Proof of concept of a Bio-Containment System for Mars Sample Return Mission

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A Mars Sample Return (MSR) mission foreseen in the 2020s envisages the collection of some tens of samples of Martian soil for return to Earth. Once collected, each sample will be stored and capped into dedicated vessels and finally fixed into a dedicated container (Orbiting Sample - OS). After the storage of all samples, the OS will be launched into Mars orbit and transferred to the Earth Re-entry Capsule (ERC) for the return trip to Earth.
The transfer of the OS into the ERC, the return phase, Earth re-entry and samples curation are subject to stringent constraints with respect to Planetary Protection requirements in order to prevent any back contamination.
As part of this transfer system, the main objective of the Bio-Containment project is the proof of concept of the sample container bio-barrier and the sealing monitoring system.
In this paper, the basic design characteristics of the Bio-containment system will be given together with an overview of the main performed hardware activity.

1) INTRODUCTION

As soon as the Orbiting Sample (OS) is captured around the Mars orbit, any contamination of the spacecraft and in particular of the ERC with Martian material must be avoided. In order to achieve this goal, a system capable to position the OS into the Bio-Container and break the chain with Mars has been put in place. It consists of sealing gaskets combined with a sterilization process. These operations are all actuated by dedicated mechanisms. Once the chain with Mars is broken, the Bio-container will be closed with two level of gasket based sealings. One of the two containment compartments is pressurized in order to enable a monitoring system the detection of possible major failures by pressure measurement. Dedicated mechanisms have been designed to execute all these operations.
Once closed, the Bio-Container will be inserted into the ERC ready for the return flight to the Earth.

During the whole return cruise the pressurized compartment of the Bio-container will be constantly monitored, so that in case the required sealing is not guaranteed, the ERC re-entry to Earth will be aborted.

The performed breadboard test campaign had the objective to verify the functionality and performance of mechanisms and the overall system capability to fulfil the basic bio-containment requirement, which is expressed as follows: *the probability that a single non sterilized particle larger than 10 nm in diameter is released into the terrestrial bio-sphere shall be below* 10^{-6}.

2) BIO-CONTAINER SYSTEM CONFIGURATION

Characterizing features of the Bio-Containment system (see also Fig. 1) are:

- two containment vessels;
- chain Breaking Lid (to support Mars chain breaking);
- two lids (each equipped with gasketing system);
- monitoring system (pressurization, pressure and temperature sensors).

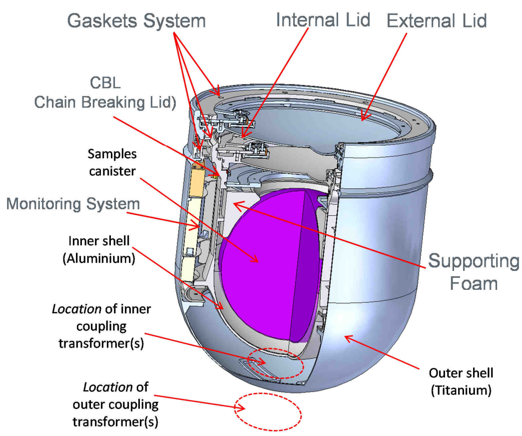


Fig.1 Bio-container Overall Schematics

The outer vessel (D= 360 mm) is foreseen in titanium also to allow ‘wireless’ power and data transfer. The Inner vessl (D= 260 mm) is foreseen in aluminium. The vessels are designed for re-entry loads and no feed throughs are utilized. Fig. 2 show the CAD drawing of the inner vessel.

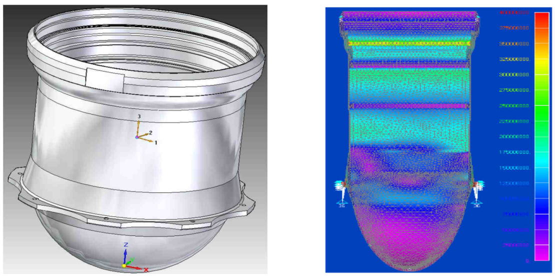


Fig.2 CAD drawing of the inner vessel and some stress analysis results

Two lids are present (one for each vessel) and each is equipped with three gaskets sealing. Gaskets of different material and working principle are foreseen to limit common cause failures. A lid schematics is shown in Fig. 3. Each lid is equipped with a safe lock mechanism.

