CONTAMINATION CONTROL APPROACH FOR EXOMARS MISSION

M. Giuliani[(1)], E. Amerio[(1)], C. Lobascio[(2)], , A. Saverino[(2)], V. Guarnieri[(2)]

[(1)] Sofiter System Engineering, corso Francia 35 – 10138 Torino, Italy
e-mail:mrco.giuliani@sofiter.it
[(2)] TAS-I - Thales Alenia Space - Italia S.p.A., Strada Antica di Collegno, 253 – 10146 Torino (Italy)
e-mail: antonio.saverino@thalesaleniaspace.com

ABSTRACT

The ESA ExoMars mission is extremely challenging: the Spacecraft will deploy on the surface of the Red Planet the first European robotic rover, which carries onboard several instruments to perform scientific investigations, including in-situ analyses of the Mars' soil. The main goal of the mission is searching for traces of past and present life up to 2 meters depth in different sites, to characterize the Mars geochemistry and water distribution, to improve the knowledge of the Mars environment and to identify possible surface hazards to future human exploration missions. Thales Alenia Space Italia (TAS-I) is the project Prime Contractor.

The mission must cope with stringent Planetary Protection an well as Cleanliness and Contamination Control requirements, in order to minimize cross-contamination between Earth and Mars, according to the COSPAR recommendations. Since the onboard scientific instruments are characterized by an extremely high sensitivity, even a tiny amount of organics could interfere with their measurements. Therefore, it is essential to avoid chemical-physical interferences that could result in a "false positive" (a compound carried from Earth is misinterpreted as from Martian origin) or even a "false negative" (a terrestrial contaminant acts to suppress the detection of a Martian species).

The contamination control required for the ExoMars mission forced to develop brand new solutions, described in the present paper, to maintain the spacecraft clean during all mission's phases.

TAS-I promoted a Screening Outgassing Test Campaign to identify, among all the contaminants potentially outgassed from the S/C materials, the chemical compounds which could interfere with life detection experiments, during the on ground integration and testing activities, the cruise to the planet and the operational phase on Mars. The Outgassing Test Campaign includes Dynamic VBQC tests and/or outgassing screenings (micro-VCM) with GC-MS (Gas Cromatography-Mass Spectrometry) to detect all chemical species released in vacuum.

Moreover, a materials selection process has been defined for all parties involved in the project, leading to the definition of a Common Preferred Material List so that the Project will be able to control all the S/C's materials avoiding arbitrarily choices by subcontractors or instrument providers. The compatibility to bioburden reduction treatments (e.g. Dry Heat microbial Reduction, DHMR) is a key parameter for the materials selection.

The maximum allowable molecular and particulate contamination levels dictated by the instruments' scientific requirements were assessed by means of semi-empirical models. Since the obtained levels are extremely stringent (especially for the most sensitive parts of the rover, where Martian samples are processed), an Ultra Cleaning process, capable to reach, verify and maintain a surface cleanliness level of about 1 ng Total Organic Carbon per cm^2, has been investigated and tailored on the peculiar implementation needs for the ExoMars project.

1. INTRODUCTION

The ESA ExoMars mission is planned to be launched in 2018; it foresees to land a rover vehicle on the Mars surface, whose main goal is searching for traces of past or extant life in terms of organic molecules by using on board instruments characterized by an extremely high sensitivity. Furthermore, the mission will also characterize the Mars geochemistry and water distribution. The full mission is described in [1].

During the mission, samples of Mars soil will be acquired down to a depth of 2 meters by using a robotic drill mounted on the Rover vehicle. Once acquired, the samples will be discharged inside the vehicle body and provided to a micro Analytical Laboratory (Analytical Laboratory Drawer - ALD) where they will be crushed and analyzed.

The challenging goals of the mission imply to deal with two different fundamental issues:

- The Planetary Protection (PP) management
- The Cleanliness and Contamination Control (C&CC)

Concerning the Planetary Protection issue, ExoMars mission is classified as IVb in COSPAR categories [2]. The landed system shall minimize the biological contamination of the planet surface, in order to preserve its pristine conditions and to avoid the detection of any form of life carried from Earth. The C&CC discipline pertains to prevent any molecular and particulate organic contamination, to avoid false positives during life detections and to guarantee the nominal performances of all contamination sensitive items until the end of mission. For these reason, a very stringent set of requirements was selected by the Prime Contractor.

