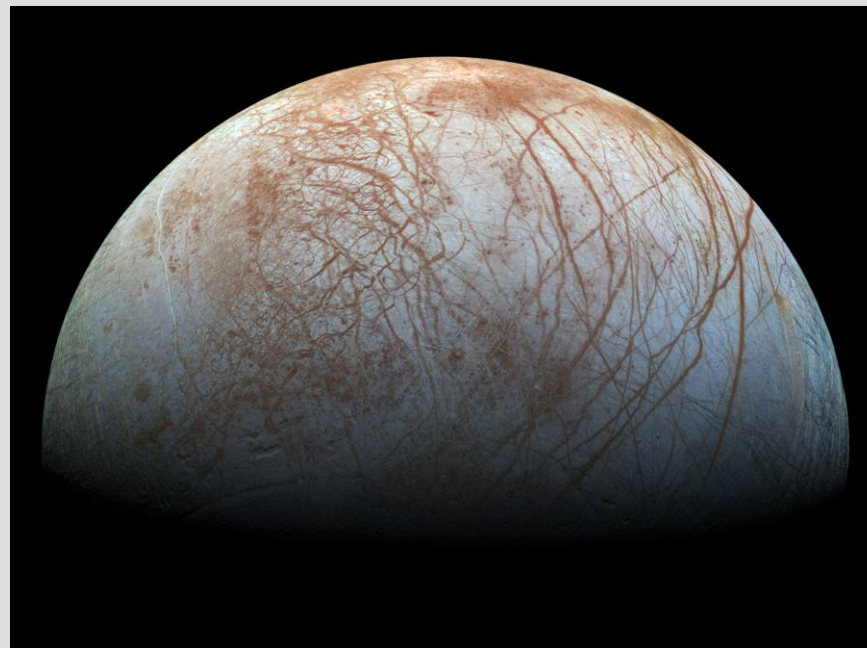


PLANETARY PROTECTION FOR THE FUTURE: ENSURING SCIENCE AND ENABLING COMMERCE

National Academies Review Committee
Planetary Protection Independent Review Board
November 22, 2019

Lisa M. Pratt
NASA Planetary Protection Officer



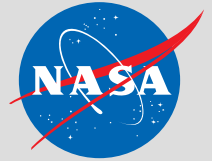
Planetary Protection Goals

Limit transfer of terrestrial life to other habitable planetary bodies (forward contamination)

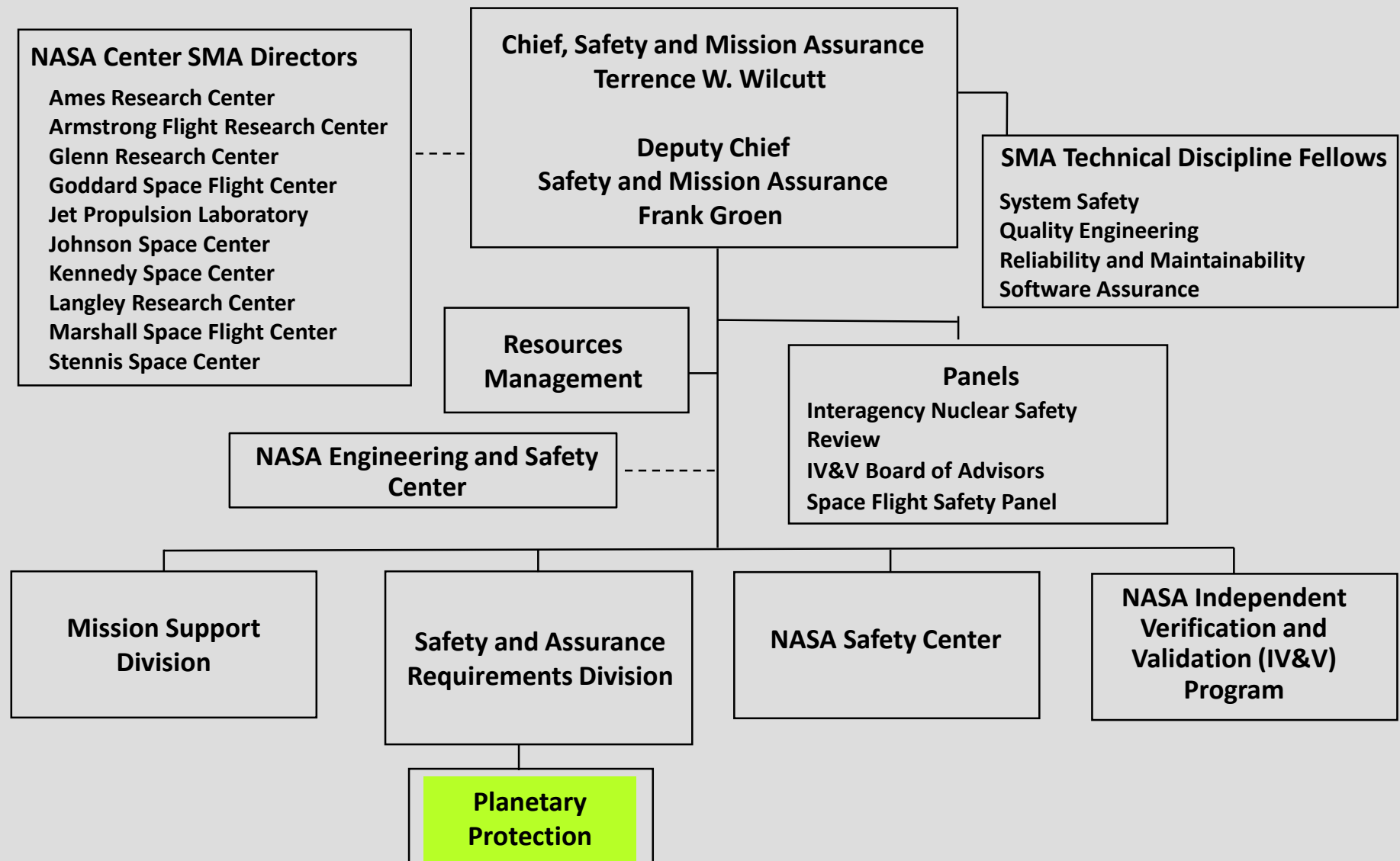
Prevent release of extraterrestrial life on Earth during spacecraft return or sample handling (backward contamination)

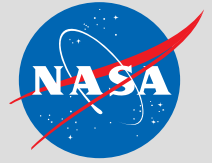


Astrotech clean facility at Vandenberg Air Force Base in April, 2018 showing final steps in assembly of the InSight mission.



Office of Safety and Mission Assurance (OSMA)





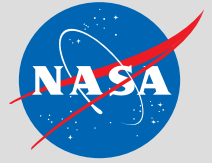
NASA Headquarters

Deputy Planetary Protection Officer Elaine Seasly, Ph.D.

Previously at Langley Research Center as lead for contamination control and planetary protection. Engineer with specialization in probabilistic risk assessment and patent law. Prior employment with Raytheon.

