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Category IVa Case Study (Mars) Illustrating Category IV missions generally:
- Main Feature is Bioburden Control
- Similar approaches valid for missions to Europa, Enceladus, depending on Mission Design
Category IV description (1)

Lander missions to a target body of chemical evolution and/or origin of life interest and for which scientific opinion provides a significant chance of contamination which could compromise future investigations.

Applicability: Mars, Europa, Enceladus

For Europa, Enceladus: Limit the probability of inadvertent contamination of a body of liquid water to less than $1 \times 10^{-4}$ per mission.

For Mars Missions: Further subdivided into 3 subcategories (a,b,c):

Category IVa: Lander systems not carrying instruments for the investigations of extant martian life are restricted to a surface bioburden level of $\leq 3 \times 10^5$ spores, and an average of $\leq 300$ spores per square metre.

[continued...]
Category IV description (2)

Category IVb: For lander systems designed to investigate extant martian life, all of the requirements of Category IVa, plus:

- The entire landed system is restricted to a surface bioburden level of $\leq 30$ spores, or to levels of bioburden reduction driven by the nature and sensitivity of the particular life-detection experiments,

OR

- The subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection must be sterilized to these levels, and a method of preventing recontamination of the sterilized subsystems and the contamination of the material to be analyzed is in place.
Category IV description (3)

Category IVc: For missions which investigate martian special regions, even if they do not include life detection experiments, all of the requirements of Category IVa apply, together with the following requirement:

- Case 1. If the landing site is within the special region, the entire landed system is restricted to a surface bioburden level of ≤30 spores.
- Case 2. If the special region is accessed through horizontal or vertical mobility, either the entire landed system is restricted to a surface bioburden level of ≤ 30* spores, OR the subsystems which directly contact the special region shall be sterilized to these levels, and a method of preventing their recontamination prior to accessing the special region shall be provided.

*assumes 300 spores/m² cleanliness followed by process to reduce by 4 logs on most resistant organism.

For both Case 1 and Case 2: If an off-nominal condition (such as a hard landing) would cause a high probability of inadvertent biological contamination of a special region by the spacecraft, the entire landed system must be sterilized to a surface bioburden level of ≤30 spores and a total (surface, mated, and encapsulated) bioburden level of ≤30+(2×10⁵) spores.
Case study – InSight
(Interior Exploration using Seismic Investigations, Geodesy and Heat Transport)

→ Target body: Mars
→ Mars Lander (360kg) based on Phoenix heritage
→ Science instruments contributed by CNES (SEIS) and DLR (HP3)
→ Launch Window May 5, 2018, on ATLAS V 401 from Vandenberg
→ 6.5-month cruise, type 1 trajectory, direct entry, landing on Nov. 26, 2018.

Followed by one Martian year of science on the surface, to:

● Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars, AND

● Determine the present level of tectonic activity and meteorite impact rate on Mars.
Requirements for case study mission 1

- As a Mars lander mission without life detection instruments, the InSight mission has been designated PP Category IVa by the NASA PPO.

- In accordance with the requirements stated in NASA Procedural Requirements document NPR8020.12 for this category and type of mission, the InSight Project is required to comply with:
  
  **Bioburden requirements:**
  - \( \leq 5 \times 10^5 \) total spores at launch, \( \leq 3 \times 10^5 \) total spores on planned landing hardware and mean exposed surface density of \(<300\) spores/m\(^2\).

  **Cleanliness requirements:**
  - Assembly and testing in ISO 8 (or better) cleanroom environments.

  **Recontamination avoidance requirements:**
  - Launch recontamination not to exceed bioburden requirements.

  **Organic inventory requirements**
  - Archiving of samples of at least 50 grams of each organic material type for which more than 25 kg is transported to Mars.
  - Documentation of organic materials for which are present on the spacecraft in quantities of \( \geq 1\) kg.

  **Probability of Impact requirements:**
  - Launch vehicle Mars avoidance of less than \( 1 \times 10^{-4} \) for 50 years after launch, and probability of a non-nominal impact of Mars by the spacecraft due to cruise phase failure shall be \( \leq 1 \times 10^{-2} \).
Additional Project requirements included:
- Average internal (behind HEPA or tortuous path) bioburden $\leq 1,000$ spores/m$^2$
- Mole shall be unpowered and cease operations immediately if tether breaks
- Ice shall not be present within reach of HP$^3$ instrument’s mole (demonstrated thermodynamically)*
- Mole shall not generate a thin liquid film as a result of operations (insufficient to transport a 50nm particle)*
- Planetary Protection Landing Site Review is required

Project utilized NASA PPO-provided “new” heat microbial reduction specifications which provide expanded implementation options (e.g., no humidity constraints, credit for manufacturing processing)

PP requirements were captured into the Level 2 Project System Requirement Document [first JPL Project to capture all PP requirements into Dynamic Object Oriented Requirements (DOORS) V&V tool].

All Level 2 and 3 requirements are under Project Change Control Board management.

