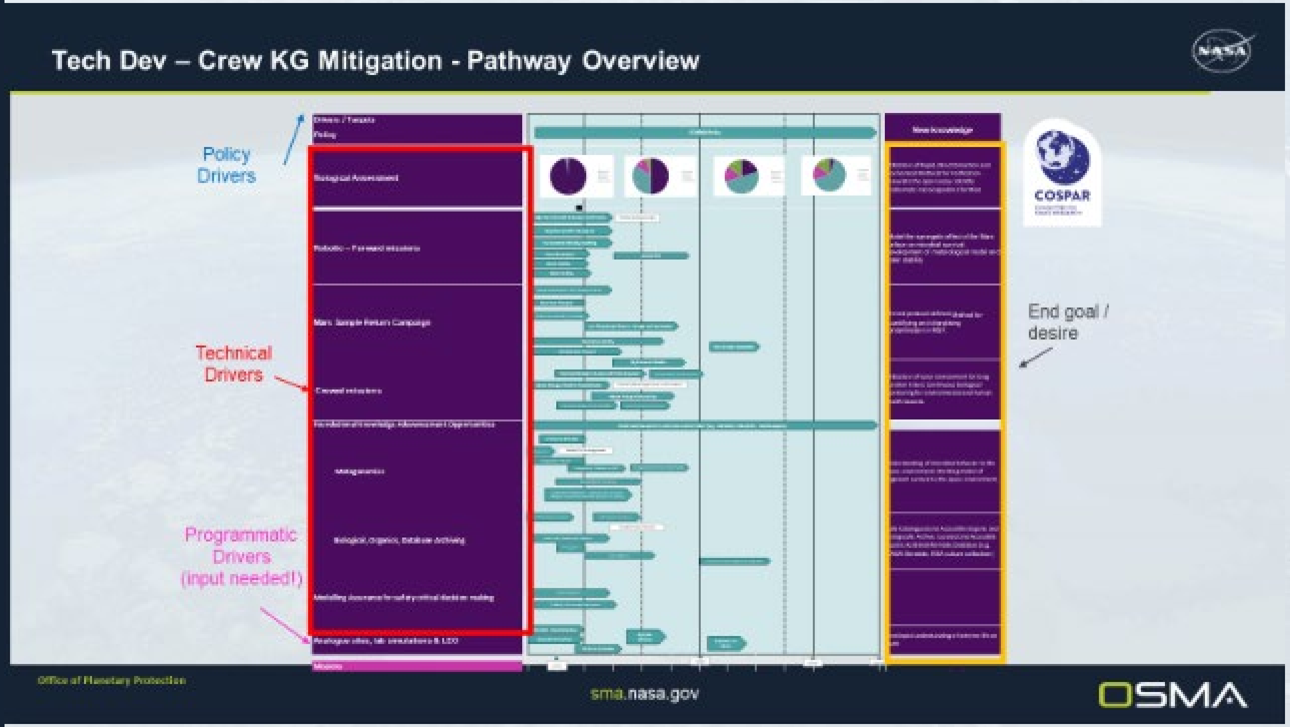
- The Technology and Operations to address backward planetary protection for the first crewed mission reflects a conservative approach
  - Containment of Mars samples (even if a prior MSR mission detected no life)
  - Quarantine of crew on return

COSPAR Perspective

The COSPAR Panel on Planetary Protection will continue to work with the different national and international space agencies, the scientific community, and other stakeholders (e.g., the private sector and industry) to develop a roadmap for coordinating research activities addressing the identified knowledge gaps.

Olsson-Francis, et al. (2023) Life Sciences in Space Research, 36, 27-35.

