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)

- Planetary Protection and Cleanliness and Contamination Control

  Delphine Faye (CNES)

- Implementation of planetary protection requirements with the examples of ExoMars2016 and ExoMars2022

  Diana Margheritis (TASI)

Trainer‘s information : Delphine Faye

- French Space Agency in Toulouse, France
- Contamination Expert - Orbital Systems Directorate since 1997
- Chemist by training (postgraduated in spectrochemistry from Lille University)
- Main duties focused on :
  - Expertise for CNES projects and technical Departments
  - Research and Technology program in partnership with space industries, other space agencies and research organisms (outgassing kinetics studies, modelling, contamination effects on spacecraft, on-ground and in-orbit contamination control)
- Planetary Protection Officer for CNES projects
- Scientific consultant for ASPEC (French Association for Contamination Studies)
- Member of ISO TC 209 Working Groups (Cleanrooms and associated controlled environments)
- Member of ECSS working groups (e.g. for ECSS-Q-ST-70-01, - 05, and former ECSS-U-ST-20C WG)

Contact email : delphine.faye@cnes.fr

OUTLINE

Biological vs. organic contamination

Planetary Protection and Contamination Control : normative approach

Best practices for Contamination Control

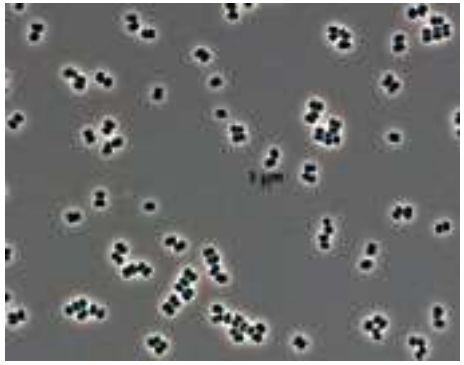
- Environmental monitoring of facilities
- Contamination Control on flight hardware
- Cleaning
- recontamination / cross contamination prevention

Future needs

What would happen if microorganisms could survive to an interplanetary voyage and multiply on any celestial body ?

Extremophile bacteria and other micro-organisms on Earth
⇨ powerful strategies to withstand hostile living conditions :
deep oceans, hydrothermal springs, glaciers, pH variation…

Some bacteria are able to sporulate, remaining viable and waiting for better conditions to reproduce.



Tersicoccus phoenicis

Very low probability
Space = hostile environment
Thermal cycling, UV radiation, charged particles
acid rains, high temperature / pressure on specific planets

BUT : risk of biological contamination seriously considered

Planetary Protection policy

PREVENTS

Forward contamination : transfer of viable organisms and bacterial endospores from Earth to another planetary body — **critical**

Backward contamination : transfer of possible biological material carried by exterrestrial samples to Earth's biosphere — **catastrophic**

Contamination can jeopardize future investigations and depends on the target body and mission type.

➢ **implementation at agency and industries level to avoid compromising the life-detection experiments and sample return missions**

- restrictions on impact probabilities for flight hardware not intended to directly contact a planet
- **contamination** control for all spacecraft elements

Contaminant (as per ECSS-Q-ST-70-01)

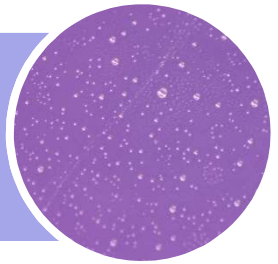
any unwanted molecular or particulate matter (including microbiological matter) on the **surface** or in the **environment** of interest, that can affect or degrade the relevant performance or life time

contamination

molecular (MOC)

film or droplets (size : from few Å to several nm)

essentially in flight but also on ground



particulate (PAC)

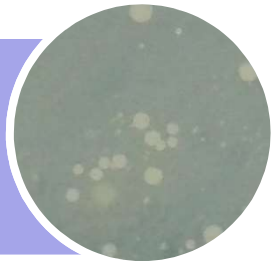
matter with observable length, width and thickness (size : µm)

essentially on ground

microbiological

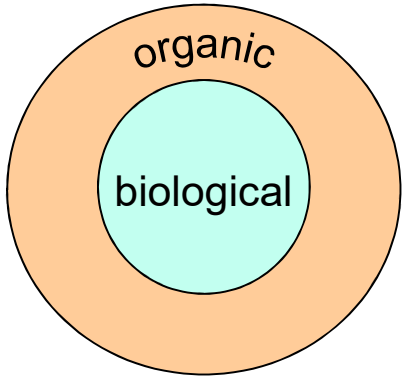
entity of micro or submicroscopic size

essentially on ground



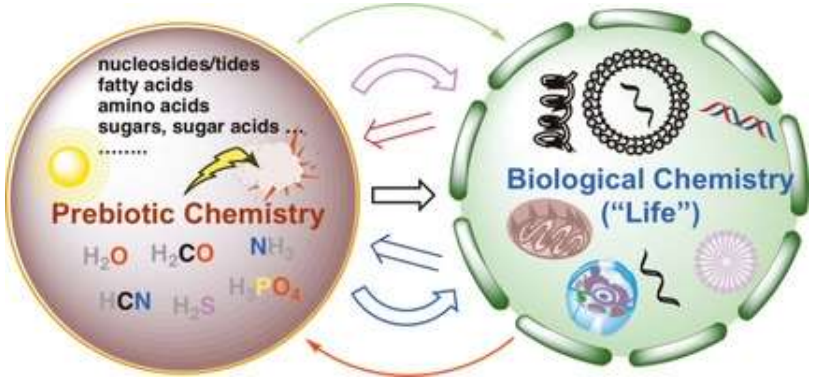
Biological vs. organic contamination

Why considering organics (MOC) and particles (PAC) in addition to biological contamination ?



