Transport to Curation Facility

Deliverable 6.3

Andrea Longobardo, Fabrizio Dirri, Ernesto Palomba

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1 Introduction

The aim of this report is to give the general requirements and a basic design of a transportation box which would include extra-terrestrial samples returned from a Sample Return Mission (SRM). The report considers in particular the transport from landing site to curation facility, whereas the transport from curation facility to laboratories are beyond the scope of this WP.
Different cases will be considered in this analysis (defined in EURO-CARES D6.1 and D6.2), i.e.:

- Restricted Case, i.e. samples needed to be kept in special conditions, because they may host life traces. This is the case of (unsterilized) samples returned from Mars and possibly from Europa.
- Unrestricted Case, i.e. samples are required to be preserved by contamination, but do not contain biological molecules at all.

In turn, two scenarios can occur in each case, i.e.:

- Nominal Scenario, i.e. no damage occurs on SRC or on returned samples)
- Non-Nominal Scenario, i.e. damage occurs on SRC and/or on returned samples

For each scenario, we will give a trade-off on how the packaging and transport operations should occur. When applicable, we will also highlight the differences in these operations, depending to the origin of the extra-terrestrial samples.

In Section 2 we will give the state of the art of transportation boxes designed and developed in previous SRM. Section 3 will be dedicated to regulatory issues concerning packaging and transport of potentially hazardous samples, as the extra-terrestrial samples. Section 4 will analyse possible landing sites and how these affect the design of transportation box. Section 5 will be devoted to a trade-off analysis aimed at identifying the general requirements of a transportation box for the three different scenarios introduced above. Section 6 will give a basic design of the transportation box. Labelling, documentation and tracking issues will be discussed in Section 7. Finally, in Section 8 conclusions will be given.

2 State of the art

SRMs considered different containers and transportation boxes of various size and shape, from Apollo Missions up to Hayabusa1 Mission (Figure 2.1). A list of performed and planned SRM's is shown in Table 2.1, with relativelanding sites, terrestrial means of transport used to move the sample from landing site to Temporary Clean Room (TCR) (if present), Transportation Box considered and contamination at landing site (when occurred), due to ground impact or to environment.

Figure 2.1 *Left*:. November 25, 1969. David E. Peterson and Richard C. Graves carry one of two Apollo 12 rock boxes off a C- 141 in Houston, on its way to the LSL. NASA PhotoS69-60229. *Right*: Japanese scientists from JAXA transport the Hayabusa space capsule (inside a box) to a clean room in Woomera Prohibited Area (June, 2010).

SRM	Landing Site	Mean of transport	TCR	Transpor-tation Box	Contami-nation	Returned samples
APOLLO (NASA)	Pacific Ocean	Ship (U.S. Navy)	No	ALSR-C containers with teflon bags	No	382 kg of Lunar rocks
LUNA (USSR)	Kazakhstan / Siberia Area (RUS)	--	--	Metal storage container	No	326 grams of Lunar soil
GENESIS (NASA)	UTTR Area (USA)	Helicopter	Yes	Special-designed cradle and then purge applied	Yes	Particles
STARDUST (NASA)	UTTR Area (USA)	Helicopter	Yes	Special-designed containers	No	Particles
HAYABUSA	WPA (AUS)	Helicopter	Yes	Designed transportati on box	No	Particles

HAYABUSA-1 (JAXA)						
HAYABUSA-2 (JAXA)	WPA (AUS)	Helicopter	Yes	Designed transportation box (Hayabusa 1 heritage)	--	ONGOING
OSIRIS-Rex (NASA)	UTTR Area (USA)	Helicopter	--	Container (Stardust heritage)	--	PLANNED (60 grams of asteroid samples expected)
CHANG'E 5 (CNSA)	Siziwang Banner (Mongolia Area)	Helicopter	--	Special cradle	--	PLANNED (2 Kg of Lunar soil expected)

Table 2.1. Summary of performed and planned SRM's, and information about landing site, means of transport for transportation box, presence of a Temporary Clean Room (TCR), type of transportation box used, occurred contamination and returned samples.

2.1 Luna 16, Luna 20, Luna 24

Luna 16, Luna 20 and Luna 24 were three successful soviet SRM's.
Luna 16 represented the first lunar SRM by Soviet Union, and came back with 101 grams of collected material of lunar soil. The Luna 16 re-entry capsule (Figure 2.2, left) landed on approximately 80 km SE of the city of Dzhezkazgan in Kazakhstan at 03:26 UT. The samples were placed in a hermetically sealed soil sample container inside a re-entry capsule.
Luna 20 was the second attempt after Luna 18 to obtain a sample from the lunar highlands. It was launched on February 14the, 1972, was able to carry on about 30 grams of collected lunar samples in a sealed capsule and landed in the Soviet Union on 25 February 1972 (Wesley and Mikhail, 2011). The Earth-return vehicle landed in Kazakhstan, where it took the Soviet team about 24 hours to locate it. Ice, wind and snow presented severe difficulties to the recovery team (Figure 2.2, right). SRC was recovered the following day and when opened proved to contain only 55 grams of lunar soil (Wesley and Mikhail, 2011). This experience raises the question of means and methods of recovering the return sample after landing on Earth.

Figure 2.2. *Left:* Luna 16 Return Capsule (Summary of Russian Planetary Lander Missions).*Right*: Luna 20 Sample Return Capsule, as it landed in the snow, February 27, 1972 (Soviet photo courtesy of NASA-GSFC, NSSDC ,ID:1972-007A).

Luna 24 was launched more than 4 years after Luna 20 on August 14, 1976 and was able to collect 170.1 grams lunar soil. It landed on Soviet Union on August 22, 1976 (Badescu, 2012). The Luna Soviet Missions samples are studied and stored at the Vernadsky Institute of Geochemistry and Analytical Chemistry, GEOKhI, of the Russian Academy of Sciences.
The information concerning the transportation box, the vehicles and methods used to transfer the samples are difficult to find. Given the historical period, it is probably that most of these information are protected by military secret.

2.2 Apollo

The Apollo program, the third US human spaceflight program carried out by NASA, was able to achieve the first large collection of extra-terrestrial materials returned to Earth (up to 382 kg of lunar rocks and soil which have been collected and studied). The main difficulties were to respect the stringent scientific requirements of non-contamination of samples.
Generally, two Apollo Lunar Sample Return Containers (ALSRC) were used (Figures 2.3-2.4) which were portable, sealable aluminium containers.

Figure 2.3. Apollo Lunar Sample Return Container (ALSRC). This container served on both the Apollo 12 and 16 missions (NASA photo S72-37196).

The outer envelope of an ALSRC was 48 x 30 x 20 cm, hinges and latches included. The exterior box dimensions were 48 x 27 x 20 cm. The box wall thickness was about 2 mm. Its capacity was about 16000 cm^3.

Figure 2.4. *Left*: Apollo 14 Sample Return Container (rock box) without samples. *Right*: Apollo 16 LSRC upon opening in the Lunar Receiving Laboratory. The box contains a large rock, several documented sample bags with the fold-over aluminium tabs, and a 4-cm diameter drive tube (NASA photo 372-36984).

The ALSRC was an aluminium box with triple seal and came from a single block of 7075 AA aluminium alloy. The lining and padding used was York mesh, a knitted 0.011 inch diameter wire, 2024 aluminium alloy. The soft metal sealing surface was an alloy of 90% indium and 10% silver. The two sealing O-rings were made of L608-6 fluorosilicone (even if much of the previous literature reports the O-rings to have been Viton A). The indium seal protector lid spacer, used prior to final sealing on the moon, were made ofteflon. The three seals on the hinged lids (one of indium (In) and two of Viton) preserved the samples in a vacuum environment during transportation back to the Lunar Receiving Laboratory (LRL) (Warner, 1970). Two ALSRC's were used on each Apollo mission and were produced by Union Carbide, Nuclear Division, Oak Ridge (TN) (Allton, 1989).

2.3 GENESIS

The Sample Return Capsule of NASA/Genesis Mission entered in Earth's atmosphere over a desert in the middle of Utah on September 8th, 2004. Simultaneously, two helicopters were waiting to transfer the Genesis capsule from landing site to TCR close to the landing site (UTTR area).
The capsule crashed into the desert due to the parachute malfunctioning and part of the inner sample capsule was breached (Figure 2.5). The damage was less severe than expected probably because of fall into fairly soft muddy ground.

Figure 2.5. Genesis return and breached images.

Eight hours after the Earth's re-entry the helicopter transported the capsule directly to TCR for inspection where the ground team rolled the cradle hold up by metal support and covered by several aluminium foil (Figure 2.6) andcollected fragments and samples of local desert soil to serve as a reference to identify possible contaminants in the future. The inspecting, cataloguing and packaging processes took four weeks to the Genesis recovery crew. About hundreds to thousands of collector fragments were found in those days.
Because of the NASA's planetary protection categorization of Genesis mission as "safe mission" for unrestricted Earth return (no chance of extraterrestrial contamination during sample collection at the L1 point happened), a transportation box was not used.

Figure 2.6. Genesis capsule being moved into TCR at UTTR

2.4 Stardust

NASA/Stardust SRM was launched on February 7th, 1999 with the aim to collect dust samples from the coma of the Wild 2 comet (distant 150 km from the nucleus) and Interstellar Particles, and return them to Earth for laboratory analysis (Brownlee, 2003).
On January 15th, 2006 the SRC re-entered to the Earth while the descent was monitored using radar and IR camera at the Utah Test and Training Range (UTTR).
The SRC temperature was measured with an IR gun (60°C). First efforts of the recovery team were aimed at minimizing all the possible exposures to contaminants by using double plastic bags (Figure 2.7) for the SRC transportation, a specific cradle as support and a positive pressure N_2 purge on the sample canister once it was returned on TCR (Sandford et al., 2006).
A So_2 gas detector was placed with the capsule between the two bags in order to confirm the SRC transponder battery had not shorted out and it came into no further contact with local soil (Sandford et al., 2010). The entire package was put on a specially designed cradle for the transportation with the helicopter up to the TCR (Figure 2.7). Rigid containers were not used before the SRC dissembling while the heat shield, the back shell and samples had each a designed transportation box fort the transfer from UTTR to JSC.
The plastic bags themselves will successively reveal a source of organic contaminations.
In order to ensure the contaminants identification, soil samples in the vicinity and under the SRC (after it was removed), water and vegetation samples were collected. Soils samples were initially stored in polyethylene bags and later transferred to clean, glass tubes and dried (Sandford et al, 2010). Gas samples were also collected in metal bottles in order to recognize gaseous product coming from the heat shield.

Figure 2.7. *Left*: the SRC transported with a double plastic bags by the recovery team. *Right*: the helicopter used for the transportation from landing site to TCR.

At TCR (in a hunger at the recovery site),the pyros and electronics were removed one hour later the recovery at landing site. After that the Sample Canister was also removed and all three components were sealed in bags and placed into a specially clean designed containers (Figure 2.8).
The Sample Container (SC) was connected to a purge system feeding it with a constant flow of ultra pure gaseous N_2. SC and purge were placed in a handling and shipping container environmental monitored (temperature and N_2 purge flow rates) during the transfer to Huston (Barrow et al., 2007).
Then, the aerogel cells were examined at NASA Curatorial facility in Johnson Space Centre (JSC) in a Class 100 Clean Room where no more than 100 particles larger than 0.5 μmwere present in any given cubic foot of air.

Figure 2.8. *Left*: Container for the Sample Return Canister and associated hardware arriving at Ellington Field near the JSC (JSC2006-E-00880, 17 January 2006). The SC was under nitrogen purge on transfer truck (image credit: NASA). *Right*: the Stardust science team member opening the box containing the Stardust canister (JSC2006-E-00884, 17 January 2006, image credit: NASA).

2.5 Hayabusa 1 & 2

The JAXA/Hayabusa 1 spacecraft launched in May 2003 reached the Itokawa NEO in September 2005 and successfully returned to the Earth after a touchdown.
The re-entry occurred on June 13th, and took place in Woomera Prohibited Area (WPA) of Australia. The SRC was found in the predicted landing site, thanks to the weak winds (Kawaguchi et al., 2010). At landing site, photography documentations and collection of soil samples were performed in order to identify possible contaminants. The packaging of the capsule into a temporary plastic bag and transportation box was performed (Figure 2.9).

Figure 2.9. *Left*: Hayabusa 1 capsule returned. *Right*: the capsule packaging performed by the recovery team into a temporary plastic bag (from JAXA Report for Hayabusa 2, May 2014).

The recovery capsule was transported to the Woomera Headquarters building with TCR facilities where explosive devices, batteriesand contaminants adhering to the capsule were removed. In this phase, the packaging into a specially designed transportation box was performed.
The transportation box has a purge function of pure nitrogen gas a temperature logger attached externally in order to monitor the thermal condition of the re-entry capsule (Yada et al., 2014) (Figure 2.10). On 17 June, the capsule was flown from Woomera's airfield in Australia to Haneda airport in Japan in a direct flight (Abe et al., 2011).

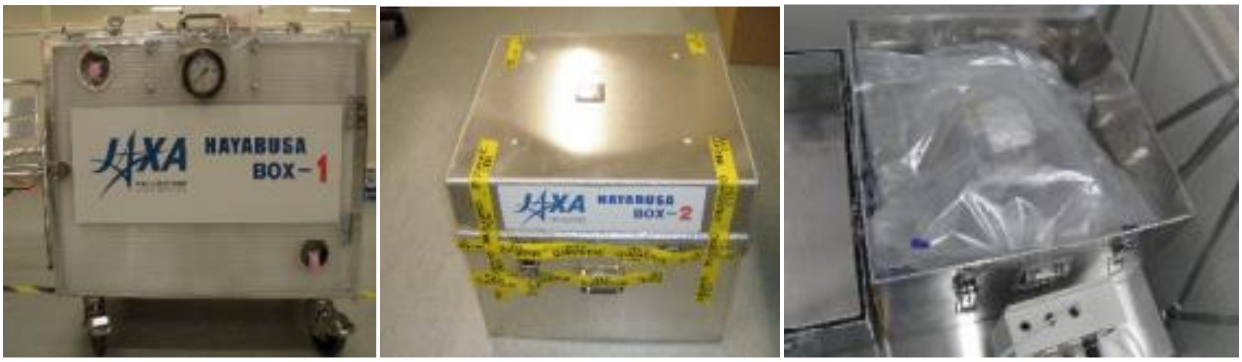


Figure 2.10. *Left and centre*: the two transportation boxes used for the Hayabusa 1 mission. The N_2 entrance and temperature sensor are placed externally. *Right*: the transportation box internal

configuration. The capsule was packaged inside the plastic bag (from JAXA Report for Hayabusa 2, May 2014).

The transportation box was opened at Sagamihara Planetary Sample Curation Facility in JAXA (by cut the sticker added by the quarantine officer of Australia): the re-entry capsule sealed in plastic bag with N_2 was removed and photographically documented (Fujimura et al., 2011). The nitrogen gas in the bag was recovered in a glass cylinder (Yada et al., 2014). After that, the an X-ray CT imaging of the capsule was performed while the thermosensor (below the outer surface of the container's flange) was removed with hand tools (Figure 2.11).

Figure 2.11. First operations performed on transportation box at JAXA Sample Curation Facility.

