



COSPAR General Assembly 2024

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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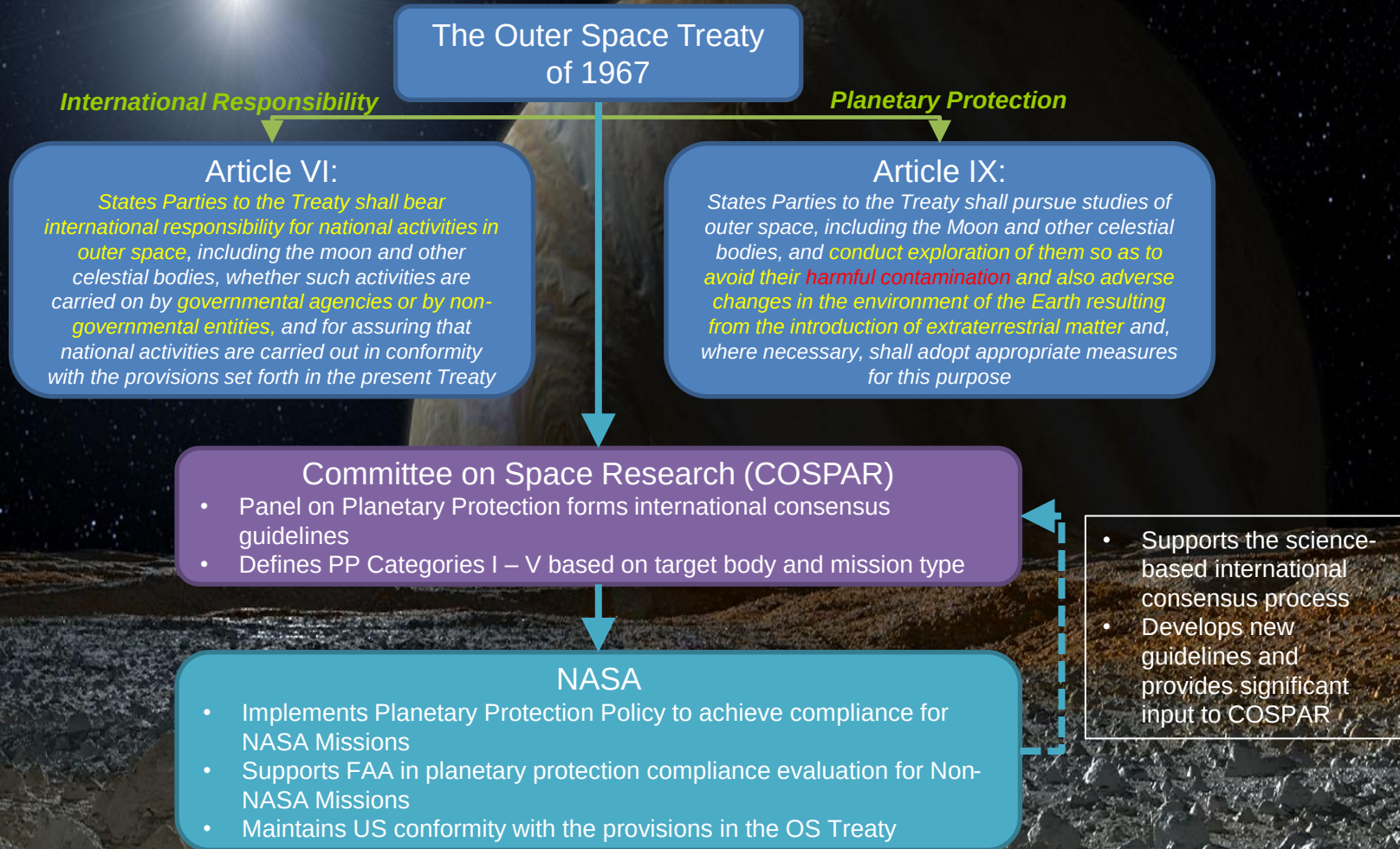
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International Planetary Protection Process

