Planetary Protection Concerns in Mars Exploration

Presentation to the SSB Committee on Planetary Protection

25 March 2021

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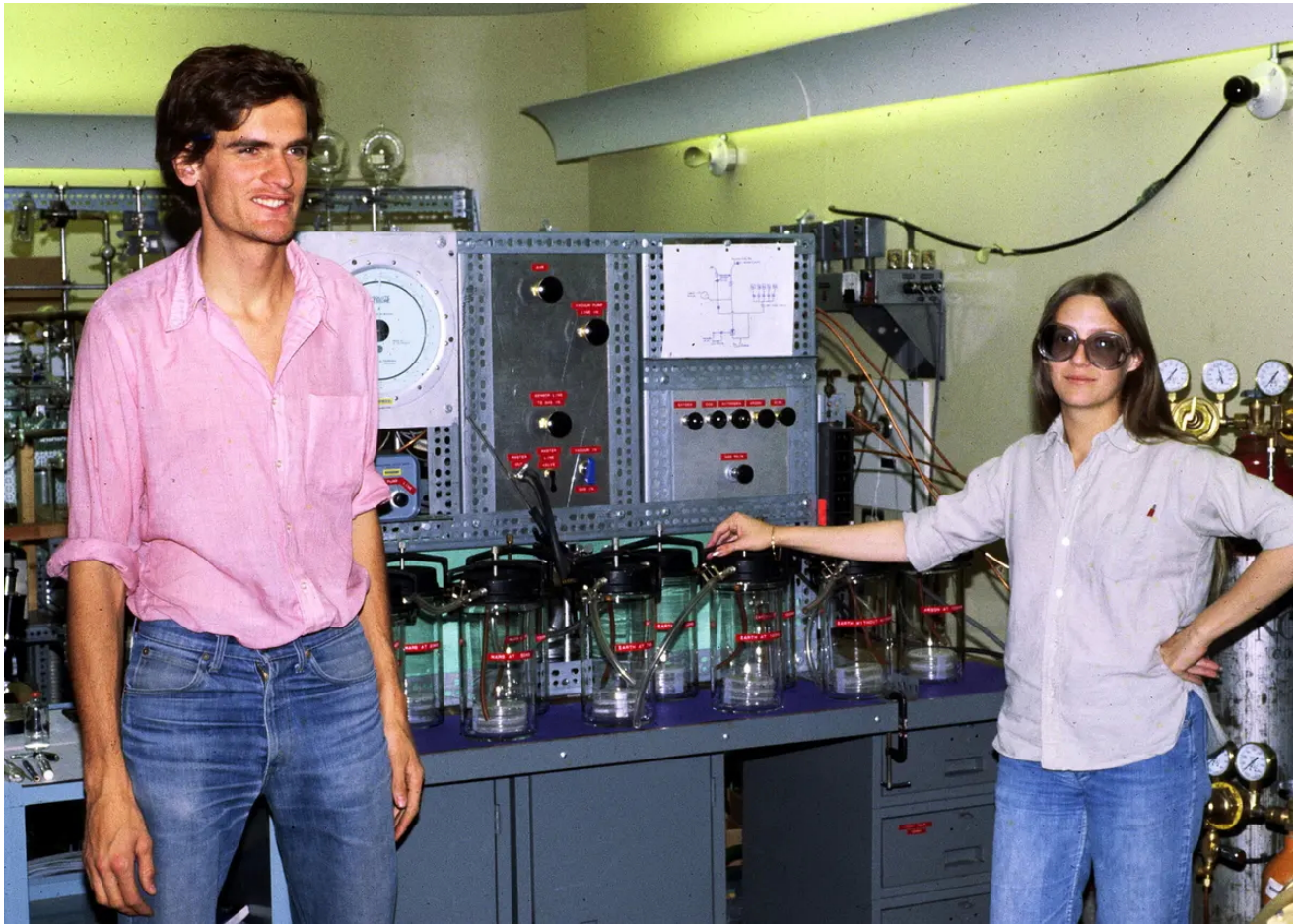
Friday Harbor Partners LLC

Looking for Positives and Negatives You Can Believe In!

