JEO & JGO
Classification, Requirements and Measures

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EJSM Instrument Workshop
18 – 20 January 2010

Outline

General:
- Planetary protection policy
- Planetary protection categories
- Methods & procedures to implement and verify requirements
- Planetary protection documentation and reviews

JEO: Requirements and Measures
- Mission requirements
- Juno as a test case

JGO: Requirements and Measures
- Mission requirements
- Use of penetrator systems

Lessons Learned from Previous NASA Missions

Planetary Protection Courses

Planetary Protection Policy, Categories and General Requirements

Planetary Protection Policy

The basic goals of planetary protection are:

- To preserve planetary conditions for future biological exploration

  Protect our investment in space science and exploration

- To protect Earth and its biosphere (including the Moon) from potential harmful extraterrestrial contamination

  Simple prudence; protect the Earth!

Formal Legal Basis

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...”

“Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies.”
(entered into force, October 10, 1967; ~100 signatories)

COSPAR and Planetary Protection

- A report issued by a sub-committee of the International Council of Scientific Unions in 1958 described the first code-of-conduct for planetary protection and recommended that the newly formed Committee on Space Research should resume responsibility for matters of planetary protection
- The first flight project using these recommendations was the Ranger project in 1961
- COSPAR maintains and promulgates a planetary protection policy and requirements for the reference of spacefaring nations as an international standard
- Dedicated planetary protection panel
- Organising working meetings, workshops and conferences to review and complement the current planetary protection policy and requirements

Planetary Protection Categorization

- NASA and ESA planetary protection policies stipulate compliance with the COSPAR planetary protection policy
- NASA/ESA Planetary protection LoA in place to ensure consistent categorization and requirements
- Mission lead Agency bears the overall responsibility for planetary protection compliance
- Planetary protection category is assigned/approved by the Agency’s PPO, based on COSPAR planetary protection policy
- Mission category depends on the combination of target body and mission type

Mission Categories

PLANET PRIORITIES	MISSION TYPE	MISSION CATEGORY
Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
Of significant interest relative to the process of chemical evolution and the origin of life, but only a remote chance that contamination by spacecraft could compromise future investigations.	Any	II
Of significant interest relative to the process of chemical evolution and the origin of life and for which scientific opinion provides a significant chance of contamination which could compromise future investigations.	Flyby, Orbiter	III
	Lander, Probe	IV
Any Solar System Body	Earth-Return *“restricted” or “unrestricted”*	V

Remote Chance of Contamination

Absence of environments where terrestrial organisms could survive and replicate

Or

Very low likelihood of transfer to environments where terrestrial organisms could survive and replicate

Significant Chance of Contamination

Presence of environments where terrestrial organisms could survive and replicate

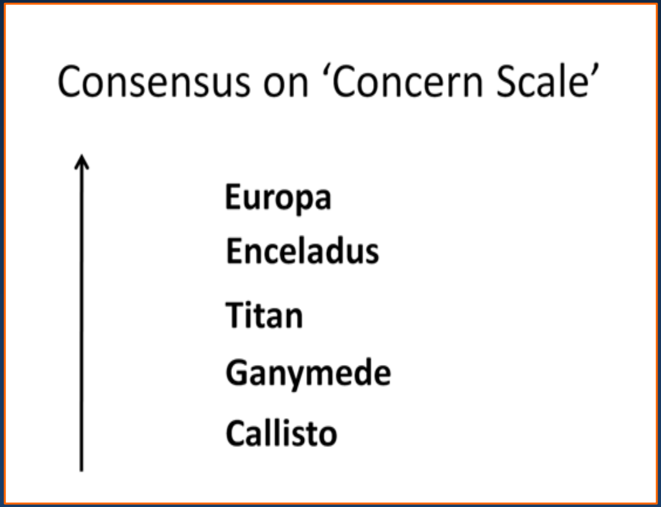
And

Some likelihood of transfer to those places by a plausible mechanism

Concern Scale

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:

- Evidence for liquid water in their interiors
- Probable depth to liquid layer (shallow or deep)
- Geologic 'youthfulness' and activity



A major difficulty was 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

Category Specific Listing

Category I: Flyby, Orbiter, Lander: Undifferentiated, metamorphosed asteroids; others TBD

Category II: Flyby, Orbiter, Lander: Venus; Moon (with organic inventory); Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; Ganymede*; Titan*; Triton*; Pluto/Charon*; Ceres; Kuiper-Belt Objects > 1/2 the size of Pluto*; Kuiper-Belt Objects < 1/2 the size of Pluto; others TBD

Category III: Flyby, Orbiters: Mars; Europa; Enceladus; others TBD

Category IV: Lander Missions: Mars; Europa; others TBD

Category V: Any Earth-return mission.
“Restricted Earth return”: Mars; Europa; others TBD;
“Unrestricted Earth return”: Venus, Moon; others TBD.

*The mission-specific assignment of these bodies to Category II must be supported by an analysis of the “remote” potential for contamination of the liquid-water environments that may exist beneath their surfaces (a probability of introducing 1 viable terrestrial organism of $<1 \times 10^{-4}$), addressing both the existence of such environments and the prospects of accessing them.

Methods & Procedures

A set of methods & procedures to implement and verify the requirements are already available to use for the project:

- For bioburden reduction – Dry Heat Microbial Reduction (DHMR)
- For bioburden evaluation – Standard assays

Other methods & procedures can be proposed by the project but require demonstration of effectiveness and are subject to approval (some are currently Agency undertakings)

