Whistleblower Response to Agency Investigation Report

OSC File No. DI-21-000239

7 October, 2022

Summary

The report that NASA submitted in response to my whistleblowing complaint entirely fails to address the concerns I raised about the role of the Mars2020 mission in a Mars Sample Return campaign, and in fact only further confirms the substance of my filing.

I filed this disclosure because NASA and the Mars Program at the Jet Propulsion Lab were failing to take appropriate precautions to assure that the Earth will be safe from biological risks associated with bringing samples collected by the M2020 mission to Earth from Mars. The substance of my complaint is that NASA repeatedly refused to take the steps necessary to ensure a future Returned Sample Analysis program would have the ability to differentiate rare Mars organisms from ubiquitous Earth contamination introduced into Mars samples collected for return by the M2020 mission.

US protocols for the containment and analysis of potentially-biohazardous planetary materials were first specified in preparation for the Apollo program in the mid-1960s. 'Restricted Earth Return' guidelines based on these procedures were developed by the international scientific community including the US Space Studies Board, and are maintained by the Committee on Space Research (COSPAR) of the International Council for Science. In 2017, the UN General Assembly recognized COSPAR guidelines as an appropriate approach for demonstrating compliance with Article IX of the 1967 Outer Space Treaty. In 2020, the US National Academies' Space Studies Board noted that no other approaches for demonstrating compliance had been identified.

The NASA report supposedly investigating my disclosures focuses entirely on the outbound phase of the M2020 mission, and ignores any link with the Mars Sample Return (MSR) campaign. However, the M2020 mission has already started MSR, because the sample collection hardware carried on the M2020 rover is intended for eventual return to Earth.

This is exactly the same behavior that prompted my whistleblowing in the first place.

[redacted]

Regulatory Framework

Presidential Directive/National Security Council-25

In the 1960s, the Apollo Program was required to comply with National Security Action Memorandum 235 on "Large-Scale Scientific or Technological Experiments with Possible Adverse Environmental Effects", under which a 1967 Interagency Agreement chartered the Interagency Committee on Back Contamination as the mechanism for assuring protection of the Earth's biosphere from extraterrestrial sources of contamination (see attached book chapter). In 1977, this memo was superseded by PD/NSC-25, "Large-Scale Scientific or Technological Experiments with Possible Adverse Environmental Effects and Launch of Nuclear Systems into Space", which is still in effect.

PD/NSC-25 requires consultation between multiple Federal agencies prior to the initiation of experiments with potential large-scale adverse environmental effects; however, NASA launched and landed the M2020 mission on Mars, and is currently collecting samples intended for Earth return, without engaging in the consultation required by PD/NSC-25, and without establishing procedures for Earth Safety Assurance that could mitigate risks from potential Mars biohazards.

In 2020, the Science and Technology Policy Institute (STPI) released a report commissioned by OSTP on planetary protection policy in the US, that addresses the applicability of PD/NSC-25:

https://www.ida.org/research-and-publications/publications/all/t/to/towards-the-development-of-a-national-planetary-protection-policy

This STPI report also notes how the COVID pandemic is relevant to Mars Sample Return:

> "All but a small part of this report was completed before the global outbreak of COVID-19, the effects of which have disrupted the world and damaged its economy. This terrestrial outbreak underlines the potential danger posed by extraterrestrial life, its consequences not predictable but now too easily imaginable. "

National Environmental Protection Act

The Code of Federal Regulations on NEPA, title 14 section 1216.306, mandates preparation of an Environmental Impact Statement for projects "which would likely receive a Restricted Earth Return categorization (as defined in Appendix A to this subpart) from the NASA Planetary Protection Office or the NASA Planetary Protection Subcommittee":

https://www.ecfr.gov/current/title-14/chapter-V/part-1216/subpart-1216.3/section-1216.306

Links to the EISs for M2020 and the 'Mars Sample Return Campaign' are available here:

https://www.nasa.gov/feature/nepa-mars-sample-return-campaign/

In letters dated 7 May and 21 Dec. 2015, following recommendations from the NASA Planetary Protection Subcommittee, as Planetary Protection Officer (PPO) I categorized the M2020 project as 'Restricted Earth Return' at subsystem level, due to the presence of sample storage hardware intended for return to Earth, per the attached documents CatLtrPartialM2020 and CatLtrFullM2020.

Despite the presence of hardware intended for eventual return to Earth, the M2020 Environmental Impact Statement does not mention Mars Sample Return, and omits Earth Safety Assurance completely: no relevant terms appear in the document.

In April 2021, NASA solicited comments on a Mars Sample Return Environmental Impact Statement (MSR EIS) that claims to address planetary protection using the "Key strategy: Contain or sterilize all material delivered from planets that may harbor life until the material is demonstrated to be safe."

Who decides when 'the material is demonstrated to be safe' at an adequate level of risk reduction? What is an adequate level of risk reduction?

Failures to document and control pre-launch Earth contamination that could be introduced into the samples during collection -- some of which are described in the NASA response to my filing -- mean that it will not be possible to assure sensitive detection of rare Mars organisms due to poorly-understood levels of background Earth contamination.

Further incidents of potential contamination during M2020 operations on Mars are documented in blogs about mission operations, including a report of 'Foreign Object Debris' being found in the sample collection system:

https://mars.nasa.gov/mars2020/mission/status/396/nasas-perseverance-cores-12th-sample-team-assessing-rovers-coring-bit/

https://mars.nasa.gov/mars2020/mission/status/397/perseverance-soon-heads-to-enchanted-lake/

In the absence of procedures and oversight having been established, in association with the M2020 mission, for tracking incidents that could affect Earth Safety Assurance and a Mars biohazard detection protocol -- how will these potential contamination events be fed forward into post-return Mars biohazard and Earth Safety analyses?

The vast majority of public comments submitted in response to the MSR EIS strongly protest against bringing Mars samples to Earth until after concerns about potential biohazards are addressed, in much greater detail than NASA has done to date:

https://www.regulations.gov/search/comment?agencyIds=NASA&filter=mars

<u>NASA policy and requirements</u>

Following the then-applicable NASA Policy Document (NPD) 8020.7G, the M2020 categorization letters provide detailed requirements taken from the then-applicable NASA Procedural Requirements document NPR 8020.12D, including the statement:

> "Requirements for Restricted Earth Return missions, of particular relevance to M2020 those regarding documentation and oversight, are described in NPR 8020.12D."

The NASA response to my whistleblowing complaint omits any mention of these relevant requirements, which include:

> 5.3.3.6: Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving Mars for return to Earth; and 3) prior to commitment to Earth reentry.

and

> 5.3.3.11 An independent science and technical advisory committee shall be constituted with oversight responsibilities for materials returned by a Mars sample return mission.

Because the M2020 mission is carrying hardware intended for return to Earth, M2020 is the first leg of a Mars Sample Return campaign, so an oversight committee should have been convened prior to the launch of M2020, to ensure appropriate responses to prelaunch contamination events as well as potential contamination events during Mars operations.

Following precedent and PD/NSC-25, this committee should have included representatives from multiple Federal agencies, and also international partners, with a structure analogous to the Apollo-era Back Contamination Committee.

Instead, NASA convened the so-called Planetary Protection Independent Review Board (PPIRB), every member of which had a career in space exploration and/or received NASA funding for other professional research. As described in the 2020 SSB report cited below, this committee's 2019 report concluded that containment requirements for Mars samples brought to Earth could be relaxed, using arguments the SSB found implausible and I, prior to my 2017 removal as PPO, regularly encountered and had to debunk.

<u>COSPAR and international planetary protection guidelines</u>

NASA requirements are designed to be consistent with both PD/NSC-25 and also international planetary protection policy, which is maintained by the Committee on Space Research (COSPAR), on the basis of scientific advice from member organizations such as the US National Academies' Space Studies Board and the European Science Foundation's European Committee on Space Science.

COSPAR has been responsible for establishing international planetary protection policies from its' inception in the early 1960s: the COSPAR Planetary Protection Policy was codified in the 1990s to provide comprehensive guidelines for complying with planetary contamination provisions of the Outer Space Treaty. In 2017, The United Nations General Assembly explicitly recognized the COSPAR guidelines as demonstrating compliance with the Outer Space Treaty, by accepting the report of the Committee on the Peaceful Uses of Outer Space, which includes the statement:

> "The Committee also noted the long-standing role of COSPAR in maintaining the planetary protection policy as a reference standard for spacefaring nations and in guiding compliance with article IX of the Outer Space Treaty."

The full report is available at:

https://documents-dds-ny.un.org/doc/UNDOC/GEN/V17/044/69/PDF/V1704469.pdf

Outer Space Treaty

Article VI of the US Constitution recognizes treaties ratified by the United States as 'the supreme Law of the Land'.

Although exactly what this means in regard to space exploration is open to dispute, as reviewed in the STPI/OSTP report cited above and also the Space Studies Board (SSB) report cited below, sections of the 1967 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* that are relevant to planetary protection, and particularly Mars Sample Return as performed by a consortium of governmental agencies like NASA and non-governmental entities such as the Jet Propulsion Lab (JPL), include:

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..."

Article VII

> "Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage..."

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..."

Scientific Motivations for Planetary Protection

Planetary protection guidelines for Restricted Earth Return missions have been developed using the best available scientific justification, that supports the policy and regulatory framework that has provided for Earth Safety Assurance since the Apollo program.

Results from the Mars Science Laboratory mission provide a clear illustration of why stringent contamination control is critical for experiments intended to detect extraterrestrial biosignatures.

In 2015, mission scientists Freissinet et al. reported high-confidence detections of carbon-based compounds from Mars, using the Sample Analysis at Mars (SAM) instrument on the Curiosity rover. This detection of Mars carbon-based compounds was quite challenging, due to high levels of Earth contamination that were introduced into the Mars material during sample collection: the conclusion that a subset of compounds was definitively from Mars required the demonstration they were not contaminants from Earth:

https://doi.org/10.1016/j.pss.2016.06.007

In 2018, Guzman et al. compared archival data from the Viking missions in the 1970s with the data from SAM, and reported the presence of these same carbon-based compounds:

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JE005544

After performing an extensive evaluation of possible Earth contamination sources for the organic compounds detected by Viking, these investigators conclude:

> "the Viking GCMS experiment could have detected organic carbon indigenous to a martian sample for the first time, almost 40 years before the detection by the Curiosity rover's SAM experiment."

Viking mission scientists interpreted the carbon compounds detected by the GCMS instrument as being due exclusively to Earth contamination. This 'failure' to detect carbon-based compounds from Mars was interpreted as indicating an absence of Mars life: as a result, Mars exploration was put on hold for over 20 years.

In contrast, Gilbert Levin, the principal investigator of the independent 'Labeled Release' life detection instrument on Viking, continued to publish papers arguing that this experiment had produced evidence of biological metabolism by Mars organisms, until his death in 2021:

https://en.wikipedia.org/wiki/Gilbert_Levin

Of the two life detection experiments on Viking, investigators supporting one experiment incorrectly interpreted their results as due entirely to Earth contamination, while the other met pre-specified criteria for detecting 'life', although with alternative explanations for the results.

An *incorrect* interpretation of the GCMS experiment was believed, over possibly-correct but ambiguous Labeled Release results. What would have been the history of Mars exploration, if the detection of carbon-based compounds on Mars had been recognized correctly in 1976?

What could be the consequences of Mars Sample Return, if overprinting from Earth contamination again prevents detection of faint signals indicating the presence of Mars life?

iMARS and the scientific community

In preparation for a Mars Sample Return campaign planned to start in the 2010s, the International Mars Exploration Working Group convened the study group for an 'international Mars Architecture for Return of Samples (iMARS) that produced a series of reports, described at:

https://planetary.aeronomie.be/index.php/projects/old-projects/imars

These reports covered in detail how samples should be handled for Mars biohazard assessment, including what kinds of controls should be performed to mitigate interference from Earth contamination.

Although not implemented in practice on M2020, the iMARS reports involved substantial participation from the JPL Mars Program, to the extent that the individual reports are hosted on the Mars Exploration Program Analysis Group website at JPL:

http://mepag.jpl.nasa.gov/reports/iMARS_FinalReport.pdf

http://mepag.jpl.nasa.gov/reports/imarsPII_report_2016.pdf

JPL has a long history of resisting planetary protection precautions, as reviewed in the attached book chapter and STPI/OSTP report. The Viking GCMS was the only experiment provided by JPL, and was also the only instrument on either lander to fail: a fact still taught to incoming JPL staff, blamed on planetary protection. Entrenched negative cultural attitudes seem likely to be contributing factors in the Mars Program's avoidance of steps necessary to mitigate the demonstrated potential for Earth contamination to overprint signals from Mars.

US National Academies' Space Studies Board

In addition to the international planetary protection guidelines maintained by the International Council for Science, of which the US National Academies is a member, NASA policies are also based on detailed recommendations from the SSB, in reports going back to the WestEx report of 1959, that had Carl Sagan as a co-author.

SSB publications are available from the Academies' website. The most recent publication on planetary protection policy is from 2020, and is an assessment of how consistent the changes proposed by NASA's 2019 PPIRB are with historical planetary protection policy and practice:

https://nap.nationalacademies.org/catalog/25773/assessment-of-the-report-of-nasas-planetary-protection-independent-review-board

The SSB identifies a number of problematic proposals that emphasize the need for NASA to ensure external coordination on policy issues, although they don't explicitly question the PPIRB membership composition in the context of 'independence'. Notably, in regard to "Areas of Inconsistency and Concern," this SSB report includes the following statement:

> "The committee finds that the naturally occurring transport of martian materials to Earth is not a scientifically compelling reason to alter planetary protection policies for returned samples from Mars."

Narrative Response to NASA's 'investigation' report

Overall, NASA's investigation evaded the entire point of my disclosure, which was about Earth Safety Assurance, specifically the fact that NASA will be unable to differentiate Earth contamination from potential Mars life in samples collected by M2020 and brought to Earth, and therefore will have no way of understanding how biohazardous these Mars samples could be.

This evasion is first indicated by the statement on pg. 1, that pretends to summarize some of my allegations:

> "NASA officials oversaw the erosion of the agency's planetary protection requirements, resulting in lowered cleanliness standards for Mars 2020 and risking the integrity of future missions;"

My disclosure is not about 'the integrity of future missions' -- it's about NASA and JPL management engaging in a long history of deliberate action that renders the agency unable to assure the safety of Earth when returning samples from Mars. The M2020 mission failed both to ensure sufficiently low levels of Earth contamination on hardware for return, and to maintain detailed records of Earth contamination possibly introduced into Mars samples.

High levels of Earth contamination increase instrument background, which reduces detection sensitivity for Mars organisms because small signals just get buried in the noise.

For example: what compounds could be introduced into the M2020 samples by the Foreign Object Debris that mission bloggers described as being discovered in the collection hardware during collection of sample 12? NASA's report neglected to mention similar potential contamination events, although this one and others took place before submission.

That NASA is completely ignoring serious concerns about potential Mars biohazards and Earth Safety Assurance in relation to M2020 is further demonstrated, in NASA's report, by the summary of requirements applied to the M2020 mission (pg. 7) -- a number of the most relevant Category V Restricted Earth Return requirements are omitted from the list provided.

NPR 8020.12D requirement 5.3.3.1 "Samples returned from Mars by spacecraft shall be contained and treated as though potentially hazardous until demonstrated otherwise." is notably missing, as are requirements 5.3.3.6-11 describing required steps for assuring safety of the Earth from returned Mars samples.

COSPAR guidelines and NASA requirements for Mars Sample Return that relate to preventing a potential release of Mars life on Earth were written under the assumption that the entire sample collection and return process would be carried out by a single mission. Under a multi-mission scenario, the post-return cleanliness requirements need to feed backwards onto the initial sample collection mission, to avoid exactly what NASA and JPL are doing with M2020.

If the first sample collection mission doesn't both ensure appropriately high levels of cleanliness and also retain detailed records describing what was done, there will be no way to determine whether indications of possible biology in the returned samples represent Mars life or Earth contamination. This basis for Earth Return guidelines has been clearly stated over decades in recommendations from the Space Studies Board, as well as both reports from the iMARS study team (see above) -- which NASA co-led with ESA, but has subsequently disregarded.

