Planetary Protection for the Proposed Outer Planet Flagship Missions

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PRE-DECISIONAL DRAFT— For planning and discussion purposes only

Topics

- Introduction to planetary protection (PP)
- Overview of NASA PP requirements
- General Points to remember
- Mission Specific Implementation
- Summary

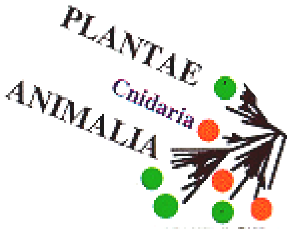
Purpose of Planetary Protection

- 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)

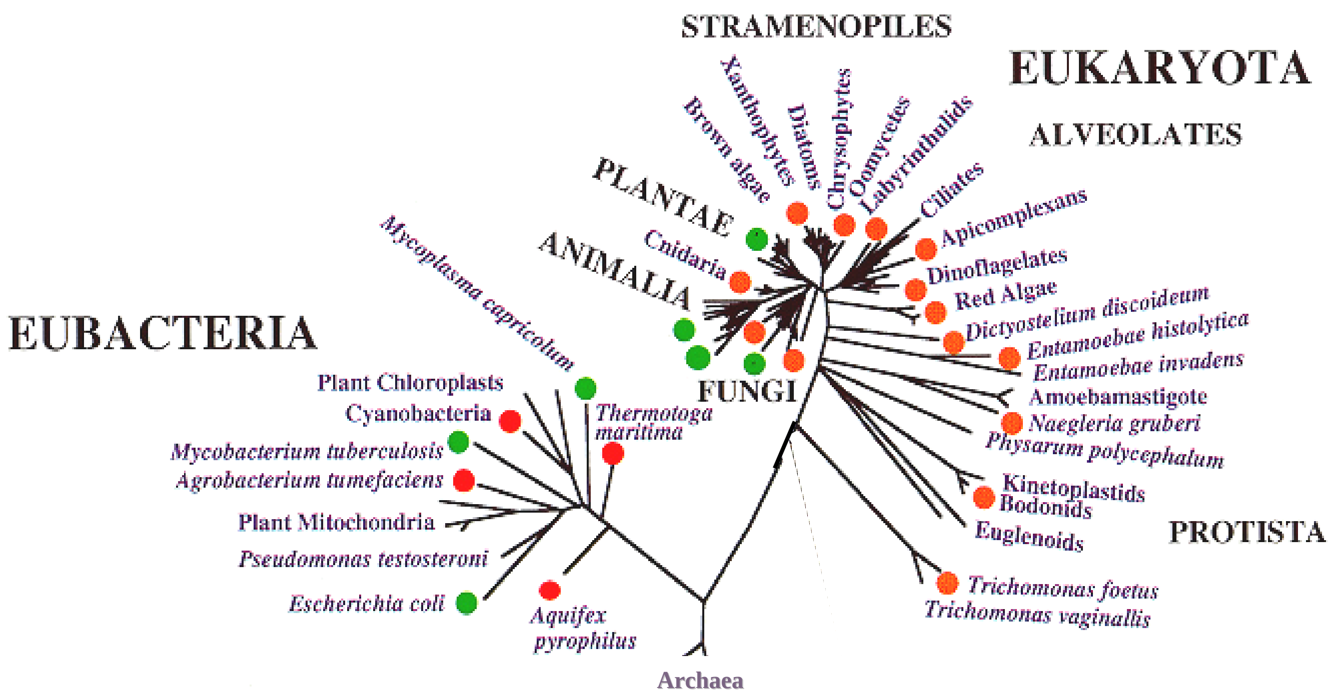
Article IX of the Outer Space Treaty of 1967:

“...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...”

