Limits of Life and the Probability of Growth on Mars: Planetary Protection Policy and Execution Implications

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NASEM Committee on Planetary Protection Virtual Meeting

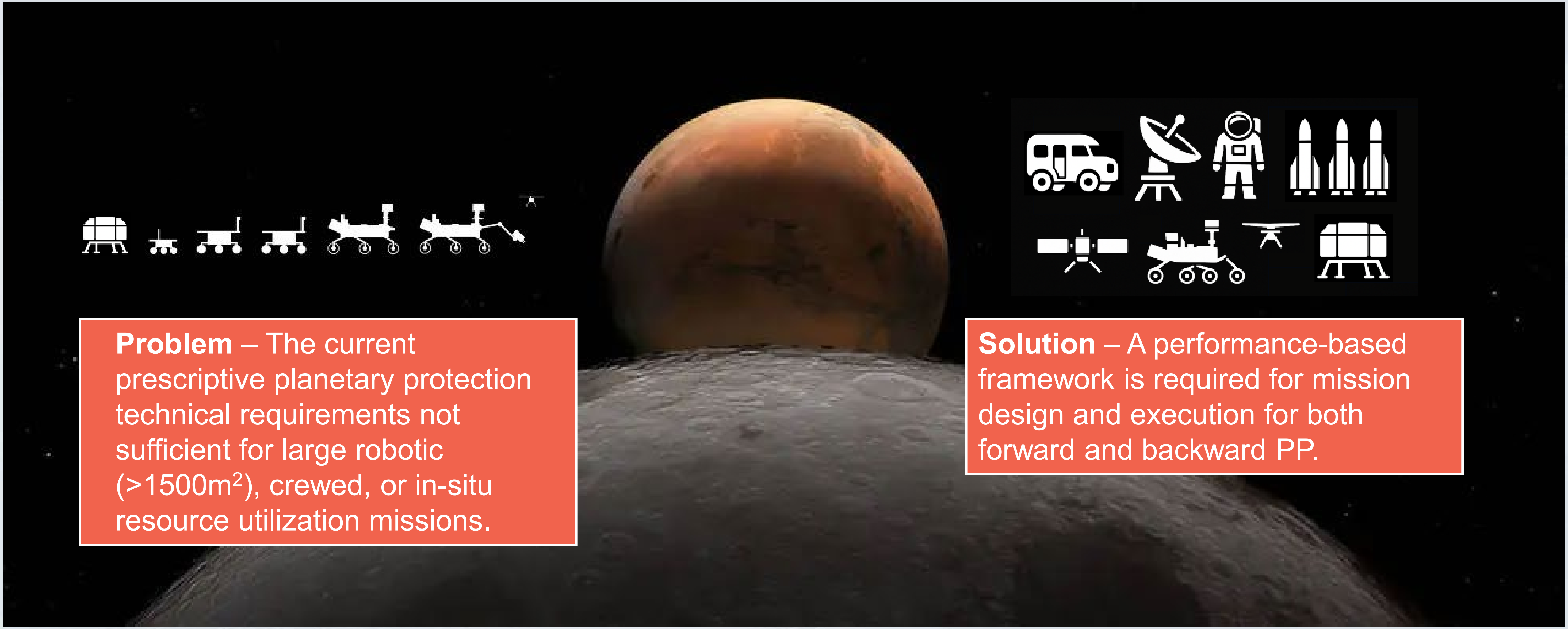
June 1, 2026

Overview

- Setting the stage to enable Mars
- Policy
- Limits of Life Defined Needs
    - *Perspective*
    - *Performance*
- Summary
- Resources

To be able to develop performance-based probability of contamination sub-models a holistic approach is necessary for probability of growth/survival expanding our current perspective special region thresholds.

Enabling Crew to Mars



Problem – The current prescriptive planetary protection technical requirements not sufficient for large robotic (>1500m^2), crewed, or in-situ resource utilization missions.

Solution – A performance-based framework is required for mission design and execution for both forward and backward PP.

Credits: NASA

OPP Document Tree

Link to NASA Planetary Protection policy and guidance documents at www.sma.nasa.gov

NPD 8700.1F
NASA Policy for Safety and Mission Success
Effective Date July 28, 2022
Expiration Date: July 28, 2027

NASA Policy Directives (NPDs)
- Documents Agency policy statements
- Describe what is required by NASA management to achieve NASA's vision, mission, and external mandates

NPR 8715.24
Planetary Protection Provisions for Robotic Extraterrestrial Missions
Effective Date September 24, 2021
Expiration Date: September 22, 2032

NASA Procedural Requirements (NPRs)
- Provide detailed procedural requirements to implement policy
- Guide how policy directives are implemented in the context of specific missions

NASA Standards
- Provide technical reqs
- Each NASA Technical Standard is assigned to a Technical Discipline

NASA-STD-8719.27
Implementing Planetary Protection Requirements for Space Flight
Effective Date: August 30, 2022

NASA-HDBK-20240016475
NASA Planetary Protection Handbook
Effective Date: January 24, 2025

NASA Handbooks
- Companion documents to NPRs and NASA Standards
- Provide supporting material such as guidelines, lessons learned, procedures, and recommendations

