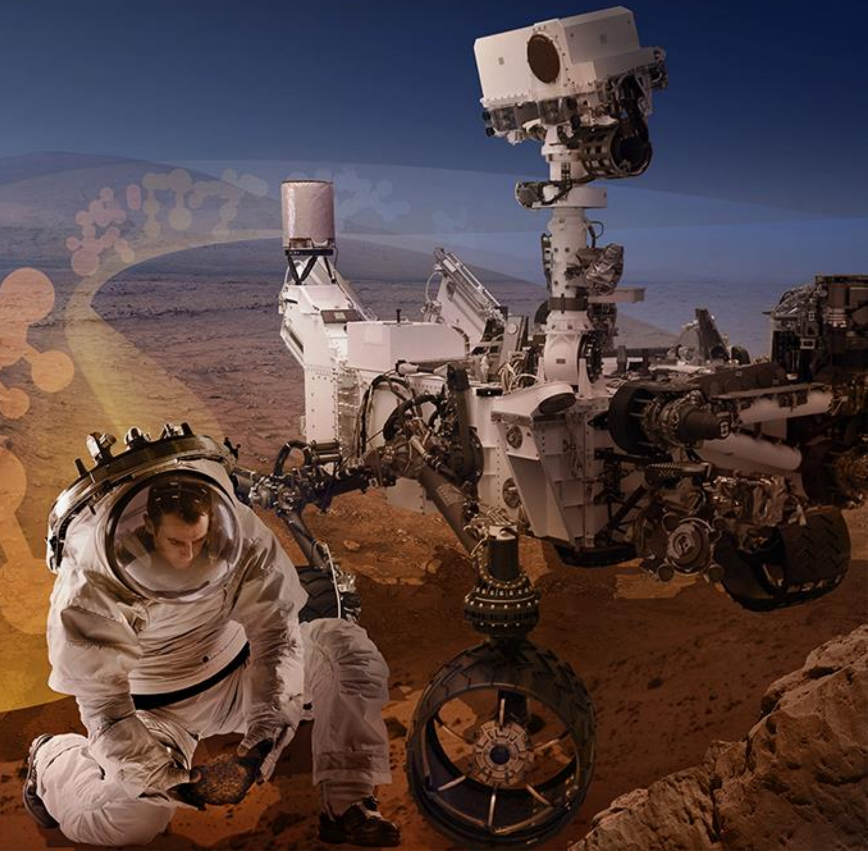
WORKSHOP

Planetary Protection Knowledge Gaps for

Human Extraterrestrial Missions



NASA's Literature Review & Identifying Notional Studies

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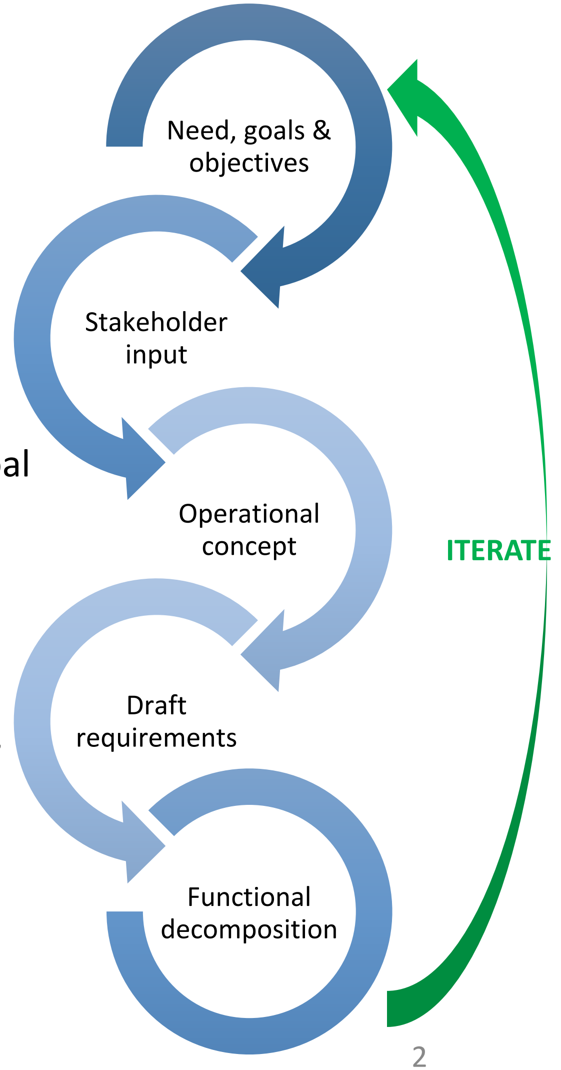
A Path to Requirements…