Tree of Life – Pre-microscopy



Tree of Life – After Microscopy (since van Loewenhoek 1676)



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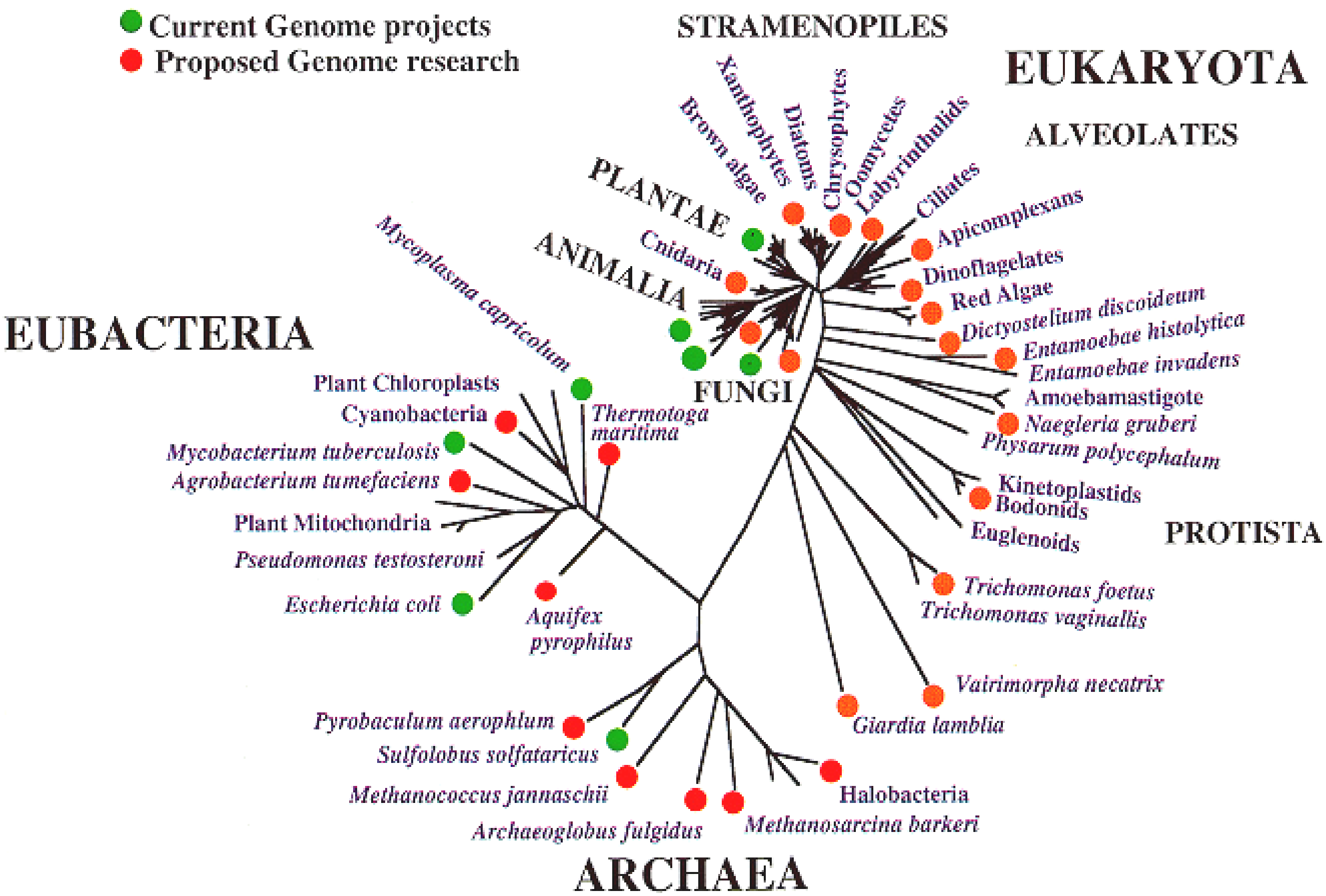
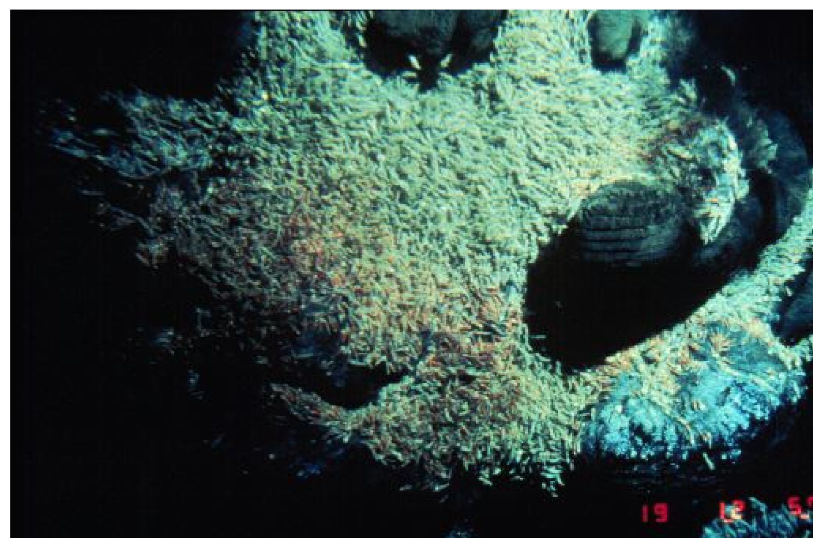
Tree of Life – After DNA sequencing discovery (1977)