The landing procedure and Return Capsule of Hayabusa 2 will be similar to Hayabusa 1 including the transportation box design. The mission will returnthe Sample Container with three filled sample catchers to Earth at Woomera Test Range in Australia.

2.6 OSIRIS-Rex

Osiris-REx is a NASA SRM that will characterize the Bennu asteroid. The launch is planned on September 2016 on an Atlas V411 from Cape Canaveral Air Station. Between August-October 2018 the approach and rendezvous phase on Bennu is planned. Following the site selection, a sequence of Touch and Go (TAG) step will be performed for the Sample Collection phase in order to obtain a minimum of 60 grams of bulk regolith and a separate 26 cm^2 of fine-grained surface material (Beshore et al., 2015). On September 2023 the SRC will enter the Earth's atmosphere and will soft the US Air Force UTTR west of Salt Lake City (Figure 2.12).

Stardust heritage procedures will help to transport the SRC (for transportation box also) to Johnson Space Center (JSC), where the samples are removed and delivered to OSIRIS-REx curation facility (ISO5, Class 100, with samples stored and processed in multiple dedicated nitrogen cabinets.). Air samples can be collected at both landing site and staging area to test for SRC outgassing. In addition, relevant soil samples will be collected from the landing site, as well as samples of any other materials the SRC may have come into contact with during landing and recovery.

In particular, the recovery team will have a portable clean enclosure (ISO7, Class 10000) established to receive and safeguard the SRC, and initiate a purge on the sample canister before transport to JSC (Righter, 2013).

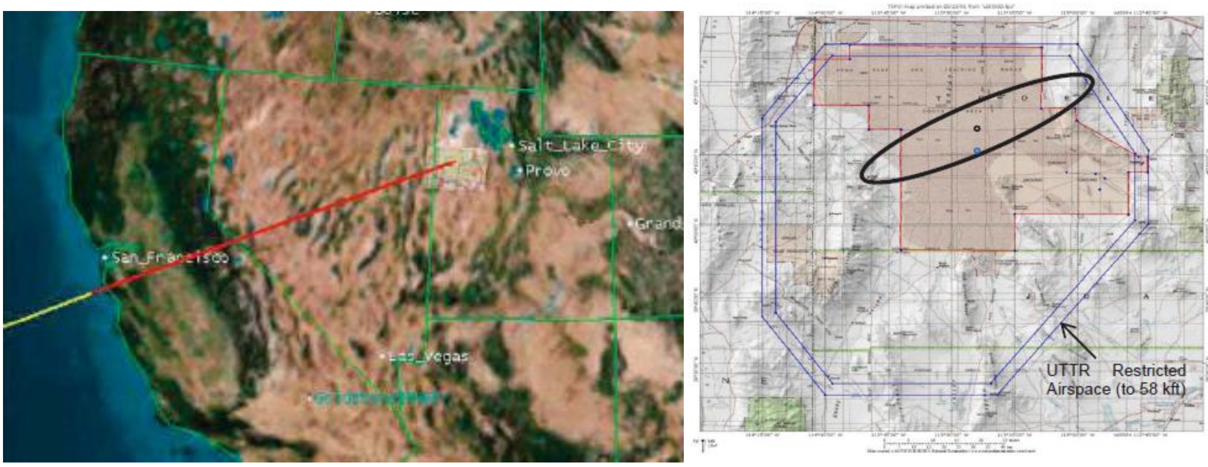


Figure 2.12. Landing site (UTTR Area) for OSIRIS-REx mission sample return.

2.7 Chang'e 5-T1 &Chang'e 5

Chang'e 5-T1 Test Vehicle was designed as a test of the strategy planned for the 2017 CNSA/Chang'e 5 lunar SRM. The aim of the mission was to test a re-entry technology crucial to China's plans of launching a complex lunar sample return mission (Chang'e-5).

After leaving on 24 October, the Chang'E-5-T1 spacecraft travelled around the Moon and then released a capsule which returned to Earth on 31th October. The capsule was recovered in a few minutes by the recovery team which performed the photography documentation (Figure 2.13, left) and packaging into a specially cradle (Figure 2.13, right). The transfer of the capsule was performed by an helicopter and then with aero-cargo to Beijing for study. This test has validated the heat shield technology, trajectory design and recovery procedures for Sample Return Chinese Mission. Chang'e 5 will be launched in 2017 an will collect up to 2 kg beneath the moon's surface and return to the Earth.

Figure 2.13. *Left*: the Chang'E-5-T1 return capsule during its recovery by the ground crews in Inner Mongolia on 31th October. *Right*: the recovery crew during the transportation at Beijing. The cradle is the support under the capsule. Credit: CNSA.

3 Regulatory issues

This section will be focused on the regulatory issues concerning the packaging and transport of extraterrestrial samples, either potentially hazardous or not. The regulations here described are based on the World Health Organization (WHO) directives about the transport of hazardous/infectious samples (WHO, 2012).
We will give in the final sub-section also some general requirements about lifting of SRC, a necessary operation before the transport, based on the NASA Technical Standard, given by the AETD (Applied Engineering and Technology Directorate)

3.1 Packaging

The packaging aims at ensuring that the transported materials:

- Arrive at their destination in good conditions (i.e. their integrity is preserved)
- Present no hazard to people or animals during the transport.

In addition, the packaging must ensure the integrity of the materials and so, in turn, timely and accurate processing of specimens.

The general WHO guideline is the following: "*The packaging shall be of good quality, strong enough to withstand the shocks and loadings normally encountered during transport, including trans-shipment between cargo transport units and between transport units and warehouses as well as any removal from a pallet or overpack for subsequent manual or mechanical handling. Packagings shall be constructed and closed to prevent any loss of contents that might be caused under normal conditions of transport by vibration or by changes in temperature, humidity or pressure*".

3.1.1 Classification of samples to be transported

We report in the following the classification of substances, as defined by WHO standards:

Category A: *An infectious substance which is transported in a form that, when exposure to it occurs, is capable of causing permanent disability, life-threatening or fatal disease in otherwise healthy humans or animals.*
Category B: *An infectious substance which does not meet the criteria for inclusion in Category A*, i.e. is capable to cause "minor" disease

The WHO standard also state that "*if there are doubt as to whether or not a substance meets the criteria it shall be included in Category A"*

According to thesedefinitions:
- Unsterilized Mars and Europa samples should be treated as "Category A" samples, since it is not known if they could contain simple forms of life which could cause disease in humans.
- Sterilized Mars and Europa samples, as well as asteroid and lunar samples should be treated as "not hazardous"

Therefore, the regulatory issues here presented concern the unsterilized Mars and Europa samples, since there is not a dangerous good regulation concerning the transport of not hazardous substances.

The flowchart for the classification of infectious substances and patient specimens, according to the WHO procedure is reported in Figure 3.1.

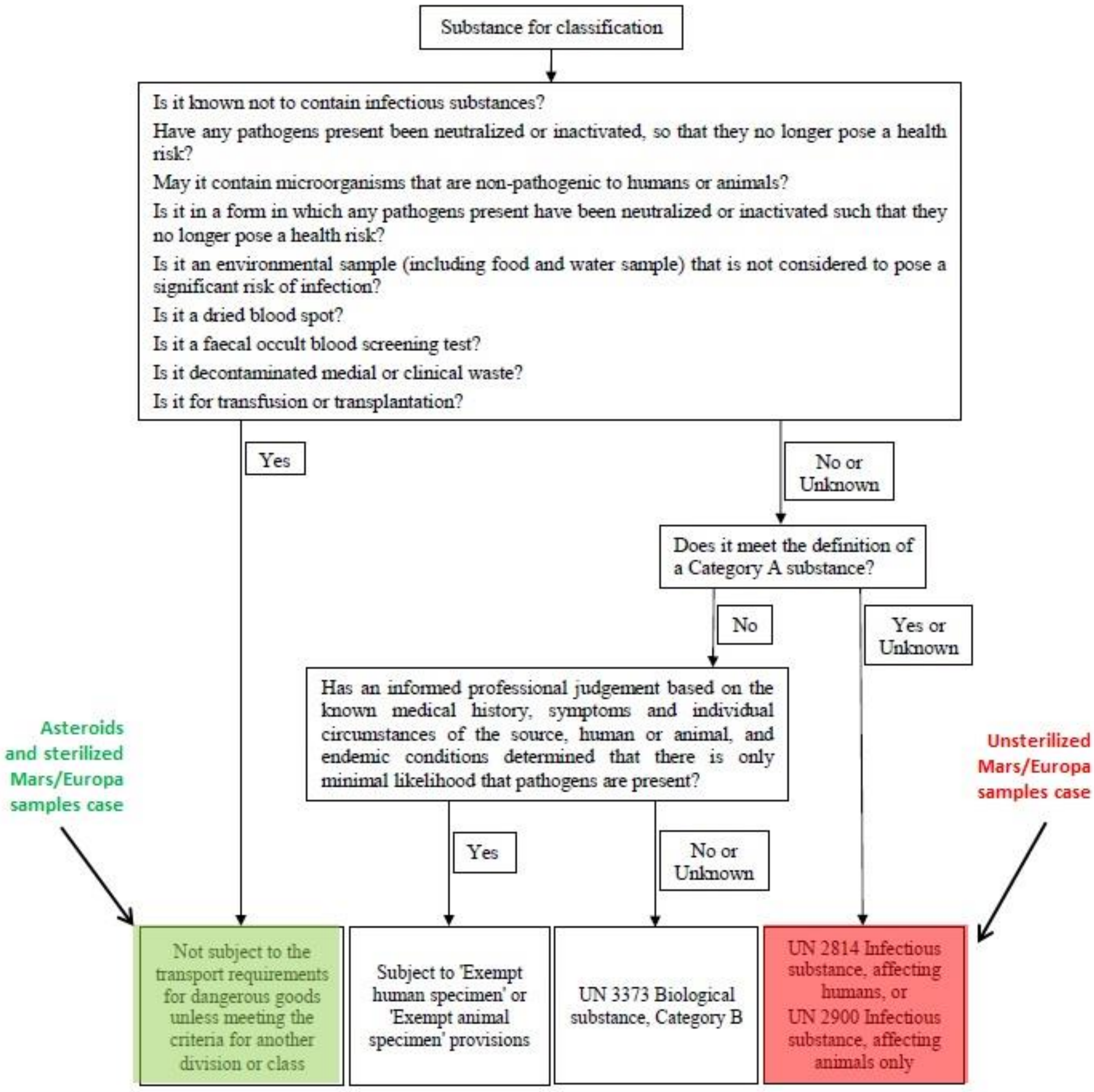


Figure 3.1. Flowchart for the classification of infectious substances and patient specimens, according to the WHO regulations (adapted from WHO, 2012). The case of asteroid, lunar and sterilized Mars and Europa samples is highlighted in green: these samples are classified as not hazardous. The case of unsterilized Mars and Europa samples is highlighted in red. According to WHO rules, these samples should be treated as Category A. This is due to the fact that the answer to the question "*Does it meet the definition of a Category A substance?*" is "*Unknown*".

3.1.2 Packaging of Category A samples

In order to maximize the security of Category A samples, WHO imposes the following rules:

- Hand carriage and transport of these samples is prohibited, even before the packaging procedure
- Inner packaging of hazardous samples must be separated from inner packaging on unrelated types of goods

Therefore, the system of packaging hazardous samples must be based on a **three layers packaging**:

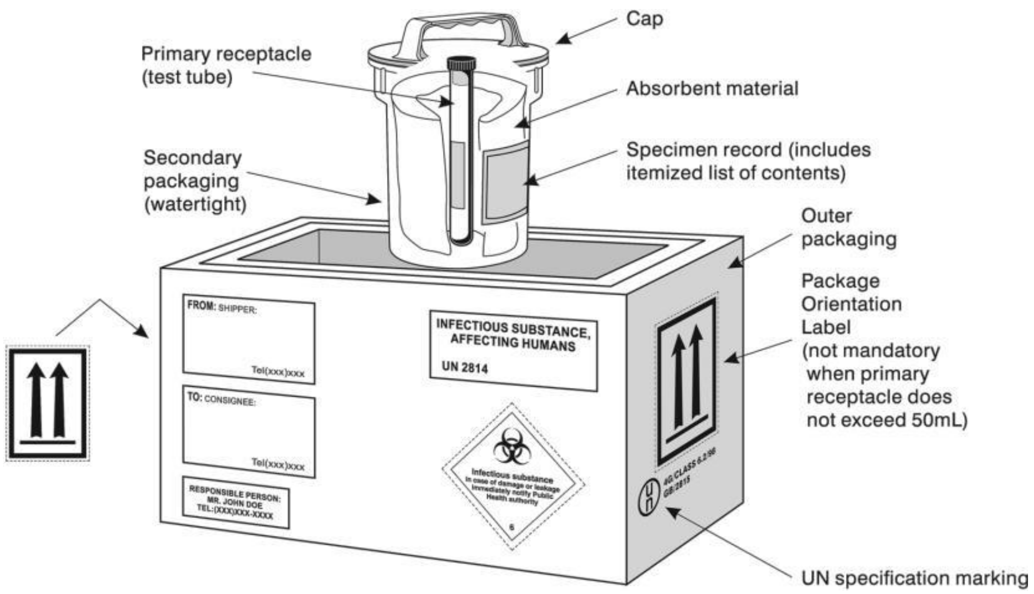
- **Primary receptacle**. It is the inner layer. It must be watertight and leak-proof and contain the samples. Moreover, it should be encapsulated with enough absorbent material, able to absorb all the fluid in case of leakage and/or breakage. If the receptacle has a capacity of more than 50 ml, it shall be oriented in the outer packaging so that the closures are upwards. Additional requirements, concerning receptacle material and type of seal apply in the case of exceptional consignments (e.g. flammable or corrosive substances, animal materials): however, transport of extraterrestrial materials is not included in these cases.
- **Secondary package**. The secondary packaging must be durable, leak-proof and watertight, too. This packaging can also contain more primary receptacles (i.e. one for each suite of samples): in the case this occurs, more absorbent material is needed to absorb the fluid in case of leakage and/or breakage. Moreover, the contact among primary receptacles should be avoided by including enough cushioned material: this is mandatory if primary is made of fragile materials.
- **Outer package**. The most external layer is required to be rigid and sufficiently cushioned. It can consist of a drum, a box or a jerrycan. The role of this package is to avoid outside influence (e.g. physical damage). At least one surface of the outer packaging must have a minimum dimension of 100 mm × 100 mm.

Both primary and secondary packages are required to survive to a differential pressure of 95 kPa and to the temperature range from -55°C to 40°C.
Additional requirements apply if the transported substance has to be kept at low temperature, i.e. should be consigned refrigerated or frozen.

- Ice, dry ice, ice pads or other refrigerants can be applied around the secondary package. Alternatively, a fourth external layer, i.e. the **overpack**, can be used, and the refrigerant applied around the outer package. The latter may consist of an insulated vessel or a flask.
- If ice is used, the overpackand the outer package shall be leakproof.
- If dry ice is used, it must not be placed inside the primary or secondary receptacle because of the risk of explosions.Moreover,the overpack shall permit the release of carbon dioxide gas.
- Other refrigerants (except liquid nitrogen) can be placed in the primary/secondary package, provided that their amount is not larger than 30 ml.

- Interior supports shall be provided to secure secondary packaging in position after the ice or dry ice has dissipated.
- The primary receptacle and the secondary packaging shall maintain their integrity at the temperature of the refrigerant used, especially in the case of liquid nitrogen.