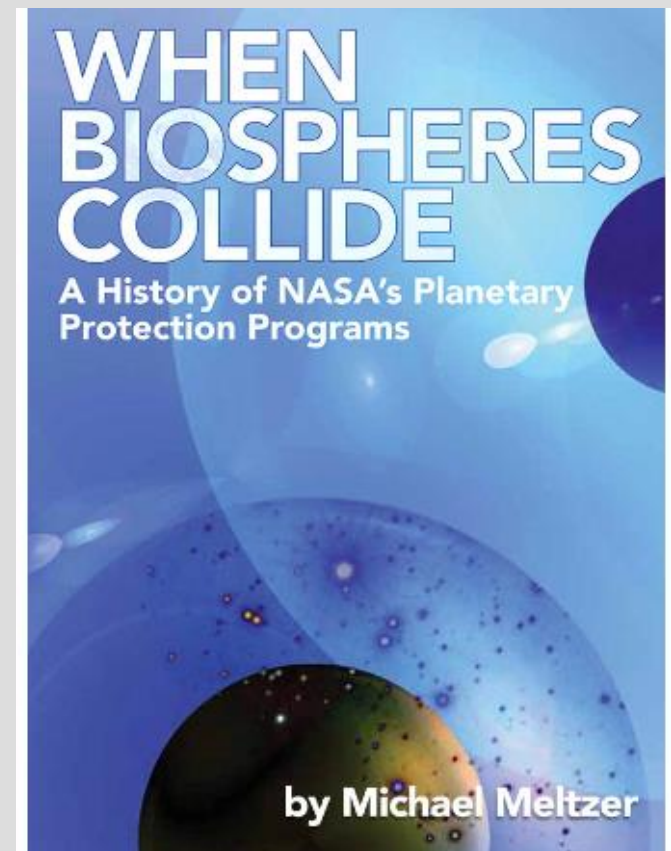
Program Scientist for Planetary Protection Research Becky McCauley-Rench, Ph.D.

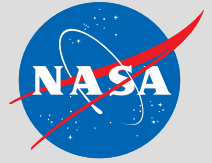
Previously at NASA Headquarters working on Space Act Agreements in procurement. Life scientist with specialization in microbiology of extremophile communities in anoxic subsurface environments.



60 Years of International Effort

- 1956: International Astronautical Federation meets to discuss lunar and planetary contamination
- 1957: successful launch of Sputnik 1
- 1958: US National Academy Science establishes Space Studies Board (SSB)
- 1958: Formation of NASA
- 1963: NASA's first Planetary Quarantine Officer on loan from the Public Health Service

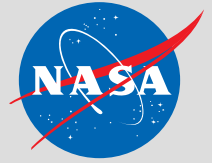




ENDURING AUTHORITY OF OUTER SPACE TREATY (1967)

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.

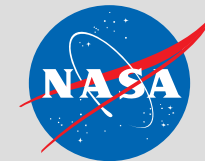
Article VI. States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, **whether such activities are carried on by governmental agencies or by non-governmental entities**, and for assuring that national activities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



Categorization

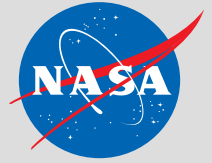
Mission Categories I to IV are based on significance of the planetary destination for:

1. understanding prebiotic chemistry and/or origin of life
2. sensitivity of each destination to contamination by terrestrial microbes



Planetary Protection Mission Categories (NASA/ESA/COSPAR Policy)

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
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
See above	Landed 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



Documentation

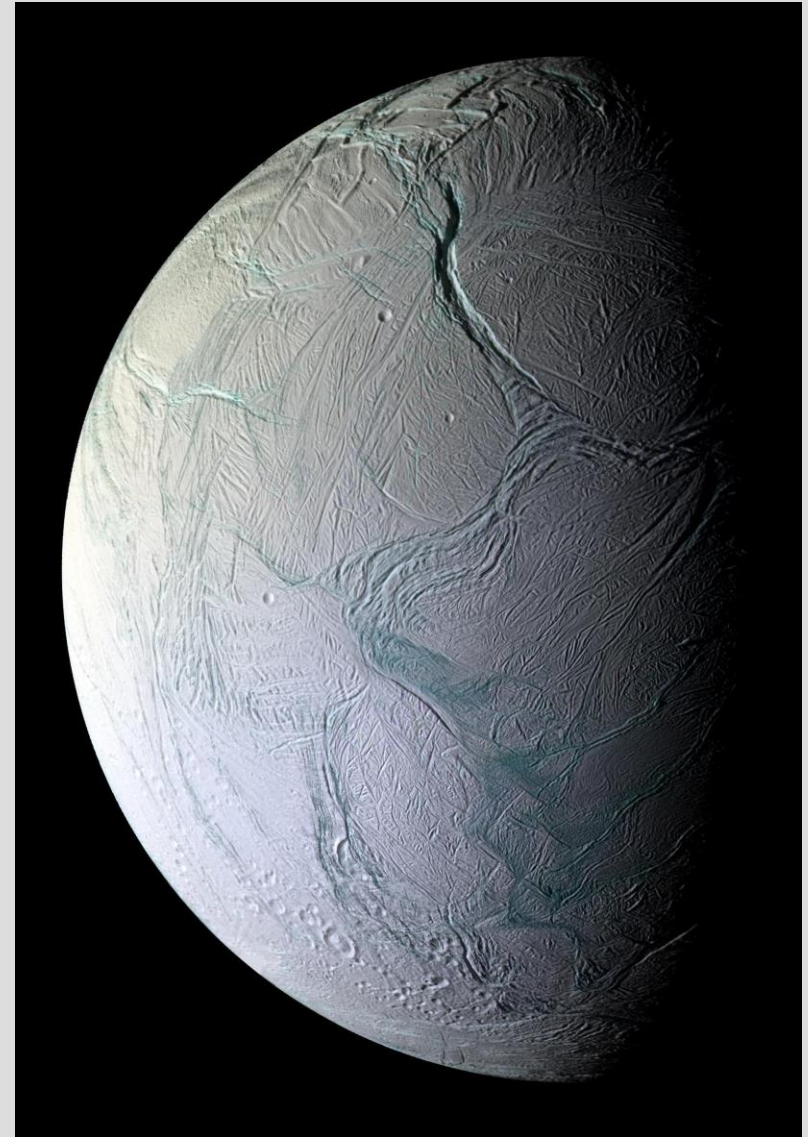
Some documentation is required for all extraterrestrial planetary missions but is not required for heliocentric or Earth orbiting missions unless there are flybys or gravity assist maneuvers involving the Moon, Venus, or category III/IV locations.

Additional mission-specific documentation and requirements are negotiated during project discussions with the Planetary Protection Officer and the designated assigned point of contact for the mission in the Office of Planetary Protection.

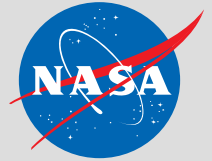
Final decisions on requirements are established currently in the planetary protection plan for the mission. Anticipate a new Requirements Document to ensure clear understanding and applicability to system engineering Detailed roles and standards in Planetary Protection Implementation Plan.

Liquid Water

If liquid water is inferred to be present at or near the surface then planetary protection assumes that there is the potential to harbor and potentially support Earth-like life.



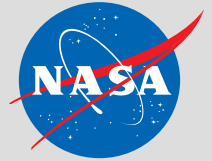
Oct. 9, 2008, NASA's Cassini spacecraft was just 25 kilometers (15.6 miles) from the surface of Enceladus.
Image Credit: NASA/JPL/Space Science Institute.



Probabilities of Contamination

NPR 8020.12D

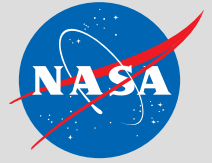
5.1		Numerical Implementation Limits for Forward Contamination Calculations not Otherwise Specified
	5.1.1	To the degree that numerical limits are required to support the overall policy objectives of this document, and except where numerical requirements are otherwise specified, the limit to be used is that the probability that a planetary body will be contaminated during the period of biological exploration shall be no more than 1×10^{-3} . No specific format for probability of contamination calculations is specified.
	5.1.2	The period of biological exploration shall extend at least 50 years after a PP Category III or IV mission arrives at its protected target and no longer than the time point after which no organisms remain viable on the spacecraft.
	5.1.3	For all launch vehicle elements leaving Earth's orbit, the probability of impacting Mars shall be less than 1×10^{-4} for a period of 50 years . The probability of impact assessment should be provided in the Planetary Protection Plan.
	5.1.4	For all spacecraft crossing Mars orbit en route to other targets, the probability of impacting Mars shall be less than 1×10^{-2} for a period of 50 years . The probability of impact assessment should be provided in the Planetary Protection Plan.
	5.1.5	In the context of missions to icy satellites, "contamination" is defined as the introduction of a single viable terrestrial microorganism into a liquid-water environment.



