Requirements of Planetary Protection

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Topics

- Review of planetary protection (PP)
- Overview of NASA PP requirements for JEO
- JEO Specific Implementation
- PP points to remember
- Summary

PP implementation for "Curiosity" (MSL)

Purpose of Planetary Protection

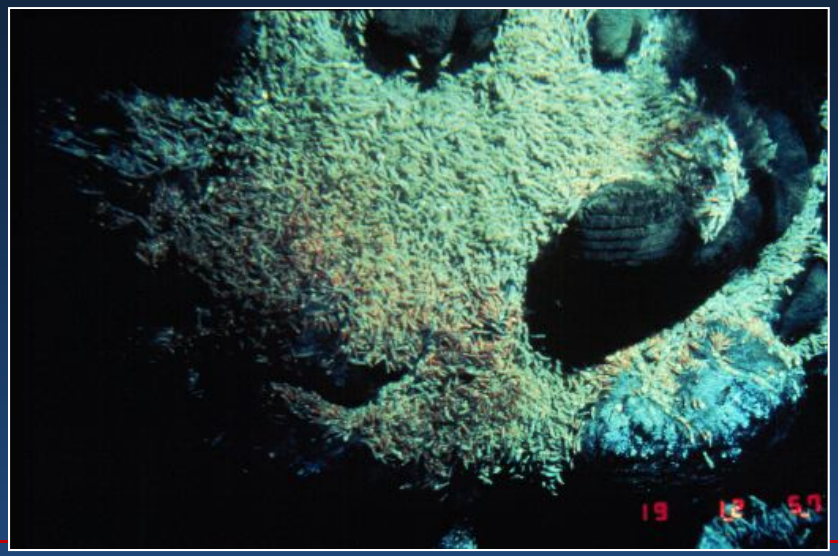
- Protect the future exploration of other solar system bodies for life, remnants of past life, and the precursors of life (forward contamination)
- Protect the Earth from possible hazards of returned extraterrestrial material (back contamination)

Article IX of the Outer Space Treaty of 1967:

"...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..."

PP implementation for MER

Earth's Deep-Sea Hydrothermal Vents: Life-as-we-didn't-know-it...



The discovery of abundant life at deep sea hydro-thermal vents in 1977 (7 months after the Viking missions landed on Mars) surprised everybody!

- It isn't that we expect to find these things out there—
- It's that we never expected to find them *here*....

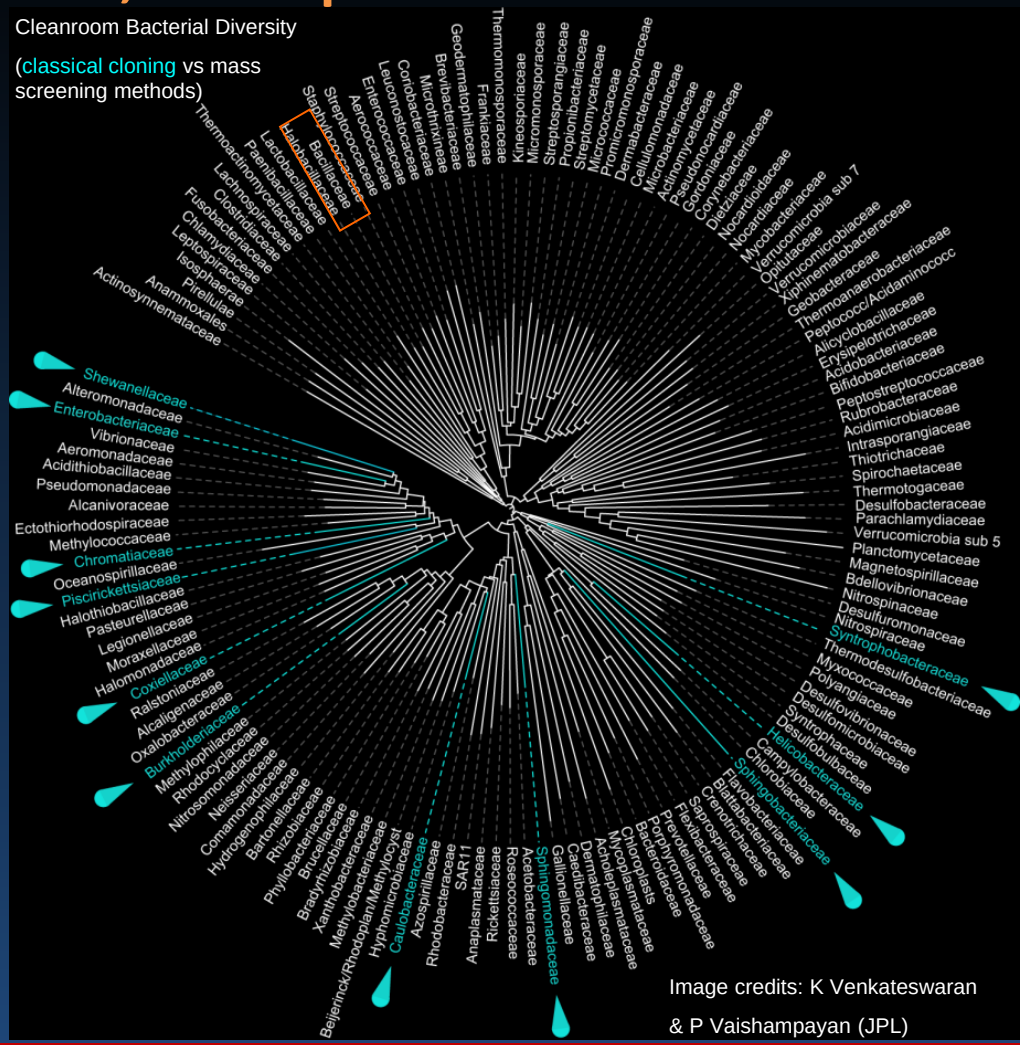
Life-as-we-now-know-it: Robust, Varied, Adaptable

