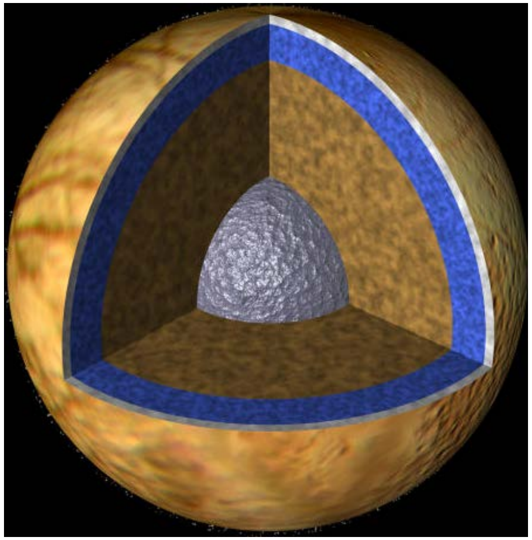
Planetary Protection for Icy Moons: updating the SSB Europa Report



C. Conley, NASA HQ

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NASA Planetary Protection Policy

- "The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized."
    - Preserves science opportunities directly related to NASA's goals, and can support certain ethical considerations; originally recommended to NASA by the NAS in 1958
    - Preserves our investment in space exploration
    - Can preserve future habitability options
- "The Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet."
    - Preserves Earth's biosphere, upon which we all depend...
- Assignment of categories for each specific mission/body is to "take into account current scientific knowledge" via recommendations from advisory groups, "most notably the Space Studies Board."
- NPR 8020.12 specifies that NASA will participate in international robotic missions only if COSPAR policy is followed, to ensure US compliance with the Outer Space Treaty

International Obligations

- The Outer Space Treaty of 1967
  - Proposed to the UN in 1966; Signed in January 1967
  - Ratified by the US Senate on April 25th, 1967
  - Article IX of the Treaty states that:

"...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 Committee on Space Research of the International Council for Science maintains an international consensus policy on planetary protection
  - COSPAR policy represents an international scientific consensus, based on advice from national scientific members, including the US Space Studies Board
  - COSPAR is consultative with the UN (through UN COPUOS and the Office of Outer Space Affairs) on measures to avoid contamination and protect the Earth under the Treaty

Category III/IV Requirements for Europa

Category III and IV. Requirements for Europa flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of an europan ocean to ***less than 1 x 10^{-4} per mission***. These requirements will be refined in future years, but the calculation of this probability should include a ***conservative estimate of poorly known parameters*** and address the following factors, at a minimum:

Probabilistic formulation takes a ‘reduction factors’ approach modified from the Coleman-Sagan probabilistic formulation.

Preventing Contamination of Icy Moons: A Coleman-Sagan Formulation

The number of microbes of type X that could survive on an icy body is based on the initial contamination level [N_{X0}] and various survival factors:

$$N_{final} = \sum_X N_{Xinitial} F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

$P_{contamination}$ is set equal to N_{final}

F_1—Total number of cells relative to assayed cells (N_{X0})
F_2—Bioburden reduction survival fraction, when applied
F_3—Cruise survival fraction
F_4—Radiation survival fraction
F_5—Probability of impacting a protected body, including spacecraft failure modes
F_6—Probability that an organism survives impact
F_7—Burial survival fraction

(Probability of growth given introduction is assumed to be 1)

- Where the organisms of type X are defined as:

Type A: Typical, common microbes of all types (bacteria, fungi, etc.);
Type B: Spores of microbes, which are known to be resistant to insults (e.g., desiccation, heat, radiation);
Type C: Dormant microbes(e.g., spores) that are especially radiation-resistant; and
Type D: Rare but highly radiation resistant non-spore microbes (e.g., *Deinococcus radiodurans*).

Juno Implementation Approach

Juno proposed to meet planetary protection requirements by avoiding impact with Europa (and other Galilean satellites) via an End-of-Mission Deorbit Maneuver.

To document a $1x10^{-4}$ probability of contamination, Juno considered (among others) the following factors:

- How reliable is the spacecraft, over the entire mission phase during which Europa is in jeopardy – i.e., what happens if it stops working by accident?
- How long will organisms survive on the spacecraft – i.e., when does 'viable' become moot?
  - Bioburden at launch
  - Survival of contaminating organisms until impact: how lethal is the space environment?
- How likely is an Europa encounter?
- Can organisms survive the impact?
- Mechanisms of transport to the europan subsurface (JUNO didn't need this)

JUNO Allocations and Estimates

Item	Current Best Estimate	Requirement Allocation
Failure Risk Analysis: Probability that spacecraft failure prevents deorbit burn	0.045	≤ 0.1
Mission Design: Probability of impact of a non-sterile spacecraft (L3 Mission System)	0.005	≤ 0.015
Spacecraft/Europa Impact Analysis: Probability of contamination in the event of an impact	<0.04	0.06
Probability of contamination of the Europan Ocean	$<9\times10^{-6}$	9×10^{-5}
Requirement	$<1\times10^{-4}$	

The ability to include additional factors in the probabilistic calculations based on mission-specific parameters allowed JUNO to determine in the early phases of mission design what would be necessary for compliance with planetary protection requirements.

