ECSS Training Session – 09.02.2022 - online

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

Space sustainability

Planetary Protection

Trainer‘s information: Diana B. Margheritis

- Thales Alenia Space, Domain Exploration & Science Italy-Space Environment
- Planetary Protection (PP) Leader and Cleanliness& Contamination Control specialist for both ExoMars 2016 and RSP (European side) missions
- PP Leader for Mars Sample Return Earth Return Orbiter Phase A/B1 Study, Sample Fetch Rover Phase A Study and in the preparation of the MSR ERO Phase B2/CD/E1 proposal
- Since 2016 instructor of the former ESA Annual PP course
- Since 2012 educator in the field of PP providing courses to people belong to and support of ExoMars program in TAS Italy and abroad
- Participation as TAS-I PP expert to the former PP of Outer Solar Systems Working Groups- Instructor of the PPOSS Workshop at CAST organized by COSPAR
- Member of former ECSS working group for ECSS-U-ST-20C
- Contact email: diana.margheritis@thalesaleniaspace.com

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Outline

- COSPAR PP Category III
- COSPAR PP Category IV
- Case study ExoMars
    - ExoMars 2016 PP Implementation
    - ExoMars Rover and Surface Platform PP implementation

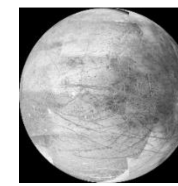
Mission Categories

Category III: Flyby and orbiter of missions to a target planet of chemical evolution and/or origin of life interest and for which scientific opinion is that a significant[2] chance of contamination could jeopardize a future biological experiment

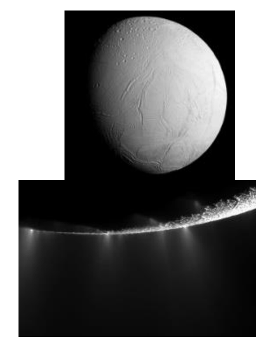
Applicability: Mars; Europa; Enceladus, others TBD

[2]Implies the presence of environments where terrestrial organisms could survive and replicate, and some likelihood of transfer to those places by a plausible mechanism

-Credit: ESA/Mars Express



-Credit: NASA/JPL/Galileo



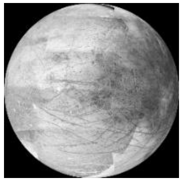
-Credit: NASA/JPL/Cassini

Mission Categories

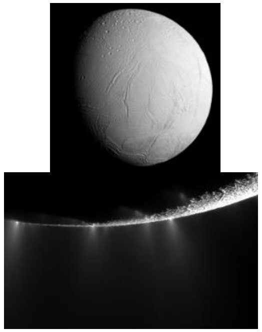
Category III- Description:

- Detailed documentation,
- Probability of Impact
- Use of cleanrooms during assembly and testing
- Possible bioburden reduction
- Possible organic inventory

-Credit: ESA/Mars Express



-Credit: NASA/JPL/Galileo



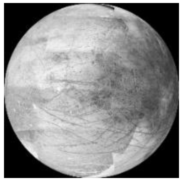
-Credit: NASA/JPL/Cassini

Mission Categories

Category IV: Lander missions on a target planet 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

Applicability: Mars; Europa; Enceladus, others TBD

-Credit: ESA/Mars Express



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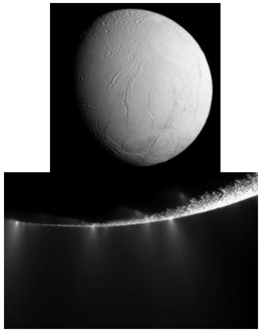


-Credit: NASA/JPL/Cassini

Mission Categories

Category IV – Description

For Europa, Enceladus: Limit the probability of inadvertent contamination of a body of liquid water by a viable terrestrial organisms to be less than $1x10^{-4}$ per mission.

Mission Categories

Category IV – Description

For Mars Missions: category IV **subdivided into 3 subcategories (a,b,c)**:

- **Category IVa**:
  - Lander systems **not** carrying instruments for investigation of Martian life and **neither land nor access** a Mars special regions (*)
  - Are restricted to a surface bioburden level of $\leq 3 \times 10^5$ spores, and an average of ≤ 300 spores per square meter.

(*) Mars special region: Region within which terrestrial organisms are likely to replicate. Any region which is interpreted to have a high potential for the existence of extant Martian life forms [COSPAR Policy on Planetary Protection, approved by COSPAR Bureau on 3 June 2021)

  - Analysis whether the SCC during nominal and off-nominal mission scenarios do not create a Mars special region in the local martian environment (e.g. SCC using radioisotope heat sources targeting areas with surface or sub-surface water ice)

Mission Categories

Category IV – Description

- **Category IVb:**
  - Lander system **carrying** instruments for investigation of extant or extinct Martian life and **neither land nor access** a Mars special region. All of the requirements of Category IVa apply, along with the following requirement:
  - The entire landed system is restricted to a surface bioburden level of ≤ 30(*) spores,

    OR

  - The subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection must be sterilized to levels of bioburden reduction driven by the nature and sensitivity of the particular life-detection experiments,

    and

  - a method of preventing recontamination of the sterilized **subsystems** and the contamination of the **material to be analyzed** is in place.

(*) assumes 300 spores/m^2 cleanliness followed by process to reduce by 4 logs in viable organisms.

Mission Categories

Category IV – Description

- **Category IVc:**
  - For missions which **investigate Mars special regions**, even if they do not include life detection experiments, all of the requirements of Category IVa apply, along with the following requirement:
  - If the landing site is within the special region (case 1), if the special region is accessed through horizontal or vertical mobility (case 2) 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/m^2 cleanliness followed by process to reduce by 4 logs in viable organisms.

Mission Categories

Category IV – Description

- **Category IVc:**
  - For missions which **investigate Mars special regions**, even if they do not include life detection experiments, 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+(2x10^5)(*) spores

(*)assumes 300 spores/m^2 cleanliness followed by process to reduce by 4 logs in viable organisms.