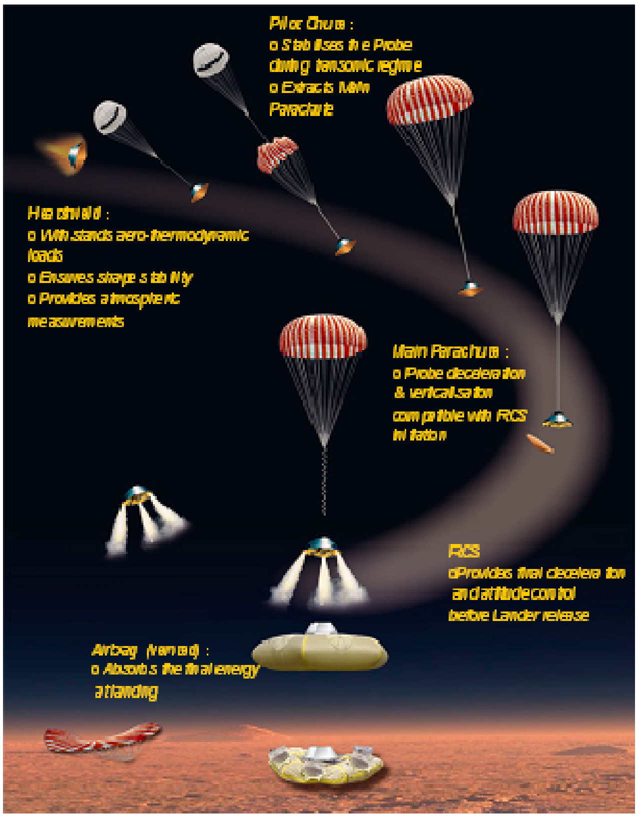

Fig. 1. Overview of the Exomars mission's profile

2. PLANETARY PROTECTION CONSTRAINTS

On behalf of the United Nations, the Committee On SPAce Research (COSPAR) states that for certain space mission/target body combinations, controls on microbial contamination must be imposed in order to avoid or minimize the biological cross-contamination of the visited target body. Five categories for target body/mission type combinations and their respective suggested ranges of requirements have been accepted by the space faring Nations and the Scientific Community.
The ExoMars mission, being a landed system with life-detection experiments not accessing a "special region" of Mars, shall fulfil the requirements of the COSPAR's category IVb [2]:

"the subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection must be sterilized to Viking post-sterilization biological burden levels, and a method of preventing recontamination of the sterilized subsystems and the contamination of the material to be analyzed is in place"

The method adopted by Viking was to sterilize the Spacecraft by means of dry heating after its final assembly (Dry Heat Microbial Reduction = DHMR). This approach was accompanied by a tight bioburden monitor and control during the Assembly Integration & Testing (AIT) phase. However, for cost and risk issues – principally associated with qualification of the spacecraft and components to survive the high temperature exposure – the alternative approach is adopted for ExoMars, in which only those parts of the spacecraft which are exposed to the sample (e.g. SPDS, Drill, Instruments) are required to meet the stringent Viking post-sterilization requirement [3,4].
Dry Heat Microbial Reduction (DHMR), is the only fully qualified sterilisation process for spacecraft and it was method adopted by Viking. It consists in heating the item to be sterilized in a controlled environment for a period sufficient to reach the desired bioburden level (e.g.: DHMR at 125°C for 6 hrs). Typically the temperatures applied during this treatment fall in the range 110-125°C while the upper limit for saturated water vapour partial pressure is 4.6 torr at STP (0°C, 760 torr).
The bioburden reduction treatment strongly interacts with the C&CC procedures. First of all because the dead bioburden is not removed by the DHMR treatment, hence it is a potential source of organic contamination; moreover the outlined process poses several issues from a C&CC point of view, because the exposure to high temperatures might produce contaminants (by out-off-gassing) that could interfere with molecular contamination control requirements. In addition, great attention has to be paid to avoid that PP procedures application would not impair the Cleanliness levels. The choice of suitable clean room and controlled environments for integration of the S/C must cope with both PP and CC constraints.
The general ExoMars PP approach is to sterilize items at component level instead of the whole assembly (Viking approach) to avoid cross molecular contamination and to guarantee the highest cleanliness of the more sensitive complex elements. This solution is principally associated with qualification of the spacecraft and components to survive the high temperature exposure.
Other bio-burden reduction methods are available, such as H_2O_2 Gas Plasma, Gamma Ray Irradiation, Electron Beam Radiation. For ExoMars S/C the surface contamination of the spacecraft will be primarily controlled by wiping with Isopropyl alcohol (70% solution with water). IPA only has a limited sporicidal effect and so wiping cannot be considered a bioburden reduction procedure per se, but the act of wiping has been demonstrated to physically remove spores from a surface.

