ECSS Training Session – 09.02.2022 - online

ECSS-U-ST-20C (1 August 2019)

Space sustainability

Planetary Protection

Agenda

- General introduction - planetary protection, ECSS-U-ST-20C, microbiology, bioburden assessment and bioburden reduction

  Petra Rettberg (DLR, D)

- Planetary protection and contamination control

  Delphine Faye (CNES, F)

- Implementation of planetary protection requirements – Case study of ExoMars

  Diana Margheritis (TASI, IT)

Trainer‘s information: Petra Rettberg

- DLR in Köln, Germany, group leader ‚Astrobiology‘
- Bio-/chemist by training
- Research interests in astrobiology, microbiology, planetary protection, life in extreme environments, habitability, radiation biology, photobiology
- P-I and Co-I of several space experiments
- Planetary protection verification assays on behalf of ESA
- Member of the COSPAR Panel on Planetary Protection
- Member of the former ESA Planetary Protection Working Group
- Member of former ECSS working groups, e.g. for ECSS-U-ST-20C

For details, see

- DLR - Institute of Aerospace Medicine – Astrobiology and
- DLR - Institute of Aerospace Medicine - Petra Rettberg, Institute of Aerospace Medicine

Email: petra.rettberg@dlr.de

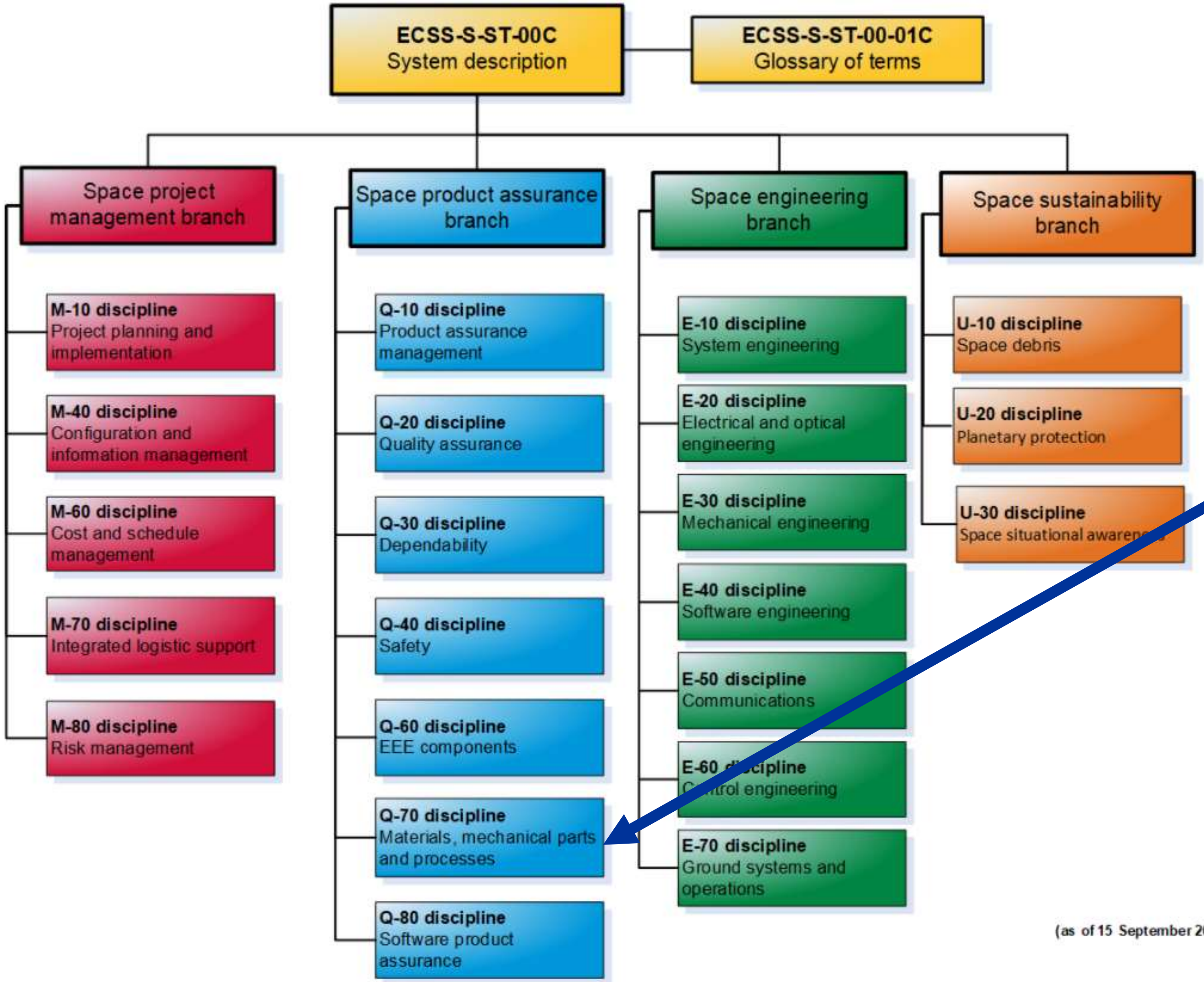
Outline

- ECSS
- Planetary protection background
- Mission categories and requirements
- Basics in microbiology
- ECSS-Q-ST-70-53, -54, 56, -57, -58
- ECSS-Q-ST-70-55 → bioburden sampling
- Summary and further reading