COSPAR Planetary Protection Categories

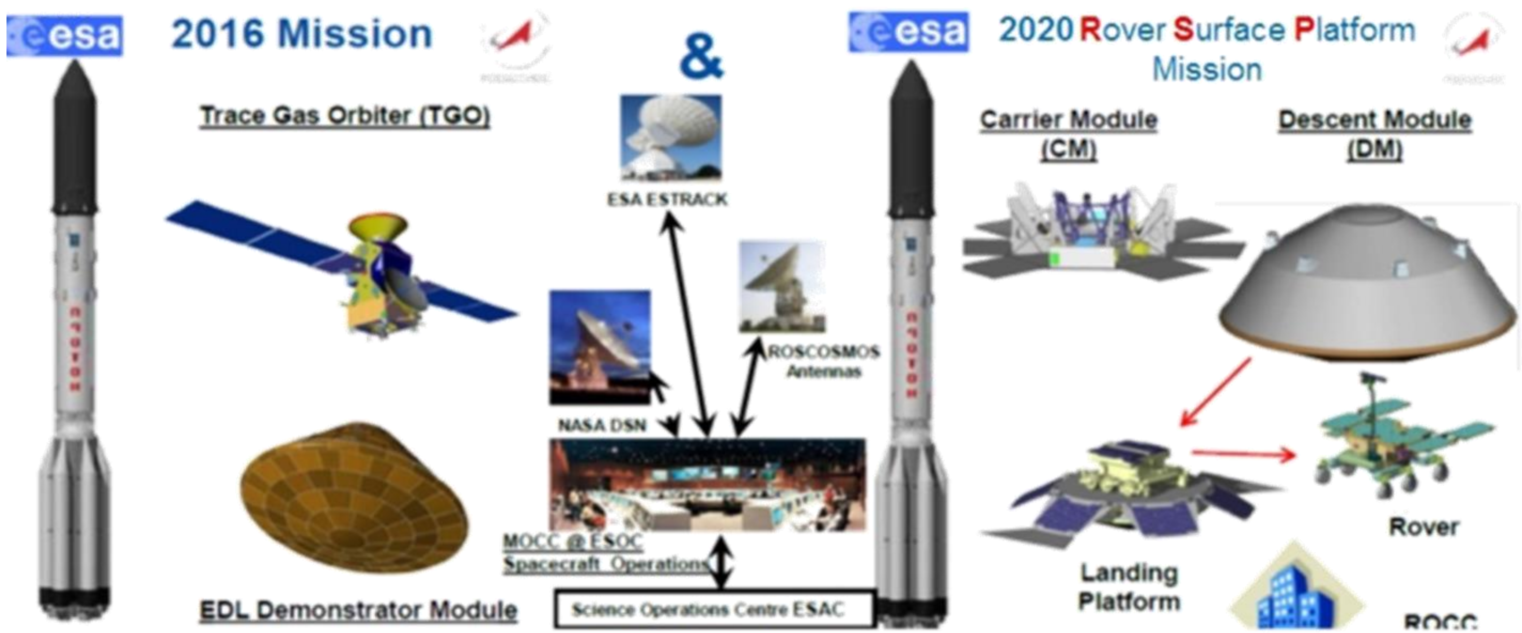
- Five Mission categories:

PLANET PRIORITIES	MISSION TYPE	MISSION CATEGORY	
Not of direct interest for understanding the process of chemical evolution. No protection of these planets is warranted.	Any	I	Ex. Flyby, Orbiter, Lander: Undifferentiated, metamorphosed asteroids; Io
Of significant interest relative to the process of chemical evolution and the origin of life, but only a **remote chance** that contamination by spacecraft could compromise future investigations.	Any	II	Ex: Flyby, Orbiter, Lander: Venus;Comets; Jupiter; Saturn; Uranus
Of significant interest relative to the process of chemical evolution and the origin of life and for which scientific opinion provides a **significant chance** of contamination which could compromise future investigations.	Flyby, Orbiter	III	Ex: Flyby, Orbiters: Mars; Europa; Enceladus
	Lander, Probe	**IV**	Ex: Lander Missions: Mars; Europa; Enceladus
Any Solar System Body	Earth Return «restricted» or «unrestricted»	V	Ex. Restricted: Mars; Europa Ex. Unrestricted: Venus, Moon

Case Study – ExoMars

ExoMars project is a broad International Cooperation between ESA and Roscosmos with Instrument contributions from NASA. Two missions:

- **ExoMars 2016** launched on March 2016
- **ExoMars Rover and Surface Platform** to be launched on 2022



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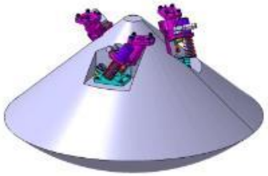
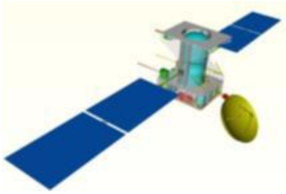
Case Study – ExoMars



ExoMars 2016: Category IVa

- lander system **not** carrying instruments for investigation of Martian life and **neither land nor access** a Mars special regions



- Planetary Protection Category III for the Trace Gas Orbiter (TGO)

ExoMars Rover and Surface Platform (to be launched on 2022): Category IVb

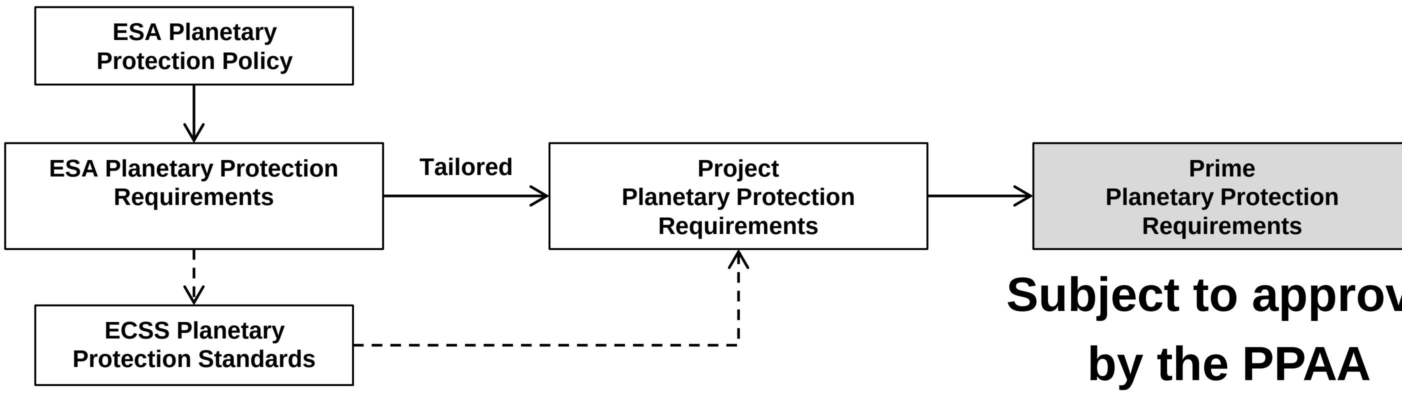
- lander system **carrying** instruments for investigation of extant or extinct Martian life and **neither land nor access** a Mars special regions