carrier for micro-organisms
could be organic

compound, material or molecule with C, O, H and/or N
⁑ the 4 reference atoms of the building blocks in biological systems



search for extra-terrestrial life : detection of organic molecules
⇨ Biological activity but also abiotic and prebiotic chemistry

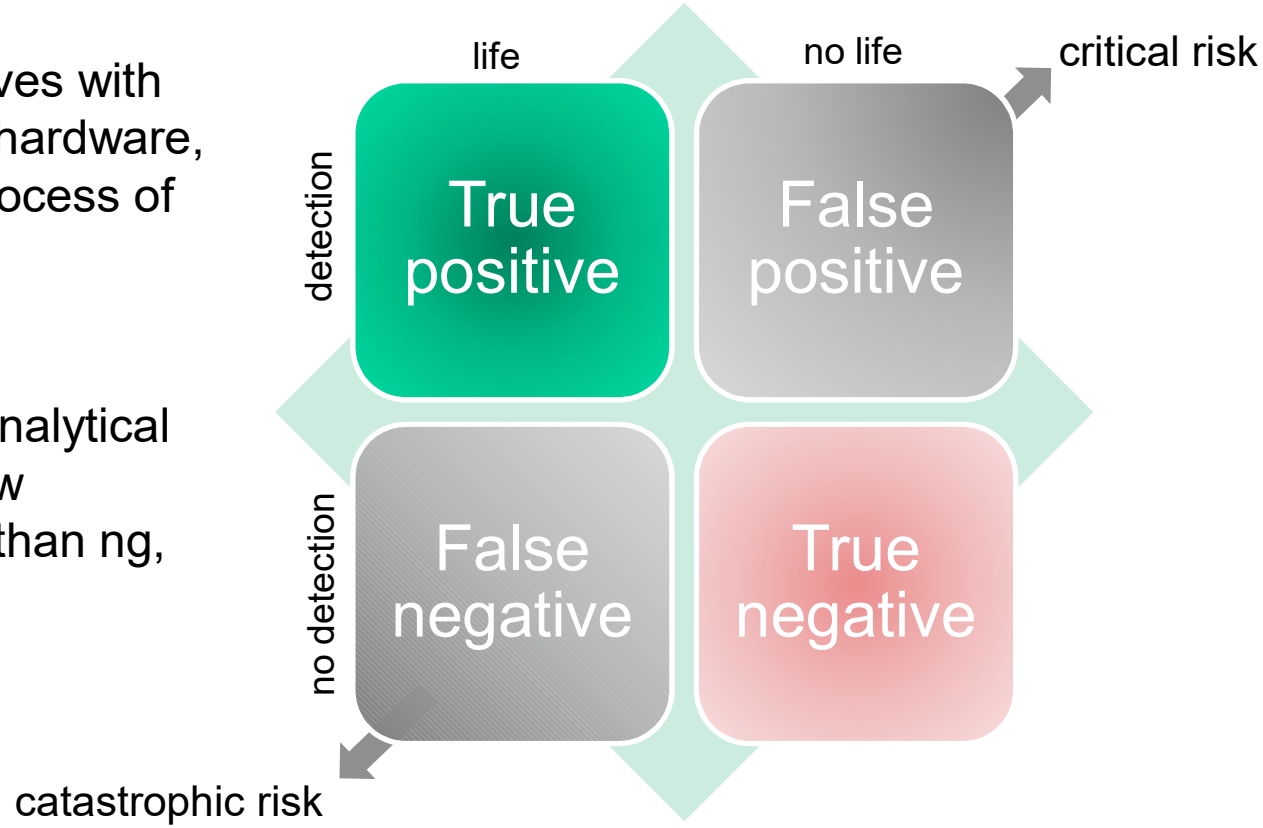
Note : carbonates, cyanides and simple oxides of carbon (e.g. CO and CO_2) are excluded.