- COSPAR as the source for policy and planning

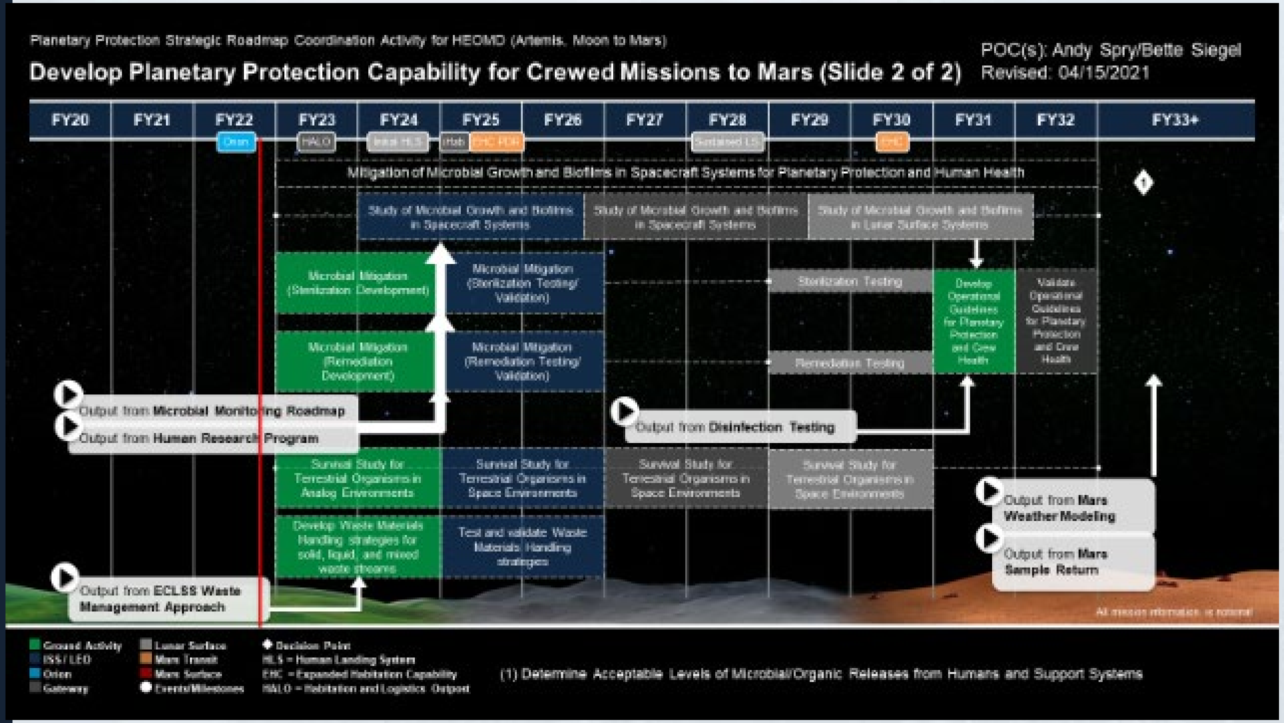


- e.g. IMEWG as a venue for coordination and action

  - *Opportunities for collaboration on instruments, small missions, launch activities, data sharing, analog activities, etc. etc….*

Closing the Knowledge Gaps – NASA/US Community Dimension

- Updating of NASA's own PP policy and planning



- NASA-wide advocacy for KG closure activities
  - *Competitive Awards, e.g. ROSES, SBIRs, EPSCoR*
  - *ESDMD Strategic Architecture Office guided work*
  - *ESDMD Mars Campaign Office guided work*
  - *Center-supported activities*
  - *Coordination with other Tech Dev activities e.g., HERA, DRATS, CHAPEA*
  - *Stakeholder Engagement (workshops, seminars etc.)*

Returning to the "How Much is too Much?" Question: Contamination Assessment – Detailed Analysis

