D7.1
EURO-CARES INTERIM TECHNICAL REPORT

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640190

1 Acronyms

AMUF: Analogue/Mock-Up Facility

BAP: Biohazard Assessment Protocol

BSL: Biosafety Level

COSPAR: COmmittee on SPAce Research

DWI: Double-Walled Isolator

ERC: Earth Return Capsule

ESCF: Extra-terrestrial Sample Curation Facility

EURO-CARES: EUROpean Curation of Astromaterials Returned from Exploration of Space

FU: Functional Unit

LD: Life Detection

MSC: Microbiological Safety Cabinets

NASA: National Aeronautics and Space Administration

PE: Preliminary Examination

PP: Planetary Protection

PRF: Portable Receiving Facility

RS: Remote Storage

SCF: Sample Curation Facility

SEC: Sample Early Characterisation

SRF: Sample Receiving Facility

WHO: World Health Organisation

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2 Introduction

EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space) is a three years (2015-2017), multinational project, funded under the European Commission's Horizon2020 research programme (No 640190).

EURO-CARES work has been organised around a first phase of literature review (January 2015-June 2015), followed by a technical phase with five work packages (see website: www.euro-cares.eu) (July 2015-March 2017), and a last phase of synthesis (April 2017-December 2017). Another work package, focused on public outreach is active throughout the project.

This deliverable is an interim technical report which summarizes the work of the technical EURO-CARES work packages. To keep the document as short and readable as possible, only the main recommendations and key points are presented here. For more details, the reader is invited to see the several technical deliverables (http://euro-cares.eu/reports).

Even though orbiters and landers are equipped with instruments which are more and more accurate to study planets, moons and asteroids, analyses are still limited in comparison to what can be done in laboratories on Earth. To obtain high-precision analyses, it is essential to bring samples back to Earth. On this basis, the objective of the EURO-CARES project is to create a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility (ESCF). It shall be mentioned here that these are early phase 0 / phase A designs and plans of the ESCF.

Samples returned from space are subject to planetary protection (PP) regulations, which are the guiding principle in the design of space missions to protect Solar System bodies from contamination by Earth life forms, and to protect Earth from possible life forms that may be returned from other Solar System bodies.

The Committee on Space Research (COSPAR) has the mandate from the United Nations to maintain and promulgate the planetary protection policy. Planetary protection is essential to preserve our ability to study astrobiologically interesting planets and moons of our Solar System. The contamination of celestial bodies by Earth organisms and organics needs to be avoided because it could lead to false-positive results (forward PP). The second aspect of planetary protection aims to protect the Earth's biosphere from extra-terrestrial agents, which might be harmful if released into the Earth environment (backward PP). Both aspect shall be considered, forward PP on returned samples, and backward PP during transport and curation phases.

COSPAR defined five planetary protection categories with subcategories dependent on the target of the mission and the type of mission (fly-by, orbiter or lander). All missions which will return extra-terrestrial samples to Earth for further analysis belong to category V. Depending on the origin of the extra-terrestrial material a category V mission can be an unrestricted Earth return mission (e.g. with samples from the Moon) or restricted Earth return mission (e.g. with samples from Mars or Europa).

- **Category V Unrestricted**: samples from locations judged by scientific opinion to have no indigenous lifeforms. No special requirements (Moon, asteroids).
- **Category V Restricted**: (where scientific opinion is unsure) the requirements include: absolute prohibition of destructive impact upon return, containment of all returned

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hardware which directly contacted the target body, and containment of any unsterilized sample returned to Earth (Mars, Europa).

Once returned to Earth, samples have to be preserved under specific conditions (depending of their origin) to remain as pristine as possible and, in the case of restricted missions, the Earth environment shall be protected, at the same time, from potential hazards. Currently, worldwide, no single facility exists that allows both types of containment, as required for a sample receiving facility for materials returned from the previously mentioned objects, such as Mars. Since it is impossible to foresee the actual risk factor of returned samples, the facilities need to have the most stringent containment level presently afforded to the most hazardous biological entities known on Earth. The infrastructure, the procedures, protocols and instrumentation, the sample handling (which is anticipated to be a major challenge), as well as the staff training shall all be adapted to PP requirements.

3 General requirements

3.1 Activities in the ESCF

In this study, the sample curation facility has been defined as follows: "Collection, handling, documentation, preparation, preservation ("into the indefinite future"), and distribution of (a limited amount of) samples for research."

The main activities to be conducted inside the ESCF are:

- to receive the return capsule,
- to extract the sealed sample container(s) from the spacecraft,
- to extract the sample(s) from the container,
- to store the sample(s),
- to curate and characterize the sample(s), as to allow further scientific activities,
- for restricted samples, to conduct life detection and biohazard assessment tests,
- to allocate samples for research, in the case of unrestricted samples; in the case of restricted samples, after biohazard assessment and potentially sterilization.