NASA's NPI provides a plan, while systems engineering practices and a healthy dose of iteration provide an approach…

- Step 1: Identify need, goals & objectives
  - Generally captured by COSPAR Guidelines for Human Missions
- Step 2: Gather knowledge & engage stakeholders
  - Completed via literature review and workshop
- Step 3: Develop an operational concept
  - NASA's Human Spaceflight Architecture Team (HAT)
  - International Space Exploration Coordination Group's (ISECG) Global Exploration Roadmap (GER)
- Step 4: Develop an initial requirement set
  - Notional requirements from the literature survey may serve as a baseline
- Step 5: Begin a functional decomposition
  - Literature review and workshop planning to identify key 'functions'
- Step 6: Iterate, iterate, iterate!
  - Will require several passes before converging on a first draft set of requirements

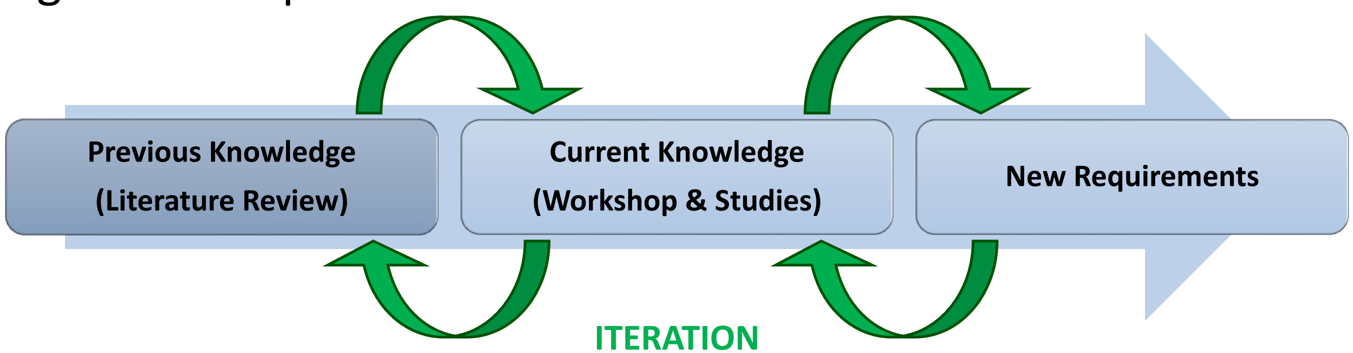


Gathering Knowledge: Background

- Per NASA NPI 8020.7:
  - Detailed studies must be conducted in order to obtain information critical to developing planetary protection requirements for human spaceflight missions
  - NASA will gather community input to determine the topics that should be studied
- Literature review a first step in gathering knowledge of:

Key Study Areas

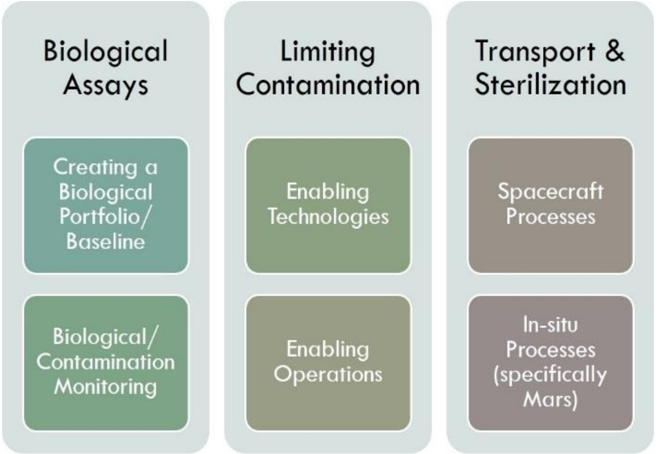
  - Capabilities to monitor microbial communities,
  - Needed technology and operational developments for minimizing contamination release, and
  - The contribution of Mars environmental processes to transport and sterilization of forward contamination
- Review commenced in November 2013 using an existing literature survey
  - *Impact of Planetary Protection Requirements on the Manned Mars Mission Design: A Quick Literature Survey (2003).* – Richard Heidmann
- Historical knowledge to be combined with findings from this workshop in iterating future requirements