Mars-Level Cleanliness

NPR 8020.12D

5.3		PP Category-specific Requirements for Mars	
5.3.2			PP Category IV for Mars is subdivided into IVa, IVb, and IVc. Missions shall comply with requirements appropriate to the subcategory they have been assigned...
	5.3.2.1		PP Category IVa. Lander systems not carrying instruments for the investigations of extant Martian life shall:
		a	Be restricted to a surface biological burden level of $\leq 3 \times 10^5$ spores in total and an average of 300 spores per square meter of exposed external and internal spacecraft surfaces.
		b	Provide an assessment of Entry, Descent, and Landing (EDL) expected performance.



NASA Standard Spore

NPR 8020.12D

5.3 Category-specific Requirements for Mars

All bioburden constraints are defined with respect to the number of aerobic microorganisms that survive a heat shock of 353 Kelvin (80°C) for 15 minutes and are cultured on Trypticase Soy Agar at 305 Kelvin (32°C) for 72 hours (hereinafter "spores").

Culturing is an industry standard for sterility assurance in human health. Heat shock is specific to assessing spacecraft in order to remove vegetative cells so only hardy organisms are enumerated.

NASA Spore Assay



Sterilization of glassware and growth media in autoclave



Heat shock of the extracted samples at 80°C for 15 minutes



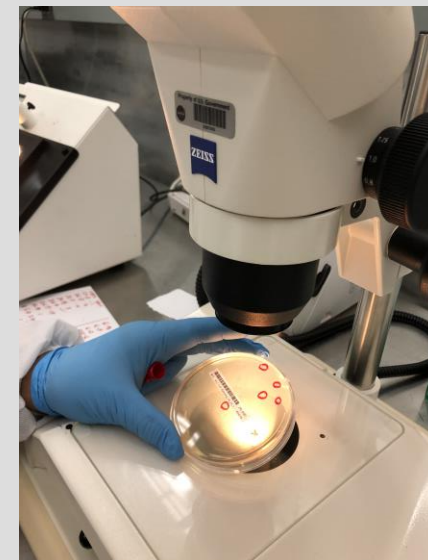
Quenching shocked samples in ice bath



Quantitative aliquots plated on Trypticase Soy Agar

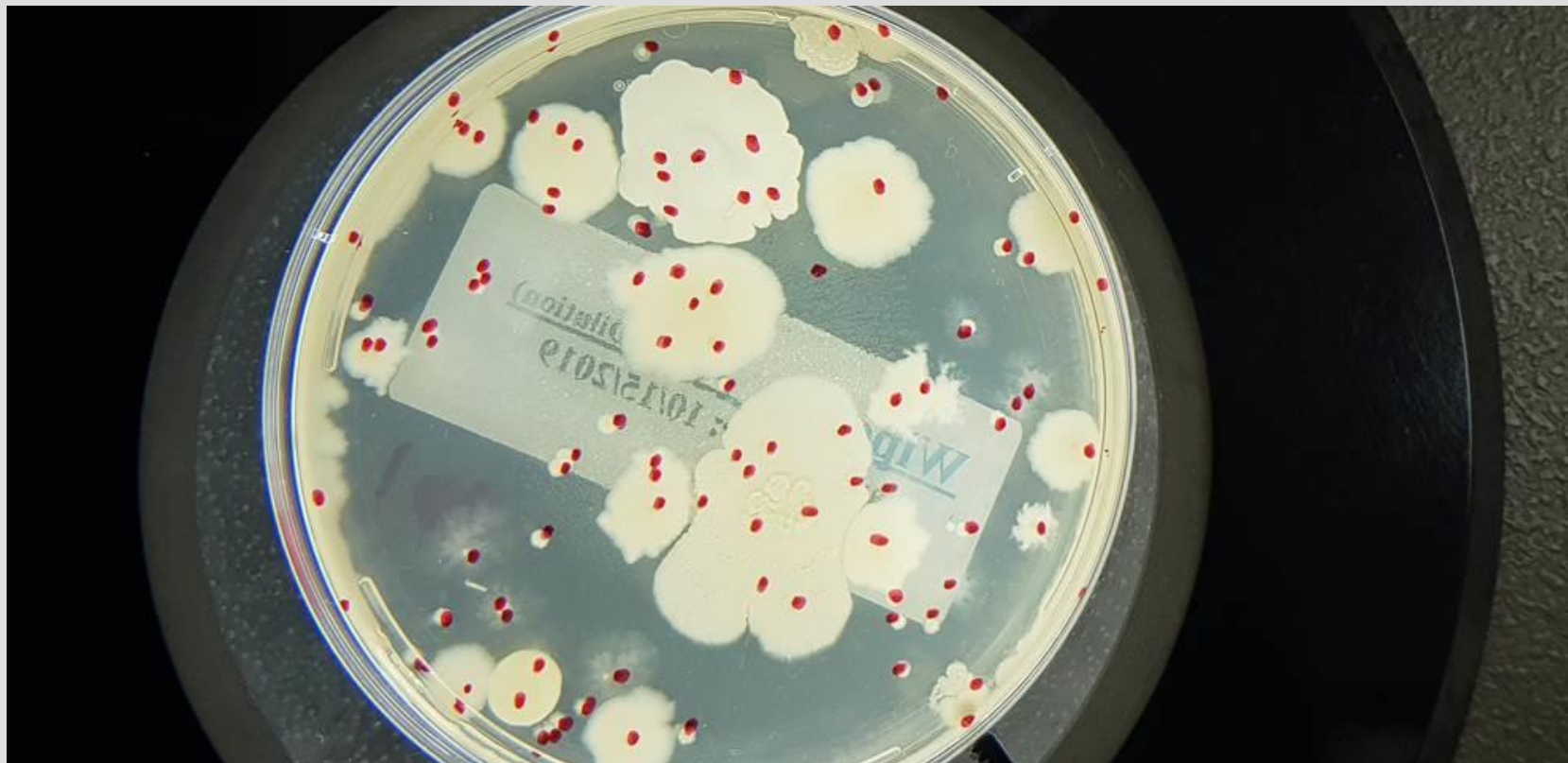


Visual enumeration of colony forming units after incubation at 32°C for 24, 48, and 72 hours

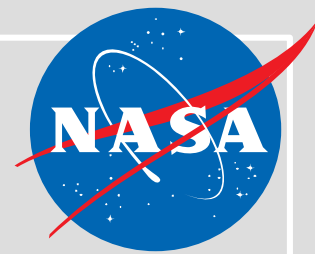


Bar coding enables reliable tracking of bioburden data

What does a bad day look like for planetary protection?