3. CLEANLINESS &CONTAMINATION CONTROL ISSUES

3.1 Requirements

TAS-I leads the Contamination Control task for the whole mission aiming at the final consolidation of the CC Requirements, including the critical top level one which reads as follows:

"All parts that come in direct or indirect contact with the samples shall satisfy the cleanliness level specified.
C: The cleanliness level in this context is focused on contamination of relevance for the life-detection experiments. The maximum amount of terrestrial contamination transferred to the organic instruments per gram of sample can be considered on the order of nano-gram TOC until further clarifications."

It was agreed with ESA that the wording "on the order of nano-gram TOC" means in the range of 1÷9 ng TOC. As this requirement on max allowed terrestrial contamination level is dictated by the sensitivities of life detection instruments and since one of them was recently removed, there are possibilities that it could be relaxed if the complementary Carbon/Nitrogen ratio can be used as additional parameter and if a library of potential contamination sources is established.
The proposed approach to relax the requirement is the following:

- Max allowed terrestrial contamination level = 50 ng TOC/g sample
- C/N ratio > 10

The Carbon / Nitrogen ratio threshold allows to limit the presence of amino-compounds

3.2 Cleanliness and contamination control approach

The nature of the sensitive life detection instruments requires the management of organic contamination, focusing on the pollution of the sample itself, the sample handling chain included in the ALD and the surrounding environment. To allow the instruments detecting to their sensitivity, the sample collected on Mars must not be contaminated by terrestrial matter. Besides TOC there are also other chemicals that may prevent the instruments from detecting microscopic life - i.e. Amine Containing Organics (ACOs): amino acids, amines, nucleobases, and amino sugars and Polycyclic Aromatic Hydrocarbons (PAHs) – and their presence should be taken into account.
The top level requirement cannot be verified on the spacecraft before launch, because the sample pathway is prone to particulate generation as well as to contamination after cleaning not only on Earth, but also during the interplanetary cruise to Mars and even on the Martian surface itself, due to outgassing and off-gassing phenomena.
The level of contamination control is driven by the sensitivity of the instruments themselves. A joint industry/ESA/instrument working group (CC-TT, Contamination Control Tiger Team) was established in order to identify a consolidated contamination control approach for ExoMars. The CC-TT dealt extensively with the organic contamination requirements for all subsystems, allowing TAS-I deriving them from top level requirements. The intention of this working group was to develop a suitable strategy to establish a contamination budget for the various subsystems and instruments in the ALD and sample handling chain. The outcomes of the CC-TT have been used to reach a consolidated contamination control approach, including a contamination control plan, budget and requirements for all sub-contractors, instrument providers, and the launch service provider.
The Goals of the C&CC must be distinguished in two different categories, that is:

- ExoMars specific needs for exobiology mission success:
  - to avoid false positives during life detections
  - to avoid false negatives during life detections

  preventing molecular and particulate organic contamination.
- Typical Contamination Control activity:
  - to guarantee the nominal performances of all contamination sensitive items until the end of the mission.

To achieve the above-mentioned goals, the Cleanliness and Contamination Control approach mainly deals with five key aspects:

1) Selection of proper materials
2) Segregation of most of the contamination sensitive items
3) Evaluation/Development of Ultra-Cleaning Technique(s)
4) Suitable AIT procedures and facilities to guarantee the required cleanliness levels during on-ground phases
5) Blank Philosophy

All these topics are discussed in the following sections.

3.2.1 Selection of Proper Materials: Off/Out-gassed Products & Testing Activity

A great effort was made not just to ensure the cleanliness of surfaces that the sample will come into contact with, but to characterize and control off/out gassed products from materials in proximity to the sample and to contamination sensitive surfaces. To this end, provisional lists of materials to be used within contamination sensitive areas were assessed for criticality (in both proximity and quantity), and materials that were deemed a contamination risk to the instruments (due to their chemical composition) have been tested for the quantity and composition of their out-gassed products. Screening Out-gassing (in vacuum) Test Campaign is on-going at ESTEC TEC-QMC Facility to test samples of critical materials, which is leading to the definition of a Common Preferred Material List so that the Project will be able to control all the S/C materials avoiding arbitrarily choices by subcontractors or instruments. It must be pointed out that tests are not standard out-gassing tests but dynamic VBQC (Vacuum Balance Quartz Crystal) tests or out-gassing screenings (micro-VCM) with GC-MS (Gas Cromatography-Mass Spectrometry) aimed to detect all chemical species released in vacuum. In parallel, the most sensitive instruments are performing their own chemical characterization on collected condensable material during a.m. tests and the harmonization among the different laboratory teams and is on-going, in order to efficiently compare the results obtained by the different analysis methods. The VBQC test facility consists of a vacuum chamber, a temperature control system, a vacuum microbalance provided with a sample hanger, three QCM's (Quartz Crystal Microbalance) which can measure the amount of material condensed on the exposed c r y s t a l and a data acquisition system. QCMs are cooled down to liquid Nitrogen temperatures and generally controlled at -75, -50 and -25°C respectively, while the sample is submitted to a standard temperature program consisting of 5 steps of 25°C/24h up to 125°C.