Two luminaries, pursuing the serious study of the potential for life on Mars

I have always considered myself a student of the Mars Underground

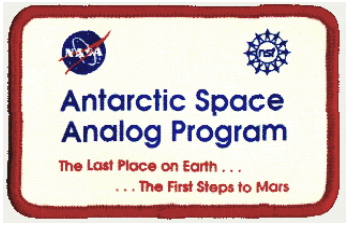


Chris McKay,
Penny Boston
U. of Colorado
Early ~1980s

Proposed Outline

- Introduction
- Some history of the current requirements
- Comments on the Statement of Task
- Comments on requested human-associated opportunities
- Crickets!

Where I Came In (Late; 1970s to 2021)



- University of Colorado (1970-1974) – BA, Environmental Biology
- Stanford University (1979-1984) – PhD, Biological Sciences
  - Models and Field Experiments on Interspecific Competition and Co-Evolution [Lesser Antilles Fieldwork]
- NASA Ames Research Center (1985-1986) – Research Associate; Models of Bioregenerative Life Support Systems, and Microbiology of Human-Associated Hydroponic Lettuce
- NASA Headquarters (1986-1993) – Life Sciences and Solar System Exploration Divisions; Exobiology Program Manager and Planetary Protection Officer
  - Developed Antarctic Space Analog Program with NSF Polar Programs [South Pole, Dry Valleys, McMurdo Sound]
- Marine Biological Laboratory (1994-1998) – Director of Research Administration and Education
  - Served on SSB COMPLEX; Fieldwork with Atlantis/Alvin, and with NASA ROVs
- NASA Headquarters (1997-2008) – Planetary Protection Officer; Senior Scientist for Astrobiology
  - Initiated COSPAR Panel on Planetary Protection in 1998; Named as First Panel Chair, 1999
  - Stepped Down as COSPAR Panel Chair in 2014, just prior to the Moscow Assembly
- East Carolina University (2008-2015) – Director, Institute for Coastal Science and Policy
- SETI Institute (2015-2020) – Senior Scientist • Friday Harbor Partners LLC (Present) – Partner, Dad

How Did We Get Here?

- Prior to the mid-1980s, NASA/COSPAR used a formula and an estimate of Pg, the Probability of Growth in a planetary environment, to determine planetary protection requirements (SSB. 1978. *Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan.*)
- To meet the numerical requirements, the study recommended "for these purposes, and these purposes alone", that NASA adopt a value of $Pg < 10^{-10}$ for the subpolar regions of the planet within 6 cm of the surface; a value of $Pg < 10^{-8}$ for subsurfaces in the subpolar regions of the planet; and it recommended that at the residual polar caps, those regions should be handled with prudence and be assigned a value of $Pg < 10^{-7}$.
- N. B. wrt Contamination Transport: One consequence of the lethal conditions on Mars, particularly regarding UV flux, is that the recommended value of $< 10^{-7}$ for Pg in the residual polar caps "applies only to terrestrial organisms that are released directly in that region. The Pg for organisms transported into the polar caps from the subpolar regions would be orders of magnitude lower. Similarly, even if Mars were to possess oases that were hospitable to terrestrial life, few if any terrestrial organisms would survive a surface or aerial trip to the oasis and few if any would ever survive an escape from the oasis."

How Did We Get Here with Mars Category IV (cont.)?

- With the new NASA/COSPAR scheme regarding mission categorization (DeVincenzi et al. 1983. A proposed new policy for planetary protection. *Adv. Space Res.* 3:13), and with time to study the Viking Mars results, the SSB was tasked to provide an update to the PP requirements for Mars.
- The report (SSB. 1992. *Biological Contamination of Mars: Issues and Recommendations*) made a number of recommendations, some of which had lasting consequences in thought and practice:
  - "The task group views the problem of forward contamination as separable into two principal issues. The first centers on the potential for growth…of whatever fractions of spacecraft populations of microorganisms are able to survive transit from Earth to the surface of Mars. The second involves importation of terrestrial organic contaminants, living or dead, in amounts sufficient to compromise the search for evidence of past or present life on Mars…."
  - "Landers carrying instrumentation for in situ investigation of extant martian life should be subject to at least Viking-level sterilization procedures." [now known as Category IVb]
  - "Spacecraft (including orbiters) without biological experiments should be subject to at least Viking-level presterilization procedures—such as clean-room assembly and cleaning of all components—for reduction of bioload, but such spacecraft need not be sterilized." [now Category IVa]

How Did We Get Here with Mars Category IV (cont.)?