Organism	Heat Survival D_{125} value (hr)	Time at 125°C to kill 10^3 (hr)
Bacillus atrophaeus *(vegetative cell)*	seconds	seconds
Bacillus atrophaeus *(spore)*	0.5	1.5
Bacillus ATCC29669	18.8	56.4
Bacillus xerothermodurans	139	416

The microbial biogeography paradigm:

"everything is everywhere; the environment selects" [what grows]

Bass-Becking, Lourens G.M. (1934)



Determining NASA Mission Category

PLANET PRIORITIES		MISSION TYPE	MISSION CATEGORY
A	Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted (no requirements)	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.	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 which could jeopardize a future biological experiment.	Flyby, Orbiter Lander, Probe	III IV
All	Any Solar System Body	Earth-Return (Can be "unrestricted" or "restricted Earth-return")	V

Planetary Protection – for JEO

- Preliminary PP categorization for JEO is category III, but formal planetary protection requirements have not been set for the baseline JEO mission
- Relevant NASA Planetary Protection documents
  - NPD 8020.7F, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft
  - NPR 8020.12C, Planetary Protection Provisions for Robotic Extraterrestrial Missions
  - NHB 5340.1B, NASA Standard Procedures for the Microbial Examination of Space Hardware*
- Categorizations are determined on a mission-by-mission basis:
  - Most current scientific information
  - Advice from the Planetary Protection Subcommittee of the NASA Advisory Council
  - Recommendations made by the Space Studies Board of the National Research Council

** To be superseded by NASA-HDBK-6022 Handbook for the Microbial Examination of Space Hardware*

Independent of a mission's categorization, the PP work that needs to be done is determined by the best available scientific information

NASA Requirements Flow-down

COSPAR

↓

NASA Policy

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Mission Category/Requirements

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PP Plan

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PP Implementation Plan

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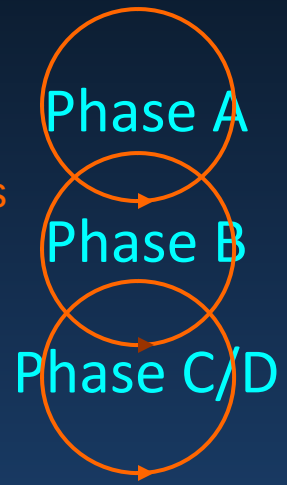
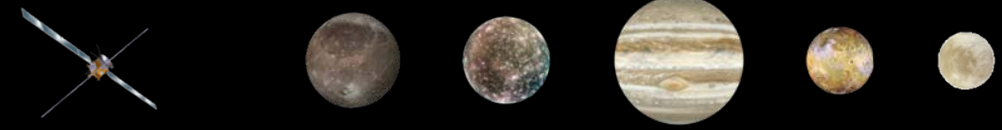
PP Implementation Activity

Compliance and LRR permission to fly

Iterative interactions with hardware owners



This iterative process needs to be introduced early in the project life cycle



JEO Planetary Protection Overview

- Category III (even though the EOM fate of the proposed JEO spacecraft is as a “hard lander”)
- Independent of the category, the principal anticipated requirement is a $1x10^{-4}$ probability of contaminating an europan ocean.
- Accepted method for assessing probability of contamination is the Coleman-Sagan formula ($P_c = N \times P_1 \times P_2 \times P_3 \times P_4 \times \ldots \times P_n$)
- It is agreed with the NASA Planetary Protection Officer that a spacecraft that is “sterile” on arrival at Europa will meet the $1x10^{-4}$ probability requirement
  - Europa has a geographically young surface, with evidence of “recent” resurfacing and a subsurface global ocean.
  - We have no acceptable means to conservatively assess likelihood of subduction into a subsurface ocean, so any spacecraft reaching the surface must be sterile (<1 survivor organism).