Inside the ESCF, a range of instruments is required to undertake a series of activities. These include:

- **Cataloguing or Sample Early Characterization (SEC)**: building a database that allows for the identification and record of each sub-sample including basic information such as written description, photo-documentation, potentially at multiple scales and in 3D, mass, etc.
- **Characterization or Preliminary Examination (PE)**: wide range of measurements, allowing preliminary determination of structure, mineralogy and organic inventory of the samples, with the aim to enable the scientific community to devise further analyses, within or outside of the ESCF. Characterization activities in the curation facility shall be conducted with little or no impact on the physical and chemical properties of the sample.
- **Life detection (LD) and biohazard assessment protocol (BAP)**: wide range of techniques to investigate the presence of life and biohazard in returned samples. Life detection analyses shall be based on a broad definition for life. Biohazard assessment shall determine if samples pose any threat to terrestrial organisms or ecosystems. Since

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potential hazards could take a multitude of forms and affect any life form, the spectrum of tests has to be diverse. LD and BAP will determine if and how it is possible to distribute sub-samples to external laboratories.

- **Sample preparation:** when allocation of sample is possible and requested, it is necessary to provide a sub-sample with specific characteristics and preparation (e.g. polished or thin section, microtome section, powder, etc.).
- **Contamination control and contamination knowledge**: monitoring of the cleanroom environment, and all cleaning and handling protocols that may impact the samples. Measurements may include direct analysis of gases or reagents used in the curation facility; the surfaces, or extracts of surfaces, of sample handling or storage devices and witness plates and test samples. A defined contamination measuring regime will be required in order to verify that samples are not exposed to unacceptable levels of contamination and that cleaning and handling procedures are meeting specification requirements. As contamination cannot be guaranteed to be zero, such measurements and witness plates will provide knowledge about what contamination the samples are exposed to during their residence and processing in the facility, providing invaluable information in the interpretation of contamination sensitive measurements performed on allocated samples.

All the activities above shall be first tested and validated using analogue samples. For practical reasons and sterility concerns, it may be necessary for the ESCF to have its own collection of analogue samples.

3.2 Planetary Protection

In general terms, the facility shall be designed, constructed and operated to prevent the release of biohazardous material to the Earth environment and vice versa, contamination of the samples by the Earth environment. It shall also allow the samples to be studied by the international scientific community, either within the facility itself, or in others laboratories, through loan of samples.

The facility that will receive samples from restricted missions shall be able to hold the samples within containment that will stop any release of an unsterilized particle. Specifically the PP requirements states that the probability of a single unsterilized particle of ≥0.1 μm being released from this facility shall be ≤ 1 x 10^{-6}.

The measures already employed for high containment facilities demonstrate that the majority of the technology necessary for a restricted Earth return mission already exists, and thus can be built upon with technologies adapted from the pharmaceutical industry. However, some new technologies will need to be further developed, such as the double walled isolator, robotic manipulation, etc.

3.3 Sample Contamination

Contamination prevention shall maintain the samples in their pristine state for long-term storage. In a first step analysis, the samples returned by missions to asteroids, the Moon or Mars will likely consist of regolith material with the following principal chemical characteristics:

- Inorganic compounds: ferromagnesian silicates, aluminosilicates, Fe and Cr oxides, phosphates, metals, sulphides, carbides, nitrides, and hydrated silicates (e.g. clays).

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- Organic compounds: soluble carbonaceous and insoluble kerogenous-like compounds, aliphatic and aromatic hydrocarbons, heterocyclic compounds, amines and amides, alcohols, carbohydrates, biomolecules and, possibly, simple life forms.

Gaseous species in the headspace of the sample tubes, potentially liquids and/or ices will also be delivered within the re-entry capsule, and shall be treated as subsamples.

Contamination is defined as molecular, liquid and particulate material that could be adsorbed or absorbed and alter the sample characteristics or degrade the returned samples. Molecular contamination is defined as any gaseous substances, whether at the trace level or not. Liquid contamination is any compound (water, organic, metal) with no fixed shape able to flow easily at room temperature and pressure. Particulate contamination is any inorganic, organic or biological small (0.1 μm to 1 mm size) solid particles.

3.4 Design Requirements

Several locations could be envisioned for the ESCF, such as a "remote location" (i.e. relatively far from uninhabited area), an existing research center, an existing governmental (or non-governmental) facility, etc. Not having constraints on this aspect, the assumption is that the ESCF is a stand-alone facility which will not use any remodeled building(s).