Examples of triple packaging for transport of an infectious substance is shown in Figure 3.2.



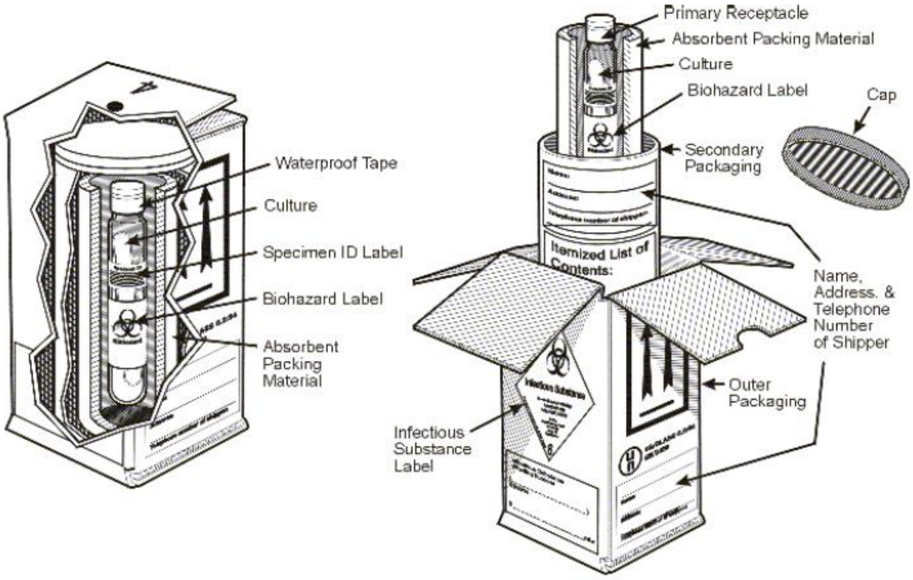


Figure 3.2. Examples of triple packaging for transport of an infectious substance (figure provided by IATA, Montreal, Canada)

All the packages can be reused, provided that disinfection or sterilization is applied in order to remove any hazard and all the not appropriate markings (see subsection 3.1.3) are removed or covered.

3.1.3 Marking and labelling

The secondary package should be labelled with a specimen record, including an itemized list of contents.

The outer package and the possible overpackshould be labelled as follows:

- Sender's name and address
- Contact of a responsible person
- Receiver's name and address
- Nation or institution
- Type of packaging
- Tested for Category A/B
- Two digits of year
- State authorizing marking allocation
- Manufacturer code
- Indication of the sample
- Orientation
- Temperature storage requirements (if any)

- Technical name of refrigerant used (if any)
- The label «In case of damage or leakage immediately notify ... », with related contacts

Concerning the "indication of the sample" field, it should be marked if the sample is:

- Veryhazardous
- Infectious
- Dangerous
- Non-flemmable
- Cryogenic

... and so on.

The marking should consist in a square set at an angle of 45° (diamond-shaped). The minimum dimensions of the markings are 100x100 mm (50x50mm for small packages), the colors should be black and white, whereas the text size is 6 mm. Example of a sample indication marking is shown in Figure 3.3.

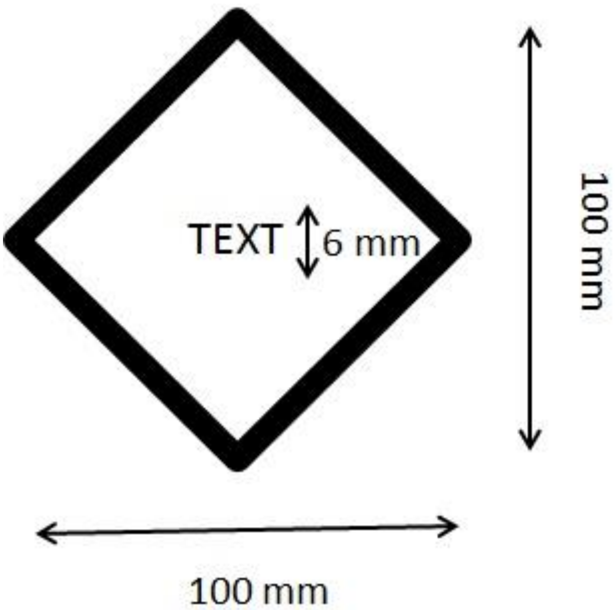


Figure 3.3. Marking for indicating the samples' conditions.

The orientation should be instead marked with a rectangle of 74x105 mm dimensions, containing two arrows indicating the orientation of the package. The marking's color can be black and white or red and white. Examples are shown in Figure 3.4. Two marks for each side of the package should be applied, possibly accompanied with the words "THIS SIDE UP" or "THIS END UP".

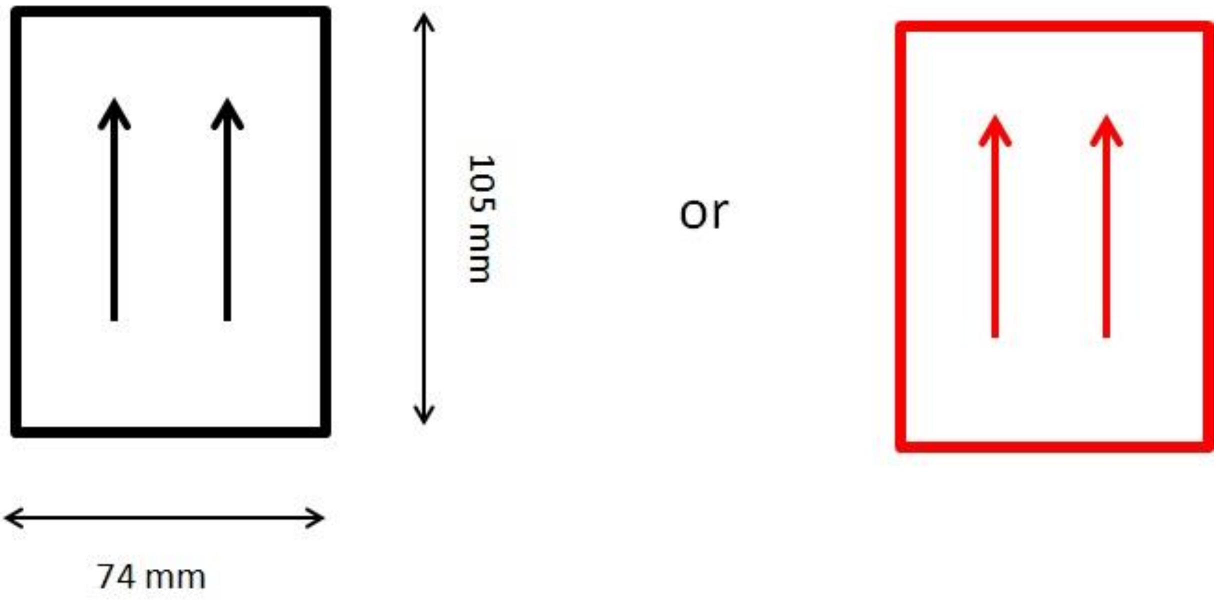


Figure 3.4. Examples of orientation markings. The words "THIS SIDE UP" or "THIS END UP" may also be displayed on the top cover of the package.

In the case of samples packed by using liquid nitrogen, in addition to the primary risk label (Figure 3.3), indicating that the sample is cryogenic, an appropriate label should be adopted. This is a 100x100 mm diamond-shape label (50x50 mm for a small package) of green and white or green and black colors, as shown in Figure 3.5 (left) .
In the case the refrigerant is dry ice, the marking should be instead white with vertical black bars: this is the marking associated to many dangerous substances (Figure 3.5, center). The mark should be accompanied by the words "DRY ICE AS COOLANT" and an indication of the net quantity of dry ice in kilograms.
If other refrigerants are used, a green and white label of minimum dimensions 74x105 mm should be adopted (Figure 3.5, right). This applies even in the case the refrigerant is liquid nitrogen, in addition to liquid nitrogen and primary risk labels.

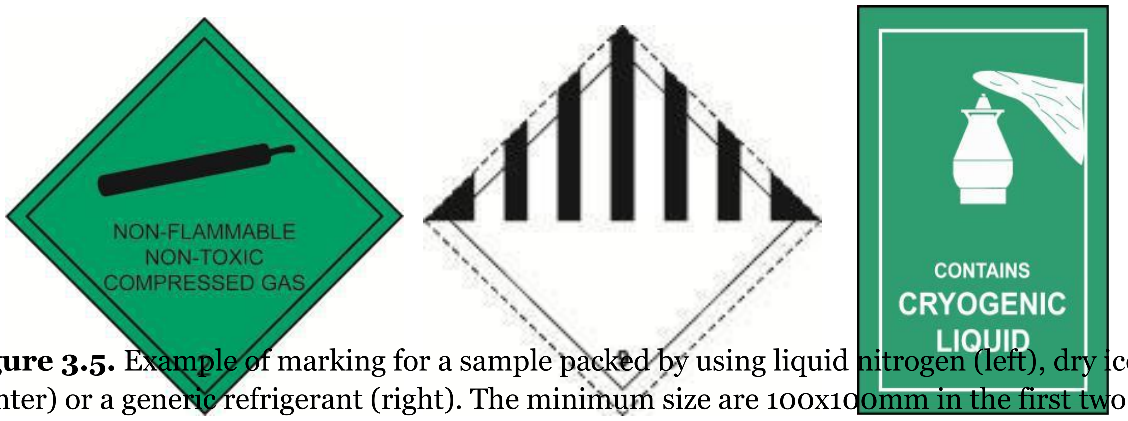


Figure 3.5. Example of marking for a sample packed by using liquid nitrogen (left), dry ice (center) or a generic refrigerant (right). The minimum size are 100x100mm in the first two cases and 74x105 mm in the second case.

3.1.4 Documentation

The documentation related to transported packages include:

- A Declaration for Dangerous Goods (an example is shown in Figure 3.6): this is not required in the case of Category B or not hazardous samples. It must state if dry ice or liquid nitrogen are used as refrigerants.
- A proforma invoice including the receiver's address, the number of packages, detail of contents, weight, value
- The words "SUSPECTED CATEGORY A", if applicable.

Moreover, an itemized list of content should be located between the secondary and the outer package.

3.2 Transport

3.2.1. Sample mass limits

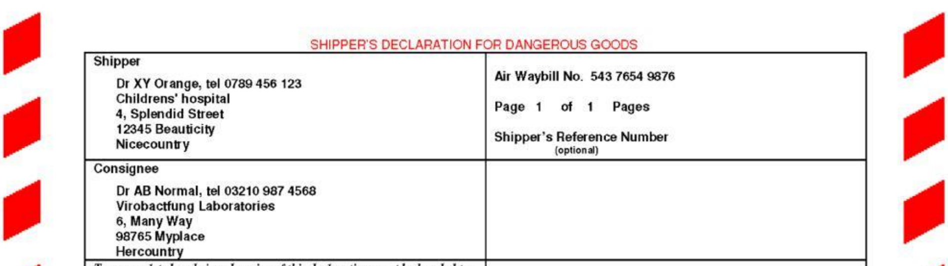
The maximum sample mass allowed by WHO for Category A substance is the following:

- **Ground transport**: no limit
- **Passenger aircraft**: 50 grams
- **Cargo aircraft**: 4 kg

These limits excludes ice, dry ice or liquid nitrogen when used to keep samples cold.
There is no sample mass transport limit for not hazardous substances.

3.2.2. Security issues

According to WHO, no reports of infection occurred by using the described packaging system, except the anthrax letters in USA in 2001.
The cases of primary containers breakage have been 106 on 4.92 millions (0.002% of cases), whereas no events of secondary containers breakage have been verified.


SHIPPER'S DECLARATION FOR DANGEROUS GOODS

Shipper Dr XY Orange, tel 0789 456 123 Childrens' hospital 4, Splendid Street 12345 Beauticity Nicecountry	Air Waybill No. 543 7654 9876 Page 1 of 1 Pages Shipper's Reference Number (optional)
Consignee Dr AB Normal, tel 03210 987 4568 Virobactfung Laboratories 6, Many Way 98765 Myplace Hercountry	

Figure 3.6. Example of a Declaration of Dangerous Goods (from WHO regulations report for transport of infectious substances)

3.3 Lifting

The lifting requirements of the transportation box and the design of Lifting Devices (overhead cranes, mobile cranes, hoists) are beyond the scope of this report.
However, we will give here a summary of the most important guidelines from the NASA Technical Standard about lifting devices, equipment and operations

According to these guidelines, there are two categories of lifting, critical and non critical.

"*Critical lifts are lifts where failure/loss of control could result in loss of life, loss of or damage to flight hardware, or a lift involving special high dollar items, such as spacecraft, one-of-a-kind articles, or major facility components, whose loss would have serious programmatic or institutional impact. Critical lifts also include the lifting of personnel with a crane, lifts where personnel are required to work under a suspended load, and operations with special personnel and equipment safety concerns beyond normal lifting hazards."*

"Noncritical lifts typically involve routine lifting operations and are governed by standard industry rules and practices except as supplemented with unique NASA testing, operations, maintenance, inspection, and personnel licensing requirements contained in this standard."

According to these definitions, lifting of a Sample Return Capsule (SRC) should be classified as ***critical***.
In this case, the following conditions and operations must be verified, according to the NASA Applied Engineering and Technology Directorate Safety Manual:

- *Identification of safety zones*. These should be delimited by appropriate barriers (rope, cones, or other) established prior to lift. Personnel on the crane should be minimized during crane movement. Any personnel on the crane shall be made aware of and avoid pinch points at their respective location.
- *Personnel certified for critical lift*. Only certified and trained operators shall be authorized to use/operate powered hoists and winches except for platform hoists where procedural controls can be provided in a technical operating procedure. Operators certified to perform critical lifts must be trained in the specific hazards and special procedures associated with the lift. Operators must also demonstrate proficiency and operating finesse with the crane/derrick using a test load for the initial certification or alternately be immediately supervised by a certified operator during the first initial lifting period. The licenses will indicate specific cranes/derricks for which the operator is certified.
- *Presence of a Safety Engineer*. They are responsible of design, testing, operations, maintenance, and inspection of lifting devices. They have to approve hazardous procedures.
- *Traceability of equipment*.
- *Stress, lift stability and safety analysis*. Stress analysis shall verify factors of safety for structural slings to a minimum of either three times yield or five times ultimate. These tests must be performed annually. The safety analysis shall, as a minimum, determine potential sources of danger, identify failure modes, and recommend resolutions and a system of risk acceptance for those conditions found in the hardware-facility-environment-human relationship that could cause loss of life, personal injury, and loss of or damage to the mobile aerial platform, facility, or load. The analysis shall be done as part of the initial activation process, included in the equipment documentation, and updated as required to reflect any changes in operation and/or configuration.

Finally, no lifting operations are allowed if winds velocity is above 23 mph (in steady state) or 40 mph, in case of knots.