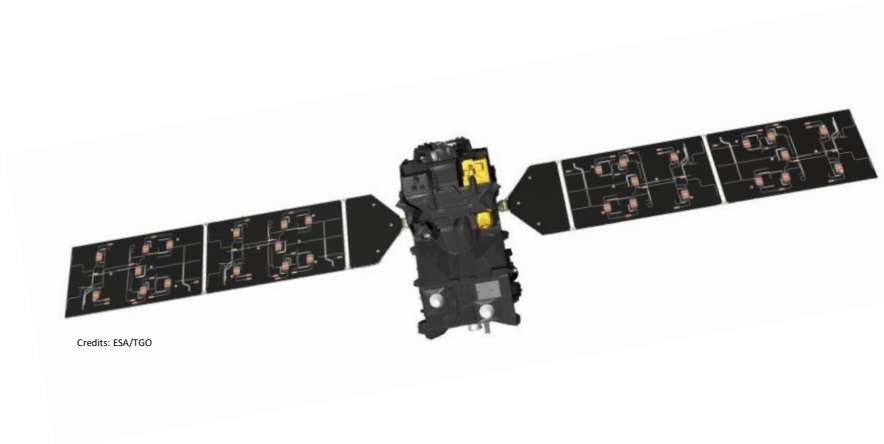




Planetary Protection Categorization

Types of Planetary Bodies	Mission Type	Mission 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



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

NID 8715.129 – Biological PP for Human Missions to Mars

PP 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 from COSPAR 2008 policy language)

COSPAR guidelines for crewed missions



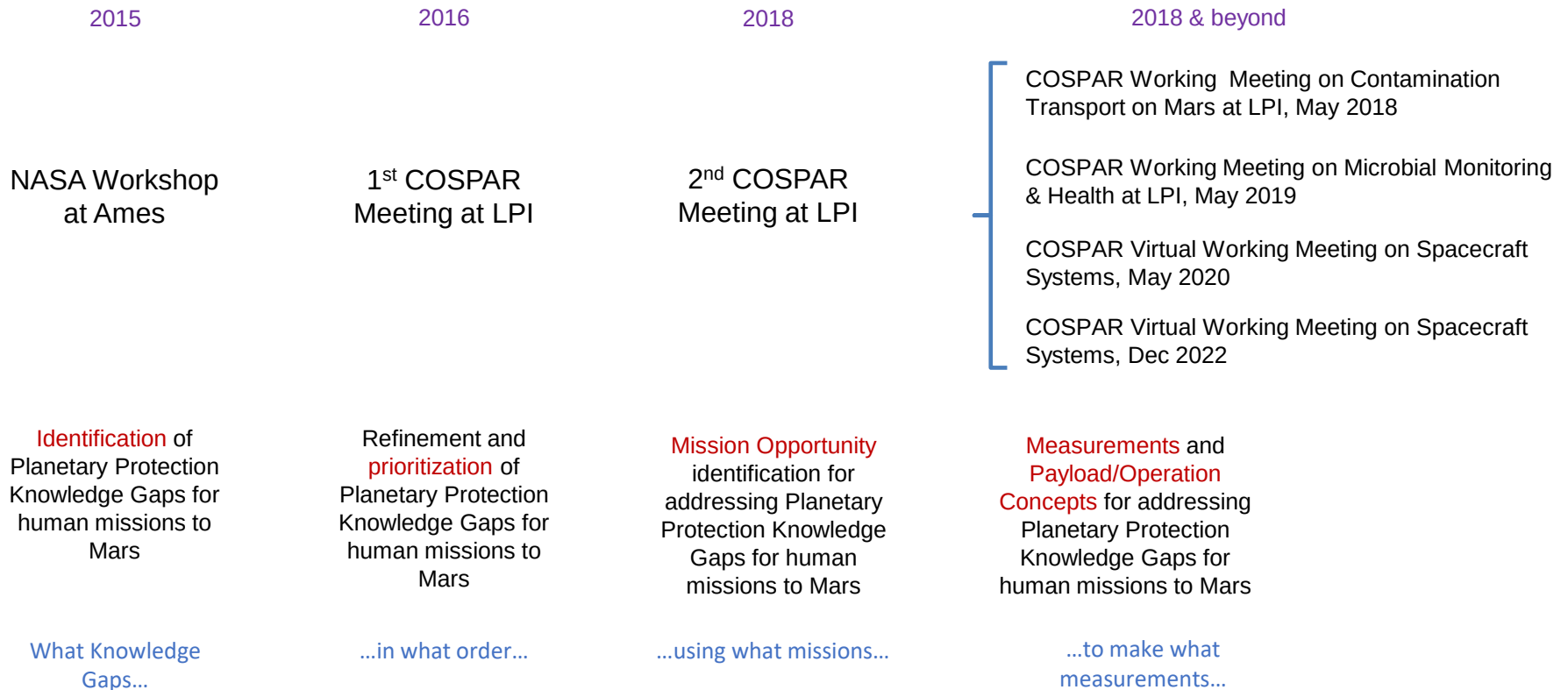
Current guidelines, in place since 2008, address:

