Case Study

Planetary Protection Category V
Unrestricted Earth Return: Hayabusa-1&2

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Category V description

Category V missions comprise all Earth-return missions. The concern for these missions is the protection of the terrestrial system, the Earth and the Moon. (The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel.) For solar system bodies deemed by scientific opinion to have no indigenous life forms, a subcategory “unrestricted Earth return” is defined. Missions in this subcategory have planetary protection requirements on the outbound phase only, corresponding to the category of that phase (typically Category I or II). For all other Category V missions, in a subcategory defined as “restricted Earth return,” the highest degree of concern is expressed by the absolute prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body or unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth. Post-mission, there is a need to conduct timely analyses of any unsterilized sample collected and returned to Earth, under strict containment, and using the most sensitive techniques. If any sign of the existence of a nonterrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure. Category V concerns are reflected in requirements that encompass those of Category IV plus a continuing monitoring of project activities, studies and research (i.e., in sterilization procedures and containment techniques).

All sample return missions to the Earth-Moon system to be sub-divided into restricted and unrestricted Earth return requirements, depending upon confidence degree of terrestrial biosphere contaminations by these samples.
Category V missions comprise all Earth-return missions. The concern for these missions is the protection of the terrestrial system, the Earth and the Moon. (The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel.)

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For all other Category V missions, in a subcategory defined as “restricted Earth return,” the highest degree of concern is expressed by the absolute prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body or unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth.
Category V description

- Post-mission, there is a need to conduct timely analyses of any unsterilized sample collected and returned to Earth, under strict containment, and using the most sensitive techniques. If any sign of the existence of a non-terrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure.

- Category V concerns are reflected in requirements that encompass those of Category IV plus a continuing monitoring of project activities, studies and research (i.e., in sterilization procedures and containment techniques).
## Category V description (RER vs. UER as of 2015)

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category I</td>
<td>Flyby, Orbiter, Lander</td>
<td>Differentiated, metamorphosed asteroids, Io, others TBD</td>
</tr>
<tr>
<td>Category II</td>
<td>Flyby, Orbiter, Lander</td>
<td>Venus, Moon (organic inventory), Comets, Carbonaceous Chondrite Asteroids, Jupiter, Saturn, Uranus, Neptune, Ganymede, Callisto, Titan, Triton, Pluto/Charon, Ceres, Kuiper Belt Objects, others TBD</td>
</tr>
<tr>
<td>Category III</td>
<td>Flyby, Orbiter</td>
<td>Mars, Europa, Enceladus, others TBD</td>
</tr>
<tr>
<td>Category IV</td>
<td>Lander</td>
<td>Mars, Europa, Enceladus, others TBD</td>
</tr>
<tr>
<td>Category V</td>
<td>Sample Return</td>
<td>(a) Restricted: Mars, Europa, Enceladus, others TBD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Unrestricted: Venus, Moon, P/Wild2, Itokawa, Bennu, Ryugu, others TBD</td>
</tr>
</tbody>
</table>


→ Recently updated in 2015 and more in progress for Mars and ocean worlds
Category V-RER description (Mars)

Sample Return Missions from Mars

Category V. The Earth return mission is classified, “Restricted Earth return.”

- Unless specifically exempted, the outbound leg of the mission shall meet Category IVb requirements. This provision is intended to avoid “false positive” indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned. A “false positive” could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.

- Unless the sample to be returned is subjected to an accepted and approved sterilization process, the sample container must be sealed after sample acquisition, and a redundant, fail-safe containment with a method for verification of its operation before Earth-return shall be required. For unsterilized samples, the integrity of the flight containment system shall be maintained until the sample is transferred to containment in an appropriate receiving facility.

- The mission and the spacecraft design must provide a method to “break the chain of contact” with Mars. No uncontained hardware that contacted Mars, directly or indirectly, shall be returned to Earth. Isolation of such hardware from the Mars environment shall be provided during sample container loading into the containment system, launch from Mars, and any in-flight transfer operations required by the mission.

- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving Mars for return to Earth; and 3) prior to commitment to Earth re-entry.

- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample.
Category V-RER description (Europa)

Sample Return Missions from Europa

Category V. The Earth return mission is classified, “Restricted Earth return.”

- Unless specifically exempted, the outbound leg of the mission shall meet the contamination control requirements given above. This provision should avoid “false positive” indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned. A “false positive” could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Europa missions.

- Unless the sample to be returned is subjected to an accepted and approved sterilization process, the sample container must be sealed after sample acquisition, and a redundant, fail-safe containment with a method for verification of its operation before Earth-return shall be required. For unsterilized samples, the integrity of the flight containment system shall be maintained until the sample is transferred to containment in an appropriate receiving facility.

- The mission and the spacecraft design must provide a method to “break the chain of contact” with Europa. No uncontained hardware that contacted Europa, directly or indirectly, shall be returned to Earth. Isolation of such hardware from the europaen environment shall be provided during sample container loading into the containment system, launch from Europa, and any in-flight transfer operations required by the mission.

- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving Europa for return to Earth; and 3) prior to commitment to Earth re-entry.

- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample (SSB 1998).
Category V description (Small Bodies)

Sample Return Missions from Small Solar System Bodies

Category V: Determination as to whether a mission is classified “Restricted Earth return” or not shall be undertaken with respect to the best multidisciplinary scientific advice, using the framework presented in the 1998 report of the US National Research Council’s Space Studies Board entitled, Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making (SSB 1998). Specifically, such a determination shall address the following six questions for each body intended to be sampled:

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)?
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms?
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?

For containment procedures to be necessary (“Restricted Earth return”), an answer of “no” or “uncertain” needs to be returned to all six questions.

For missions determined to be Category V, “Restricted Earth return,” the following requirements shall be met:

- Unless specifically exempted, the outbound leg of the mission shall meet contamination control requirements to avoid “false positive” indications in a life-detection and hazard-determination protocol, or in any search for life in the sample after it is returned. A “false positive” could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later missions to that body.
- Unless the sample to be returned is subjected to an accepted and approved sterilization process, the sample container must be sealed after sample acquisition, and a redundant, fail-safe containment with a method for verification of its operation before Earth return shall be required. For unsterilized samples, the integrity of the flight containment system shall be maintained until the sample is transferred to containment in an appropriate receiving facility.
- The mission and the spacecraft design must provide a method to “break the chain of contact” with the small body. No uncontaminated hardware that contacted the body, directly or indirectly, shall be returned to Earth. Isolation of such hardware from the body’s environment shall be provided during sample container loading into the containment system, launch from the body, and any in-flight transfer operations required by the mission.
- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving the body or its environment for return to Earth; and 3) prior to commitment to Earth re-entry.
- For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample (SSB 1998).
### Category V Description (Small Bodies)

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>No special containment and handling warranted beyond what is needed for scientific purposes</td>
<td>Strict containment and Handling warranted</td>
</tr>
</tbody>
</table>

#### Ia
**High Degree of Confidence**
- Moon
- Io
- Dynamically new comets
- Interplanetary Dust particles

#### Ib
**Lesser Degree of Confidence**
- Phobos
- Deimos
- Callisto
- C-type asteroids (Ryugu)
- Undifferentiated metamorphosed Asteroids (Itokawa, Bennu)
- Differentiated asteroids
- *All other comets*
- Interplanetary dust particles

#### Notes:
1. Evaluation on case by case basis.
2. Samples from the outer 10 meter.
3. Samples from the same parent bodies of this group.
4. Limitation of available data led to a conservative assessment => need for containment

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# Case study – Hayabusa-1 & 2