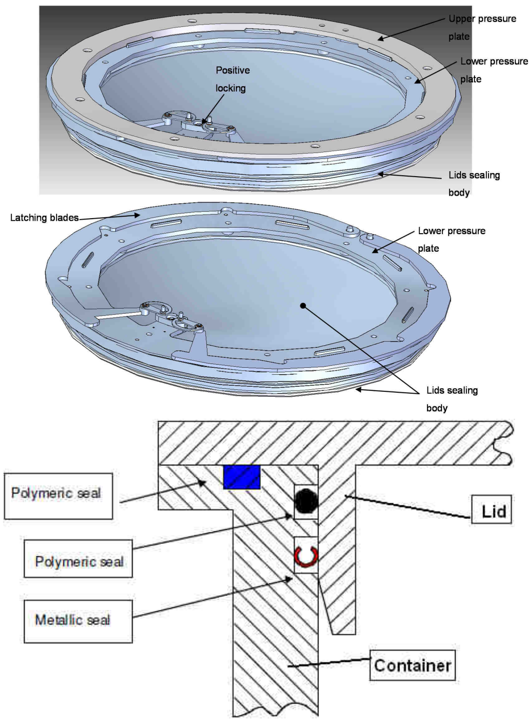


Fig. 3 CAD drawing of one of the lid and a possible schematic for gasket placement

A special mechanism (End Effector) has been developed to automatically close the lids. The mechanism is characterized by the following features/performances (see also Fig. 4):

– three clamps for final stroke and tightening;
– management of the lids (with different size);
– actuator based on Motor-Reduced;
– ball screw for output stage

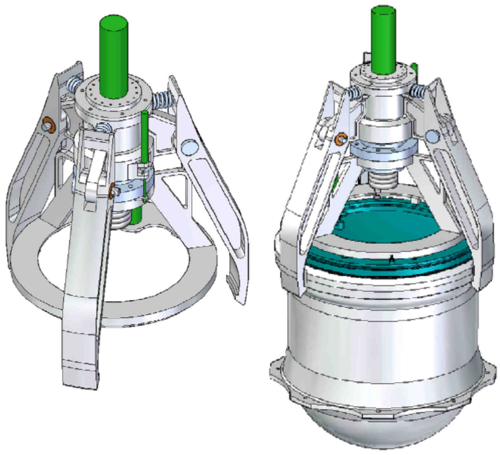


Fig. 4 Schematics of lid closing mechanism (End Effector)

Another important element of the Bio-Containment system is the Chain Breaking Lid (CBL) in charge to achieve the final bio-separation. The main features of the CBL (see also Fig. 5) are:

– made by two detachable halves;
– separation interface sterilized during integration;
– outer rims sterilized while in operation by thermal wave.

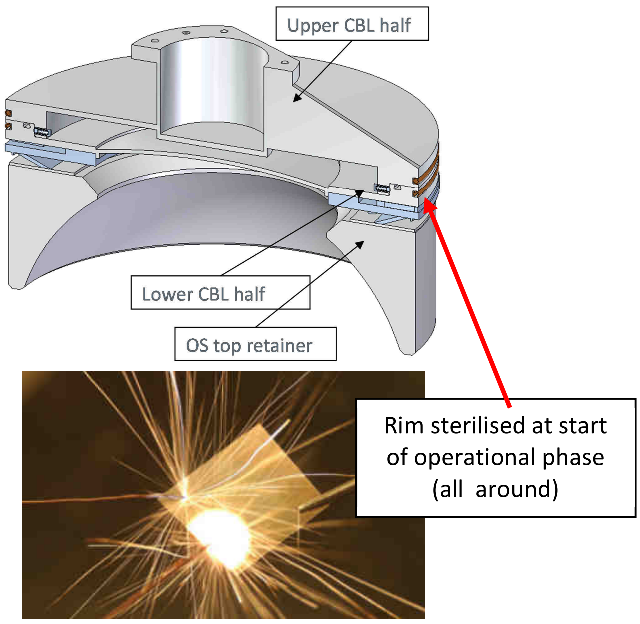


Fig. 5 Schematics of CBL

Concerning the monitoring system (which internal location is shown in Fig. 6) is characterized by the following:

- Power/Data transfer through a solid metallic wall;
- Transfer power from the external environment inside the metallic container sufficient to keep charged the internal energy storage system (some tens of milliwatts, minutes per day);
- Transfer data from the internal sensors and devices to the external environment (hundereds bit/s bandwidth);
- Manage the internal sensors and actuator and operate the correct operations sequence.