- 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

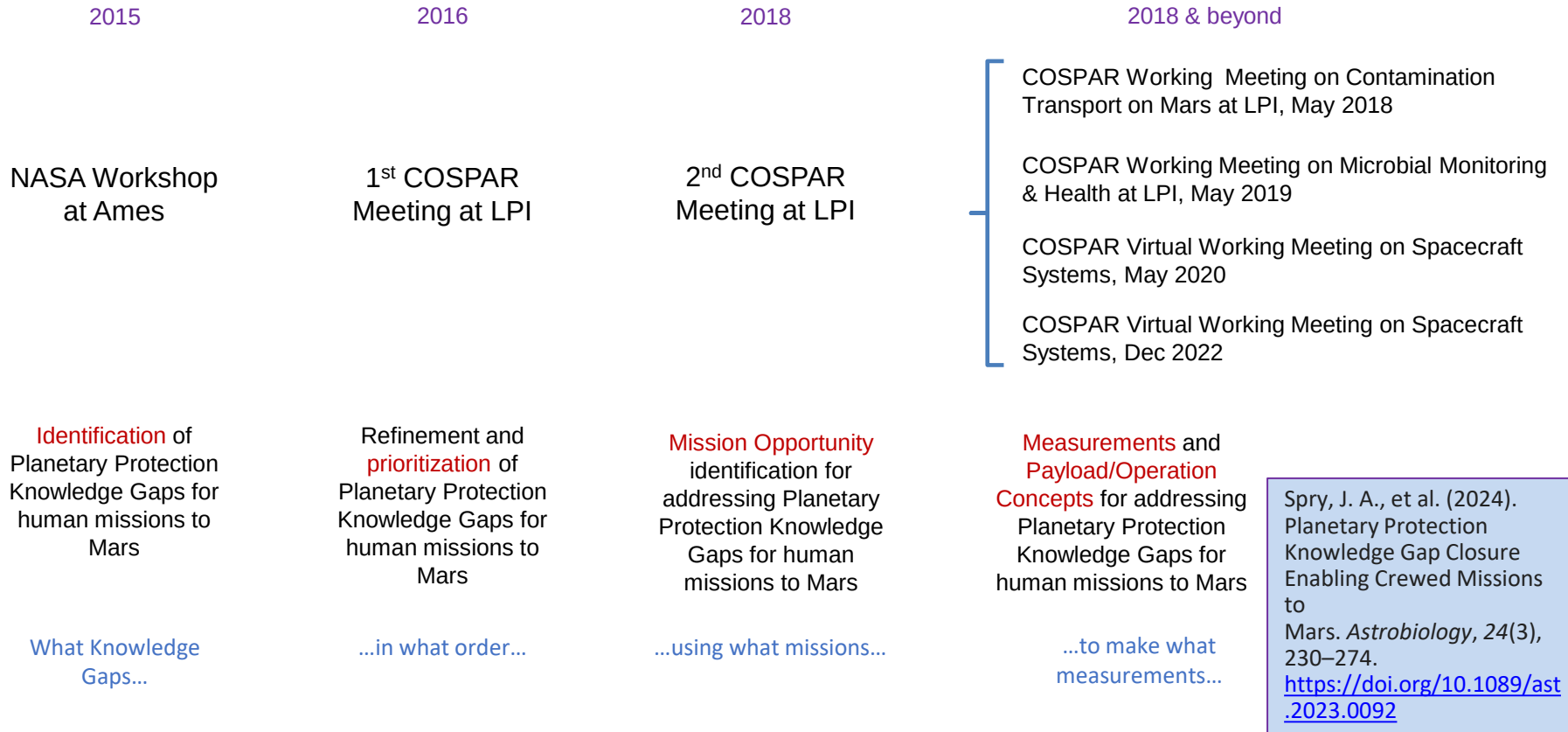


Assessment of Knowledge Gaps for future crewed missions



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

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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