During the Apollo Program, the applicable regulation under which the Lunar Back Contamination Committee was constituted was PD/NSC-25, on "Scientific or Technological Experiments with Possible Large Scale Adverse Environmental Effects...", and the STPI/OSTP report cited above concluded that this regulation also should apply to Mars Sample Return. Decades of SSB recommendations, as well as long-standing NASA requirements documents, support the establishment of a modern equivalent of the Apollo-era Back Contamination Committee to exert *independent* oversight as part of the preparations for Mars Sample Return.

NASA used to have a FACA-chartered NASA Planetary Protection Advisory Committee (charter attached as PPACcharter), that included agency and international liaison members specifically to serve as an informal interim coordination mechanism. These liaisons were eliminated from the Terms of Reference of the non-FACA Planetary Protection Subcommittee in 2009 (attached as PPStor), before it was disbanded in 2016. Timing suggests these decisions could be a response to my actions as PPO in highlighting the need -- to NASA upper management, as well as the State Dept. and the FAA -- to establish a new Back Contamination Committee for Mars Sample Return.

The ad hoc "Boards, Working Groups, Teams, and Reviews" suggested on pg 38 of NASA's report -- particularly if convened by the Mars Program or otherwise supported by NASA/SMD -- are entirely opaque to oversight, and have the potential to be highly conflicted if, as with the PPIRB, the membership is composed of NASA-funded or industry insiders. The 2020 SSB report cited above emphasized the particular importance of truly independent and balanced oversight.

Committees that are funded directly by the organization they purport to oversee are much less 'independent' that the NASA Advisory Council subcommittee used to be, even after the FACA charter was lost. Across multiple 'independent' reviews of M2020 implementation, NASA experts who participated, and expressed views that diverged from the Mars Program party line, were subsequently penalized.

The most blatant demonstration that NASA has allowed M2020 to evade requirements related to Earth Safety Assurance is provided by the extremely brief discussion of contamination-related issues in NASA's report responding to my filing.

The 'System Deviation' mentioned on pg. 15 was apparently granted on the basis of a claim from the project that "Mars/Earth safety is unaffected." Further down the page -- after stating that M2020 samples could be contaminated above baseline levels -- NASA's report notes:

> "Failure to meet the baseline total organic does not present a significant threat to planetary protection but potentially affects some Mars sample return science".

In the context of detecting potential indications of Mars life, the 2018 iMARS report came to precisely the opposite conclusion about contamination affecting science but not planetary protection. On pg. 16, the iMARS team concludes:

> "Scientists now recognise that sample analyses required to meet planetary protection requirements are more or less the same ones they would want to perform in the interest of scientific investigation"

This means that degradation of science related to Mars biosignature detection also degrades Earth Safety Assurance. NASA's repetition of claims that increases in Earth contamination do not affect Earth Safety Assurance demonstrates **exactly** the substance of my disclosure.

Pp. 20-22 of NASA's report describe the steps taken by the M2020 project to document the level of cleanliness the Sampling and Caching system, particularly the 'Fluid Mechanical Biobarriers' was predicted to achieve. The explicit assumption by M2020 that contamination from areas of the rover not considered 'sample intimate hardware' would never reach the samples is not questioned by the author of NASA's report -- which is odd, because this person should be quite familiar with the Genesis mission, where contamination redistributed from distant parts of the spacecraft has been an enduring scientific challenge:

https://curator.jsc.nasa.gov/genesis/contamination.cfm

One of the major objections to M2020's proposed implementation, raised by the PPO and PPS in the last meeting before the PPS was disbanded in 2016, is that the assumptions about the performance of the sampling/caching hardware were not adequately tested. Multiple additional 'independent' reviewers also expressed concerns that the 'challenge' protocol and CFD modeling proposed by M2020 did not accurately represent the potential for contamination, including NASA employees also subsequently blacklisted for these contributions. Neither of the M2020 approachs considered more than a very small number of diurnal pressure/temperature cycles -- despite the sample collection hardware being exposed on Mars for many hundreds of days -- nor were the electrostatic and electromagnetic environments evaluated under deployed conditions.

Even if the contamination control measures might have been adequate for hardware maintained at the mandated level of cleanliness, the sections of NASA's report on 'Verification and Validation' and 'Issues' describe a large number of cleanliness violations during assembly, test, and launch. Given the lax attitude to these violations demonstrated by NASA in this report, the potential for additional introduction of undocumented contamination is high. This further degrades NASA's ability to assure Earth Safety by ensuring sensitive detection of possible Mars biohazards in returned samples.

In conclusion: NASA's report documents confirmation that NASA **has *not*** taken the necessary steps to provide an appropriate level of Earth Safety Assurance for samples collected by the M2020 mission, as mandated in NASA requirements and COSPAR guidelines, following recommendations from the Space Studies Board and European Space Science Committee, and fully endorsed by multiple international scientific teams including iMARS.

When I was PPO, and attempting to impose Restricted Earth Return requirements on the M2020 mission -- specifically including feed-forward from the M2020 mission into the Earth Return campaign -- the Mars Program and JPL management refused to comply with requirements they perceived as being too inconvenient and costly. Fulfilling my responsibilities as PPO specified in NPD 8020.7, I communicated these violations to the highest levels of NASA management, and filed a whistleblowing disclosure after being penalized for doing my job.

NASA's investigation report fails to identify any actions taken to ensure the M2020 project complies with planetary protection requirements for Restricted Earth Return. After the sample collection leg of a proposed Mars Sample Return mission has landed on Mars, it is physically impossible to determine whether the amount of Earth contamination being introduced into the samples is likely to swamp out a sensitive detection of Mars life.

Many of the public comments on the NEPA MSR EIS website take a very clear position: to avoid inadvertent release of possible Mars organisms on Earth, samples that are too contaminated to allow sensitive detection of Mars life should not be brought to Earth.

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Rep y to Attn of: Science Mission Directorate

21 Dec., 2015

[redacted]
Project Manager
M2020 Project
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

Subject: Full Planetary Protection Categorization of the Mars 2020 Mission

Dear [redacted]:

I have reviewed the requests that the Project has submitted for a Planetary Protection Categorization of the M2020 mission. Those communications, taken together, do not provide sufficient information to ascertain the degree to which Mars 2020 Project is proposing to deviate from requirements specified in NASA Procedural Requirements document (NPR) 8020.12D. Therefore, this categorization letter reiterates the standard set of requirements for the mission described, taken from NPR 8020.12D and clarified in the Partial Categorization Letter dated 7 May 2015. If the Project intends to propose deviations from these requirements, they should be justified using the formal deviation request process developed for this purpose.

The mission description provided in support of the Project's categorization requests indicates that the M2020 flight system is based on MSL heritage hardware, and will consist of a cruise stage; entry, descent, and landing system; and a radiothermal-powered rover with science payload. The rover payload includes a novel subsurface sampling system and novel caching hardware that are intended to collect and enclose samples for possible future return to Earth.

In addition, information describing instruments selected for the M2020 mission indicates that the rover-carried science payload has the capability to perform near-surface measurements of organic 'biosignature' compounds *in situ*, with at least parts per million (ppm) sensitivity.

The M2020 Project plans to exclude landing in or on Mars Special Regions.

Due to the presence of a "returnable" sample caching system, including hardware that is intended in future to be returned to Earth, the M2020 mission represents the first element of a possible future Mars Sample Return campaign, and therefore receives a designation of Planetary Protection Category V Restricted Earth Return. Requirements for Restricted Earth Return missions, of particular relevance to M2020 those regarding documentation and oversight, are described in NPR 8020.12D.

To support this categorization, the outbound leg of the M2020 mission shall be required to comply with requirements for Planetary Protection Category IVb, which may be implemented at subsystem level, as a mission to Mars that will not access Special Regions but that will conduct "scientific investigations of possible extraterrestrial life forms, precursors, and remnants" per the NASA policy statement in NPD 8020.7G. These requirements apply to both hardware caching samples for return to Earth, and to *in situ* biosignature detection instruments, which incur requirements to maintain contamination at levels "driven by the nature and sensitivity" of the instruments, per NPR

8020.12D. All requirements contained within NPR 8020.12D that are relevant to a Category IVb Mars mission shall apply to the M2020 mission.

Some relevant Category IVb-subsystem and Category V Restricted Earth Return requirements from NPR 8020.12D are clarified below. In some cases, the language below reiterates or refers to language contained in M2020 Project Level 1 requirements; the purpose of this is to ensure appropriate coordination and oversight by the NASA Planetary Protection Officer (PPO) of project requirements relevant to planetary protection and possible future sample return.

Absence from this list in no way implies that other relevant requirements from NPR 8020.12D are waived. Because the M2020 Project is still developing a design and operational approach for sample caching, and considering information received by my office that the M2020 payload accommodation has not yet closed, additional planetary protection requirements may be levied to ensure compliance of the M2020 final architecture, per NPR 8020.12D Section 2.7.1.

1. Clarification of NPR 8020.12D Section 5.3.2.2.b implemented at subsystem level:

Requirements for *in situ* instruments investigating 'precursors or remnants' of life:

1.1 The M2020 Project shall prevent contamination by Earth compounds of Mars materials subjected to *in situ* analysis above the levels negotiated with instrument providers as part of instrument accommodations.
   a) pre-launch cleanliness levels and post-launch operations necessary to ensure adequate contamination prevention shall be derived by the Project and reported as part of implementing planetary protection requirements
   b) compliance shall be monitored by the PPO in addition to project/program processes

Requirements for hardware collecting samples intended for possible future return to Earth:

1.2 Hardware subsystems that are involved in the acquisition, delivery, and storage of samples intended for future return to Earth shall be cleaned to a level of <300 heat resistant 'spores' per m^2 of hardware surface and also cleaned to levels of organic cleanliness derived as described in section 3.1.b of this letter, enclosed in a physical biobarrier that is not subsequently opened until operations at Mars, and subjected to a validated biological reduction process (e.g., Dry Heat Microbial Reduction) that achieves at least four orders of magnitude of microbial reduction.

1.3 Recontamination shall be prevented as described under section 3 of this letter.

1.4 Pre-launch hardware cleanliness shall be verified by test:
   a) verification of biological cleanliness shall be performed following accepted NASA processes
   b) a similar level of verification shall be performed for organic cleanliness, following validated processes
   c) a microbial inventory covering at least 99% of organisms present, as demonstrated by rarefaction curve analysis using total environmental sequencing of samples collected from subsystem hardware assembly environments, shall be provided in the M2020 Post-Launch Report
   d) typical PPO audit activities, as described for biological cleanliness in NPR 8020.12, shall be accommodated for both biological and organic cleanliness

2. Clarification of NPR 8020.12D Sections 5.3.2.3.c and 5.3.2.5.c, requirements for avoiding access to or creation of spacecraft-induced special regions:

2.1 Due to the presence of a radiothermal generator (RTG) used to power the M2020 rover, the M2020 Project shall ensure that candidate landing sites exclude the following from the post-parachute-opening 3-sigma landing ellipse:

a) locations with ice or hydrated minerals at depths of <5 meters (based on MSL impact calculations), for which exposure to an RTG could cause liquid to be liberated sufficient to mobilize a particle of <50nm in size
b) Special Regions as formally defined in NPR 8020.12D Section 5.3.2.5 or as modified by mutual agreement prior to launch, pending evaluation of the definition rendered by the 2014-15 MEPAG/SSB/ESF evaluations, and subject to review by the NASA Planetary Protection Subcommittee
c) transient Special Regions on the rover created by the presence of an RTG are included in these constraints: their absence shall be demonstrated by test and analysis pre-launch. Any evidence collected during rover operations that suggest higher potential for special regions than predicted shall be reported per 2.4.

2.2 In addition to the standard reviews, the final candidate landing sites shall undergo an independent review, organized by the PPO, as part of the pre-launch landing site selection process and prior to the preparation and presentation of landing site options to the Science Mission Directorate Associate Administrator.

2.3 Later access to locations identified in 2.1, via either vertical or horizontal mobility of rover elements, shall be prohibited.

2.4 Checkpoints shall be instituted as a standard element of rover operations, to ensure appropriate reporting to and oversight by the NASA PPO.

3. Clarification of NPR 8020.12D Sections 5.3.3.2 and 5.3.2.7, requirements for Category V Restricted Earth Return:

3.1 The M2020 Project shall ensure that Mars samples intended for possible future return are not contaminated by terrestrial organic compounds or viable organisms at levels above those specified below, through final deposition of sample tubes on Mars:
a) the probability that a single viable organism is introduced into each sample shall be less than the limit obtained by multiplying the internal surface area of a sealed sample tube, in m^2, by the Viking post-sterilization surface bioburden limit of 0.03 viable organisms per m^2
b) terrestrial organic contamination shall be limited to levels below < 1 ppb of any Tier 1 organic compound per sample, and < 10 ppb Total Organic Carbon per sample. A deviation may be requested in the event that the methods used to validate this requirement can with confidence distinguish between the draft Level 1 baseline (10 ppb) and threshold (40 ppb) requirements, and measurements demonstrate compliance with threshold but not baseline. (reference: draft Project L1 requirements and the 2014 MEP Organic Contamination Panel output)

3.2 Sample tubes shall be designed for opening after return to Earth in a manner that will prevent contamination of samples above permitted limits during sample extraction.

3.3 The M2020 Project shall ensure that hardware is maintained at cleanliness levels necessary to comply with organic compound and viable organism contamination requirements. Specifically, the Project shall:
a) derive the levels of hardware cleanliness necessary to ensure compliance, taking into account the potential for volatile and particulate recontamination at each phase of the mission
b) demonstrate, by analysis and test, that recontamination prevention approaches ensure maintenance of required sample cleanliness during all nominal rover operations through final deposition of sample tubes on Mars
c) develop cleanliness verification strategies to document compliance with pre-launch hardware cleanliness derived requirements
d) submit the above to OPP for review, acceptance, and subsequent compliance auditing

3.4 Documentation of relevant information on the M2020 mission, including detailed information about operations at Mars, and also information on interfaces between the M2020 Project and future elements of a Mars Sample Return Campaign, shall be provided to the PPO in the form of a draft/partial Earth Safety Analysis Plan.

Planetary protection requirements derived from NPR 8020.12D and this categorization letter, including approved requests to deviate from these requirements, shall be formally documented in the appropriate Project documents, including the Program Level Requirements Appendix (Level 1 requirements) and associated lower level requirements. The Project's planetary protection implementation approaches shall be formally documented in the appropriate project-level plans: the Planetary Protection Plan, which details the planned approach to compliance with planetary protection requirements; the Planetary Protection Implementation Plan, which details the Project's implementation of the Planetary Protection Plan; and other subsidiary documents as relevant.

The M2020 draft Level 1 and lower-level derived requirements include language that deviates from requirements specified in NPR 8020.12D, but data to support acceptance of these deviations has not yet been provided. All requests for deviations from requirements in NPR 8020.12D or approved process specifications shall follow the formal deviation process that has been provided to the Project by the PPO, and shall include sufficient data to demonstrate equivalence. Deviation requests to use processes not currently accepted by the NASA PPO shall document process validation at a level that meets accepted US or international standards (e.g., FDA QSR 820.75, ISO 13485 7.5.2). Deviation requests for hardware systems shall be supported by sufficient documentation to demonstrate readiness equivalent to TRL-6, in line with other PDR gate products. Approved requests for major deviations shall be included as appendices to the Project's Planetary Protection Plan; accepted deviation requests submitted subsequently shall be appended to the PP Plan, under change control, or other planetary protection documentation as appropriate.

To ensure appropriate coordination and oversight by the PPO of Project requirements relevant to planetary protection and possible future sample return, and responding to findings in the Office of Chief Engineer's 2013 report on MSL Lessons Learned, all changes to M2020 Project Level 1 requirements relevant to planetary protection, as well as lower-level derived requirements affecting planetary protection compliance that would normally come under project or program control, shall be submitted to the PPO for review and approval prior to acceptance or implementation by M2020.

I look forward to continuing work with the M2020 Project on implementation of planetary protection requirements, in this very exciting opportunity to prepare for returning samples from Mars.