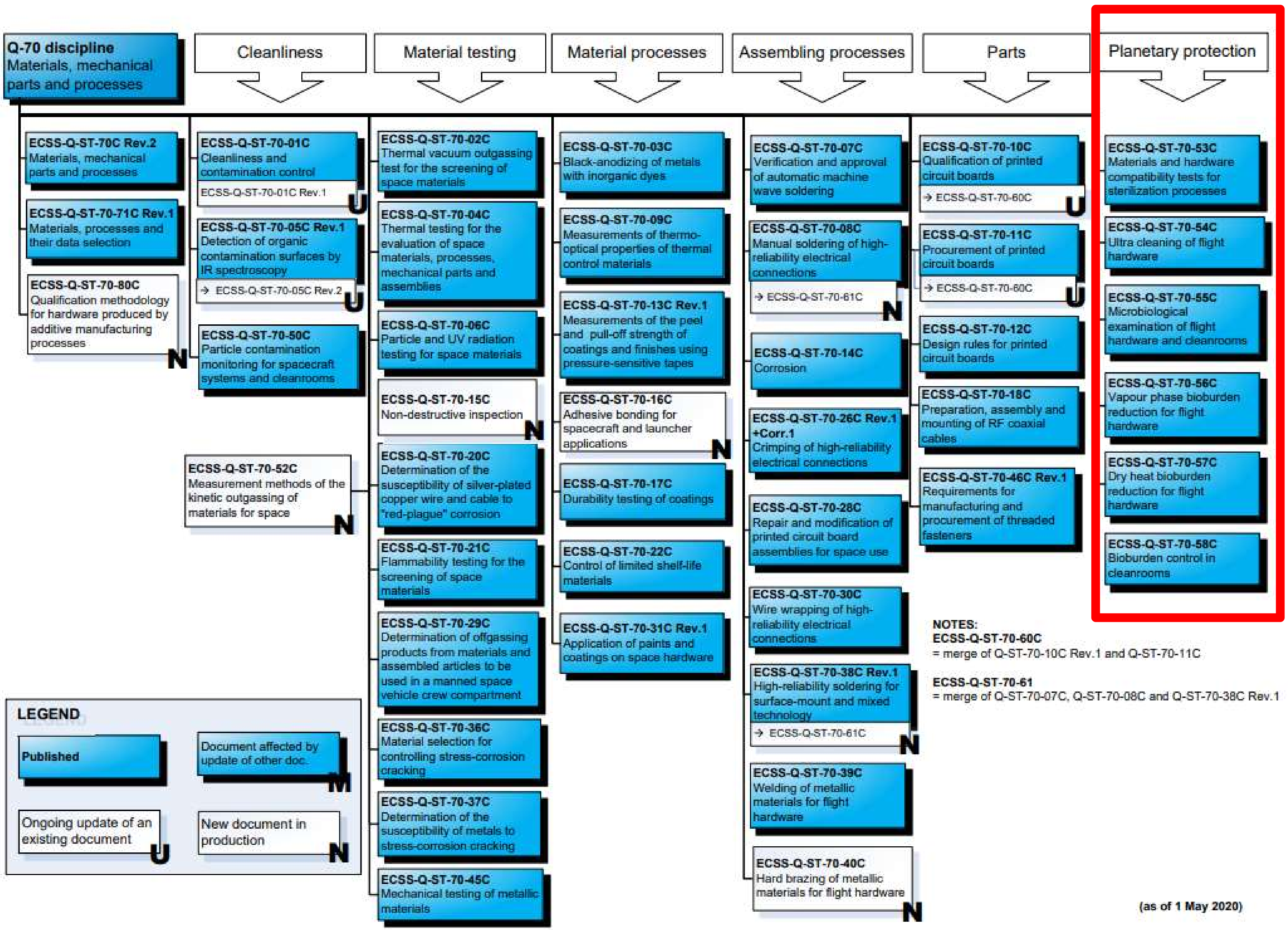
European Cooperation for Space Standardization (ECSS)

- European organization within the European space sector http://www.ecss.nl
- Produces technical standards (requirements) for space projects, including planetary protection (PP)
- Members: ESA (European Space Agency – 22 Member States), Eurospace (55 space industries from 14 European States), ASI (Agenzia Spaziale Italiana – Italy), CNES (Centre National d'Etudes Spatiales – France), CSA (Canadian Space Agency – Canada), DLR (German Aerospace Center – Germany), NSO (Netherlands Space Office – The Netherlands), UKSA (United Kingdom Space Agency – United Kingdom)
- Observers: Eumetsat, CEN (European Committee for Standardization), EDA (European Defense Agency)

ECSS Disciplines



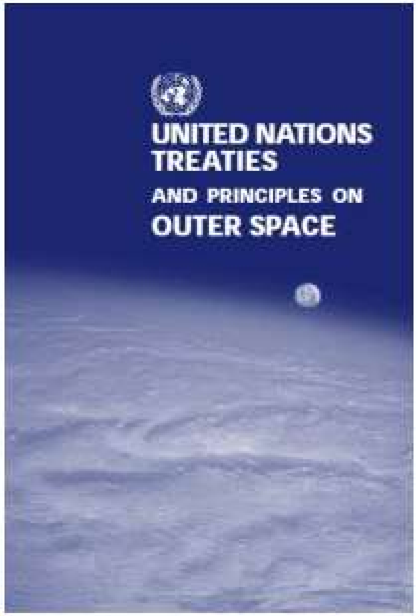
(as of 15 September 2021)