Coleman Sagan Rationale for JEO

- This approach removes many of the poorly defined/debatable/ unresolvable factors in the probability relationship, which simplifies the PP requirement to a probability of contamination at EOI, $P_{c[EOI]}$:

$$P_{c[EOI]} = N \times P_{cruise\ survival} \times P_{radiation\ survival} \leq 1$$

- Suitably conservative figures would be utilized for P_{cs}, P_{rad}, and N:
  - P_{cs} and P_{rad} would be based on the spectrum of organisms present, adopting the classification system of the Space Studies Board, 2000 report, as implemented in the Juno planetary protection approach.
  - N would be obtained from the combination of:
    - direct biological measurement
    - accepted parametric estimates taken from the NASA policy specifications
    - reduction following sterilization processing
    - estimate for recontamination based on the ATLO environment

JEO PP requirements would be stringent and unique, and would have many design implications

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PP implementation for “Curiosity” (MSL)

JEO Planetary Protection Overview

- JEO proposes to meet the PP requirement by sterilizing some hardware by either performing Dry Heat Microbial Reduction (DHMR) or another approved technique before launch and allowing the jovian radiation environment to sterilize other hardware.

Key paradigm: Penetrating sterilizing process must be used

- High level guidelines:
  - Hardware sees more than 7Mrad: sterilized en route.
  - Hardware sees less than 7Mrad: must be dry heat processed (T>110°C) or otherwise sterilized before launch.
- Recontamination may be managed through surface sterilization technologies, including chemical sterilants and UV irradiation

JEO Planetary Protection Approach (1)

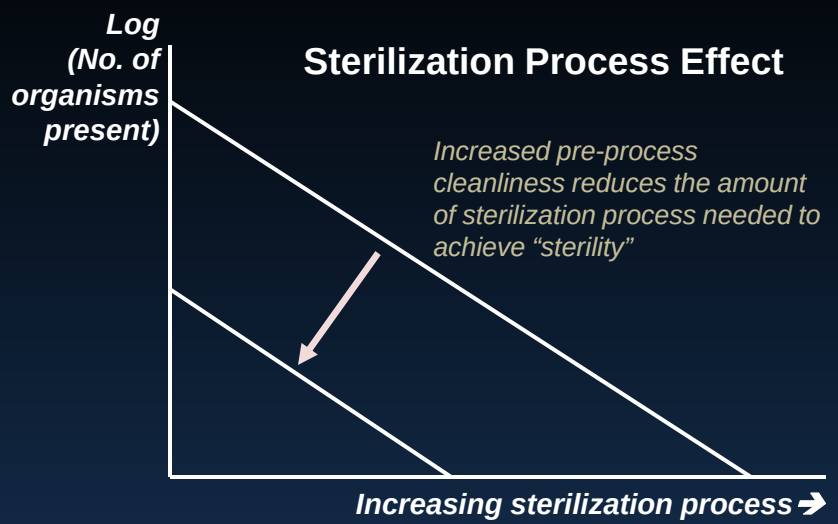
- Baseline is Standard Class 100,000 Assembly
  - Closest historical model is MRO (orbiter, bioburden control)
  - Additional requirements for recontamination control
- Ensuring Compatibility of Hardware
  - Design guidelines, Approved Parts and Materials List, parts and materials evaluations and issue resolution
  - Participation in trades and design of flight system and payload
  - Recent Mars Program studies on performing “Viking like” sterilization of MER and MSL did not identify any flight system “showstoppers”
  - Planetary Protection Approach Review (PPAR) scheduled in mid-Phase B to confirm approach with experts and the NASA PPO
- Radiation modeling is key to determining which hardware sees sterilizing dose of radiation and which needs DHMR sterilization to achieve sterility.