4 Landing site influence on transportation box design and operations

A landing site of a SRM is required to be isolated and a remote area poorly populated and with limited buildings. For these reasons, military, desert and steppe regions are the best candidate as final landing site. In particular, military areas, e.g. Utah Test and Training Range, give some advantages in terms of signal and visual controlling of the re-entry capsule. On the other hand, these areas are regulated by stringent rules.
This section is aimed at evaluating the influence of different landing sites (with their environment characteristics) ondesign, packaging and transport of transportation box.
Landing sites selected for the future European sample return mission could be:

1. KZ - Kazakh steppe
2. RUS - Siberia area
3. USA – Utah Test and Training range (UTTR)
4. USA – White Sands Area (WSA)
5. USA – Wallops
6. AUS – Woomera Prohibited Area (WPA)
7. SWE – Vidsel Test Range (VTR)
8. MNG - Siziwang Banner Area

These would be the conditions for landing in an ideal scenario (D6.1):

A. the sample would be landed in a dry area
B. the internal temperature of the sample would be below the water freezing point
C. the sample must not be contaminated by dust
D. in non-nominal scenario, areas subjected to heavy rain and muggy ground should be avoided

In Table 4.1 are listed the possible landing site areas with their environmental characteristics and criticalities for the recovery and transportation box design.

Region/Area	Average temperature range (°C)	Dust/ snow storm	Average precipitation/ month (mm)	Biological contamination	UXO	Population
Kazakh steppe	-18 to 26	Yes	18-41	No	No	No
Siberia	-25 to 17	Yes	14-72	No	No	3/km²
Utah Test and Training Range	-3 to 32	Rare	0.5-80	Yes	Yes	No
White Sands	-6 to 36	Yes	21-97	Yes	Yes	No

Wallops	-2 to 27	Rare	73-106	--	No	--
Woomera Prohibited Area	6 to 35	No	13-20	--	Yes	No
Vidsel Test Range	-18 to 22	Rare	14-58	No	Yes	No
Siziwang Banner	-15 to 20	Yes	5-60	--	No	<3/km²

Table 4.1. Environmental characteristics of possible landing sites.

In order to select at best the landing site, the information listed in Table 4.1 should be considered together with the trade-off analysis performed in D6.1, based on security and site history issues (Table 4.2). In this report we only consider the possible influence of each landing site on the box design.

Provision	WSMR	UTTR	Wallops	WRC	Kaz	Esrange
Nationality	US	US	US	Common Wealth	Kazakhstan	EU
Visas required	YES	YES	YES	YES	YES (easy)	NO
Active Landing	YES	YES	YES	YES	YES	YES
Passive Landing	Probably	Probably	Probably	YES	YES	Probably
Direct liaison	NO	NO	YES	YES	Unknown	YES
Military	YES	YES	NO	YES	YES	YES
Security	YES	YES	YES	YES	Limited	YES
Radar	YES	YES	NO	YES	Unknown	YES
Beacon tracking	Unknown	Unknown	Unknown	YES	Unknown	YES
Access	Good	Good	Good	Good	Limited	Good
Nuclear history	NO	YES	NO	YES	NO	NO
Chemical history	NO	YES	NO	YES	YES	NO

Table 4.2. Landing site trade-off analysis performed in D6.1. WSMR=White Sands; WRC=Woomera; Kaz=Kazakh Steppe; Esrange=Sweden. The "traffic light" indicator is used to show advantages and disadvantages of each site, i.e. red=disadvantage, yellow=unknown or indifferent; green=advantage.

4.1 Kazakh steppe (Karaganda area)

Karaganda Area is a territory flat steppe located in Kazakhstan in central Asia. It has a humid continental climate with warm summer and very cold winters. The average temperature goes from -18 to 26°C with lowest and highest records of -43°C and +40 in 2002. Different landing sites are possible as: Baikonur, Astana, Karaganda and Arkalik (Figure 4.1). From Karaganda all landing zones are reachable inside of hours.

The advantages for the recovery and capsule transportation phases are:

1. Karaganda is a semi-arid region with a continental climate: the average temperatures in July range from 20 to 26°C, and -12 to -18°C in January
2. it is a vast region with low population and few buildings
3. the plains can also make the recovery and transport easier. The steppes are a wide flat expanse suitable for unguided landings
4. a clear path for radio signals between the launch site and vehicle
5. good room for manoeuvre for the operations in situ with the possibility to use MI-8 helicopters.

On the other hand, the disadvantages are:

1. possible dust contamination during the landing due to the light composition of the soil
2. very high winds sweep across the plains (not critical for lifting)
3. sandy terrain

At winter season, the lower temperature could be critical for transportation box while the dust contamination should be avoided and limited during the recovery phase (Figure 4.1).

Figure 4.1. A dust cloud raised during a capsule landing in Karaganda area (NASA Webpage: https://www.nasa.gov/mission_pages/station/structure/elements/soyuz/landing.html).

4.2 Siberia area

Siberia area is an extensive geographical region in North Asia extending from Ural Mountains to Pacific Ocean. Siberia region has been used several times by Russian Space Agency as landing site for capsule re-entry, specially for Luna sample return missions (e.g., Luna 24 landed on 22 August 1976, about 200 km southeast the Surgut city in western Siberia) (Wesley and Mikhail, 2011). Generally the climate varies dramatically and it is characterised by short summer and long winters.

Most of population lives in the south of Siberia where the climate is continental humid. The average temperature in January is -20°C and +20°C in July. The abundance of sunshine and different kind of soil (steppe, taiga, permafrost) and mild temperature (summer season) in Siberia, make it reliable as possible landing site. In particular, the Western Siberia is characterized by gray

soils forest steppe belt and river (Novosibirsk region) while the central taiga characterized the subzones of the Transbaikal region. North is tundra soils and south is sod soils. The Eastern Siberia can be excluded as landing site due to the lowest temperature (-70°C) characterized by peat and marshy surface due to suppression of microflora.
In the latter case, the transportation box should be designed with an internal heating to maintain the sample at "room temperature" (see Doc.WP6.1 Preparation for recovery).
The precipitation in Siberia is generally low, exceeding 500 mm only in Kamchatka and in Primorve, in the extreme south where monsoonal influences can produce quite heavy summer rainfall (bad conditions for recovery phase and sample transportation).

4.3 Utah Test and Training Range area

Utah Test and Training Range (UTTR) is a military testing and training area located in Utah's West Desert. This area has been used as landing site for Genesis and Stardust mission and the upcoming OSIRIS-REx mission (Kirk et al, 2007). UTTR could provide many advantages as:

1. it is easier to localize the landing position of the SRC thanks to the airspace above much controlled
2. free of visual obstacles (vegetation, buildings, etc.)
3. no additional security measures are necessary for a recovery on a military installation
4. UTTR personnel are familiar with helicopter operations
5. numerous facilities and resources are available to assist with the recovery, including suitable
6. buildings for the temporary clean room, off road vehicles, etc.
7. semiarid state

Being a military and desert area, UTTR shows many disadvantages (Fellows et al., 2006):

1. a lot of unexploded ordinance (UXO) (Figure 4.2, *Left*)
2. a lot of local depression containing pools of water and huge areas of mud
3. high temperature excursion day/night in summer
4. inflexible military rules (the mission operations are not a top priority task for the site). Non-US nationals have very restricted access to the facility.
5. contaminated areas by biological warfare chemicals that are off limits forever (it is impossible to recover the capsule in these contaminated areas) (Figure 4.2, *Right*)
6. difficulties to bring along the cameras and helicopters

Precipitation is usually short and generates small quantities of water in the arid environment while intense thunderstorms can occur. Annual precipitation over the UTTR-North is about 150 mm (Doelling et al., 1980) whereas larger storms can cause local ponding in surface depressions (for only a few days due to the high evaporation rates).
Temperatures vary widely annually and diurnally while the averages range monthly goes from -3°C in January to 26°C in July. Midsummer daytime temperatures generally reach 32°C and midwinter overnight temperatures are generally below freezing (National Oceanographic and Atmospheric

Administration, NOAA, 1993). Average relative humidity is 35% in the summer and 65% in the winter. Early morning fog and haze is common in the winter.

The UTTR area should not affect the transportation box design due to the stable temperature during the day. Probably, the recovery procedure must be well determined at this landing site.

Figure 4.2. *Left*: UXO at UTTR. *Right*: contaminated area in Utah desert

4.4 White Sand Area (USA)

White Sands Area (WSA) is a New Mexico region (USA) located at 25 km southwest of Alamogordo at an elevation of 1291 meters. This region is 710 km² and comprises sand dunes of gypsum crystals, a relatively rare dune-forming mineral.
The White Sands Test Facility (WSTF) us a U.S. government rocket engine test facility for space flight materials and rocket propulsion system (Skarsgard et al., 2002), managed by Lyndon B. Johnson Space Center (NASA).
The WSA shows a groundwater contamination (Newton and Allen, 2014; Strepo et al. 2001) due to historical operations using propellants and industrial solvents. The contaminants include N-nitrosodimethylamine (NDMA), N- nitrodimethylamine (DMN), and several volatile organic compounds as perchloroethene (PCE), trichloroethene (TCE), and Freons. WSA is subjected also to strong winds which are able to move the dust particles from the valley floor to more than 1200 meters over the mountains (Figure 4.3, *Left*). UXO can be present due to the military rocket tests (Figure 4.3, *Right*) (http://www.wsmr.army.mil/ux/Pages/default.aspx).

Figure 4.3. *Left*: dust plumes in White Sands Area. The picture stretch more than 120 km. *Right*: UXO advertisement.

4.5 Wallops Islands (USA)

Wallops Flight Facility (WFF) is located in the Eastern Shore of Virginia (USA) and is the NASA's principal facility for suborbital and small orbital research missions. It is provided by rocket launch site to support science and exploration missions for NASA and other agency and it is equipped with fixed location instrumentation assets with radar, telemetry receivers and command transmitters (NASA Report by URS Group Inc., 2010).
The climate exhibits a substantial annual variation but a fairly uniform precipitation rate. The precipitation is distributed around 1100 mm per year with the highest rate occurring during the summer. The annual mean temperature vary considerably (from 4°C of January up to 32°C in June). Snow is relatively rare while the wind are comprised between 4-6 m/s. Occasionally, hurricane can pass along this area, accompanied by extremely heavy precipitation (http://www.climate-charts.com/USA-Stations/VA/VA893739.php).

4.6 Woomera Area (AUS)

The Woomera Prohibited Area (WPA) in Australia is regulated by the Defense Act 1903, Defense Force Regulations 1952 and the WPA Rule 2014 (http://www.defence.gov.au/woomera/about.htm).
It is a desert isolated area with sparsely population with high summer and cool winter temperatures. Rainfall is rare while the climate is generally warm and dry. The area's stable climatic conditions virtually assure the ability to conduct ground and recovery operations (Strom, 2005).
WPA is able to offer many advantages as:

1. stableweatherconditions
2. low population density
3. ability of the range to enforce strict security and limit over flights during launch and test activities

whereas the disadvantages and risks are:

1. rainfall (infrequently)
2. dust contamination
3. temperature-humidity high variations
4. high wind for capsule re-entry (could be critical)
5. unexploded ordnance (UXO) associated to WPA testing activities
6. bad conditions of roads and tracks (unmaintained, sandy, corrugated) after rain events

Because of the WPA environment, a recovery procedure should take into account:

1. the removal of contaminants adhering to the capsule.
2. the cleaning before enclosure (and draining if landing in water) into transportation box and execution of the gas purge during transportation.
3. the contamination sensors could be put into the transportation box in order to monitor the contamination with terrestrial materials.
4. the acquisition of scientific documentary photography, collection of the circumference rocks/soil samples to compare them in case of contaminations.

Considering the environmental characteristics, the transportation box design will be not affected by WPA area conditions.

4.7 Visdel Region (SWE)

Vidsel Test Range (VTR) is a Swedish strategic national test Area managed by the Swedish Defence Material Administration (FMV) and situated about 900 km north of Stockholm. It is located in the north of Sweden, in a region with extremely low population and little air-traffic and with a restricted airspace (7.200 km^2 in size).

The installation includes a military base, a runway and is always used as a Swedish and European missile test site (UXO can be present).

The climate is generally cold: the average temperature are below 0°C in January and snowfallsare common. Snow covers the ground nearby all the year from October while the most of country is ice-bounded in winter.

VTR shows many advantages as:

1. a controlled recovery procedure by military team
2. few restrictions from other air or ground activities
3. undisturbed testing of sensor systems
4. the test facilities are secure and well-suited for testing a possible re-entry capsule

The disadvantages are:

1. snowfalls
2. low temperatures

Excluding the low temperatures, the transportation box design should not significantly change.

4.8 Siziwang Banner (MNG-CHN)

Siziwang Banner, China's Inner Mongolia Autonomous Region is located about 80 km north of the capital of Inner Mongolia. Siziwang Banner area is a semi-arid desert steppe with an elevation averages 1400 m.

The climate is windy in spring, with low precipitation in summer, and dry and cold throughout winter (Nadin et al., 2015). The annual average temperature, precipitation and evaporation are 4.1 °C, 305 mm and 2213 mm, respectively (Li et al., 2014). The main vegetation type is desert steppe with the dominant plant species of the study area are short flower. Winds are strongest and dust storms are frequent. In particular, dust storms have been more frequent during the last years (Kemp et al., 2013).

For Chinese space program, a special road has been constructed from Wulanhua to Honggor to support the recovery of the Shenzhou spacecraft at pasture land called Amugulang. This allows the Chinese recovery team to track the progress of re-entry near the landing site and to quickly reach thesite (about 40 min from facility base).

A small recovery truck with a crane will lift the capsule and place on the rear to transport it back to the space centre (no transportation box won't be used).

Considering the desert-steppe region and environmental characteristics, the transportation box design has not particular requirements.

4.9 Conclusions

Different landing sites have been screened and their environment characteristics have been evaluated in order to assess the impact on transportation box design. In particular, the desert and steppe regions are the better candidate due to stable climate and weather conditions. Otherwise, the landing sites subjected to dust storm and strong wind should be avoided in order to make easier the recovery procedure.

Thus, for a transportation box design we need to take into account:

1. the temperature of the sample/external environment
2. humid environment/water contamination (heating system on transportation box)
3. dust storm and strong winds (samples contamination)

Samples, e.g. rock core, regolith, ice and gas, will be subjected to extreme temperatures range during the re-entry and landing phases in a desert, i.e. Utah, Woomera, or in a cold area, i.e. Vidsel Test Area. A best procedure would maintain the sample at constant room temperature (i.e. the curation facility temperature).

Generally, this procedure is easy, but for a cold sample, a cold storage maybe required and a dedicated transportation box might be evaluated.

In case of humid condition and water condensation on the plastic bag and transportation box walls, a separated heating system (some resistances managed externally) should be installed on internal walls of transportation box. However, this case will be not considered in the following sections.

5 General requirements of transportation box

Past and future Sample Return Mission (SRM) need to satisfy planetary protection of returned samples, respecting the biohazard rules, i.e.contamination minimization and assessment.
This can be done by means of a design of a special transportation box, used at landing site to package the Sample Return Capsule (SRC) and to transfer it to curation facilities.
As a general rule, the contaminants (in particular the organic ones) should be recognized when possible and their amount should be minimized. For these reasons it is important to characterize the nature of potential contaminants in order to preserve the scientific integrity of rock/dust samples.
"Witness coupons" can be used to track the introduction of contaminates during the manufacture, flight, and recovery of the spacecraft, and during the subsequent removal of the samples from the capsule (Sanford, 2011).
In order to guarantee a perfect contamination-free environment and reduce the contamination risks, an appropriate transportation box design has to be considered. The transportation box should be:

- reliable to transport the sample up to a quarantine facility
- consistent with regulatory requirements for safe transport of potentially hazardous materials
- approved by pre-arranged permits to ensure a rapid and uncomplicated transfer activity
- provided of different rock/dust sample sections/cabinets.