Q-70 discipline
Materials, mechanical parts and processes
Cleanliness
Material testing
Material processes
Assembling processes
Parts
Planetary protection
ECSS-Q-ST-70C Rev.2
Materials, mechanical parts and processes
ECSS-Q-ST-70-71C Rev.1
Materials, processes and their data selection
ECSS-Q-ST-70-80C
Qualification methodology for hardware produced by additive manufacturing processes
N
ECSS-Q-ST-70-01C
Cleanliness and contamination control
ECSS-Q-ST-70-01C Rev.1
U
ECSS-Q-ST-70-05C Rev.1
Detection of organic contamination surfaces by IR spectroscopy
→ ECSS-Q-ST-70-05C Rev.2
U
ECSS-Q-ST-70-50C
Particle contamination monitoring for spacecraft systems and cleanrooms
ECSS-Q-ST-70-52C
Measurement methods of the kinetic outgassing of materials for space
N
ECSS-Q-ST-70-02C
Thermal vacuum outgassing test for the screening of space materials
ECSS-Q-ST-70-04C
Thermal testing for the evaluation of space materials, processes, mechanical parts and assemblies
ECSS-Q-ST-70-06C
Particle and UV radiation testing for space materials
ECSS-Q-ST-70-15C
Non-destructive inspection
N
ECSS-Q-ST-70-20C
Determination of the susceptibility of silver-plated copper wire and cable to "red-plague" corrosion
ECSS-Q-ST-70-21C
Flammability testing for the screening of space materials
ECSS-Q-ST-70-29C
Determination of offgassing products from materials and assembled articles to be used in a manned space vehicle crew compartment
ECSS-Q-ST-70-36C
Material selection for controlling stress-corrosion cracking
ECSS-Q-ST-70-37C
Determination of the susceptibility of metals to stress-corrosion cracking
ECSS-Q-ST-70-45C
Mechanical testing of metallic materials
ECSS-Q-ST-70-03C
Black-anodizing of metals with inorganic dyes
ECSS-Q-ST-70-09C
Measurements of thermo-optical properties of thermal control materials
ECSS-Q-ST-70-13C Rev.1
Measurements of the peel and pull-off strength of coatings and finishes using pressure-sensitive tapes
ECSS-Q-ST-70-16C
Adhesive bonding for spacecraft and launcher applications
N
ECSS-Q-ST-70-17C
Durability testing of coatings
ECSS-Q-ST-70-22C
Control of limited shelf-life materials
ECSS-Q-ST-70-31C Rev.1
Application of paints and coatings on space hardware
ECSS-Q-ST-70-07C
Verification and approval of automatic machine wave soldering
ECSS-Q-ST-70-08C
Manual soldering of high-reliability electrical connections
→ ECSS-Q-ST-70-61C
N
ECSS-Q-ST-70-14C
Corrosion
ECSS-Q-ST-70-26C Rev.1 +Corr.1
Crimping of high-reliability electrical connections
ECSS-Q-ST-70-28C
Repair and modification of printed circuit board assemblies for space use
ECSS-Q-ST-70-30C
Wire wrapping of high-reliability electrical connections
ECSS-Q-ST-70-38C Rev.1
High-reliability soldering for surface-mount and mixed technology
→ ECSS-Q-ST-70-61C
N
ECSS-Q-ST-70-39C
Welding of metallic materials for flight hardware
ECSS-Q-ST-70-40C
Hard brazing of metallic materials for flight hardware
N
ECSS-Q-ST-70-10C
Qualification of printed circuit boards
→ ECSS-Q-ST-70-60C
U
ECSS-Q-ST-70-11C
Procurement of printed circuit boards
→ ECSS-Q-ST-70-60C
U
ECSS-Q-ST-70-12C
Design rules for printed circuit boards
ECSS-Q-ST-70-18C
Preparation, assembly and mounting of RF coaxial cables
ECSS-Q-ST-70-46C Rev.1
Requirements for manufacturing and procurement of threaded fasteners
ECSS-Q-ST-70-53C
Materials and hardware compatibility tests for sterilization processes
ECSS-Q-ST-70-54C
Ultra cleaning of flight hardware
ECSS-Q-ST-70-55C
Microbiological examination of flight hardware and cleanrooms
ECSS-Q-ST-70-56C
Vapour phase bioburden reduction for flight hardware
ECSS-Q-ST-70-57C
Dry heat bioburden reduction for flight hardware
ECSS-Q-ST-70-58C
Bioburden control in cleanrooms
NOTES:
ECSS-Q-ST-70-60C
= merge of Q-ST-70-10C Rev.1 and Q-ST-70-11C
ECSS-Q-ST-70-61
= merge of Q-ST-70-07C, Q-ST-70-08C and Q-ST-70-38C Rev.1
LEGEND
Published
Document affected by update of other doc.
M
Ongoing update of an existing document
U
New document in production
N
(as of 1 May 2020)

Legal framework for planetary protection

The legal basis for planetary protection was established in Article IX of the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies (Outer Space Treaty):

"...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..."