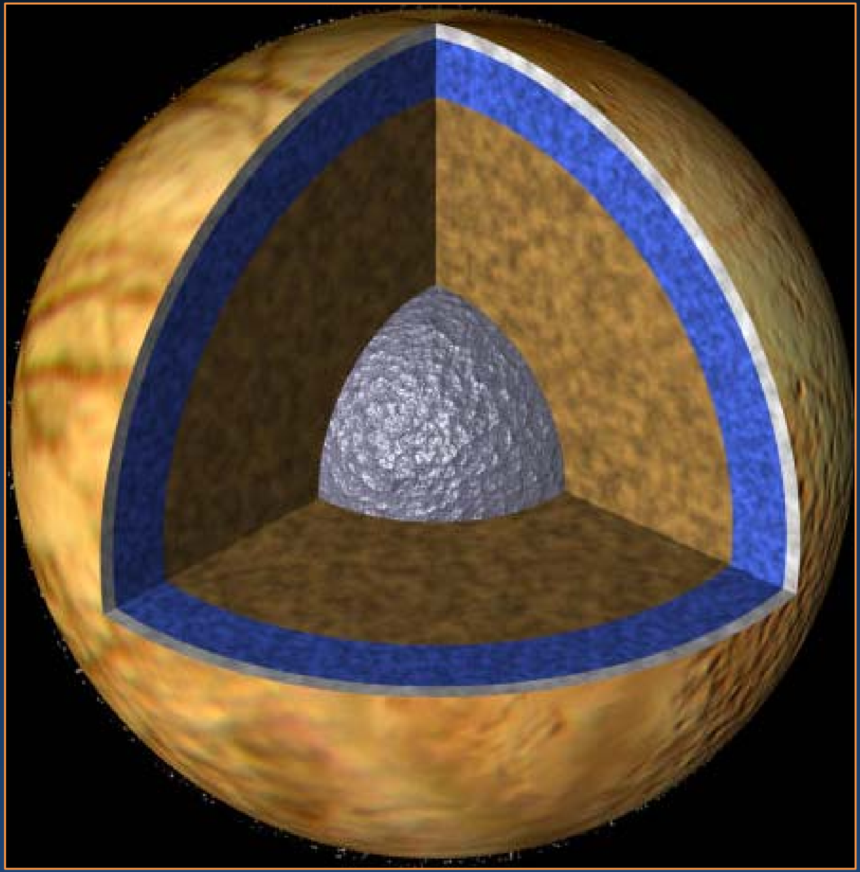
Documentation and Reviews

Description of the planetary protection organisation, schedule and resources have to be identified in the projects Project Plan.

Specific documentation for Cat. II and III are usually reviewed at key project/Agency reviews:

Document	Review
Planetary protection plan	PDR
Planetary protection implementation plan	CDR
Pre-launch report	FRR
Post-launch report	< 6 month post launch
(Extended mission report	As required)
End-of-mission report	End-of-mission review

JEO: Requirements and Measures



Preventing Contamination of Icy Moons: An example probabilistic approach

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:

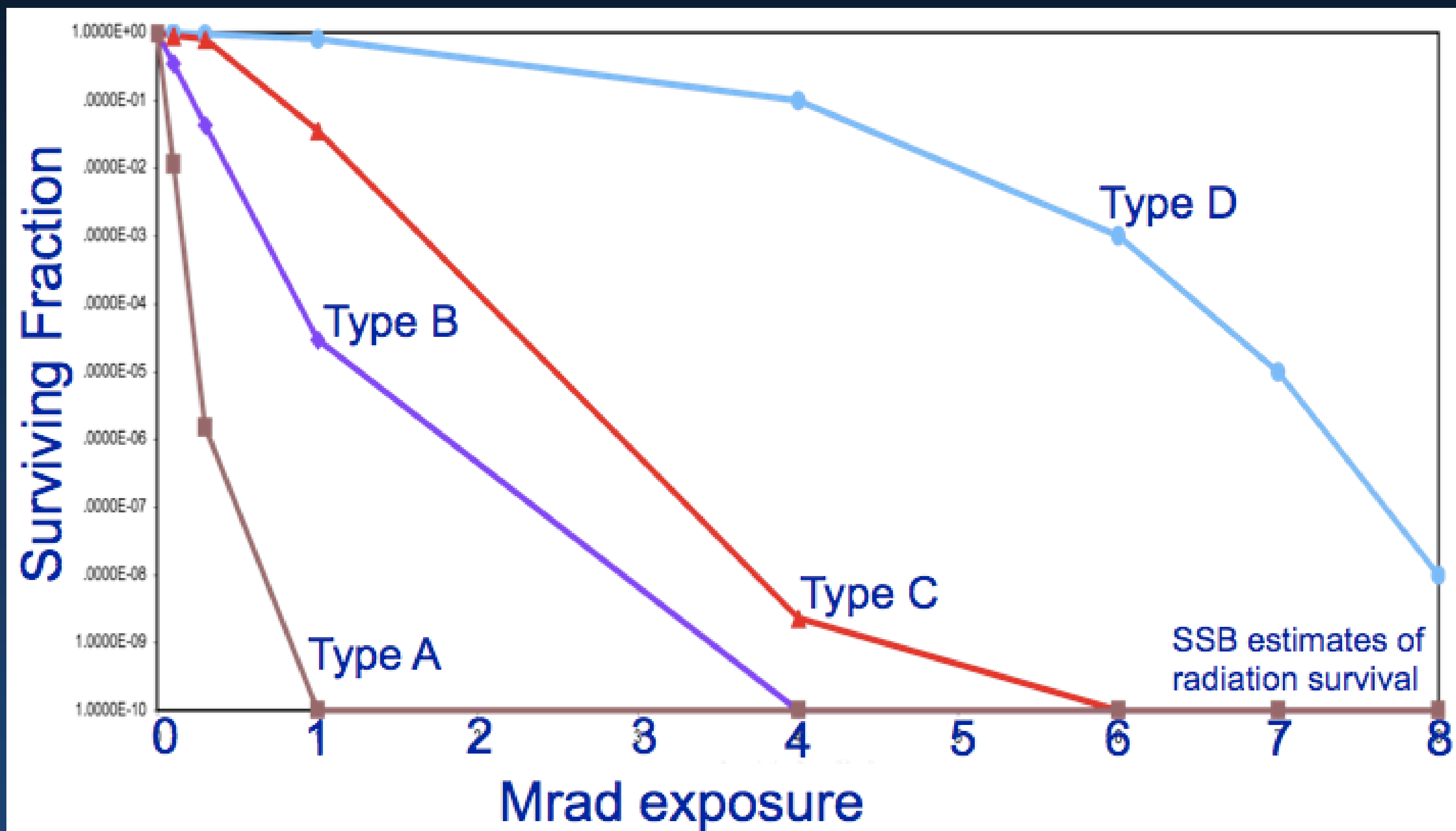
$$N_{Xs} = N_{X0}\, F_1\, F_2\, F_3\, F_4\, F_5\, F_6\, F_7$$

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*).