- So that is where the NASA Standard Assay comes in, despite the categorization scheme's implicit changes. For even a longer-term effect, the 1992 report also presented other challenges:
  - "The task group recommends that efforts be initiated immediately to adopt state-of-the-art methods for use in the determination of bioload." This was a challenge because NASA management was unwilling to provide extensive (sufficient) funding to develop new methods that would be equivalent to the Viking ones, instead of the known NASA Standard Assay.
  - "Missions carrying humans to Mars will contaminate the planet. It is therefore critical that every attempt be made to obtain evidence of past and/or present life on Mars well before these missions occur. The issues of forward and back contamination have societal, legal, and international implications. These implications are serious, and they deserve discussion and attention." We hear this a lot, but it may not be true to the degree stated here….
  - "The task group recommends as essential that efforts be made (1) to assess the legal limits (and implied liabilities) in existing legislation that relates to martian exploration and (2) to pursue the establishment of international standards that will safeguard the scientific integrity of research on Mars. Furthermore, the task group recommends that NASA make a strong effort to obtain international agreement for a planetary protection policy." We did that, through COSPAR.

How Did We Get Here with Mars Category IV (cont.)?

- To a degree, the PREVCOM Report (SSB. 2006. *Preventing the Forward Contamination of Mars)* doubled-down on the 1992 report on one hand, and conflicted with it, a bit, on the other:
- "NASA should require the routine collection of phylogenetic data to a statistically appropriate level to ensure that the diversity of microbes in assembly, test, and launch operations (ATLO) environments, and in and on all NASA spacecraft to be sent to Mars, is reliably assessed." Yay, SSB!
- "NASA should take the following steps to transition toward a new approach to assessing the bioburden on spacecraft:
  - Transition from the use of spore counts to the use of molecular assay methods that provide rapid estimates of total bioburden (e.g., via limulus amebocyte lysate (LAL) analysis) and estimates of viable bioburden (e.g., via adenosine triphosphate (ATP) analysis). These determinations should be combined with the use of phylogenetic techniques to obtain estimates of the number of microbes present with physiologies that might permit them to grow in martian environments.
  - Develop a standard certification process to transition the new bioassay and bioburden assessment and reduction techniques to standard methods.
  - Complete the transition and fully employ molecular assay methods for missions to be launched in 2016 and beyond."

How Did We Get Here with Mars Category IV (cont.)?

- The PREVCOM Report (SSB. 2006. *Preventing the Forward Contamination of Mars)* doubled-down on the 1992 report on one hand, and conflicted with it, a bit, on the other:

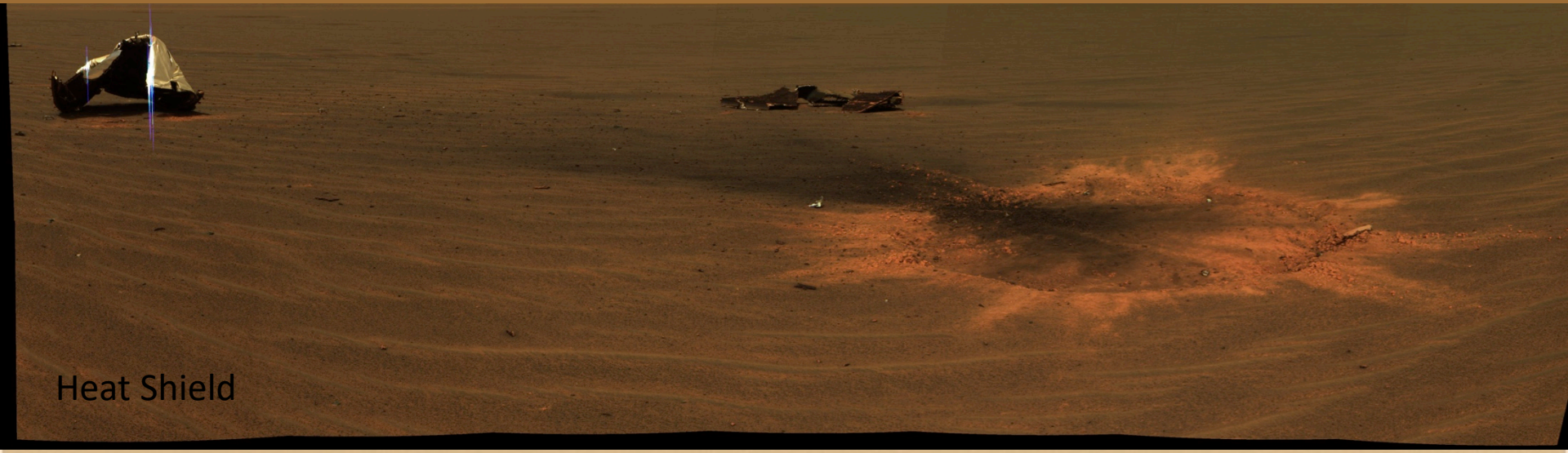
➢ It was notable that a special categorization was not recommended for life-detection missions (on the part of planetary protection), but that rigorous controls on non-living components of a mission (e.g., organics, etc.) *were* recommended. [Bye-bye Category IVb?]