Legal framework for planetary protection

COSPAR maintains and promulgates a planetary protection policy* for the reference of spacefaring nations, both as an international standard on procedures to avoid organic constituent and biological contamination in space exploration, and to provide accepted guidelines and requirements in this area to guide compliance with the wording of the Outer Space Treaty.

* The COSPAR PPP from 3 June 2021 can be downloaded from the COSPAR webpage:
→ PPPolicy_2021_3-June.pdf (cnes.fr)

COSPAR Panel on Planetary Protection (PPP)

Chair and Vice-Chairs

CNRS (F), UN, ESA

Members appointed by space agencies

Representatives of space industry are invited to the open COSPAR PP Panel meetings.

Solar System) and

F (Life Sciences as Related to Space)

Ex-officio member

Space Studies Board – US National Academies of Sciences, Engineering, and Medicine)

https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/

Rationales for COSPAR's planetary protection policy and associated requirements

- The Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission (backward planetary protection).
- The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized (forward planetary protection).

→ **ECSS-U-ST-20C:** The content of this document has been coordinated with the already existing ESA and NASA standards to ensure that requirements, documentation and reviews cover the needs and obligations of international partners for joint missions or contributions to a third party mission.

ECSS-U-ST-20C (1 August 2019)

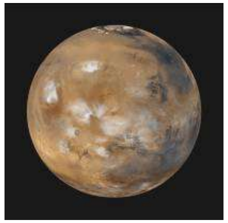
This standard contains planetary protection requirements, including:

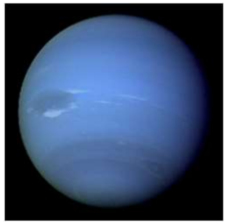
- Planetary protection management requirements;
- Technical planetary protection requirements for robotic and human missions (forward and backward contamination);
- Planetary protection requirements related to procedures;
- Document Requirements Descriptions (DRD) and their relation to the respective reviews.

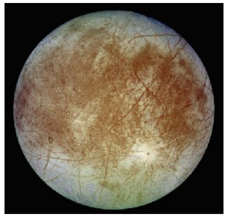
This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

Planetary protection categories

- Five different planetary protection categories, in some cases with subcategories, have been defined.
- They reflect the level of interest and concern that contamination can compromise actual and future investigations.
- The categories and associated requirements depend on the **target body** (e.g. Moon, Mars, Europa, asteroids …), on the **mission type** (flyby, orbiter, lander) and the **mission goal** (e.g. for Mars - with or without life detection experiments).







Fotos: ESA/NASA

Mission categories

Category I: Any mission to a target body which is **not of direct interest** for understanding the process of **chemical evolution**

Flyby, Orbiter, Lander: Undifferentiated, metamorphosed asteroids; Io; others TBD

Category II: All types of missions to those target bodies where there is **significant interest** relative to the process chemical evolution, but where there is only a remote chance that contamination carried by a spacecraft could jeopardize future exploration

Flyby, Orbiter, Lander: Venus; Moon; Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; Ganymede; Callisto; Titan; Triton; Pluto/Charon; Ceres; Kuiper-belt objects; others TBD

Mission categories

Category III: Flyby and orbiter missions to a target planet or moon of **chemical evolution and/or origin of life interest** or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment

Flyby, orbiters: Mars; Europa; Enceladus, others TBD

Category IV: Lander missions on a target planet of **of direct interest** for understanding the process of **chemical evolution** for which scientific opinion provides a significant chance of contamination which could jeopardize future biological experiments

Lander missions: Mars; Europa; Enceladus, others TBD

Mission categories

Category V: All Earth return missions

The concern for these missions is the **protection of the terrestrial system** (the Earth and the Moon). For the set of planets deemed by scientific opinion to have no indigenous life forms, a special subcategory "safe for Earth return" is defined.

"Unrestricted Earth return": Moon; Venus, others TBD

"Restricted Earth return": Mars; Europa; Enceladus, others TBD

→ inbound leg of MSR mission

Definitions

- **Bioburden**
  - quantity of viable microorganisms measured with a specified assay

  → **How many microbes are there?**

- **Biodiversity**
  - identification of species of microorganisms measured with specified assays

  → **Which microbes are there?**

- **Sterilisation**
  - validated process used to render product free from viable microorganisms

  → **Inactivating/killing of microbes**

Mission categories and approaches

Mars surface missions

Quantitative bioburden limits

- Maximal allowed numbers and density of spores and heat-tolerant microorganisms measured with a specific assay
- Sub-/categories – life detection, special regions, sample return

Details about category III and IV, subcategories, associated requirements and implementation → presentation of Diana Margheritis

Mission categories and approaches

Missions to Europa and Enceladus

Probabalistic approach

The probability of inadvertent contamination of a subsurface ocean by viable terrestrial organisms shall be ≤ 1×10^{-4} per mission.

The calculation of this probability should include

- bioburden at launch,
- cruise survival for contaminating organisms,
- organism survival in the radiation environment adjacent to Europa/Enceladus,
- probability of landing on Europa/Enceladus,
- mechanisms and timescales of transport to the europan/enceladan subsurface,
- organism survival and proliferation before, during, and after subsurface transfer.