R. Krishnamurthy, Life's Biological Chemistry: A Destiny or Destination Starting from Prebiotic Chemistry?, Chemistry Europe, vol. 24, 2018

Through life detection experimentation and biohazard testing protocols :

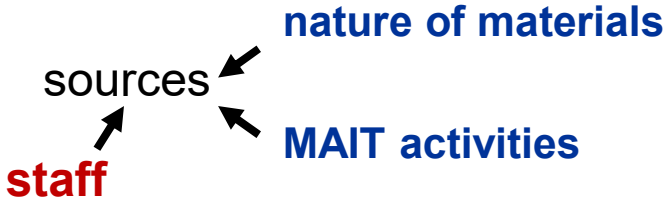
aim : to avoid false positives with organics on/in the space hardware, introduced through the process of exploration

may be detected by the analytical techniques used : very low detection threshold (less than ng, down to pg)



Confusion matrix

Sources of organic contamination

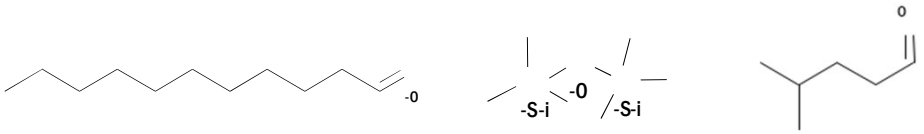


atmospheric fallout or surface transfer on ground

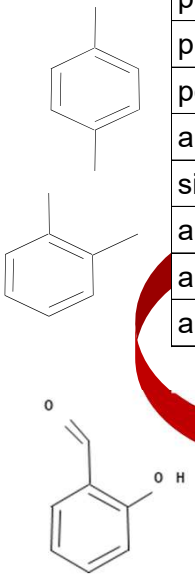
outgassing of polymer materials

materials damage due to vacuum, extreme temperature and radiation environments exposure

structures, resins, varnishes, paints, adhesives, tapes…



contaminant	polymeric source	abundance
phtalates	polyesters ; urethane	high
phenols	epoxies	high
polybenzimidizoles	Kapton®	high
aromatics	multiple	high
silanes ; siloxanes	silicones	medium
alkenes	multiple	medium
aliphatic carbonyles	multiple	medium
aromatic amines	urethane ; epoxies	low



C, O, H, N

Organic contamination
contamination by organics *including* living entities

Planetary Protection and Contamination Control

Cleanliness and organic contamination control : a **basic requirement at every step** of a project development

- ✓ prevents performance loss of space systems due to particulate and molecular contamination
- ✓ shall be compliant with the accuracy of the scientific instrumentation dedicated to the detection of organic contaminants in extraterrestrial samples
- ✓ preserves science integrity

⇨ impact on system design, spacecraft and lander integration process and mission scenario

normative approach for Contamination Control

contamination levels driven by sensitivity of the on-board instruments all along the different phases of development and operation of the spacecraft **based on risk assessment**

efficient cleanliness & contamination control plan

- depending on mission requirements

- compatible with the project schedule

2 documents
CRS
C&CCP

highly recommended
very helpful guidelines

Relevant standards

- **ECSS : Space Product Assurance**
- **ISO : Cleanrooms**

standardized measures, common to space agencies and all involved entities

ECSS standards - Q branch

standard	title	date
ST-70	materials, mechanical parts and processes	2019
ST-70-01	**cleanliness and contamination control**	***under review***
ST-70-02	thermal vacuum outgassing test for the screening of space materials	2008
ST-70-05	detection of organic contamination of surfaces by infrared spectroscopy	*under review*
ST-70-29	the determination of offgassing products from materials and assembled articles to be used in a manned space vehicle crew compartment	2008
ST-70-50	particles contamination monitoring for spacecraft systems and cleanrooms	2011
TM-70-52	kinetic outgassing of materials for space	2011
ST-70-53	materials and hardware compatibility tests for sterilization processes	2008
ST-70-54	ultra cleaning of flight hardware	2017
ST-70-55	microbial examination of flight hardware and cleanrooms	2008
ST-70-56	vapour phase bioburden reduction for flight hardware	2013
ST-70-57	dry heat bioburden reduction for flight hardware	2013
ST-70-58	bioburden control of cleanrooms	2008
ST-70-71	data for selection of space materials and processes	2017

ISO and other standards

standard	title	date
ISO 14644 series : cleanrooms and associated controlled environments		
part 1	classification of air cleanliness by particle concentration	2015
part 2	monitoring to provide evidence of cleanroom performance related to air cleanliness by particle concentration	2015
part 8*	classification of air cleanliness by chemical concentration	*under review*
part 9*	classification of surface cleanliness by particle concentration	*under review*
part 10*	classification of surface cleanliness by chemical concentration	*under review*
part 13	cleaning of surfaces to achieve defined levels of cleanliness in terms of particle and chemical classifications	2017
IEST-STD		
CC1246E	product Cleanliness Levels – Applications, Requirements, and Determination	2013

ECSS-U-ST-20

PP requirements

PP plan

PP implementation plan

Organic materials inventory

Pre-launch PP report

Post-launch PP report

Extended mission PP report

End-of-mission PP report

Contamination Requirement Specification

ECSS-Q-ST-70-01

Cleanliness and Contamination Control plan

PAC & MOC measurement report

Cleanliness declaration of conformity

Declared Material and Process Lists

Cleanliness shall be controlled and monitored, and the last assays must meet the specifications.