<table>
<thead>
<tr>
<th></th>
<th>Hayabusa-1</th>
<th>Hyabusa-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives</strong></td>
<td>Verify key technology needed for deep space round trip exploration</td>
<td>C-type asteroid sample return and improvement of the deep space round trip exploration technology</td>
</tr>
<tr>
<td><strong>Mission Target</strong></td>
<td><strong>Itokawa: S-type, sub-km NEO</strong></td>
<td><strong>Ryugu: C-type, 1-km NEO</strong></td>
</tr>
</tbody>
</table>
| **Major Payload Instruments** | • Sampling System  
• Earth Return Capsule  
• Multi-band Optical Camera  
• LIDAR  
• Near Infrared Spectrometer  
• X-ray Fluorescence Spectrometer  
• Micro-Rover  
• Target Markers | • Sampling System  
• Earth Return Capsule  
• Small Carry-on Impactor with DCAM  
• Multi-band Optical Camera  
• LIDAR  
• \(3 \, \mu \text{m} \) Near Infrared Spectrometer  
• Thermal Imaging Camera  
• Micro-Rover  
• Micro-Lander  
• Target Markers |
| **Mission Epoch** | **2003-2010**                                                             | **2014-2020**                                                                                                                           |
Case study – Ryugu Sample Return Hayabusa-2

Discovered by LINEAR in 1999
Eccentricity (e) = 0.19022
Inclination (i) = 5.8838 deg.
Semi-major Axis (a) = 1.18961 AU
(q = 0.96332 AU, Q = 1.41589 AU)
Longitude of Ascending Node = 251.61793 deg.
Argument of Perihelion = 211.43332 deg.
Mean Anomaly (M) = 74.62464 deg.
Orbital Period (P) = 473.918 days (1.30 years)

Rotation period: 0.3178 days (~7.6 hours)
(\(\lambda, \beta\) = (331, 20), (73, -62))
Axis ratio = 1.3 : 1.1 : 1.0
Size: 0.87 \(\pm\) 0.02 km (Mueller et al., 2010)
Visual Geometric Albedo: 0.070 \(\pm\) 0.006
H = 18.82 \(\pm\) 0.021, G = 0.110 \(\pm\) 0.007
Type: Cg (SMASH: absence of the absorption at 0.7 \(\mu\)m)
Meteoritic Analog: Carbonaceous Chondrites
Thermal Inertia: 200-600 Jm\(^{-2}\) s\(^{-0.5}\) K\(^{-1}\) (lower than for Itokawa, suggesting the presence of smaller particles, < cm-sized, in the regolith, though likely not fine dust)
1. **Liquid water:** Liquid water may safely be considered a requirement for life on small solar system bodies, because the chemistry on which life is based must take place in solution, and there is no other plausible solvent.

2. **Energy sources:** A source of energy to support the origin and continuation of life in any environment is a thermodynamic necessity. For the extraterrestrial environment, the energy sources are both geochemical and photosynthetic.

3. **Organic compound:** Chemical building blocks for organic polymers must be available.

4. **Temperature:** The temperature limits for the survival of metabolically active cells (160 °C) at 1 atm are likely to apply to extraterrestrial organisms also unless their biochemistry does not depend on the formation of amide, ester or phosphodiester bonds.

5. **Radiation intensity:** Extraterrestrial biopolymers are unlikely to differ greatly from terrestrial biopolymers with respect to radiation sensitivity.

6. **Comparison to natural influx to Earth:** Earth receives natural influx of extraterrestrial material, mainly in the form of cosmic dust. Some materials may be delivered in ways that shield it from sterilizing temperatures or radiation.
**Requirements for case study mission 1**

**Six Questions for Assessing the Biological Potential of Small Bodies**

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No or Uncertain</th>
<th>Yes</th>
<th>No or Uncertain</th>
<th>Yes</th>
<th>No or Uncertain</th>
<th>Yes</th>
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<td>Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?</td>
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</table>

**Strict Containment and Handling Required = “Restricted Earth Return”**
PPP Question # 1

Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?