Mission categories and approaches

Missions to small Solar system bodies

> A small Solar System body is an object in the Solar System that is neither a planet, a dwarf planet, nor a natural satellite, e.g. comets, asteroids, trojans, centaurs and trans-Neptunian objects.

Categorization of missions to small Solar system bodies not elsewhere discussed in ECSS-U-ST-70C shall be made on a **case-by-case basis**.

Principles für human missions to Mars

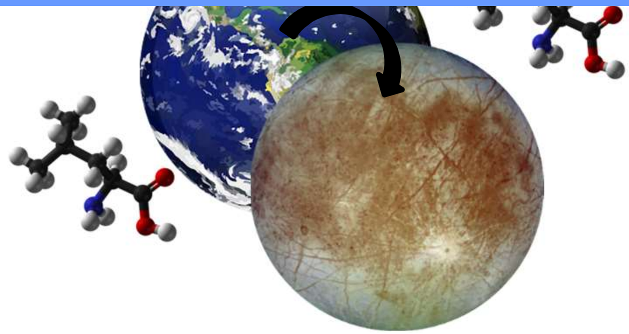
- **No specific requirements have been issued for human missions to Mars yet**.
- The intent of the planetary protection policy is the same whether a mission to Mars is conducted robotically or with astronauts.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only, if human-associated microbiological contamination is understood and controlled.
- COSPAR/NASA/ESA organized workshop series (2016 – 2020) to refine planetary protection requirements for human missions to Mars identified two high priority knowledge gaps that would also apply to robotic missions:
  - Natural transport of (terrestrial biological) contamination on Mars
  - Synergistic biocidal effects of the martian environment on the survival and growth of spacecraft (robotic and human) associated microbiota

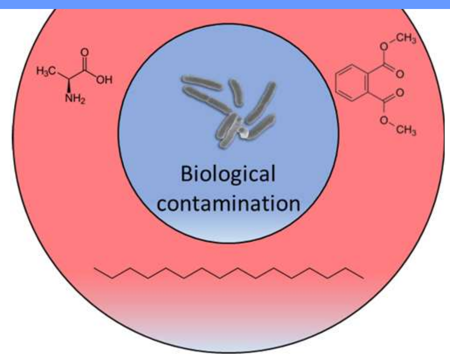
  → **Further research is needed!**

Planetary protection and organic contamination control

Organic contamination in the context of planetary protection can be considered as any terrestrial organic matter that could be mistaken for, or whose signal could overwhelm and mask, an extraterrestrial organic signature.

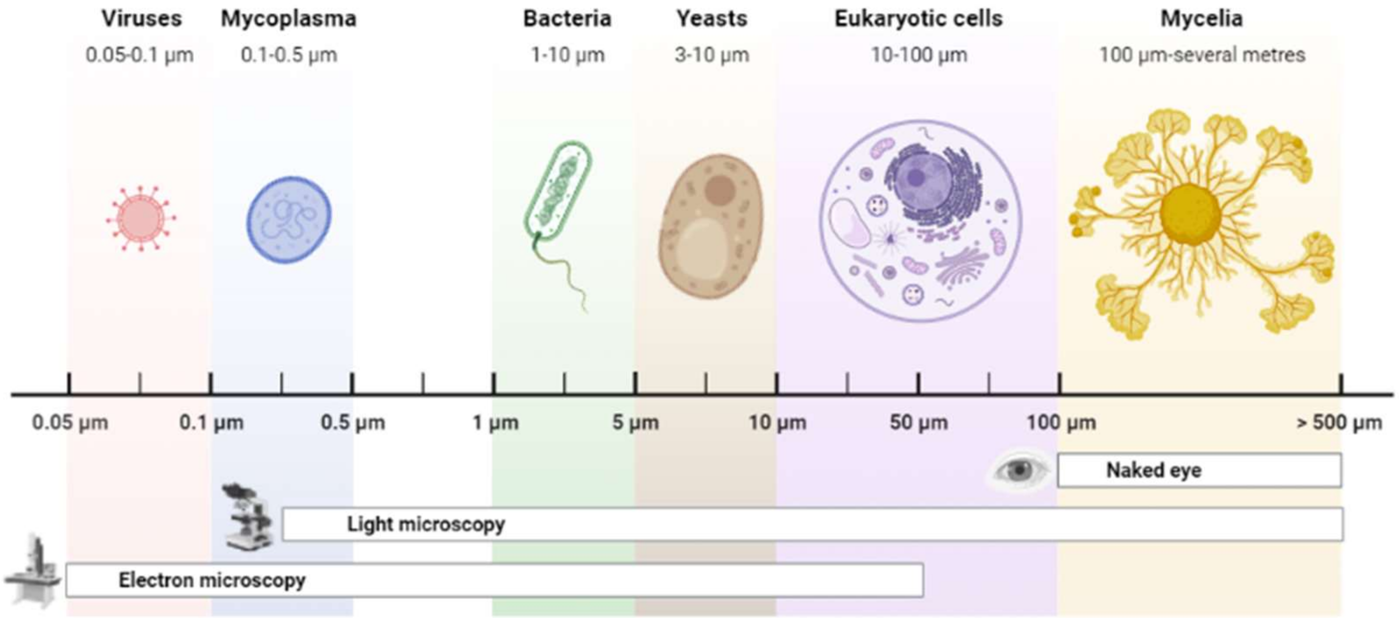
Details about planetary protection, contamination control and implementation
→ presentation of Delphine Faye





Basics in microbiology

- Microorganisms are very small and not visible by the naked eye.