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*....

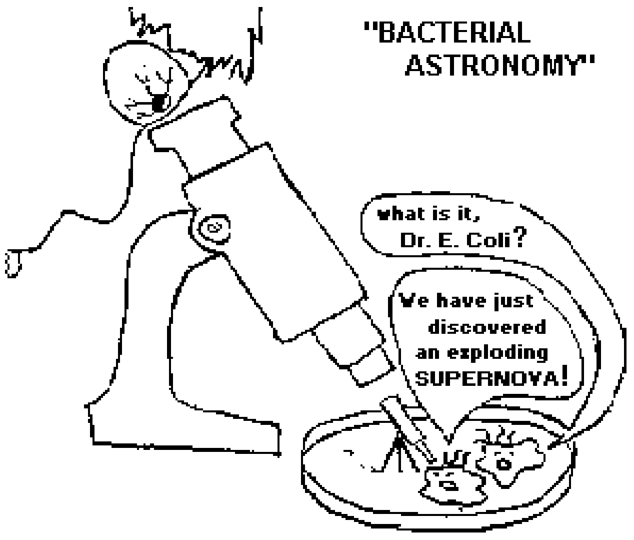
Planetary Protection vs. Contamination Control

- Contamination control
  - Particulate and molecular contamination
    - On payload instruments for proper function
    - On flight systems as required for instruments above
- Planetary protection (forward contamination)
  - Biological and organic contamination
    - Required on all flight hardware that reaches another planet
    - For the protection of the planet for *future* science
- Overlaps
  - Some but not all methodologies in common
  - PP interest in life detection and potential sample return

Planetary Protection: Determining Mission Category

Factors of Interest:

- Target Body Type
  - How interesting is it from a “Life in the Universe” perspective
- Mission Type
  - Flyby/Orbiter/Lander/Sample return
- Mission Purpose
  - Geophysics vs Life Detection



Planetary Protection Mission Categories

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

Actual Mission Categories

- N/A: Space Shuttle, ISS
- Cat I: JWST (formerly NGST)
- Cat II: Deep Impact, Stardust, Galileo#, Cassini/Huygens*
- Cat III
  - Bioburden: MRO
  - Orbital Lifetime: Odyssey, MGS
  - Flyby: Dawn
- Cat IV:
  - a: Pathfinder, MER, Beagle 2
  - b: Viking**, ExoMars
  - c: Phoenix, MSL
- Cat V
  - Unrestricted: Genesis, Stardust
  - Restricted: any future "MSR"

Data from Galileo resulted in a re-categorization of Europa, Ganymede, and Callisto

*Data from Cassini/Huygens might result in a re-categorization of Titan and Enceladus

**Viking would be classified as a IVb mission according to current definitions

Planetary Protection – a moving target

- Individual formal planetary protection guidelines have not been set for each of the destinations being studied. The NASA Planetary Protection Officer (PPO), Dr. Catharine Conley (cassie.conley@nasa.gov, (202)358-3912), is available to provide further guidance on the planetary protection categorization, requirements, and, strategy for each study. NASA requirements for Planetary Protection are found in NPD 8020.7F, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, and the subsidiary documents NPR 8020.12C, Planetary Protection Provisions for Robotic Extraterrestrial Missions, and NPR 5340.1C, NASA Standard Procedures for the Microbial Examination of Space Hardware, or revisions. Categorizations are determined on a mission-by-mission basis, applying the most current scientific information, with advice from the Planetary Protection Subcommittee of the NASA Advisory Council and considering recommendations made by the Space Studies Board of the National Research Council.