ExoMars – 2016 Mission

COSPAR Category IVa – Planetary Protection Implementation

ExoMars – 2016 Mission

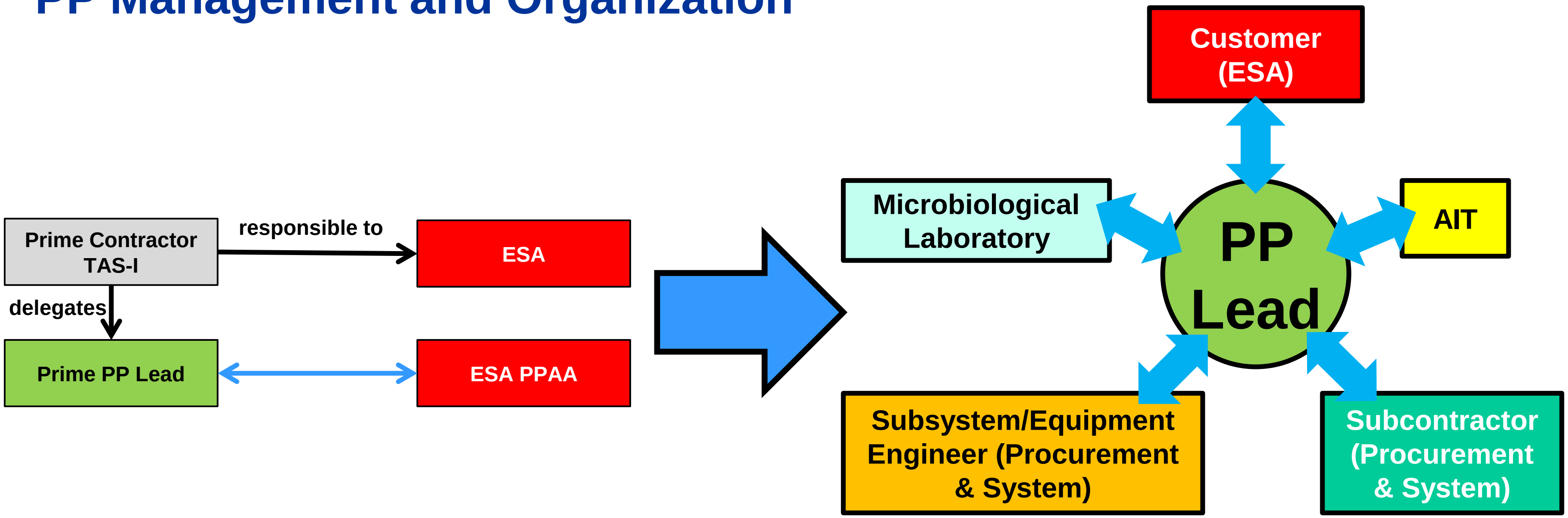
Documentation Hierarchy



Subject to approval by the PPAA

ExoMars – 2016 Mission

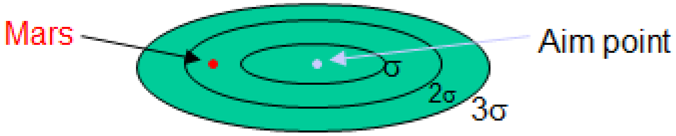
PP Management and Organization



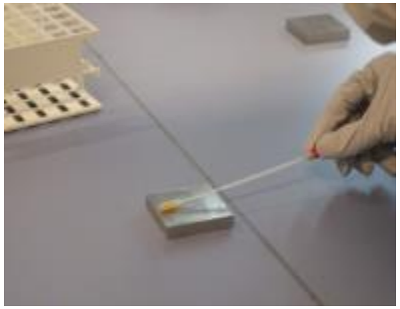
- **P-PPL** define, manage and organize **PP activities** at all levels

ExoMars – 2016 Mission

PP Implementation



- **General requirements**
  - Management and documentation
  - Organic material inventory (> 1Kg)
  - 50 g org used > 25Kg , stored by customer for 50 year
- **Impact probability requirements**
  - Impact probability constraints for launcher upper stage
  - Impact probability constraints for orbiter system
  - by analysis
- **Bioburden requirements**
  - Bioburden allocation
  - Bioburden reduction
  - Cleanroom class
  - Independent bioburden verification
  - by tests/estimations

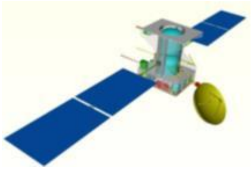


ExoMars – 2016 Mission

Impact Probability constraints

1. **Launch Vehicle upper stage**
   – **The probability of impact on Mars** by the Proton upper stage Breeze-M shall be ≤ 1×10^{-4} for the first 50 years after launch

2. **Trace Gas Orbiter:** One of the following conditions shall be met:



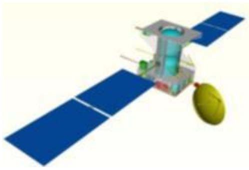
– **The probability of impact on Mars** by the SCC is
≤ 1×10^{-2} for the first 20 years after launch,
and
≤ 5×10^{-2} for the time period from 20 to 50 years after launch.

OR

– The total bioburden of the spacecraft, including surface, mated, and encapsulated bioburden, is < 5×10^{5} bacterial spores.

ExoMars – 2016 Mission

Impact Probability constraints



Approach

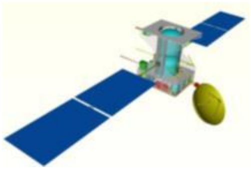
- Identification of those **critical mission phases** during which an unrecoverable SCC failure could lead to an unwanted impact (crash)
- Assess the **probability of failure** of those SCC systems potentially leading to an unwanted impact
- Consider additional effects due to **micro meteoroids** and space radiations
- Consider additional effects of human errors

Input data:

- Critical mission phases durations (based on Mission analysis - trajectory data and parameters)
- Space environment, in particular: Radiation environment, Micrometeoroid environment
- Spacecraft Reliability Prediction Analysis or Fault Tree Analysis

ExoMars – 2016 Mission

Impact Probability constraints



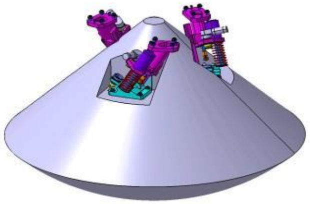
The overall probability of crash on Mars was calculated as the sum of probabilities of crash due to different failure causes: failures generated by micrometeoroid impact, ground error, overheating, MSA and TGO failures