- Some microorganisms can form spores.
- Bacterial spores are resistant to many physical and chemical stressors.

Basics in microbiology

- Microorganisms exist almost everywhere on Earth.
- They can survive extremely harsh conditions.

Microbes are everywhere!

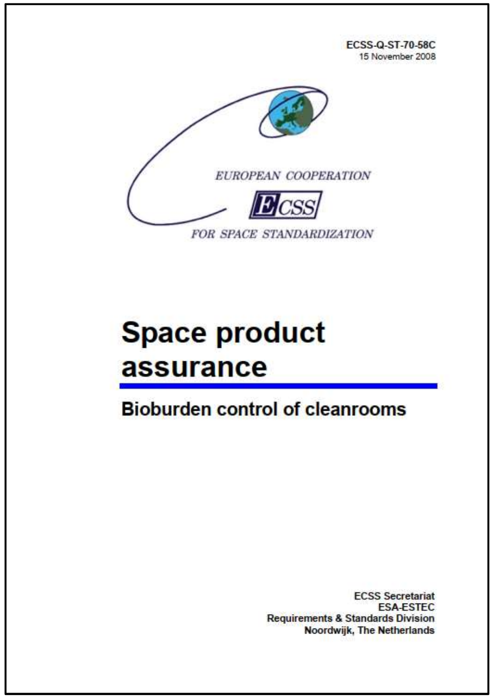
- Each microbe has specific growth requirements... only about 1% of all microorganisms are cultivable.
- Different molecular methods have been established to study the uncultivable microbial diversity.

Cleanroom / spacecraft microbiology

- Most microbial contaminants are human-associated.
- Cleanroom isolates can be more resistant than comparable laboratory strains.
- Spore-formers are present in cleanrooms mainly as spores.
- A broad diversity of microbes is present, with different adaptations.
- The contamination is not homogenously distributed.

https://www.genome.gov/about-nhgri/Director/genomics-landscape/june-6-2019-Human-Microbiome_Project

How to built a spacecraft with PP constraints?


ECSS-Q-ST-70-58C
15 November 2008

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Bioburden control of cleanrooms

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ECSS-Q-ST-70-58C

This standard establishes the **principles and basic methodology for microbiological control of cleanrooms** and associated controlled environments with planetary protection constraints.

How to clean space hardware?


ECSS-Q-ST-70-54C
15 February 2017

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Ultracleaning of flight hardware

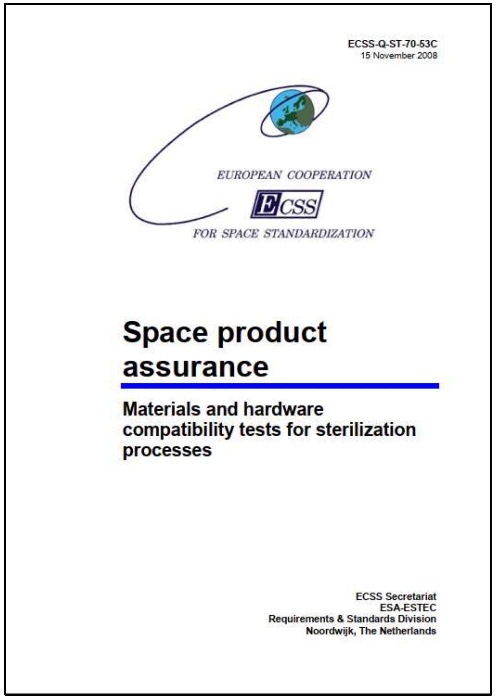
ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ECSS-Q-ST-70-54C

This standard addresses

- process **descriptions**,
- process **validation**,
- cleanliness **control and monitoring**,
- recontamination **prevention**,
- **quality** assurance.

How to select a suitable sterilisation method?


ECSS-Q-ST-70-53C
15 November 2008

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Materials and hardware compatibility tests for sterilization processes

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

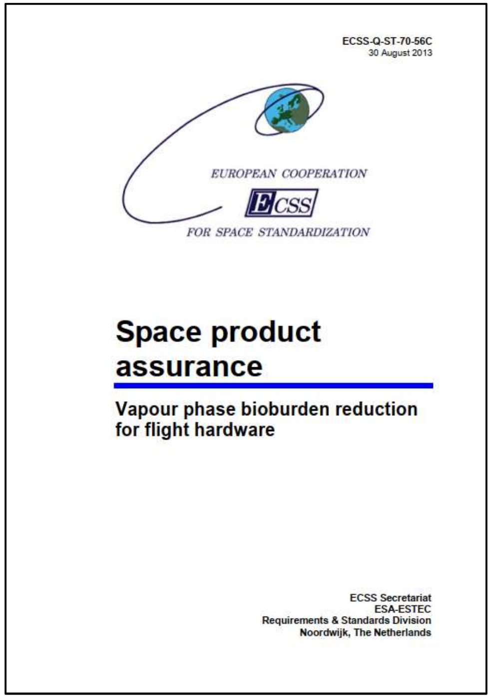
ECSS-Q-ST-70-53C

A properly formulated and executed test program for all hardware elements that have to undergo sterilization is essential to guarantee their nominal performance and to prevent any immediate or long-term detrimental effects.