➢ "It appears likely that most microorganisms exposed to the martian UV environment and unable to gain access to the martian subsurface will rapidly die. Moreover, because windblown dust particles on Mars have diameters in the range of 1 to 2 microns, transport via dust particles is also likely to lead to rapid death, and so windblown transport of microorganisms on Mars seems unlikely to contaminate distant parts of Mars." [But see Osman et al. 2008. AEM 74:959–970; and many others]

- Also, picking up a partial suggestion from the 1992 report, PREVCOM recommended:

➢ "In light of new knowledge about Mars and the diversity and survivability of terrestrial microorganisms in extreme environments, NASA should work with COSPAR and other appropriate organizations to convene, at the earliest opportunity, an international workshop to consider whether planetary protection policies for Mars should be extended beyond protecting the science to include protecting the planet." [A workshop on Ethical Dimensions was held in 2010 at Princeton]

Opportunity Visiting Its Own Debris (Bug-Farm?)



Whatever we do, the realities of nominal and off-nominal operations need to be anticipated!

CoPP Statement of Task (and Questions/Comments)

- The Committee on Planetary Protection (CoPP) shall write a report that identifies criteria for determining locations or regions on Mars that are potentially suitable for missions of less restrictive bioburden than the current requirements for Category IV (Let's say the COSPAR version, since they are current and published)
  - Category IVa and IVc are governed by criteria affecting locations or regions; Category IVb is applied independent of locality—Are locality-based bioburden requirements all the Committee is addressing? What about contamination knowledge requirements?
  - And why not take a look at requirements for Category III, while you are at it? Current requirements are a function of orbital lifetime (with a possible relationship to bioburden) or total bioburden landed (after breakup and burn up analyses.

I encourage you to look at Mars orbiter requirements!

- There are some specific limitations of the orbital lifetime approach
- The proposed alternative given here was a casualty of the 2016 Istanbul Assembly cancellation

On Adopting a Proactive Approach to the Disposition of Mars Orbiters
COSPAR PPP.1-0005

John D. Rummel, Robert Shotwell, and Hoppy Price

There are currently three U.S. orbiters at Mars plus two orbiters from other nations. At the end of each mission, it is desirable to dispose of the vehicle in a condition where it would present no hazard to other orbiters and to potential future crewed vehicles, while meeting planetary protection constraints. There is currently no way to accurately track and confirm positions of these orbiters after they are no longer being actively tracked from Earth, and due to the extremely "bumpy" nature of the Martian gravity field the position of these vehicles rapidly becomes unknowable . The current COSPAR Planetary Protection Policy for Mars includes a throwback to an earlier era of planetary exploration. The Policy's provisions for the disposition of Mars orbiters includes an option "to meet orbital lifetime requirements" of 20 years (at 99% probability) and 50 years (at 95% probability) after launch (which we will call option 1), or option 2, requiring total (surface

Statement of Task (Questions/Comments; cont.)

- The report shall also illustrate the use of those criteria by identifying some potentially acceptable locations that meet those criteria and are suitable for reduced bioburden criteria.
  - Assuming that there are any such locations, given the range of potential criteria. One could conceivably (per the PREVCOM Report; 2005) also identify *new* locations that are unsuitable for entry under the current bioburden treatment levels. These, instead, would need to be subjected to an even more thorough treatment known (in the PREVCOM report) as "Level 5 Bioburden Reduction." Does NASA wish to hear about those, too?
- Additionally, the report shall consider the appropriateness of mission activities that occur beneath the Martian surface in these locations and how deep such mission activities should be allowed.
  - This is particularly concerning with respect to caves on Mars and drilling. Note that under current bioburden levels for Category IVc, no mission activities below the surface are restricted ('inappropriate'), but perhaps they should be more restricted than currently.

Statement of Task (Questions/Comments; cont.)