Gathering Knowledge: The Process

- Searching of publications identified 105+ potential sources of information
  - Sources identify stakeholders in spaceflight operations, technology development, and science communities
- Documentation was divided into the 3 key study areas of the NPI:
  - **Human health & microbial monitoring**
  - **Technology & operations for contamination control**
  - **Natural transport of contamination on Mars**
- Recurring themes culminated in:
  - **Draft Requirements** – 41 identified
  - **Notional Studies** – 34 identified
  - **Needed Technology Developments** – 28 identified

				Bio Assays		Limiting		Environment	
Title	Primary Author	Date	Overview Description	Quantification	Monitoring	Technologies	Operations	Spacecraft	Surface
COSPAR Planetary Protection Policy, 20 Oct 2002, as amended 24 Mar 2011	COSPAR	2011	The official source of COSPAR Planetary Protection Policy applicable to robotic and human missions including general principles specifically relevant to mission planning and implementation as well as operating guidelines.				X		
Safe on Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface	National Research Council	2002	Investigates the hazards and associated risks likely encountered by the first human visitors to Mars. Recommends precursor measurements, if any, to be made prior to the first human mission. While investigates back contamination, does not address forward contamination.				X		
Planetary Protection Issues in the Human Exploration of Mars	Criswell, M.E., Race, M.S., Rummel, J. D., Baker, A.	2005	Frequently referred to as the "Pingree Park Report", this paper summarizes the results of five main working groups focusing on protecting against forward and back contamination while also protecting astronaut health. The result of the workshop was a detailed listing of recommendations including needed areas of future research. MUST READ!				X		
Life Support and Habitation and Planetary Protection Workshop Final Report	Fisher, J.W., Hogan, J.A., Joshi, J.A., et. al.	2006	Final report documenting the potential influence of Planetary Protection policies on activities in the Advanced Life Support (ALS), Advanced Extravehicular Activity (AEVA), and Advanced Environmental Monitoring and Control (AEMC) communities. MUST READ!	X	X	X	X	X	X



Identifying Notional Studies Through Literature

- **Step 1: Read**
  - Fisher, J. W., Hogan, J. A., Joshi, J. A., Race, M. S., Rummel, J. D. (Eds.) (2006). *Life Support and Habitation and Planetary Protection Workshop Final Report*. (NASA/TM-2006-213485)
  - Conley, C. A., & Rummel, J. D. (Eds.). (2010). *Planetary Protection for Human Exploration of Mars.* Acta Astronautica, v. 66, p. 792-797.
  - Race, M. S. (Ed.). (2008). *Impact of Planetary Protection on Environmental Characterization and Hazards Mitigation Technologies.*

> The Planetary Protection community needs to develop a classification system of Mars surface sites based on level of scientific interest and define "zones of operation" ranging from "no human contact" to "unlimited contact". Lastly, the PP community needs to

- **Step 2: Formulate a study goal**

> Study O5: Develop a formal zoning classification system for identifying zones of biological, scientific, contamination and operational importance. *Need:* Using a 'zonation' approach will protect more sensitive regions from contamination in addition to keeping the crew safe from potential biological dangers.[1,3,5]

Examples of Notional Studies

- Examples of notional studies identified:
  - Develop a formal zoning classification system for identifying zones of biological, scientific, contamination and operational importance.
  - Quantify the effects of wind dispersion of forward contamination on the surface of Mars through modeling.
  - Develop experiments that challenge Earth organisms with simulated Mars environmental conditions.
  - Identify probable biological targets in the Martian environment by looking at what types of organisms would be likely to exist and survive in the Martian environment, based on terrestrial studies.
  - Identify human factors considerations with relation to planetary protection and how they might be addressed (e.g., consequences of fatigue and implementing planetary protection protocol).
- In all cases…
  - Source documentation was referenced
  - Results addressed “what needs to be done” vs. “what is being done”
- Full literature review results to be published:
  - Johnson, J. E. (2015) *A Path to Planetary Protection Requirements for Human Exploration: A Literature Review and Systems Engineering Approach*, submitted for publication
  - Advances in Space Research Special Issue: New Challenges for Planetary Protection