Crew PP Readiness Assessment

- Crew applicable

- Crew applicability being updated
- Top level forward and backward PP objectives present

- STD – crew applicable; performance-based framework present
- STD – crew technical reqs.
- HDBK – crew applicable; amenable to updates accordingly
- HDBK – crew technical guidance

CANCELED - NID 8715.129 ("Mars NID") *Biological Planetary Protection for Human Missions to Mars*

White Paper – Architecture-Driven PP Considerations for Crewed Missions to Mars

Moon-to-Mars Architecture Site

Priority Objectives

Safeguarding the Earth from adverse environmental impacts (safety)

Preventing harmful contamination (science)

Assumptions

Landed missions ≠ closed systems

Crew will be exposed to Mars

Crew + systems are a constant source of bioburden, unlike robotic spacecraft.

Microbial assessment + control of human associated contamination = key to preserving astrobiological exploration (PP enabling science)

Guidelines

Maintain intent of PP to avoid harmful contamination

Backward PP will require strategy and design concepts (assurance case, isolation, containment, monitoring, quarantine).

Knowledge gaps (KGs) mitigated

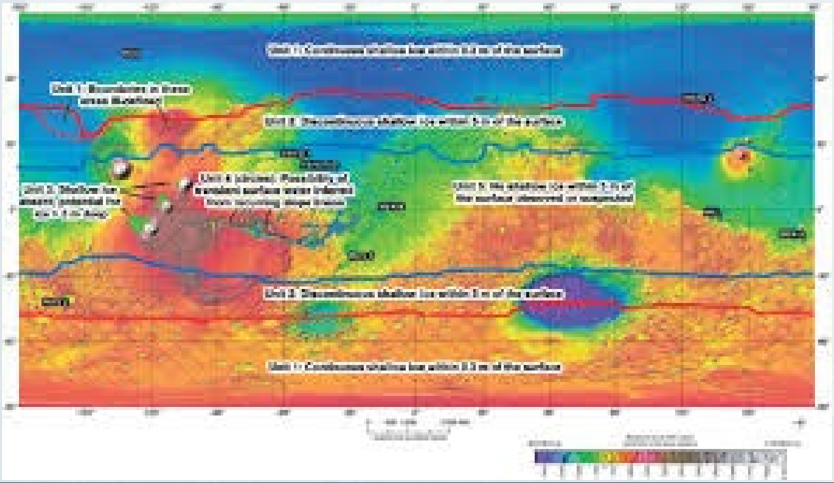
Baseline understanding of site

Why do limits of life matter for PP?

Foundational Discipline Assumptions
1. Address terrestrial life as we know it
2. Intent derived from replication limits

Prescriptive - Special Region Definitions

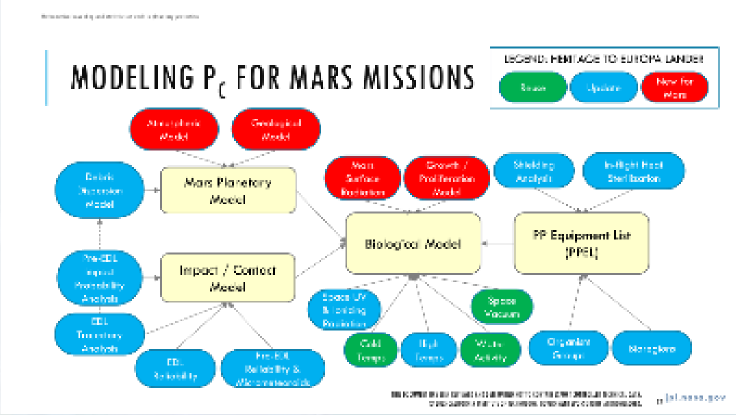
- **Notable scientific consensus parameters**
  - ***Availability of Water (Aw)***
  - ***Temperature***
  - ***Time Duration***



Rummel, et. al 2014 https://doi.org/10.1089/ast.2014.12

Performance - Probability of Contamination

- **Pc = P(r) × P(t) × P(survival/growth) × N**
  - ***Probability of release***
  - **Probability of transport to habitable region**
  - **Probability of survival/growth**
  - **Number of organisms / harmful contamination**



Example of the network of submodels and analysis required for Mars missions. Image credit: NASA/JPL Mike DiNicola

Prescriptive - Special Region Definitions

Special Region Policy - PP Category IVc

A Special Region is any natural or spacecraft-altered location on Mars where: terrestrial microbes could replicate, or extant Martian life could plausibly exist.

- Key environmental thresholds (500-year timescale): Water Activity (aw): ≥ 0.5 Temperature: ≥ –28 °C
- Types of special regions

Mars environments historically tied to liquid water or habitability indicators:
- Gullies
- Confirmed / partial RSL
- Spring or groundwater sources
- Modern outflow channels
- Methane-associated regions
- Geothermal areas

Spacecraft-Induced - Areas where mission hardware unintentionally makes Mars more habitable:
- RTGs or heat sources creating warm subsurface zones
- Warm electronics assemblies
- Commodity releases (water, habitat venting, etc.)