November 2019 Ground Service Equipment
sampled during pre-launch pathfinder

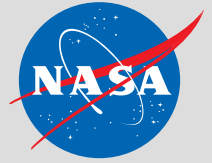


Lethality is based on hardy organisms

Table 3. Experimental D-values of *Bacillus* ATCC 29669 spores

Bacillus ATCC 29669 Spores							
		Ambient Humidity			Controlled Humidity		
Temp.(°C)	Units	D-value	St. dev.	3 sigma D-value	D-value	St. dev.	3 sigma D-value
115^a	Days	3.35	NA	NA	1.92	NA	NA
125	hr.	18.8	3.79	22.6	10.10	0.26	11.0
150	Min	66.4	3.96	80.8	40.0	1.14	44.1
170	Min	9.76	0.423	11.3	4.90	4.90	5.39
200	Sec	20.5	0.660	22.9	17.8	0.46	19.5

A 90% reduction in growth population is one D-value (decimal reduction)



Dryness and Lethality

At 125 °C, the ambient humidity and controlled humidity lethality rate constants are statistically different at the 99.00% confidence limit:

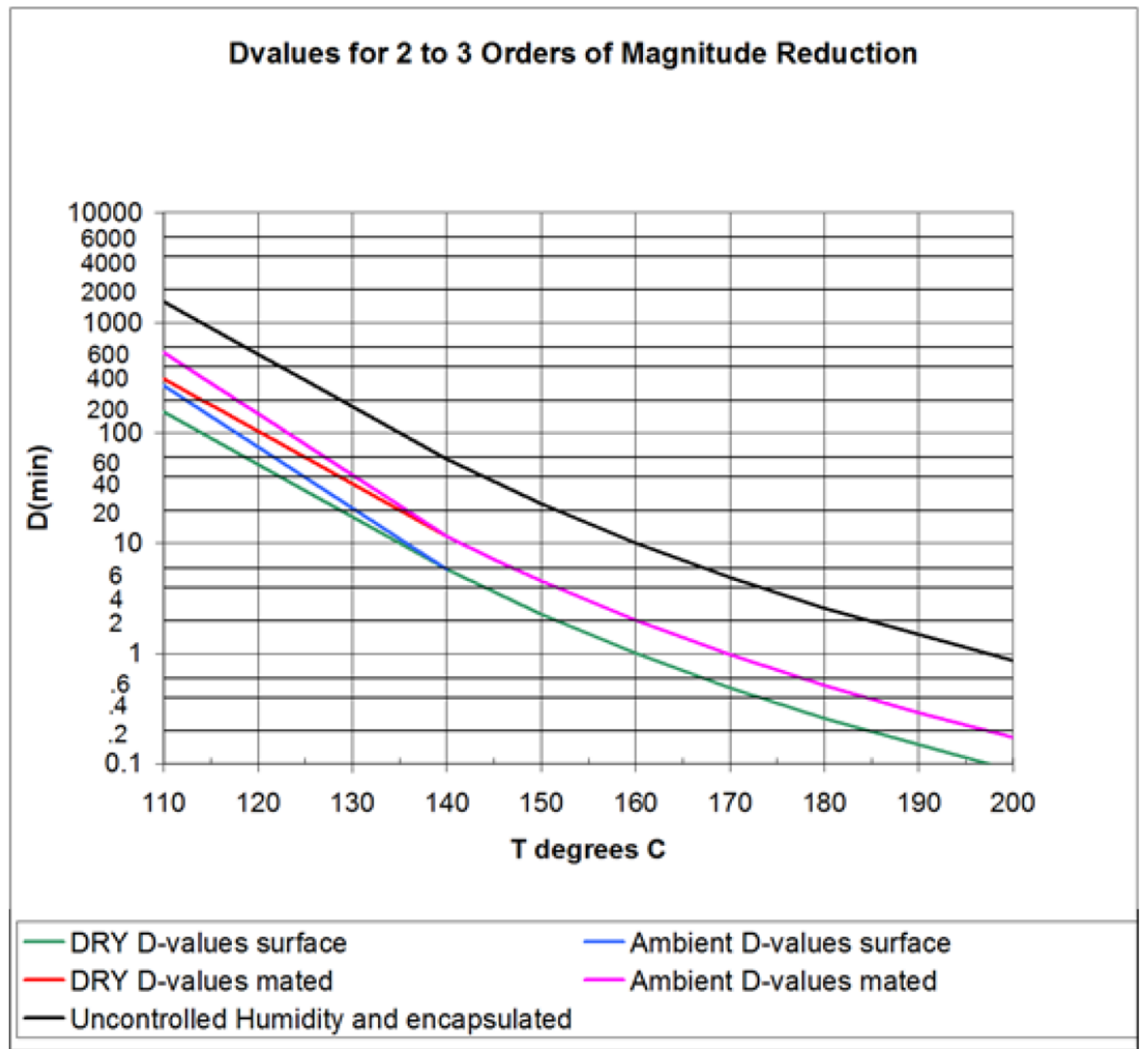
Dryness increases lethality of exposure to heat at 125 °C or below

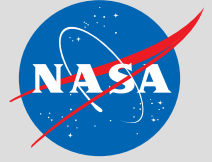
At 135 °C, 150 °C and 170 °C, the ambient humidity and controlled humidity lethality rate constants are statistically the same at the 95% confidence limit:

Dryness does NOT increase lethality above about 130 °C



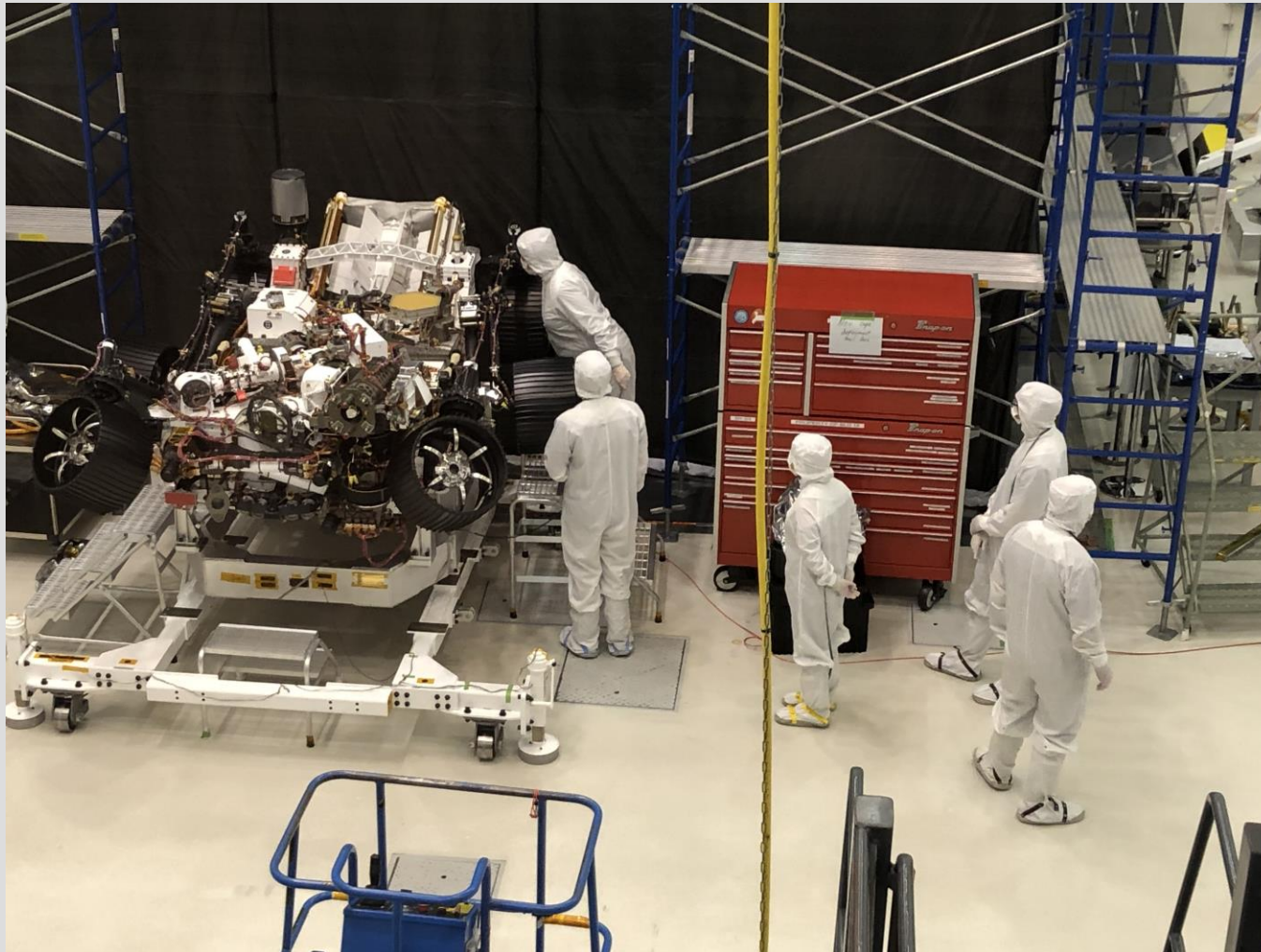
ECSS-Q-ST-70-57C
30 August 2013





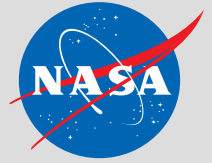
BREAK

Mars 2020 Rover Inspection After Transportation



Mars 2020 planetary protection team sampling rover after return to VAF
from environmental testing outside cleanroom conditions.