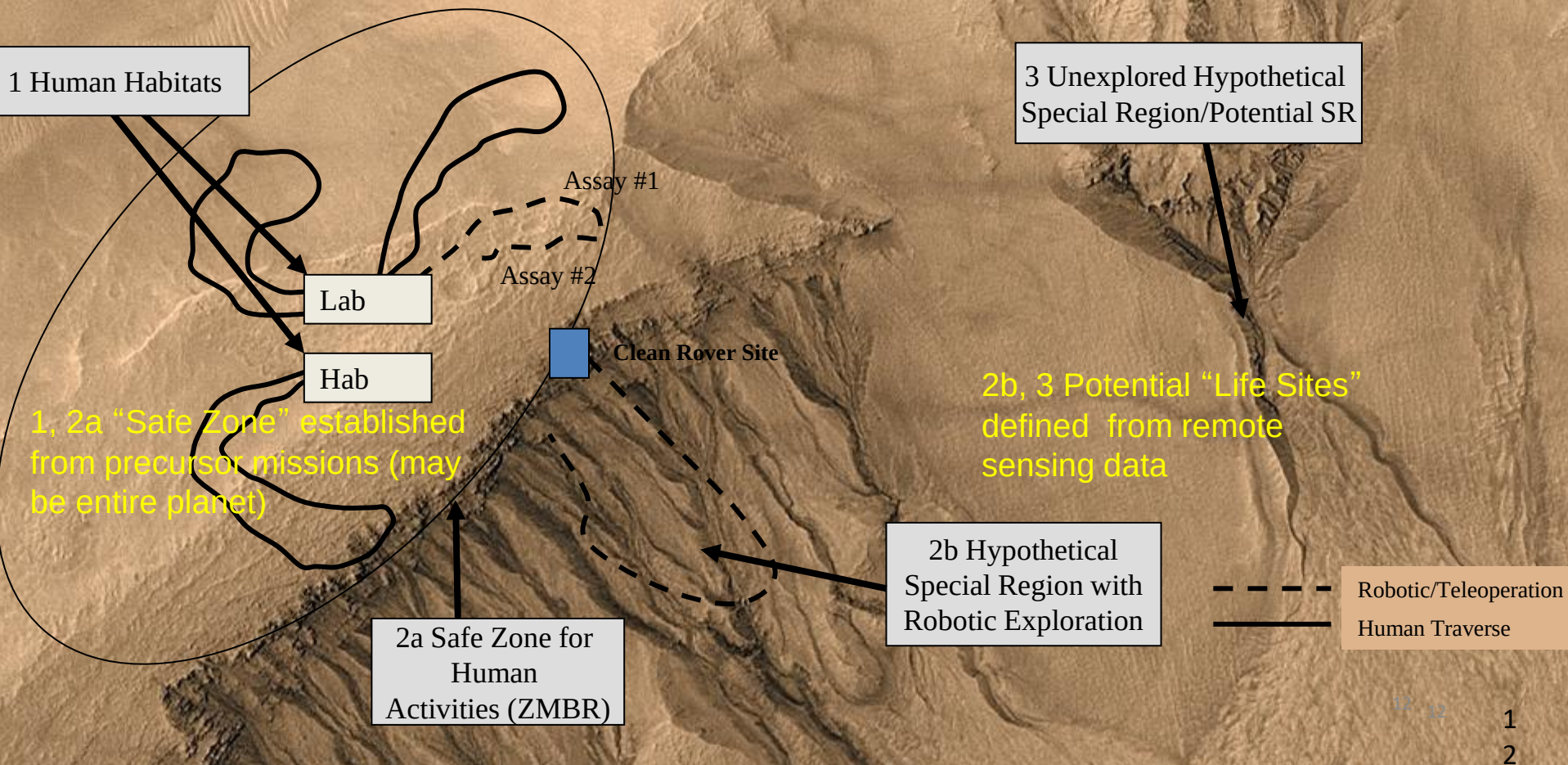
- **Technology and operations for contamination control**
 - Designs, methods and procedures for controlling contamination release of human spacecraft systems