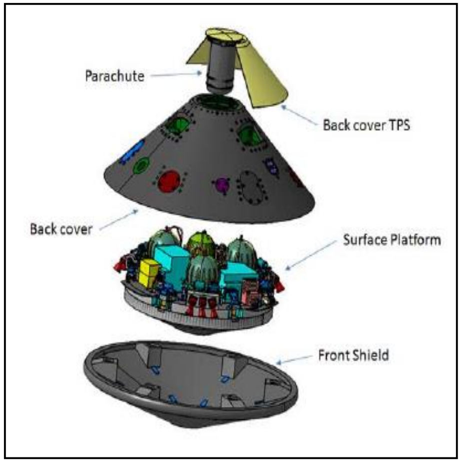
Probability of impact requirements can have an effect on the qualification of hardware (e.g., solar arrays for aerobraking), the trajectory design, the delta-v budget (re-targeting), and spacecraft design (e.g., location of tanks, additional micrometeoroid protection)

All activities necessary to perform a probability of impact analysis are interdisciplinary and require the interactions between different engineering disciplines!

ExoMars – 2016 Mission

Bioburden constraints for EDM at launch (cat. IVa)





- Total(*) bioburden ≤ **$5x10^5$** bacterial spores
- Exposed internal and external surface bioburden ≤ **$3x10^5$** bacterial spores
- Average surface bioburden density ≤ **300** bacterial spores/m^2

(*)Total bioburden: surface, mated, and encapsulated

ExoMars – 2016 Mission

Bioburden Budgets

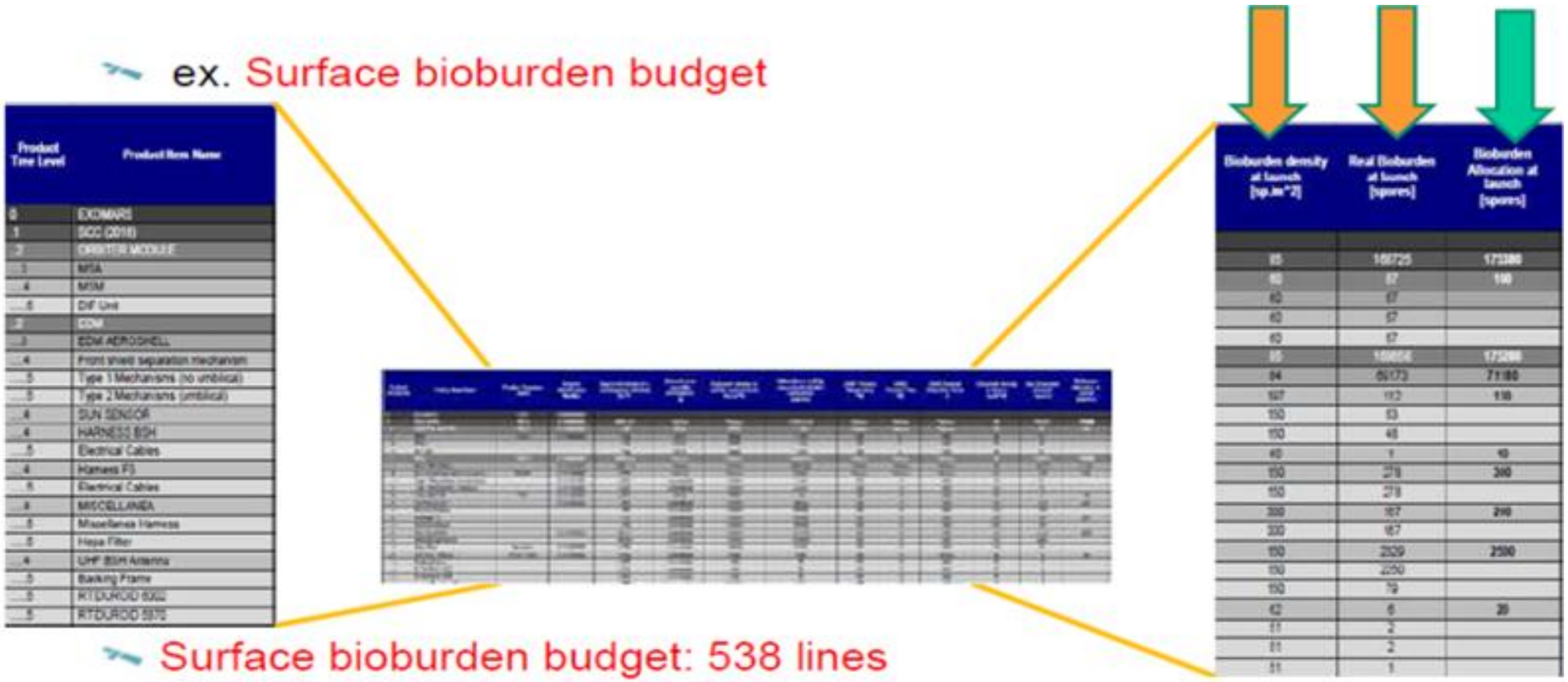
- Surface bioburden budget
  - To be within the surface bioburden constraints
  - allocated for all EDM elements
  - measured by bioburden assay procedures

- Encapsulated bioburden budget
  - No constraints; to be included in the total bioburden
  - allocated only for hard landing EDM elements
  - estimated/ measured by dedicated tests

ExoMars – 2016 Mission

Bioburden Budgets

- ex. Surface bioburden budget



- Surface bioburden budget: 538 lines
- Encapsulated bioburden budget: 386 lines

ExoMars – 2016 Mission

- From bioburden budget: → **Definition of log-reduction for each item and ATLO controlled environments class**
- Steps:

1. Sterilization of Flight H/W items
2. Integration of sterilized items in bioburden controlled environments
3. Environmental tests (at equipment, subsystem, module level)
4. Launch campaign: in bioburden controlled environments

Recontamination prevention and surface bioburden checks (including cleaning if necessary) in all the steps

ExoMars – 2016 Mission

Bioburden Assay Plan

- **for each item before sterilization**
- **before closing not-accessible surfaces**
- **during AIT/AIV, Env.Test activities**
- **at launch site**