- Implications for Mission Design
  - Enhanced bioburden reduction requirements
  - Restricted mobility/traverse access
  - Need for SR modeling (thermal, volatiles, RTG footprint)
  - Routing, drill access, and sampling limits

Special Region Background (1 of 3)

- Special regions first introduced in 2002 (Rummel *et al.* 2002) with prescriptive terms defined from 2005-2008 (Beatty *et al.* 2006, Kminek *et al.* 2010).
  - *regions "which terrestrial organisms are likely to replicate"*
  - *"any region which is interpreted to have a high potential for the existence of extant martian life."*
- 2013 - 2014 Special Regions Reevaluated (Rummel *et al.* 2014)
  - New missions being planned by NASA and ESA
  - New orbital and surface asset Mars science data
  - *"Thus, we define the basic parameters of a Special Region (without margin) as a location where:*
    - *the temperature (T) is 255K (- 18C) or above (Finding 3-1)*
    - *water activity (a_w) is above 0.60 (Finding 3-4)."*

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DOI: 10.1089/ast.2014.1227

News & Views

A New Analysis of Mars "Special Regions": Findings of the Second MEPAG Special Regions Science Analysis Group (SR-SAG2)

John D. Rummel,[1] David W. Beaty,[2] Melissa A. Jones,[2] Corien Bakermans,[3] Nadine G. Barlow,[4] Penelope J. Boston,[5] Vincent F. Chevrier,[6] Benton C. Clark,[7] Jean-Pierre P. de Vera,[8] Raina V. Gough,[9] John E. Hallsworth,[10] James W. Head,[11] Victoria J. Hipkin,[12] Thomas L. Kieft,[5] Alfred S. McEwen,[13] Michael T. Mellon,[14] Jill A. Mikucki,[15] Wayne L. Nicholson,[16] Christopher R. Omelon,[17] Ronald Peterson,[18] Eric E. Roden,[19] Barbara Sherwood Lollar,[20] Kenneth L. Tanaka,[21] Donna Viola,[13] and James J. Wray[22]

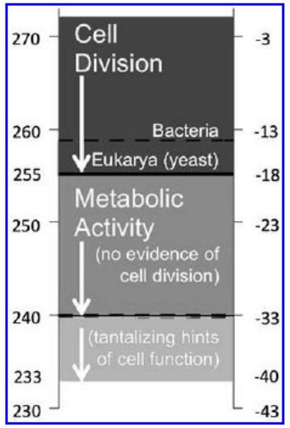


FIG. 6. Temperature limits of cell division and other metabolic activity in terrestrial microbes as described in references listed in Table 2.

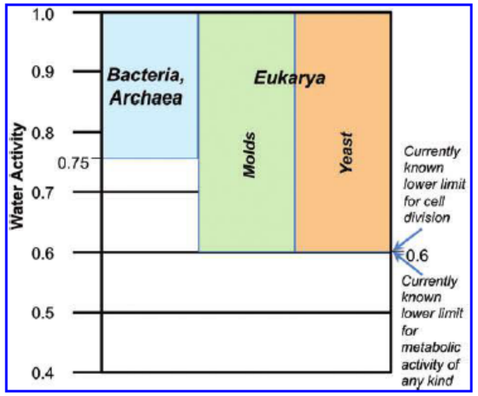


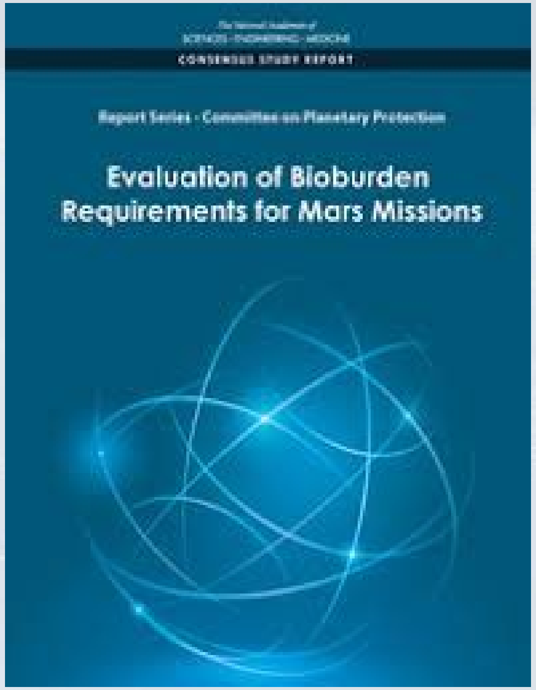
FIG. 7. The limits of microbial survival relative to water activity (a_w) as currently represented in the literature. Color images available online at www.liebertonline.com/ast

Special Region Background (2 of 3)