Furthermore, the container should undergo a decontamination processes due to deposition of terrestrial organisms on the external box surfaces or inside (Cohen, 2003).

5.1 Handling

The procedures of recovery and handling are described in D6.2. Here we summarizes the two suggested procedures for unrestricted and restricted missions, respectively.
The flow diagram for unrestricted missions is shown in Figure 5.1. The operations in this case include preliminary inspection of the landing site and of the SRC just after the landing, SRC packaging and transport. The packaging operation may be also performed in situ, in a temporary clean room specifically placed near the landing site. Pros and cons of using a temporary clean room are discussed in D6.2.
The flow diagram for restricted missions is shown in Figure 5.2. The inspection and recovery procedure in this case include additional operations, such as a more detailed inspection of the landing site (both from remote and in situ), collection of soil/plants from the landing site, a more accurate SRC cleaning. Moreover, in case of non-nominal scenario, a tent should be placed over the landing site in order to excavate soil and then either sterilize it in situ or transport it for future sterilization or secure storage.

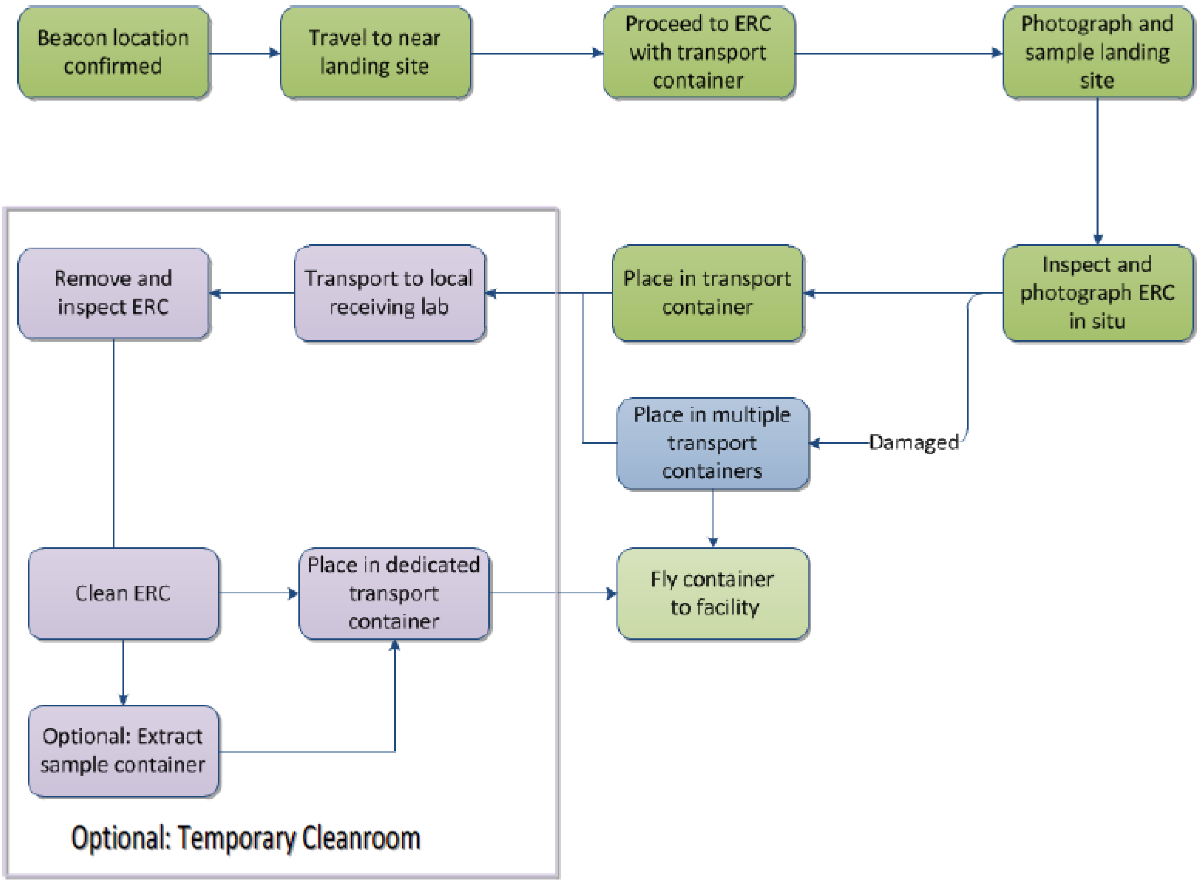


Figure 5.1. Functional flow for recovery and initial operations in an unrestricted mission scenario (from EURO-CARES D6.2). The operations in the purple box takes into account the possibility to use a temporary clean room, placed near the landing site. The "blue" operation should be performed in non-nominal scenario.

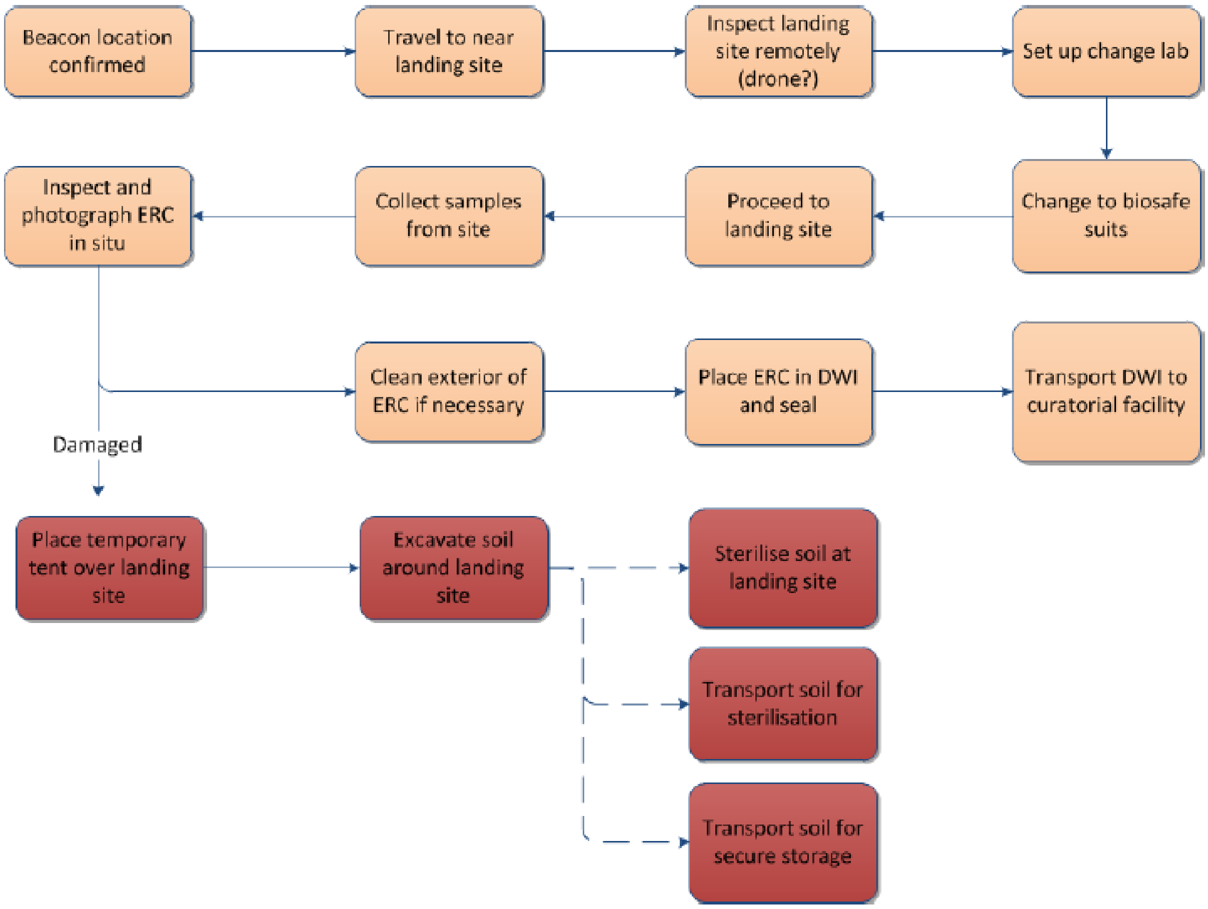


Figure 5.2. Functional flow for recovery and initial procedures in a restricted mission scenario (from EURO-CARES D6.2). The "magenta" operations refer to a non-nominal scenario.

5.2 Packaging

5.2.1 Primary receptacle

In the case of the triple packaging proposed by WHO and adopted in this report (see Section 6), the primary receptacle is the most internal container, in contact with the sample. According to this definition, the primary receptacle would coincide with the sample canister (SC) inside the SRC (Figure 5.3). However, we consider the entire SRC as primary receptacle, in order to be more conservative and to take into account the possibility of non-nominal scenario, and because it is generally not planned to extract the SC from SRC. Therefore, the SRC is considered in this report as a "unique" layer, but in fact shows one or two internal layers, i.e. the biocontainer (only for restricted missions) and the sample container (including directly the returned planetary samples), see Figure 5.3.
The design of SRC depends on the mission scenario and is beyond the scopes of this WP.

The primary receptacle coincides with SRC even if it is damaged. The triple packaging is indeed thought in order to prevent contamination (from samples and to samples) even in the case the primary receptacle has failures.

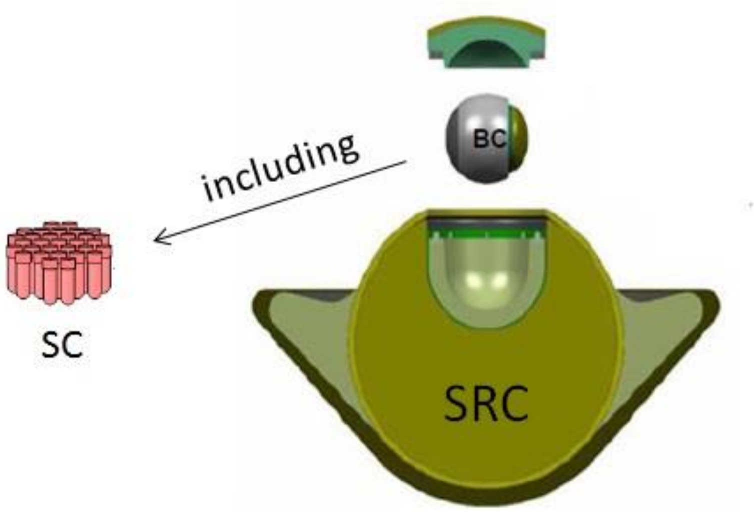


Figure 5.3. Primary receptacle. The Sample Container (SC) is included in the Biocontainer (BC), in turn included in the Sample Return Capsule (SRC), which coincides with the primary receptacle of the proposed package.

5.2.2 Absorbent material

According to WHO guidelines, absorbent material should be located between the primary receptacle and the secondary packaging, in order to absorb possible fluids transported in the primary receptacle in the case the latter has breakage or leak. This minimizes the probability that a possibly hazardous fluid comes out the secondary package.
The occurrence of absorbent material should be taken into account in transportation boxes for restricted missions, the only one returning possibly hazardous samples, since in returned Martian (or Europan) samples some compounds may pass from solid to liquid phases due to capsule heating e.g. during the atmosphere descent.
Polypropylene is the absorbent material most commonly used for many applications (e.g. mats, poly drums, spill containment), and shows many advantages that make it suitable even for a transportation box, i.e.:

- it shows one of the lowest density (about 0.9 g/cm^3) among the polymers, and hence has a lower influence on the total mass of the box;
- it has a high melting point (about 170°C) and hence has a minimal probability to contaminate the samples. In the (unlikely) case the internal layers of the box reach these high temperatures, anti-oxidants may be added to polypropylene in order to prevent its

degradation: this process is common in current industrial applications and hence is not critical.

Polypropylene shows instead some weaknesses:

- it becomes brittle below -20°C (its glass transition temperature) and hence can become a source of contamination
- it can be degraded by the presence of microbial communities (Cacciari et al. 1993).

The former issue occurs if the landing site temperature is lower than -20°C or if the transportation box needs to be cooled at that temperature. Among the landing sites considered, Siberia area is the only one which may reach these low temperature (Table 4.1), and hence this issue is not critical for any other landing sites among those proposed.As described in next session, transportation box cooling has never been required for restricted missions. Only lunar samples may be required to be cooled, but these are unrestricted samples and hence do not require absorbent material.

Degradation due to microbes takes at least 40 days to occur (Cacciari et al. 1993) and hence should not be critical, since the time needed to transport the box from landing site to curation facility is by far lower.

5.2.3 Secondary package

The secondary package consists of a plastic bag. According to WHO requirements, plastic material should have a good mechanical resistance and a low permeability. In addition, a low outgassing rate is a fundamental property, since it allows minimizing the risk of contamination of samples.

Outgassing rates of several polymers are shown in Table 5.1 (from Peacock et al. 1980).

Polymer	Unbaked, 1 h pumping
Fluoroelastomer	4×10^{-7}–2×10^{-5}
Buna-N	2×10^{-7}–3×10^{-6}
Neoprene	5×10^{-5}–3×10^{-4}
Butyl	2×10^{-6}–1×10^{-5}
Polyurethane	5×10^{-7}
Silicone	3×10^{-6}–2×10^{-5}
Perfluoroelastomer	3×10^{-9}
Teflon	2×10^{-8}–4×10^{-6}
KEL-F	4×10^{-8}
Polyimide	8×10^{-7}

Table 5.1. Outgassing rate (inTorr/s) of different polymers (from Peacock 1980).

The polymers with the lowest outgassing rate are Polyurethane (or Adiprene, polyether or polyester di-isocyanate copolymer), Teflon (tetrafluoroethylene polymer), KEL-F (or Neoflon, chlorotrifluoroethylene copolymer) and Perfluoroelastometer (or Kalrez, tetrafluoroethylene-

perfluoromethylvinyl ether copolymer). These outgassing rates can be even diminished of one-two orders of magnitudes by applying a baking pre-treatment on the polymer, e.g. 16-hours baking at 100°C or 4-hours baking at 200°C (Peacock 1980).
The following trade-off is therefore performed on these four materials and is based on:

- wear/abrasion resistance
- water permeability (water resistance is a needed property)
- nitrogen permeability (since the outer can be filled with nitrogen, a low nitrogen permeability is required in order to keep secondary as separated as possible from outer)
- CO2 permeability (since CO2 might be released from Martian samples and hence might contaminate the internal environment)
- linear coefficient of thermal expansion (it should be low in order to minimize the risk of permeability increase due to thermal expansion)
- maximum operating temperature (it should be outside the range of working temperature of the box)
- cost

Table 5.2. summarizes these properties of the four polymers.