Closing the Gaps…

- This workshop will help to assess "state of knowledge" & identify *actionable* areas of future study
- Step 1: Learn
  - Gather the knowledge presented throughout the main sessions
- Step 2: Discuss
  - Assess the research currently underway, compare to notionally identified studies
- Step 3: Identify knowledge gaps
  - **Capture the hard questions…**from our zonation example…
    - What material is vented by EVA, habitats, etc.?
    - How is it dispersed through the environment?
    - How is the local environment conducive to life?
    - What is the probability of microbial life surviving at given distances and times?


Questions?
Back-up & notional study listing follow

Identified Notional Study Themes

- Microbial & Human Health Monitoring
  - Microbiome Research: Microbiome research and ability to detect extraterrestrial perturbations
  - Biological Assay Techniques: Minimal mass/volume and low consumable/waste product biological assay techniques
  - Microbial Growth Monitoring: Monitoring growth and survivability of human & habitat associated microbial populations in space environments
- Technology & Operations for Contamination Control
  - Cleaning & Sterilization: Cleaning and sterilization technologies for in-situ application
  - Spacecraft Contamination: ECLS loop closure and mitigation of spacecraft effluents
  - Spacesuit/Mobility Contamination: Technologies for contamination control of human surface mobility systems and spacesuits
  - Surface Support System Contamination: Contamination control and localized special region prevention for support systems (ISRU, Power, etc.)
  - Exploration Operations: Human surface exploration operational strategies for mitigating contamination
  - Quarantine Measures: Quarantine measures for preventing back contamination
- Natural Transport of Contamination on Mars
  - Mars Particulate Transport: Transport mechanisms on the Mars surface
  - Mars Sterilization: Potential sterilization effects of the Mars environment
  - Clean-up: Environmental clean-up of inadvertent release of unsterilized terrestrial material
  - Mars Material & Crew Health: Crew health and habitat microbiome impacts from Mars material

Microbial & Human Health Monitoring Notional Studies

Microbiome Research:

- Develop a definition of the term “biosignature” and individual limits for the release of each identified biosignature.
- Develop a catalog of all known possible signatures of life.
- Develop an organic contaminant ranking/allowable concentration listing to categorize them according to planetary protection & science risks.

Biological Assay Techniques:

- Evaluation of basic tests to monitor the crew’s medical condition and understand their responses to pathogens or adventitious microbes.

Microbial Growth Monitoring:

- Conduct extremophile research to quantify the microbial hitchikers that may accompany a deep space mission.
- Develop experiments that challenge Earth organisms with simulated Mars environmental conditions.
- Identify probable biological targets in the Martian environment by looking at what types of organisms would be likely to exist and survive in the Martian environment, based on terrestrial studies.

5 Key References, including:

Rummel, J. D. (2005). *Technical Challenges in Meeting the Next Decade’s Planetary Protection Requirements.*

Allen, C. A., et. al. (2001). *Humans and Robots Collaborating in the Search for Life Beyond Earth.*

Technology & Operations for Contamination Control Notional Studies

- <u>Cleaning & Sterilization:</u>
  - Develop operational measures for cleaning (i.e., build upon HACCP physical hazard approach).
  - Develop a level of cleanliness/sterilization required for subsurface/drilling equipment.
  - Investigate methods of scientific sample containment and in-situ sample canister sterilization to 'break the chain' of contact with the Mars surface (suggested investigation includes a 'dress rehearsal/test').
- <u>Spacecraft Contamination:</u>
  - Perform analyses of mission scenarios using various Advanced Life Support (ALS) technology suites to comply with predicted requirements. If the calculated costs of plausible solutions are deemed excessive, seek further verification or reexamination of PP and scientific requirements.
  - Develop a policy/approach for the jettison of waste material in deep space and in vicinity of planetary bodies.
  - Develop a waste material disposal plan that identifies the required probability of containment failure, duration of containment, characteristics of disposed material (e.g., sterile), and effect of container location and subsurface depth.