- Current special region assessments have focused on "*terrestrial organisms that may be carried inadvertently by spacecraft*" --> robotic associated organisms.
  - To enable crew to Mars we need to now consider organisms from the built environment, human associated, biofilms etc…
- "*Organism-based parameters not at the limits of life, and thus not defining Special Regions.*" These include nutrient availability, chaotropic compounds, and biocidal impacts (e.g., pressure, radiation).
  - To enable crew to Mars we need to be able consider parameters of cellular replication performance in its entirety.
- In 2006 margin was applied to the Aw and temp parameters to account for unknowns in both the limits of life and unknowns on Mars. This same margin practice was recommended in 2014 and adopted in current policy.
  - *-0.1 Aw margin added → 0.6 observed to 0.5 policy*
  - *-10°C temp margin added → -18°C observed to -28°C policy*
  - *To enable crew to Mars we need to be informed by the communities' risk posture on uncertainty.*

Special Region Background (3 of 3)

- Report Series: Committee on Planetary Protection: Evaluation of Bioburden Requirements for Mars Missions (2021)
  - *“The committee adopts the −28°C (245 K) limit, which includes a safety margin to the observed temperature of −18°C (255 K) for cell division, as proposed for Mars Special Regions by COSPAR.”*
  - *The experimentally-determined water activity limits for the growth of fungi and bacteria are 0.605 and 0.635, respectively, and the lower limit for bacteria and archaea is proposed to be 0.611. The committee adopts the water activity value of 0.5 used by COSPAR for terrestrial microorganism replication.*[61]



http://nap.edu/26336

<u>Performance</u> - Probability of Contamination

Mars Planetary Protection Requirement Landscape

- COSPAR §4.6 "…*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.*"

Policy Perspective: Robotic = Crew

Forward PP Example

P_c

Robotic, Prescriptive

Policy Objective: control the risk of "harmful contamination"

Guidelines: bioburden constraints for a Category IVa mission

Detailed Guidelines: $\leq 5\times10^5$ spores

Implementation: Rover harness needs heat microbial reduction bakeout 150°C, 25 h

Crew

Policy Objective: control the risk of "harmful contamination"

Contamination Goal: Pc?

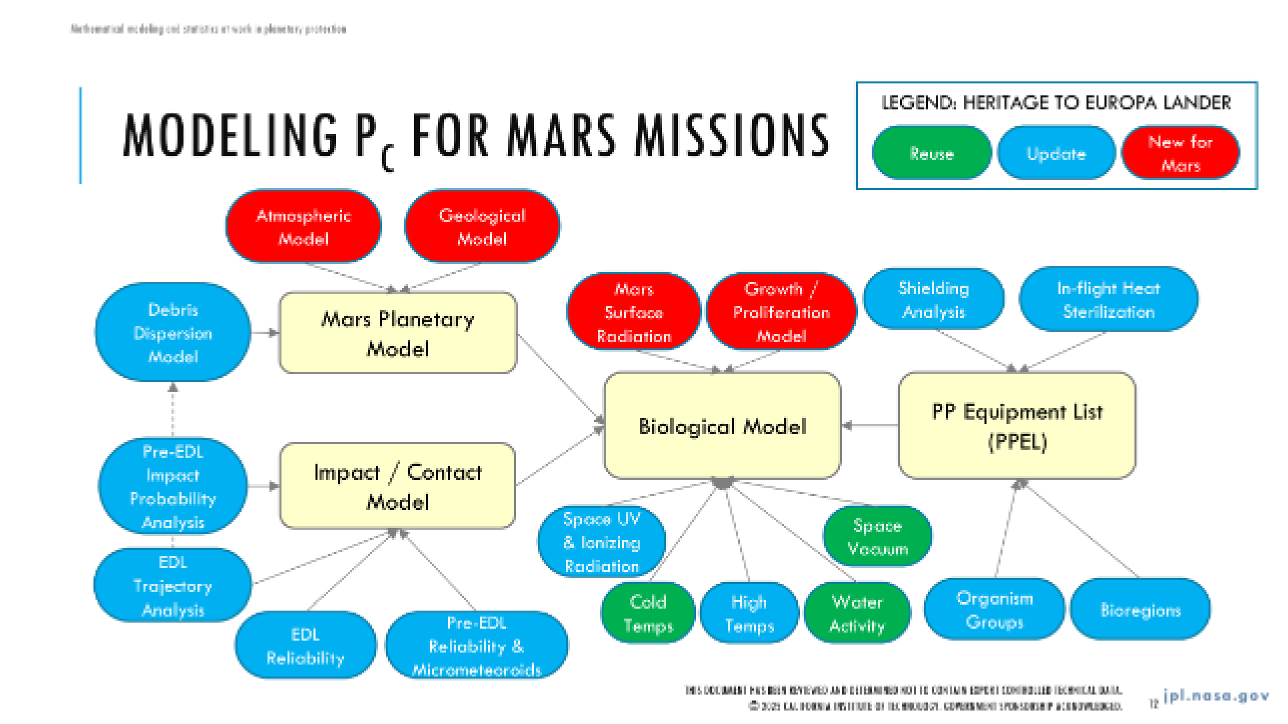
Guidelines: TBD

Detailed Guidelines: TBD

Implementation: TBD

Spry, J. A., et al. (2024). Planetary Protection Knowledge Gap Closure Enabling Crewed Missions to Mars. *Astrobiology*, *24*(3), 230–274. https://doi.org/10.1089/ast.2023.0092