Microbes are More Radiation Resistant than Electronics...



Type A: Typical, common microbes

Type B: Spores of typical microbes

Type C: Dormant microbesthat are especially radiation-resistant;

Type D: Rare but highly radiation resistant non-spore microbes (e.g., *Deinococcus radiodurans*).

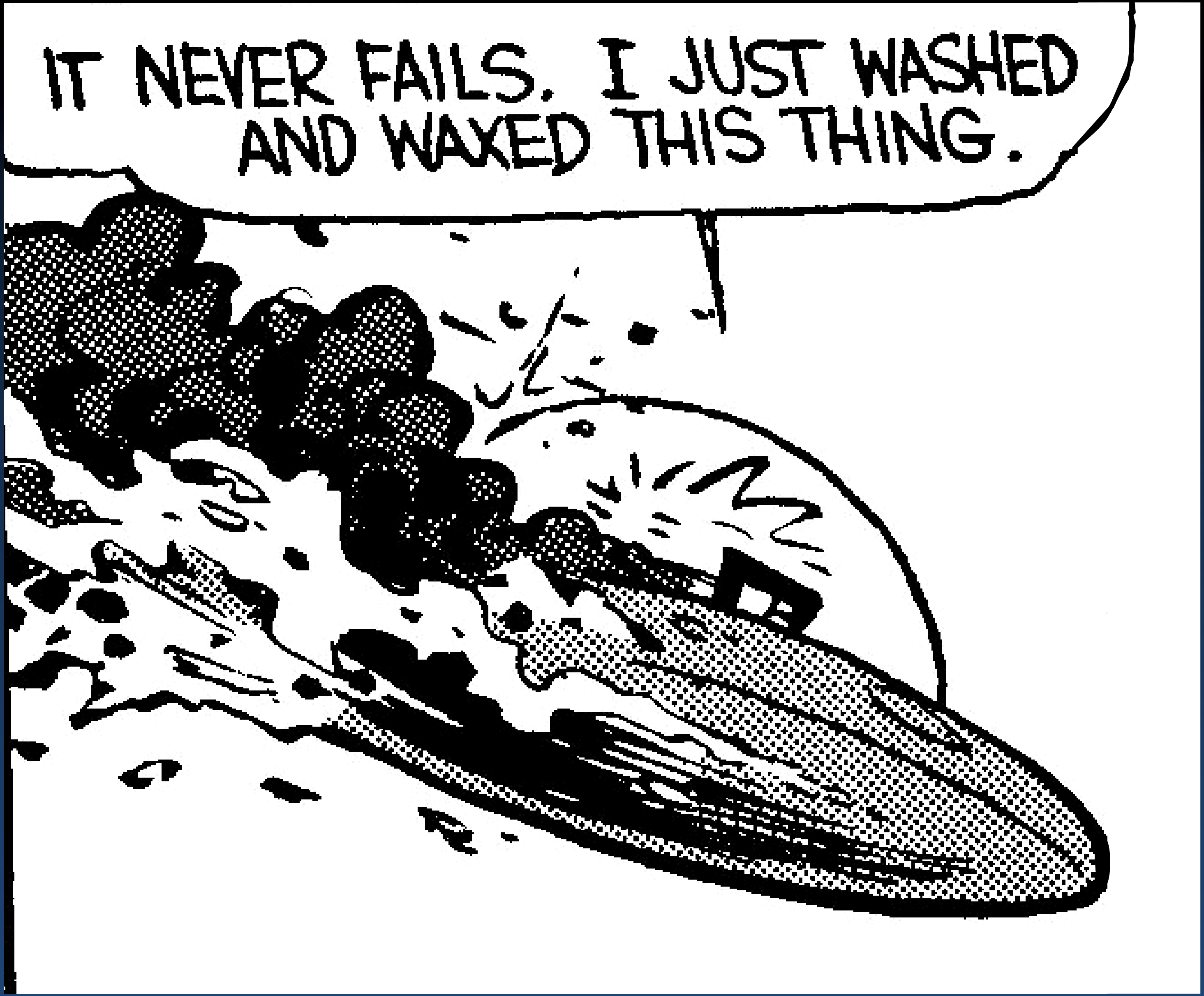
Requirements for JEO

The probability of inadvertently introducing a single viable microbe into a liquid water body (e.g., subsurface ocean) shall be less than 1x10^{-4} over the entire course of the mission.

- The calculation of this probability should include a conservative estimate of poorly known parameters, and address the following factors, at a minimum:
  - Bioburden at launch
  - Survival of contaminating microbes during cruise
  - Microbe survival in the Jovian radiation environment
  - Probability of surviving impact on Europa (after EOI, assume 1)
  - The mechanisms of transport to the europan subsurface (assume 1)
  - Reliability of spacecraft control systems and spacecraft trajectory after failure
- *The period during which contamination is of concern extends from the point at which Europa is first in jeopardy, for the length of time that microbes remain viable on the spacecraft.*

Additional Measures for JEO

- Evaluation of impact probability includes propagation of orbital trajectory assuming failure after each trajectory change maneuver. Impact energy may be considered when evaluating probability of survival given impact.
- Previous experience suggests that bioburden control will be necessary, requiring the use of cleanroom technology, cleaning of parts before assembly, and monitoring of spacecraft assembly facilities to understand the bioload and its microbial diversity, including specific problematic species.
- Bioburden reduction treatments are likely to be needed to eradicate problematic species in/on shielded components. These may include parts manufacturing processes, the application of approved technologies such as DHMR, or the validation and application of sterilization modalities suitable for treatment of specific hardware subsystems.
- Any penetrator elements for Europa carried on JEO must comply with the project's implementation approach.



Be prepared for the unexpected...