4 Key References, including:

Fisher, J. W., et. al. (2006). *Life Support and Habitation and Planetary Protection Workshop Final Report*

Conley, C. A., et. al. (2008). *Planetary Protection for humans in Space: Mars and the Moon.*

Clark, B. C. (2003). *In-Space Sterilization for Safe Early Demonstration of Control of Back Contamination.*

Technology & Operations for Contamination Control Notional Studies Cont.

- <u>Spacesuit/Mobility Contamination:</u>
  - Quantify the level of biological and chemical material released from current concept space suits over the course of nominal, predicted traverse operations.
  - Identify the potential physical (chemical or biological) impacts that identified spacesuit and ALS leakage constituents would have in regard towards planetary protection forward contamination concerns.
  - Identify the level of microbial spore density and chemical/organic constituents allowable for EVA surface operations.
  - Define specific surface task activities for EVA that would require the implementation of appropriate planetary protection measures.
- <u>Surface Support System Contamination:</u>
  - Identify the impact of planetary protection requirements on the design and operations of ISRU systems.

Technology & Operations for Contamination Control Notional Studies Cont.

- <u>Exploration Operations:</u>
  - Develop a formal zoning classification system for identifying zones of biological, scientific, contamination and operational importance.
  - Develop an interface/boundary definition between surface and sub-surface environments.
  - Develop acceptable separation limits between sub-surface exploration activities and human operations.
  - Identify human factors considerations with relation to planetary protection and how they might be addressed (e.g., consequences of fatigue and implementing planetary protection protocol).
  - Develop a listing of contingency events and associated fault tolerance relative to planetary protection.
  - Develop a training program/approach for future exploration crews.
- <u>Quarantine Measures:</u>
  - *No specific studies currently identified.*

Natural Transport of Contamination on Mars Notional Studies

- <u>Mars Particulate Transport:</u>
  - Characterize the properties of Martian dust.
  - Quantify the effects of wind dispersion of forward contamination on the surface of Mars through modeling.
  - Quantify the effects of spacecraft venting (nominal & contingency) on contaminate dispersion on Mars.
  - Quantify the characteristics of a Mars ‘special region’. Current verbal definitions state “any region on Mars that may reach both a minimum temperature of -25^{0}C and a water activity of 0.5”
  - Identify, based on known parameters, potential human landing sites and exploration zones with a low (TBD) probability of allowing mission-associated microbial or organic contamination to enter a Mars special region.

6 Key References, including:

Rummel, J. D. (2006). *Astrobiological Exploration and Human Missions: First Steps*

Race, M. S. (2008). *Impact of Planetary Protection on Environmental Characterization and Hazard Mitigation Technologies.*

Natural Transport of Contamination on Mars Notional Studies Cont.

- <u>Mars Sterilization:</u>
  - Quantify the effects of flash sterilization (e.g., atmospheric re-entry) on microbial survival to identify both a minimal heating level and duration that provides TBD probability of sterilization.
  - Quantify the sterilization effects of Mars orbit/upper atmosphere UV radiation.
  - Quantify the sterilization effects of Mars surface UV radiation, thermal environment, and pressure.
  - Quantify the level of contamination associated with the Apollo landings through in-situ measurement.
- <u>Clean-up:</u>
  - *No specific studies currently identified.*
- <u>Mars Material & Crew Health:</u>
  - *No specific studies currently identified.*

Examples of Notional Requirements

General/Policy Requirements:

- 4.0 Human missions shall assume that Martian life exists and is hazardous until proven otherwise.

Forward Contamination Requirements:

- 5.0 Forward contamination of Mars from terrestrially-associated microbial contaminants shall be minimized.
    - 5.1 Human missions shall not affect or otherwise contaminate “special regions” of Mars.
    - 5.2 Landing sites shall be selected such that nominal and off-nominal operations shall have a low (TBD*) probability of allowing microbial or organic contamination to enter Mars special regions. *Note 10^{-4} probability is being used for introducing an Earth microbe to a liquid water body on any icy moon.