Planetary Protection requirements – PRR, SRR

➡ set of Planetary Protection requirements : can be tailored to the specific project

1. Mission description
2. Planetary Protection category
3. Planetary Protection management requirements,
4. Technical Planetary Protection requirements
5. Planetary Protection methods and procedures
6. Planetary Protection documentation and reviews

ECSS-U-ST-20

Planetary Protection plan – SRR, PDR

➡ primary planning document describing how the project meets the PP requirements

consolidated planning for all mission phases involving all actors
(payload providers, launch service provider, and international partners)

1. Mission description
2. Assessment of the consequences to implement the PP requirements with respect to design, development, schedule and operations
3. General implementation approach → example with Diana's presentation
4. PP documentation and reviews
5. Description of probability of impact analysis
6. PP activities and events in the project schedule
7. Compliance matrix against the PP requirements
8. Consequences for planned non-conformances or waivers
9. Verification matrix against the PP requirements

ECSS-U-ST-20

Planetary Protection implementation plan – PDR, CDR

➡ contains all relevant information about the detailed implementation of the PP requirements in line with the PP plan

1. Flight system description
2. Description of facilities
3. Bioburden control plan
4. Bioburden reduction plan
5. General implementation approach
6. Updated list of waivers and NCRs and associated impact analysis

example for EXOMARS with Diana's presentation

ECSS-U-ST-20

Pre-launch Planetary Protection report – FAR, FRR

➡ demonstration whether the project meets the PP requirements

1. Deviation from PP requirements and plan and PP implementation plan
2. Results of contamination control measures (processed data of bioburden assays for the entire product tree)
3. Update of probability of impact analysis
4. Update for probability of contamination analysis
5. Organic materials inventory

ECSS-U-ST-20

Organic Materials Inventory – CDR, FRR

Cat II ⇨ V

➡ document the organic material on the spacecraft

- required if the probability of impact is considered significant
- for **each organic material** present above a specified limit agreed with PPAA (typically 1 kg)

- same level of information already part of the project **Declared Material List**

M < 0,1 kg	0,1 kg < M < 1 kg	M* > 1 kg
Traces *identifiable organic materials*	small amounts	actual amounts

*If bulk organic constituents > 25 kg : 50 g samples of all organic materials required for archiving under controlled conditions for 50 years after launch

database : information on materials collected and their physical location at the archive (e.g. for Viking, Mars Pathfinder, MRO, Phoenix Lander, Mars Exploration Rovers, MSL, Maven and Insight missions)

ECSS-U-ST-20

Template example for organic materials inventory

satellite / instrument XX Declared Materials List (DML)											
Programme name: xx				CI number: *Group (title):*			Doc. ref.: Issue-rev.:			Date:	
1	2	3	4	5	6	7	8	9			10
								9.1	9.2	9.3	
Item number	Commercial identification or standardized designation	1) Chemical nature 2) Product type	Procurement information 1) Manufacturer & distributor name 2) Procurement specification ref., issue, rev. & date	Processing parameters	Use and location 1) Subsystem code 2) Equipment code 3) Use	Environmental code 1) R 2) A 3) T	Size code 1) A 2) V 3) M	Validation references 1) CORR 2) SCC 3) FLAM 4) OFFG 5) OUTG	1) Justification for approval 2) Prime comments	Prime approval status	1) Customer approval status 2) Customer comments
10. Adhesives, coatings, varnishes											
10.1.1.ETCA	DC93500	1) Silicon 2) Two parts	1) Dow Corning 2) E3846MC10S 02/02/1984	Mixture:10/1 in g Curing:4h/65 °C	1) PCU 2) Experiment tray 3) Part potting	1) G 2) V 3) 3-4	1) 2) 3) M3	5) TML = 0,30 %, RML =0,28 %, CVCM = 0,03 % according to ECSS-Q-ST-70-71	1) ECSS-Q-ST-70-01	A	A
11. Adhesive tapes											
12. Paints and inks											
13. Lubricants											
14. Potting compounds, sealants, foams											
15. Reinforced plastics (including PCBs)											
16. Rubbers and elastomers											
17. Thermoplastics (e.g. non-adhesive tapes and foils [MLI])											
18. Thermoset plastics (including PCBs)											
19. Material aspects of wires and cables											

see ECSS-Q-ST-70 (Annex A) and ECSS-Q-ST-70-01

For missions to the Moon :

- *description of the products released by propulsion and life-support systems*
- *quantitative and qualitative description of the major chemical species*
- *Indication of the minor chemical species and their amount*

Launch

End of Mission

Post-launch Planetary Protection report – 6 months after launch

- effects of events (ground processing, launch, commissioning phase…) from submission of the pre-launch PP report

Extended Mission Planetary Protection report - before the commitment for the extended mission

- evidence of the continued compliance with PP requirements with activities identified for the extended mission phase (deviations, updated probability analysis)

End-of-Mission Planetary Protection report - 6 months after EOM

- degree to which the project meets the PP requirements throughout the complete mission (deviations, updated probability analysis and disposition and condition of all launched flight hardware)

Contamination Requirement Specification – SRR

- specifies cleanliness and contamination levels to be achieved at different MAIT, launch and mission stages (MOC & PAC) - budget

  The CRS defines and identifies the spacecraft items and the environmental areas that are sensitive to contamination and describes the effects of contaminants on their performance.