The collected data from these tests are being used both to proscribe the use of certain materials (especially within the UCZ) harmonizing the material choices, and to determine contamination budgets. In fact the VBQC test permits to perform a long term prediction of the outgassing phenomenon [5],[8] in function of the temperature of the materials.

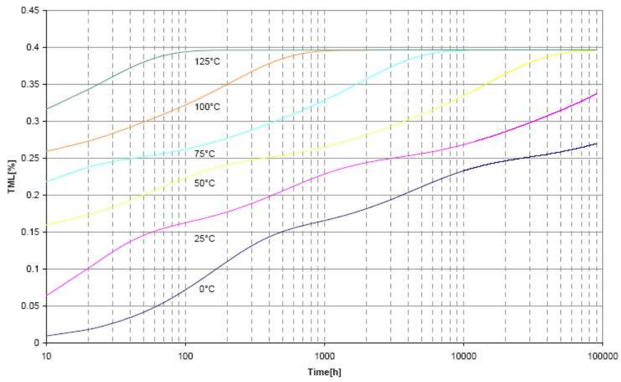

Fig. 2. Example of total mass loss long term prediction for the RV CFRP panel

The testing activity is related not only to materials samples, but also to critical equipment; as instance, several motors/actuators populate the ExoMars Rover since they are required for the sample handling, crushing and distribution to the analytical instruments as well as for the other mechanisms actuation: during their functioning particles could be shed, and debris could be potentially generated due to wearing of ball bearings, sleeves, extra self heating due to increased friction etc. Since the released particulate can contain organics, a dedicated Particle Generation Test Campaign is planned, in order to perform an assessment of the amount and chemical nature of particulate released from motors while they are operated in a simulated Martian atmosphere in flight configuration (including sealings, gearboxes, etc.) , under representative load conditions, mode of operation and temperatures. From the collected data TAS-I will be able to determine the final configuration of motors inside the UCZ (whether encapsulated or not) as well as to acquire fundamental data to refine the actual assumed contamination potential in the Contamination Model.

3.2.2 Segregation of Contamination Sensitive Items - Ultra Clean Zone (UCZ)

The need to contain not only the sensitive life detection instrument(s) and sample handling systems within the ALD, whilst preventing recontamination from the rest of the system has led to the concept of the Ultra Clean Zone (UCZ). The UCZ (Fig. 3) represents a segmentation of the ALD to isolate the most contamination sensitive elements (including the SPDS) from less sensitive but proximate equipment. This will minimize the hardware that is subject to the strict contamination control measures.

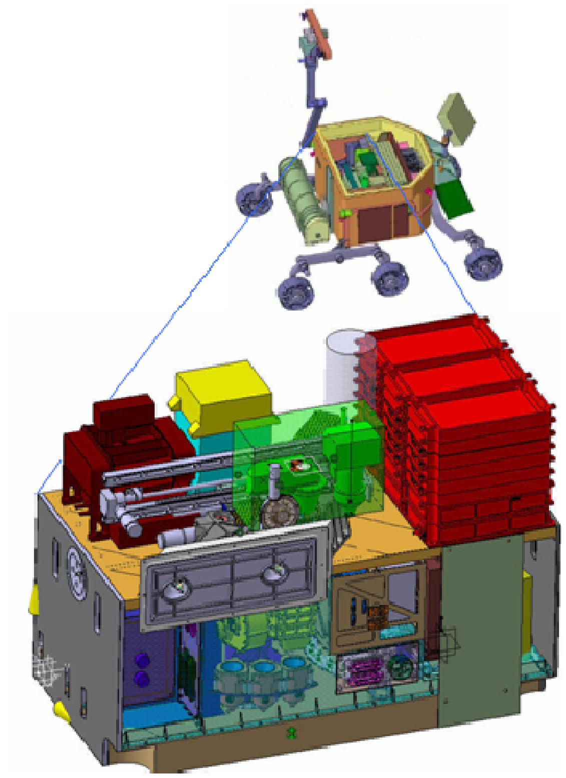

Fig. 3. Internal layout of the ALD showing the pressurised UCZ containing the contamination sensitive instruments