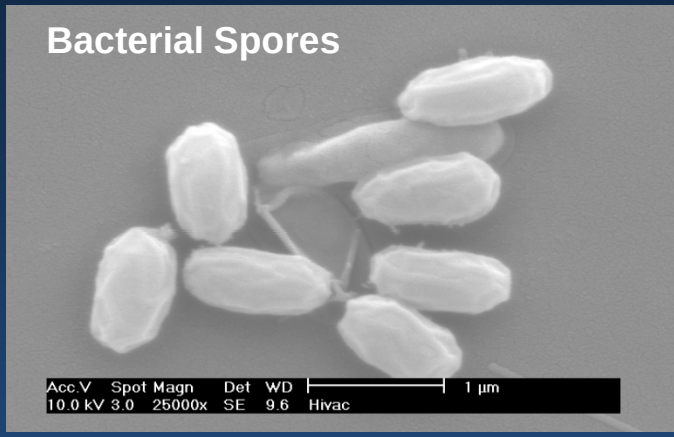
JEO Planetary Protection Approach (2)

- Each hardware element would be required to demonstrate compatibility with
  - Dry heat microbial reduction (DHMR)
  - Environmental radiation sterilization
  - Other sterilization approach agreed and accepted by the PP subject matter expert
- Cleanliness would be maintained by protecting from recontamination prior to launch with
  - HEPA filters
  - Biobarriers (per Phoenix)
  - Capability need already identified for aseptic integration
- Data from the operational phase of the mission, particularly during the Jovian tour, would inform the true irradiation environment experienced by the hardware.
  - This would give confidence that the required level of sterilization is achieved prior to EOI
  - Extending the pre-EOI tour to achieve a given irradiation dose for PP purposes would be investigated prior to the PPAR

Typical Hardware PP Implementation

- Biological contamination control
  - Clean benches, handling controls, cleaning
- Bacterial burden accounting
  - Materials and accessibility issues
- Microbial reduction
  - Design for tolerance of process
- Recontamination prevention
  - Design covers, bagging, and proper storage
  - Consider ATLO and testing
  - Flight biobarriers
- Record keeping
  - Assay results, process data, hardware treatment history, surface areas, organics list, etc.





Baseline Microbial Reduction Process

- Dry heat microbial reduction
  - Standard process specifications exist
  - Optimal in range 110°C to 125°C (50 to 5 hours) to achieve four order of magnitude reduction in bioload (under review)
  - Research is completing to increase to a broader temperature range and greater log reduction (needed)
  - Can be synergistic with a contamination control bakeout
  - No post-processing bioassays required (but pretreatment assays are typically used)

PP implementation for DS2 before mounting to MPL

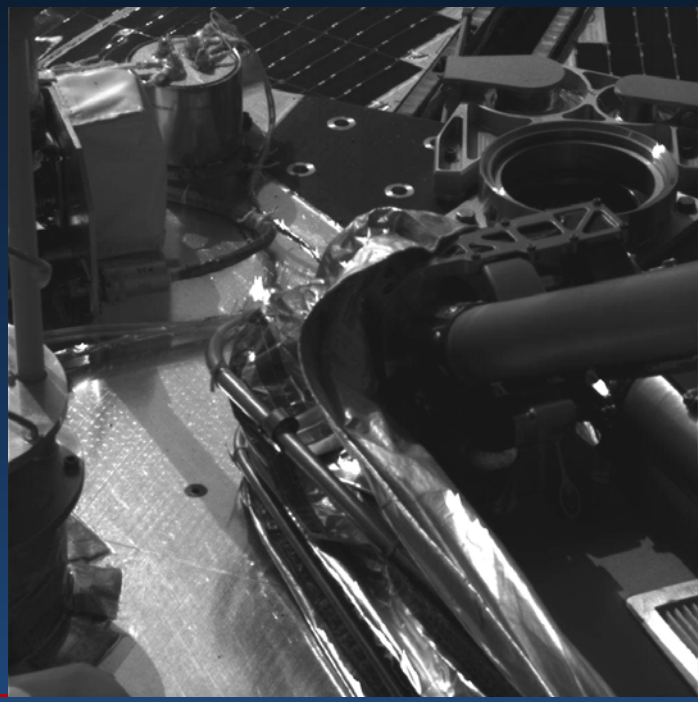
Alternative Microbial Reduction Processes

- Ionizing radiation (e.g. Gamma)
  - Alternate penetrating technology
- Hydrogen peroxide/ Hydrogen peroxide plasma
  - Surface only, requires bioindicator or proxy
- Other modalities possible (UV irradiation, etc.)
  - Require case by case validation
- Sterile at manufacture option
- Care needs to be taken to control recontamination, especially if multiple sterilization processes are deployed
- ATLO issues need to be addressed

Hydrogen peroxide plasma chamber

Biobarrier Implementation - Phoenix

- Needed to protect sampling arm from pre-launch/ launch/cruise/landing recontamination
- Similar strategies may be required for JEO instruments, e.g. with open apertures