The detrimental effects to be anticipated during sterilization depend on the applied process.

The objective of this standard is to ensure a successful mission by the definition of a **test protocol and acceptance criteria** for the determination **of hardware compatibility with sterilization processes**.

How to reduce the bioburden?


ECSS-Q-ST-70-56C
30 August 2013

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Vapour phase bioburden reduction for flight hardware

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

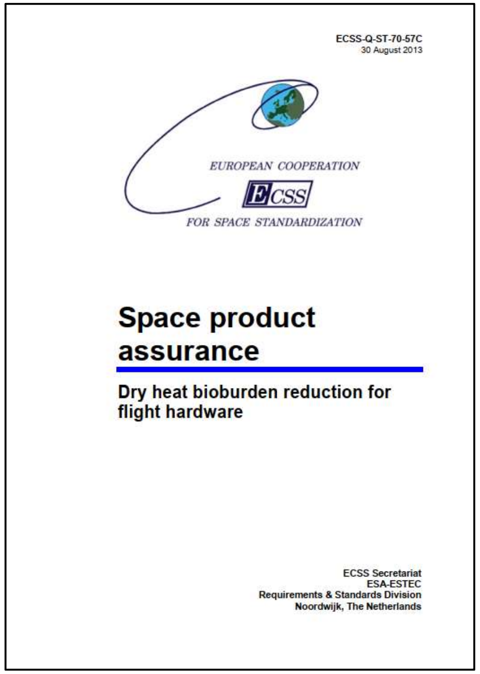
ECSS-Q-ST-70-56C

This standard specifies procedures for the reduction of microbiological contamination of flight hardware using **hydrogen peroxide** vapour.

The procedures specified in this standard cover:

- Reduction of microbiological contamination on exposed surfaces
- Reduction of microbiological contamination in controlled ambient and vacuum environments.
- This standard also specifies requirements for the conditioning of the flight hardware, bioburden reduction cycle development, and equipment to be used for applying a bioburden reduction procedure.

How to reduce the bioburden?


ECSS-Q-ST-70-57C
30 August 2013

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Dry heat bioburden reduction for flight hardware

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ECSS-Q-ST-70-57C

This standard defines procedures for the reduction of microbiological contamination of flight hardware using heat.

The procedures specified in this standard cover:

- Reduction of microbiological contamination on exposed surfaces, mated surfaces and encapsulated material
- Reduction of microbiological contamination in dry, ambient and uncontrolled humidity environments.

This standard also specifies requirements for the conditioning of the flight hardware, bioburden reduction cycle development, and equipment to be used for applying a bioburden reduction procedure.

How to measure the bioburden?


ECSS-Q-ST-70-55C
15 November 2008

EUROPEAN COOPERATION
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Space product assurance

Microbial examination of flight hardware and cleanrooms

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ECSS-Q-ST-70-55C

This standard defines test procedures for **quantitative and/or qualitative microbiological examination** of surfaces of flight hardware and in microbiologically controlled environments (e.g. cleanroom surfaces, cleanroom air, isolator systems).

The test methods described in this standard apply to controlling the microbiological contamination on all manned and unmanned spacecraft, launchers, payloads, experiments, ground support equipment, and cleanrooms with planetary protection constraints.

ECSS-Q-ST-70-55C

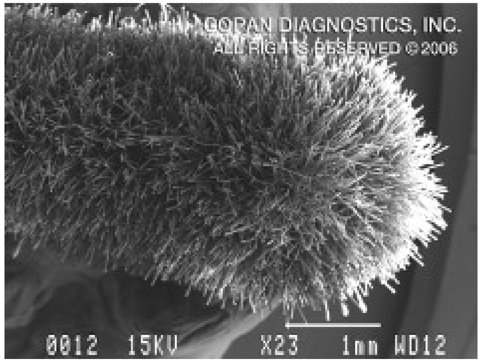
The following test methods are described:

- **Surface** and **air** sampling and detection of biological contaminants with swabs, wipes, contact plates and air samplers, followed by **cultivation** for bioburden determination.

- Sampling of biological contaminants followed by **DNA analysis** from swabs and wipes.