Planetary Protection – fixed once a category is set

- Historical implementations of PP have not resulted in changed categories in phases A-D
    - Phoenix
- Historical implementations of PP have resulted in changed payloads
    - Viking

PP Mission Categories* and Hardware (H/W) Requirements

- Categories with no PP hardware requirements
  - Category I: any mission type (except sample return) to the Sun, the Moon, Mercury, or undifferentiated, metamorphosed asteroids
  - Category II: any mission type (except sample return) to Venus, Jupiter, Saturn, Uranus, Neptune, Pluto, the outer planet satellites (except Jupiter icy moons: Europa, Ganymede, Callisto), comets, or other asteroids
- Category with modest PP hardware requirements
  - Category III: flybys and orbiters - Mars (some Mars orbiters) and flybys - Jupiter icy moons
    - Class 100 K clean room assembly/maintenance
    - Mars orbiters must have adequate orbital lifetime

***Categories per NPR 8020.12C (Appendix A) are advisory only. Others TBD pending NRC or other-source recommendations. NASA PPO sets the category.**

PP Mission Categories and H/W Requirements (cont.)

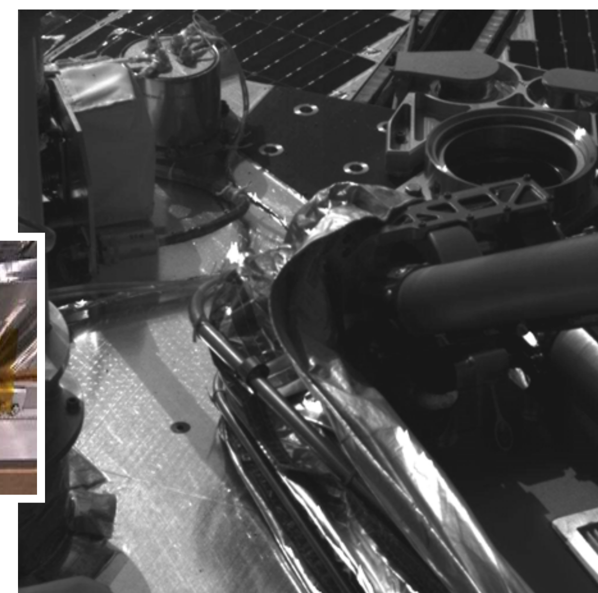
- Categories with rigorous PP hardware requirements
  - Category III: orbiters to Mars (without adequate orbital lifetime) and Jupiter icy moons
    - Class 100 K clean room assembly/maintenance
    - Stringent limit on spores (bacteria) on surfaces, in joints, and in the bulk of nonmetallic materials (total spores)
    - Organic material inventory (archival samples of materials present in large quantities)
  - Category IV: landers or probes to Mars and Europa (and per advisory, Ganymede and Callisto)
    - Mars without life detection, Category IV-A: as above, except stringent limits on accountable (unprotected) surfaces only
    - Mars with life detection, Category IV-B: as above, but the strongest limit on total spores (baseline is sterility)
    - Mars to special regions (regardless of instrumentation), Category IV-C (locations or depths of special biological interest: like IV-B)
    - Icy Moons: 10^{-4} probability of contamination of a subsurface ocean

PP Mission Categories and H/W Requirements (cont.)

- Categories with rigorous hardware requirements (cont.)
  - Category V: Earth return from any extraterrestrial solar system body (except the Moon)
    - For “restricted Earth return,” the most stringent requirements on sample containment and the prevention of the return of contaminated hardware
    - For “unrestricted Earth return,” no back contamination requirements
    - For both “restricted Earth return” and “unrestricted Earth return,” forward contamination requirements per the outbound category of the mission if there were no return, except that for “restricted Earth return,” if that would be category IV, category IV-B or C rules apply (as appropriate).