Example: Juno Implementation Approach

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

To document a 1×10^{-4} probability of contamination, Juno considered (among others) the following factors:

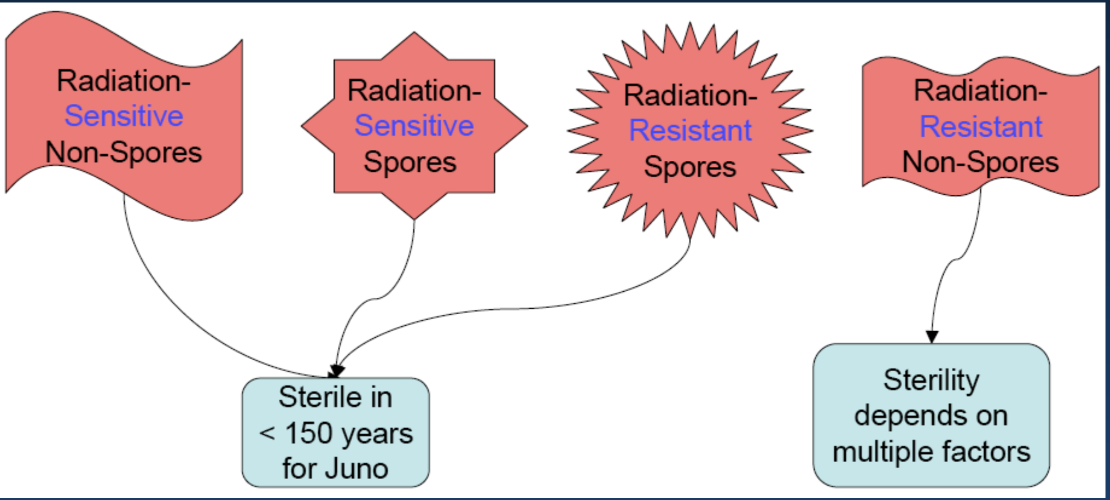
- How reliable is the spacecraft, over the entire mission phase during which Europa is in jeopardy – i.e., what happens if it stops working by accident?
- How long will microbes survive on the spacecraft – i.e., when does 'viable' become moot?
  - Bioburden at launch
  - Survival of microbes until impact: how lethal is the space environment?
- How likely is an Europa encounter?
- How many microbes survive the impact?

Microbe Survival Time

The total number and fractions of microbe types may be measured directly and/or estimated based on cleanroom and manufacturing processes.

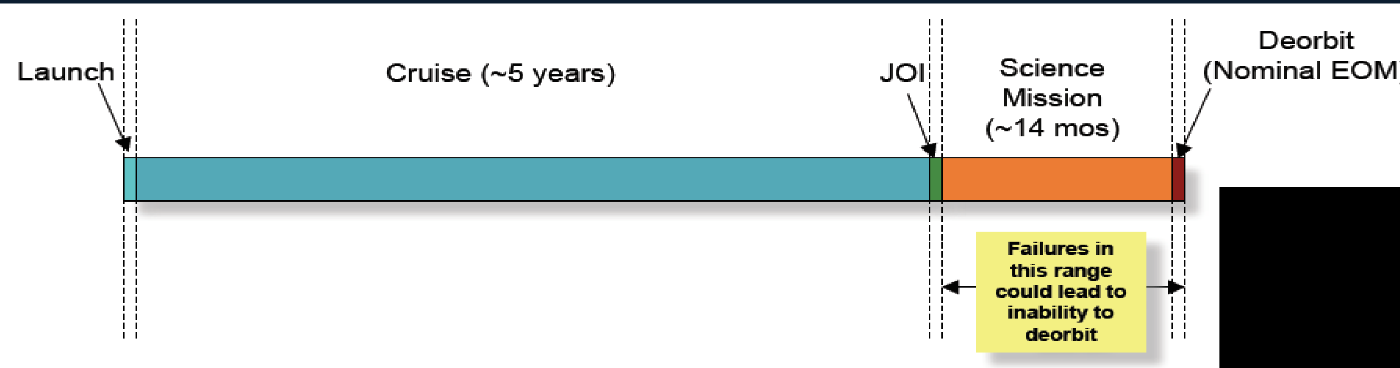
Juno must avoid Europa until all organisms are dead.

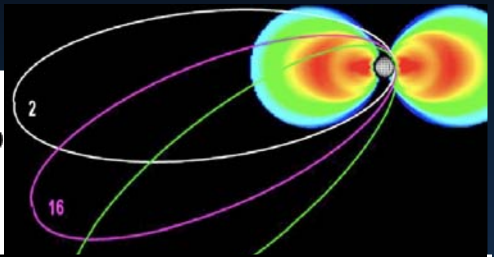
Radiation-sensitive microbes and spores (dormant microbes) that are resistant to radiation should be dead within 150 years in the Juno radiation environment.

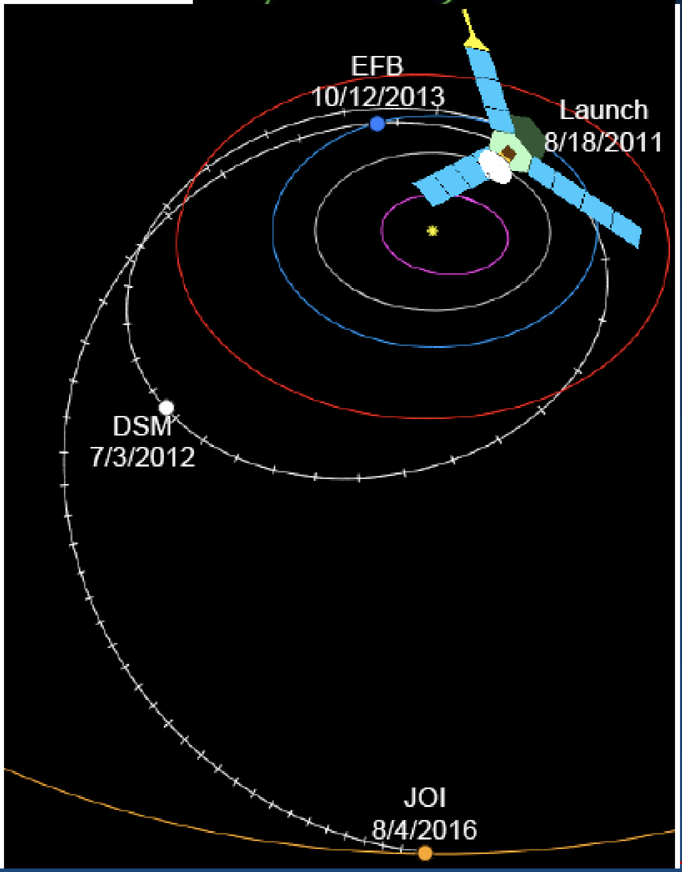


Radiation-resistant non-spores must metabolize to repair radiation damage. Based on the available literature, Juno may assume that microbes exposed only to temperatures below -80^{o}C after spacecraft failure, or in locations exposed to vacuum, could not metabolize to repair radiation damage. Resistant non-spores in those conditions were combined with sensitive non-spores, resulting in spacecraft sterility somewhere between 150 and 300 years.