Cordially,

[redacted]

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Rep y to Attn of: Science Mission Directorate

07 May, 2015

[redacted]
Project Manager
M2020 Project
Jet Propulsion Lab
4800 Oak Grove Dr.
Pasadena, CA 91109

Subject: Partial Planetary Protection Categorization of the Mars 2020 Mission

Dear [redacted]:

I have reviewed the multiple requests that the project has submitted for a Planetary Protection Categorization of the M2020 mission. Currently, insufficient information has been received by my office to provide a complete Planetary Protection Categorization; however, this partial categorization letter is provided in recognition of the impending Key Decision Point B Directorate Program Management Council review, to demonstrate progress on establishing planetary protection requirements for the M2020 mission. The project is currently engaged in processes outlined in NPR 8020.12D, including Appendix C, communicating with the Planetary Protection Officer (PPO).

The mission description information provided in support of the categorization requests to date indicates that the M2020 flight system is based on MSL heritage and will consist of a cruise stage; entry, descent, and landing system; and a radiothermal-powered rover with science payload. The rover payload includes a subsurface sampling system and caching hardware that are intended to collect and enclose samples for possible future return to Earth.

In addition, information describing instruments selected for the M2020 mission indicates that the rover-carried science payload has the capability to perform near-surface measurements of organic 'biosignature' compounds *in situ*, with at least ppm sensitivity.

The M2020 project plans to exclude landing in or on Mars Special Regions.

Based on information provided in your letters and other information available to the Office of Planetary Protection, the outbound leg of the M2020 mission shall be required to comply with requirements for Planetary Protection Category IVb implemented at subsystem level, as a mission to Mars that will not access Special Regions, but that will conduct "scientific investigations of possible extraterrestrial life forms, precursors, and remnants" per the NASA policy statement in NPD 8020.7G, both *in situ* and if cached samples are returned to Earth. All requirements contained within NPR 8020.12D that are relevant to a Category IVb Mars mission shall apply to the M2020 mission.

In addition, due to the presence of a "returnable" sample cache including hardware that is intended in future to be returned to Earth, the M2020 mission represents the first element of a possible future Mars Sample Return campaign, and hereby receives a designation of Planetary Protection Category V Restricted Earth Return, per NASA and international policy. Requirements for Restricted Earth Return missions, of particular relevance to M2020 those regarding documentation and oversight, are also described in NPR 8020.12D.

Some relevant Category IVb-subsystem and Category V Restricted Earth Return requirements from NPR 8020.12D are clarified below. In some cases, the language below reiterates or refers to language contained in M2020 Project Level 1 requirements; the purpose of this is to ensure appropriate coordination and oversight by the PPO of project requirements relevant to planetary protection and possible future sample return.

Absence from this list in no way implies that other relevant requirements from NPR 8020.12D are waived. Because the M2020 project is still developing a design and operational approach for sample caching, additional planetary protection requirements may be levied as the M2020 architecture is finalized, per NPR 8020.12D Section 2.7.1.

1. Clarification of NPR 8020.12D Section 5.3.2.2.b implemented at subsystem level, requirements for *in situ* instruments investigating 'precursors or remnants' of life:

1.1 The M2020 project shall prevent contamination by Earth compounds of Mars materials subjected to *in situ* analysis above the levels negotiated with instrument providers as part of instrument accommodations.
- a) pre-launch cleanliness levels and post-launch operations necessary to ensure adequate contamination prevention shall be derived by the project and reported as part of implementing planetary protection requirements
- b) compliance shall be monitored by the PPO in addition to project/program processes

2. Clarification of NPR 8020.12D Sections 5.3.2.3.c and 5.3.2.5.c, requirements for avoiding access to or creation of spacecraft-induced special regions:

2.1 Due to the presence of a radiothermal generator (RTG) used to power the M2020 rover, the M2020 project shall ensure that candidate landing sites exclude the following from the post-parachute-opening 3-sigma landing ellipse:
- a) locations with ice or hydrated minerals at depths of <5 meters (based on MSL impact calculations), for which exposure to an RTG could cause liquid to be liberated sufficient to mobilize a particle of <50nm in size
- b) Special Regions as formally defined in NPR 8020.12D Section 5.3.2.5 or as modified by mutual agreement prior to launch, pending evaluation of the definition rendered by the 2014-15 MEPAG/SSB/ESF evaluations, and subject to review by the NASA Planetary Protection Subcommittee

2.2 In addition to the standard reviews, the final candidate landing sites shall undergo an independent review, organized by the PPO, as part of the pre-launch landing site selection process and prior to the preparation and presentation of landing site options to the Science Mission Directorate Associate Administrator.

2.3 Later access to locations identified in 2.2.1, via either vertical or horizontal mobility of rover elements, shall be prohibited.

3. Clarification of NPR 8020.12D Sections 5.3.3.2 and 5.3.2.7, requirements for Category V Restricted Earth Return:

3.1 The M2020 project shall ensure that Mars samples intended for possible future return are not contaminated by terrestrial organic compounds or viable organisms at levels above those specified below, through final deposition of sample tubes on Mars:
- a) the probability that a single viable organism is introduced into each sample shall be less than the limit obtained by multiplying the internal surface area of a sealed sample tube, in m^2, by the Viking post-sterilization surface bioburden limit of 0.03 viable organisms per m^2
- b) terrestrial organic contamination shall be limited to levels below < 1 ppb of any Tier 1 organic compound per sample; < 10 ppb Total Organic Carbon per sample (reference: draft Project L1 requirements and the 2014 MEP Organic Contamination Panel output)

3.2 Sample tubes shall be designed for opening after return to Earth in a manner that prevents additional contamination of samples during extraction.

3.3 The M2020 project shall ensure that hardware is maintained at cleanliness levels necessary to comply with organic compound and viable organism contamination requirements. Specifically, the project shall:

a) derive the levels of hardware cleanliness necessary to ensure compliance, taking into account the potential for volatile and particulate recontamination at each phase of the mission
b) demonstrate, by analysis and test, that recontamination prevention approaches ensure maintenance of required sample cleanliness during all nominal rover operations through final deposition of sample tubes on Mars
c) develop cleanliness verification strategies to document compliance with pre-launch hardware cleanliness derived requirements
d) submit the above to OPP for review, acceptance, and subsequent compliance auditing

In addition to the above, planetary protection requirements derived from NPR 8020.12D, as well as additional requirements developed during the ongoing process of categorization per NPR 8020.12D Appendix C, shall be formally documented in a subsequent update to this Partial Categorization Letter and the appropriate Project documents, including the Program Level Requirements Appendix (Level 1 requirements) and associated lower level requirements as well as documentation required by NPR 8020.12D.

To ensure appropriate coordination and oversight by the PPO of project requirements relevant to planetary protection and possible future sample return, all changes to M2020 Project Level 1 requirements relevant to planetary protection, as well as lower-level derived requirements affecting planetary protection compliance that would normally come under project or program control, shall be submitted to the PPO for approval prior to acceptance or implementation by M2020.

I look forward to continuing work with the M2020 project on implementation of planetary protection requirements on this very exciting opportunity to prepare for returning samples from Mars. Best wishes for the success of your mission.

[redacted]

12.5 Planetary Protection

CONTENTS

12.5.1 INTRODUCTION

12.5.1.1 Overview of Planetary Protection Considerations

Previous sections of this book have reviewed in great detail the historical and ongoing efforts to understand the origin and evolution of life on Earth, as well as the potential for life to exist on other planets. One of the critical questions in searching for life elsewhere is to ensure that contamination from Earth does not interfere with detection of extraterrestrial signals—this could lead to interpretation of results that are either "false-positive" (e.g., reports of fossil Mars life in the meteorite ALH84001 that was subsequently shown to be abiotic; see Steele et al. 2010) or "false-negative" (e.g., failure to identify indications of Mars organic compounds in data from NASA's Viking missions to Mars; see Glavin et al., 2013; Freissinet et al., 2015). The potential for Earth contamination to interfere with scientific investigations of other planetary objects and the need for international standards to reduce this risk were recognized internationally around the launch of Sputnik (e.g., Committee on Contamination by Extraterrestrial Exploration [CETEX], 1958, 1959). Very rapidly thereafter, guidelines and practices were put in place to prevent contamination; these are collectively known today as "planetary protection," as described in detail by Meltzer (2011). Planetary protection policy and guidelines are founded in the best available scientific knowledge and maintained by the International Council for Science to provide consensus standards, for use by all countries and space exploration activities, as part of complying with United Nations (UN) treaty obligations. The policy and guidelines are regularly updated to reflect new scientific discoveries, following a process that continues to this day.

12.5.1.2 Relationship to Astrobiology and Planetary Exploration

All missions coming in close proximity to other planets have a potential to introduce Earth contamination, which could reduce confidence in scientific conclusions relating to extraterrestrial life detection. In addition, the introduction of Earth organisms capable of surviving for long periods in a dormant state could put in jeopardy future human goals such as settlement or terraforming, which are entirely outside the scope of near-term scientific missions or other exploration activities. Control of Earth contamination on planetary spacecraft is a technological challenge that has been surmounted on multiple occasions, most notably during NASA's
AQ 1 Viking program in the 1970s (Daspit et al., 1988) and the European Space Agency (ESA's) ExoMars missions ongoing today. "Forward contamination" is the term used to describe these processes, which have risks that can be determined and quantified—at least to the extent that we understand the capabilities of Earth organisms and non-living contamination to be present on spacecraft, and persist after introduction
AQ 2 to planetary environments.

In contrast, potential risks resulting from the introduction of extraterrestrial organisms into the environment of the Earth, termed "backward contamination," are entirely unknown and currently unquantifiable, because, to date, we have no evidence regarding the characteristics of possible extraterrestrial life and thus no basis to assess pathogenicity or ecological consequences. From a policy and regulatory standpoint, these uncertainties about the actual risks of backward contamination are compounded by challenges associated with detecting extraterrestrial life, if it is present. The two Viking and the Mars Science Laboratory (MSL) missions to Mars carried sensitive instruments to detect metabolic activity (Viking) or organic compounds (Viking and MSL) on Mars (e.g., Glavin et al., 2013; Freissinet et al., 2015). Each of these missions returned data indicating levels of Earth contamination that exceeded detection limits for Mars organics, and these data were interpreted as non-detections of Mars life—however, in the case of the Viking Life Detection Package, one of the principal investigators still publishes papers disputing this conclusion (e.g., DiGregorio et al., 1997).

In 1964, a decade prior to the Viking missions, the US Space Science Board (SSB) was asked to evaluate backward contamination issues for NASA's Apollo program and future Mars missions. It noted that "negative findings could provide a sense of security which might well be false" (Space Science Board [SSB], 1964). The possibility that extraterrestrial organisms could be hazardous, either to the environment of the Earth or to humans directly, makes detecting them at very high sensitivity a primary concern for ensuring the safety of the Earth.

12.5.1.3 Interfaces with Wider Society

On Earth, humans have a long history of transporting biological organisms from one location to another, which has often caused major disease outbreaks and/or ecosystem disruption, as reviewed in Mann (2011) and many others. It is not knowable, until we have an example of extraterrestrial life, whether that life could become pathogenic or disrupt the ecosystems that humans rely on. In contrast, we do know that Earth organisms inadvertently transported on spacecraft could interfere with future objectives of human settlers, as they have done on Earth in the past. Avoiding the accidental transport of Earth organisms, before decisions are made to introduce them, is a long-term concern for planetary protection, because one single release of a self-replicating entity into a habitable environment can engender a persistent population and thus cause permanent contamination.

For the reasons mentioned above, it is essential to address planetary protection at the highest levels of global societal decision-making, which for 60 years has been done via the UN and the International Council for Science. In addition, to ensure that one bad actor does not cause permanent damage to everyone, individual nations have obligations under the 1967 Outer Space Treaty to take appropriate measures to ensure that all exploration of other planets carried out under their auspices, whether governmental or private/commercial, follows the same guidelines. Space exploration is the first effort in human history for which we, as a global society, have recognized the potential risks of contamination before it happened, and planetary protection is the first time humanity as a
species has taken responsible steps to prevent it. AQ 3

12.5.2 PLANETARY PROTECTION: DEFINITION AND SCOPE

Planetary protection covers explicitly the search for extraterrestrial life and also the potential for Earth life to interfere with future human objectives: the focus of planetary protection is exclusively on biological contamination and does not address other kinds of contamination such as radiation or physical detritus. Due to the very high level of concern for protecting the Earth on which we all live, relative to the more limited concern about contaminating other planets, the guidelines and policy for planetary protection are divided, conceptually, on the basis of whether spacecraft are only traveling outward to other planetary bodies and therefore could cause forward contamination, or whether there is an expectation that hardware will return back to Earth, possibly carrying extraterrestrial material, which could release backward contamination.

12.5.2.1 Forward Contamination Concerns

Spacecraft traveling to another planetary body (moon, asteroid, comet, etc.) have the potential to cause forward contamination by depositing organic material and/or organisms from Earth onto the target object. Forward contamination is of concern for planetary protection only to the extent that contaminants could interfere with scientific or other human objectives at the target object. The vast majority of objects in the solar system are known to support conditions inhospitable to all Earth life (e.g., no atmosphere, too irradiated, and too dry), and therefore, spacecrafts going to them are not controlled to prevent introduction of Earth organisms. To the extent that a non-habitable object is of scientific interest for understanding the origin and evolution of life in the solar system, which involves studying whatever organic compounds could be present, a mission may be required to provide a list of materials present on the spacecraft and to report locations where spacecraft hardware is left at end of mission. Missions going to non-habitable targets are required to provide only a straightforward set of documentation about hardware composition, spacecraft operations, and final disposition.

In contrast, when a planetary body has the potential to provide a habitat for Earth organisms, spacecraft traveling to them are required to avoid introducing Earth organisms into habitats: this involves applying very strict decontamination procedures to hardware that could introduce Earth organisms and also (or instead) avoiding contact of contaminated hardware with potentially habitable environments. Currently, three solar system objects are of concern for contamination by Earth life: the planet Mars, and the moons Europa around Jupiter and Enceladus around Saturn. Other planetary bodies may be added to this list as additional potential habitats are identified, and requirements to prevent contamination of them should be put in place. Missions going to habitable targets are required, as part of as part of mission formulation, to submit and receive approval for detailed plans that describe proposed decontamination procedures; during hardware assembly and launch operations, they will undergo regular inspections and extensive reviews to confirm compliance prior to launch, and after launch, they continue to ensure contamination avoidance during spacecraft operations, as well as to provide information about relevant research findings and report final hardware disposition.

12.5.2.2 Backward Contamination Concerns

When spacecraft hardware is being brought back to Earth after contact with another planetary body, it is of primary concern to ensure the safety of the Earth's biosphere and everything that lives in it. Again, the focus is on biological contamination, so the same conceptual distinction is made relating to habitability and the potential for extraterrestrial life—defined as biochemistries that could function in the surface physical environment (temperature, pressure, etc.) of Earth—with very different levels of concern around preventing release of material from "potentially habitable" versus "non-habitable" target objects. Missions returning from all non-habitable target objects, including the Earth's Moon and near-Earth asteroids, follow planetary protection guidelines to provide documentation of the target's non-habitability during mission planning phases and receive no further planetary protection requirements once appropriate review is completed.

As with forward contamination, restrictions are only imposed on spacecraft returning from objects that might host extraterrestrial life, which is *by definition* considered biohazardous until tests demonstrate otherwise—currently, this includes the three "potentially habitable" objects: Mars, Europa, and Enceladus. If other solar system objects are found, in future, to host physical conditions that could support biochemistries also potentially active on Earth, then these other objects would be added to the short list requiring stringent precautions for sample return. Missions sending hardware intended for return from potentially habitable targets are required stringently to limit contamination from Earth that could interfere with detecting extraterrestrial life, as well as all requirements appropriate to the particular outbound mission—these missions are also required to maintain an archive and detailed record of potential Earth contaminants and the provenance of samples collected, in a format that can be provided to a pre-return "Earth Safety" review process that will be carried out at international level (e.g., Haltigin et al. 2018; Kminek et al., 2018). AQ 4

Appropriate documentation on the return status of all missions also needs to be carried through whatever local/national approval processes apply to a re-entry event into the Earth's atmosphere.