Crew Health Requirements:

- 6.0 Crews shall be protected from direct contact with Martian materials until testing can provide verification that exposure to the material is safe for humans.
    - 6.1 “Safe Zones” of operation shall be established that are demonstrated to be safe for human exploration.
    - 6.2 A quarantine capability for both the entire crew and for individual crewmembers shall be provided during the mission in the event of uncontrolled contact with a Martian life-form.

Back Contamination Requirements:

- 7.0 Back contamination from Mars to Earth shall be minimized and its prevention considered highest priority.
    - 7.1 Space suits used for the surface exploration of Mars shall not enter the return/ascent vehicle.
    - 7.2 EVA tools used for the surface exploration of Mars shall not enter the return/ascent vehicle.

Requirement, Study, and Technology Cross-over

- Some of the requirements, studies & technologies identified by the literature survey showed the need for synergy and iteration
- Example:
  - Notional Requirement:
    - 5.2: *Landing sites shall be selected such that nominal and off-nominal operations shall have a low (TBD) probability of allowing microbial or organic contamination to enter Mars special regions.*
  - Suggested Studies (selected examples):
    - Quantify the characteristics of a Mars 'special region'.
    - Develop a level of cleanliness/sterilization required for subsurface/drilling equipment.
    - Quantify the sterilization effects of Mars surface UV radiation, thermal environment, and pressure.
    - Develop a formal zoning classification system for identifying zones of biological, scientific, contamination and operational importance.
  - Notional Technology Development Area:
    - Active monitoring systems that detect markers/organisms of terrestrial origin due to human-associated activities.

Functional Decomposition: Areas of Technology & Operations

- Literature survey identified many areas for technology and operational development affected by planetary protection
- Technology needs are being incorporated into NASA's Space Technology Roadmap

- ECLS system development
- Waste processing & disposal
- Closed-loop & recycling capabilities
- Vehicle venting & leakage

- Biodiagnostics & medical treatment
- Quarantine measures

- Ingress & egress
- Zones of microbiological interest
- Use of robotics
- Drilling equipment
- In-situ resource utilization (ISRU)
- Extravehicular Activity (EVA) suit development, procedures, & tools
- Power systems (heat generation)

- Biological monitoring (in-situ microbe detection)
- Material inventories (process products & streams)
- Decontamination & sterilization techniques
- Landing & operational site selection

- Sample handling procedures
- Sample containment
- Sample analysis

Planetary protection touches areas where microbes could live, grow, or transfer

Iteration: Building a Requirements Solution

- First results of literature review and workshop will inform needed studies
- Study results will address unknowns in notional requirement set
  - Will provide answers to the questions “why?” and “to what degree?”
- First draft of requirements will need to be circulated among stakeholders to solicit input
  - Will inform additional needed studies
  - Operational impacts of requirements may be evaluated by testing
    - Ground testing and simulations (analogue missions)
    - International Space Station
    - Cis-lunar destinations such as with the Asteroid Redirect Mission (ARM) concept
    - Lunar surface exploration
- There will not be a perfect set of requirements, but we need to start guiding hardware development now!

Current COSPAR Guidelines for Human Missions to Mars

- Implementation guidelines per current COSPAR policy (paraphrased):
  - **Continuous monitoring and evaluation** of terrestrial microbes will be needed to address forward and backward contamination concerns
  - A **quarantine capability** (for individuals & entire crew) is needed during and after the mission
  - Need to develop comprehensive planetary protection **protocols for combined human and robotic aspects of mission**
  - Neither robotic systems nor human activities should contaminate "**Special Regions**"
  - **Uncharacterized sites should be evaluated** by robotic precursors prior to crew access
  - **Pristine samples** or sampling components from uncharacterized sites or Special Regions should be **treated as** planetary protection category V, **restricted Earth return**
  - An onboard **crewmember** should be designated as **responsible** for implementing planetary protection measures during the mission
  - Planetary protection **requirements** will be **based on conservative approach** and not relaxed without scientific review, justification, and consensus
- **Anticipate further dialog and discussion as these initial COSPAR guidelines give way to detailed requirements**

The key to effective and cost-efficient implementation of planetary protection guidelines is early consideration and frequent discussion during the first stages of mission design and hardware development!