ECSS-Q-ST-70-01

Cleanliness and Contamination Control Plan – PDR

➡ details measures to achieve the required cleanliness levels and maintain them during the life of the programme, from design to end-of-life

can be tailored to a specific project

1. Description of sensitive items and sources of contaminants
2. Cleanliness requirements
3. Selection of materials and processes
4. Mitigation and corrective actions
5. Environments and facilities
6. MAIT activities

ECSS-Q-ST-70-01

Contamination Control
risks prevention and mitigation

early stage

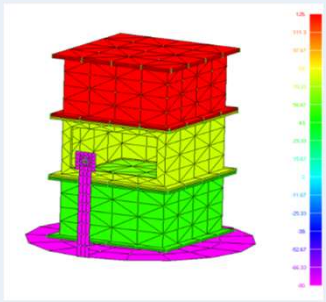
identification of sensitive surfaces

identification of contaminant sources

selection of materials
standard criteria :
RML<1% and CVCM <0,1 %

design
(events, heaters, covers…)

quantification of contamination levels



contamination modelling

AIT stage

assembly/integration in cleanroom ISO 8 or 5

covers
sealed bags

contamination control by different means

purging

thermal vacuum bakeout

appropriate cleaning method

regular inspection key points

ECSS-U-ST-20 and associated normative references wrt cleanliness

ECSS-Q-ST-70-01

Space product assurance – Cleanliness and contamination control

ECSS-Q-ST-70-55

Space product assurance – Microbial examination of flight hardware and cleanrooms

ECSS-Q-ST-70-58

Space product assurance – Bioburden control of cleanrooms

Generic technical requirements

ECSS-U-ST-20

5.2.1 Flight hardware assembly ECSS-U-ST-20_1430008

Except as specified in 5.3.2.1d (for upper stages), all flight hardware subject to planetary protection constraints shall be assembled and maintained until and including launch in ISO class 8 cleanrooms “in operation”, or better, as specified in **ECSS-Q-ST-70-01**.

ECSS-Q-ST-70-55C, Annex A

5.1.1 General provision

e. Cleanliness and contamination control requirements according to **ECSS-Q-ST-70-01** shall be applied for space hardware.

5.3.3 Performing microbiological assays

NOTE 2 : Sterile operations and sample processing are performed in laminar flow environment according to ISO 5 particulate cleanliness level defined in ISO 14644-1

Generic technical requirements

ECSS-Q-ST-70-58C

5.2 Operational requirements

5.2.1 Cleanroom class

a. Bioburden controlled environments shall be equivalent at least to airborne particulate cleanliness class ISO 7 “in operation” in conformance with ISO 14644-Part 1.

b. Bioburden controlled environments shall be continuously monitored in conformance with ISO 14644-Part 2.

Contamination Control
Examples of best practices

Cleanroom environment

ISO 14644-1 definition : room within which the number concentration of airborne particles is controlled and classified, and which is designed, constructed and operated in a manner to control the introduction, generation and retention of particles inside the room.

Restriction for materials, equipment, consumables


ESA cleanroom ISO 5

ISO classification number (N)	Maximum concentration limits (particles/m³ of air) for particles equal to and larger than the considered sizes shown below (concentration limits are calculated in accordance with equation (1) in 3.2)					
	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1 020	352	83	
ISO Class 5	100 000	23 700	10 200	3 520	832	29
ISO Class 6	1 000 000	237 000	102 000	35 200	8 320	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000
NOTE Uncertainties related to the measurement process require that concentration data with no more than three significant figures be used in determining the classification level						