12.5.2.3 International, National, and Agency-Level Obligations and Responsibilities

The current set of accepted international consensus guidelines on how to implement planetary protection is held by a permanent committee of the International Council for Science, the Committee on Space Research (COSPAR) (Kminek et al., 2017). The 1967 Outer Space Treaty, more accurately the "United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," is the major international agreement governing how treaty signatories ("States Parties to the Treaty") go about exploring and using outer space (United Nations [UN], 1966). This treaty has been signed by all countries involved or interested in space exploration, numbering over 100 and including North Korea (United Nations [UN], 2018).

The United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS) is the committee of the United Nations in which discussion of matters related to the treaty takes place. The UN-COPUOS, in its 60th meeting report to

AQ 5 the UN General Assembly in 2017, "*noted the long-standing role of COSPAR in maintaining the planetary protection policy as a reference standard for spacefaring nations and in guiding compliance with article IX of the Outer Space Treaty*" (United Nations Committee on the Peaceful Uses of Outer Space [UN-COPUOS], 2017). This recognition reiterates the role that COSPAR has played over the 60 years AQ 6 since its creation in 1957 (described below and reviewed in Meltzer, 2011).

States parties to the Outer Space Treaty, by signing and ratifying the document, agree to abide by all 17 treaty articles, including Article IX which reads, in part:

> "*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.*"

The COSPAR planetary protection policy addresses "*harmful contamination*" in the context of forward contamination and "*adverse changes in the environment of the earth resulting from the introduction of extraterrestrial matter*" in the context of backward contamination. As noted previously, other forms of contamination or environmental damage are not addressed by the COSPAR planetary protection policy or guidelines.

Other articles of the Outer Space Treaty impose additional obligations on States Parties to the treaty that are relevant to planetary protection. Article VI requires that:

> "*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.*"

Further, States Parties must assure that:

> "*The activities of non-governmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty.*"

In general, each State Party to the Outer Space Treaty has assigned the responsibility to ensure compliance with international planetary protection guidelines to their national space agency, which, in some cases, also requires cooperation with other national agencies that regulate activities within the Earth's atmosphere. In the case of the ESA, which is a regional organization with multiple national members, the responsibility of each State Party to ensure compliance with planetary protection policy and guidelines, for ESA missions in which they participate, has been transferred to ESA. Individual States Parties are also responsible for developing internal processes to provide the required "*authorization and continuing supervision*" of the actions of their non-governmental entities.

12.5.3 A BRIEF HISTORY OF PLANETARY PROTECTION

12.5.3.1 Early Concerns

Fictional accounts of interplanetary travel causing biological contamination, including ecological damage and pathogenicity (e.g., Wells, 1898), reflect historical experiences from European colonialism and the Columbian Expansion. For related historical reasons, "planetary quarantine" was the term used instead of "planetary protection" prior to the mid-1980s, but the practices and precedents are identical. Planetary protection as a practice began after World War II, with concerns expressed by scientists involved in organizing the 1957–1958 International Geophysical Year. In preparatory discussions, the international scientific community recognized that advances in rocketry would soon permit artificial satellites to be launched from Earth to the Earth's Moon and other planets. Concerns about potential biological contamination were first raised at the 7th International Astronautical Congress held in Rome, Italy, in September 1956 (Phillips, 1974; Meltzer, 2011). Both the United States (US) and the Soviet Union (USSR) announced plans to launch Earth-orbiting satellites for scientific research purposes, with the USSR launching two Sputnik satellites in 1957 and the US launching the Explorer and Vanguard satellites in 1958, as reviewed in Doyle and Skoog (2012).

Starting in 1958, with the formation of UN-COPUOS and COSPAR, as well as multiple national space agencies, extensive discussion of how to prevent biological contamination by planetary spacecraft took place in the international community, including Europe, the US, and the USSR, facilitated by interactions associated with the International Geophysical Year (e.g., Committee on Contamination by Extraterrestrial Exploration [CETEX], 1958, 1959). Within the US, the National Academy of Sciences (NAS) convened a working group known as the West Coast Committee on Extraterrestrial Exploration (WESTEX), chaired by Melvin Calvin and including Joshua Lederberg and the graduate student Carl Sagan, that supported the NAS' newly formed Space Science Board as well as COSPAR. Discussions held during WESTEX meetings, as documented in their final report and appendices (Space Science Board [SSB], 1959), addressed all the concerns of planetary protection that inform policy today, emphasizing both their historical basis and global scope.

Statements made in 1959 by this committee, on the topic of transporting extraterrestrial materials to Earth, are surprisingly pertinent in providing clarity to current debates:

> "*We know of many unhappy examples of biological competition from the introduction of new organisms into fresh niches—e.g., many insect pests in the US; rabbits and prickly pear in Australia, smallpox into the New World, and syphilis into Europe. Even the relatively limited damage of these incidents should not be duplicated as a byproduct of space research.*" (WESTEX Report, pg. 17)

"*Finally, it may be remarked that the task of evaluating the potential hazard of a planetary biota will be multiplied if this has to be isolated from organisms inadvertently transferred from Earth.*" (WESTEX Report, pg. 18)

12.5.3.2 Evolution of Planetary Protection Policy and Guidelines

During the late 1950s and early 1960s, frequent discussions were held in the international arena that informed the development of guidelines on how to respond to policy-level concerns about planetary contamination and potential consequences for scientific research and other human endeavors (reviewed in Phillips, 1974; Meltzer, 2011). The need for a risk-based approach that included the careful sterilization of spacecraft hardware was recognized very early, and methods for accomplishing this were proposed and evaluated (e.g., Space Science Board [SSB], 1959, 1964). Early missions implemented an approach based on a "probability of contamination" model, with information gained from each mission, leading to refinements in policy and guidelines over time.

In the 1980s, COSPAR accepted a conceptual shift in the formulation of planetary protection policy, moving from an explicit risk-based probabilistic approach to the "by exception" approach used today (COSPAR internal decision memo No. 7/84, accepting the proposals in DeVincenzi et al., 1983). This shift responded to accumulated scientific data, showing that most solar system objects were not contaminable by Earth life and, therefore, by inference, were also unlikely to host extraterrestrial life that could be biohazardous to the Earth. Four categories of possible outbound missions were described, as in Table 12.5.1, determined by the level of interest in the target object for understanding the origin and evolution of life and also the mission operations to be performed.

Missions to objects not of concern for understanding the origin and evolution of life are assigned Planetary Protection Category I, with no further documentation or other requirements. Missions to objects that do not provide natural habitats for Earth life but that could retain organic and prebiotic compounds of scientific interest are assigned Planetary Protection Category II, and limited documentation of mission operations is required—this includes the vast majority solar system objects. Missions to solar system objects that could provide habitats for Earth life—as noted previously and currently include Mars, Europa, and Enceladus—are assigned Planetary Protection Category III if hardware is not intended to contact the target object (flyby and orbiter missions) and assigned Planetary Protection Category IV if hardware is planned to contact the target (probe and lander missions). Because of the considerable interest in Mars as a target of human exploration beyond purely scientific investigations, and the more extensive information available about the planet, Planetary Protection Category IV landed missions to Mars are further divided on the basis of landing site and mission objectives, as described in the "future missions" section later.

In addition, a fifth category of "Earth Return" missions was established, recognizing explicitly the much higher priority placed on protecting the biosphere of the Earth than elsewhere, as noted in Table 12.5.1. This Earth Return category, Planetary Protection Category V, is divided into "Restricted" and "Unrestricted" Earth Return, determined by evaluating scientific data supporting the hypothesis that samples to be brought to Earth contain no extraterrestrial life, which is by definition considered biohazardous. For most solar system objects, this is accomplished by responding to the six questions listed in Table 12.5.2, about conditions on those objects and the natural influx of material to Earth.

When data are inconclusive or support the presence of possible habitats, as is true for Mars, Europa, and Enceladus, then a designation of Planetary Protection Category V "Restricted Earth Return" is given. Planetary Protection Category V "Restricted Earth Return" applies to all missions involved in a sample return effort—this is to ensure that information needed to support the pre-return Earth safety analysis and post-return biohazard test protocol is captured and retained by early outbound missions as well as the final return leg. Each mission carrying hardware intended for possible future return to Earth, including missions that emplace hardware possibly to be retrieved by future mission activities, also receives requirements appropriate to that particular orbiter or lander mission.

TABLE 12.5.1
Planetary Protection Mission Categories

	Planet Priority	Mission Type	Mission Category
A	Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
B	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
C	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 that could jeopardize a future biological experiment. Substantial documentation and mitigation are required.	Flyby, Orbiter Lander, Probe	III IV
All	Any solar system body	Earth Return "*Restricted*" or "*Unrestricted*"	V

TABLE 12.5.2
Six Questions for Restricted Earth Return

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO_2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)?
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life-forms?
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, for example, via meteorites, of material equivalent to a sample returned from the target body?

12.5.3.3 Planetary Protection Policy Applied to Early Programs

12.5.3.3.1 Soviet Decontamination Efforts

Soviet scientists were involved, from the earliest international discussions, in raising concerns relevant to planetary protection, and it was reported to the international community that early Soviet lunar missions did comply with the nascent guidelines being developed by COSPAR. These announcements had significant influence on decisions made within the US to ensure that early NASA missions would be decontaminated, as documented in a memo dated September 14, 1959, from the executive director of the SSB, Hugh Odishaw, to the first NASA Administrator T. Keith Glennan (Space Science Board [SSB], 1959, pg. 84), and also in the final report of WESTEX, which states: "*We applaud the respect for these considerations on the part of the USSR in the light of Academician Topchiev's announcement that Lunik-II has been decontaminated*." (Space Science Board [SSB], 1959, pg. 13)

Throughout the 1960s, it was reported in public that Soviet spacecraft sent to Mars and Venus had been "sterilized," but there was significant uncertainty in the West as to what this actually meant, as reviewed in Meltzer (2011). Questions were raised, in the international community, about the benefit of implementing stringent sterilization protocols on some spacecraft, if other spacecraft had already delivered Earth organisms to the same target—as if a single contamination event would render completely useless all subsequent efforts to limit additional contamination. This is a little like someone asking "Why should we keep brushing our teeth, after we've eaten our first candy-bar?"

12.5.3.3.2 Ranger

A number of NASA's early missions were managed by the Jet Propulsion Lab (JPL) in Pasadena, California, which, along with all other NASA facilities, was instructed to ensure appropriate sterilization of planetary spacecraft, in October 1959, following the recommendations from the SSB mentioned previously (see Hall, 1977 for details). Prior to this, JPL had established a program to develop methods for spacecraft sterilization, which presented a paper at the 10th International Astronautical Congress, containing the statement "*Sterilizing space probes is an engineering nuisance, however, the same ordeal has confronted surgical crews for quite some time. In both instances, anticipation of the task is necessary.*" (Davies and Comuntzis, 1959, included in Space Science Board [SSB], 1959). Paradoxically, at the same time, JPL also began designing a multi-purpose planetary spacecraft bus, called "Vega," that did not include any sterilization-tolerance requirements in the design constraints.

This design was adopted for use in the Ranger program in 1959, by which time it had already undergone considerable preliminary testing and refinement (Hall, 1977). In 1960, JPL staff proposed a sterilization protocol that involved subjecting components, subsystems, and the assembled spacecraft system to 125°C before shipment to the launch site, with a final ethylene oxide gas treatment applied at the launch site to eliminate organisms that might have recontaminated spacecraft surfaces during transport and launch preparations. Despite the plan to apply a system-level heat treatment, design constraints for the Ranger program, including those provided to subcontractors and instrument contributors, did not include heat tolerance among the requirements, and very little testing was done, during development of Ranger spacecraft hardware, to evaluate the tolerances of spacecraft components and subsystems to heat treatment.

Despite the October 1959 memo requiring spacecraft sterilization, and associated 1960 protocol, only a few of the components selected for the Ranger spacecraft, and none of the early engineering or flight models, were tested for compatibility with heat sterilization treatment. The first hardware to undergo a heat sterilization protocol was the flight model of the first lander spacecraft, Ranger 3. Multiple materials' incompatibilities and failed components were identified during subsequent testing, which required extensive re-work. At the time, JPL reported "*Although no failures are directly traceable to heat damage, it is felt that heat sterilization does shorten the expected life of electronic components*" (Hall, 1977, pg. 124). Today, military specifications for high-reliability hardware require an operational high-temperature burn-in phase, to eliminate defective components at risk for early failure (MIL-STD-810G, 2008).

After the launch of Ranger 3, which included a prelaunch ethylene oxide gas treatment (tolerance to which was also not mentioned in design constraints), the spacecraft "performed flawlessly" (Hall, 1977, pg. 147), but incorrect commands transmitted from ground control caused the spacecraft to lose contact, without accomplishing any mission objectives other than impact on the Moon. Despite this successful performance, the reaction from Ranger project managers was to attribute the failure to heat sterilization (Hall, 1977, pg. 125):

> "*Although lacking firm evidence that this requirement caused the equipment failures, JPL now requested and received more waivers from NASA Headquarters on heat sterilizing certain crucial components.*"

Rangers 4 and 5 underwent only partial heat sterilization treatments, though they were subjected to pre-launch ethylene oxide gas because this was not considered a risk to spacecraft hardware—yet both missions were unsuccessful, with failures in spacecraft bus control systems despite electronic components having been exempted from heat treatment.

In 1962, after the failure of Ranger 5, the program was extensively reorganized, with new management and a much-strengthened quality-assurance program, and the program received approval to cease all sterilization treatments. In 1963, a few months prior to the planned launch of Ranger 6, it was discovered that a particular type of diode, used by the hundreds throughout each of the Ranger spacecraft, was often defective and susceptible to shorting in microgravity, "*with potentially disastrous consequences*" (Hall, 1977, pg 197). Potentially defective components were replaced extensively in Rangers 6 through 9, with much better quality control on the replacements—even so, the cameras on the Ranger 6 spacecraft did not function, though the rest of the mission was accomplished successfully. Rangers 7, 8, and 9 were considered to be fully successful and returned imagery that was of considerable interested to both the scientific community and the general public, as well as useful to the Apollo program for landing site selection.

The Ranger program was instrumental in establishing processes in space mission formulation that balance scientific and engineering concerns, as well as quality-control programs and interfaces for project management, that have subsequently become widely implemented on NASA's robotic missions. The influence of the Ranger program on the development (or lack thereof) of standard approaches for spacecraft sterilization is not so well recognized but is still considerable.

12.5.3.3.3 Apollo

The Apollo program remains the most complex effort in space exploration attempted prior to 2018, involving astronauts landing on another planetary body and returning to Earth with samples, as well as both samples and astronauts being subject to isolating containment and analytical and biohazard testing after return to Earth. Apollo was, applying current planetary protection policy, a Planetary Protection Category V Restricted Earth Return campaign, including all the additional health and safety concerns associated with human spaceflight. The history of the Apollo program has been covered extensively elsewhere (e.g., Launius, 1994), so only two aspects of the Apollo program are mentioned here, as being of particular relevance to planetary protection.

In the words of US President Kennedy, the Apollo program was established for "landing a man on the moon and returning him safely to earth"—more for purposes of political and technological positioning than for scientific investigation (Launius, 1994). Even before the inception of the Apollo program, it was understood that the return of astronauts and extraterrestrial materials back to Earth had the potential to introduce extraterrestrial biohazards, as reviewed previously and by Meltzer (2011), and the US Government recognized that these risks needed to be controlled. In 1963, after questions were asked about backward contamination in Congress (Meltzer 2011), President Kennedy signed National Security Action Memo 235, on "*Large-Scale Scientific or Technological Experiments with Possible Adverse Environmental Effects*" (JFK Library, 1993), which established a process that required presidential approval prior to conducting any such experiments, in consultation with the NAS and other relevant federal agencies (e.g., the State Department). In particular:

> "*Experiments which by their nature could result in domestic or foreign allegations that they might have such effects will be included in this category even though the sponsoring agency feels confident that such allegations would in fact prove to be unfounded.*"

and

> "*international scientific bodies or intergovernmental organizations may be consulted in the case of those experiments that might have adverse environmental effects beyond the U.S.*"

This memo, declassified in 1993, was applicable both to US nuclear testing activities and to the Apollo program.