The UCZ is a sealed, pressurized volume with an overpressure of 0.1 bar with respect to the external environment using ultra pure Argon. This approach has been adopted to remove the need for complicated and untested organic filters on the UCZ venting pathway. Once on Mars, the UCZ will be depressurized after the first drilling operation, by opening its inlet port, exiting the CSTM (Core Sample Transportation Mechanism) and the associated vessel to acquire the sample. From this moment on, the UCZ volume will be filled with Martian atmosphere

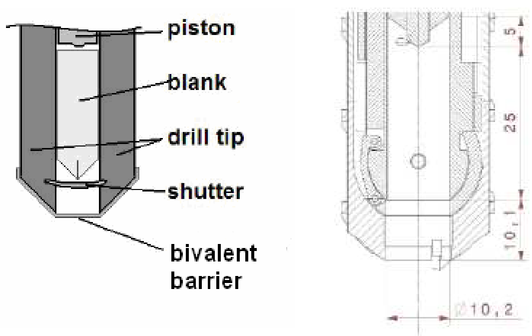

Fig. 4. Drill Tool Acquisition Chamber configuration.

The Drill Tool Acquisition Chamber is considered part of the UCZ volume, although physically outside of the Rover body and not pressurized; in fact it represents the very first surface that comes in contact with the Martian sample. Therefore its cleanliness level shall be equal to the other SPDS surfaces. To guarantee this stringent cleanliness level the Drill Tip is sealed with a so-called Bivalent Barrier (- BiBa- able to block both microbial and molecular contamination) until the first sample acquisition, when it is perforated by the drilling operation itself. The selected material for Bi-Ba is Double Aluminized Kapton., and its use is foreseen as light cover also during on-ground phases in order to prevent recontamination on most sensitive items.

3.2.3 Ultra Cleaning Techniques

Obviously, during the Assembly Integration and Test (AIT) of the ALD, the surfaces of equipment that will get in contact with the Martian sample, and those in close proximity to it will need to be ultra-cleaned to remove organic residues. It must be stressed that usual precision cleaning methods are not sufficient to achieve the extremely low cleanliness levels required for UCZ and sample pathway surfaces (in the order of ng/cm^2), therefore dedicated collaboration with Ultra Cleaning centre of excellence (i.e. Fraunhofer Institut Produktionstechnik und Automatisierung) has been put in place to solve the issue. Currently, various methods of ultra-cleaning (e.g. degreasing, CO_2 snow cleaning, laser /plasma cleaning) are under investigation at project level for use on the UCZ equipment and sample handling chain. Since the cleaning techniques under investigation are being selected based on their capability to reach extremely high cleanliness levels, usually these methods are called Ultra-Cleaning Techniques.

TAS-I is involved in the definition of the most suitable technique to ultra clean the UCZ surfaces at levels of the order of ng/cm^2, as well as dedicated procedures to verify this level and to maintain it after cleaning.

Feasibility tests of different cleaning technologies are in the pipeline, in regards of different methods, several materials and their combinations, surface structures and geometries, accessibility, amount and kind of contamination. This testing activity is devoted to prove the compiled cleaning concept on test specimens and representative parts in order to assure its effectiveness on the ExoMars sample pathway equipment. Moreover, it will be demonstrated also the implementation feasibility of the selected ultra cleaning method during the assembly and integration phases in TAS-I clean-rooms; several Concurrent Engineering activities are being held in order to optimize the ALD/UCZ configuration to address the activity towards a "design for clean-ability" approach.

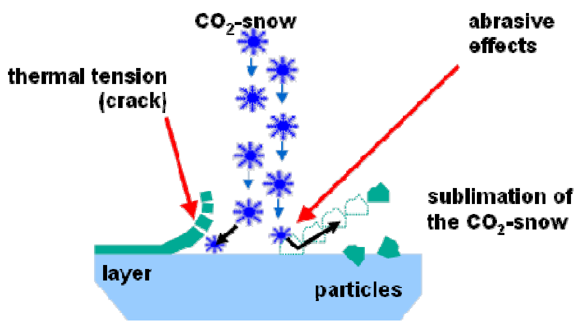

Fig. 5. Snow cleaning technique

The most promising candidate as Ultra Cleaning Technique appears to be the CO_2 Snow Cleaning: this process removes micron and submicron particulates and hydrocarbon-based contamination by means of a snow stream confined in a N_2 jet, impinging onto the surfaces to be cleaned. It is non-destructive, nonabrasive, residue-free, based upon the expansion of either liquid or gaseous carbon dioxide through an orifice. The contamination layer is removed by means of the synergic effects of the nucleation of small dry ice particles and a high velocity gas carrier stream. Upon impact with a dirty surface, the dry ice media removes particles by momentum transfer, local sublimation of CO_2 snow which traps and carries away the contamination and also thanks to the thermal tension induced by the CO_2 snow jet, which freezes the contamination layer.Finally, the high-velocity gas blows the contaminants away.