Item	Basis	Specification (if any)	Notional	Conversion factor (mass etc. to CFU)	Start Condition:Day -3 (DST Hatch Closure)	End condition: Day 33 (MAV Arrival at DST & Waste left behind)
Food for 36 days	0.294kg/crew/day reduced stock over time arrives with lander 3	<10000cfu/kg	10000cfu/kg	2.94kg/d	2116800	0 TBD based on margin policy
Crew Microbiome	constant, arrive with lander 3	1E+13/person	1E+13/person	2 crew	2.00E+13	2.00E+13
Urine (0.320ml/d)	accumulates over time: dropoffs at logistics/waste transfer EVAs	<10000/ml	1000/ml	1000ml = 1kg; 320ml/d	1920000	21120000
Solid (fecal) Waste (Kg)	0.3kg/crew/day accumulates over time: dropoffs at logistics/waste transfer EVAs	1E+14/kg	1E+14/kg	0.6kg/day	1.8E+14	1.98E+15
Shed Waste (all sources)	accumulates over time: skin cells, hair, etc.: air filter dropoffs at logistics/waste transfer EVAs TBD	NA	TBD	Estimate to difficult, based on Ganesh et al 2019 and Checinska et al. 2015 + others: use Equilibrated Crewed	NA	NA
Equilibrated Crewed Environment (PR =10 m3)	Assume PR is equilibrated to ISO9 cleanliness by the time it reaches the Martian surface	8320000/m3 @>2um 293000/m3 @>5um	10% of particles >2ur	Estimate, based on Ganesh et al 2019 and Checinska et al. 2015 + others	8320000	8320000
Clothing	Starts clean, goes to dirty/waste	NA	400g clothing/astronaut/ 2days =30x400=12kg	Whitehead et al. 2023 dirty = 415 bacteria/g/day	(Assume sterilized)	9960000
Hygiene Products 0.4L	Starts clean, goes to dirty/waste	100	100	400g, not cleaner tha	2640	1095600
Drinking Water (36d?)	Starts clean ends up as urine	0	0	2.79L/d min.	0	(margin?)
Breathable Air (36d?)	Starts clean, ends as	0	0		0	(margin?)

Returning to the "How Much is too Much?" Question: Contamination Assessment – Key Takeaways

Item	Basis	Specification (if any)	Notional	Conversion factor (mass etc. to CFU)	Start Condition:Day -3 (DST Hatch Closure)	End condition: Day 33 (MAV Arrival at DST & Waste left behind)
Food for 36 days	0.294kg/crew/day reduced stock over time arrives with lander 3	<10000cfu/kg	10000cfu/kg	2.94kg/d	2116800	0 TBD based on margin policy
Crew Microbiome	constant, arrive with lander 3	1E+13/person	1E+13/person	2 crew	2.00E+13	2.00E+13
Urine (						20000
Solid (fe						3E+15
Shed W sources						NA
Equilibr Environ m3)						20000
Clothing	dirty/waste		clothing/astronaut/ 2days =30x400=12kg	2023 dirty = 415 bacteria/g/day		60000
Hygiene Products 0.4L	Starts clean, goes to dirty/waste	100	100	400g, not cleaner tha	2640	1095600
Drinking Water (36d?)	Starts clean ends up as urine	0	0	2.79L/d min.	0	(margin?)
Breathable Air (36d?)	Starts clean, ends as	0	0		0	(margin?)

Key Contamination Risk Assessment Takeaways:

~ 2.0 x10^{15} Organisms introduced to Mars in 3-lander crewed mission

Comprising:

- ~ 1.98 x10^{15} Organisms associated with solid (fecal) metabolic waste
- ~ 2.0 x10^{13} Organisms associated with the crew (who leave at EOM)
- ~ 2.1 x10^{7} Organisms associated with urine waste storage
- ~ 2.29 x10^{8} Organisms associated with pressurized/unpressurized hardware
- ~ 1.5 x10^{7} Organisms associated with other waste articles
- ~ 2.0 x10^{7} Organisms associated with potential operational activities

Summary

- The COSPAR Planetary Protection Policy and Guidelines include approaches for controlling forward and backward contamination at Mars.
- Approaches for robotic missions are well developed and have successfully guided exploration and preserved scientific integrity for over 50 years.
- Approaches for crewed missions are still in development, but require a paradigm shift from robotic methods.
- A path to achieving that shift is already identified through closure of knowledge gaps identified in the COSPAR workshop series.
- Work to develop a Knowledge-based Risk-informed Decision Making Process in under way.
- Knowledge gap closure will be a team effort – with room for everyone to contribute!