- Modeling framework parameters can be mitigated by knowledge gaps.
- Specific sub-models that are dependent on landing site characterization include:
  - *Atmospheric*
  - *Geological*
  - *Radiation*
  - *Growth and proliferation*
- PP Crew knowledge gap (KG) workshops
  - *2015-2022, 7 workshops*
  - *International community engagement*
  - *Helped to identify PP KGs for safe and sustainable exploration and utilization of Mars.*



Example of the network of submodels and analysis required for Mars missions. Image credit: NASA/JPL Mike DiNicola

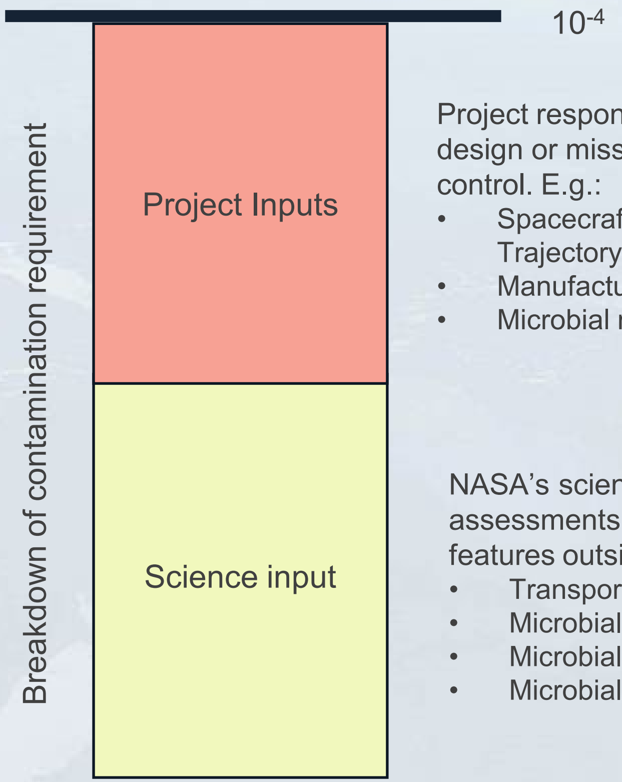
Probability of Contamination (Pc)

Pc = P(release) × P(transport to habitable region) × P(survival/growth) × N(contamination characterization)

Parameter Category	Mars Science Inputs Used
Release probability (Pr)	Dust/sand erosion rates, surface particle analyses, impact/EDL physics informed by Mars data
Transport probability (Pt)	Mars weather models, dust storm climatology, atmospheric models, geological transport models
Survival/growth probability (Pg)	Radiation environment, temperature* cycles, water activity*, regolith chemistry, empirical survival data
Contamination Characterization (N)	Number, type, functionality of microbial contamination

*existing special region parameters

NASA STD: *probability of "harmful" contamination ≤1x10^{-4}…*



Project responsibility: risk assessments tied to design or mission features within a Project's control. E.g.:

- Spacecraft/instrument reliability and design
  Trajectory design
- Manufacturing and processing practices
- Microbial monitoring and management

NASA's science community responsibility: risk assessments tied to geological and biological features outside a Project's control, E.g.:

- Transport processes and geology
- Microbial release
- Microbial survival
- Microbial growth

There is a tradespace between of project and science inputs for harmful contamination.

Probability of Contamination Viking Spec Value Background

Scientific consensus is a reiterative process to inform PP Policy and NASA Programs.

Date	Reference	Mars (pg)	Summary Of Activity
May-70	Leningrad COSPAR	1.00E-03	Panel recommends that until further information is available the Jovian planets will be treated with the same quarantine requirements using the same parameters currently applied to Mars; and that this probable is to be further pursed (e.g. studying the multiplication of microorganisms in simulated environments.
Jul-70	Woods Hole Meeting	1e-4 to 10e-9	Recommended a range of Pg values based on estimation approaches even-odds; .0999 confidence upper limit
Aug-70	PPO Letter to Viking Manager	1.00E-04	Planning value of Mars recommendation based on lower bounds of Woods Hole Meeting
Dec-70	SSB Approval of Woods Hole Summary	1e-4 to 10e-9	SSB Approval of Woods Hole Summary and Final Copy Approval
Dec-70	NASA Letter to NASA/SSB	1.00E-04	NASA Acknowledges 1e-4 to SSB as the value to implement
Jan-71	PPO Letter to Viking Manager	1.00E-04	NASA Implementation now official to programs
Jul-71	NASA Letter to NASA/SSB	1.00E-06	Notice that SSB has not yet acted on new policies
Jul-71	NASA Letter to NASA/SSB	1.00E-06	Requests SSB action on NASA's New Policies - P(g) 1e-6 for Mars and that outer planets be treated like Mars using Mars Parameters
Aug-70	NASA Letter to NASA/SSB	1.00E-06	Making SSB to act on new policies
Aug-71	NASA Letter to NASA/SSB	1.00E-06	Asking SSB to act on Pg = 1e-6 for Mars
Aug-71	PPO Letter to Viking Manager	1.00E-06	New NASA policies; no mention of SSB response
Oct-71	Program Manager to PPO	1.00E-06	Consults with Kastel of SSB re their reaction of 1e-6 for Mars. Has asked for opinions and appears more members are in favor than opposed.
Nov-72	Summary with Ad Hoc Group	1.00E-06	Mars Pg vote= 1e-4 (6), 1e-6(13), 1e-8 to 1e-9 (7); outer planets presents confusion with Mars like assumptions; cannot accept COSPAR outer planets recommendations as a result ; outer planets need to be independent of Mars
Feb-72	SSB Review of NASA PQ Policy - Denver Meeting	1.00E-06	Mariner 9 doesn't lead to an agreed upon reduction of P(g); hasn't had enough time to review outer planets but suggests <1e-4
Dec-73	NASA 8020.12 Spec	1.00E-06	Viking Program Value