* Detailed on following slides
Implementation of requirements

Maximum Accounted Bioburden Requirement:

→ 500,000 spores allocated to a budget

<table>
<thead>
<tr>
<th></th>
<th>spores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lander</td>
<td></td>
</tr>
<tr>
<td>PHX Landed Hardware (minus parachute)</td>
<td>32,000</td>
</tr>
<tr>
<td>Parachute</td>
<td>32,000</td>
</tr>
<tr>
<td>New External Lander Hardware and LM Reserves</td>
<td>35,000</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td></td>
</tr>
<tr>
<td>SEIS</td>
<td>20,000</td>
</tr>
<tr>
<td>HP3</td>
<td>25,000</td>
</tr>
<tr>
<td>IDS</td>
<td>25,000</td>
</tr>
<tr>
<td>APSS</td>
<td>25,000</td>
</tr>
<tr>
<td>Impacting Hardware (PHX actuals)</td>
<td>100,000</td>
</tr>
<tr>
<td>Launch Recontamination (MSL heritage value from Atlas V)</td>
<td>22,000</td>
</tr>
<tr>
<td>Project Held Reserves</td>
<td>160,000 (32%)</td>
</tr>
</tbody>
</table>
Implementation of requirements

Bioburden management via PPEL (Planetary Protection Equipment List)

- Analogous to the MEL (Mass Equipment List)
Implementation of requirements

Special Analyses – Landing Site Analysis

- Landing Site Characterization – Demonstrate Landing Site is NOT a Special Region (Aw>0.5 AND T>-18°C)
- Modeling shows the bounding sub-surface temperatures over the full Mars year on specific sols of the InSight Mission. HP3 penetration phase expected ~sol 67-100. Thermal model verification performed.
- The short-lived temperature elevation of the subsurface above ambient due to HP3 hammering and thermal conductivity measurement activities is on the order of 10–50°C. Mean subsurface temperatures at this site are -55°C, producing thermal elevations to ~0°C.
- The regolith in the Elysium region is dry and ice-free, preventing HP3 heating from generating water activities in pore spaces from exceeding the threshold for microbial activity. The maximum possible water activity (Aw = rh/100) of 0.09.

Fulfils CatIVa Requirements – NOT a CatIVc Mission
Implementation of requirements

Special Analyses – Thin Film Analysis
• Background - A) hydrous mineral composition in martian soil capable of dehydration in the -55°C –0° range; conservative as it accounts for MgSO₄ minerals not likely at equatorial sites and B) factors in the maximum quantities of water lost from dehydration of those minerals.
• A pulse of a small quantity of water due to the mole would generate 8 to 10 monolayer equivalents in the immediate mole vicinity. This would return to its equilibrium value of 2 monolayers within hours.
• Liberated water would flow in under capillary action, spreading out in all directions. But, the maximum film thickness is too small to entrain a 50 nm particle and is both a short-lived and small-distance phenomenon.

Fulfils CatIVa Requirements – NOT a CatIVc Mission
Implementation of requirements

Partner-Contributed Payload Management

• Specific InSight Project PP Payload Implementation Plans.

• Instrument Providers then generated own Institutional (i.e. CNES and DLR) Planetary Protection Plans.

• Flow down of PP requirements to L4 payloads.

• Frequent telecons and email exchanges (effective & efficient communication).
  – Implementation approach questions
  – Assay updates

• PP participation / topic area of discussion for HP3 and SEIS weekly telecons.

• PP assay of interfaces; hardware certification process; status bio-assays on site at CNES and DLR with InSight planetary protection engineer.
Implementation of requirements

Special Analyses – Still have to comply with Impact Avoidance Requirements

• L2-PSRD-113: The InSight project injection aimpoint for launch shall be biased away from Mars such that the probability of the launch vehicle upper stage impacting Mars is less than $1.0 \times 10^{-4}$ for 50 years after launch.

• Directed to consider Centaur anomalies in the assessment.
  – Anomalies include: Failure to separate, failure to perform CCAM, failure to blowdown.

• Approved PPO Plan Forward:
  1. Design the biased aimpoints and CCAM attitude to ensure a minimum first-pass probability of impact less than $0.5 x 10^{-4}$ for all anomalous scenarios.
  2. Design the blowdown attitude to ensure that the Mars encounter is sufficiently far away that the $\Delta V$ from the gravity assist is insufficient to place the Centaur on a 50-year resonant trajectory in the nominal scenario.
  3. Perform 5,000-case, 50-year Monte Carlo propagations of the three anomalous scenarios to determine the Beta distribution shape parameters for the 50-year probabilities of impact.
  4. Generate one million samples of each of the six Beta distributions representing the probability of an anomaly and the resulting 50-year probability of impact.
  5. Combine the six million-sample sets and analytical probabilities to determine the distribution of the estimate of the total probability of impact.

• Approved methodology being written up and submitted to a peer reviewed journal.
Things to remember

- Establish and maintain an end-to-end bioburden accounting approach.
- Pay attention to the details of provenance (manufacturing credit), inside/outside cleanliness, interfaces/environments, test activities, hardware processing, recontamination.
- Plan ahead for PP facilities needs and incorporation of PP into the ATLO flow.
- Time/resources need to be built in for high stringency cleanroom operation.
- Successful implementation needs good communication between PP implementors, hardware engineers, launch vehicles operations, project management, contributing hardware partners – so build in PP up front!