Following public expressions of concern about backward contamination, NASA consulted with the US Public Health Service, which assigned a liaison officer to support the development of a "quarantine" program. This resulted in the formation of an "Interagency Committee on Back Contamination" (ICBC), chartered to provide oversight of both astronaut quarantine and curation of lunar materials. The committee included the three US regulatory agencies covering public health, agriculture, and the environment, as well as two additional "interested agencies": the NAS and NASA. A formal interagency agreement was established that required high-level interagency consultation prior to acting on any decision that was not "*in accordance with the unanimous recommendation of the agencies represented on the Interagency Committee on Back Contamination*." NASA is not a regulatory agency, so this structure ensured that the regulatory agencies would exert effective oversight, even though over half the individual members of the ICBC were NASA staff (Radley and Rosen, 1969).

The interagency coordination framework that was established during the Apollo program, which was founded on the best-available scientific advice and included the regulatory agencies responsible for ensuring the health and safety of humans, animals, and agricultural activities, and the wider environment, was sound. In practice, the ICBC did perform oversight of the Apollo program's sample return activities and issued determinations regarding astronaut quarantine and biohazard testing of lunar materials, including termination of the quarantine program after Apollo 14. However, it was very fortunate that lunar samples, in fact, are not biohazardous to astronauts or the Earth, because the implementation of quarantine measures during the Apollo program would not have been adequate to prevent release. Reluctance on the part of those responsible for implementing the program was motivated by disputes over jurisdiction and authority, cost concerns, and a rather widespread perception within the space exploration community that precautions were unnecessary, as reviewed in Meltzer (2011). Many very valuable lessons can be learned from the Apollo program, both on practices that were surprisingly foresighted, and should be replicated, and on aspects of sample return and post-return operations that would benefit from improvement.

One rather famous example, which would be good not to repeat, involves biological analyses performed on the Surveyor 3 camera, which were claimed to show survival of Earth organisms after traveling round trip to the Moon (Rummel et al., 2011). The Surveyor robotic mission landed on the Moon in 1967 and was not subject to decontamination procedures for planetary protection. The Apollo 12 mission landed near the Surveyor 3 site in 1969, and astronauts collected hardware from the Surveyor 3 lander spacecraft, including a camera, for return to Earth. The Apollo 12 astronauts and other lunar samples that had been collected were subject to quarantine and containment procedures; in contrast, the camera from Surveyor 3 was placed in a laminar flow hood and subjected to biological sampling. The organism *Streptococcus mitis*, commonly found in the human respiratory tract and rapidly killed by desiccation, was the only organism isolated from the camera and was found in only one sample collected very late in the sampling period. The sampling process was filmed, and these films document that the "sterile technique" practices used by the technicians collecting samples would not, today, be considered adequate to maintain sterile culture conditions. In addition, a photographer leaned into the hood and took close-up still images, just prior to biological sampling, of the location on the Surveyor 3 camera, from which the *S. mitis* organism was collected. The appearance of *S. mitis* in cultures from the Surveyor 3 camera prompted a review, during which the Surveyor 3 spacecraft engineering model was found possibly to have been contaminated by *S. mitis*. Following this observation, it was concluded that the organism collected after return must have survived the round-trip travel between the Earth and the Moon, including years of exposure on the lunar surface.

Several logical fallacies, of concern to planetary protection, can be identified in this procession of events, which would be better avoided in the future. First, given that lunar quarantine procedures were supposed to be in place, how is it that the Surveyor 3 camera was sampled in what was effectively a shirt-sleeve environment, with a photographer present in street clothes rather than within containment? Second, the conclusion that a desiccation-sensitive organism must have survived several years of exposure to hard vacuum should have required some additional supporting data beyond the merely
AQ 7 circumstantial—the principle "Extraordinary claims require extraordinary evidence" does apply. Finally, the collection of unsterilized hardware by astronauts, who are subject to quarantine, adds the risk that they could be exposed to pathogenic Earth organisms from the collected hardware, possibly invalidating the purpose of a quarantine altogether. *Streptococcus mitis*, though mostly harmless, is a facultative human pathogen that can cause infective endocarditis—which was not, in the 1960s, an easy disease to diagnose. The trajectory of the Apollo program, and the future of human spaceflight, might have been quite different if, during quarantine, the Apollo 12 astronauts had come down with fever, bruising, exhaustion, stroke, and possibly heart or kidney failure.

12.5.3.3.4 Viking

If one early robotic exploration program stands out from all others for effective planetary protection compliance, that is the Viking program, which in the 1970s sent NASA's first lander missions to Mars (Daspit et al., 1988). The Viking program was managed by NASA Langley Spaceflight Center in Virginia, with prime contractor support from the Martin Marietta Corporation, and the lander spacecraft carried scientific instruments contributed by several academic institutions as well as other US government facilities. Each of the two Viking landers was transported to Mars by a Viking orbiter spacecraft, which carried replicate sets of scientific experiments. The two Viking landers returned the first meteorological, physical, and seismological measurements, as well as performed both metabolism- and chemistry-based life detection experiments, from two locations on the surface of Mars (Ezell and Ezell, 1984).

The Viking landers carried a suite of instruments designed to detect chemical constituents of possible Martian organisms, as well as metabolic indicators of possible Mars life. Both of these instrument payloads received cleanliness requirements that were more stringent than the rest of the Viking lander spacecraft (Daspit et al., 1988), to protect the integrity of the scientific results obtained from them. The chemistry-based experiment utilized a gas chromatograph-mass spectrometer (GC-MS) instrument to measure gases that evolved as Martian regolith was heated, results from which were interpreted at the time to indicate the presence of cleaning fluids used before launch from Earth. However, in 2017, it was reported that low-abundance peaks from the Viking GC-MS data indicate the presence of compounds, in the Viking samples, that were definitively identified by the Curiosity rover's Sample Analysis at Mars instrument as being Martian in origin (e.g., Glavin et al., 2013; Freissinet et al., 2015). The metabolic experiments included several culture cells that provided conditions predicted to support growth of Martian organisms, as well as the ability to heat samples of Mars regolith to temperatures expected to inactivate any organisms, as discussed in DiGregorio et al. (1997). The results from this suite of experiments, known as the "Life Detection Package," definitely detected heat-labile chemical reactivity but were inconclusive as to whether this was consistent with biological metabolism. At the time, because the GS-MS instrument data were interpreted to indicate the absence of organic material in the regolith samples,

the Viking results were interpreted as a failure to detecting Mars life, although this interpretation has subsequently been
AQ 8 questioned (e.g., Navarro-Gonzalez et al., 2006).

The Viking program undertook the most stringent implementation of planetary protection requirements ever attempted, involving component or subsystem-level heat treatment to reduce microbial populations present inside the items or materials; careful cleaning of hardware surfaces to reduce the levels of heat-resistant microbes to fewer than 300 per square meter of spacecraft surface; packaging of the entire assembled lander and heatshield into a "bioshield" that was overpressured through launch, to prevent recontamination after heat microbial reduction; and finally, shortly prior to launch, a full-system heat microbial reduction treatment of the lander spacecraft inside the bioshield for over 40 hours at 112°C, which was demonstrated to reduce the levels of viable microbial contamination on lander surfaces by four orders of magnitude. The key to the successful implementation of this effort was the complete acceptance of planetary protection requirements on the part of project staff, including the Project Manager James Martin and the Project Scientist Gerald Soffen, both at NASA Langley, with strong support from program staff at NASA Headquarters (Daspit et al., 1988).

From the very beginning of the program, planetary protection requirements were fully captured in the design constraints for the landed hardware and integrated with controls on approved parts and materials, as well as testing, assembly, and operational procedures, that were followed by almost all
AQ 9 hardware contributors (see below). Viking Program staff at Langley were well-educated about planetary protection, having consulted with members of WESTEX, and studied heat-sterilization of hardware since 1964 (Ezell and Ezell, 1984) as well as attended meetings of the planetary protection advisory committee for several years prior to the start of the program in 1969 (Daspit et al., 1988). Although questions were raised about the need for heat microbial reduction prior to the start of the Viking program, once that was confirmed, on the basis of life-detection science contamination concerns as well as international policy considerations, planetary protection was managed as just another element required for project success.

From the start, it was recognized that electronic components and other spacecraft materials were not necessarily pre-qualified to tolerate temperatures planned for the final system-level heat microbial reduction, so the majority of parts and materials was acquired and tested in bulk. Issues related to heat treatments appeared on the project manager's "Top 10 Concerns" lists early during the program (Ezell and Ezell, 1984), but all of these were retired, by appropriate qualification, substitution, or process modification, by mid-1972, prior to the assembly of spacecraft hardware. During hardware assembly, an extensive model testing program was carried out; it included evaluation of heat tolerance, starting with smaller and then larger subsystems and continuing with full lander system qualification models. No significant issues were found after both of the flight systems underwent the full-system heat microbial reduction, validating the general assessment by Viking managers that the testing and qualification program significantly reduced risk and increased the reliability of the spacecraft (Daspit et al., 1988).

It is certainly true that the Viking requirement for heat tolerance required extensive component testing and replacement of susceptible parts and materials in heritage hardware, which might appear to increase program cost. However, multiple Viking managers observe that the bulk purchases and extensive testing program also had cost benefits, in reducing the need to evaluate components case by case, and then re-work
subsystems after they failed. For new hardware subsystems, AQ 10
requirements for heat tolerance could be addressed during the design phases and if done well should not have increased cost significantly, beyond the difference in component prices (Daspit et al., 1988). When these design constraints were not addressed adequately, both cost and schedule slips were the result, as demonstrated for the camera system originally con-
tracted to the company TRW (Ezell and Ezell, 1984). AQ 11

In the case of the GC-MS instrument, that was contributed by JPL, heat-tolerance requirements were not addressed effectively during the design phases, and a number of problems with this instrument were reported. The GC-MS instrument on the Viking 2 lander, which was located at higher latitude and therefore experienced greater thermal cycling, failed during the extended mission phase, with one engineer on that team attributing the problem to weaknesses induced by the pre-launch full-system heat microbial reduction. However, other Viking managers noted that the GC-MS team was reluctant to accept the heat-tolerance requirements, to a greater extent than other hardware providers (see Daspit et al., 1988). It is possible that this reluctance on the part of some JPL engineers to embrace heat sterilization is influenced by corporate memory of the Ranger program discussed previously.

It is sometimes claimed that planetary protection required 10% of the total Viking program budget, with an implication that this is an unreasonable cost for a mission that both protects the target of exploration and performs experiments searching for extraterrestrial life (e.g., Fairén et al. 2018). However, as described previously, it is not actually possible to pull out a subset of the Viking expenditures and label it as "planetary protection," because implementation was so completely integrated into overall project management. It is more relevant, for students of astrobiology, to understand that the total Viking program budget was about $1 billion, in 1975 dollars, with the Life Detection Package costing $59 million and the GC-MS costing $41 million (Ezell and Ezell, 1984). These actual costs demonstrate that the two instruments on Viking, addressing research of the greatest interest to astrobiology, together cost 20% of the total program budget—including all the effort to establish how to accomplish full-system heat microbial reduction and other associated cleaning processes. More recent estimates of the cost to retrofit a modern Mars rover for full-system heat microbial reduction, done independently by ESA and NASA, suggest that this cost has remained at the equivalent of one major science instrument (e.g., Rummel and Conley, 2018). Whether the equivalent of one science instrument is a reasonable cost to answer key research questions in astrobiology is an important advocacy question for the astrobiology community to address.

It is a consistent conclusion among people involved in the Viking program that the requirements for full-system heat microbial reduction provided significant benefits to the reliability and success of the missions and was not as difficult to implement as initially anticipated. The most important lesson to learn from historical missions, for planetary protection in the future, was summarized very well by the Viking Project Manager, James Martin (quoted in Daspit et al., 1988):

> "*There are many young people at JPL and elsewhere working on these problems, and they are so enthused by the technologies they're working on that they don't realize the extent of the impact PP and Contamination control requirements can have or how that impact can enlarge as a problem the longer it is neglected. The PP requirements should be expressed in a more forthright and regulatory sense, so that people aren't allowed to forget about it until five or ten years from now when they suddenly discover that 'you really can't make a widget that you can heat.*'"

12.5.4 APPLICATION TO MISSIONS IN PREPARATION

12.5.4.1 Outer Planets Missions

12.5.4.1.1 Probability of Contamination

It has been suggested that the greatest volume of environments providing conditions suitable for the growth of microbial life from Earth could be in the outer solar system, in the form of subsurface liquid water within the moons of the giant planets, and also any water that might remain liquid in the interiors of Kuiper Belt objects. Such habitable environments are of concern for planetary protection, to the extent that the probability of introducing a single viable Earth organism into a liquid water environment must be held lower than 1×10^{-4} per mission, which applies to both lander and orbiter/flyby missions and must take into account spacecraft and operational reliability. Fortunately for mission planners, it is thought to be extremely difficult to access potential liquid water volumes within the vast majority of objects in the outer solar system: a recent analysis of Ganymede, which is the object currently considered to have the most-accessible water after Europa and Enceladus, suggested that viable Earth organisms deposited on the surface would have a probability much lower than 1×10^{-4} of reaching subsurface liquid water (Grasset et al., 2013).

For this reason, missions that would not encounter Europa or Enceladus receive no *a priori* restrictions on hardware cleanliness, for planetary protection; rather, these missions are required to ensure, by careful operation of the spacecraft, that any liquid water bodies discovered during the mission are not contacted by spacecraft hardware, even after the mission ends. This requirement was applied, in the past, to the missions that discovered potential habitats within Europa and Enceladus: the Galileo spacecraft was de-orbited into Jupiter, and the Cassini spacecraft was de-orbited into Saturn, in order to protect the newly discovered watery moons of those planets. The Juno mission to Jupiter, which will not encounter Europa during the prime mission, plans to dispose the spacecraft into Jupiter—but they also performed calculations to show that, should the deorbit maneuver fail and the inactive Juno spacecraft impact Europa at some point in the future, the impact energy would be so high as to incinerate all remaining viable organisms, in a sufficiently high fraction of the total impact cases in Monte Carlo simulations that the $<1 \times 10^{-4}$ probability requirement was met (Bernard et al., 2013).

12.5.4.1.2 Cleanliness and Life Detection

The detection of extraterrestrial life is of relevance to planetary protection because extraterrestrial organisms are by definition considered biohazards: this is based on long experience from Earth that introduced species can become invasive or pathogenic. For this reason, outbound-only missions to outer solar system objects that carry life detection investigations do not receive additional cleanliness requirements from planetary protection on the basis of instrument capabilities, beyond the 1×10^{-4} probability of contaminating liquid water and potential habitats.

In contrast, additional organic and biological cleanliness requirements will be imposed on sample return missions from potentially habitable environments in the outer solar system (currently Enceladus or Europa), to ensure adequate levels of confidence in the results of the post-return biohazard test protocol. During the Apollo program, sample collection hardware was carefully cleaned and samples were (in principle) quarantined until a biohazard test protocol had been completed. Subsequent to Apollo, a notional "Draft Test Protocol for Detecting Biohazards" has been established (Rummel et al., 2002), during the course of multiple rounds of studies preparing for missions that would collect samples and return from Mars. This draft test protocol requires additional refinement (e.g., Kminek et al., 2014), to establish requirements on the level of statistical confidence needed to make a determination that extraterrestrial samples are "safe for release"—which is a risk assessment that needs to be made at a global societal level, not solely by space scientists or space agency staff (e.g., Haltigin et al., 2018). Confidence that the test protocol is not generating false-negative results would, of course, be reduced in proportion to the amount of Earth contamination present in collected samples, and it depends on the capabilities of instruments used to make measurements.

The development of biohazard test protocols and associated contamination requirements is ongoing.

12.5.4.2 Mars Missions

12.5.4.2.1 Planetary Protection Requirements for Mars: It's Complicated

The planet Mars has been explored more extensively than any planet in the solar system other than Earth; likewise, Mars is also the focus of a wider diversity of human interests. From the earliest discussions of Mars exploration, the potential for future human colonization/settlement and the possibility of terraforming Mars were taken seriously, and the potential for biological contamination from Earth to interfere with these long-term goals was recognized (e.g., Space Science Board

[SSB], 1958). In response to the rapidly increasing scientific information about Mars and recognizing the diversity of short-term and long-term goals in Mars exploration, planetary protection requirements for Mars have undergone more discussion and refinement than those for any other target of exploration.