1974 – Assessment of the Probability of Contamination Mars Report

Final Report

ASSESSMENT OF THE PROBABILITY
OF CONTAMINATING MARS

Prepared for:

PLANETARY PROGRAMS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

NASA CONTRACT NASW-2535

(NASA-CR-138522) ASSESSMENT OF THE PROBABILITY OF CONTAMINATING MARS Final Report, 5 Jul. 1973 - 5 Feb. 1974 (Stanford Research Inst.) 163 p HC $11.25 CSCL 03B G3/30 N74-26299 Unclas 40861

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

- Replaces the single-parameter Sagan–Coleman model with a four sub-model chain (Bio-Burden → Release → Transport → Reproduction)
- Computes a mission-specific contamination probability, P(c) = 6×10^{-6} per Viking lander.
- Critiques single Pg usage and proposes decomposition ➔ P(G) values and explicit sub-probabilities (e.g., survival in dust storms, reaching usable water).
- Needed explicit treatment of:
  - Microbe types and survival characteristics.
  - Release mechanisms + UV lethality.
  - Martian environmental uncertainties (water, nutrients).
- Growth Probabilities by Release Mechanism
  - Implantation (soft or hard landing): 2.8×10^{-5}
  - Erosion (covered, mated, encapsulated): 2.8×10^{-7}
  - Vibration (survival probability): 5.3×10^{-6}

1978 – Space Studies Board Report on Recommendations on Quarantine Policy for Mars…

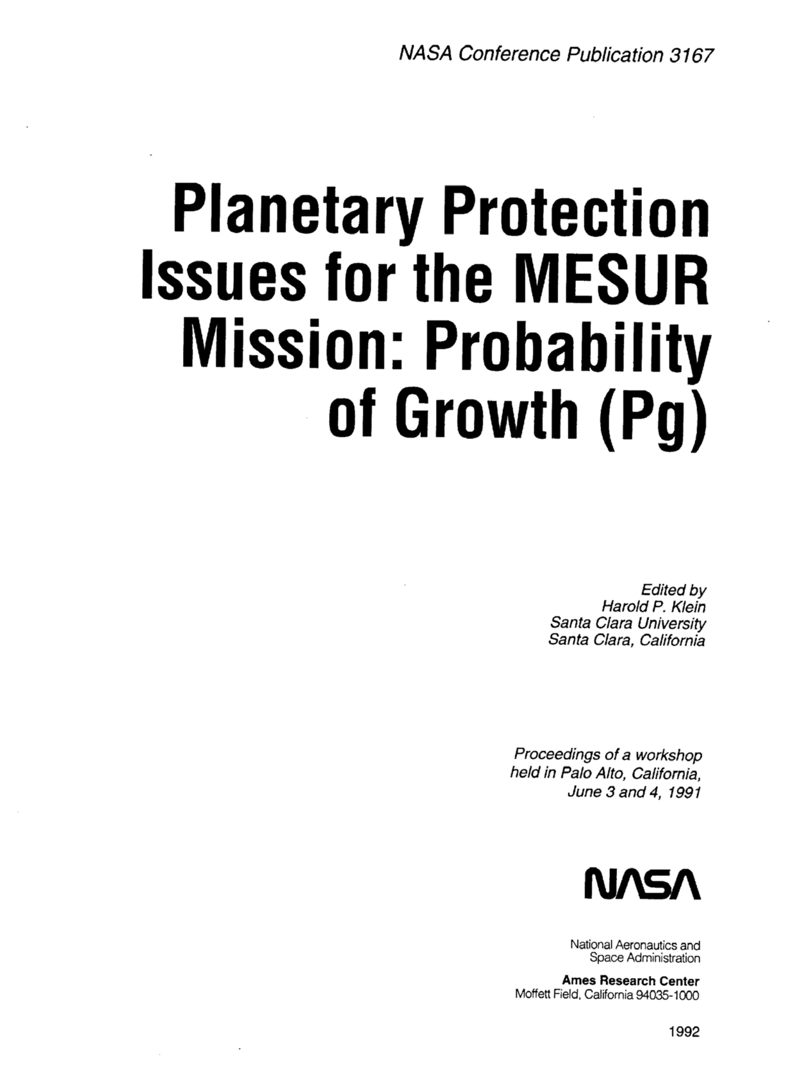
0984983 PB83-192070 78-0096
Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan
(Final rept)
National Research Council, Washington, DC.
Corp. Source Codes: 019026000
1978 83p
Languages: English
NTIS Prices: PC A05/MF A01 Journal Announcement: GRAI8316
Country of Publication: United States