	Polyurethane	**Teflon**	**Neoflon**	**Kalrez**
Density (g/cm^3)	1.2	2.2	2.1	2.0
Wear/abrasion resistance	Excellent	Excellent	Very Good	Excellent
Water permeability (10^8scmm s^{-1} cm^{-2} cm atm^{-1})	260-9500	27	0.5	40
Nitrogen permeability (10^8scmm $s^{-1}$$cm^{-2}$ cm atm^{-1})	0.4-0.11	0.14	0.004-0.03	0.05-0.3
CO_2 permeability (10^8scmm s^{-1} cm^{-2} cm atm^{-1})	10-30	0.12	0.02-1	5.8-6.0
Linear coefficient of thermal expansion (10^5 °C^{-1})	3-15	5-8	4-7	23
Maximum operating temperature (°C)	90	280	200	275
Cost (€/kg)	0.3-0.4	5-20	20-60	3000-5000

Table 5.2. Properties of Polyurethane, Teflon, Neoflon and Kalrez (Peacok 1980). Peacock (1980) does not indicate the permeation data of Kalrez and the reported values are relative to Viton (having similar permeation properties). The water permeability of Neoflon is obtained from Bahada (2009). Costs have been obtained by a market analysis.

Polyurethane is not suitable for our scopes due to its high water permeability and low maximum operating temperature. Karlez has overall good mechanical and thermal properties, but its cost is too high with respect to other polymers.
Teflon and Neoflon (KEL-F) are the best trade-off. Linear coefficient of thermal expansion and density are similar for the two materials and the maximum operating temperature is not critical in none of the two cases. Neoflon has a lower permeability to water, nitrogen and CO2, but also a

lower resistance to abrasion and is at least three times more expensive. The selection of the materials will therefore depend on the mission scenario.
If insulation of samples is the most important issue (this can be the case of restricted missions), Neoflon would be more indicated. If the SRC mass is large (i.e. >50 kg), the mechanical resistance of the secondary package may play a more important role, and hence Teflon would be preferred. However, if no particular requirements are needed (e.g. unrestricted mission, low-mass SRC), Teflon would be the best choice, in order to minimize the total cost.

5.2.4 Cushioned material

No particular requirements are needed for the cushioning materials, except a good mechanical resistance. Polymers commonly used for cushioning (e.g. polyurethane, polypropylene) hold these property, as well as a low outgassing rate.
Design and testing of cushioning should take into account the current ASTM standards (i.e. D1596, D3332, D4168, D6198, D6537), in order to verify their capability to protect for shocks.

5.2.5 Outer package

The fundamental properties of the material selected for the outer package should be:

- A high rigidity and resistance to breakage (in order to withstand to shocks/collisions experienced during the transport to curation facility)
- A low outgassing rate, in order to minimize the risk of contamination inside the box.

The first property is peculiar of metallic alloys (stainless steel, aluminium, magnesium, titanium, zink and copper alloys) as well as of carbon fiber and other carbon compounds (e.g. SiC, TiC). However, the latter show an outgassing rate of 10^{-6}torr l s^{-1} cm^{-2} (e.g. Craig Jr 1980), whereas the outgassing rate of metallic alloys (except zink alloys) is from one to three orders of magnitude lower (Table 5.3).
Therefore, our trade-off analysis will be based on metallic alloys, only. Other parameters to be considered are:

- Thermal conductivity, since a low thermal conductivity guarantees a better thermal insulation of returned samples, which could be a mission requirement;
- Density, related to the overall mass of the box
- Cost

A summary is given in Table 5.3.

Alloy	**Young Module (GPa)**	**Outgassing rate (10^{-6}torr l s^{-1} cm^{-2})**	**Density (g/cm^3)**	**Thermal conductivity (W/m K)**	**Cost (€/kg)**
Stainless steel	195-215	0.05	8	16-24	1.3-1.5
Aluminium	70-80	0.6	3	230	1.5-1.7
Magnesium	40-45	1	1.7	120	1.6-1.8
Titanium	85-130	0.1-0.3	4.5	6	10-12

Copper	120-150	0.7	9	400	4-4.5

Table 5.3. Physical properties, thermal properties and costs of metal alloys (Patrick 1973; Edelmann 1992; Koyatzu et al. 1996; Hattel 2014; Moshey 1982)

Stainless steel is by far the lowest outgassing material, since its outgassing rate is at least one order of magnitude lower with respect to other alloys. Moreover, it has a low thermal conductivity and is the cheapest material. It is also among the materials easiest to clean. The only weakness is its high density, and this may be an issue for packaging of large SRC, especially in the case the transportation box requires an additional layer (the overpack, see subsection 5.2.7).
If the overall transportation box mass is much larger than required, the best option might be to use titanium alloy instead of stainless steel, allowing almost to halve the outer mass. The main issue of titanium concerns its high cost, at least seven times the steel's cost, making titanium an improbable alternative. Therefore, the best option would be aluminum alloy. The major weakness of the latter is its high thermal conductivity, but this could be not critical if no temperature storage requirements are given on returned samples. In fact aluminum has been used for Apollo, Hayabusa (together with steel) and Stardust missions (sub-section 2.2). Hence aluminum could represent a good, alternative outer material, provided that the influence of its outgassing rate (ten times that of steel and two times that of titanium) on samples contamination should be evaluated, especially for non-nominal scenario.

5.2.6 Purge gas

The outer has to be filled with an inert atmosphere, in order to inhibit oxidation and hydrolysis of minerals within the sample. The internal pressure can range from 0.1 mbar to 1 bar, depending on requirements on the sample storage.
In previous sample return missions, transportation boxes were filled by N_2. However, Argon is mainly used for sample storage in laboratory, because is more inert and has a lower heat conductivity: the latter minimizes the possibility of heat exchange inside the container and hence guarantees a uniform heat distribution and a lower probability to change the samples temperature.
Table 5.4 summarizes reactivity (with elements which may occur inside a transportation box), thermal conductivity and costs of both gases. Rules for transporting are not reported since are the same for the two gases, and hence are not an argument for selection.

	Nitrogen	**Argon**
Reactivity	Reaction with steel above 400°C Reaction with Al in presence of O_2 traces for T > 500°C Reaction with Ti at 1200°C	None
Thermal conductivity (W/m K)	0.026	0.016
Average cost (c€/10l)	7	15

Table 5.4. Chemical and thermal properties, and costs, of nitrogen and argon. Reference for nitrogen reactivity information: Bracconi and Gasc 1994, Bouriannes and Manson 1971, Pierson 1996).

Argon is better than nitrogen from both a chemical and thermal point of views. However, the nitrogen reactivity and its larger thermal conductivity are critical only at high temperatures (i.e. from 400°C). these temperatures will not be reached, we suggest to use nitrogen (as done in previous mission) as inert gas, due to its larger availability and lower cost.

5.2.7 Overpack

The overpack should be required when the box environment needs to be controlled in stronger detail, e.g. real-time contamination monitoring inside the outer and inner packages. This is the case for restricted samples, which should be preserved with special care (see sub-section 5.2.9). The overpack should in fact include both the triple packaging (primary, secondary and outer) and instrumentation needed to control the box environment (subsection 6.2).
According to WHO guidelines (sub-section 3.1.2), the overpack is needed even if the samples have to be cooled: in this case the outer is surrounded by a refrigerant, and then enclosed in the overpack.
Intermodal (or ISO) containers commonly used for many applications could represent a good overpack layer, since they are made principally of steel, which guarantees a good rigidity, stacking strength and low outgassing rate, are durable, not expensive (1600-1800 euro for Container Unit), and guarantee a worldwide common interface to multiple transport modes including road, rail, air and shipping with port infrastructure designed specifically to handle such containers without unloading the contents (e.g. Figure 5.4). Standard containers are the 20' (6 x2.4 x2.6 m, internal area of 33 m^2) and the 40' (12.2 x2.4 x 2.6 m, internal area of 67.5 m^2). Larger height containers (2.9 m high instead of 2.6 m) are also available. In addition, ISO Containers have been modified for numerous specialist operations because of their availability and the common interface provided on the eight corners of their steel construction. ISO containers also include doors of 2.3 x 2.3 m.
If the package needs to be cooled, an ISO refrigerant container could be considered, when the cooling can be guaranteed by a refrigeration plant. Generally, a total loss system is used because of the refrigerated containers are not common for air transport. Total loss systems are small containers that use either dioxide (dry ice) or liquid nitrogen: the former skips the liquid phase altogether and by a process of sublimation vaporizes directly from the solid state (Taylor and Francis 1999). An internal refrigeration system requires a separate power source to function located outside the container. The land-based electrical points, power from a container ship or from diesel generators attached to trucks on road journeys can supply the refrigeration system. Full size intermodal containers equipped with these "cryogenic" systems can maintain their temperature for 30 days. Refrigerant Containers are available in every standard lengths laid down in ISO 6346 which sets out the internationally ISO container dimensions.

Figure 5.4. ISO container inside a C-17A Globemaster III (from EURO-CARES D6.1)

5.2.8 Refrigerant

Refrigerant, if needed, should be inert in order to minimize the risk of contamination. Ice and dry ice are not inert, since may cause loss of H_2O or CO_2, respectively.
Therefore, liquid nitrogen is the unique refrigerant suitable for transportation boxes.

5.2.9 Control of box environment

The transportation box should have the possibility to measure the pressure of the inert atmosphere inside the outer package. This will allow to detect if leakage is present. A pressure change may also be related to forward contamination of samples (i.e. contamination from terrestrial environment to samples). It is also important to control and change the internal pressure, especially in the case of package damage.
The real-time monitoring of temperature is also crucial in order to understand the thermal "history" of transported samples during their trip from landing site to curation facility: this may be useful to reconstructe.g. possible phase transitions and change of chemical structure occurred in the sample, due to temperature variations.

The possibility to change temperature in real-time is needed only if samples are required to be kept cold during the journey. This may be the case of lunar samples, whereas no requirements on sample temperature have been given in other missions performed so far.
Finally, a real-time monitoring of backward contamination (i.e. contamination from samples to external environment) is necessary for transport of restricted (hazardous, Category A) samples. This will be obtained by installing a proper instrument in the ISO container area not occupied by triple packaging. Next sub-section is devoted to a trade-off between instruments aimed at this end. The installation of a such instrument will obviously allow to measure in real-time forward contamination, too, not only in terms of pressure but also in terms of contaminants composition.
This detail is not required to be measured in real-time for unrestricted missions. However, it would be possible to evaluate, after the package arrival at curation facility, the contamination occurred inside the outer package, by placing one or more witness plates inside the box: these are small (1-200 cm^2) and light (3-40 grams) devices, and hence would not represent a criticality for transport.
Table 5.5 summarizes the needed operation for unrestricted and restricted samples.

	Unrestricted	**Restricted**
Pressure real-time monitor	Needed	Needed
Pressure real-time control	Needed	Needed
Temperature real-time monitor	Needed	Needed
Temperature real-time control	Needed only if required from mission	Not Needed
Contamination real-time monitor	Not Needed	Needed
Contamination monitor (after arrival)	Needed	Needed

Table 5.5. Summary of needed and not needed operations during the transport.

5.2.10 Contamination control instrumentation

This sub-section is devoted to a trade-off among the following instruments aimed at monitoring the real-time contamination in the box atmosphere:
- Gas Chromatograph/Mass Spectrometer (GCMS)
- Thermal Desorption Tubes (TDT)
- Thermogravimeter, based on Piezoelectric Crystal Microbalance (PCM)

The trade-off analysis will be based on:
- Allowed measurements
- Sensitivity
- Mass
- Resistance due to shock/vibration during flight

A summary is given in Table 5.6.

	GCMS	**TDT**	**PCM**
Measurement	Full composition of	Measurement of organic	Measurement of organic

	atmosphere	abundance	abundance
Sensitivity	10^{-2}-10 ppb	10^{-2}-10^{-1} ppb	0.2-50 ng/cm^2
Mass (kg)	20-50	1-3 (without electronics)	0.05-0.1 (without electronics)
Flight-proven	Yes	No	Yes

Table 5.6. Characteristics of contamination-monitoring instruments.

GCMS separates the sampled gases by means of Gas Chromatography, and then determines their elemental composition and abundance by means of Mass Spectroscopy. Hence it gives a more complete information with respect to the other two techniques, because provides the full composition of the atmosphere inside the box.
TDT extracts organic compounds by collecting them on a sorption tube, and then separates them by means of a Gas Chromatograph. However, it is not able to detect the most volatile organics (which do not bind on the sorption tube analyte), such as methane, which can be present in Mars meteorites (e.g. Mousis et al. 2016).
PCM measures the mass of organic material deposited on its sensible area, retrieving its abundance. A thermogravimetric analysis can characterize the organic material by measuring its sublimation temperature or enthalpy (e.g. Dirri et al. 2016).
TDT offers the best sensitivity in terms of abundance, down to ppt. GCMS sensitivity is similar. PCM provides a mass measurement, and its mass sensitivity corresponds to an abundance of $1ppm/[\left(\frac{p}{100mb}\right)*\left(\frac{V}{1m^3}\right)]$, i.e. it cannot be better than 100 ppb.
On the other hand, PCM are the most advantageous in terms of mass, but TDT are also light. GCMS is by far the heaviest instrument. Even if it provides the most complete information, TDT and PCM may be preferred for their lower mass and because they provide the essential information (i.e. contaminationfrom organic compounds).
Due to its high sensitivity, TDT would be the most suitable instrument in the case of ground transport of transportation box.
Contrarily, it would not be considered for air transport, since their durability has been proven to be insufficient for use on military cargo aircraft (Harshman et al., 2015). In the latter case, GCMS would be preferred if the mission requires a ppb sensitivity, whereas PCM would guarantee a lower box's mass and hence higher portability and lower costs for transport.

5.3 Lifting

The lifting operations should be performed according to the general NASA AETD rules, summarized in sub-section 3.3. There rules are independent and hence do not affect the transportation box's design.

5.4 Transport

The transport operation shall start only after approval by the Recovery team leader.

5.4.1 Ground and ship transport

There are no limitations for box transport by ground or ship. The weakness of these solutions is the much larger journey duration.

5.4.2 Air transport

Any aircraft might be used for transporting unrestricted (not hazardous) samples. Only cargo aircraft may be used for transporting restricted (Category A) samples, unless the total sample mass is lower than 50 grams (sub-section 3.2.1).
However, the transport of a box filled with pure nitrogen is not permitted on commercial flights, and hence military aircrafts may be preferred.

6Transportation box basic design

The packaging operation aims at preserving samples from terrestrial contamination (forward contamination).
In restricted missions, the samples are classified as "Category A", and the package should also protect human people from damage and/or disease (backward contamination). In this case, the requirement would be more strict and hence the (at least) triple packaging required by WHO guidelines must be applied.
In this section, we will give a basic design of transportation box for unrestricted (sub-section 6.1) and restricted samples (sub-section 6.2). Each design takes into account that a non-nominal scenario (i.e. SRC damage) could verify. The SRC can be classified as:

- Small, if its mass is lower than 20 kg
- Medium, if its mass is comprised between 20 kg and 50 kg
- Large, if its mass is comprised between 50 kg and 100 kg

We will present a unique design, independent of SRC mass, except when specified.
Finally, alternative designs for particular cases, i.e. canister extraction from SRC (sub-section 6.3) and samples storage at low temperature (sub-section 6.4), will be discussed.