Spacecraft and hardware not intended to impact Mars are allowed to meet planetary protection requirements by avoiding impact onto Mars. Launched hardware items that were not maintained in a controlled clean environment—e.g., the upper stages of launch vehicles—are required to avoid impact onto Mars, for a period of 50 years after launch, at a probability of 1×10^{-4}. It is preferred that spacecraft intended to orbit or flyby Mars should also avoid Mars impact for a period of 50 years, though with a relaxed probabilistic constraint—this involves no greater cleanliness than assembly in controlled environments typical for spaceflight hardware assembly. If, however, impact avoidance is not feasible for orbiter spacecraft, due, for example, to aerobraking, then orbiter missions may demonstrate that they deliver no more organisms to Mars than are permitted on landed hardware that is expected to break open on impact.

Current planetary protection requirements for the cleanliness of hardware landing on Mars depend both on where the hardware is intended to land and on the purpose of the hardware. The Viking program imposed additional cleanliness requirements on some hardware, to ensure the integrity of the life detection experiments by removing contamination from Earth that could interfere with the detection of signals from Mars. No indications were observed of Earth organisms being present, so the terminal heat microbial reduction and additional cleaning of the Life Detection Package did accomplish the goal of eliminating Earth life. However, despite the program's best efforts, signals interpreted as Earth contaminants were the most abundant compounds measured by the Viking GC-MS instruments. At the time, it was assumed that these Earth contaminants were the only compounds present and that no organics from Mars had been detected (e.g., Space Science Board [SSB], 1977). Because the Viking landers were not collecting Mars samples for return to Earth, this interpretation did not put in jeopardy the safety of the Earth, which is of paramount importance to planetary protection.

12.5.4.2.2 "Average" Mars

After the Viking program demonstrated that most of the Martian surface is cold and dry, providing very limited resources that could support Earth life, cleanliness requirements for Mars landers were relaxed, to eliminate the four-order-of-magnitude heat-reduction step and protection from recontamination implemented on Viking (DeVincenzi et al., 1996). This basic level of cleanliness is required for all Mars missions, and missions receive a designation of Planetary Protection Category IVa if they do not carry life detection instruments or plan operations to access more-habitable locations on Mars.

Before the terminal full-system heat reduction, the Viking landers had been cleaned to 300 heat-resistant organisms per square meter of spacecraft surface over about 1000 square meters of area and also carried approximately 200,000 heat-resistant organisms in the interior of the spacecraft. The number of heat-susceptible organisms was not measured as part of the requirement, because any heat treatment that killed resistant organisms would eliminate susceptible organisms at a much higher rate. These relaxed requirements of less than 300 heat-resistant organisms per square meter, less than 300,000 heat-resistant organisms over all surfaces exposed to the environment of Mars, and less than 500,000 heat-resistant organisms in total (this includes organisms inside hardware that could break open on impact, such as heat shields, backshells, and parachutes), are necessary to meet Planetary Protection Category IVa.

12.5.4.2.3 Special Regions on Mars

Following orbital observations in the 2000s that confirmed the presence of active gully systems and water ice in the near-subsurface of Mars, the Viking requirement for four-log microbial reduction with recontamination prevention was reinstated for missions targeting locations on Mars where environmental conditions have the potential to provide, at least transiently, temperatures and available water that could support growth of Earth life. So-called Mars Special Regions are, as of 2017, defined as locations where temperatures reach above −28°C and "water activity" (1/relative humidity) reaches above 0.5 (equivalent to 50% relative humidity). These regions include features on Mars where the presence of such conditions is in question (Kminek et al., 2017). Each project planning a landed mission to Mars is required to do an analysis of their proposed landing sites, to establish whether Special Regions might be present: only if Special Regions are not within a landing ellipse that includes 3 standard deviations of targeting error after parachute opening (3-sigma) would a project be designated Planetary Protection Category IVa. Missions that do target areas with potential Special Regions inside the 3-sigma landing ellipse are designated Planetary Protection Category IVc and are required to use microbial reduction processes and recontamination prevention to achieve Viking-equivalent cleanliness of <0.03 viable Earth organisms per square meter of exposed spacecraft surface. Missions intended to access Special Regions outside the landing ellipse are required to clean at least the subsystems used for such access to Viking-equivalent levels and protect them from recontamination by other spacecraft hardware.

It is relevant to note that the definition of Special Regions, originally adopted in the mid-2000s, does not follow historical precedent in setting conservative limits on parameters of concern to planetary protection, with room for subsequent relaxation: in the 2010s, the temperature limit for Special Regions had to be reduced from −25°C to −28°C, after additional data on the capabilities of Earth organisms were obtained.

12.5.4.2.4 Mars Life Detection

The highest concern for planetary protection is to avoid "harmful contamination" of the environment of the Earth, which includes imposing appropriate constraints on future round-trip missions, robotic and human. In this context, false-negative results from in situ experiments to detect Mars life are of considerable concern, because future requirements would be set based on an incorrect assessment of potential risk. One example of the consequences of false-negative results is that Mars exploration was put on hold for 20 years because “Viking had shown there were no organics” (Space Science Board [SSB], 1977)—yet recent data from the SAM AQ 12 instrument informed a re-evaluation of Viking data, which identified Martian organic compounds not recognized previously (e.g., Glavin et al., 2013; Freissinet et al., 2015).

Missions to Mars that carry instruments capable of detecting Mars “*life forms, precursors, and remnants*,” in the language of the COSPAR policy (Kminek et al., 2017) automatically also are capable of detecting biological and organic contamination from Earth and receive a separate designation of Planetary Protection Category IVb. To address the greater policy-level concern about Mars life (by definition considered biohazardous) being brought to Earth, life detection missions are required, in addition to landing site constraints, to ensure that hardware subsystems with a potential to contaminate the life detection experiments meet the equivalent of the Viking lander overall requirements: cleaned to 300 resistant organisms per square meter of surface area, protected from recontamination, and reduced by four orders of magnitude. As noted previously and in histories of the Viking Program, this level of cleanliness is less than what was required for the Viking GC-MS and Life Detection Package, which was set based on the scientific objectives of those instrument (Daspit et al., 1988). Currently, rather than setting specific numerical limits on non-viable Earth contamination, planetary protection policy specifies that such requirements be set “*driven by the nature and sensitivity of the particular life detection experiments*” (Kminek et al., 2017), with the expectation that appropriate limits would be established by the instrument teams and project management during payload selection and accommodation, and subsequently monitored for compliance, along with all other planetary protection requirements. This is an effective approach for *in situ* experiments, but when samples are returned to Earth, additional considerations pertain.

12.5.4.2.5 Mars Sample Return

Mars is of astrobiological interest as a potential habitat for extraterrestrial life and therefore has the potential to host life that is, by definition, considered potentially biohazardous to the Earth. For this reason, missions planned to collect samples from Mars and bring them to Earth receive the designation “Planetary Protection Category V Restricted Earth Return,” which means that spacecraft hardware must be cleaned to levels that will ensure that Earth contamination is not introduced into Mars samples in quantities that could invalidate the biohazard test protocol that will be performed after return to Earth (e.g., Haltigin, 2018). This is in addition to meeting all requirements appropriate for mission operations at Mars, as well as ensuring that documentation of potential contamination is collected and provided for pre-return Earth Safety analyses and reviews. During the return phase of the mission, samples are required to be contained, so as to ensure a probability of less than 1×10^{-6} that a particle greater than 10 nanometers in size is released into the environment of the Earth, including particles adhering to spacecraft surfaces, as discussed in Haltigin (2018). In the special case of sample return from one of the moons of Mars, additional calculations would be needed to assess the amount of material from Mars present in the collected samples, due to recent impact ejection events, such as the 60-km Mojave impact crater (Chappaz et al., 2013).

After Mars samples have landed on Earth, it is required to contain them at levels equivalent to the strictest biosafety level (BSL-4/P-4, used for, e.g., ebola virus) and also protect them from Earth contamination while early analyses and the biohazard test protocol are performed (Rummel et al., 2002). This is required to ensure that the risk to the Earth from retaining Mars samples is acceptably low. For Restricted Earth Return missions, “acceptably low” is a regulatory determination that has not yet been fully developed—currently, there is a containment requirement but not a biohazard test confidence requirement. Containment procedures are required to ensure that the risk of releasing extraterrestrial material into the Earth’s environment is kept under one in a million, which was recommended based on comparison with other risks that human societies accept (European Science Foundation [ESF], 2012).

12.5.4.3 Human Missions

Human missions to other planetary targets almost invariably involve a return trip to Earth—as such, they would receive requirements equivalent to Planetary Protection Category V. Current planetary protection policy includes guidelines for human missions that focus predominantly on forward contamination. Protection of the Earth must be ensured, but specific practices to accomplish this have not been established—the Apollo program provides useful precedent in some areas and cautionary experience in others.

As with robotic missions, planetary protection concerns for human missions are divided conceptually by “habitable” vs. “non-habitable” targets: when humans explore non-habitable targets, neither contamination of the astronauts or the Earth nor contamination of the target by Earth life is relevant. Mars is the only feasible target for human exploration that is considered as potentially hosting native extraterrestrial life and is potentially “habitable” for Earth microbes; thus, human missions to Mars have received the most policy-level consideration (e.g., Space Studies Board [SSB], 2002; Conley and Rummel, 2010; Kminek et al., 2017; Haltigin et al., 2018).

It is recognized that human missions are unlikely to be fully contained; thus, provisions must be made to address contamination of astronauts by Mars material, as well as contamination of Mars by Earth microbes. By analogy, with the requirements for Special Regions, approaches have been proposed for early human missions that involve allowing a greater level of contamination in areas where humans travel, while protecting Special Regions to currently required levels. The degree of separation needed would be based on the technical capabilities of the hardware and human support systems, which currently are not well-established. As is routine for planetary protection, the collection of additional scientific information may lead to relaxation of requirements, once it is demonstrated that the initial level of stringency is not needed.

Two additional factors pertain to the human exploration of Mars, which are not currently covered in planetary protection policy—yet these issues will need to be addressed at a policy level, before such events occur that require a response from the global society. The first question is the extent to which the environment of Mars might be toxic to astronauts or Earth microbes, in the absence of a Mars biota—this needs to be understood in order to assess the potential for false-positive indications of biohazards in samples from Mars. Measurements made on Mars suggest that the dust contains ~1 weight-percent of oxy-chlorine compounds, which are known to be toxic to humans and some Earth microbes. An understanding of the potential toxicity of Mars dust may be important to assess overall risk of human missions to Mars and to provide information both to the astronauts performing missions and to the societies that pay for them.

The second question, which is explicitly excluded from planetary protection policy but still needs to be addressed, is the extent to which Earth microbes could change during spaceflight, resulting in increased biohazard after they return to Earth. This issue was raised by the NASA Advisory Council but has not yet received significant attention, despite experiments from the International Space Station that seem to indicate increased virulence in *Salmonella* grown in microgravity (Sarker et al. 2010).

Societal perception and acceptance of these risks will be greatly facilitated by providing accurate and complete information, starting as early as possible in the process of mission development.

12.5.5 OPEN ISSUES IN INTERNATIONAL POLICY

12.5.5.1 Relationship of International Policy to National Obligations

The 1967 Outer Space Treaty, by its title, provides for "*the Exploration and Use of Outer Space*," and planetary protection guidelines, although maintained by the scientific organization COSPAR, also apply more broadly than just scientific exploration. Whether the COSPAR guidelines represent legally binding "customary law" has not yet been tested in court, although their recognition in 2017 by UN-COPUOS as a "*long-standing... reference standard... in guiding compliance with article IX of the Outer Space Treaty*" could strengthen that case. All the major international agreements on space exploration have elements that support planetary protection practices (Achilleas and Crapart, 2003), with the state responsible for space objects also being responsible for mitigating "*harmful contamination*" caused by them. In addition, the international framework of environmental law, although focused on terrestrial activities, includes language that could reasonably be extended to backward contamination brought to Earth by sample return missions (Achilleas and Crapart, 2003). In addition, the 1992 Convention on Biological Diversity, Article 3, states the principle that states have "*the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction*." Whether such areas extend beyond the environment of the Earth has again not yet been tested in court, but it has been suggested that a plausible case could be made (Achilleas and Crapart, 2003).

Supporting these international obligations, some countries also have national laws that address environmental protection aspects of space activities. For example, the Russian Federation, in Decree No. 5663-1, states the principle of "*provision of safety in space activity, including protection of the environment;*" and prohibits actions "*to create harmful contamination of outer space which leads to unfavourable changes of the environment,*" (UNOOSA, retrieved 2018). Although the US has not yet passed legislation addressing planetary protection, several sections of the Code of Federal Regulations describe the applicability of the National Environmental Protection Act to Earth Return missions. In addition, the 1975 Presidential Directive that superseded the Apollo-era NSAM-235, PD/NSC-25 on "*Scientific or Technological Experiments with Possible Large-scale Adverse Environmental Effects and Launch of Nuclear Systems into Space*" specifies a consultation process that would need to be followed prior to implementing a Category V Restricted Earth Return Mission.

12.5.5.2 Application of Planetary Protection Guidelines to Commercial Missions

It is only recently that non-governmental entities have developed capabilities to engage in activities of concern for planetary protection, and the mechanisms for ensuring "*authorization and continuing supervision*" (UN, 1967) of private space exploration are still under development. Within the US, the commercial launch approval process overseen by the Federal Aviation Administration requires consultation with the State Department and NASA, and planetary protection compliance for commercial launches has been addressed. Other countries may have more straightforward internal structures for establishing legal and/or regulatory frameworks for commercial space exploration.

With the increasing interest and activity in private space exploration, and considering the potential for global negative consequences due to the release of a hazardous extraterrestrial entity, formal processes, both nationally and internationally, will undoubtedly be needed. Although planetary protection is the aspect of commercial space exploration with the broadest potential consequences, the establishment of an appropriate regulatory framework for commercial space activities is an issue that extends far beyond planetary protection. For example: if one commercial entity identifies a valuable target and another entity succeeds in reaching the same target more rapidly, how will rights and responsibilities for use of that target be determined?

12.5.5.3 International Concerns Around Restricted Earth Return

Over the past decade, the iMARS Working Group, chartered by the International Mars Exploration Working Group, has explored requirements for Mars Sample Return and made considerable progress on developing an architecture for handling Mars samples brought to Earth (Haltigin et al., 2018). The major concern for backward contamination is to prevent release of extraterrestrial organisms over the entire time for which extraterrestrial material is stored on Earth, thus the precautions taken involve two steps (e.g., Rummel et al, 2002; Kminek et al., 2014). First, the hardware returning to Earth must be carefully designed to reduce the risk of accidental breach to an acceptably low level, until the hardware is placed in a properly designed containment facility. In addition, the samples brought to Earth must undergo careful testing for possible extraterrestrial life, which is, by definition, considered biohazardous. This "Biohazard Test Protocol" must be performed early during the post-return sample analysis period, to minimize the risk of accidental release due to failures in containment. To ensure that the test protocol can detect extraterrestrial biology with high sensitivity, hardware used to collect extraterrestrial samples must be carefully cleaned of Earth contamination, and information retained about the potential for contamination to introduced from the earliest mission phases. This set of requirements was recommended during the US Apollo program, to minimize the potential for "false negative" results due to the masking low levels of extraterrestrial biosignatures by higher levels of Earth contamination (e.g., Space Science Board [SSB] 1964).

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The most significant long-lasting consequence of space exploration for human society and the environment of the Earth would be backward contamination, the release of a novel extraterrestrial entity that has adverse effects—this was recognized as a potential problem in the 1950s and is explicitly prohibited by Article IX of the Outer Space Treaty (UN, 1967). It has been recommended that COSPAR guidelines specify a probability of no more than "one in a million" that potentially viable extraterrestrial material be released into the Earth's environment, a limit that was proposed after a survey of risk/benefit evaluations that are considered acceptable for other human activities (European Science Foundation (ESF), 2012; Haltigin et al., 2018). As mentioned previously, many spacefaring nations have national laws on environmental protection, as well as the existing international agreements—but the specific applicability of national and/or international regulatory frameworks to Restricted Earth Return efforts remains to be elaborated.