November 2019



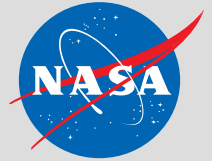
Clipper Workshop Experiment

Project manager, Barry Goldstein, and Planetary Protection Officer, Lisa Pratt, collaborated on setting objectives for the three-day workshop:

- Validate the modeling framework for Europa Clipper Planetary Protection.

- Agree on model input values, or on a plan to derive/identify appropriate model inputs.

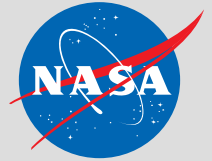
- Develop workshop concurrence regarding future research plans and their priority.



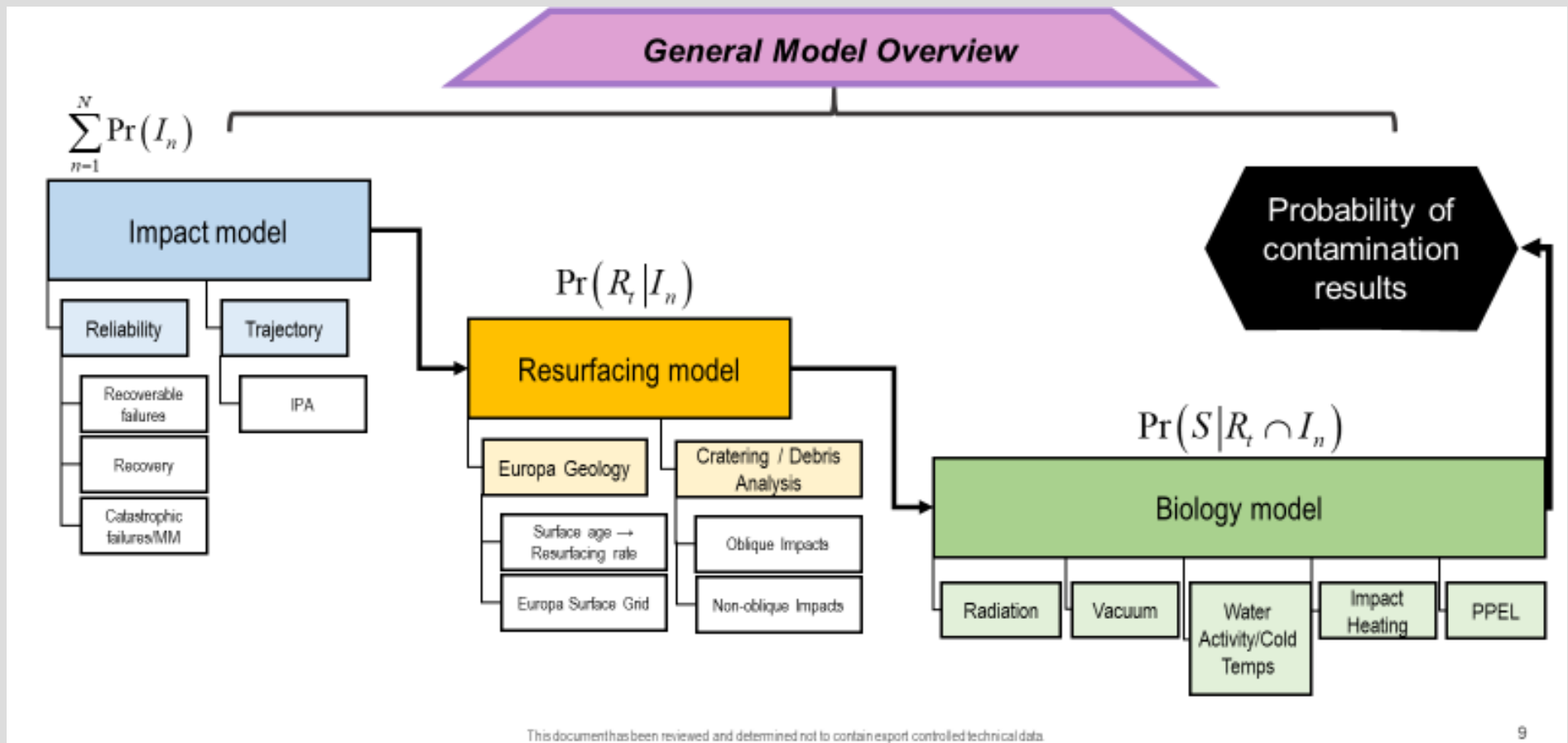
Outside Subject-Matter Experts

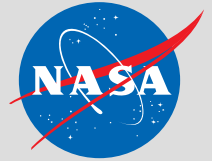
A panel of multidisciplinary experts were assembled to provide consultation and guidance at the workshop.

Last Name	First Name	Organization	Discipline
Bakermans	Corien	Penn State University	Microbiology – Permafrost
Christner	Brent	University of Florida	Microbiology – Deep Ice
Collins	Geoff	Wheaton College	Europa Science/Geology
Gribok	Andrei	Idaho National Lab	Statistician
Heinstein	Martin	Sandia	Physics – high-velocity impact heat
Kattenhorn	Simon	University of Alaska	Europa Science/Geology/Tectonics
Littlefield	David	University of Alabama	Cratering Physics
Parker	Jeffrey S.	Advanced Space	Physics- orbital mechanics/dynamics
Regberg	Aaron	Johnson Space Center	Microbiology – Fungi
Schuerger	Andrew	University of Florida	Microbiology – Community
Taber	Bill	JPL	Applied Mathematics/Probability
Youngblood	Robert	Idaho National Lab	Risk Analysis/Reliability Engineering



Clipper Probability Risk Assessment for Europa Contamination

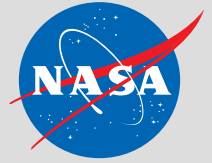




Agreements and Direction (1)



- The period of biological exploration (POBE) for the Clipper Mission is defined as 1,000 years, ending in the year 3,000.
- Based on probabilistic risk assessment and a qualitative assurance case, Clipper poses a risk less than 1×10^{-4} to Europa and other icy bodies in the Jovian system for inadvertent introduction of a viable organism into an ocean or body of liquid water.
- Europa Clipper will perform responsible microbial reduction. The project will demonstrate a clean spacecraft with spore density less than 300 spores/m² for HMR tolerant parts and less than 1000 spores/m² for HMR sensitive components.
- Components that can be cleaned and reach 2.5 Mrad by first potential impact and/or impact heating will be considered to carry less than 1,000 spore/m²

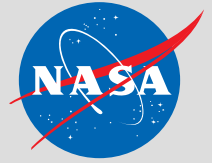


In addition to the NASEM Consensus Study *Report
Review and Assessment of Planetary Protection
Policy Development Processes* (2018)

and

The report from NASA's Planetary Protection
Independent Review Board

Multiple other US and international reviews and working groups are studying the future of planetary protection in light of upcoming human missions, Mars sample return, and the growing community of commercial and private stakeholders.