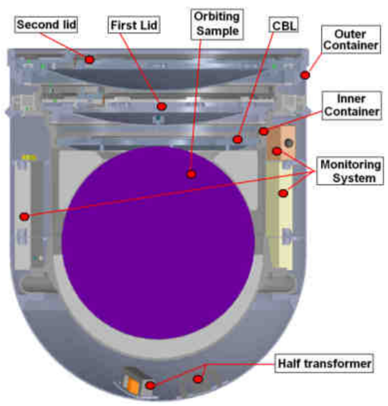


Fig. 6 Schematics of the Biocontainer and location of the monitoring system and coupling transformers

The schematics of the internal electronics of the monitoring system is shown in Fig.7 and the functions performed are the following:

- Coupling transformers
- Rectifier Regulator
- Power Storage
- Data Tx (OOK logic)
- Smart Logic Controller
- Voltage regulator, Voltage monitor, Bus monitor
- Motor and Hall sensors
- P-T sensors

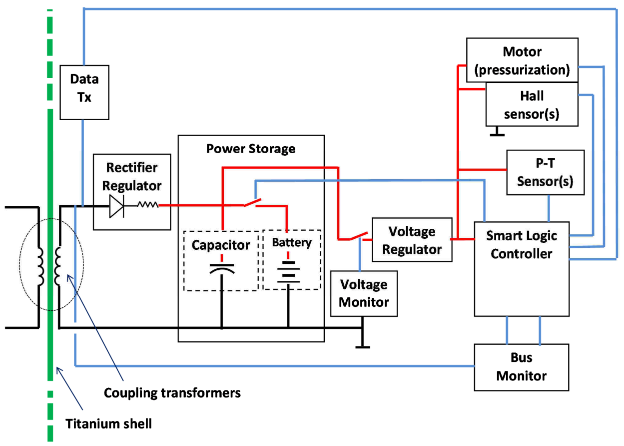


Fig. 7 Overall Scheme of internal electronics of Wireless System

The internal pressurization (in the range of 300-400 mBar) is achieved by perforating a small metallic reservoir containing Argon. The pressurization system (reservoir, puncher and actuator) are schematized in Fig. 8.

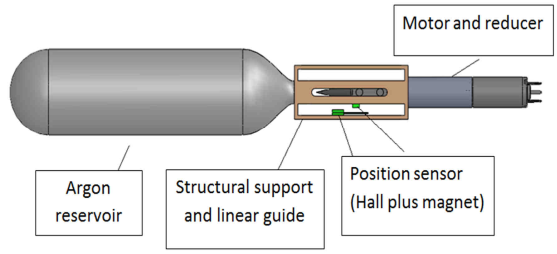


Fig. 8 Schematics of pressurization system elements

For safety and reliability aspects, the monitoring system is presently foreseen in triple redundancy and some implementation schematics is shown in Fig. 9.

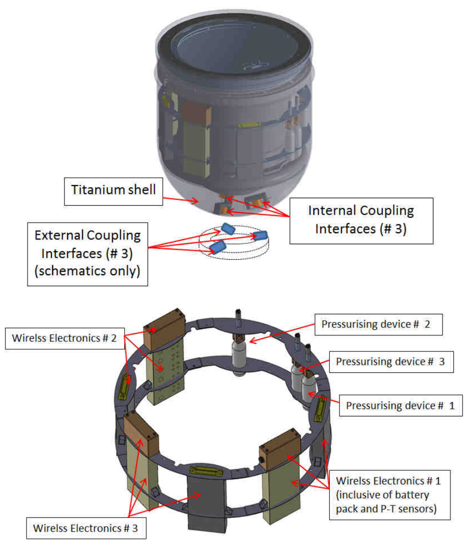


Fig. 9 Some implementation schematics for triple redundancy

3) Breadboards Models

In the course of the activity several parts have been manufactured at Bread Board level and tested. The item manufactured have been relevant to both Bio-container parts (see schematics in Fig. 10) and Monitoring system parts (see table in Fig. 11).