12.5.6 SOCIETAL CONSIDERATIONS

12.5.6.1 Ambiguity in a "Detection" of Extraterrestrial Life

Planetary exploration is currently done almost entirely by using taxpayer funding—even companies that have planetary missions in preparation, such as Moon Express, receive considerable government funding. Responsible use of these funds requires that the benefits of investment in planetary exploration outweigh the risk of loss, including loss due to lack of investment elsewhere. This is a societal decision, not a scientific or engineering one, so societal perception of exploration activities and scientific conclusions is critical. After the Viking missions reported a non-detection of Mars life, no missions were sent to Mars for several decades, despite continued interest on the part of spaceflight engineers and Mars scientists (Space Science Board [SSB], 1977), because funds were allocated elsewhere. If it had been recognized at the time that the Viking mass spectrometers did, in fact, detect Mars organic compounds, albeit at low levels (Glavin et al., 2013; Freissinet et al., 2015), the trajectory of Mars exploration would likely have been quite different.

The need to ensure accuracy in the conclusions of a life/biohazard detection protocol is of much greater importance when the samples being analyzed have been brought back to Earth. There has recently been some confusion regarding contamination control requirements supporting a Biohazard Test Protocol, resulting from conflation of concerns associated with "false positive" and "false negative" results (e.g., Space Science Board [SSB] 2017). From the standpoint of interpreting scientific data, this results from ambiguity about which "null hypothesis" is being tested (Kminek et al., 2014). Astrobiologists and scientists interested in detecting extraterrestrial life will err on the side of not announcing a finding of "life" until they have high confidence in the detection: they are testing the null hypothesis "there is **no** life in these samples." If Earth contamination is detected but there are not signals clearly indicative of extraterrestrial biosignatures, this would be interpreted as a "non-detection" of extraterrestrial life. This approach is consistent with careful scientific discovery, and it also ensures that no harm is done to scientists' or space agencies' reputations, from holding over-enthusiastic press conferences.

12.5.6.2 The Potential for Unidentified Biohazards

In contrast, concerns for Earth Safety require avoiding the release of potential biohazards into the environment of the Earth, and therefore, they need to test the contrary null hypothesis: to ensure safety of the Earth if samples are released, it is necessary to disprove the hypothesis "there is **extraterrestrial** life in these samples" (e.g., Kminek et al., 2014; Haltigin et al., 2018). When testing this null hypothesis, the detection of any Earth contamination would indicate the presence of biosignatures that could also be associated with extraterrestrial biohazards, and very careful further testing would be required to evaluate this possibility at acceptable levels of statistical significance. Samples can certainly be analyzed in containment, while biohazard testing is ongoing—in fact, many of the measurements made will inform both scientific and regulatory communities—but the risk that a breach in containment could release a potential biohazard increases the longer the question remains unanswered. This is a societal question, as much as a scientific one: the public will be affected, if a breach occurs, so they will also want to know how safe the samples are. The space agencies bringing extraterrestrial samples to Earth have an obligation and responsibility to provide accurate answers.

12.5.6.3 Quarantine and Settlement

The concern about detection of potential biohazards does not stop after the first Mars sample return mission, but the challenge of differentiating Mars life from Earth contamination will become progressively more difficult. Robotic exploration can be accomplished while maintaining stringent levels of cleanliness; however, once human missions to Mars are initiated, the concerns increase in ways that are outside the purview of planetary protection. All organisms known to be hazardous to humans are from Earth: this includes overt pathogens (e.g., *Clostridium tetani*) and environmental hazards (e.g., *Stachybotrys* fungi). Despite cleaning protocols, pathogenic organisms have been identified on the International Space Station (e.g., Lang et al, 2017), though fortunately, they have not yet caused illness in astronauts. Societal concerns could change rapidly, if an astronaut were to become ill from a spaceborne pathogen—as human spaceflight becomes more common, policies to control transport of Earth organisms will need to be developed.

Once humans attempt to settle elsewhere, those environments will facilitate independent evolution, and the possibility of exchanging biohazardous organisms that are originally from Earth will need to be addressed. Current and historical quarantine procedures may not be adequate, when people, with their microbes, want to go back and forth. If an infectious disease or hazardous organism has never been present in an environment, what rules should be imposed to control introduction? How should they be different for independently replicating (e.g., most bacteria and archaea) vs. obligate-parasite (e.g., viruses and some eukaryotic parasites) entities? What about quiescent or zoonotic infections that have no vector, for example, a human with trichinosis or malaria? Should the rules be different for infections that could spread, given an appropriate environment, such as *Giardia* and *Clostridium difficile*? All of these issues should be considered, at least at a policy level, before the actual circumstances develop.

12.5.7 SUMMARY AND CONCLUSIONS

This chapter provides a brief summary of planetary protection policy and implementation, including the current context and historical aspects of its development as well as outlining applicability to select future missions. The issues that planetary protection addresses range from the highly technical, including astrobiological and other scientific questions, as well as engineering implementation, to the purely societal and legal, including concerns over invasive species and negotiation of international regulations. As with most technical and academic endeavors, the wider context in which researchers carry out their studies may have an enormous impact on the research that can be performed. It is important for all educated citizens but particularly for researchers involved in esoteric and expensive taxpayer-funded work, to participate in the social and cultural conversations that surround them.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CHARTER OF THE
PLANETARY PROTECTION ADVISORY COMMITTEE
OF THE
NASA ADVISORY COUNCIL

ESTABLISHMENT AND AUTHORITY

The NASA Administrator, having determined that it is in the public interest in connection with the performance of duties imposed on the Agency by law and with the concurrence of the General Services Administration, establishes the NASA Planetary Protection Advisory Committee (the "Committee") of the NASA Advisory Council (the "Council"), pursuant to the Federal Advisory Committee Act, 5 U.S.C. App §§ 1 et seq.

PURPOSE AND DUTIES

1. The Committee will advise the NASA Administrator through the NASA Advisory Council on Agency programs, policies, plans, and other matters pertinent to the Agency's responsibilities for biological planetary protection, as defined in NPD 8020.7, including NASA planetary protection policy documents and components, implementation plans, and organization. The Committee will provide a forum for advice on interagency coordination and intergovernmental planning related to planetary protection. The Committee will review and recommend appropriate planetary protection categorizations for all bodies of the solar system to which spacecraft will be sent. The scope of the Committee's responsibilities will not include issues that pertain solely to the quality and interpretation of scientific experiments and data.

2. The Committee will draw on the expertise of its members and other sources to provide advice and make recommendations to the Council. The Committee will hold meetings and make site visits necessary to meet its responsibilities. The Committee will review reports and recommendations of its subcommittees, panels, and/or task forces and include them, if adopted, in its reports to the NASA Advisory Council.

3. The Committee shall function solely as an advisory body and will comply fully with the provisions of the Federal Advisory Committee Act.

SUBCOMMITTEES, TASK FORCES, AND PANELS

1. Subject to the approval of the Associate Deputy Administrator, the Committee is authorized to establish subcommittees for particular aspects of planetary protection. Subcommittees will be established under Terms of Reference that are approved by the Associate Deputy Administrator. Subcommittees report their proposed findings and recommendations only to the full Committee for its consideration. Subcommittee durations will be 2 years, renewable subject to the review of the Associate Administrator, Office of Space Science, and the NASA Advisory Committee Management Officer.

2. Subject to the approval of the Associate Deputy Administrator, the Committee is authorized to establish temporary task forces for special studies. Task forces of the Committee will be established under Terms of Reference that are approved by the Associate Deputy Administrator. Task forces provide their reports only to the full Committee for its consideration. Task force durations will be specified in their Terms of Reference and are renewable only with the approval of the Associate Deputy Administrator.

3. Members of the Committee may organize themselves into panels of particular areas regarding planetary protection.

MEMBERSHIP

1. The Committee will consist of 15 to 20 members selected to ensure a balanced representation among industry, academia, and Government. The Committee members, collectively, should have the skills and capabilities to assess the issues and risks of forward and backward biological contamination for planetary missions and for biological contamination associated with the launch and return of spacecraft in interplanetary missions and their potential failure modes. At least four of the Committee members shall be persons knowledgeable in one or more of the fields of bioethics, law, public attitudes and the communication of science, the Earth's environment, or related fields. One member shall be also a member of the Space Science Advisory Committee, and one shall be a member of the Life and Microgravity Sciences and Applications Advisory Committee.

In addition to the above-designated members, nonvoting representatives shall be solicited from the following US Government agencies:

Department of Agriculture
Department of Energy
Department of Health and Human Services
—National Institutes of Health
—Centers for Disease Control and Prevention
Department of Interior
Department of Transportation
Environmental Protection Agency
National Science Foundation
Executive Office of the President

Other Government representatives may be solicited in the future with the approval of the Associate Administrator for Space Science.

The Committee shall also invite the participation of nonvoting liaison representatives from other national and international organizations undertaking joint solar system exploration missions with NASA.

2. The Chair will be appointed by the Administrator. Members will be appointed by the Associate Administrator for Space Science with written concurrence of the Associate Deputy Administrator.

3. The Chair will be a member of the NASA Advisory Council.

4. Chairs of subcommittees and task forces usually will be members of the Committee; members of the subcommittees and task forces are associate members of the Committee and participate only in the work of the subcommittee or task force to which they have been appointed by the Associate Administrator for Space Science.

5. Members will be appointed for 3-year terms. At the discretion of the Associate Administrator for Space Science, members may be reappointed for a second 3-year term.

6. Members will be appointed as Special Government Employees and be subject to standards of ethical conduct for Special Government Employees of the Executive Branch.

ADMINISTRATIVE PROVISIONS

1. The Committee will report to the NASA Advisory Council. The NASA Advisory Council will determine whether or not to formally forward committee recommendations to the NASA Administrator. The Administrator responds, for NASA, to those recommendations.

2. The Committee will meet two to three times a year. Meetings will be open to the public, except when the General Counsel and Advisory Committee Management Officer determine that the meeting or a portion of the meeting will be closed to the public in accordance with the Government in the Sunshine Act or that the meeting is not covered by the Federal Advisory Committee Act. Meetings of subcommittees, task forces, and panels will be held as required.

3. The Executive Secretary will be appointed by the Associate Administrator for Space Science and will serve as the Designated Federal Official.

4. The Office of Space Science will provide staff support for the Committee. The estimated annual operating cost totals approximately $115,000, including 0.35 workyears for staff support.

5. Members of the Committee will not be compensated for their services but will, upon request, be allowed travel and per diem expenses as authorized by 5 U.S.C. 5701 et seq.

DURATION

The Committee shall terminate 2 years from the date of this charter unless earlier terminated or renewed by proper authority by appropriate action.

Daniel S. Goldin — Feb. 13, 2001

Administrator — Date

PLANETARY PROTECTION SUBCOMMITTEE

TERMS OF REFERENCE

The Planetary Protection Subcommittee (PPS) is a standing Subcommittee of the NASA Advisory Council (NAC or the Council) Science Committee, supporting the advisory needs of the Administrator, the Science Mission Directorate (SMD), and other NASA Mission Directorates as required. The scope of the Subcommittee includes programs, policies, plans, hazard identification and risk assessment, and other matters pertinent to the Agency's responsibilities for biological planetary protection. This scope includes consideration of NASA planetary protection policy documents, implementation plans, and organization. The Subcommittee will review and recommend appropriate planetary protection categorizations for all bodies of the solar system to which spacecraft will be sent. Outside the scope of the Subcommittee's responsibilities are issues that pertain solely to the quality and interpretation of scientific experiments and data.

Per NPD 1150.11, the Subcommittee will be managed under procedures that ensure the same spirit of openness and public accountability that is embodied by the Federal Advisory Committee Act (FACA). This includes public meetings as appropriate and public access to Subcommittee records.

MEMBERSHIP

The membership of the Subcommittee will consist of leading scientists with relevant expertise drawn from industry, academia, independents and Government institutions. The Administrator, acting on recommendations of the Council Chairman, the NAC Science Committee, and the Associate Administrator for SMD, will appoint the Chair and members of the Subcommittee. Appointments generally will be for a three-year term, with re-appointment and replacement at the discretion of the Administrator, advised by the Council Chair, the Chair of the NAC Science Committee, and the Associate Administrator for SMD. A Vice Chair will be selected from among the members by the Subcommittee Chair in consultation with the Chair of the NAC Science Committee.

In addition to regular members, nonvoting representatives from other U.S. Government agencies with an interest in planetary protection will be invited as Subcommittee observers. Nonvoting liaison representatives from other national and international organizations undertaking joint solar system exploration missions with NASA also will be invited as Subcommittee observers. Invitations to participate as observers in these two categories will be issued by the SMD Associate Administrator.

MEETINGS

The Subcommittee will meet 2-3 times per year, as necesssary. For joint meetings with other Council Science Subcommittees, meeting agendas will be coordinated with the Chair of the NAC

Science Committee and will be responsive to requests from the Administrator, the SMD Associate Administrator, and the Chair of the Subcommittee.

REPORTING

The Subcommittee will report to the Council via the Council's Science Committee. Records of Subcommittee meetings, such as summaries of findings and minutes, will be kept by the Subcommittee's Executive Secretary and will be posted on the web for public access after approval by the Subcommittee Chair.

ADMINISTRATIVE PROVISIONS

The Executive Secretary of the Subcommittee will be appointed by the SMD Associate Administrator. Staff support and travel funds for Subcommittee members for regular meetings will be provided by SMD although other Mission Directorates may provide support for specific activities.

DURATION

The Subcommittee will terminate on expiration of the charter of the NAC unless that Charter is renewed by the Administrator. It may be terminated otherwise at the discretion of the Administrator. If the Subcommittee terminates, all appointments to it also terminate.

Whistleblower Comments on Agency Responses to Supplemental Questions

OSC File No. DI-21-000239

15 July 2023

Summary

NASA's responses to OSC's supplemental questions, submitted after NASA's initial investigation failed adequately to address my whistleblowing concerns, continue to confirm the basis for my initial filing: Starting with the Mars2020 mission, NASA's program of Mars Sample Return is putting the Earth at risk of contamination by extraterrestrial biohazards, because the program will be unable to detect Mars biosignatures in samples brought to Earth from Mars due to excessive contamination by Earth biology.

NASA justifies waiving planetary protection requirements for low levels of Earth contamination by claiming the probability of Mars biohazards should be low, ignoring decades of international scientific consensus that emphasize the risk is not zero. These decisions violate NASA policies on planetary protection, US regulations including the National Environmental Protection Act and PD/NSC-25 on Experiments with Possible Large-scale Adverse Environmental Effects, and Article IX of the Outer Space Treaty.

Some possible negative consequences of a Mars biohazard release are illustrated by the recent global COVID pandemic: massive societal upheaval and many trillions of dollars in economic damage.

Further, actions taken by NASA and the Mars Exploration community after my initial filing have introduced conflicts of interest into the management of planetary protection, both at NASA and also within the larger US government, potentially leading to lax oversight of commercial space exploration and collaboration with international partners.

If consistent and appropriate regulatory oversight of planetary protection is not implemented before Mars materials are brought to Earth -- by either public or private missions -- undetected martian biohazards could be released into the environment of the Earth and cause potentially-global negative consequences.

The amount of Earth biological contamination known to be present on Mars2020 hardware collecting samples at Mars means biosignatures will certainly be detected in samples, if the hardware is returned to Earth. The safety of Earth should not rely on assuming that no Mars biohazards are present, just because Earth contaminants were found.

[redacted]

Narrative Response

Cover Letter

The undated letter signed by Casey L. Swails, that accompanies NASA's supplemental report on OSC questions transmitted in March 2023, attempts to explain why NASA's failure to implement planetary protection on Mars2020 in accordance with NASA's own policies is not "*a violation of law, rule, or regulation; gross mismanagement; an abuse of authority; or a substantial and specific threat to public health.*"

This cover letter states that NASA planetary protection policies "*allow for processes to waive or modify requirements by responsible officials when appropriate*", and then goes on to state that the NASA Planetary Protection Officer (PPO), the Associate Administrator for the Science Mission Directorate (MDAA), and the Chief of the Office of Safety and Mission Assurance (SMA), via their approvals of waivers, all:

> "*were aware that regolith (as opposed to rock) samples would exceed certain baseline parameters but concluded that the risks were acceptable in light of various mitigations*."