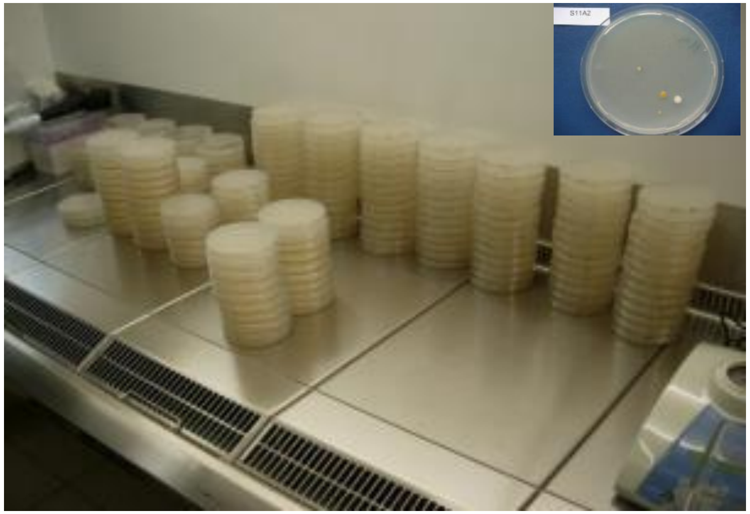
→ continuously updated

ExoMars – 2016 Mission

Microbiological Laboratory

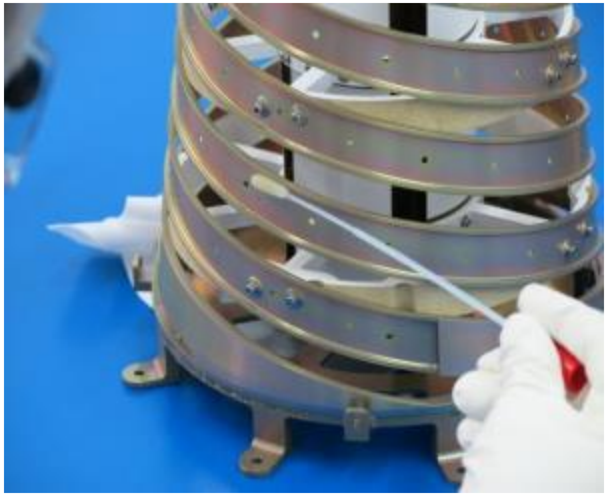
- **Certified ExoMars Microbiological laboratory with certified personnel Choice of centralized activity at TAS-I Turin**

- **ESTEC (NL) Microbiological laboratory for EDM payloads**



ExoMars – 2016 Mission

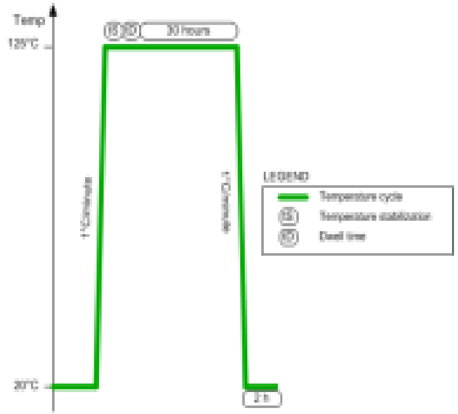
Requirement: Bioburden assays as per ECSS-Q-ST-70-55C tailored for ExoMars



ExoMars – 2016 Mission

Requirement: Sterilization as per ECSS-Q-ST-70-57C Dry Heat Microbial Reduction (DHMR)

- DHMR to reduce surface, mated and encapsulated spores -pending of the thermal cycle applied
- First evaluation of material and hardware compatibility with bioburden reduction procedures as per **ECSS-Q-ST-70-53C**
- Material, Part ,component and item compatibility with DHMR (incl. CTE) verification and qualification testing (e.g. 3 cycles)
- Preparation of Bioburden Reduction PLAN
- Bioburden assays before sterilization
- Sterilization T range: 110-125C
- 3-4 log reduction



ExoMars – 2016 Mission

Sterilization processes

Bioburden reduction process	Followed by European Industries and Agency
DHMR	ECSS-Q-ST-70-57C
HYDROGEN PEROXIDE	NA
UV RADIATION	NA
GAMMA RADIATION	NA

Ovens in Turin premises

Oven in ESTEC premises (parachute)

ExoMars – 2016 Mission

Controlled environments for ExoMars

- Requirement: ISO 8 or better for flight HW assembly
- ISO 8 HC (*) for support
- ISO 7 HC and ISO 7 HC Portable Tent for EDM integration and opened EDM activities
- ISO 8 with precautions for TGO integration, launch stack assembly, fairing

(*) HC Highly Controlled = spores measured on cleanroom surfaces and airborne

ISO 14644 – 1(1999): Classification of air cleanliness

ECSS-Q-ST-70-58C (2008): Bioburden control of cleanrooms

ExoMars – 2016 Mission

Training Program

- Level 1: project team, sub-contractors and instrument providers
- Level 2: all personnel working in bioburden controlled environments
- Level 3: supervisors

More than 300 people trained during ExoMars 2016 Mission

ExoMars – 2016 Mission

Recontamination prevention

- Continuous bioburden monitoring
- Dedicated and cleaned transport containers
- Dedicated approach for GSE and tools
- Venting box in EDM backshell; Bioseal

ExoMars – 2016 Mission

Recontamination prevention

- Use of sterile consumables: IPA 70%, wipes, covers/biobarriers/ packaging material, fluids
- Garments: decontaminated undergarments, bunny suit and hood; sterile mask and gloves

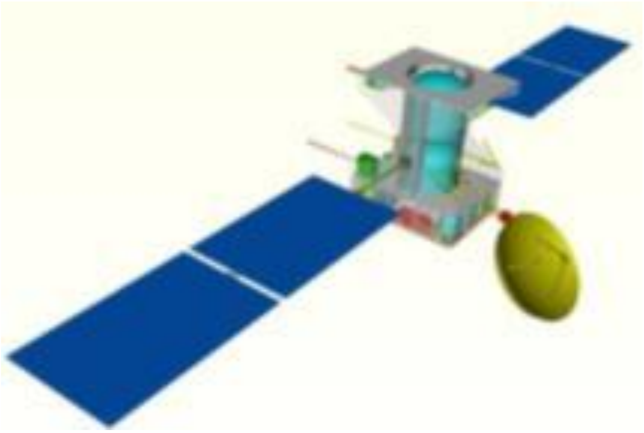
- **During environmental tests and launch campaign**