- **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 Illustrating Need for “Zoning”



*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



1

PRE-DEPLOYED CARGO

- 25-ton class payload Mars lander
- Ascent vehicle propellant, Fission Surface Power, and surface mobility/propellant transfer system

2

PRE-DEPLOYED CREW ASCENT VEHICLE

- Partially-fueled

3

CREW

- Two crew land/live in pressurized rover
- Provides habitation and mobility for 30 days
- Supports science and exploration operations

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

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



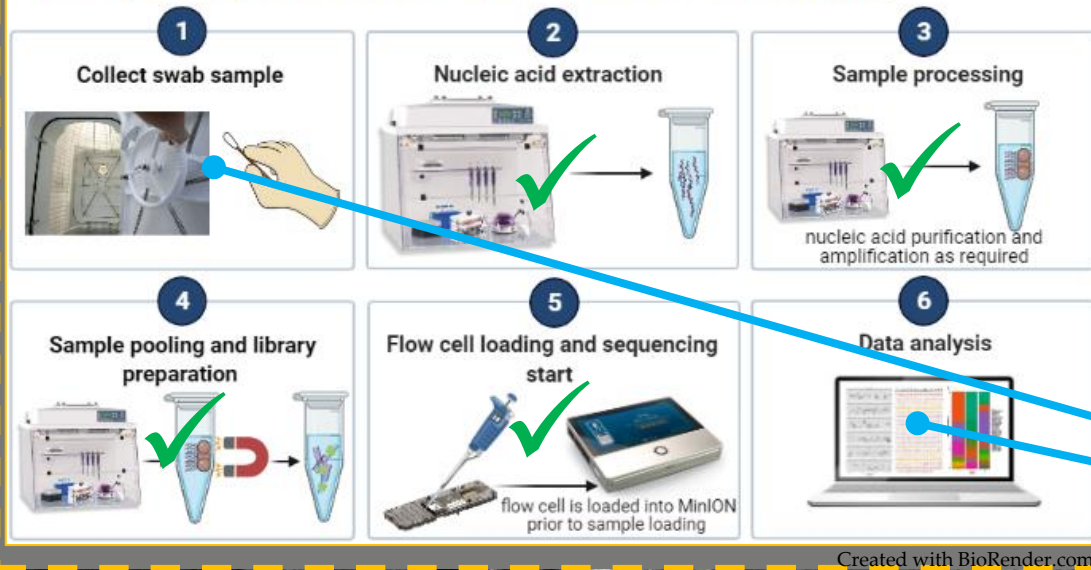
Microbial & Human Health Monitoring Knowledge Gaps	Parameter	Figure of Merit/Current Best Estimate	Notes
1A. Microbial monitoring of the environment	Detection and monitoring of microorganisms inside the habitat and in the Mars environment	TBD based on data from analog research to establish baseline information and decision-making strategies	MiniON technology with appropriate front-end (sampling) and back-end (bioinformatics) processing (Conclusion of the 3 rd 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 3 rd 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 5 th 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 3 rd Meeting.

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

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

Microbial Monitoring Technologies for Planetary Protection

Concept of Operations for in situ Microbial Profiling



Front-end Sample acquisition and back-end Bioinformatics will likely be different for CHP and PP

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 2 nd 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 2 nd 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 2 nd 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 2 nd 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 2 nd Meeting
3C. Effect of biocidal factors on survival factors on	Effect of UV on terrestrial indicator organisms	Survival vs time	Conclusion at the 2 nd 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

factors

cultivable population

allow assessments under 3D to be made

7

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 4 th 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 5 th 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 6 th 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 6 th Meeting
2D. Design of quarantine facilities/methodologies at different mission phases	Crew Quarantine	Crew isolated on return (21 days [tbd] cf. Apollo)	Conclusion of 6 th 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 6 th 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 6 th 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.

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 workshop series.
- Knowledge gap closure will be a team effort – with room for everyone to contribute!





Questions?

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