- The CoPP shall determine whether the following criteria are necessary and sufficient to determine if a location on Mars is appropriate for missions with lower bioburden requirements than the current Category IV and provide methods a mission could use to show it meets the criteria. If the following criteria are not sufficient, the CoPP shall provide those that are deemed necessary. [Note that "lower bioburden" still involves implementation with some sort of bioburden measurement.]

- Criteria might include:
  - Temperatures at the landing site and locations of mission activities are below -25°C, or water activity is less than 0.5 (Note: water activity = water vapor pressure of a solution/vapor pressure of pure water). These are the MEPAG SR-SAG2 parameters now reflected in COSPAR policy.
  - Mission activities will go no deeper than a certain distance below the surface, [but see Mars Polar Lander; DS-2],
  - Landed spacecraft are not capable of melting the [volatiles contained in the] regolith, and
  - Proposed landing and/or mission activity sites do not contain geomorphological characteristics of [present-day] flowing [?] water, such as recurring slope lineae, etc.

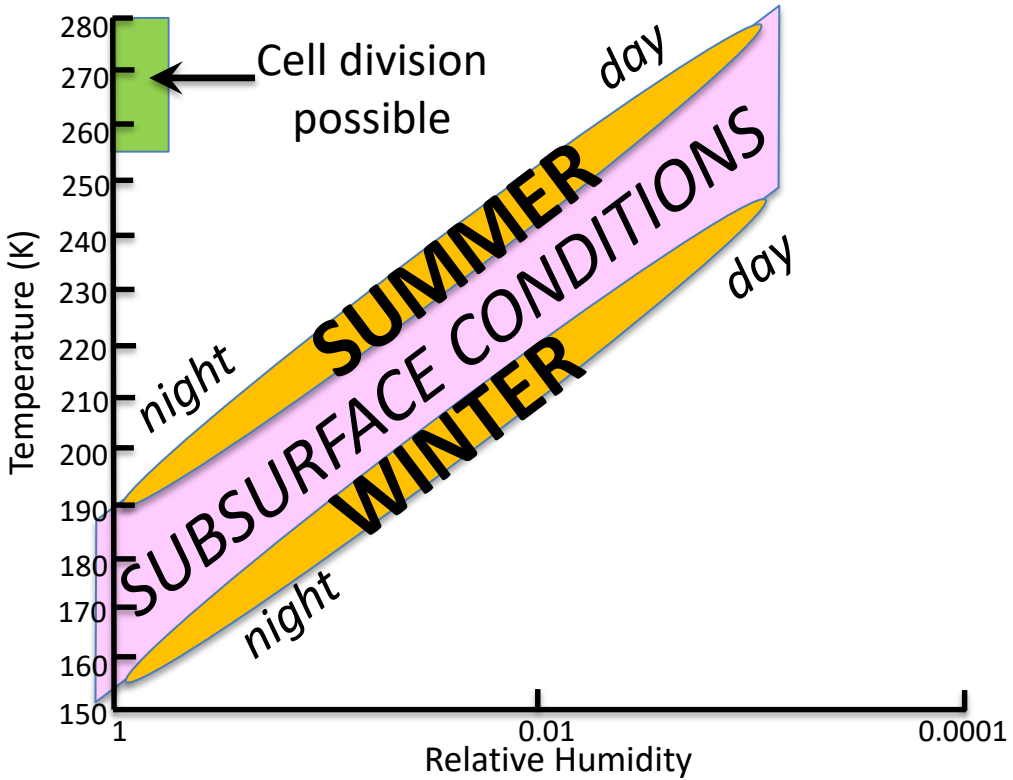
Other Questions/Comments

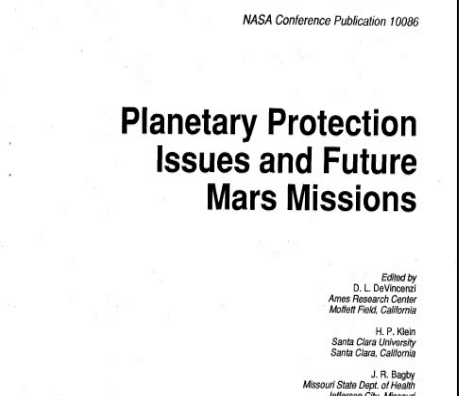
- Important to acknowledge latent effects of imported Earth organisms (McKay, Lederberg, Levinthal, et al.)
- And these organisms could be spread from Olympus Mons to Hellas Basin
- Need control of forward bioburden to avoid false-positives in sample return missions (e.g., Perseverance)
- Mars is tough (Schuerger et al.) but not impossible (Osman et al.) for a suite of Earth microbes
- Phoenix RH vs. Temp from 2014 MEPAG study (simultaneity?)
- “Gold” rules for avoiding Mars life
  - LR/Organics argument (Does the LR experiment show a positive result? Are there organics present?) Get SAM to the landing site….
- Humans on Mars?
- Antarctic Rules and Reasons (plus cleanup)