ExoMars – 2016 Mission

Recontamination prevention

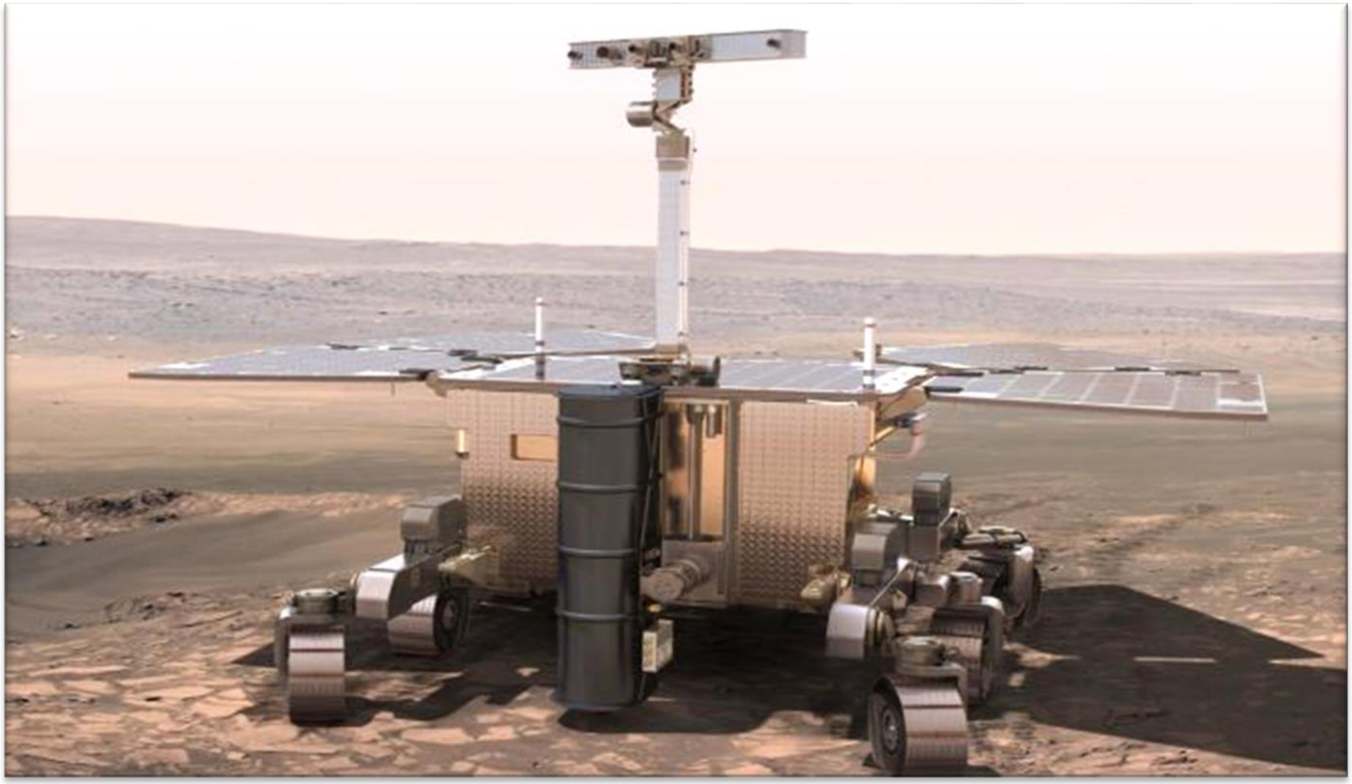
- external surfaces ≤ 1000 sp/m2 verified pre-launch in order to avoid EDM recontamination during the launch (req implemented by the Prime)

- External TGO MLIs DHMR processed



ExoMars – 2022 Mission

COSPAR Category IVb – Planetary Protection Implementation



ExoMars – 2022 Mission

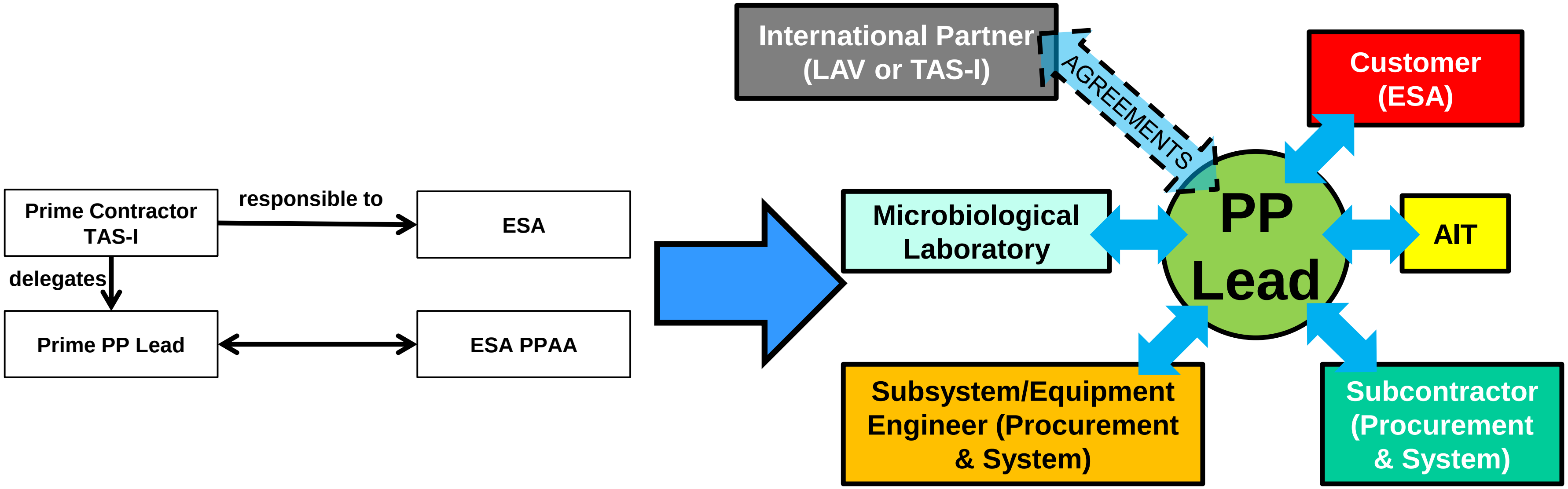
PP Management and Organization

- Lavochkin (LAV), Prime of the Russian industries
  - developer of the Russian Descent Module (DM)
  - Responsible for SCC AIT and associated PP implementation

- Thales Alenia Space – Italia (TAS-I), Prime of the European industries
  - developer of European mission elements and associated PP implementation
  - responsible or the Spacecraft Composite (SCC) requirements and design