Answer #1: “UNCERTAIN”. Recent discoveries provide mounting evidences that there was water on and in main belt C-type asteroids. However, “liquid” cases for NEOs of the same type are less certain.

- Aqueous alteration of primitive parent body material is well known from carbonaceous chondrite samples, in which liquid water penetration likely ended billions of years ago.

- Water ice and organic absorption signatures are recently reported for the surface of (24) Themis (C-type main belt asteroid).

- Discovery of “main belt comets” raises a possible water presence inside Co-location of hydrated minerals and organic compounds are suggested for carbonaceous chondrites.

- Dormancy period of hypothetic spores must be in the order of billions of years in a dry environment.
PPP Question #2

Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?

Answer #2: “NO”. Primitive meteoritic material could provide sufficient energy resources to potential life-forms.

- Both photosynthetic and chemical processes are considered at the near earth space.
- Chemical reduction-oxidation (red-ox) reactions playing the key role
- Mineralic components like phyllosilicates, sulfides, phosphates, carbonates, silicates provide nutrients like S, P, Ca, Mg, K, Fe, Cl, etc.
- Mautner et al. (1997) reported that microbial life and plants have been grown on Murchison extracts.
PPP Question #3

Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO$_2$ or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?

Answer #3: “NO”. Carbonaceous meteorites contain organic material to support growth of organisms.

- Primitive meteoritic material usually contain a “few” percent of carbon
- Carbon phases are ubiquitous in primitive meteorites
- Tagish Lake meteorites have up to 5 % organic content (D/T-type?)
- Callahan et al. of NASA/GSFC (2011) reported some nucleobases such as DNA blocks (Adenine, Guanine) and nucleobasis analogs were extracted from Antarctic meteorites
- Organic inventory makes them scientifically interesting
PPP Question # 4

Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e. >160° C)?

Answer#4: “NO” for most of pristine materials as 1999 JU3 perihelion does not exceed the recommended temperature on its surface. “YES” for local heat maximums like impact craters.

- Usually in meteorites there is no evidence that this temperature has been exceeded significantly.
- Surface temperatures usually do not exceed 130° C in NEO orbits, unless very close perihelion (e.g., 1989 UQ @ 0.67 AU >200° C).
- Impact processes create very local extreme temperatures.
PPP Question # 5

Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilisation of terrestrial life-forms?

Answer#5: “YES”. Given the extremely long exposure time with slow turn over rate, a sterilisation of the top surface is assumed. Also sub-surface materials for both monolithic bedrock and regolith layers to be excavated by artificial cratering are assumed to be sterilized by galactic cosmic rays and radionuclides contained in the carbonaceous chondritic interior of the target body.
Two Sampling Sequences of Hayabusa-2

(1) **Surface Sampling**, the same as the Hayabusa-1
   * Safe area (no boulders at s/c size in the landing ellipse)
   * Choose the sites for both scientific and operational merits
   * Up to two different locations
   * Impact sampling by projectiles
   ➔ **Sterilization is sufficient by solar UV radiation, vacuum, and other space parameters**

(2) **Sub-surface Sampling** to be attempted *a few weeks after* SCI crater formation
   * If the new fresh crater is identified
   * If temporal dust torus settled down to be safe
   * If the vicinity of the artificial crater meets safety requirement of landing
   * Only once, either inside or just outside of the crater
   * Total mass is at a range of $>100$ mg
   ➔ **Sterilization process must be examined as a function of time and depth**
Surface Sampling and Sterilization

(1) **Surface Sampling, the same as the Original Hayabusa**

- Safe area (no boulder at the s/c size in the landing ellipse)
- Choose the sites for both scientific and operational merits
- Up to two different locations
- Impact sampling by projectiles

➡️ **Sterilization is sufficient by solar UV radiation, vacuum, and other space parameters**

10’s of seconds of exposure to extraterrestrial solar UV radiation in space killed 99% of bacterial spores (Experiment on Spacelab 1: *B. subtilis* spores) (Horneck, et al., MMBR, 2010)
Depth Estimate of an Artificial Crater by SCI