Spacecraft Reliability





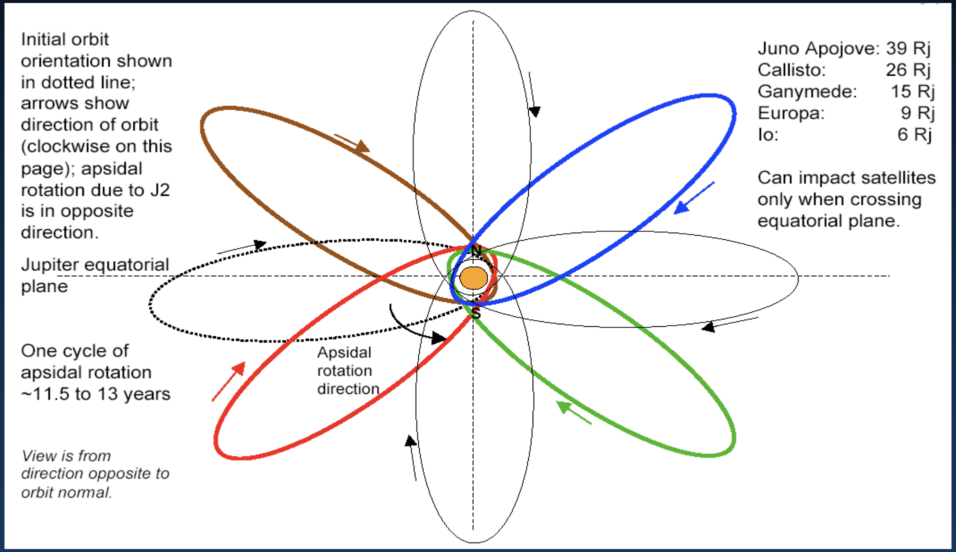


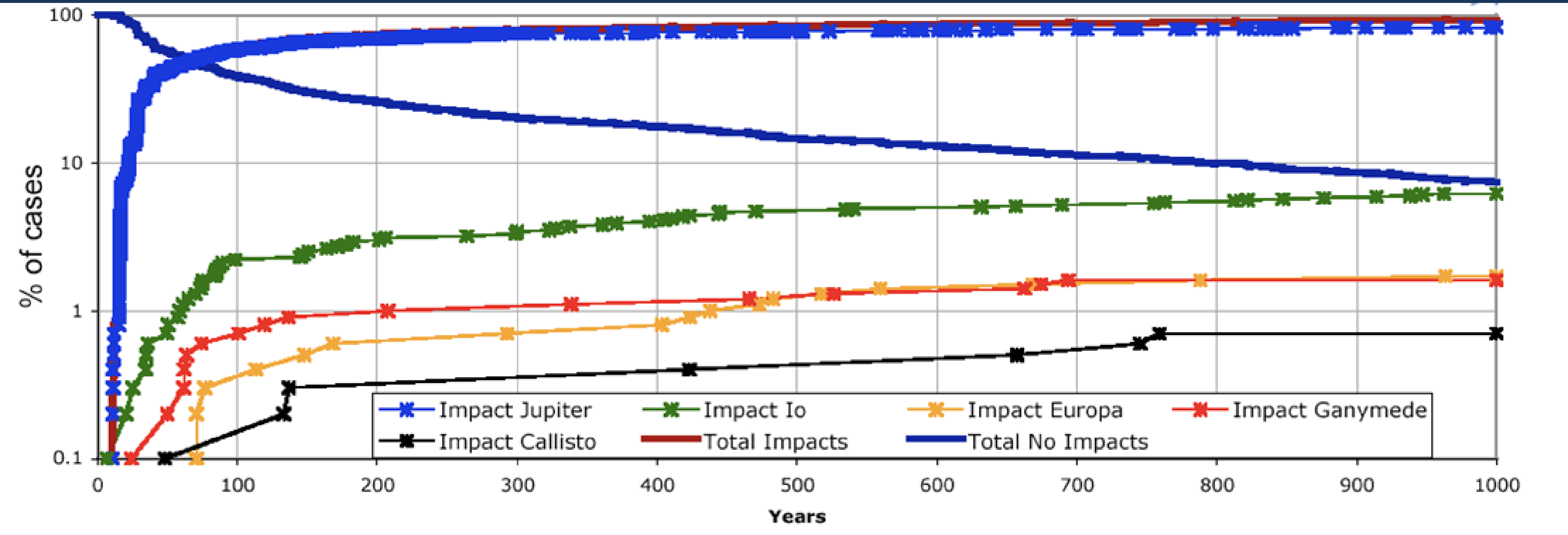
Spacecraft reliability contributes to planetary protection compliance over the period during which a failure might lead to encounters with Europa (or other protected targets). Juno has allotted a 5% probability of spacecraft failure over the course of the active mission, based on probabilistic risk assessments of hardware and the jovian environment (micrometeoroids, etc.)

Therefore, Juno must include additional factors to address the probability of contamination given deorbit burn failure.