from ISO 14644-1:2015

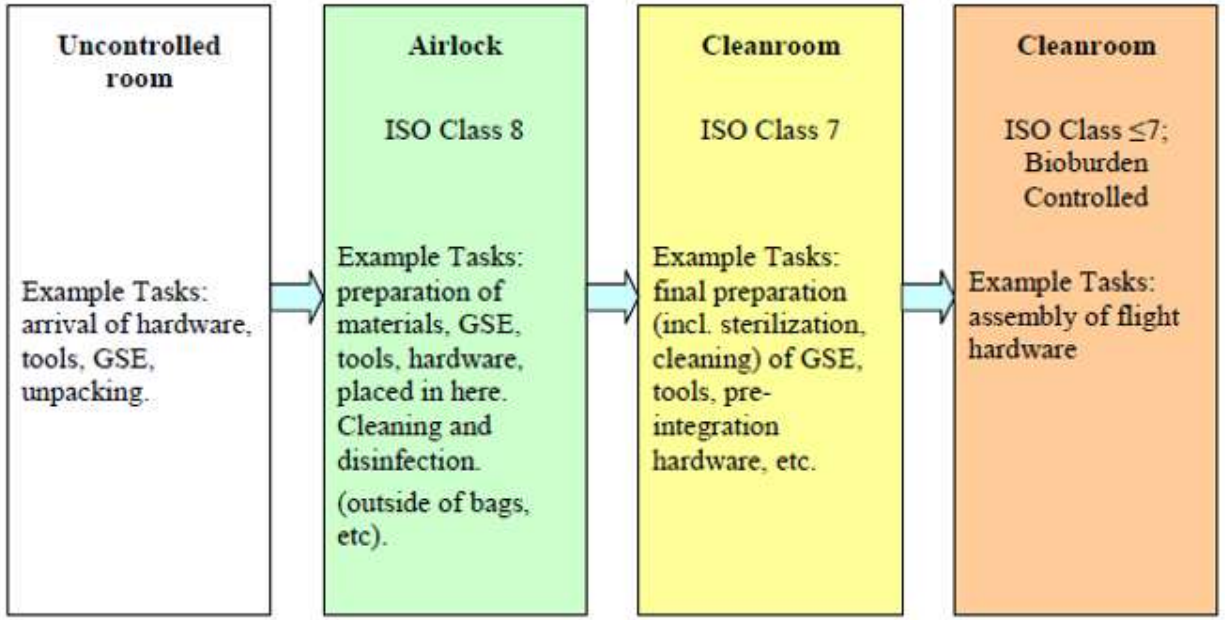
ECSS-Q-ST-70-58C, Annex E

E.4 General guidelines for cleanroom design and operation

E.4.1 Design : general

Access to the bioburden controlled environment should be through **successive layers of controlled environments.**

Different environments can be accommodated in a single cleanroom.



Shell-like contamination control concept

Different flows for personnel and material

Limited number of trained operators

Contamination Control
Examples of best practices

TARANIS – ISO 8

Insight/SEIS – ISO 5 HC

Contamination Control
Examples of best practices

Physical parameters monitoring

Temperature, humidity, pressure, vibration, electrostatic

Other cleanliness attributes monitoring

Chemical, viable, nanoscale concentrations in the air
Particle, chemical, viable, nanoscale concentrations on the surfaces

Contamination Control
Examples of best practices

actual MOC and PAC measurements according to 2 ECSS standards in cleanrooms / TVAC test

For MOC : ECSS-70-05C

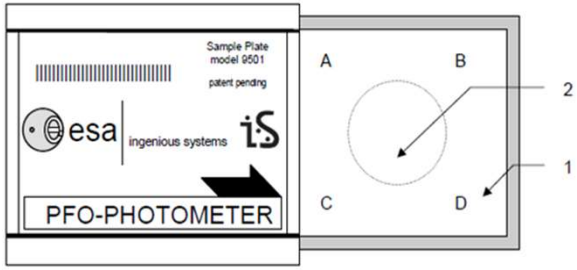
ZnSe
4000 cm^{-1} to 400 cm^{-1}

CaF_2
4000 cm^{-1} to 1300 cm^{-1}

4 types of contaminants
hydrocarbons
esters
methylsilicones
phenylsilicones

FTIR analysis

For PAC : ECSS-70-50C



PFO witness plate
1: total area of sedimentation (18,9 cm^2)
2: real measured surface (disc of 15 mm dia.)

measurement of the **obscuration factor**
no information on size distribution and number of particles

→ passive witness plates

Organic contamination can be monitored directly on hardware (wipes).

Contamination Control
Examples of best practices

other measurements in cleanrooms

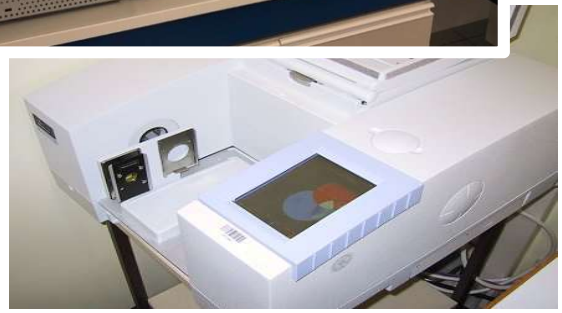
AMC analysis

Air sampling on adsorbent phases / GC/MS or FID

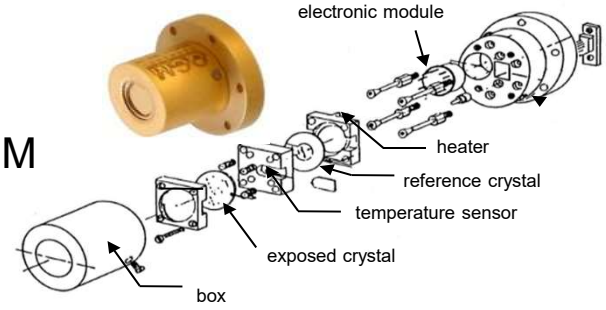
NVR

Direct FTIR analysis of the deposit with a spectrophotometer

Mass measurement with microbalance

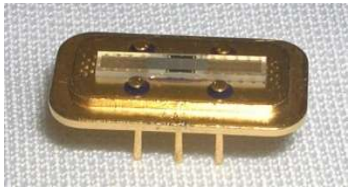


QCM



sensitivity : 1.56 ng/cm²

SAW



sensitivity : 0.01 ng/cm²

real-time measurement

Contamination Control
Examples of best practices

Bioburden monitoring of cleanroom air and surfaces

Average surface spore density for cleanroom classes "in operation" (exposed and mated but non-encapsulated)	ISO class 7 cleanroom or better, highly controlled:	50 spores/m²
	ISO class 7 cleanroom or better, normally controlled:	500 spores/m²
	ISO class 8 cleanroom, highly controlled:	1 000 spores/m²
	ISO class 8 cleanroom, normally controlled:	10 000 spores/m²
	Uncontrolled environment:	10^5 spores/m²

from table 5-1, ECSS-U-20 : Bioburden estimation

Assays methodology : *see Petra's presentation*

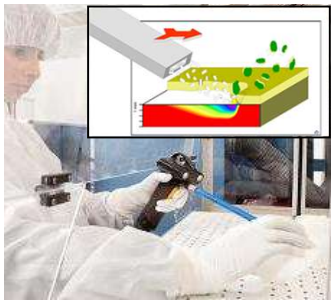
Contamination Control
Examples of best practices