(1) Monolithic Bedrock (Impact experiment)
Conchoidal Shattered Diameter~2 m, Depth~20 cm
=> Difficult to conduct pin-point landing (<10m) safely

(2) Rough Terrain (= Boulder Piling Region)
Fracture boulders but no craters; Exposed fresh surfaces
=> Difficult to conduct pin-point landing safely

(3) Smooth Terrain (= Gravel to Powdery Regolith Region)
(3-A) Gravity Regime Scaling by Housen and Holsapple:
Diameter~10.2 m, Depth~200 cm
=> Possible to conduct pin-point landing safely
(3-B) Scaling from Microgravity Impacts by Takagi and Yano:
Diameter~4 m, Depth~80 cm
=> Marginal to conduct pin-point landing safely
(3-C) Hydrocode Simulation by Okamoto and Yano:
Diameter~2 m, Depth~40 cm
=> Difficult to conduct pin-point landing safely
Sterilization processes must be examined as a function of depth:

1. Sub-surface Temperature level
2. Penetration of GCR, with gardening effect
3. Radionuclides exposure inside carbonaceous chondrite composition

### (1) Sub-Surface Temperature Level

- Thermal Inertia of 1999 JU3: $\Gamma = 200-600 \text{ Jm}^{-2} \text{ s}^{-0.5} \text{ K}^{-1}$ (Mueller, et al., 2010)
- Interior Thermal Profile of 1999 JU3 Mid-day: (Michel and Delbo, Icarus, 2010)

Heat sterilization of indigenous life in the sub-surface region does not seem effective.

<table>
<thead>
<tr>
<th>$\Gamma$ (Jm$^{-2}$ s$^{-0.5}$ K$^{-1}$)</th>
<th>Surface Temp. (K)</th>
<th>Sub-surface Temp. (K)</th>
<th>Equilibrium Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>370</td>
<td>285</td>
<td>15</td>
</tr>
<tr>
<td>1000</td>
<td>340</td>
<td>295</td>
<td>30</td>
</tr>
</tbody>
</table>
Sub-Surface Sterilization

(2) Penetration of GCR and Microorganism Survival

* Exposed time for survival of at least 100 spores from $10^8$ spores ($10^{-6}$ survival rate in single layer)
- No shielding: $\sim 0.7$ Myr
- With 1m-thick shielding: $\sim 1.1$ Myr


• 1999 JU3 Case:
- Bulk density (porosity $\sim 0.5 \times$ grain density $\sim 2.5$) = $\sim 1.3$ g/cc : 2.3xMartian Soil Model
- Shielding Depth Limit (80cm for Mars)
  = Dose: $\sim 0.059$Gy/yr at $\sim 180$ cm
  (Close to the (3-A) Case depth of 200 cm)
  = Survival exposed Time: $\sim 1.1$Myr at $\sim 180$ cm
  = Total dose: $65k$Gy in $1.1$Myr

Cf.: Background dosage of GCR: 0.1-0.3 Gy/yr
- $50k$~$1$Myr to kill rad-hard microorganisms on the exposed surface
- $\sim 10$Myr up to $>100$cm ($0.01$ Gy/yr order) in depth, with density unknown (Clark, et al., 1998)

BIOSTACK concept to determine biological effects of single heavy ions of CR (Bücker and Horneck, 1975)
<Monolithic>
- 10cm~1m scale depth for regolith on 1-10 km-sized asteroids (Housen, et al., Icarus, 1979)
- 50-160m depth for regolith on a 30-km-sized asteroid (Wilson and Keil, MAPS, 2001)

⇒ Smaller asteroids have thinner regolith; easier for sterilization

<Rubble Pile>
* Granular mobility and convection at work in Itokawa, a sub-km asteroid, resulting accumulation and size sorting at potential low regions (Miyamoto, et al., Science, 2007)
- Analyzed Itokawa grains have residence time to GCR exposed depth: <~8Myr (Nagao, et al., Science, 2011)