Questions?

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Contamination vs. Harmful Contamination

Contamination	Harmful Contamination
Contamination* Unwanted material present on or in the spacecraft/spacecraft assembly environment or introduced into the environment of a solar system body.	**Harmful Contamination*** Unwanted material on the surface of a solid material, or incorporated into a solid, liquid, or gas that damages the integrity of the study of chemical evolution and the origin of life at another solar system body, or that has negative consequences for humans and Earth's biosphere.
Expected: There is a non-zero amount of contamination expected for spacecraft.	**To Be Limited and Avoided:** What is the tipping point from "contamination" to "harmful contamination?"
Contamination Control: Practice to control contamination of spacecraft & spacecraft assembly environments to acceptable limits.	**Planetary Protection:** Practice to limit contamination of solar system bodies (Forward PP) and avoid harmful contamination of Earth (Backward PP).
Focuses on: Particulate contamination, molecular contamination, & sometimes biological contamination.	**Focuses on:** Biological contamination & molecular contamination.
Contaminants of Concern: Not all contaminants are the same. Requirements depend on what the contamination is, where it is, and how much.	**Contaminants of Concern:** Biological – Spores & viable terrestrial organisms Molecular - ???

**Definitions from NASA-STD-8719.27*

First Principle: Harmful Contamination – Planetary Protection

SCIENCE Responsibility

- There's a cost of doing business. Exploration comes at "some" cost. All space activities will have some level of contamination. The question is when does it become an issue?
- Day-to-day trade space for the scientific process and the design of experiments (e.g., signal to noise, limit of detection etc.).
  - Ability to interpret analytical results with meaningful conclusions
  - Statistical significance – uncertainty, what defines acceptably low, stable, and well-characterized? (OCP Report 2014)