Implementation to Achieve Compliance

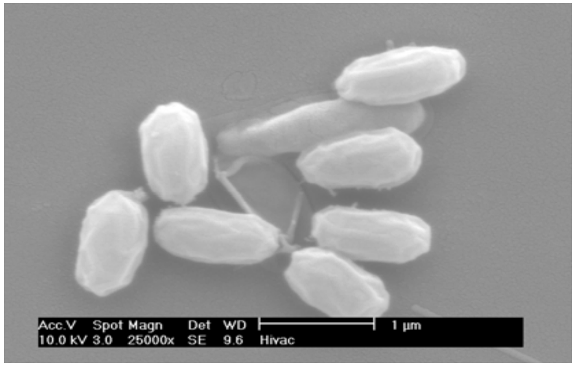
- Source of requirements
  - Project-specific requirements in PP Plan and Subsidiary Plans
- Hardware input/planning—input to PP Implementation document
  - Identification of hardware not exempt from PP biological cleanliness requirements



Phoenix robotic arm biobarrier

Typical Hardware PP Implementation

- Biological contamination control
  - Clean benches, handling controls, covers and cleaning
- Bacterial burden accounting
  - Materials and accessibility issues
- Microbial reduction
  - Design for tolerance of process
- Recontamination prevention
  - Design covers, bagging, and proper storage
- Record keeping (assay results, process data, hardware treatment history, surface areas, organics list, etc.)
- All of the above apply to hardware from outside sources, except when otherwise exempt from PP requirements



Bacterial Spores

Approaches for H/W of Category III Missions with Rigorous H/W Requirements and for Category IV and V

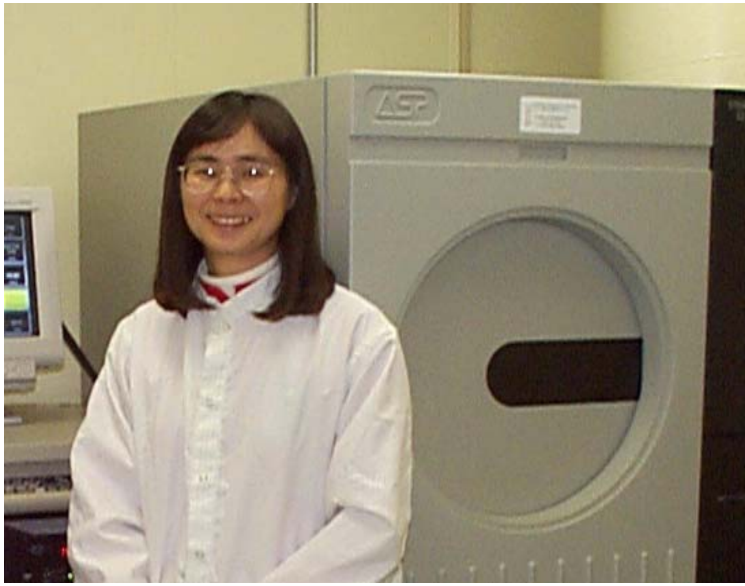
- Designing for cleanability
  - Smooth surfaces
  - Accessibility before closeout
- Minimizing accountable surfaces X not applicable to Europa
  - Isolation by high-efficiency particulate air (HEPA) filters or sealing
- Designing for microbial reduction
  - Tolerance for process (e.g., heat at 104ºC or more)
  - Especially important for impacting hardware, with *bulk* spore burden rules
- Designing for recontamination prevention
  - Closed at closeout (no gaps)
- Other desirable/undesirable design features
  - Unique for specific hardware items

Microbial Reduction Processes

- Dry heat microbial reduction
  - **Not equivalent to a contamination control bakeout**
  - Standard process specifications exist
  - No post-processing bioassays required (but pretreatment assays are typically used)
  - Optimal in range 110ºC to 125ºC (50 to 5 hours) to achieve 4log reduction in bioload (in review)
  - Research is completing to increase to a broader temperature range and log reduction

Microbial Reduction Processes

- Hydrogen peroxide plasma
  - Requires bioindicator or proxy
- Other modalities possible (ionizing radiation, UV irradiation, etc.)
  - Require case by case validation
- Care needs to be taken to control recontamination, especially if multiple sterilization processes are deployed.