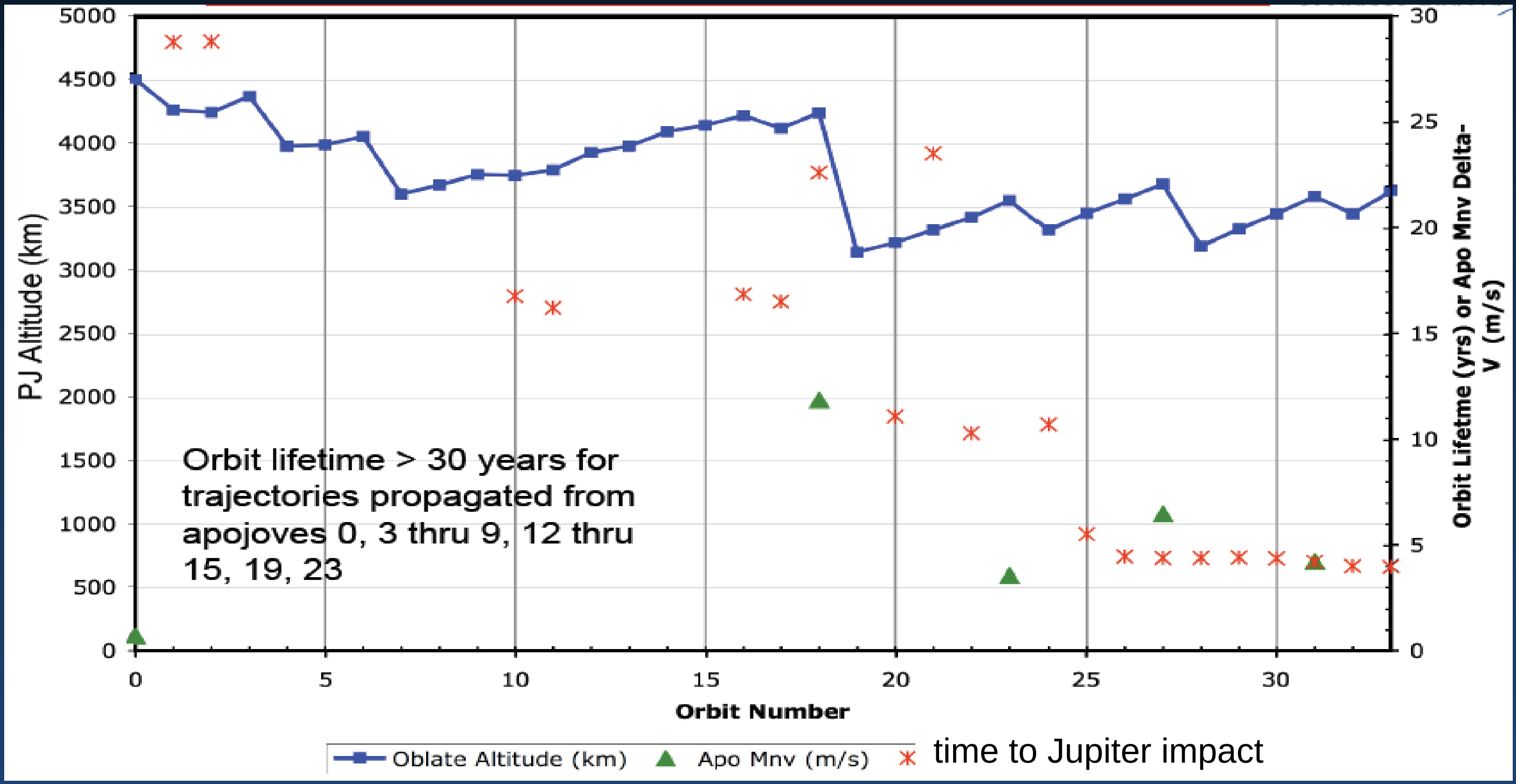
Orbital Lifetime

Based on orbital simulations (both Monte Carlo and deterministic) and assuming failure after each trajectory change maneuver, Juno has a slightly less than 1% chance of impacting Europa in 300 years.





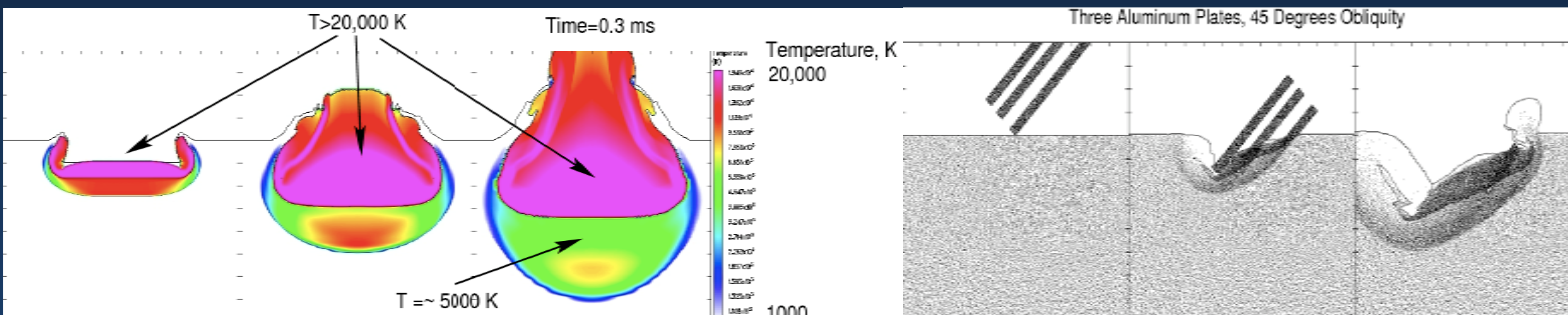
Trajectory Modeling after Spacecraft Failure



Juno performs one trajectory change maneuver per orbit. Simulations indicate that Juno will most likely impact Jupiter within 30 years even should the spacecraft fail before the mission ends. Encounters with objects in the Jovian system after spacecraft failure have significant effects on orbital trajectory.

Impact Survival

Based on orbital simulations, 99% of JUNO impacts into Europa will be travelling at >20 km/second. 98% of those impacts will be at an obliquity of <80^{o} that can be modeled using a 'stacked plate' approach.



Taking conservative assumptions about ice density and impact heating, and assuming that organisms are killed by 500^{o}C for 0.5 sec., only 4% of impacts have a possibility of leaving a viable organism on the europan surface:

Assume all of the 4% lead to contamination.