This report evaluates the current internationally agreed upon planetary quarantine policy, which calls for a probability of contamination (Pc) 0 is less than 0.001 for each planet over the 20 years 1974 to 1994. The probabilistic formulation used by NASA (National Aeronautics and Space Administration) includes Pg, the probability that a terrestrial organism could be deposited on the planet and grown. This report reevaluates the current quarantine policy with respect to Mars, Jupiter, Saturn, Uranus, Neptune, and Titan. The report concludes that the probabilistic basis underlying these quarantine policies is inadequate, and it underemphasizes the experimental search for terrestrial organisms capable of growth under conditions believed to exist on target planets. Alternative experimental approaches are proposed.

Descriptors: *Quarantine; *Planets; Infectious diseases; Contamination; Policies; Foreign countries; Microorganisms; Mars(Planet); Jupiter(Planet); Saturn(Planet); Uranus(Planet); Neptune(Planet); Titan(Planet)
Identifiers: NTISNASNRC
Section Headings: 6E (Biological and Medical Sciences--Clinical Medicine); 22A (Space Technology--Astronautics); 57U (Medicine and Biology--Public Health and Industrial Medicine); 84GE (Space Technology--General)

- Viking findings (GCMS water % driven) impacting Mars P(g) parameters considered were water, temperature, UV, oxidants and organics compounds.
- Proposed a region-based Pg values (surface/subsurface/polar) and recommend very conservative Pg assignments
  - *Pg* $< 10^{-10}$ *(subpolar surface),*
  - *Pg* $< 10^{-8}$ *(subpolar subsurface),*
  - *Pg* $< 10^{-7}$ *(polar).*

1992 – PP Issues for the MESUR Mission: Probability of Growth (Pg)



NASA Conference Publication 3167

Planetary Protection Issues for the MESUR Mission: Probability of Growth (Pg)

Edited by
Harold P. Klein
Santa Clara University
Santa Clara, California

Proceedings of a workshop
held in Palo Alto, California,
June 3 and 4, 1991

NASA

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

1992

- Re-evaluates the Mars Pg (probability of growth) that had been used in policy and planning.
- P(g) depends on where microbes land (regional habitability), with stronger conservatism (lower Pg) than NASA's 10^{-6} used circa Viking.
- Panelists largely affirm or further lower the 1978 Space Studies Board (SSB) region-based Pg values (surface/subsurface/polar).
- It does not compute an overall P(C) for a specific mission.

How we might apply scientific consensus incorporating feedback into a risk-based approach to uncertainties….understanding our limitations….

Uncertainty Category	Likelihood	Consequence (Impact on P(c)	Why It Matters
1. Existence & Accessibility of Liquid / Usable Water	High uncertainty	Very High	SRI: "Reach usable water" is a tiny gate probability that dominates P(C). MESUR: Lack of liquid water is the #1 reason panelists push Pg → ~0.
2. Microbial Survivability Under UV + Oxidants	High	High–Very High	SRI relies on survival-in-transit terms (e.g., ~0.01). MESUR: Viking oxidants & UV considered fatal to nearly all terrestrial microbes on surface.
3. Temperature–Pressure Habitability (T/P Windows)	Medium–High	High	SRI and MESUR note growth requires temperatures & pressures permitting liquid water; Mars rarely provides this. Pg lowered because such windows are unlikely.
4. Regolith Chemistry (Oxidants, Salts, Organics, Inhibitors)	Medium	Medium–High	SRI includes nutrient/inhibitor terms; MESUR cites oxidants and lack of organics as substantial Pg suppressors.
5. Dust Transport, Burial, & Shielding Physics	Medium	Medium	SRI uses dust-driven transitions (lofting survival ~0.01, shielding ~0.5). MESUR: dust may shield but does **not** raise Pg without water.
6. Rarity & Distribution of Habitable Niches (Geothermal Oases)	Low–Medium	High locally / Low globally	Both documents recognize rare geothermal sites could support growth; but global Pg stays low due to joint improbability (existence × landing).
7. Regolith Microphysics (Porosity, Diffusion, Brine Retention)	Medium	Low–Medium	Influences microhabitat stability; important but secondary to water/UV gates.

Uncertainty is inevitable; thus, capturing intent and limitations to findings are going to be important – our models will need to factor this uncertainty in from the subject matter experts.

National Aeronautics and Space Administration

PLANETARY PROTECTION

2026 METAGENOMICS WORKSHOP

ESTABLISHING AN IMPLEMENTATION ROADMAP

JET PROPULSION LABORATORY | VON KARMAN AUDITORIUM

NOVEMBER 2026

THE 2026 METAGENOMICS IN SPACEFLIGHT:

Establishing an Implementation Roadmap workshop is scheduled for Nov. 2-6, 2026, at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. The purpose of the meeting is to provide a collaborative forum for generating solution-driven approaches involving metagenomics for risk-informed decision-making during flight operations.