The two documents cited as relevant in the cover letter, NASA Procedural Requirements (NPR) document 8020.12D and Interim Directive (NID) 8020.109A on 'Planetary Protection Provisions for Robotic Extraterrestrial Missions", both use identical wording in the requirement for making decisions about Mars sample contamination:

> "*5.3.3.11 An independent science and technical advisory committee shall be constituted with oversight responsibilities for materials returned by a Mars sample return mission.*"

Multiple scientific committees going back to 2014 deliberated extensively to establish baseline contamination requirements for Mars2020 sample return hardware. The NASA officials who approved the waiver, two of whom were neither planetary scientists nor experts on planetary protection, hardly qualify as 'an independent advisory committee'.

The cover letter cites NID 8020.109A, which expired in 2019, as if it supersedes NPR 8020.12D, which is the document applicable to the Mars2020 mission -- but it neglects to cite NPR 8715.24, which is the current NASA policy. All three documents include requirements to presume that "*returned samples contain hazardous biological material*" until test results support a different conclusion. NPR 8715.24 imposes the following requirement on the same three NASA officials mentioned in the cover letter as deciding to waive the baseline contamination requirements on Mars2020:

> "*3.4.3 The MDAA, in coordination with the Chief, SMA and the PPO, shall negotiate a process to assure the safety and containment of Earth-return samples, governed under PD/NSC-25, Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space, in consultation with OIIR, relevant U.S. government agencies, and international partners.* "

The wording of Presidential Directive/National Security Council-25 (PD/NSC-25), which subsumed regulations imposed on the Apollo Program Lunar Sample Return, is quite specific: the Directive covers experiments reasonably subject to "*allegations that they might have major and protracted effects on the physical or biological environment*", which "*are to be included under this policy even though the sponsoring agency feels confident that such allegations would in fact prove to be unfounded.*"

Procedures specified in PD/NSC-25 include working with the Directors of the Office of Science and Technology Policy and what is now the Environmental Protection Agency (provision 1); consulting with the Secretary of State, National Academy of Sciences, and "*international scientific bodies or intergovernmental organizations*" when experiments could have "*adverse effects beyond the US*" (provision 6); and obtaining approval from the President when an experiment "*may involve particularly serious or protracted adverse effects*" (provision 7). Provision 8 mandates "*early and widespread dissemination of public information explaining the purpose, benefits, and assessments of impacts.*"

Waiving baseline contamination requirements on hardware designed to collect presumed-to-be-hazardous Mars samples should qualify for the "*protracted adverse effects*" category of PD/NSC-25 -- particularly when the accepted baseline requirements were subject to considerable dispute over concerns around potential lack of stringency and masking of Mars biosignatures (e.g., the 2014 Organic Contamination Panel Dissenting Report).

Despite naming the same three officials, the letter provides no evidence that the provisions in NPR 8715.24 or PD/NSC-25 were followed -- instead, it notes that safety assessment protocols have not yet been established, which is in direct contravention of decades of scientific advice based on lessons learned from the Apollo Back Contamination Committee. The letter also includes a bizarre aside about hexane being effective for some uses but not others, and reiterates a comment from the previous NASA response to the effect that Mars2020 achieved similar levels of bioburden control as previous Mars missions.

This last apparent non-sequitur is actually quite supportive of my initial filing, because every Mars mission to date that was equipped with appropriate instruments ***has detected*** Earth contamination carried along on the spacecraft. My comments of 7 October 2022 cite scientific evidence from the Viking and Mars Science Laboratory missions that demonstrate results initially interpreted as indicating only Earth contamination in samples analyzed by Viking actually masked the presence of organic compounds from Mars. Levels of biological cleanliness achieved on even the cleanest previous mission left ***contamination that already interfered*** with the sensitive detection of possible Mars biosignatures.

As PPO, since 2009 I advocated for the applicability of PD/NSC-25 to Mars Sample Return: its' inclusion in NPR 8715.24, although that document took effect after the launch of the Mars2020 mission, serves to confirm the relevance. In light of NASA requirements and US presidential directives, this cover letter provides evidence confirming all of the violations it mentions, except the 'specific' qualifier to the public health threat, have occurred.

Developments since 2021

NASA's acknowledgement of PD/NSC-25 as applicable to Mars Sample Return is a positive step, but a number of other developments have taken place since my removal as PPO and whistleblowing activities that are both problematic and relevant to my original filing.

i) The first has to do with the structure of NASA's Safety and Mission Assurance (SMA) reorganization and the placement of planetary protection within it. As PPO, my position was located at NASA Headquarters and reported to the Associate Administrator of the Science Mission Directorate. The new SMA structure has the Planetary Protection Officer located at the Jet Propulsion Laboratory (JPL), where the Mars Program is managed, reporting through several layers of local management before reaching NASA Headquarters.

JPL is notorious for an organizational culture in which flight projects take precedence over 'line' organizations; this structure has regularly been cited for lack of transparency leading to project delays or failures. In 2022, the Independent Review Board investigating delays on the Psyche mission (1) found that "*A culture of "prove there is a problem" led to important issues raised by team members being disregarded*" and " *JPL institutional issues are serious and require urgent action.*"

When people tasked with exerting regulatory oversight are co-located within a culture where their colleagues actively resist elevating potential problems, the pressure to relax oversight becomes intense. For planetary protection on Mars Sample Return, inadequate oversight could put the environment of the Earth at risk.

ii) The second recent development involves how NASA/JPL are compartmentalizing the National Environmental Protection Act (NEPA) environmental impact process for Mars Sample Return, by segregating the Mars2020 mission from the rest of the Sample Return campaign.

The Preliminary Environmental Impact Statement for Mars Sample Return (PEIS, 2) claims that all environmental impact assessments related to Mars2020 were addressed during the Mars2020 NEPA process.

However, the Mars2020 Final Environmental Impact Statement (FEIS, 3) addresses only the *launch* of the Mars2020 mission, and provides no information about levels of Earth contaminants present in sampling hardware, nor does it mention how (in)action by the Mars2020 project could affect Earth Safety after sampling hardware return. The FEIS response to public feedback suggesting "*leave Mars long-distance*" is: "*Actions not related to the Mars 2020 mission are beyond the scope of the EIS.*"

The Mars Sample Return PEIS continues the compartmentalization of Mars2020 from the rest of Sample Return, by arguing for a low probability of viable Mars organisms being harmful or present in samples brought to Earth. It then implies this somehow relieves the need for high-sensitivity sample analysis within containment:

> "*Because it is currently thought the potential for pathogenic effects from the release of small amounts of Mars samples is regarded as being very low, the analysis of Health and Safety in Section 3.4 focuses on the design mitigations and protocols utilized to minimize the potential risk associated with Mars sample release during landing and recovery.*" (2, pg 3-4; paraphrased on pg. 3-9).

The *a priori* position that hypothetically low biohazard reduces concern is an explicit violation of requirements in NPR 8715.24 and section 5.3.3.1 of NPR 8020.12D and NID 8020.109A, which requires that "*Samples returned from Mars by spacecraft shall be contained and treated as though potentially hazardous until demonstrated otherwise.*"

The Mars Sample Return PEIS discusses the required biohazard test protocol in three paragraphs of a 342 pg. document, and allocates responsibility for developing it to "*A multidisciplinary team of scientists and experts (e.g., engineers, occupational safety and health professionals, BSL-4 facility managers, etc.)*". Information about the level of Earth contamination introduced into samples to be returned is an essential input for understanding how sensitive a test protocol could possibly be, since contamination levels determine measurement background and baseline detection sensitivity -- but how the proposed future team is intended to obtain such information is left undisclosed.

The PEIS does specify that this team is to rely on findings of the Sample Safety Assessment Protocol (SSAP) working group of the Committee on Space Research (COSPAR), which may sound impressive to an uninformed reader. In reality, NPR 8715.24 requires only:

> "*reasonable efforts to implement planetary protection measures generally consistent with the COSPAR Planetary Protection Policy and Guidelines or the planetary protection measures NASA would take for like missions.*"

As noted in presentations associated with the PEIS rollout, the only NASA missions analogous to Mars Sample Return occurred during the Apollo Program: containment failures during the Apollo Lunar Sample Receiving process were widespread and are well-documented (see 4 for recent media attention).

iii) The third recent development is perhaps the most concerning, as it involves a systematic subversion of the US scientific advisory process that should ensure government actions around planetary protection are transparent under the Federal Advisory Committees Act (FACA), and based on a solid and unbiased scientific foundation.

In 2015, as PPO and following recommendations from the Planetary Protection Subcommittee (PPS) of the FACA-chartered NASA Advisory Council, I categorized the Mars2020 mission as the initial element of a Mars Sample Return campaign, on the basis that hardware carried on the Mars2020 mission is intended for return to Earth so any future biohazard detection protocol would require information about Earth contamination introduced during sample collection by Mars2020. This perspective met with strong opposition from NASA management, and the PPS was allowed to meet only twice more.

Starting in 2018, the NASA Advisory Council convened several short-lived committees that included planetary protection among other commercial and technological subjects, but as of July 2023 there appears to be no committee within the NASA Advisory Council designated as having responsibility for providing independent external advice on planetary protection. The Planetary Science Advisory Committee website includes the explicit caveat that "*Responsibility for biological planetary protection is outside the purview of the PAC.*"

In parallel, the Space Studies Board of the US National Academies of Sciences, Engineering, and Medicine (NASEM) started taking on more 'advisory' responsibilities for planetary protection, and in 2020 NASEM convened a 'Committee on Planetary Protection' (CoPP), sponsored by NASA, that has engaged in a meeting schedule much more frequent than permitted by the budget of the NAC/PPS. Between September 2020 and July 2023, the CoPP met 35 times, of which 15 meetings were fully closed, 19 meetings were partially closed, and only one meeting, a 'Public Briefing' on 7 October 2021, was entirely open.

The membership of the NASEM CoPP is heavily skewed towards commercial and non-academic professionals: of the 13 members listed in July 2023, three are 'independent consultants' who specialize in commercialization of space, two are current or former space agency employees, and one is employed by a company specializing in space exploration. This contrasts with the Committee on Astrobiology and Planetary Sciences, on which only two of the 19 members hold positions with duties not focused on basic scientific research. Only two members of CoPP have any expertise in biology, despite the primary goal of planetary protection being to prevent contamination by biohazards.

The new co-chair of the CoPP, installed in March 2023, is Dr. Lennard Fisk, whose revisionist history and negative perception of planetary protection when serving as President of COSPAR was strongly disputed in print by the first and longest-serving Chair of the COSPAR Panel on Planetary Protection (5). The COSPAR SSAP working group is identified in the Mars Sample Return EIS as the source of advice on implementing a biohazard detection protocol, yet meetings of international organizations are not subject to FACA -- and meetings of the COSPAR Panel on Planetary Protection, historically open to all COSPAR colloquia attendees, under Dr. Fisk's presidential tenure were increasingly closed.

The National Academies are also not formally subject to FACA, and the limited material made available as having been discussed by the CoPP includes a significant fraction that advocates for further relaxation of planetary protection requirements specifically to facilitate commercial space exploration. Given this, the level of closed discussion and apparent conflicts-of-interest among committee members of the CoPP is unusually high.

The potential consequences of a decision to relax planetary protection requirements on commercial Mars missions are no different than for Agency missions. PD/NSC-25 mandates public communication only after a decision is made, but both NEPA and FACA require more widespread public consultation and transparency than is evident to date.

How will regulatory compliance be assured, if the US government starts making decisions based on advice from predominantly closed international and NASEM meetings?

Detailed Responses to Follow-up Questions

Question 1: As with the original NASA report, this response carefully selects only a subset of disclosures to address, and the information being left out is as important as the parts of the questions for which responses are given. The response to Question 1 makes no effort to justify the 'system deviation' other than to say it was approved by several bureaucrats. It then proceeds to describe some "*mitigations*" proposed as effective for removing surface contamination from the drill bit -- but which certainly would not have any effect on contamination covering other surfaces, such as the interior of the sample collection tubes where contamination is easily transferred to Mars samples.

Further, the approach of using "*vibration to further clean the inside of the regolith bit*" could be counterproductive, in that questions have been raised about the potential for contaminants to be abraded or leached out of the material from which the hardware is made: my source is verbal communication from a Mars scientist who requested to remain anonymous due to fear of retaliation. Concerns about leaching-, abrasion-, or vibration-induced contamination are entirely omitted from the NASA response.

Question 2 requests directly an explanation for the claim, repeated both in the first report and the last lines of this response to question 1, that "*failure to meet baseline TOC does not present a significant threat to planetary protection but rather potentially affects some Mars sample return science.*"

NASA's response is missing not only information, but also any process of logical inference. Starting at the end, the last several lines of the response -- which may be a quote or paraphrase from the COSPAR Sample Safety Assessment Framework? -- state:

" *The sample safety assessment purpose is to exclude biological origin. Total organic carbon exceeding requirements may potentially hinder pace of the process by requiring additional investigation of organic-rich regions slowing the overall sample safety assessment* "

Since the need "*to exclude biological origin*" is the primary focus of planetary protection -- being absolutely essential for assuring Earth Safety from extraterrestrial biohazards -- to allow higher-than-baseline TOC to "*hinder pace of the process*" can't be anything other than a threat to planetary protection: every day in containment is another chance for containment to fail.

A substantial fraction of the Question 2 response is dedicated to explaining the different categories of contamination being considered, to make the point that the organic compounds created by biological organisms represent only a limited subset of all compounds it is possible to make using organic chemistry. However, the 'tier 1' compounds are proposed to be biology-related based on Earth biology, which may be quite different than organisms from Mars.

The reiteration that a safety assessment protocol has not yet been established also begs the question of how the approach for dividing Earth contaminants into different tiers of compounds was validated, and why it was considered to be adequately informative for evaluating the presence of potential Mars biohazards?

The cited 'Sample Safety Assessment Framework' should focus primarily on the sensitivity of measurements to detect the presence of a potentially-very-small number of viable Mars organisms -- because viable organisms are predicted to be the most damaging potential biohazards -- and only secondarily attempt to distinguish between small-molecule compounds that could be made via biological or non-biological processes.

Instead, the response to this question appears entirely oblivious to the certainty that higher levels of Earth (biological) contamination will make detection of "*biomarker compounds*" more inevitable -- yet at the same time will open even wider the question of whether any of the detected biomarkers are actually ***from Mars***.

As detailed in my previous response, on Mars in the 1970s the Viking project failed to answer this question correctly -- it wasn't until 2015 that the Mars Science Laboratory confirmed the Viking-era detection of Mars organics, that previously had been discounted as Earth contamination.

Knowing which planet a biomarker comes from is absolutely "*significant*" for planetary protection to assure Earth safety -- and presumably also for Mars science, since we already know there's life on Earth. Evidently, the NASA/JPL Mars Program hasn't learned this, despite five decades and many billions of taxpayer dollars invested in Mars exploration.

<u>Question 3</u> addresses the hexane wash, and received a response so tautological that there's not much inference to pick apart. No matter how often NASA declares that what Mars2020 did was 'approved' or 'accepted' by some bureaucrat or NASA-sponsored committee, this repetition does not address the actual potential for Earth contamination to interfere with detecting Mars organic compounds that could indicate potential Mars biohazards.

If the US and EU taxpayers who are funding Mars Sample Return truly understood the risks, would they really consider it worthwhile to spend additional billions of dollars/Euros to repeat the 50-year-old mistakes made by Viking -- not to mention possibly putting the environment of the Earth at risk from undetected Mars organisms in samples brought here?

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(1) Report and NASA Response to Psyche Independent Review Board Investigation: https://go.nasa.gov/3UtmbOz

(2) NASA Preliminary Environmental Impact Statement: https://www.regulations.gov/document/NASA-2022-0002-0175

(3) Mars2020 Federal Register Announcement of Final EIS, links to documents on page: https://www.federalregister.gov/documents/2020/01/24/2020-01179/national-environmental-policy-act-mars-2020-mission

(4) Scoles, S. "Cosmic Luck: NASA's Apollo 11 Moon Quarantine Broke Down" The New York Times, 9 June, 2023: https://www.nytimes.com/2023/06/09/science/nasa-moon-quarantine.html

(5) Rummel, J.D., 2023. Space Research Today, No. 216, COSPAR, pp. 58-61.