Phoenix robotic arm biobarrier:
Left – Concept prototype
Above – Flight unit showing deployment detail, pre-launch
Right – Deployed unit at Mars

Issues and Considerations for Instrument Providers

- Design for cleanability
- Design for microbial reduction
- Design for recontamination prevention
- Design for ATLO flow/schedule
- Design out other undesirable features

Instrument developers may have to develop sterilizable versions of current sensors or to select alternate (e.g. DHMR robust) sensors, or alternative sterilization approaches

Consider early and discuss with the PP experts: Some instruments components are known to have issues with sterilization

Design for Cleanability

- Current approach assumes capability to maintain post-sterilization recontaminant spore density at 300/m^2.
- Design features need to be driven by sterilization process effect
- Typical features:
  - Smooth surfaces
  - Robust surface finish
  - Accessibility before closeout
- Material selection choices
  - Surface finishes (e.g. anodizing vs. coatings, different coating choices)

Design for Microbial Reduction

- Aim for tolerance of process (e.g., heat at 110°C or more)
- Use Class S/MIL specification parts (from APML)
- Allow margin – for gradients and for repeat (rework/hierarchical) processing
- Material selection choices
  - Metallic vs. organic
  - Dimensional stability/Coefficient Thermal Expansion mismatch issues
  - Effects on adhesives and lubricants
- Consider split assembly options: e.g. separate electronic elements (non-rad. hard) from other (heat sensitive) parts of instruments

Design for Recontamination Prevention

- Trade between open structure/jovian irradiation sterilization and enclosure/dry heat sterilization (other factors include mass and ease of rework)
- Closed at closeout (no gaps)
- Use of HEPA filters on enclosures (sizing for launch environment, testing of filters)

Design for ATLO Flow/Schedule

- Understand end-to-end ATLO Interface including integration/testing sequences and implications for recontamination
- Consider rework issues and develop mitigation strategies
- Integrate calibration sequences with ATLO and sterilization activities
- Baseline early testing
- Local *in situ* sterilization may be required during ATLO e.g. aseptic mating of two sterile components.

Design out Other Undesirable Features

- Other undesirable features
  - Unique for specific hardware items
  - Instrument subject matter expert (SME) and PP SME identify and resolve as a team

- Viking Lessons Learned (from Harrison Wroton, Viking Biology Instrument Manager):

  'In the final analysis, " what we ended up doing with the biology instrument was the highest level of failure analysis diagnostic corrective action activity that I've ever seen; we just had to make a religion out of doing it." It was the only salvation for us, because we knew that when we got down to finishing these instruments, "we couldn't go back and diddle with them!" There was a big test series that we had to put them through prior to that point, followed by the instrument sterilization, so we had to get everything just as right as we possibly could. "And I'm really so pleased that we did, because I think they worked perfectly."'

Points To Remember

- NASA HQ sets policy; The Project plans and implements to achieve compliance with the policy
- The PP SMEs work as part of the Project team, with both the Project and the Planetary Protection Officer to find an acceptable solution
- Requirements apply to all the hardware, including instruments
- Implementation methods and required activities may impact other assemblies and subsystems (a reason this is in discussion early!)

Points To Remember (cont.)

- Introduce into hardware design early
  - Confer with PP SME's
  - Incorporate an *approach* to PP compliance into design
  - Preferred sterilization technologies:
    - *Penetrating*: DHMR, Irradiation
    - *Surface only*: VHP, others *etc.*
  - Incompatible hardware cannot fly

Resources

- PP Overviews and general info:
  - http://planetaryprotection.nasa.gov/pp/
  - All of the Planets, All of the Time - Planetary Protection at NASA Billings, L. & Rummel, J.; Space Times. Vol. 43, no. 1, pp. 12-15. Feb. 2004
- PP Policy documents:
  - COSPAR: http://cosparhq.cnes.fr/Scistr/PPPolicy(20-July-08).pdf
  - NASA:http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8020_012C_&page_name=main
- PP for Europa:
  - NRC(SSB) Report: Preventing the Forward Contamination of Europa (2000)
- Contacts:
  - NASA Planetary Protection Officer (PPO), Dr. Catharine Conley (cassie.conley@nasa.gov, (202)358-3912) – advice on PP categorization, policy and requirements
  - JPL Planetary Protection POCs,
    - Dr. J. Andy Spry – general information on the PP approach for JEO
    - Laura Newlin – specific advice on PP for individual instrument concepts

Summary

- Planetary protection is recognized as a significant issue for the JEO mission
- Planetary protection policy is mature for Europa
- The JEO mission study has a mature but challenging PP implementation approach based on DHMR and environmental irradiation