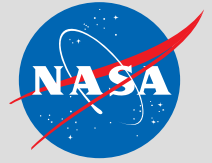


2019 Review by the Science and Technology Policy Institute (STPI)

Towards the Development of National Planetary Protection Policy

Current Policy Issues:

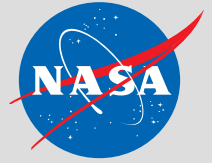
- Upcoming human missions to Mars
- Growing private interest in science and human exploration missions
- Upcoming sample return missions from celestial bodies that may harbor life
- Emergence of new technologies and approaches for sterilizing instruments and spacecraft
- Improved techniques and tools for more accurate and precise life detection
- Revolution in the understanding of terrestrial life, including the discovery of unexpected extremophiles and the abundance of Earth organisms that cannot be grown in the lab



2019 Review by the Science and Technology Policy Institute (STPI)

STPI found that:

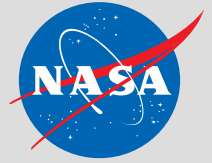
- Stakeholders disagree regarding the appropriate level of stringency in planetary protection.
- Stakeholders disagree on the types of harm that should be considered by planetary protection.
- There are varying opinions among stakeholders regarding efforts to prepare for sample returns from celestial bodies that may harbor life.
- Expected growth of participation by the private sector introduces complications into a previously government and science-led system.
- Outside stakeholders find that NASA's planetary protection policy and updating process lacks transparency.



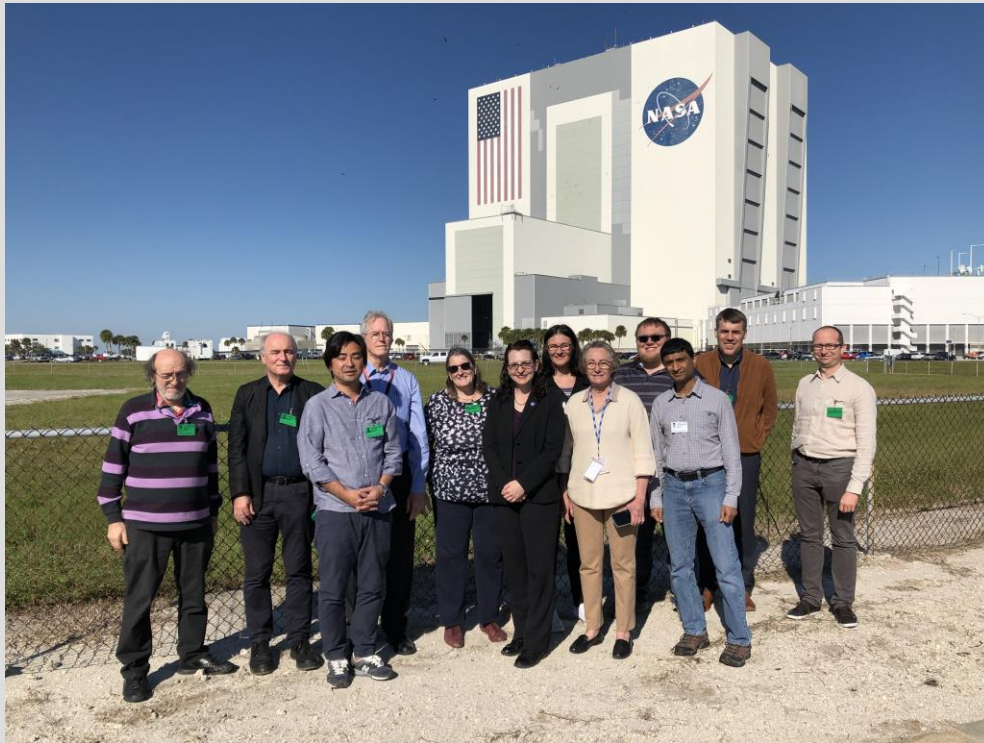
Sample Safety Assessment Protocol (SSAP)

Working Group established by COSPAR

Assess if there are indications of martian life, extant or extinct, in any martian material and spacecraft hardware exposed to martian material and if this would constitute a biological hazard to the terrestrial biosphere, while maintaining the scientific integrity of the overall material from Mars to the maximum extend possible.



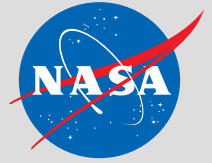
SSAP Working Group November 19-20 Kennedy Spa



Aisle tour of vehicle assembly building



Bioburden and Curation Lab for
Mars 2020



JPL/HQ Planetary Protection Sterilization Working Group (SWG)

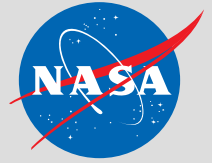
The SWG was asked to consider five questions associated with sterilizing a putative extraterrestrial life form or biological agent:

- Can we utilize Earth micro-organisms as analogs for assessing sterilization of Mars micro-organisms? Which specific Earth microorganisms or biological agents are targets for testing?
- What is the likelihood of sterility of Mars material exposed to solar UV and other space environmental factors during sampling, ascent, and transit to Earth?
- At what temperature/time can “complete” sterilization be assured and what does “complete” mean?
- What is the sterilizing effectiveness of cold plasma and various other chemical modalities currently used for sterility assurance by industry? Are there synergistic benefits to combining modalities?
- What would be needed to define the process for certification of a sterilization modality for backward planetary protection?

JPL/NASA Sterilization Working Group



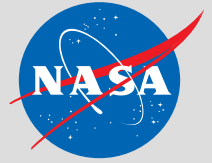
Members of the SWG include six individuals from health-care industries and medical device manufacturers, four individuals from universities and research institutes, two individuals with biodefence and disease experience, and one individual with scientific drilling experience.



Key Take Away Message:

There is flexibility in how the biological cleanliness requirements for life-detection on Mars are executed.

Modalities for sterilization of organisms and deactivation of biological agents (e.g. prions, viruses toxins) are being developed as part of Mars sample return. Testing and certification of sterilization methods will provide critical technology advancements for life detection missions on Mars.



Mars Sample Return in Early 2030's

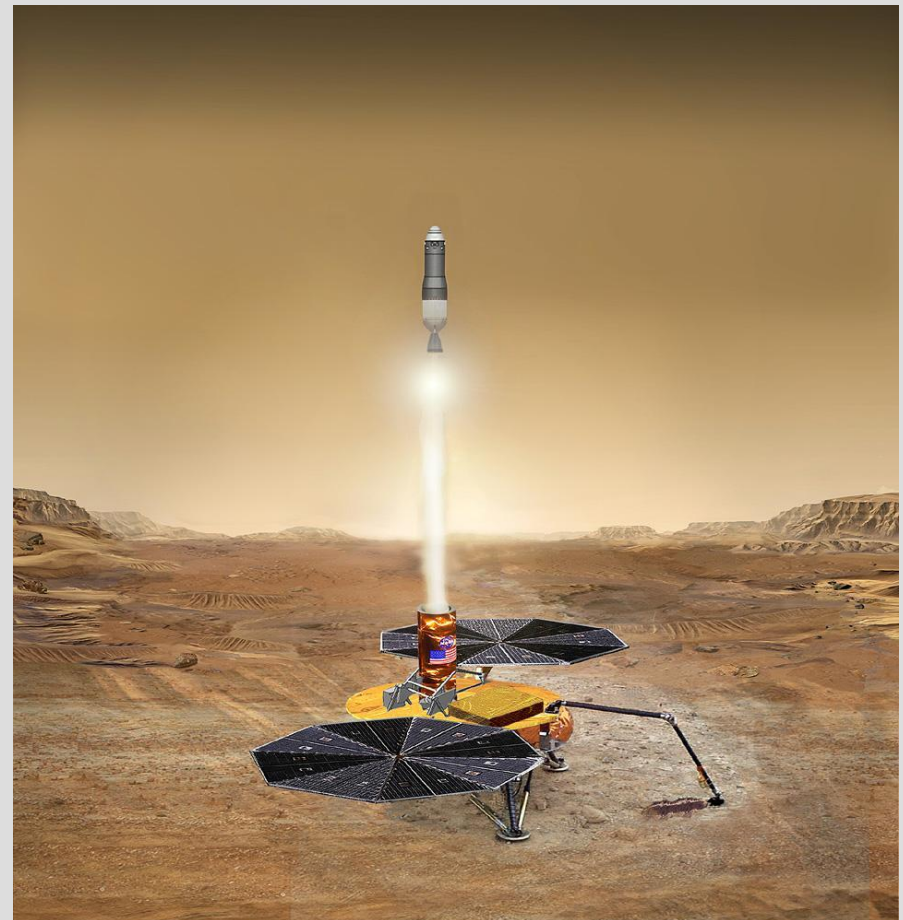
Direct Benefits for Human Missions

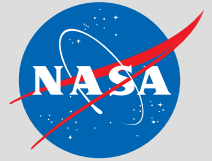
- Demonstration of ascent rocket for Mars
- Development of sterilization modalities for use in Moon and Mars habitats
- BSL-4-Type biological containment and handling for putative extraterrestrial life
- Unsterilized Mars samples on Earth for advanced biological study
- Chemical and physical characterization of martian dust