6.1 Unrestricted case

In the unrestricted case, there are no health safe issues and hence no regulation about packaging. The only requirement is the minimization of forward contamination.
Therefore the secondary package is not necessary, and the SRC (primary) may be simply enclosed in the outer package, filled with purge gas. If the SRC is damaged (not nominal scenario) and hence

samples risk to be exposed, the plastic bag (secondary package) can be added, but only if the plastic material has an outgassing rate lower than the metallic alloy composing the outer package: this helps to preserve samples from forward contamination.
The outer design should take into account:

- a pressure sensor (to ensure the a constant atmospheric pressure)
- a temperature sensor (to monitor the possible temperature variations induced from external environment)
- an entrance for gaseous N2 for a controlled atmospheric environment

The mechanical characteristic should have:

- an insulated internal wall, in order to maintain constant temperatures inside the box
- cushioned internal walls, in order to avoid internal collisions or shifting
- rigid external walls to withstand collisions
- four wheels, to simplify the outer movement
- mechanical supports (e.g. pads) in order to avoid mechanical stress

Therefore, the outer (Figure 8.1) is composed by a single section with several pads to limit the mechanical stress, an inert gas entrance(blue in Figure 8.1), a gate valve for inert gas removal (black in Figure 8.1) during the analysis procedure, micro-connectors for external temperatures monitoring (light blue in Figure 8.1) and pressure monitoring (green in Figure 8.1). The pressure would be maintained with pumping system controlled by pressure sensor. Considering the sample transport from landing site to transportation box, the purge gas atmosphere should be done after the sample positioning into the box. The seals can be made of stainless steel surrounded by O-ring which are available in a wide range of materials (Teflon, Nitrile, Silicon, Viton). Viton has been the most used in the past for O-rings, due to its adequate compression to form a reliable, vacuum-tight seal (contrarily to Teflon) and to its low outgassing rate (Total Mass Loss of 0.07%, against values of 0.3% for Silicone and of 1% for Nitrile).
Some pads (light yellow, Figure 8.1, right) are positioned at the bottom to reduce the mechanical stress and collisions. The mechanical latch (stainless steel) are four per side and are positioned on each corner. A grip (not shown in figure) will help to move the outer in the laboratory facility and will be useful to guarantee the box hermetic closure.
Handles are also to be considered even if they are not included in Fig.8.1 (due to its possible different positions on the box). In particular, two handles per side can be taken into account.

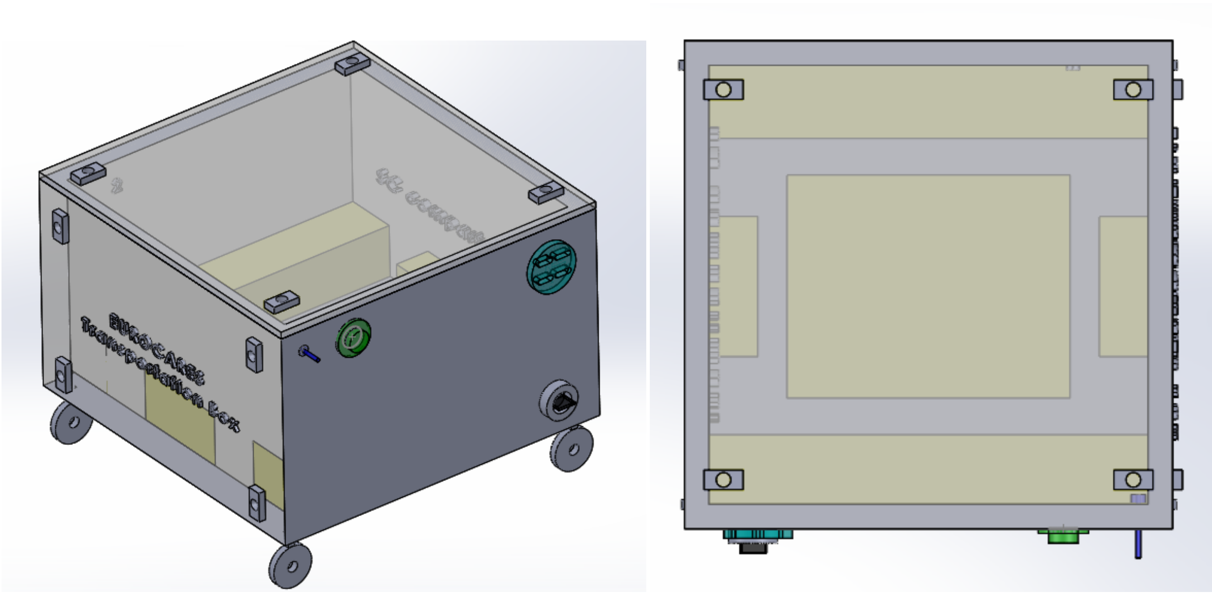


Figure 6.1. *Left*. Outer package configuration. The four valves on the lateral wall are devoted to inert gas (N2 or Ar) entrance (gray), pressure monitoring (green), temperature monitor (light blue) and pressure control (black). *Right*. Top view, the internal pads (light yellow) are shown.

A view of the schematic structure of the transportation box in unrestricted case is shown in Figure 6.2.

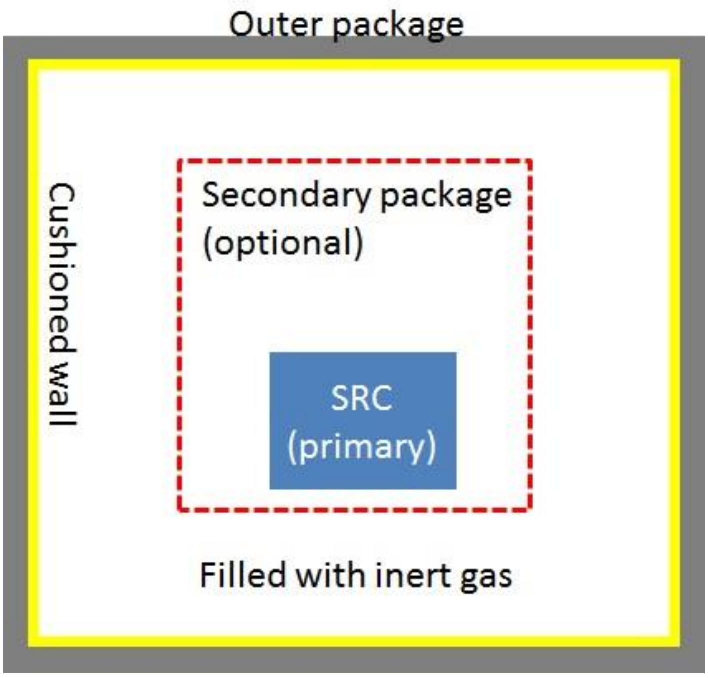


Figure 6.2. Schematic view of transportation box structure for unrestricted mission. The primary (SRC) is enclosed in the outer package (metallic alloy), having cushioned walls and filled with an inert gas (preferably nitrogen). The secondary package (plastic bag) may be needed only in non-

nominal scenario and only if the plastic material has an outgassing rate lower than the metallic alloy.

6.2 Restricted case

Samples from restricted missions are potentially hazardous and hence in this case the triple packaging required by WHO must be applied. This means that the secondary package (plastic bag) is mandatory, differently than unrestricted case.
The outer characteristics are the same as unrestricted case and will be not repeated here. This configuration ensures health protection, due to the very low probability of packaging failure (sub-section 3.2.2).
The outer is then enclosed in an ISO container (overpack), which also contain instrumentation for contamination and environmental control inside the outer, as well as to accelerometers to control the box motion.
The ISO container used in restricted scenario should follows the following characteristics:

- a mechanical stops to fix the outer wheel on the RC surface
- a passive or active anti-vibration mount
- an insulated material between the internal and external walls to isolate the internal environment

Configuration and schematic view of the transportation box in restricted case are shown in Figure 8.3 and 8.4, respectively.

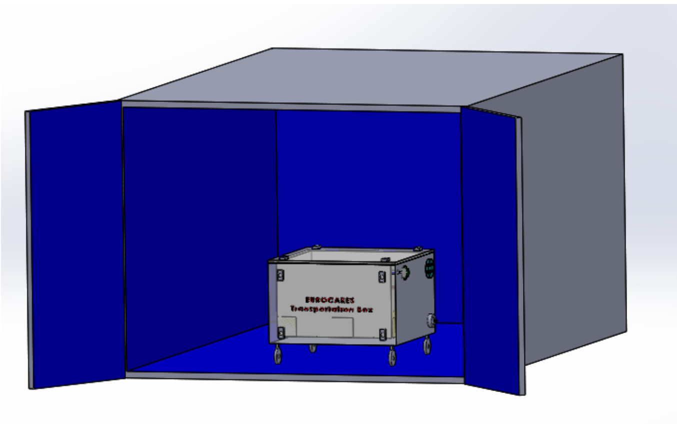


Figure 6.3. Configuration of the transportation box outer (gray) enclosed in the ISO container (blue) for restricted missions.

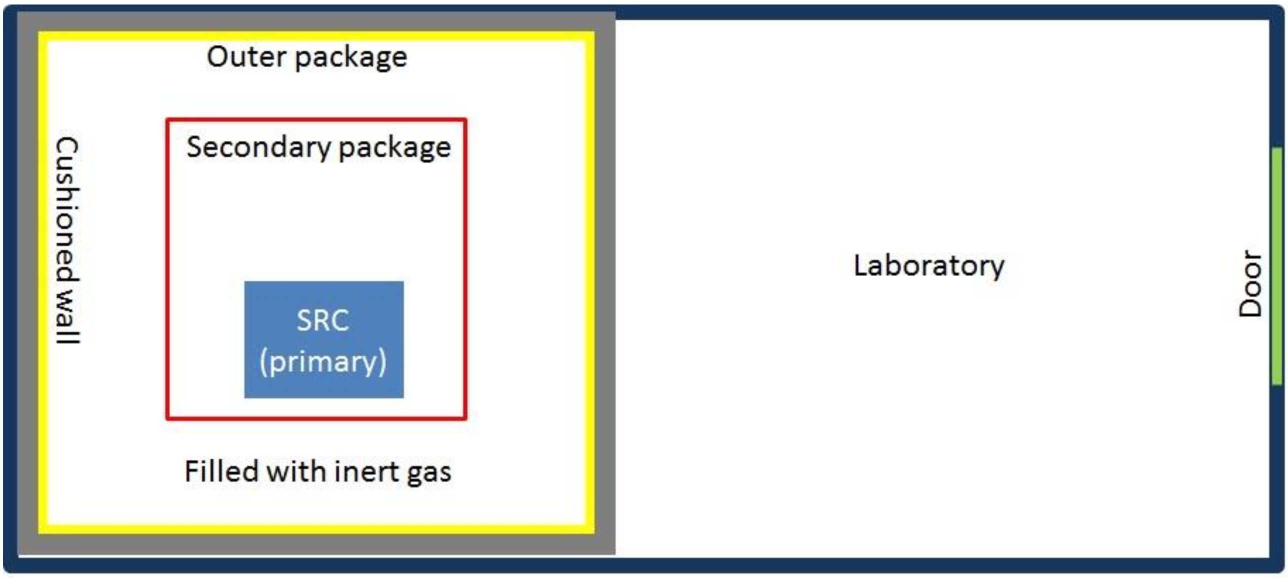


Figure 6.4. Schematic view of transportation box structure for restricted mission. The primary (SRC) is enclosed in a secondary package (plastic bag), in turn enclosed in the outer package (metallic alloy), having cushioned walls and filled with an inert gas (preferably nitrogen). The ISO container includes both the triple package and instrumentation for controlling contamination, environment and motion.

6.3 Alternative design: canister extraction from SRC

We discuss here the case of non-nominal scenario, where the sample canister (SC) may need to be extracted from SRC before packaging. If there is no need to monitor contamination of the "empty" SRC, we can adopt the same design discussed in previous sub-sections, with the difference that the primary will be composed of the SC, only, rather than the whole SRC. The "empty" SRC would be transported by means of a cradle.
If instead it is required to evaluate the different contamination degree occurred on SC and SRC, we may have two options:

- To consider two different transportation boxes for SC and SRC, respectively
- To consider a unique transportation box with two compartments, dedicated to SC and SRC, respectively.

In the first case, the transportation box of SC will have the same design as discussed in previous sub-sections, whereas the SRC will be placed in a "simplified" outer with only one pad to limit the mechanical stress, a micro-connector for external temperatures and humidity control (light blue in Figure 8.5) and pressure control monitor (green in Figure 8.5). A gaseous N2 entrance is not necessary as well as the gate valve. If samples comes from a restricted mission, only the SC transportation box should be placed in the ISO container.

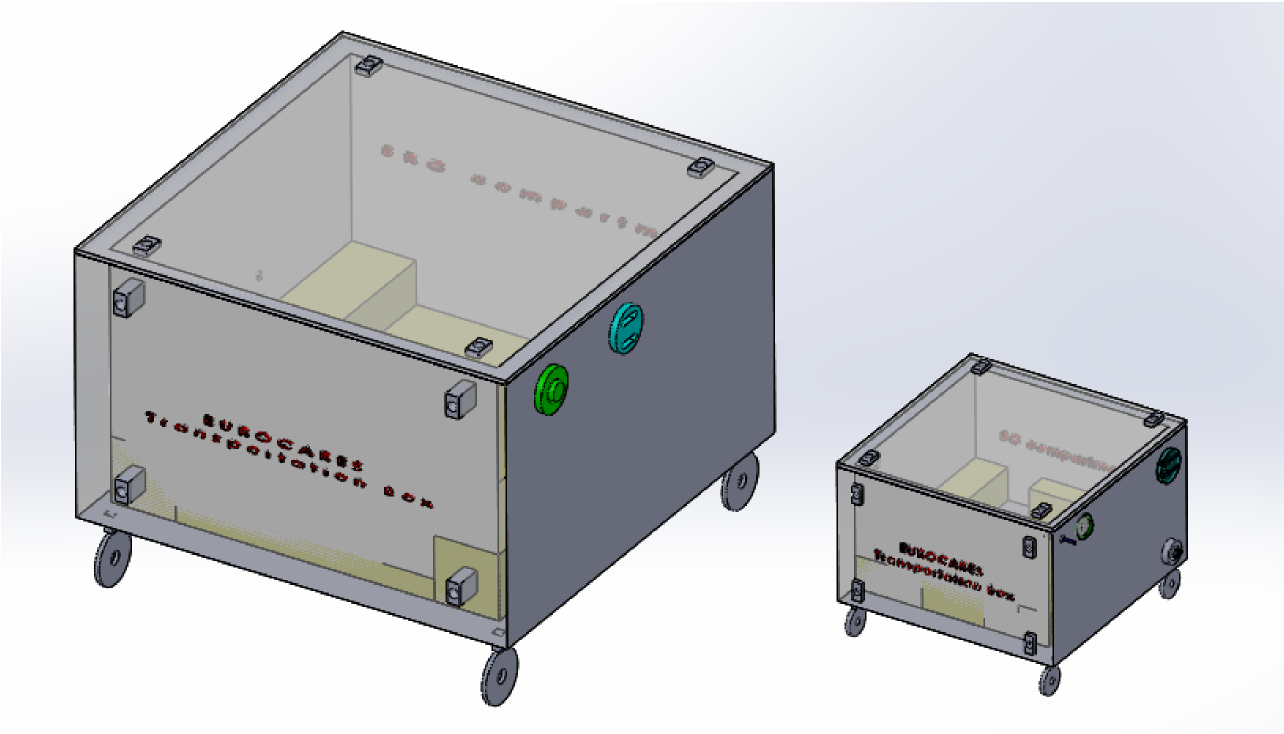


Figure 6.5. Transportation box outer for SRC (left) and SC (right) in the case they have to be separated.