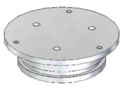
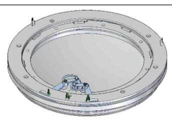
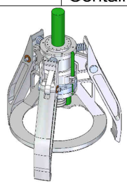
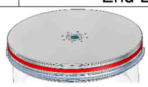
Lid	 Container test Lid BB	 Lid BB	
Container	 Container Test BB	 Simplified container BB	 Container BB
Closure Device	Closed by hand	 End Effector BB	
CBL	 CBL BB		

Fig. 10 Summary of bio-container Breadboard parts

- Pressurization device
- Wireless I/F
- Inner electronics
- Outer Electronic (for test purposes)
- Separatior Ti plate

Fig. 11 Summary of monitoring system Breadboard parts

From Fig. 12 to Fig. 15 are shown a selection of pictures of the manufactured/tested parts.

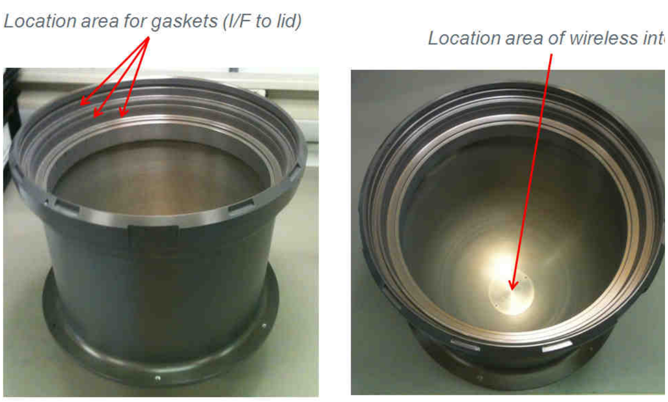


Fig. 12 Complete inner container

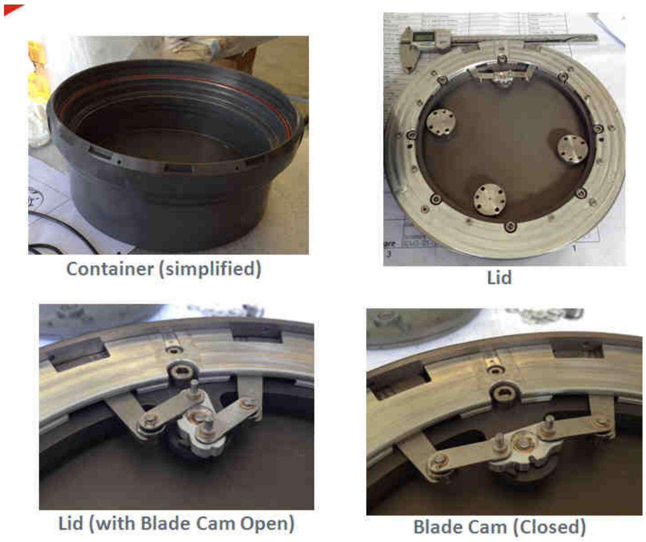


Fig. 13 Simplified container and lids (with close mechanism)

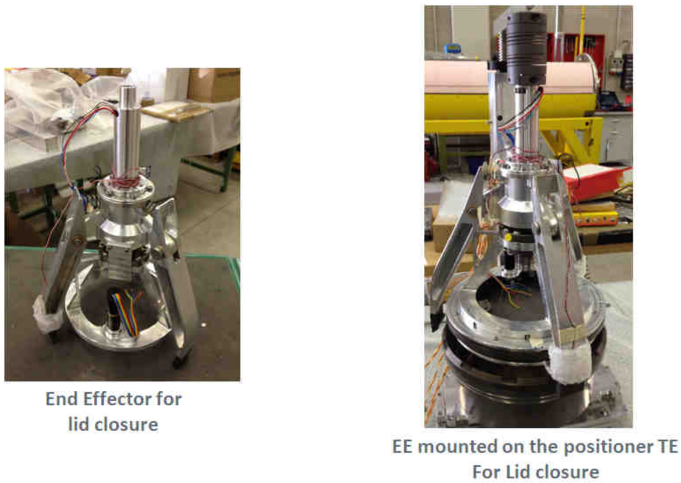


Fig. 14 Closing mechanism (End Effector)