As the complexity of future missions increases, metagenomics-based approaches allow for an expansion of tools and methods to assess biological contamination during mission operations. This workshop will serve as a proactive effort to enable operational decision-making and support a paradigm shift from current prescriptive requirements to a risk-informed decision-making framework. Attendees will seek to develop an actionable plan to bridge the gap between current state-of-the-art technology and its implementation.

Presentations may include topics on:

- Technology Roadmap and Current Progress on the Mitigation of Knowledge Gaps
- Current Status / State-of-the-Art Technology
- Safety Critical Decision-Making
- Standardized Practices for Spaceflight Implementation
- Technology Needs
- Dark Matter

To learn more about the event and to register, visit the event website by scanning the QR code.

Summary

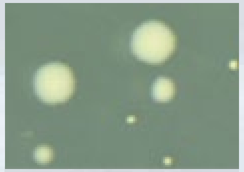
- Policy parameters of Aw and temperature require frequent assessment to continue to evaluate thresholds and margin risk posture. NASEM last reviewed these values in 2021.
- Prior groups have only considered organisms that could likely be transferred to the surface of Mars which is limited by robotic exploration. To enable crew to Mars we need to broaden this to consider human and human associated contamination vectors.
- Probability of growth has been the focus of many working groups, workshops, studies and Space Study Boards over the years.
- To be able to develop performance-based probability of contamination sub-models a holistic approach is necessary for probability of growth/survival expanding our current perspective special region thresholds.

"Planetary protection is an enabler. It preserves scientific return, ensures Earth safety, and strengthens NASA's role as a global leader in responsible exploration. As we enter a new era of crewed deep-space missions and sample return, PP is essential to maintaining the trust, integrity, and safety that define NASA."

Backup

Resources Available Through The OPP Website

Articles

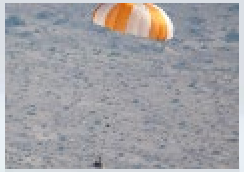

What Are Spores?


How to Build a Clean Spacecraft


Cleanroom Gowning or How to Dress in the Cleanroom

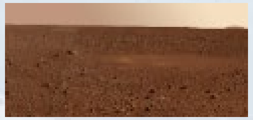

Ground Support Equipment


Protecting the Planet: Planetary Protection vs. Planetary Defense


OSIRIS REx Sample Return Doesn't Pose a Risk to Earth's Biosphere


Bioburden Accounting Tool Release

Organic Inventory Workshop

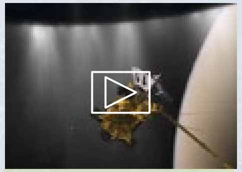

PP Crewed Knowledge Gaps

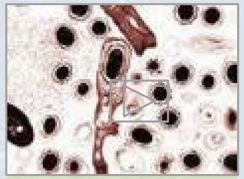

COSPAR PP Policy Update


Updated Handbook Release

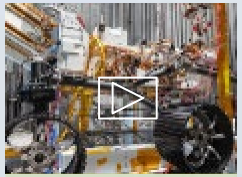

Lunar Reporting Forms

Videos

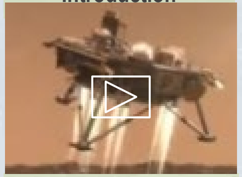

Planetary Protection: An Introduction

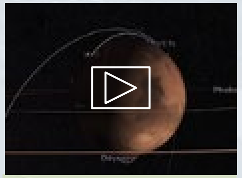

Just How Small is a Spore?


Forward and Backward PP Overview


Behind the Spacecraft Perseverance


PP Spore Assay


Mission Design and PP Categorization


Probability of Impact


Ocean Worlds


End of Mission Disposition


Planetary Protection: Handbook Update Webinar

Missions & Studies


Mission Reports

NASEM Study Reports

https://sma.nasa.gov/sma-disciplines/planetary-protection

Landing Site Tailored Approach Example

Pc Parameter	What it means (plain-English)	Tailored inputs & approach
Release	Can microbes actually be released from hardware/activities into the environment?	Use **EDL/impact breakup** and **surface scouring** submodels; fold in **aeolian erosion** with observed dust/sand behavior (derived from M2020 operational context), replacing Viking-era image heuristics. Reference PP model subnetworks and brainstorm formulations for Mars.
Transport	If released, can they be carried to places that could support life?	Run **Mars weather/CFD-based transport** ensembles tuned to boundary-layer winds and dust event patterns (drawn from the workshop science track and PP Handbook guidance on transport mechanisms).
Survival & Growth (Pg)	Will the environment allow survival or replication?	Parameterize **radiation (UV/ionizing)**, **thermal cycles**, **water activity/brines**, **regolith shielding** from the PP workshop's Pg framework; couple directly into the Pc survival/growth term.
Habitable-zone access	Do accessible microenvironments exist near exploration activities?	Leverage **Special Regions** criteria and precursor mapping; incorporate near-surface ice/brine context and accessibility bounds in region.
QC & Sensitivity	How sure are we and what drives uncertainty?	Apply **Bayesian** and **tornado charts**; run **bounding analyses** where input distributions are immature; document workshop peer review/V&V lineage.