⇒ Much longer than 1.1 Myr (Mileikowsky) and slightly shorter than 10Myr (Clark)

Cf.: Regolith Gardening Time: 2000+-290Myr (!!)
Sub-Surface Sterilization

(3) Radionuclides Exposure inside Carbonaceous Chondrites

• Typical radionuclides discovered in Allende meteorite (Rancitelli, et al., Science, 1969): $^7$Be, $^{22}$Na, $^{26}$Al, $^{40}$K, $^{46}$Sc, $^{48}$V, $^{51}$Cr, $^{54}$Mn, $^{57}$Co, $^{60}$Co, $^{232}$Th

→ 3Myr exposure time, 50cm diameter in size before atmospheric entry

• Major long-lived radionuclide contributors (Sears and Dodd, in Meteorites and the Early Solar System, 1988): $^{40}$K (530 ppm), $^{232}$Th (2.9 x $10^{-3}$ ppm), $^{235/238}$U (8.5 x $10^{-3}$ ppm) in the solar system abundance

→ Present remaining after 3.5Ga: $^{40}$K (~0.01%), $^{232}$Th (~100 %), $^{235/238}$U (~99%)

Cf. Natural radionuclides:

➢ The Highest Martian Meteorite case in 3.5Ga: ~2.8MGy
➢ The Highest Granites on Earth in 3.5 Ga: ~175MGy

➢ Total Dose for Carbonaceous Chondrites: ~5.9MGy in 3.5 Ga

→ It is believed that aqueous alteration occurred inside the parent body of 1999 JU3 right after its accretion at ~4.5-3.5 Ga; thus there is enough time to provide dosage to kill indigenous spores, if ever emerged, by the present time.
Sub-Surface Sterilization: Summary

* Nominal surface sampling is sufficient for sterilization by solar UV radiation.
  • The deepest depth estimate of the artificial crater on regolith layers is ~200 cm and sampling attempt will be taken place a few weeks after the crater formation (UV sterilization is in effect for some degrees)

• Sterilization processes assessment:
  (1) Sub-surface Temperature level
  ➔ Heat sterilization of indigenous life in 200cm depth sub-surface of 1999 JU3 does not seem effective
  (2) Penetration of GCR, with gardening effect
  ➔ Gardening depth and time in the local area are unknown; yet Itokawa proved granular convection on the sub-km asteroid and its samples experienced <8Myr GCR exposure. The ~200 cm-deep crater floor of 1999 JU3 regolith layers may be at the marginal depth of shield limit to protect indigenous life in <1.1 Myr (Mileikowsky, et al.) or in >10Myr (Clark et al.) with an uncertainty
  (3) Radionuclides exposure inside carbonaceous chondrite composition
  ➔ Carbonaceous chondrites contain a number of long-lived radionuclides and its aqueous alteration occurred inside the parent body of 1999 JU3 right after its accretion at ~4.5-3.5 Ga. It is long enough to provide sufficient dosage to kill indigenous life by the present time.
PPP Question #6: Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth e.g. via meteorites, of material equivalent to a sample returned from the target body?

Answer#6: “YES”. With variations over time, the asteroidal (and certainly NEO) material including carbonaceous chondrites and micrometeorites has been collected on the Earth in large quantities.

- Spectral comparison to date considers carbonaceous chondrites as representative of C-type asteroids.
- There are indications that certain materials are under represented in the world’s meteorite collection (e.g. brittle carbonaceous material).
- Today’s incoming stream of meteoritic material may be not representative and may vary over time.
- For NEO, the material should have been already arrived at the Earth.
Requirements for case study mission 1
Small Body Six Question Results: Unrestricted ER

Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?

UNCERTAIN

Themis, Main belt comets and Zag/Monahan meteorites

Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?

NO

Does the preponderance of scientific evidence indicate that there was never sufficient organic matter in or on the target body to support life?