ExoMars – 2022 Mission

PP Management and Organization



ExoMars – 2022 Mission

PP Requirements

- General
- Impact probability
- Bioburden
- Mars samples contamination requirements

ExoMars – 2022 Mission

PP Requirements – Impact probability

1. **Launcher upper stage:** The probability of impact on Mars of the launcher upper stage shall be

   $\leq 1x10^{-4}$ for the first 50 years after launch

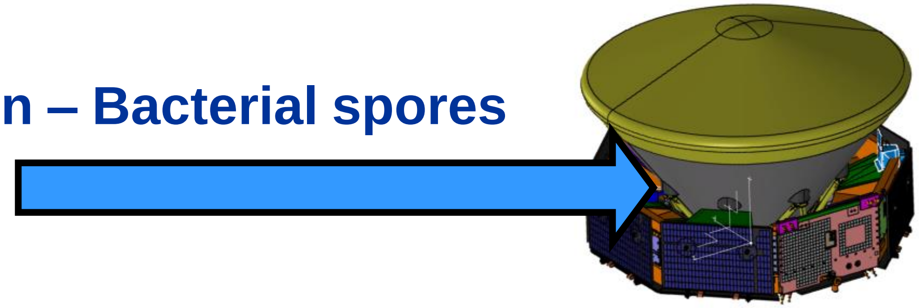
2. **Spacecraft:** The probability of impact on Mars by the SCC, including CM-DMC separation, shall be

   $\leq 1x10^{-2}$

ExoMars – 2022 Mission

PP Requirements – Bioburden – Bacterial spores

Spacecraft ≤ 500.000 (*) **(Total)**



with

Descent Module ≤ 300.000 (*) **(surface bacterial spores on exposed internal and external surfaces)**

Rover Module ≤ 20.000 (surface bacterial spores on exposed internal and external surfaces)

and

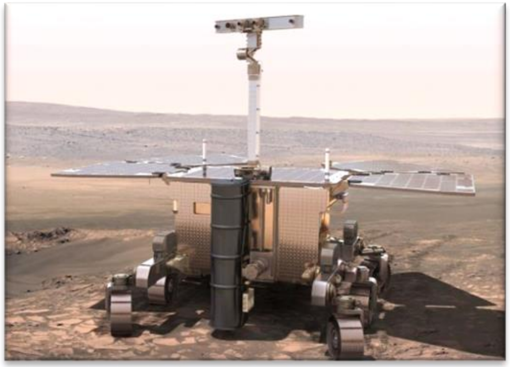
Average surface bioburden density on DM and RM ≤ 300 bacterial spores/m^2 on exposed internal and external surfaces.

(*) including 20% ESA Project margin)

ExoMars – 2022 Mission

PP Requirements – Bioburden – Bacterial spores

Average surface bioburden on the RM subsystems **involved in the acquisition, delivery, and analysis of martian samples for life detection** shall be **≤ 0.03** bacterial spores/m^2



ExoMars – 2022 Mission

PP Requirements – Mars Sample Contamination Requirement

The **maximum terrestrial organic** contamination level per substance class and **per gram of Martian samples** for life detection shall be:

Substance class	Contamination level per gram of martian sample delivered for life detection
Material from biological sources	$\leq 50 * 10^{-9}$ gram
Monomers of Kapton, Mylar and PTFE	$\leq 500 * 10^{-9}$ gram
Fluorinated technical lubricants	$\leq 500 * 10^{-9}$ gram
Any other organic compound	$\leq 50 * 10^{-9}$ gram

ExoMars – 2022 Mission

PP Implementation – Bioburden

1. **500,000 spores allocation** (including the recontamination during the launch campaign):

Module	Surface bioburden at delivery [spores]	Total bioburden at delivery [spores]	Surface bioburden at launch [spores]	Total bioburden at launch [spores]
SCC	#	400000	#	500000
CM	#	40000	#	40000
DMC	170000	360000	270000	460000
DM	150000	340000	250000	440000
RM	20000	#	20000	#

2. **Preparation of the SCC bioburden budget** which includes the DM, RM, CM bioburden budgets plus recontamination during ATLO

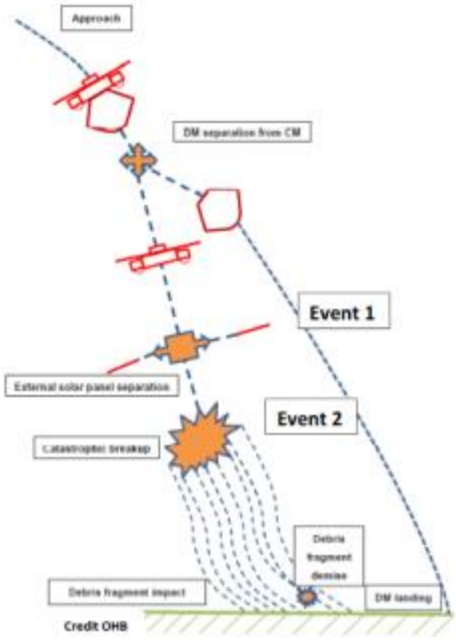
   CM budget prepared taking into account the **outputs of the CM BuBu analysis**

ExoMars – 2022 Mission

PP Implementation – Bioburden

- **Break-up/burn-up (BuBu) of the CM** entering the Martian atmosphere is **used to claim bioburden reduction** if the conditions of 500° C for ≥ 0.5 seconds are reached

- CM Bubu analysis includes the consolidated CM design and final landing parameters
  - CM bioburden budget to be prepared taking into account BuBu outputs
  - Identification of the CM elements to be sterilized / bioburden densities



CM external surfaces ≤ 1000 sp/m2 (MLIs DHMR processed) to avoid DM recontamination during the launch (req implemented by the Prime)

ExoMars – 2022 Mission

PP Implementation – General

- Flow down of customer PP requirements into **Project System Level PP requirements document**
- Flow down of Prime PP requirements into equipments/subsystems spec., subcontractors spec. and all system level specifications.
- Issue of PP Plan including PP documentation to be released by the Prime with the related reviews
- Flow down of Prime PP requirements into DM-CM, DM-RM, LV-SCC, RM-Payloads **IRDs**
- From **bioburden budgets**→ definition of log-reductions (items) and ATLO controlled environments
- Recontamination prevention and surface bioburden checks (including cleaning if necessary)

ExoMars – 2022 Mission

Requirement: Bioburden assays as per ECSS-Q-ST-70-55C tailored for ExoMars

- Several certified Microbiological Laboratories with certified personnel in:

  TASinI Turin (IT), ADS Stevenage (UK), OHB Bremen (GE), IBMP (Ru), ESTEC (NL), Bioclin (F), NASA (USA)

ExoMars – 2022 Mission

Sterilization processes

Bioburden reduction process	Followed by European Industries and Agency	Followed by LAV
DHMR	ECSS-Q-ST-70-57C	ECSS-Q-ST-70-57C
HYDROGEN PEROXIDE	ECSS-Q-ST-70-56C	NA
UV RADIATION	NA	LAV procedures
GAMMA RADIATION	NA	LAV procedures

- All the flight hardware to be sterilized has to be **compatible** with the selected sterilization process
- **ECSS-Q-ST-70-53C** used to evaluate material and hardware compatibility with bioburden reduction procedures

ExoMars – 2022 Mission

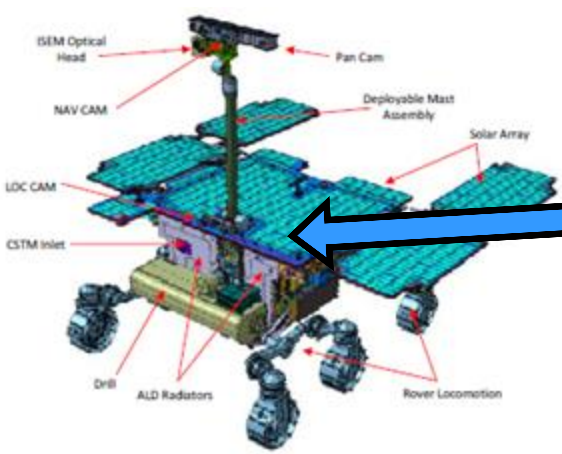
Controlled Environments

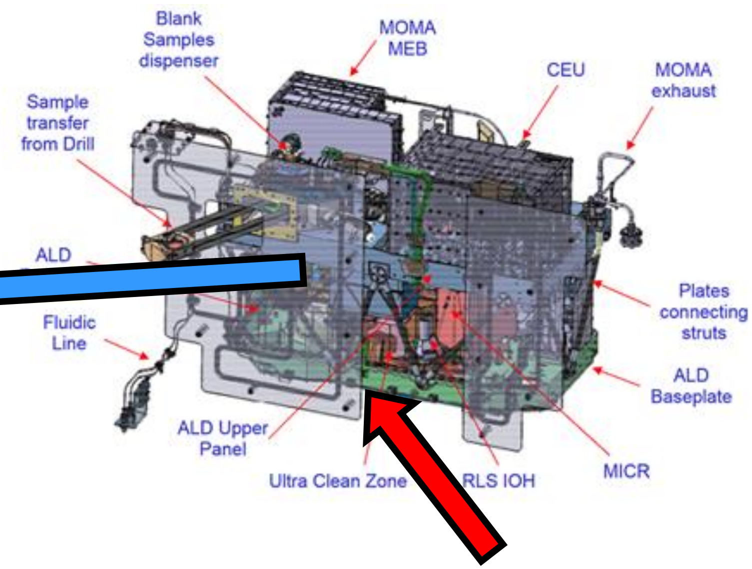
- Requirement: ISO 8 or better for flight HW assembly
- ISO 7 HC for DM (TASinI), RM (ADS, TASinI), ALD/Drill except UCZ (TASinI) integration
- ISO 7 HC portable Tent for opened DM and RM activities
- ISO 8 HC (support)
- ISO 8 (with precautions) for CM integration (OHB), launch stack assembly, fairing (Cosmodrome Baikonur)
- ISO 5 HC for transport and aseptic operations (TASinI)
- ISO 3 sterile AMC-controlled wrt sel. organics for UCZ ALD integration (TASinI)

ExoMars – 2022 Mission

PP Implementation – Bioburden and Mars Sample Contamination Requirement

- Identification of RM Ultra Clean Zone (UCZ) or contamination controlled RM volume and surfaces in contact with Martian samples when collected, processed and analyzed





Rover Module

ALD including UCZ

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PP Implementation – Mars Sample Contamination Requirement

- **RM flight H/W parts on the Mars sample path or UCZ parts**
  - **Disassembled, cleaned** and **packed** (in ISO 5 env.) with high performance techniques;
  - **4-log sterilization** to achieve **0.03** bacterial spores/m2
  - **Transportation to the GBT** into an sterile environment ISO 5 **w/o breaking sterilization chain**

ExoMars – 2022 Mission

PP Implementation – Mars Sample Contamination Requirement

- **RM flight H/W parts on the Mars sample path or UCZ parts**
  - **Ultracleaning and UCZ AIT** in **sterile environment** to preserve item's sterility.
  - **UCZ closure and overpressurization with dedicated FGSE**

  - **Bottom-up approach is used to derive the contamination of the Martian sample at the End of life sample as a sum of the different contributions** (UCZ surface and airbone contamination, Drill tool chamber contamination and RM external surfaces off-gassing)

PP Documentation and Reviews

Title	Preliminary	Final	PPAA Approval/Review	EXM 2016	EXM 2022	
PP Requirements	PRR	SRR	A	Y	Y	Set of PP reqs
PP Plan	SRR	PDR	A	Y	Y	Primary planning describing how the project meets the PP reqs
PP Implementation Plan	PDR	CDR	R	Y	Y	Provide information about the detailed implementation of the PP reqs in line with the PPP
Pre-Launch PP Report	FAR	FRR	R	Y	Y	To demonstrate the project meets the PP reqs, in particular bioburden allocations
Post-Launch PP Report		No later than 6 months after launch	R	Y	TBW	To account for effects of events from submission of the Pre-launch PP report
Extended Mission PP Report		Before the commitment for the extended mission	R	NA		To provide evidence of continuing compliance with PP reqs considering the activities of the extended mission phase
End-of-Mission PP Report		No later than 6 months after end-of-mission	R	TBW	TBW	To describe the degree to which the project meets the PP reqs throughout the complete mission
Organic Materials Inventory	CDR	FRR	R	Y	Y	To document the org. material on the spacecraft

- PRR: preliminary requirement review; SRR: system requirement review; PDR: preliminary design review; CDR: critical design review; FAR: final acceptance review; FRR: flight readiness review

PP Documentation and Reviews

- Implementation of PP requirements is not limited to PP documents but need to be reflected in the affected project documentation e.g. system requirements specification, quality plan, AIT and AIV plan, VCD

- NCR related to PP are always major

Thanks for your attention!

Questions?