Planetary Protection in a project setting:

" Protecting the Earth from the scum of the universe"

…and vice versa

Planetary Protection in a project setting:

“Planetary Protection is something I’ve had done to me more than once”

Planetary Protection in a project setting:

- Independent of the reality, compliance is required:

Points To Remember

- NASA HQ sets policy; The Project plans and implements to achieve compliance with the policy
- The PP Subject Matter Experts 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 Project PP Lead
  - Incorporate an *approach* to PP compliance into design
  - Get your input into the PP Implementation Plan
- Supply PP Lead with necessary information and material samples
- Record-keeping required for approval by NASA Planetary Protection Officer prior to launch and for End of Mission Report*

***PP compliance for Project does not end with launch**

Topics

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- Overview of NASA PP requirements
- General Points to remember
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TSSM Planetary Protection Overview

- The proposed End of Mission (EOM) fate of TSSM (as per the current study) as a "hard lander" on Titan TODAY means that it would need to meet the Planetary Protection Category II requirements of NPR 8020.12C.
- The proposed EOM fate of TSSM as a "hard lander" on Titan, to be launched in the next decade is expected to be that it would need to meet the Planetary Protection Category III requirements of NPR 8020.12C.
- The principal requirement is a 1x10^{-4} probability of "inadvertant contamination of a liquid water body".
- It is agreed with the NASA Planetary Protection Officer that a spacecraft that does not create an environment conducive to the replication of terrestrial biology will be in compliance.

  (Time constant guide = "the period of biological exploration" aka 1000 years)
- The key criteria are that the spacecraft will not cause viable terrestrial organisms to be placed in an environment with T>-80C (>193K).
- TSSM proposes to meet this requirement by:
  - Passive/active deorbit at end of mission, ensuring avoidance of geographic/thermal anomalies.
  - Analysis to confirm that local RTG (baseline power source) heating will not transgress the "limits of life" and/or that RTGs will not co-locate with contaminated hardware.
  - (In situ payload is not addressed in this study)
- Tour trajectories will also be required to avoid collisions with Titan or Enceladus that would place spacecraft hardware in contact with subsurface liquid water at the appropriate probability level (Cassini requirement: 1x10^{-3} total per object for the whole mission)

JEO Planetary Protection Overview

- The EOM fate of the proposed JEO spacecraft as a "hard lander" on Europa means it would have to meet the Planetary Protection Category III requirements of NPR 8020.12C.
- The principal requirement is a 1×10^{-4} probability of contaminating an europan ocean.
- It is agreed with the NASA Planetary Protection Officer that a spacecraft that is "sterile" on arrival at Europa will meet the 1×10^{-4} requirement.
- JEO proposes to meet this 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.
- High level guidelines*:
  - Hardware sees more than 7Mrad: sterilized en route.
  - Hardware sees less than 3Mrad: must be dry heat processed (T>110°C) or otherwise sterilized before launch**.
  - Hardware sees 3-7Mrad: combination approaches may be possible.

* Interpretations based on the 2002 NRC SSB Preventing the Forward Contamination of Europa study, and accepted in the Juno PP report.

** The proposed plan, where JEO would crash and break open, means that sterilization through solid materials must be performed, limiting approaches to heat and ionizing radiation. However, recontamination may be managed through surface sterilization technologies, including chemical sterilants and UV irradiation.

Comparison of TSSM/JEO PP Rationale

	JEO	TSSM
Target/Mission Categorization	III	II (but managed based on anticipated change to III/IV)
Planetary Protection Requirement basis	NHB8020.12C – avoidance of contamination of an Europan (*water*) ocean at the $P< 1x10^{-4}$ level	Anticipated requirement to avoid contamination of a liquid water body at the $P< 1x10^{-4}$ level
Planetary Protection Implementation	Ensure the spacecraft is sterile (statistically <1 viable organism) by time of Europa orbit insertion	Ensure the spacecraft does not land in a region conducive to terrestrial replication, and that RTG (baseline power source) heat induced replication cannot occur
Scientific basis of approach	Europa has a geographically young surface, with evidence of recent liquid water flow 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.	Titan has a geographically young surface, but with evidence of liquid water flow constrained to a small proportion of the surface. Avoidance of these regions means that any terrestrial contaminants will always be in environments not conducive to replication.