NO

Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperature? (i.e. >160°C)

NO for pristine materials

Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms?

Uncertain for the deepest interior

Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?

YES but... “Exact Ryugu fragments” cannot be identified

CATEGORY V: No Strict Containment nor Handling Required

YES for surface craters
YES for both long exposed surfaces and sub-surfaces in the SCI excavated depth
“After careful consideration with respect to the COSPAR Planetary Protection Policy, Colloquium attendees considered the categorization of the Hayabusa-2 mission and agreed that it should be considered Category II, outbound, with particular attention needed to avoid impact with Mars under all mission scenarios. In addition, the attendees agreed that the mission’s asteroid target (1999 JU3) meets the COSPAR classification for a body from which a Category V mission with “unrestricted Earth-return” is warranted. This agreement concurs with the recommendation of the NASA Advisory Council’s Planetary Protection Subcommittee, which also considered the categorization at their May 2012 meeting in Washington, DC.”

Signed by Dr. John Rummel, the Chair
Hayabusa-2’s Implementation Records

• **Fiscal Year of 2011**: Hayabusa2 project officially approved.

• **January 2012**: Space Activities Commission (SAC) of the Government of Japan approved Hayabusa-2 mission. (SAC commenced its review in June 2011)

• **March 2012**: CDR of Hayabusa2 completed.

• **Fiscal Year of 2012**: Manufacturing of subsystems started.

• **May 2012**: NAC Planetary Protection Subcommittee presentation

• **May 2012**: COSPAR PPP Colloquium at Alpbach recommended the categorization

• **July 2012**: At COSPAR2012 GA, PPP resolution granted

• **Jan.– Apr. 2013**: The first interface tests


• **July 2014**: At COSPAR2014GA, Mars impact probability reported and accepted

• **Dec. 2014**: The spacecraft was launched by H-IIA at Tanegashima Space Center
Implementation of requirements
Orbital Analysis for Impact Probability to Mars

• The question raised after the NAC-PPP Subcommittee presentation

• JAXA is to provide necessary calculation results of the Mars impact probability in 50 years after the launch calculation to satisfy the COSPAR PPP stakeholders before the COSPAR 2014 GA.

• Important Notes:
  (1) The orbital inclination of 1999 JU3 to the invariant plane is 5.8838 degrees.
  (2) The H-IIA upper stage is ballistic and will not reach to 1999 JU3 without IES delta-V and Earth swing-by.
  (3) The spacecraft only reaches to the target by non-Kaplarian trajectory resulting the IES operation

• We only consider off-nominal events during deep space cruising (i.e., double contingencies of all IES dying and loss of attitude control), which only then the spacecraft follows an Keplarian orbit in the maximum probability to impacting Mars

Eccentricity (e) = 0.19022
Inclination (i) = 5.8838 deg.
q = 0.96332 AU, Q = 1.41589 AU
Implementation of requirements
Impact Probability to Mars: See Details in Chujo`s Lecture

- Failure probability
  - System failure rate
  - Meteoroid kill rate

Impact probability after failure
This differs depending on missions.
Simple analysis? High-fidelity Monte-Carlo simulation necessary?

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario</td>
<td>Disruption of all the 4 IES grids</td>
<td>Penetration of 1 of the 12 RCS thrusters</td>
<td>Dark current by impact intruding to spacecraft circuits through the honeycomb panel</td>
</tr>
<tr>
<td>Component dimension</td>
<td>150 mm diameter</td>
<td>64 × 64 mm</td>
<td>1.6 × 1.0 × 1.25 m</td>
</tr>
<tr>
<td>Minimum mass of meteoroid</td>
<td>8 × 10^{-6} g</td>
<td>1 × 10^{-4} g</td>
<td>1 × 10^{-3} g</td>
</tr>
<tr>
<td>Kill rate</td>
<td>2.5 × 10^{-7} [yr^{-1}]</td>
<td>2.1 × 10^{-4} [yr^{-1}]</td>
<td>2.6 × 10^{-2} [yr^{-1}]</td>
</tr>
</tbody>
</table>
## Implementation of requirements