3.2.4 Suitable AIT procedures and facilities - UCZ Integration

The Ultra Cleaning process would be efficient only if it is performed in a highly controlled environment, w.r.t. both particulate and molecular contamination. The same concept must be applied to AIT operations, otherwise the beneficial effects of the cleaning would be immediately vanished after few minutes of the ultra-clean H/W exposure to the integration environment. For this reason, the Ultra-Cleaning technique definition is coupled with the definition of an associated "clean environment", as well as suitable AIT procedures to assembly the most contamination sensitive items while maintaining their cleanliness level.
The tailoring of TAS-I lab facilities w.r.t. Ultra Cleaning needs is being carried out; furthermore, great attention is being paid to identify and optimize critical control steps during the AIT phase, determining where and when the cleaning should take place for each part in order to minimize the recontamination risks. Material flow, personnel flow and behaviour, workplace design, handling packaging and shipping concepts are key parameters to define suitable environment and procedures for UCZ AIT phase. The integration activities in TAS-I premises, where the whole S/C is assembled, will be performed in a ISO7 Highly Controlled Environment, except for a dedicated Ultra Clean environment for the UCZ.
Moreover, in the frame of the general mission descoping, simplification and cost containment, a great effort has been made by TAS-I in order to reduce the complexity of Contamination Control achievement for the whole mission, without compromising the validity of scientific investigation. In particular, the required cleanliness levels have been relaxed where possible, allowing the AIT phases for the majority of subcontractors to take place in usual ISO8 cleanrooms instead of highly controlled environment, and consequently saving costs and streamlining the assembly procedures, as well as speeding up the schedule. The main outcomes of the a.m. simplification lead to relax the particulate cleanliness level for Rover Module RM inner regions from 300 to 500 level, fully compatible with an ISO8 clean-room type. Since the areas whose cleanliness requirement was relaxed are placed behind space-qualified HEPA filters, a dedicated assessment based on the HEPA filters efficiency corroborates the requirement modification.

3.2.5 Blank Philosophy

The Final Cleanliness Verification will be performed directly on Mars by the on-board Instruments. For this reason, several ceramic blanks will be carried onboard, inside the UCZ and delivered to instrument by a dedicated dispenser in order to be submitted to the same path pertaining to real Martian samples. A functional End-to-End test of the SPDS on ground will be possible processing a blank.
Moreover blanks will be processed on Mars to:

- Re-calibrate instruments
- to clean the sample handling chain
- to establish the reached "noise" threshold before operations
- for several checks in case of life detection

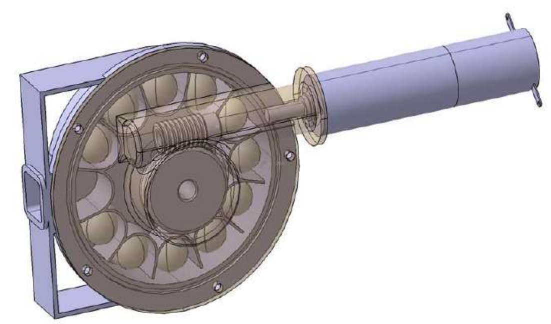

Fig. 6. Blank Dispenser

3.3 Contamination allocation modeling for the UCZ

In order to define a suitable flow down of the top-level CC requirement assigned to TAS-I, an Allocation Model for the UCZ has been set up, taking into account all possible contamination sources, all mission phases until End of Mission (EOM) and the detailed design. The model is described in detail in [7]. The great attention paid to the contamination of the UCZ and the sample's pathway is necessary to assess the contamination of these areas, which are the most critical from a contamination point of view, since they are in direct contact or in proximity with the Martian Sample; once the allowed contamination levels for the most critical volume (UCZ) are established, the same approach can be easily transferred to the Exomars outer regions, deriving the CC requirements for the entire mission. It must be stressed that all ExoMars areas other than those pertaining to the UCZ (Drill Tool included) are not particularly critical from a contamination point of view, therefore no particular issue is expected for maintaining their cleanliness until EoM.

The cleanliness levels of the items of the UCZ was derived from the requirement mentioned above which specifies the maximum allowable organic contamination of the sample as "in the order of the nanogram of TOC (Total Organic Carbon) per gram of sample". Starting from this assumption, a maximum allowed quantity of 9 nanograms of TOC per gram of sample can be considered.