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	$<9\text{x}10^{-6}$	$9\text{x}10^{-5}$
Requirement	$<1\text{x}10^{-4}$	

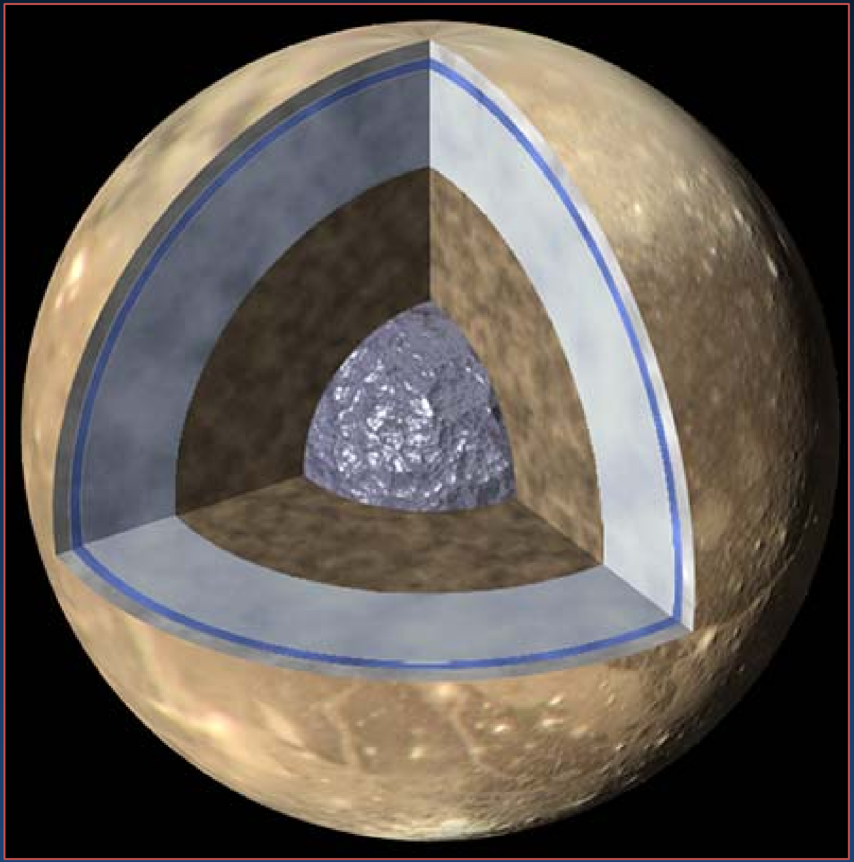
The ability to include additional factors in the probabilistic calculations based on mission-specific parameters allowed JUNO to determine in the early phases of mission design what would be necessary for compliance with planetary protection requirements.

JEO Summary

The probability that one viable terrestrial microbe is introduced into an ocean on Europa shall be < 1×10^{-4}

- Prior to Europa Orbit Insertion (EOI), the probability of contamination will depend strongly on
  - bioburden at launch (active reduction likely needed)
  - spacecraft reliability
  - detailed orbital trajectory
  - associated radiation environment
  - velocity and angle of impact with Europa
- The project proposes that the spacecraft (including penetrators) will be sterile at EOI
  - it is possible that the spacecraft will need to be sterile prior to EOI, in order to meet the probability of contamination as the orbit is pumped down to prepare for orbit insertion
  - the project may choose to request mass models and bioburden estimates as part of instrument selection

JGO: Requirements & Measures



JGO Requirements

Probability that one viable terrestrial microbe is introduced into an ocean (or other habitable environment) on Ganymede shall be $< 10^{-4}$

In principle, analysis has to include:

- Bioburden at launch
- Cruise survival
- Survival in the Jovian radiation environment
- Probability of impact on Ganymede
- Mechanism(s) and timescale for transport to the ocean

JGO Measures

Considering that the S/C disposition is de-orbiting to Ganymede:

- Describe mechanism(s) and timescales for transport to the ocean
  (more or less done, tune in after July 2010 for COSPAR response)
- Consider bioburden control for H/W

Recommended scope for bioburden control until further notice:

- Assembly, testing and launch in ISO 8 cleanroom condition
- Perform biological assays during the course of the H/W final assembly
- Assess temperature/time profiles of manufacturing processes, especially for items behind radiation shielding
- Estimate reduction based on agreed bioburden levels, inactivation rate and S/C radiation dose mapping

JGO Requirement

Probability that one viable terrestrial microbe is introduced into an Europan ocean shall be $< 10^{-4}$

In principle, analysis has to include:

- Bioburden at launch
- Cruise survival
- Survival in the Jovian radiation environment
- Probability of impact on Europa
- Mechanism(s) and timescale for transport to the ocean

JGO Measures

Considering that the mission is not targeting Europa – focus on probability of impact analysis on Europa, including:

- Single/multi pass analysis
- Reliability of flight system
- Meteoroid impacts
- Out of control cases

Provide first analysis for SRR.

Use of Penetrator System

For Ganymede:

- Probability of impact analysis for Europa
- Bioburden control as for JGO system
- After amount of radioactive material for RHU/RTG is defined, perform an analysis to evaluate impact on local/global environment (post SRR)

For Europa:

- Bioburden control as for JEO system
- After amount of radioactive material for RHU/RTG is defined, perform an analysis to evaluate impact on local/global environment

Potential impact on JGO system:

- Additional element for probability of impact analysis for Europa (if JGO is targeting Europa at any time)
- Recontamination control between JGO and penetrator
- After amount of radioactive material for RHU/RTG is defined, perform an analysis to evaluate impact on local/global environment (post SRR)

ATTENTION: Relying on post-launch bioburden reduction (i.e., use of the Jovian radiation field) needs to be correlated with the reliability/out of control cases and associated mission phases