Subsurface Conditions at the PHX Site

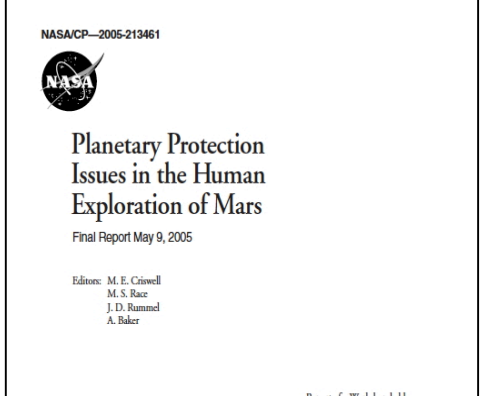
- Phoenix collected data during the summer
- Thin films in the regolith will be at conditions far removed from those needed for cell division.

Finding 4-12: Environmental conditions at the Phoenix site, both at the surface (measured) and in the regolith (modeled) are incompatible with cell division. Note, however, that both sufficient water activity (as a vapor) and warmer temperatures may be present in the summer within the same 24-hour cycle, but never simultaneously.

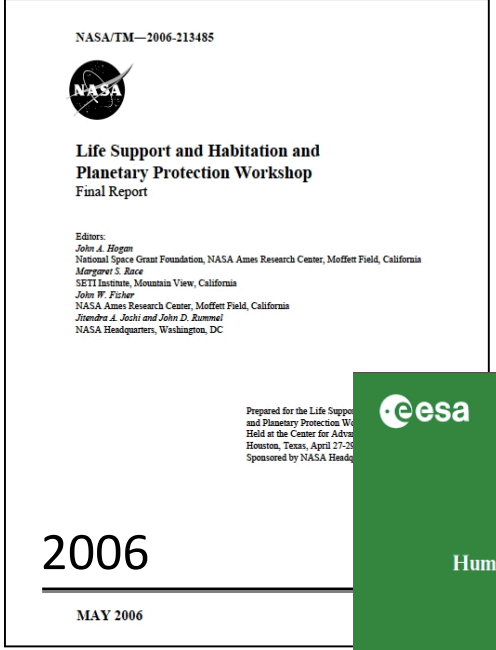




1992

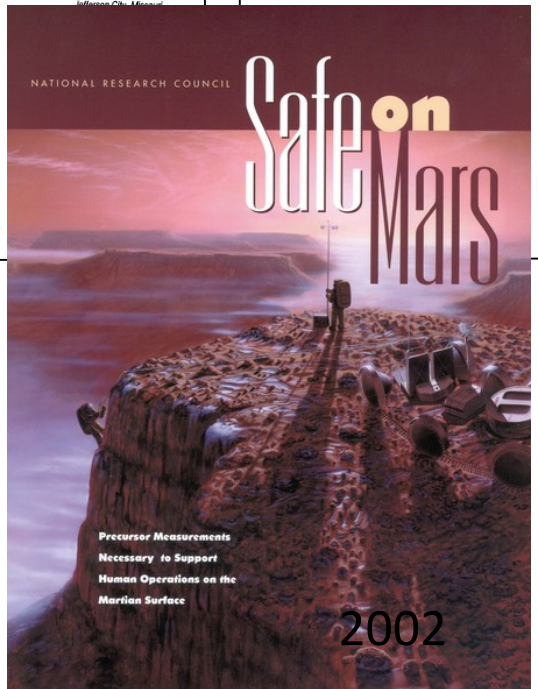


2005



2006

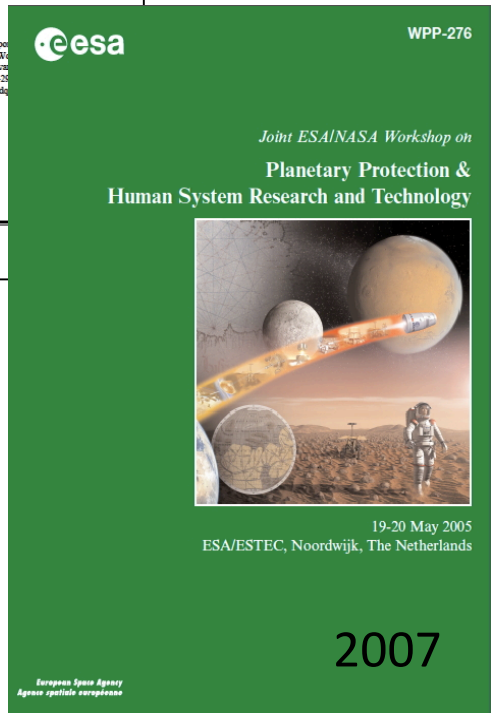
Planetary Protection and Human Missions reports; Dates given are publication dates



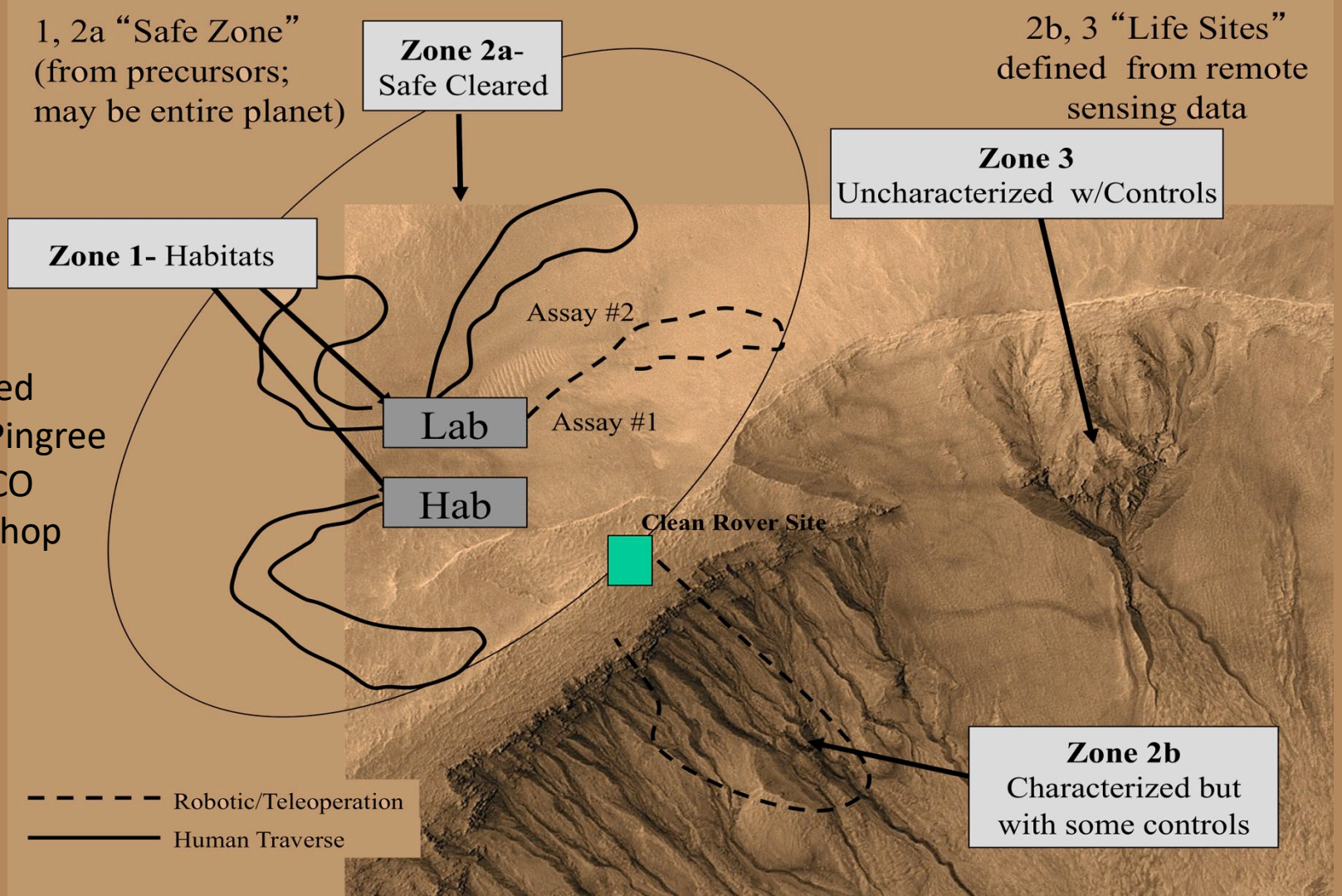
2002

Reports are from Workshops in 1990, 2001, 2005, 2005, plus ASEB study in 2002

Plus NASA/COSPAR workshops annually, beginning in 2015, with focus on SKGs



2007



Adapted from Pingree Park, CO Workshop (2001)