PP Responsibility

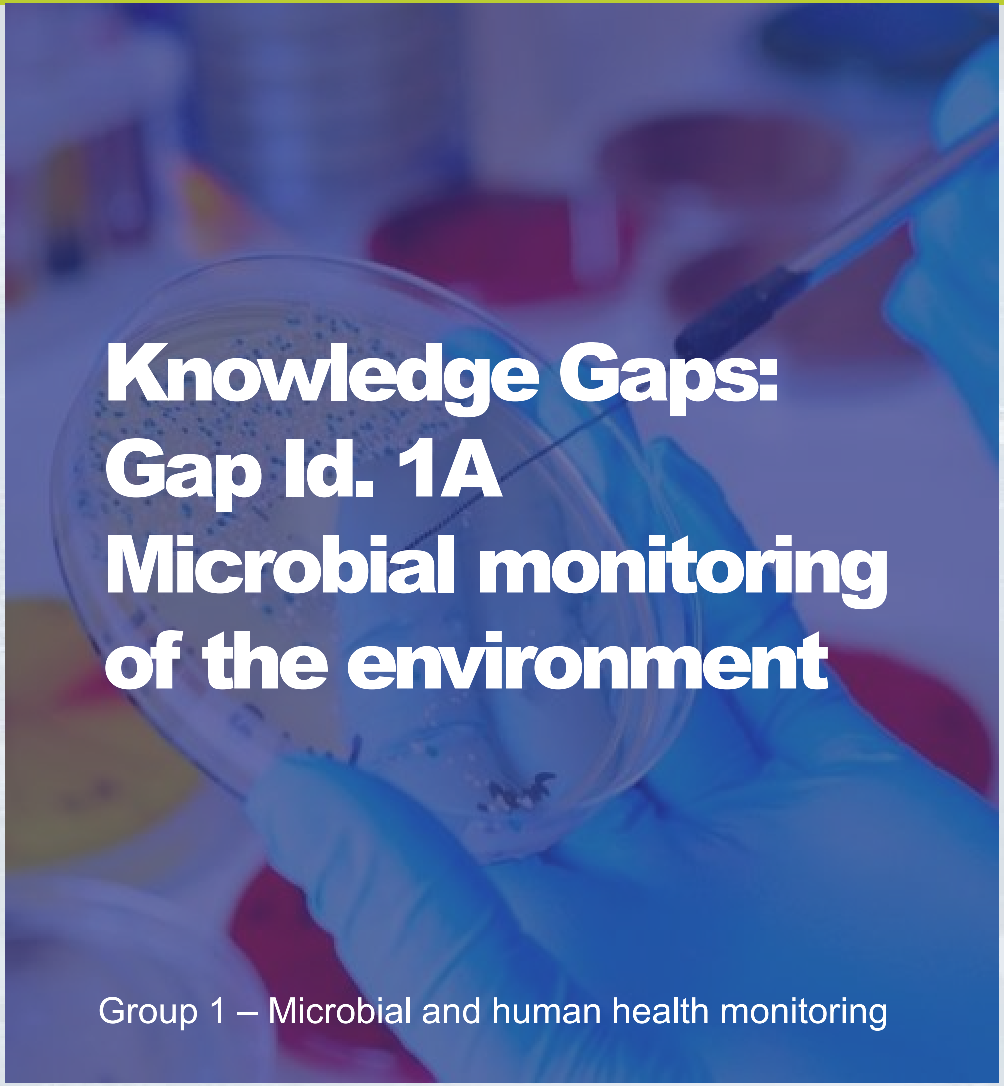
- PP Policy needed to help define objectives and develop performance metrics based on science need. (Assuming this is not a one size fits all answer.)
- PP Policy needs a balanced solution to enable science but does not replace science's role.
- Enables science by defining an internationally agreed upon set of practices.
- What defines this trip wire for science?
  - Limit of detection? Projected limit of detection?
- Is this different for
  - Current mission(s)?
  - Future missions? Is there a time dimension to project?
- What's the balance point for science return vs. barriers to exploration? Can you plan for the unknowns or a bad day?

Contamination

What is the organic material of concern?
Concentration of concern?

Knowns vs. Unknowns?

Harmful



Knowledge Gaps: Gap Id. 1A Microbial monitoring of the environment

Group 1 – Microbial and human health monitoring

1. What systematic microbial monitoring is required ?
2. What monitoring is required on human missions ?
3. What is the mutation rate in flight ?

Knowledge Gaps: Gap Id. 1A Microbial monitoring of the environment

Group 1 – Microbial and human health monitoring

MORE SPECIFIC QUESTIONS

- Where is the right spot to monitor?
- How clean is clean enough?
- Can one be too clean?
- 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?

Tasks: Gap Id. 1A
Microbial monitoring of the environment

1
Take samples from spacecraft facilities and systems at higher frequency than currently taken (including air filters within the International Space Station)

2
Take contained microorganisms on missions (or simulated mission environments) to determine the mutation rate in the space environment (through comparative genomics)

3
Laboratory test to improve the understanding of microbial persistence in the space environment using targeted simulations (on Earth and on future missions)

4
Define the hazards in human health of introducing new organisms into a system

5
Tackle molecular biology gaps (low biomass, ketone, etc.) and standardise the method

6
Determine which organic materials might be dangerous for human health and develop VOC sensor technologies to monitor levels

7
Develop use of machine learning and AI to determine

Group 1 – Microbial and human health monitoring

Envisioned Resources – Biology, space environmental, reliability, contamination control, chemistry lab, material and processing, digital twin, AI