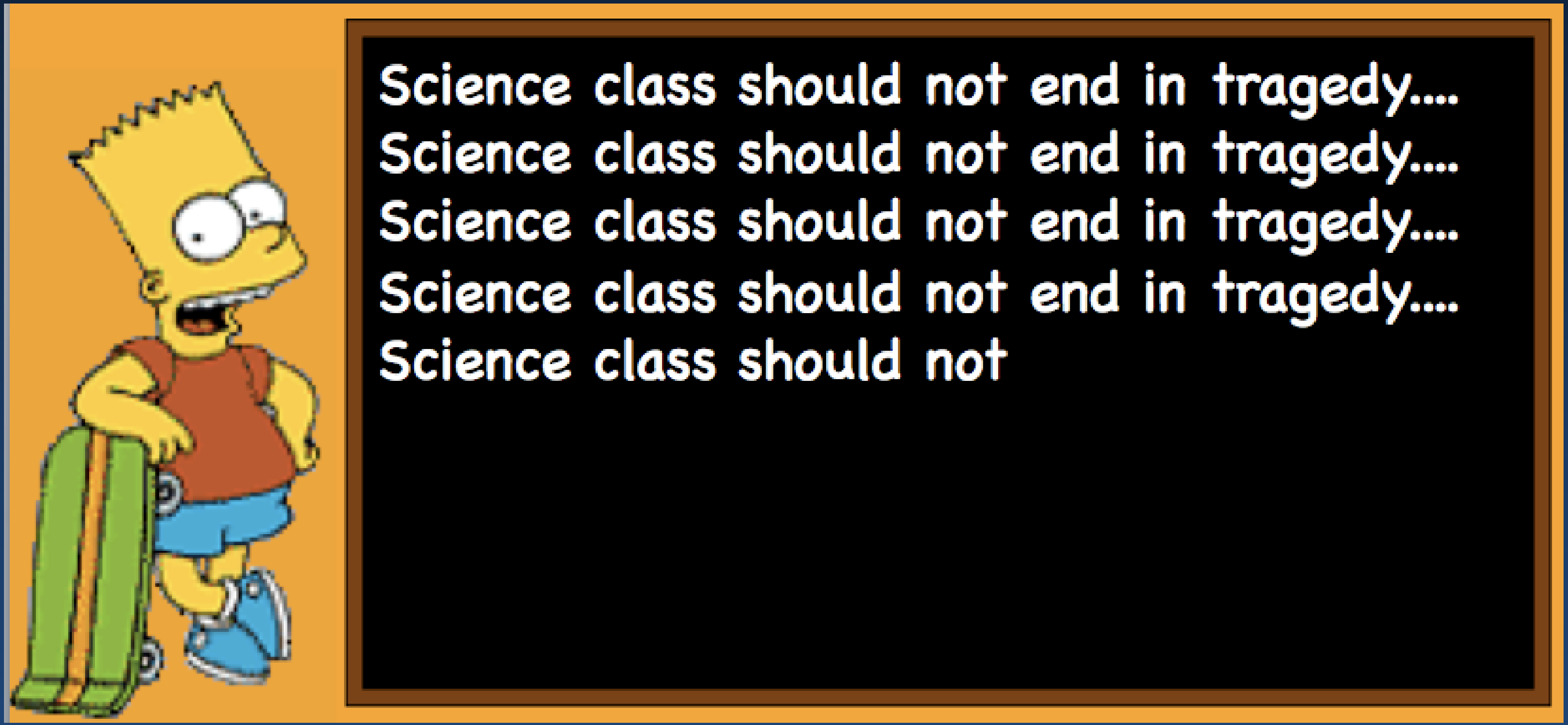
Summary for JGO

For JGO and penetrator system until SRR:

- Probability of impact analysis for Europa (FS)
- Take into account passive bioburden control pre-launch (FS+PL)
- Provide S/C radiation dose levels (internal and external) and fold in expected bioburden density and inactivation parameter for microbes (FS+PL)
- Understand that a penetrator to Europa might have some consequences for the bioburden control of the JGO system (FS)
- Consider DHMR compatibility assessment for penetrator material/component test programme (FS+PL)
- Become familiar with the planetary protection requirements – join one of our courses (FS+PL)

Decision point for need of active bioburden control based on available project analysis and COSPAR position is SRR

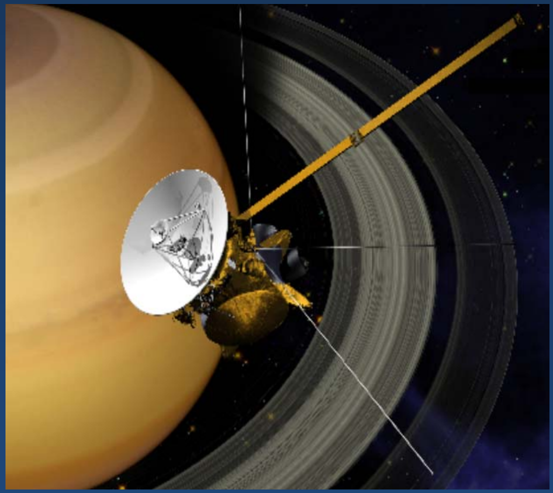
Lessons Learned from Previous Missions:



New Results Can Alter Mission Implementation

Both Galileo and Cassini included clauses in their Planetary Protection Plans that required notification of the Planetary Protection Officer should results obtained by the mission indicate that an object encountered by the mission might merit protection at a category higher than the mission was assigned, to facilitate negotiation of project operations to ensure appropriate protection of the object.

- Galileo End of Mission was to deorbit into Jupiter, to protect Europa
- Cassini will probably deorbit into Saturn, to protect Enceladus
  - Fortunately, Huygens on Titan is very cold...



Design Tips for Planetary Protection

Designing for Planetary Protection is a lot like designing for radiation exposure: Early and Often is good...

- Contamination issues are different for surfaces vs. internal volumes
- Starting clean and keeping things clean is better than killing later
  - Humans are dirty: good cleanroom practices minimize recontamination

- Consider parts qualifications and manufacturing processes when selecting components
  - Heat kills microbes: 5hr at 125C reduces numbers by an order of magnitude
  - Parts not qualified above 70C may withstand higher temperatures if treated while inactive: use a test program and approved parts list

Design Tips for Planetary Protection (cont.)

- Dry heat is an approved sterilization modality, but others may be acceptable with appropriate verification and documentation
- Design for the environment: take advantage of conditions after launch
  - Shield only what's necessary to be protected
  - Minimize use of pressure vessels (vacuum improves kill)
  - Design for impact sterilization

Planetary Protection Courses

Annual joint NASA/ESA Planetary Protection Course

- 2.5 days course covering regulations, implementation of requirements, and laboratory practice
- Next one 2nd quarter of 2010 at Harwell, UK, and
- 2nd half of 2010 at KSC, US
- Contact us or the respective JEO/JGO projects if you are interested