The contamination of the sample from its collection until the delivery to the analytical payloads can be originated by two different phenomena:

- the organic molecules deposited on the surfaces touched by the sample
- the organic molecules contained in the atmosphere encountered by the sample which can be adsorbed by the sample

The proposed model allocates the 50% of the maximum allowable TOC contamination to the first contribution and the remaining 50% to the second one.

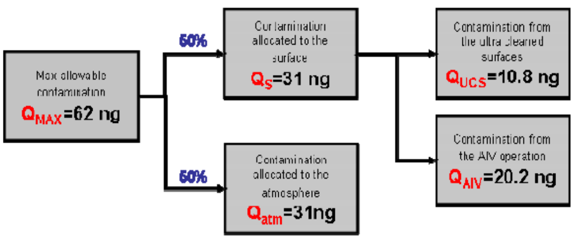

Fig. 7. Contamination allocation budget.

Considering the sample as a cylinder with a diameter of 1 cm and a height of 3 cm, it is possible to calculate the maximum allowable TOC mass on it (Q_{max}) as:

$$Q_{\max} = C_{\max} \cdot m_s = 62ngTOC$$

$$m_s = \rho \cdot V_s = 6.9g$$

Where

C_{max} : fraction of organic carbon (90%)
V_s : sample volume
m_s : mass of the sample
ρ : the average density of the Martian soil ($\rho = 2.9$ g/cm^3) at 2 meters of depth.

The value used for C_{max} is a conservative assumption: it means to assume that all organic contamination is constituted by aromatic molecules, which have the highest carbon content in mass (e.g benzene ≈ 92 %).

At present the best reachable surface cleanliness level by means of the state-of-the-art Ultra Cleaning technologies is 1ng/cm^2. Considering the surfaces of the SPDS and Drill Tip, the surface contamination is:

Q_{soc} = *organic surface contamination = 0.9* $Q_{dc,tot}$
= 1080 nanograms of TOC

Being $Q_{dc,tot}$ the surface contamination pertaining to all areas in direct contact with the sample. Since the assumed ultra cleaning level (1 ng/cm^2) is the maximum obtainable with the actual ultra cleaning technologies, the organic contamination transfer via direct contact is considered reduced to the 1% of the maximum organic surface contamination Q_{soc} calculated.

Q_{ucs} = *contamination from the ultra cleaned surfaces*
= 0.01 Q_{soc} *= 10.8 ng of TOC*

The maximum contamination allowed during the AIV operation can be calculated as difference between the total allowable surface contamination (Q_s) and the contamination of the ultra clean surfaces (Q_{ucs})

$$Q_{AIV} = Q_s - Q_{ucs} = 20.2 \text{ ng of TOC}$$

The contribution which derives from the organics diluted in the atmosphere encountered by the sample is Q_{atm}. During its pathway, the sample will be exposed to the Mars atmosphere during its dumping phase into the CSTM container and transfer inside the UCZ area. Then it will be moved inside the UCZ, encountering an atmosphere volume which can be roughly considered as the projection of the cross-vertical section of the sample during its pathway trajectory (V_{enc}).

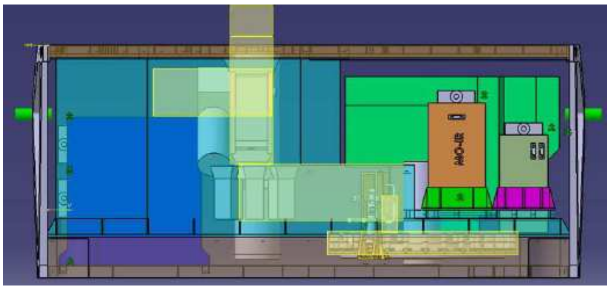

Fig. 8. Encountered Volume in the UCZ

The contamination of the sample due to the UCZ atmosphere can be assumed to derive from all the organics contained in the volume of gas encountered by the sample during its transit. This assumption does not take into account the possibility that molecules in proximity of the Encountered Volume V_{enc} could also contaminate the sample, therefore, a corrective factor has been applied to V_{enc} , defining a V_{enc^*}.
The following assumptions were made:

- the organic contamination contribution of the atmosphere encountered by the sample during the releasing phase into the UCZ (from sampling until inlet port discharge) shall be the 5% of the Q_{atm} :

$$Q_{atm,\ out} = 0.05\ Q_{atm} = 1.5 \text{ ng of TOC}$$

- the organic contamination contribution of the Vc is the remaining 95% of the Q_{atm} :

$$Q_{atm,\ vc} = 0.95\ Q_{atm} = 29.5 \text{ ng of TOC}$$

- the amount of organic contaminants diluted in commercial ultra-pure Argon foreseen for the UCZ pressurization has been calculated and it is negligible