Cleaning methods and procedures

validated to reach a cleanliness level below the threshold of scientific instrumentation

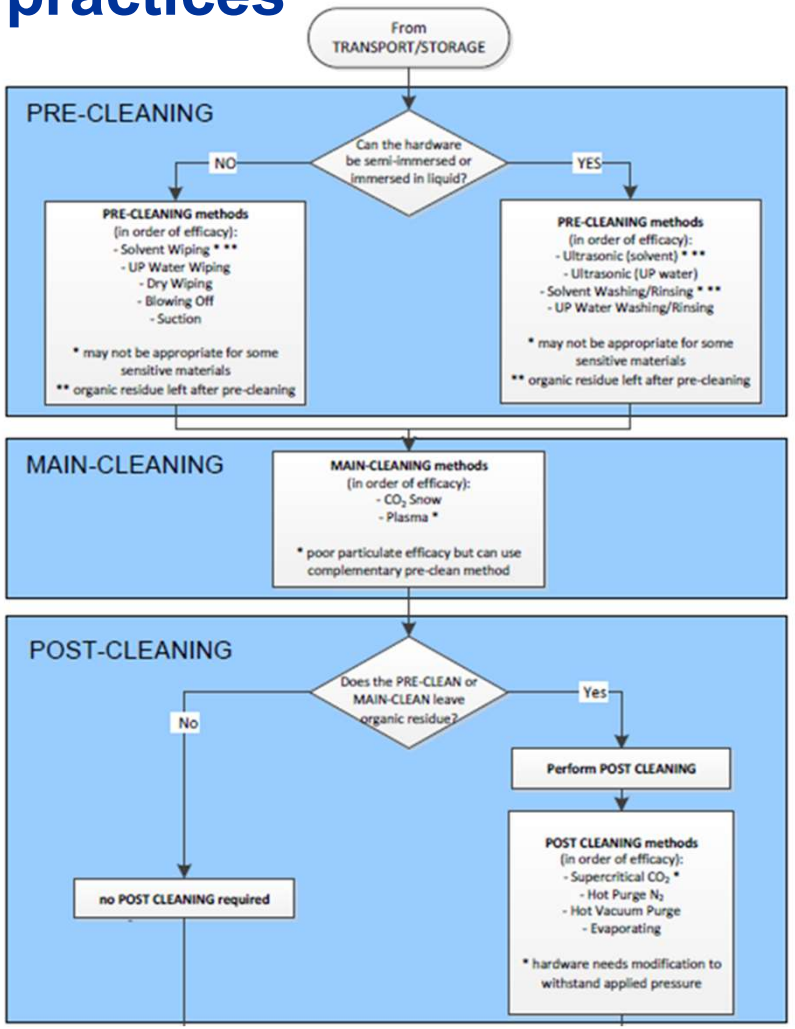
Main methods described in ECSS-Q-ST-70-54

- Wiping (dry or wet)
- CO_2 spray cleaning
- Solvent cleaning
- Detergent cleaning
- Vacuuming
- Plasma cleaning
- Ultraviolet / ozone cleaning
- Ultrasonic cleaning
- …



CO_2 spray cleaning

Compatibility with materials and flight hardware

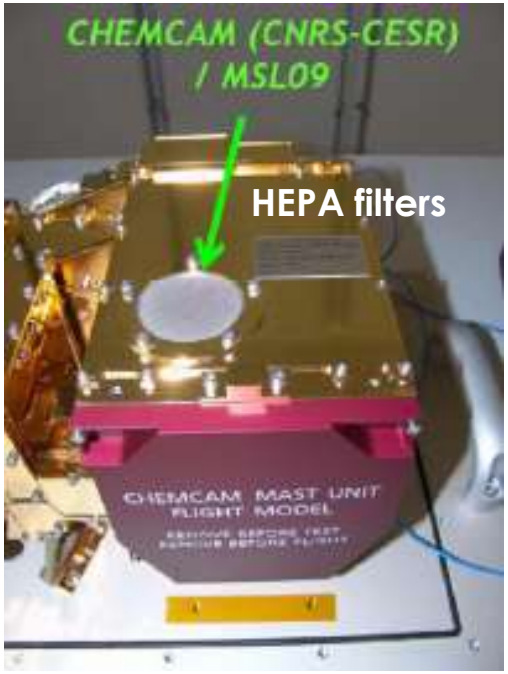


Bioburden reduction by sterilization: *see Petra's presentation*

Contamination Control
Examples of best practices

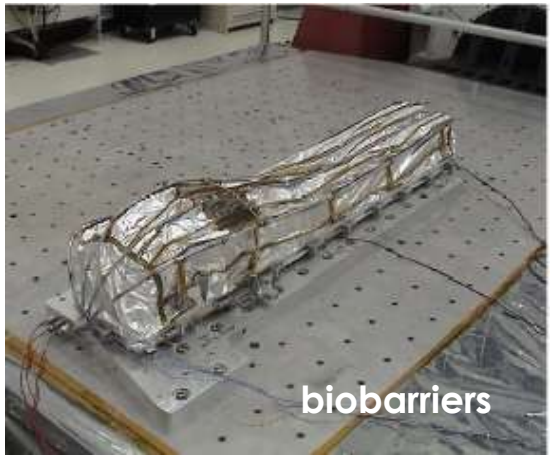
Preventing recontamination

All decontaminated equipment shall be packaged into 2 bags.