Surface sampling with swabs

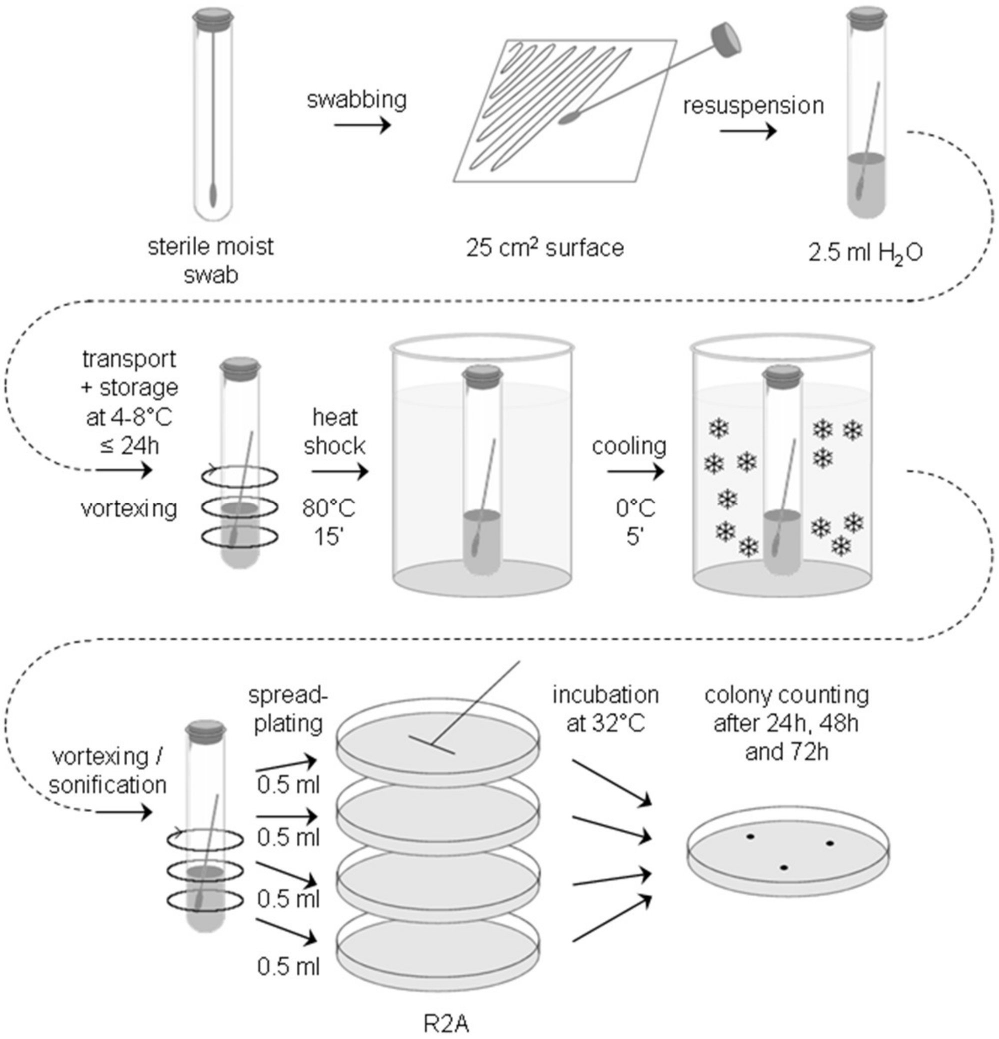
Electron Microscope photograph of a nylon flocked swab.



For areas up to 25 cm^2

Bioburden analysis with the planetary protection standard assay

for the enumeration of aerobic mesophilic heat tolerant spores and vegetative bacteria

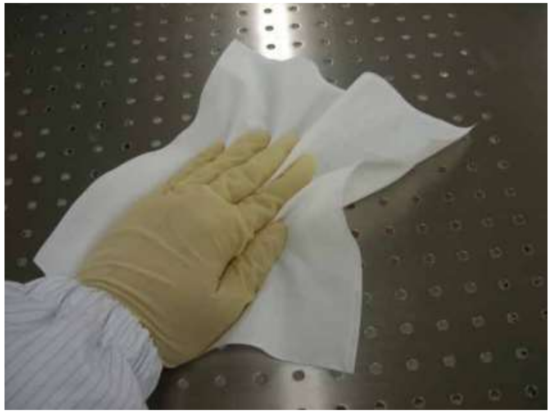


Results after 72h of incubation

Surface sampling with wipes

For areas up to 1 m^2

Analysis in analogy to the swab assays



Sampling in different cleanroom classes

ISO 5

ISO 8

Planetary protection requirements

- have to be taken into consideration from the very beginning,
- limit the allowed bioburden of a spacecraft for category III, IV and V (restricted) missions,
- have a major impact on mission design,
- have a major impact on spacecraft hardware and payload
  - material selection
  - spacecraft design
  - sterilisation strategies
  - assembly, integration and testing,
- necessiates documentation, reviews, management structures,

Planetary protection requirements

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- have a major impact on mission design,
- have a major impact on spacecraft hardware and payload
  - material selection
  - spacecraft design
  - sterilisation strategies
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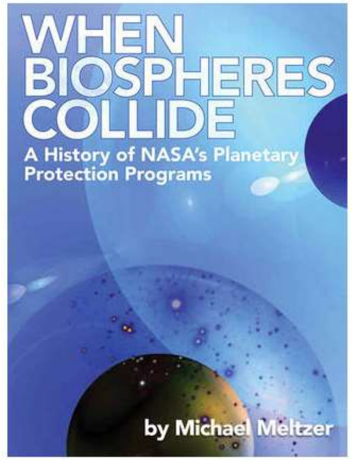
- necessiates documentation, reviews, management structures,
- **are implemented since the Viking missions (1976).**



The history of planetary protection is presented by tracing the responses to interplanetary concerns on NASA's missions.
Credits: NASA

The International Planetary Protection Handbook

Description of the state of the art and good practice for implementing planetary protection requirements

→ Introduction and general informations
→ Case studies for different PP categories
→ Lessons learned from past missions
→ Implementation in different space agencies

Free download from the COSPAR webpage:
https://cosparhq.cnes.fr/assets/uploads/2021/02/PPOSS_International-Planetary-Protection-Handbook_2019_Space-Research-Today.pdf

EC Horizon 2020, grant agreement 687373,
Planetary Protection of Outer Solar System (2016 – 2018)


Thank your for your attention!