ASEB Report: Safe on Mars (2002)

- The committee recommends that NASA establish zones of minimal biologic risk (ZMBRs) with respect to the possible presence of Martian life during human missions to Mars. In order to do so, NASA should conduct a precursor *in situ* experiment at a location as reasonably close to the human mission landing sites as possible to determine if organic carbon is present. The measurement should be on materials from the surface and down to a depth to which astronauts may be exposed. If no organic carbon is detected at or above the life detection threshold, the landing site may be considered a ZMBR. If no measurement technique can be used to determine if organic carbon is present above the life detection threshold, or if organic carbon is detected above that threshold, a sample should be returned to Earth for characterization prior to sending humans to Mars.

Principles and Guidelines for Human Missions to Mars*

The intent of this planetary protection policy is the same whether a mission to Mars is conducted robotically or with human explorers. Accordingly, planetary protection goals should not be relaxed to accommodate a human mission to Mars. Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ. General principles include:

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- For a landed mission conducting surface operations, it will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars, or their support systems, will inevitably be exposed to martian materials. [*As adopted in 2008 by the COSPAR Council]

In accordance with these principles, specific implementation guidelines for human missions to Mars include:

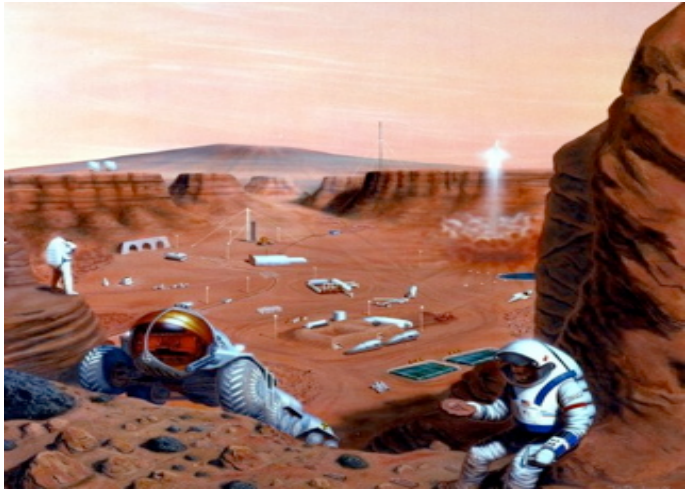
- Human missions will carry microbial populations that will vary in both kind and quantity, and it will not be practicable to specify all aspects of an allowable microbial population or potential contaminants at launch. Once any baseline conditions for launch are established and met, continued monitoring and evaluation of microbes carried by human missions will be required to address both forward and backward contamination concerns.
- A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a martian life-form occurs.
- A comprehensive planetary protection protocol for human missions should be developed that encompasses both forward and backward contamination concerns, and addresses the combined human and robotic aspects of the mission, including subsurface exploration, sample handling, and the return of the samples and crew to Earth.
- Neither robotic systems nor human activities should contaminate “Special Regions” on Mars, as defined by this COSPAR policy.

Implementation Guidelines (cont.):

- Any uncharacterized martian site should be evaluated by robotic precursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission.
- Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.
- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.
- Planetary protection requirements for initial human missions should be based on a conservative approach consistent with a lack of knowledge of martian environments and possible life, as well as the performance of human support systems in those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

MEPAG SR-SAG2
Human Exploration of Mars and Special Regions

- Human exploration of Mars requires access to resources, including
  - Water
  - Oxygen
  - Protection from radiation
  - Fuel for vehicles
- These resources are available on Mars and will require access to surface or near-subsurface materials, some of which may be found in Special Regions



- Special Regions are in part defined on the availability of water, making them a potential source of water and oxygen, in addition to their science value
- Protocols need to be established so that human activities do not inadvertently affect areas designated as Special Regions or cause non-Special Regions to become Special.
  - The spread of terrestrial biological contamination could also impact life support systems, and the availability of Mars resources to human explorers.

Questions ??