The organics concentration inside the V_{enc^*} can be calculated as:

$$C_{Venc^*} = \frac{Q_{atm,V_{enc^*}}}{V_{enc^*}}$$

Considering a homogeneous distribution of the contaminants in the UCZ atmosphere, the total amount of TOC inside it can be calculated as:

$$Q_{atm} = C_{V_{enc^*}} V_{ucz}$$

It has to be considered that after the landing, the UCZ will be opened and the Argon atmosphere will partially outflow because of its overpressure w.r.t. the external environment. Considering both the Argon and the Mars atmosphere as perfect gases, it can be assumed that the portion in mass of Argon that will remain in the UCZ will be proportional to the pressure ratio (0.035) between the inner environment and the external .For this reason, considering a homogeneous concentration of the contaminants present in the UCZ atmosphere, the TOC content that can be diluted in the UCZ volume after its opening is:

$$Q_{atm,end} = \frac{Q_{atm,ucz}}{0.035 \cdot k}$$

Where $K=1.5$ is a coefficient that takes into account that a portion of contaminants can remain in the UCZ volume because of back flow phenomena at the outlet port and introduces a further conservative element in the model. Considering that the organics diluted in the UCZ Argon atmosphere can be only generated by the OFF-gassing phenomena during all phases until beginning of operations, the OFF-gassing rate can be derived as follows:

$$OFFgassing\ rate = Qatm,\ end\ /\ t_m = 3.1E\text{-}18 \text{ ng of } TOC/cm^2 / sec$$

Where t_m is the time of mission expressed in second.
This value takes already into account the fraction of contaminants that outflow during the venting of the UCZ atmosphere during its opening on Mars.

The Contamination Allocation Model demonstrates that the CC Control during AIT phase is particularly important to obtain and maintain the desired cleanliness level . It must be noticed that the model is extremely dependant on the percentage of transferred contamination C_t (transfer of ultra cleaning residuals from direct contact surfaces to the sample); As clearly depicted in the Fig. 9, , the increasing of C_t reduces both the maximum OR and the allowable contamination amount Q_{AIV} during the UCZ AIV phase. Therefore a narrow margin is allowed for C_t : its highest value (C_t = 5.7 %) means that all the sample's contamination is due to direct contact with ultra cleaned surfaces.

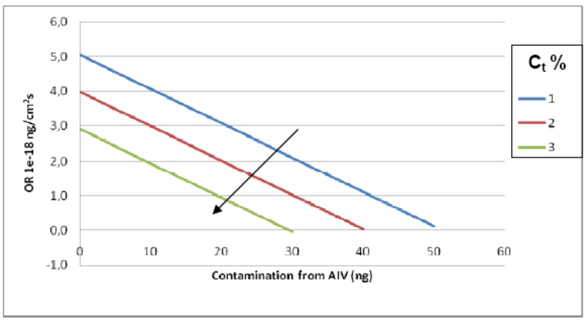

Fig. 9. Influence of the Contamination Transfer Coefficient on Outgassing Rate OR for UCZ surfaces and on allocated contamination during UCZ AIV

The extremely low OR obtained imposes an accurate material selection: a complete organic materials inventory has to be provided at DMC-level, and it is planned to be delivered for the next Project phase.
The inventory includes: identifier, chemical composition, use, mass estimate, rating and reference for out-gassing, process parameters, and supplier. In addition, a sample of any organic material used at RM-level, including the drill system, the SPDS, and payload, is planned to be archived under appropriate conditions and control up to the end of the mission, and subsequently released to ESA.

It must be stressed that the proposed Contamination Model is mainly devoted to allocate the top level CC requirement; TAS-I in parallel performed several bottom-up calculation, in order to check the practical feasibility of this requirement. From all calculations is restated that it is extremely demanding and stringent therefore TAS-I is now focusing on relatively simple models to acquire the necessary confidence on obtained numbers rather than sophisticated simulations difficult to be interpreted and contextualized in the Mars Environment. The goal is to use the acquired confidence to critically review the S/W outgassing/offgassing simulations planned to be accomplished by the Project Preliminary Design Review.

4. CONCLUSIONS

It appears evident that stringent constraint are envisaged both for the for the Assembly, Integration and Test phase and for the OGR of the UCZ surfaces.
However, the TAS-I strategy is to minimize as much as possible the areas characterized by strict Cleanliness & Contamination Control impositions, in order to increase the possibility to fulfil the top level requirement. The ExoMars Program is still in phase B2X, therefore there is sufficient time to verify and consolidate the outlined approach and for its practical implementation.

5. REFERENCES

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