Equipment subject to sterilization shall be packaged into 2 successive similar bags and the bags must be qualified for the sterilization method

Equipment subject to surfaces bio / organic cleaning must be packaged after cleaning in 2 successive sterile bags



Future needs*

- **Innovative techniques / methodologies** (real-time monitoring, cleaning, sterilization, surface treatment, alternative methods…)

- **Modeling** : a key tool to demonstrate cleanliness compliance (distribution, resuspension of deposited biological matter…)

  Particulate and molecular transport modeling : already existing
  Modeling and analysis of particulate flux : applicable for assessment of forward contamination ?

*https///sbir.nasa.gov (2022 phase I solicitation)

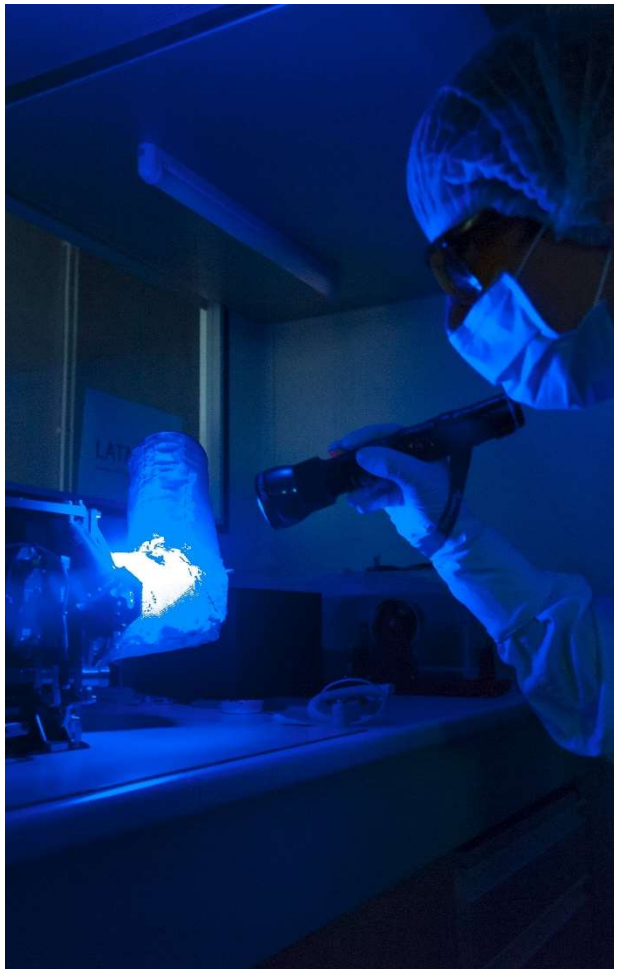
To ensure the success of a planetary mission

- application of a normative approach for cleanliness
  - definition of cleanliness requirements (PP and CC)
  - implementation of specific measures for contamination control and bioburden reduction for all the life of the mission
  - appointment of a PPO in the project team in close partnership with CC Engineer

	Requirement	MSL actual
S/C total spores	<500,000	278,000
Landed Hardware	<300,000	56,400
Impacting Hardware	Total minus landed	221,600
Spore density (m^2)	300	22

ACRONYMS

AIT	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
AMC	Airborne Molecular Contamination
ATLO	Assembly, Test, and Launch Operations
CDR	Critical Design Review
COSPAR	Committee on Space Research
CVCM	Collected Volatile Condensable Material
DHMR	Dry Heat Microbial Reduction
DML	Declared Material List
DNA	DeoxyriboNucleic Acid
EOM	End of Mission
FAR	Flight Acceptance Review
FID	Flame Ionization Detection
FRR	Flight Readiness Review
FTIR	Fourier Transform InfraRed
GC/MS	Gas chromatography/Mass spectrometry
GSE	Ground Support Equipment
HEPA	High Efficiency Particulate Air
ISO	International standardization Organization
LRR	Launch Readiness Review
MLI	MultiLayer Insulation
MOC	Molecular Contamination
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSR	Mars Sample Return
NA	Not Applicable
NVR	Non Volatile Residues
PAC	Particulate Contamination
PP	Planetary Protection
PPAA	Planetary Protection Approval Authority
PPO	Planetary Protection Officer
PRR	Preliminary Requirements Review
RML	Recovered Mass Loss
SRR	System Requirements Review
TBD	To Be Defined
TBW	To Be Written
TC	Technical Committee
TVAC	Thermal Vacuum Test
UCZ	Ultra Clean Zone



Thank you !