In the second case, it would be possible to monitor the SC and SRC at the same environmental conditions. In this case, the SC and SRC will be separated by a steel cushion section (Figure 8.6).

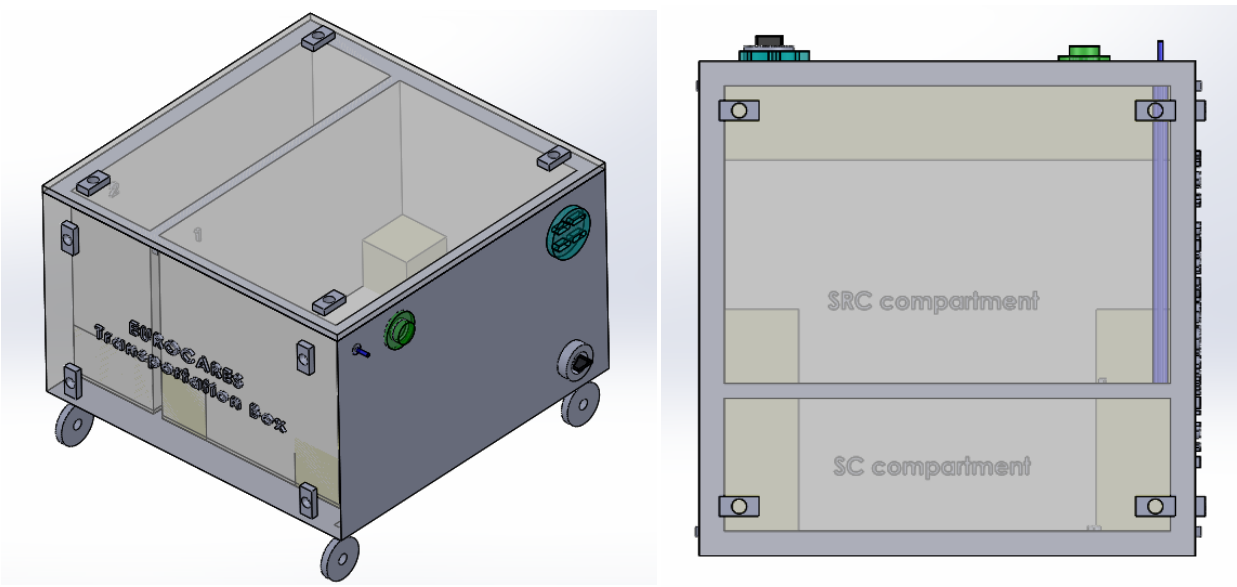


Figure 6.6. Outer configuration in the case SRC and SC are separated but transported in the same box.*Left*: the outer is provided of connectors for temperature monitoring (light blue) and pressure

controlling (green). *Right*: top view, two (for SC and SRC) compartments are shown. The light yellow sections are pads to reduce collisions and mechanical stress.

6.4 Alternative design: samples storage at low temperature

In a lunar sample return mission (unrestricted case), returned samples may be required to be kept at low temperature even during transport from landing site to curation facility.
In this case, an additional layer should be added to the package discussed in sub-section 8.1. This would consist in an ISO refrigerant container (RC), which would allow to reach and maintain low temperatures by means of a refrigeration plant (see example in Figure 8.7).

Figure 6.7. Refrigerant Container with a separate refrigeration system (http://web.cimc.com/res/products_en/container/Reefer/SpecialReefer/200912/t20091222_2340.shtml#).

The following requirements should be reached:

- the external wall of the outer container should be built with conductive material, in order to facilitate the sample conservation at low temperatures (in this case aluminium or copper would be preferred to steel)
- the refrigeration system has to cool the RC internal surface
- the RC external wall should be built with insulated material
- the RC should hold out against the cold temperatures reached
- mechanical supports have to be provided to ensure the outer stability

7 Labelling, documentation and tracking

7.1 Labelling and documentation

The issues concerning labelling of transported boxes and related documentation are discussed in this sub-section, discerning between nominal and non-nominal case.

7.1.1 Nominal case

We propose here to follow the labelling and documentation guidelines from WHO, appropriately adapted to the case of Sample Return Missions.
In particular, the "sender's name and address" the "receiver's name and address" fields should be replaced with the landing site and curation facility address, respectively. The "Nation or institution" field should be replaced with the agency supporting the mission, whereas an additional field should be considered, giving details of the mission itself.
The "Tested for Category A/B" field is not applicable, while it would be more appropriate to indicate from where the samples were returned, e.g. Mars, asteroids (indicating the asteroid name), Moon, including the region and the coordinates of the sampling site.
The "indication of sample" field will indicate when the samples are kept at low temperature or if are potentially hazardous (i.e. restricted samples).
All the markings concerning orientation of the box and used refrigerants apply likewise as indicated by WHO (Figures 3.4 and 3.5).
A comparison between WHO guidelines and their proposed re-arrangement in case of shipping of extra-terrestrial samples from sample return mission is given in Table 7.1.

WHO field	**Sample return mission field**	**Example**
Sender's name and address	Landing site name and address	Karaganda Area, address, ZIP, country
Contact of a responsible person	Contact of a responsible person	Name and surname, address, ZIP, country, phone number, mobile number, e-mail
Receiver's name and address	Curation Facility name and address	EuroCares Facility, address, ZIP, country
---	Mission name	MarcoPolo mission
Nation or institution	Space Agency	ESA
Type of packaging	Type of packaging	Triple packaging
Tested for Category A/B	Origin and coordinates of sampling site	Mars, CalorisPlanitia, 32.6°N, 197.7°E
Two digits of year	Two digits of year	16
State authorizing marking allocation	State authorizing marking allocation	Kazakhstan
Manufacturer code	Manufacturer code	Manufacturer code
Indication of the sample	Indication of the sample	See Figure 3.3
Orientation	Orientation	See Figure 3.4

Temperature storage requirements	Temperature storage requirements	Keep the sample at -20°C
Technical name of refrigerant used	Technical name of refrigerant used	Dry ice as coolant, see Figure 3.6.
«In case of damage or leakage immediately notify … », with related contacts	«In case of damage or leakage immediately notify … », with related contacts	«In case of damage or leakage immediately notify … », with related contacts

Table 7.1. Labelling marks according to the WHO guidelines (first column) and proposed adaptation to Sample Return Missions (second column), with relative examples (third column).

Concerning the documentation, we also propose to adopt the WHO guidelines. Hence, the documentation associated to a transportation box including extraterrestrial samples from a sample return mission would include:

- A Declaration for Dangerous Goods (an example is shown in Figure 3.6) which would indicate if the sample are potentially hazardous (i.e. restricted samples) and if dry ice or liquid nitrogen are used as refrigerants. In the case none of these conditions is verified, the Declaration is not needed.
- A proforma invoice including the curation facility address (including ZIP and country), the number of packages, detail of contents, weight, value
- The words "SUSPECTED CATEGORY A", in the case of samples from restricted missions.

Moreover, an itemized list of content should be located between the secondary and the outer package.

7.1.2 Non-Nominal case

In the non-nominal case, additional marking should be considered.
A new marking indicating that SRC (i.e. the primary receptacle) is breached or damaged should be applied. We propose here a diamond shape of 100x100 mm (50x50 in the case of small packages), with white words on red (or black) background (Figure 7.1, left), i.e. the reverse of markings commonly used by WHO and which we propose to adopt for nominal case. The mark should indicate the letters "NN" (i.e. not-nominal), having a minimum size of 6 mm (adopting the WHO rule).
All the details concerning damage or breakage of the SRC, as evidenced in the visual inspection and recovery operations, should be addresses in an dedicated report, which would be added to the documentation related to the package shipping (i.e. Declaration of Dangerous Goods, proforma invoice and the words "SUSPECTED CATEGORY A").
Additional details concerning the samples should be instead pointed out by means of one or more additional marks on the outer package of the transportation box, to be accompanied to the "non-nominal" warning marks shown in Figure 7.1 (left). The mark should indicate, e.g., if the samples:

- have been exposed on air;
- have been in contact with water;
- have been in contact with dust;

- have been already contaminated by surrounding environment, by the package itself or by refrigerant used
- are suspected to be contaminated by surrounding environment, by the package itself or by refrigerant used

... and so on.

This could be indicated with a rectangle shape of 74x105 mm dimensions, according to the WHO guidelines, containing white words on red (or black) background (Figure 7.1, right), i.e. the reverse of markings commonly used by WHO and which we propose to adopt for nominal case. The mark should include three capital letters, having a minimum size of 6 mm (adopting the WHO rule), and indicating the damage or the possible damage occurred to extraterrestrial samples. In Table 7.2, we propose some acronyms which would indicate different anomalous conditions which could verify on returned samples after a landing in a non-nominal scenario. The list is not demanded to be exhaustive and many other cases may be added.

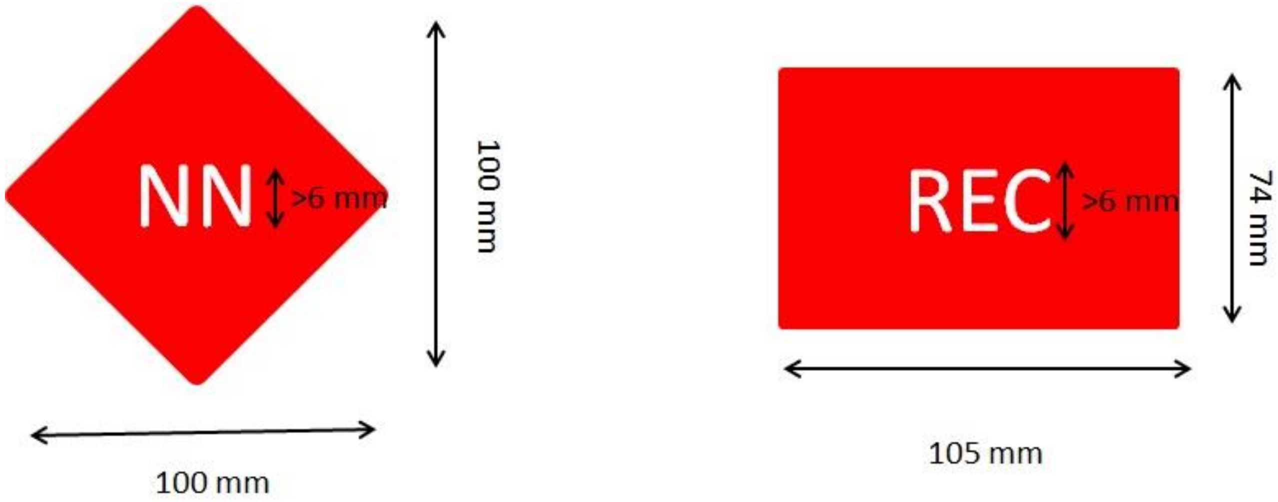


Figure 7.1. Proposed marks to apply on the outer package of the transportation box in case of non-nominal scenario. The diamond-shape mark (on the left) would indicate that a non-nominal scenario has been verified. The rectangle-shape mark (on the right) would give details about the damage or possible damage occurred to samples (see Table 7.2 for details).

Acronym	Meaning	Explanation
EXA	Exposed to Air	Samples have been exposed to terrestrial atmosphere
EXD	Exposed to Dust	Samples have been in contact with terrestrial dust
EXW	Exposed to Water	Samples have been in contact with terrestrial water
REC	Risk of Environmental Contamination	There is a risk that samples have been

RIC	Risk of Internal Contamination	contaminated by surrounding environment (REC), by packages itself (RIC) or by refrigerant (RRC). It could be verified that this occurred only after the samples reached the curation facility
RRC	Risk of Refrigerant Contamination	
VEC	Verified Environmental Contamination	Samples have been surely contaminated by surrounding environment (VEC), by packages itself (VIC) or by refrigerant (VRC).
VIC	Verified Internal Contamination	
VRC	Verified Refrigerant Contamination	

Table 7.2. Proposed acronyms to apply on the outer package of the transportation box to indicate the damage or possible damage occurred to returned extraterrestrial samples. The list The list is not demanded to be exhaustive and many other cases can be considered.

7.2 Tracking

The transportation box should be equipped with a commercial GPS receiver, in order to track its journey from landing site to curation facility.
In addition, the personnel working on recovery, packaging and transport operations should communicate to the receiver (in our case, the Curation Facility) when:

- the SRC is recovered
- the SRC packaging operations are concluded
- the transportation box is loaded on the vehicle for ground transport from landing site to airport
- the transportation box is unloaded from the vehicle and loaded on the aircraft for air transport
- the transportation box is unloaded from the aircraft and loaded on the vehicle for ground transport from airport to Curation Facility

With this combined system GPS-personnel, it will be always possible to know the position and the operations being performed on the transportation box.
Finally, personnel must communicate any unwanted event occurred during the transport, e.g. vehicles/aircraft failure, necessity to perform emergency landing, package breakage and consequent repackaging, and so on.

8 Conclusions and requirements compliance

Analysis of previous missions and of current regulations led to define a basic structure of a transportation box. It is based on a layered configuration, developed as follows (from inner to external layer):

- *Primary receptacle*. It basically coincides with the Sample Return Capsule. It may be surrounded by absorbent material (polypropylene would be preferred).

- *Secondary package*. It is a plastic bag (preferred material: Teflon), needed for restricted missions. In unrestricted case, it may be considered only for non-nominal scenario.
- *Outer package*. Rigid container (preferred material: stainless steel or, alternatively, aluminum alloy) with cushioned walls, filled with inert gas (nitrogen would be preferred), and equipped with pressure and temperature sensors, and witness plates (for contamination control after arrival).
- *Overpack*. It is an ISO container, needed only for restricted case. It includes the triple package and instrumentation for contamination, environment and motion monitor. The selection of instrumentation depends on mission requirements in terms of mass, costs and transport.

Each package needs to be accompanied with related markings (indicating conditions of the sample, information on the landing and shipping details) and documentation.

Alternative designs for special cases (SRC opened in the landing site, samples to be kept cold) have been discussed.

The list of EURO-CARES requirements for transport is discussed below.

FL-10	The transport container shall guarantee isolation from the Earth atmosphere, particulate and molecular matter whilst also avoiding organic contamination and preserving the integrity of the capsule
	The transportation box configuration has been developed accordingly with this requirement.
FL-20	The capsule shall be contained within an ultrapure nitrogen atmosphere in the transport container.
	The outer package is filled with inert gas. A trade-off between nitrogen and argon has been performed, leading to conclusions that nitrogen would be a better choice.
FL-30	The transport container shall protect the samples from any expected (TBC) mechanical shock and vibration experienced during transportation to the recovery facility.
	Considered materials are compliant with this requirement.
FL-40	Transport of the capsule within the transport container shall only be permitted after approval by the Recovery team leader.
	The proposed transport procedure comply with this requirement.
FL-50	The safety and security of the samples shall be the responsibility of the Recovery team leader.
	The Recovery team leader should coordinate packaging operation, marking application, and documentation preparation in order to ensure safety and security of samples.
FL-60	The transport container shall be able to withstand a temperature range of (TBD) degC.
	The nominal temperature range is from -55°C to 40°C (WHO regulation). To reach higher temperature is not critical. Lower temperature can be reached by considering an ISO refrigerant container.

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