Comparison of PP Approaches

- JEO (as currently proposed)
  - Cat III orbiter/"hard lander" as previously described
- Juno
  - Cat II Jupiter orbiter
  - Required to demonstrate avoidance of contamination of Europa by trajectory design, even in passive (post EOM) state.
  - Trade between:
    - sterility due to irradiation/elapsed time/spectrum of organisms present and (low) probability of impact with Europa for a given trajectory, plus
    - impact velocity, which in conditions where impact may occur, will be high enough to vaporize all spacecraft hardware to a high probability.

JEO Planetary Protection Implementation

- Baseline is Standard Class 100,000 Assembly
  - Closest historical model is MRO (orbiter, bioburden control), but with additional requirements for not recontaminating hardware that does not receive a sterilizing radiation dose during the jovian tour.
- Radiation Model Influence
  - Radiation modeling will inform the implementation of PP by determining which hardware sees sterilizing dose of radiation and which needs DHMR sterilization to achieve sterility by Europa Orbit Insertion. …
- Compatibility of Hardware
  - PP Lead staffed very early in project (Pre-Phase A) and involved with design guidelines, parts and materials evaluations and issue resolution.
  - PP will be intimately involved in development of flight system and payload to ensure that, as much as is possible of the flight hardware is compatible with DHMR, independent of the anticipated current sterilization plan (included as a requirement in the Approved Parts and Materials List).
  - Recent Mars Program studies on performing "Viking like" sterilization of MER and MSL did not identify any technical "showstoppers".
- ATLO Interface
  - There is a significant trade space for PP re-contamination control and ATLO flow/schedule. This will be worked iteratively as the spacecraft PP implementation and ATLO sequence are further developed.
- Planetary Protection Approach Review scheduled in mid-Phase B to confirm approach with experts and the NASA PPO.

JEO Planetary Protection Issues and Challenges

- Radiation/Vacuum Effects on Microorganisms
  - The 2002 NRC Space Studies Board study is conservative. Current research is leading to a full inventory of all microorganisms on spacecraft surfaces.
    - *An augmentation to this research to gain full understanding of radiation resistant organisms may reduce the conservatism (radiation dose to achieve sterility) applied to the spacecraft.*
  - Exposure of radiation resistant organisms to space vacuum constrains their radiation resistance
- Known Hardware Issues
  - Some instruments components (e.g. sensor compatibilities) are known to have issues with dry heat sterilization.
    - *Instrument developers will be required to develop sterilizable versions of current sensors or to select alternate (DHMR robust) sensors.*
  - Li-Ion batteries cannot be dry heat sterilized.
    - *An alternate sterilization technology (irradiation is preferred) is one option.*
    - *An alternate battery technology will be selected (with mass/ power penalty).*
- Known Implementation Issues
  - Local *in situ* sterilization may be required during ATLO e.g. mating two sterile components.
    - *This approach will need to be developed, but chemical (Vapor-phase Hydrogen Peroxide) and physical (uv, surface heating) alternatives exist.*
  - There will be ATLO flow and schedule issues as a result of PP implementation, particularly with regard to recontamination and spacecraft test environments.
    - *These will be addressed during the development of the ATLO approach and detailed schedule.*
  - Further study may show that enhanced cleanliness facilities may be required in ATLO.
    - *The solution is known (temporary clean tents), but with cost/schedule impact.*

Issues and Considerations for Instrument Providers

- Consider split assembly options: separate e.g. electronic elements (non-rad. hard) from other parts of instruments
- Understand integration sequences and implications
- Raise rework issues and develop mitigation strategies
- Integrate calibration sequences with ATLO and sterilization activities
- Baseline early testing

- 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."'

Summary

- Planetary protection is recognized as a significant issue for both TSSM and JEO mission studies.
- Planetary protection policy is mature for Europa, with policy for Titan in the process of being formally updated based on Cassini-Huygens data, and with the continuing possibility of change based on new scientific data.
- The proposed JEO mission study has a mature but challenging PP implementation approach based on DHMR and environmental irradiation.
- The proposed TSSM mission study has a viable PP implementation approach developed, based on analysis, and avoidance of PP sensitive locations/features.