Preventing Biological Contamination of Earth

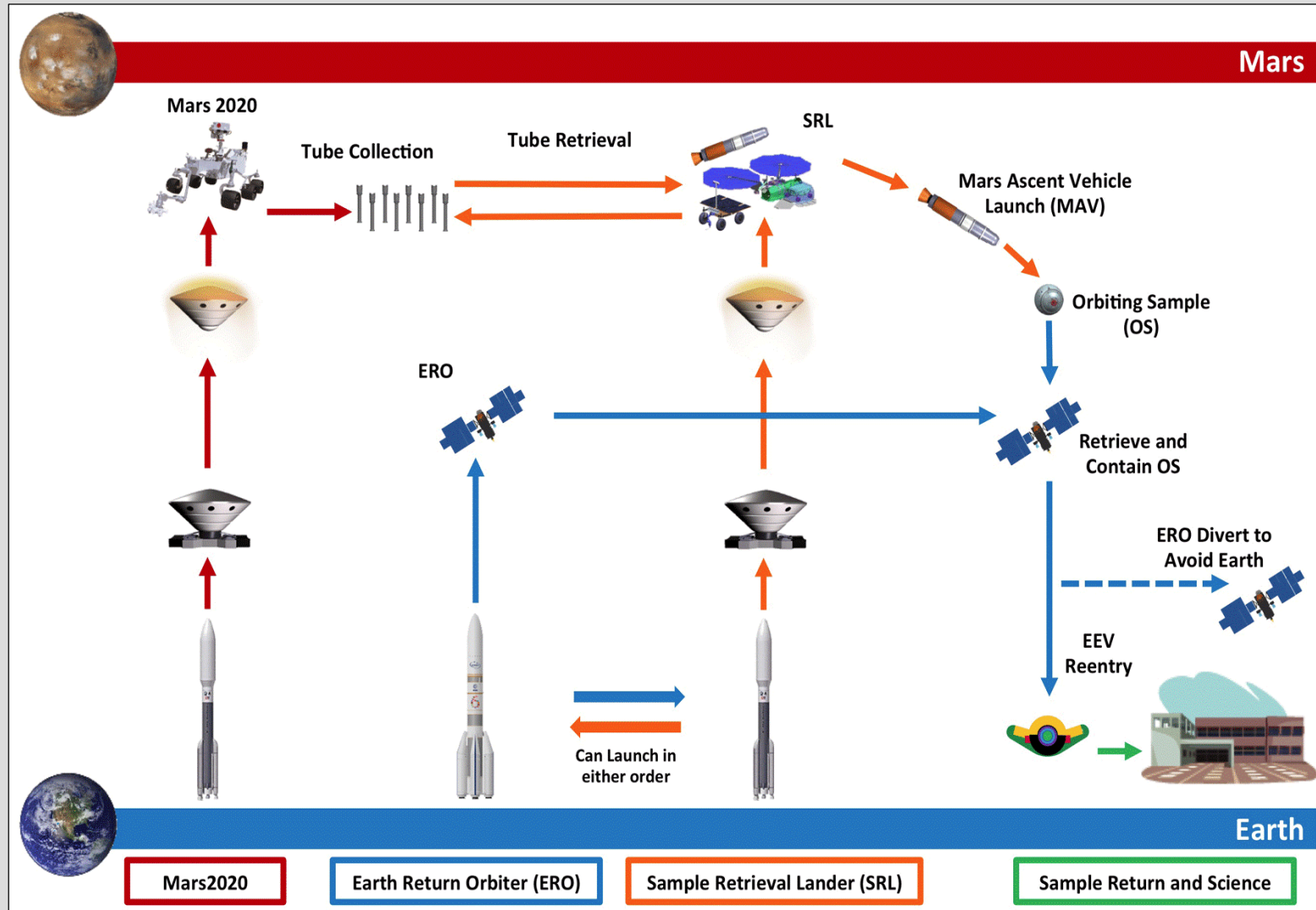
NASA/ESA Mars Sample Return starts with the Mars 2020 rover which will drill and cache samples. Two spacecraft will launch in 2026 to collect the samples tubes with a small fetch rover, transfer samples to orbit with an ascent rocket, rendezvous with an orbiting spacecraft, and return samples to Earth for study.

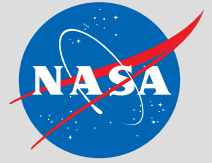
<https://www.jpl.nasa.gov/missions/mars-sample-return-msr/>





NASA/ESA Integrated Campaign Mars Sample Return

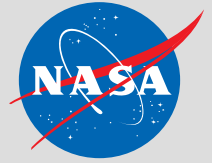




Research to Close Knowledge and Technology Gaps

In addition to verifying the biological cleanliness of spacecraft during assembly, the Office of Planetary Protection supports research for robotic and human missions with destinations at Mars, Europa, and Enceladus.

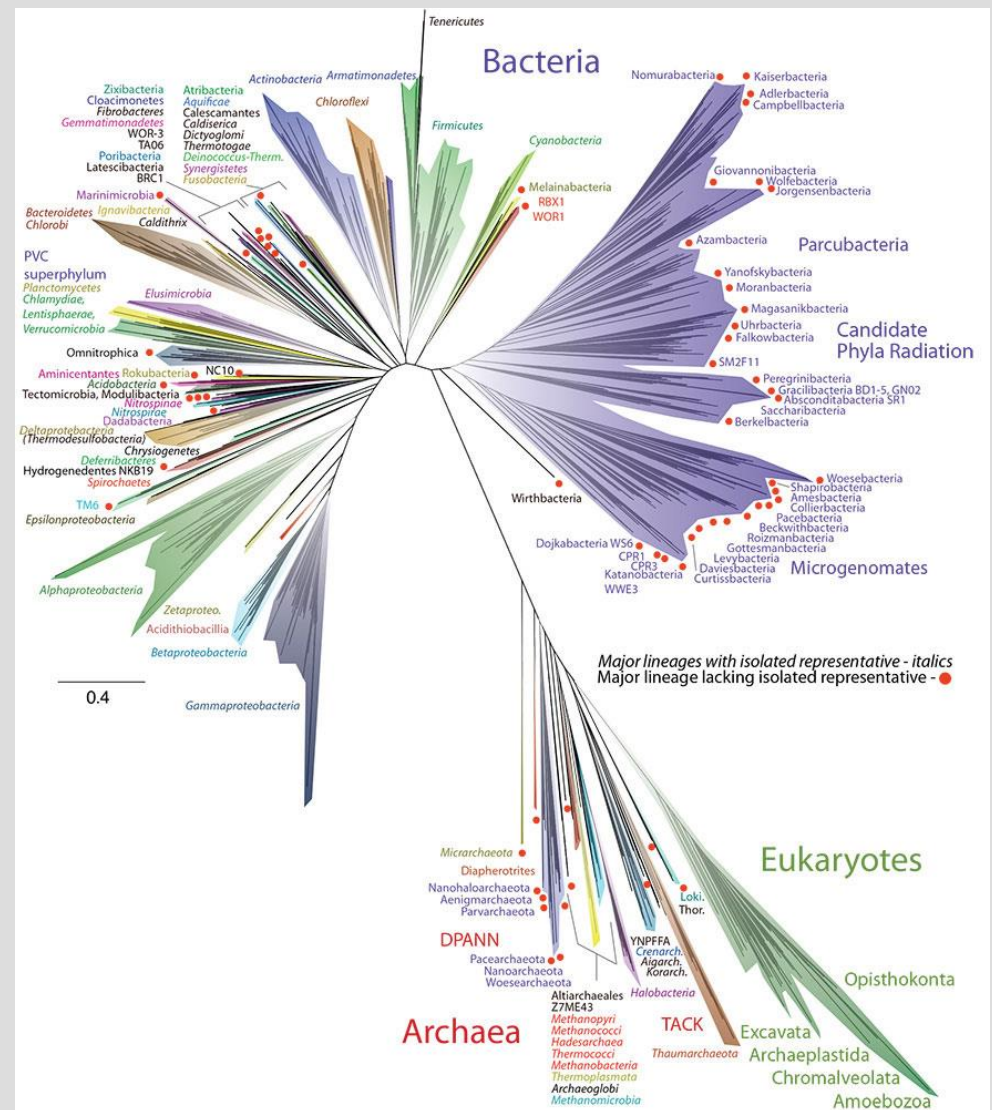
- Genomic and metabolomic characterization of terrestrial organisms on spacecraft
- Innovative chemical and spectral tools for rapid detection of bioburden on spacecraft
- Sterilization modalities for use on putative extraterrestrial organisms