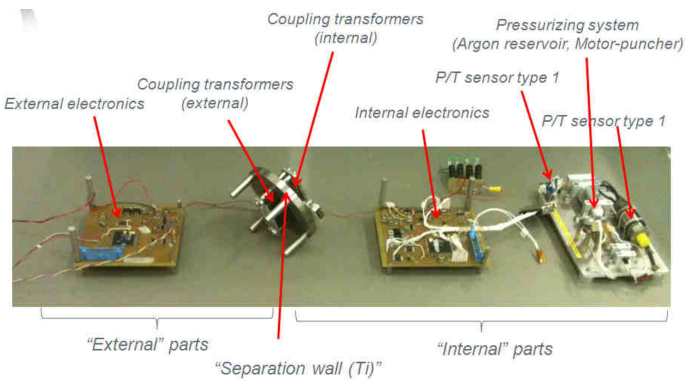


Fig. 14 Monitoring System parts

Fig. 15 Basic pressure/temperature transducers
(Off the shelf items)

4) TESTING ISSUES

Several tests have been performed on the Bread Board parts throughout the activity and a qualitative summary is reported in Tab. 1

- Measurement of the leak rate on the:
  - Calibrated Hole
  - Gaskets of the different types
  - Vessel-Gasket combinations
- Lid-Vessel closure by using the developed effector (with misalignments) with the different gaskets
- 'Escaping of particles' test (by using nanometers class particles e.g. d= 20 – 100 nm) through both calibrated hole and gaskets
- CBL verification and rim sterilization
- Pressure and temperature sensors characterization
- Wireless I/F test for power transmission, data transmission, misalignment robustness
- BB System integrated test

Tab. 1 Summary of performed tests

In Fig. 16 are shown a selection of pictures of taken during lid closure and gas leak test testing.

Fig. 16 Lid closure test (left), leak rate test (right)

Fig. 17 shows the set-up utilized during the particle leak test (in support to the verification of the basic Planetary Protection requirement).

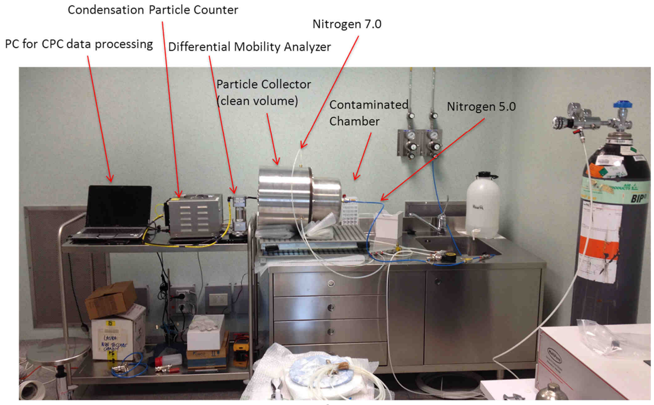


Fig. 17 Set-up utilized for the particle leak test

5) APPROACH FOR COMPLETE BIO-CONTAINMENT PERFORMANCE PROJECTION

The approach utilized for the overall verification of the basic planetary protection requirement is based on the following steps:

- Starting point are the mathematical model developed (for gas and particles escape) and the specific leak tests for gas and particle
- *Model verification – Gas leak rate calibration (using 9 μm calibrated hole)*
  - Model/True gas leak comparison for validation
- *Model calibration- Particle rate calibration through calibrated holes (9µ and 20μm)*
  - Model/True particles leak comparison for validation
- *Gaskets characterization (using measured He data leak rate and measured particles leak)*
  - Viton gaskets
  - Silicon gaskets
  - Metal gaskets
- *Complete BCS simulation with 10 nm particle size and argon gas in the intermediate container*

The Bio-containment system mathematical model schematics (for gas and particle escape estimation) is shown in Fig. 18. The application of the approach above described allows the determination of the pressure trend and particle escape trend in all simulated compartments (including the particles escaped outside the system).

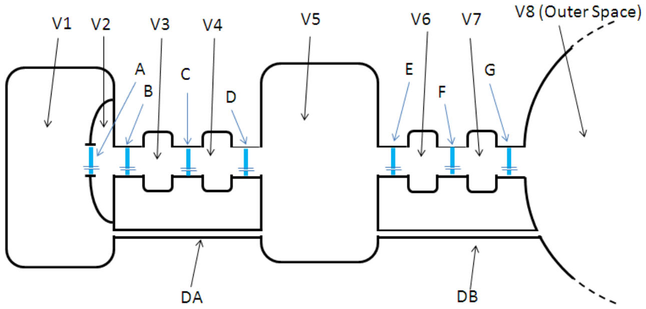


Fig. 18 Overall Bio-container scheme used for the gas and particle escape Mathematical Model definition

The modelling is based on seven chambers (the eight is the 'outside') and seven gasketing system. For the gas, molecular plus viscous flow has been considered. For the particles (in Brownian motion) molecular flow has been utilized.