### Impact Probability to Mars: Results and Conclusion

**Nominal Window Case**

<table>
<thead>
<tr>
<th>Trajectory Leg</th>
<th>IES ΔV/RCS ΔV</th>
<th>Impact probability (no swing-by) $\int p_{\text{no_swby}} dt$</th>
<th>Impact probability (swing-by) $\int p_{\text{swby}} dt$</th>
<th>Failure probability</th>
<th>Total probability $\int (p_{\text{no_swby}} + p_{\text{swby}}) q dt$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection</td>
<td>No/No</td>
<td>1.0e-14</td>
<td>1.9e-12</td>
<td>2.1e-3</td>
<td>4.1e-15</td>
</tr>
<tr>
<td>Earth to Earth</td>
<td>Yes/Yes</td>
<td>4.1e-13</td>
<td>1.9e-11</td>
<td>2.4e-2</td>
<td>4.1e-14</td>
</tr>
<tr>
<td>Earth to Asteroid</td>
<td>Yes/Yes</td>
<td>0</td>
<td>3.7e-11</td>
<td>6.8e-2</td>
<td>8.8e-14</td>
</tr>
<tr>
<td>Asteroid Proximity</td>
<td>No/No</td>
<td>0</td>
<td>0</td>
<td>4.1e-2</td>
<td>0</td>
</tr>
<tr>
<td>Asteroid to Earth</td>
<td>Yes/Yes</td>
<td>0</td>
<td>3.4e-9</td>
<td>2.8e-2</td>
<td>8.0e-12</td>
</tr>
<tr>
<td>TOTAL Probability</td>
<td></td>
<td>4.1e-13</td>
<td>3.4e-9</td>
<td>1.6e-1</td>
<td>8.1e-12</td>
</tr>
</tbody>
</table>

Total probability for backup windows 1 and 2 are 8.0e-12 and 5.6e-7, respectively.

-> The Hayabusa-2 mission satisfies the COSPAR requirement that the Mars impact probability should be less than 1e-4 for 50 years after launch for all mission scenarios.
Implementation of requirements
Regular Progress Reports for Outbound Cat II

Category-2:

➡️ Degree of Concern:
Record of planned impact probability and contamination control measures

➡️ Range of Requirements:
Documentation only (all brief):
(1) PP plan
(2) Pre-launch report
(3) Post-launch report
(4) Post-encounter report
(5) End-of-mission report
Category-5:

(A) Restricted Earth Return

Degree of Concern:
- No impact on Earth or Moon
- Returned hardware sterile
- Containment of any sample

Range of Requirements:
- Category-2 documents +
- Pc analysis plan
- Microbial reduction plan
- Microbial assay plan
- Trajectory biasing
- Sterile or contained returned hardware
- Continual monitoring of project activities
- Project advanced studies/research

(B) Unrestricted Earth Return

Range of Requirements: None
Things to remember

- All sample return missions regardless a target body are in Category V.
- In the Cat V, there are two sub-categories as restricted and unrestricted earth returns (RER & UER).
- RER targets such as Mars, Europa, and Enceladus must be scientifically prepared for protections of both (potential) biospheres in outbound and inbound legs.
- The Cat V missions to solar system small bodies are determined their categorizations in a case-by-case basis, based upon the upmost scientific knowledge at a time of the category proposal to COSPAR PPP.
- In order to judge RER/UER categorizations, small body sample return missions must go through the six question series.
- If the Cat V UER category is granted by COSPAR, no further range of requirements are requested, except regular mission progress reports for all and Mars impact probability analysis for those missions having a potential to go beyond the Martian orbit.
- Mission design and spacecraft system may be affected by the PPP categorization. Act early to propose the COSPAR PPP categorization and get approved prior to finalizing the mission scenario and design.