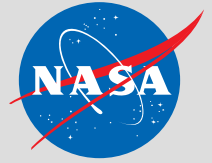


Genomic Revolution in Life Science

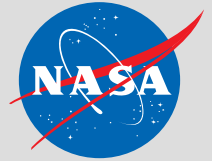
Many bacteria and archaea are known only from their environmental genome: the great uncultured majority.

Hug et al., 2016, Nature Microbiology

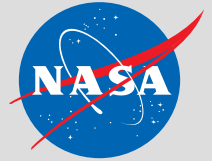




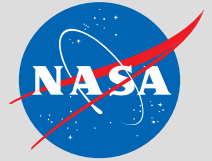
14 Major Recommendations from PPIRB report which the Office of Planetary Protection will lead



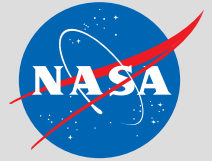
14	MR	General Overarching	Major Recommendation: To reduce project inefficiencies, PP requirements should be finalized early in mission formulation and should avoid past practices of adding new or unexpected PP requirements, including in categorization letters.	Agency	Internal Long-Term	PPO
15	MR	General Overarching	Major Recommendation: PP requirements on missions should be written to define PP intent, rather than detailed implementation methods, thereby allowing projects to select and/or develop implementations most suitable to meet their PP requirements from a systems standpoint.	Agency	Internal Short-term	PPO
26	SR	General Overarching	Supporting Recommendation: The PPO should implement both well-documented and transparent PP requirements and requirements waiver processes for all missions with NASA involvement.	Agency	Internal- Short-term	PPO
29	SR	General Overarching	Supporting Recommendation: NASA should assess how to streamline PP implementation for ultra-low cost planetary missions.	Agency	Internal Short-term	PPO
33	SR	General Overarching	Supporting Recommendation: These contractual requirements (Space Act Agreements and some NASA contracts require NASA 8020.12 PP compliance, which in turn invokes COSPAR policy/guidelines) should be reviewed by NASA to simplify compliance where possible and to avoid overconstraining the means of meeting NASA intent.	Agency	Internal Short-term	PPO



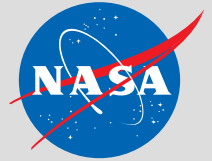
50	SR	Human Space-flight	Supporting Recommendation: NASA should review COSPAR's humans to Mars principles and guidelines to assess which should be followed, discarded, or updated for NASA's first human Mars expedition.	Inter-national	External Short-term	PPO
54	MR	Private Sector Initiatives and Missions	Major Recommendation: In addition to balancing the needs of science and exploration, PP policy should also recognize that it is both a NASA and a national objective to encourage private sector space initiatives and commercial robotic and human planetary missions. The National Aeronautics and Space Act of 1958, as amended, explicitly states that one of NASA's functions is to "seek and encourage, to the maximum extent possible, the fullest commercial use of space." ⁸ Additionally, the 2010 National Space Policy expressly directs Federal agencies to "minimize, as much as possible, the regulatory burden for commercial space activities" and to "refrain from conducting United States Government space activities that preclude, discourage, or compete with U.S. commercial space activities." ⁹	US Federal	External Short-term	PPO



59	SR	Private Sector Initiatives and Missions	Supporting Recommendation: The U.S. should continue to encourage international PP forums to include private sector stakeholder participation.	Inter-national	External-Short-term	PPO
67	SR	Robotic Mars Sample Return	Supporting Recommendation: NASA should carefully trade the implications of the degree and types of PP sterilization techniques for Mars samples with the implications for various types of science measurements.	Agency	Internal-Short-term	SMD/PPO
68	SR	Robotic Mars Sample Return	Supporting Recommendation: NASA should continue to engage experts from the medical, pharmaceutical, and personal care industries to advise on effective sterilization protocols. Such engagement provides meaningful insights from adjacent fields, demonstrates NASA's due diligence to the public, and offers lessons on effective communication to non-experts regarding safety for both robotic sample return and for future human missions to Mars.	Agency	Internal-Long-term	PPO



70	MR	Ocean Worlds Exploration	Major Recommendation: The PP requirements for ocean worlds exploration should be reassessed in light of this finding: "Major Finding: The fraction of terrestrial microorganisms in spacecraft bioburdens that has the potential to survive and amplify in ocean worlds is likely to be extremely small. ^{12,13} Further, any putative indigenous life in subsurface oceans on Europa, Enceladus, or Titan is highly unlikely to have a common origin with terrestrial life. Any such life would be readily distinguishable from terrestrial microorganisms using modern biochemical techniques. As a consequence of these findings, the current bioburden requirements for Europa and Enceladus missions (i.e., <1 viable microorganism) appear to be unnecessarily conservative."	Inter-national	External Long-term	PPO
76	SR	COSPAR	Supporting Recommendation: NASA should broadly communicate that its PP policy is consistent with COSPAR history, and is specifically focused on reducing biological forward contamination that could interfere with future astrobiological investigations and backward contamination that might have adverse impacts on Earth's biosphere.	Agency	Internal Short-term	PPO
77	SR	COSPAR	Supporting Recommendation: To reduce confusion, NASA should develop and then use a standard glossary of PP related terminology, including for example "spacecraft cleanliness," "forward biological transport," and "backward biological transport."	Agency	Internal Short-term	PPO



43	MR	Human Spaceflight	Major Recommendation: NASA should expeditiously develop PP guidelines for human missions to Mars, whether those missions are conducted by NASA, other international agencies, or private entities. We note that the title of NPD 8020.12 includes the phrase “For Robotic Extraterrestrial Missions”, acknowledging the implicit need for a future PP policy addressing non-robotic missions. A subset of future Mars missions are expected to be neither crewed missions nor traditional scientific robotic missions, but missions of other types that could involve crew or crew-support vehicles (e.g., habitat placement, pre-staged cargo emplacement, test flights of human vehicles). Explicit clarification is needed as to which policies apply to each type of Mars mission, including such un-crewed, non- or not- primarily science-driven activities.	Agency	Internal Short-term	PPO
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