6) ORBITING SAMPLE HANDLING SYSTEM: A POSSIBLE CONFIGURATION

A possible overall configuration for a complete Orbiting Sample Handling System (OSHS) is schematically shown in Fig. 19. Visible from the picture are the main elements in charge of the handling: the Capture Mechanism, the Bio-Containment related items (insertion mechanism into vessels, CBL, lids and related mechanisms) shown in the green background, ERC lid closure mechanism (in lower pink background), ERC.

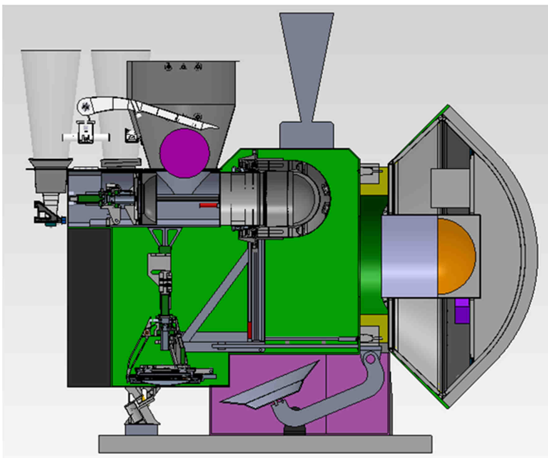


Fig. 19 A possible configuration for a complete Orbiting Sample Handling System

In Fig. 20 is shown, schematically, an example of sequence; optimization of overall OSHS configuration can be done.

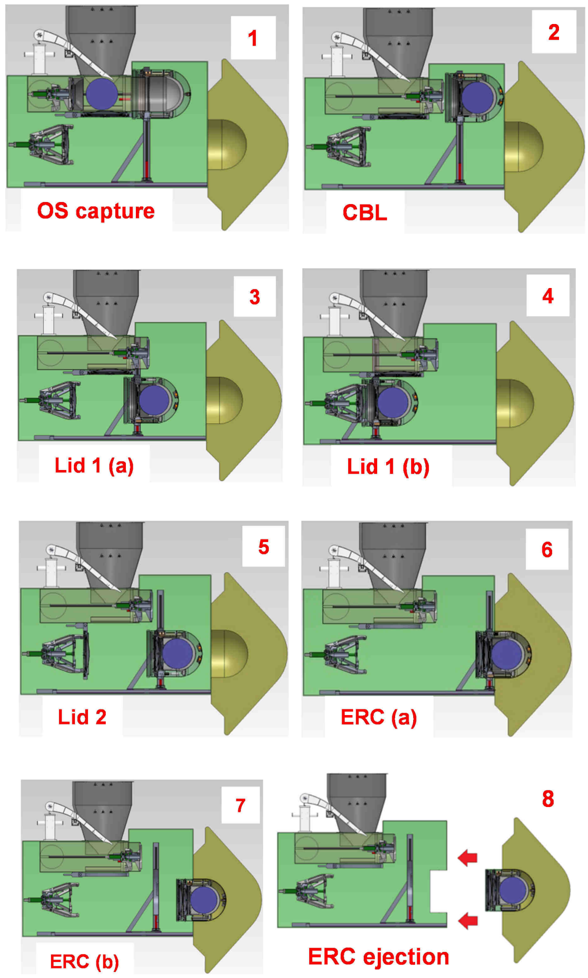


Fig. 20 Some steps of handling sequence (schematics)

7) CONCLUSIONS

An important design and development activity is presently being concluded on the bio-containment system for the possible future Mars Sample Return Mission. Several parts have been detail designed, manufactured and tested and the results so far achieved seems compatible with the overall objectives. Some more development is being planned

The final key requirement related to 'very low particle escape probability' is coped with by making use of the test results achieved in terms of leak rate and particle escape and propagating them via a mathematical model of the complete bio-container.