COSPAR Workshops on Icy Bodies

“Workshop on Planetary Protection for Outer Planet Satellites”

15 - 17 April 2009 Vienna, Austria

“Workshop on Titan Planetary Protection”

9 - 10 December 2009 Pasadena, California

Basic Concept for the Workshops

- Review planetary protection recommendations from the US SSB, and others, on
  - Small bodies of the solar system
  - Europa
  - Mars Special Regions (limits of life)
- Review what is known, or suspected, about the Outer Planet Satellites and other small bodies of the solar system
- Attempt to classify these objects with reference to the overall understanding of them, and their potential to support Earth life
- Review the implications of these findings on the Outer Planets Flagship missions, and other potential mission inputs, and then promulgate the final set.

Preventing the Forward Contamination of Titan?

COSPAR Workshop Example Calculation of Contamination

The number of organisms that will Survive on Titan is based on the initial contamination level [N_0] and various survival factors:

$$N_s = N_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

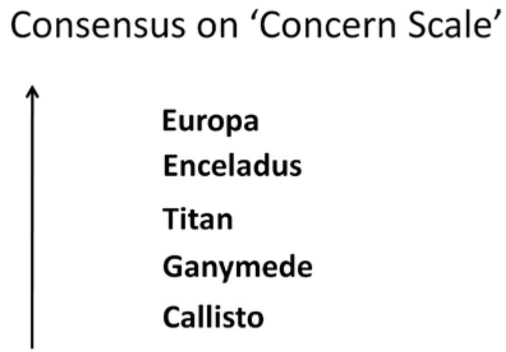
F_1—Bioburden Reduction Treatment	1
F_2—Cruise Survival Fraction	10^{-1}
F_3—Radiation Survival in the Near-Surface/Orbital Environment	10^{-1}
F_4—Probability of Landing at an Active Site	2×10^{-3}
F_5—Burial Fraction (Below the “Cap”)	1×10^{-4}
F_6—Probability of Getting “There” on the Conveyor	1
F_7—Probability that an Organism Survives and Proliferates	
During Landing (F_{7a})	1
On the Surface (F_{7b})	1
During Transport (F_{7c})	10^{-2}
In Ocean (F_{7d})	1
N_0 One Million Microbes...or More	10^6+
N_s	2×10^{-5}

We need N_s to be less than 1×10^{-4}

Key Uncertainties in Current Knowledge

There seems to be consensus on the relative ranking of the satellites in the Jupiter and Saturn systems with respect to the degree of concern for planetary protection. This ranking results primarily from a combination of:

1. Evidence for liquid water in their interiors,
2. Probable depth to liquid layer (shallow or deep),
3. Geologic ‘youthfulness’ and activity



- A major difficulty is a lack of agreement in the planetary community regarding the mechanisms and time scales of the geological processes which might result in the exchange of material between the surface and the liquid layers.

- New data and research in several different areas are needed, including spacecraft and telescopic observations, theoretical modeling, laboratory measurements, and related astrobiologic studies.

SSB Europa Report Update Request

As NASA prepares for these future collaborative missions, it would be very helpful for the SSB to review the findings of the 2000 Europa report and incorporate conclusions from a series of recent workshops on planetary protection for icy bodies sponsored by COSPAR, in which it was determined that the probabilistic approach for regulating contamination of icy bodies should be retained to accommodate the wide range of objects for which requirements must be set. Ideally, this study would update and expand previous SSB recommendations to cover, as much as is currently feasible, the entire range of icy bodies in the outer solar system (asteroids, satellites, Kuiper-Belt Objects, comets) in light of current scientific understanding and ongoing improvements in mission-enabling capabilities and technologies.

- Review the findings of the 2000 Europa report
- Incorporate conclusions from recent COSPAR workshops on planetary protection for icy bodies
- Expand previous SSB recommendations to cover the wide range of icy bodies in the outer solar system

Specific Points to Consider

Specifically, the SSB would consider the following subjects and make recommendations, as appropriate, in a report to NASA:

- The possible factors that usefully could be included in a Coleman-Sagan formulation describing the probability that various types of missions might contaminate with Earth life any liquid water, either naturally occurring or induced by human activities, on or within specific target icy bodies or classes of objects;
- The range of values that can be estimated for the above factors based on current knowledge, as well as an assessment of conservative values for other specific factors that might be provided to missions targeting individual bodies or classes of objects; and
- Scientific investigations that could reduce the uncertainty in the above estimates and assessments, as well as technology developments that would facilitate implementation of planetary protection requirements and/or reduce the overall probability of contamination.

Alles sollte so einfach wie möglich gemacht werden, aber nicht einfacher.

Albert Einstein

Everything should be made as simple as possible, but not simpler.