The architectural layout shall encourage meetings and communication between personnel to increase working efficiency and cooperation.

The architectural layout shall encourage a pleasant work environment. Since cleanroom workers show significantly higher sick leave statistics than other personnel, this requirement shall not be overlooked.

Security shall be layered according to risk associated with samples/personnel/building in general. Scientific units shall be protected from a range of natural (such as seismic hazard) and non-natural hazards. The human/restricted samples interaction shall be highly limited or even eliminated, for safety and security reasons.

Additionally, the facility shall be designed in order to avoid unnecessary resource or energy use, both in the building and operational phase (material selection, energy efficiency, etc.). It shall be cost-effective by considering the whole life cycle, including the initial design and construction costs, operations and maintenance as well as disposal.

3.5 Flexibility, adaptability, and modularity

The facility shall ideally be flexible, adaptable and modular in order to adapt to:

- a wide variety of missions
- samples from different environments
- samples with and without biohazard

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4 ESCF Workflows

The activities undertaken within the facilities have been defined and translated into workflows, for samples and operations:

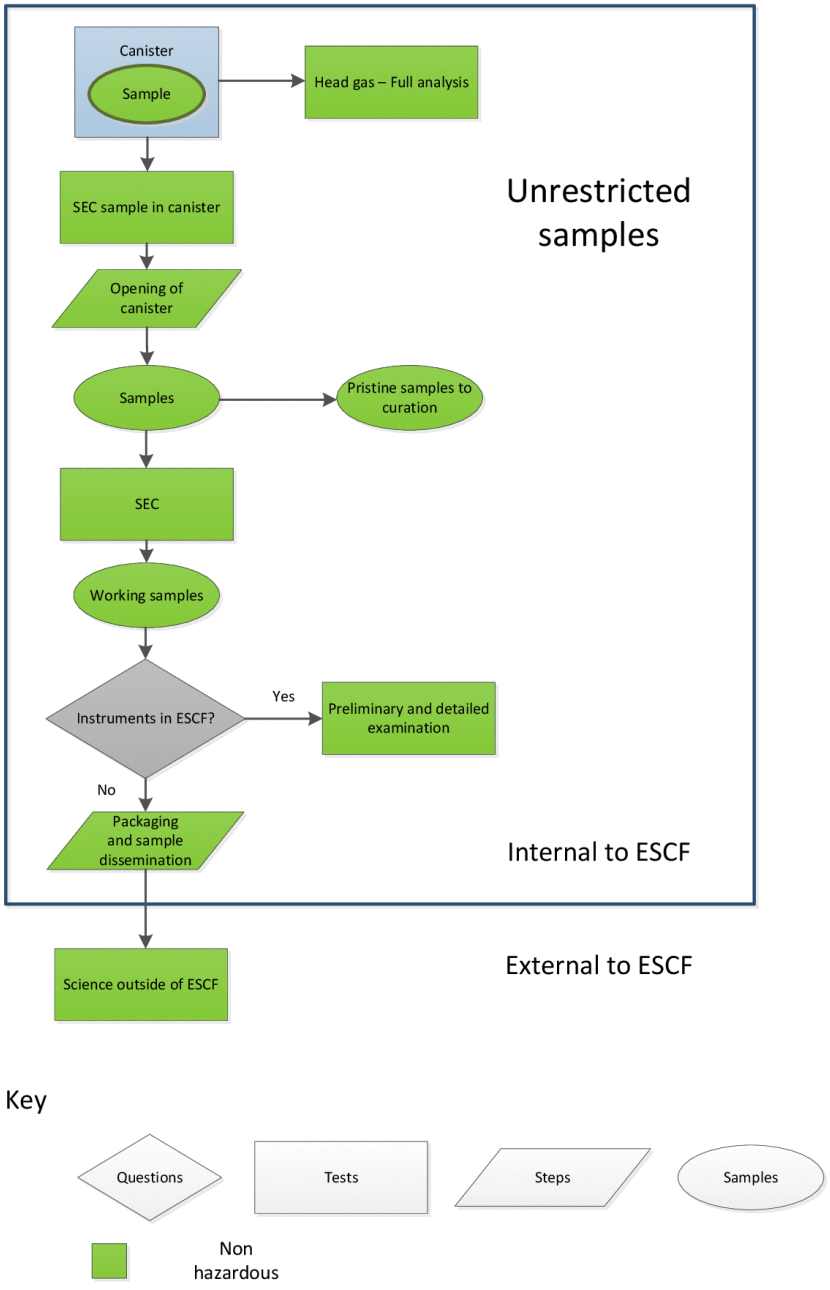

Figure 1. Unrestricted samples workflow.

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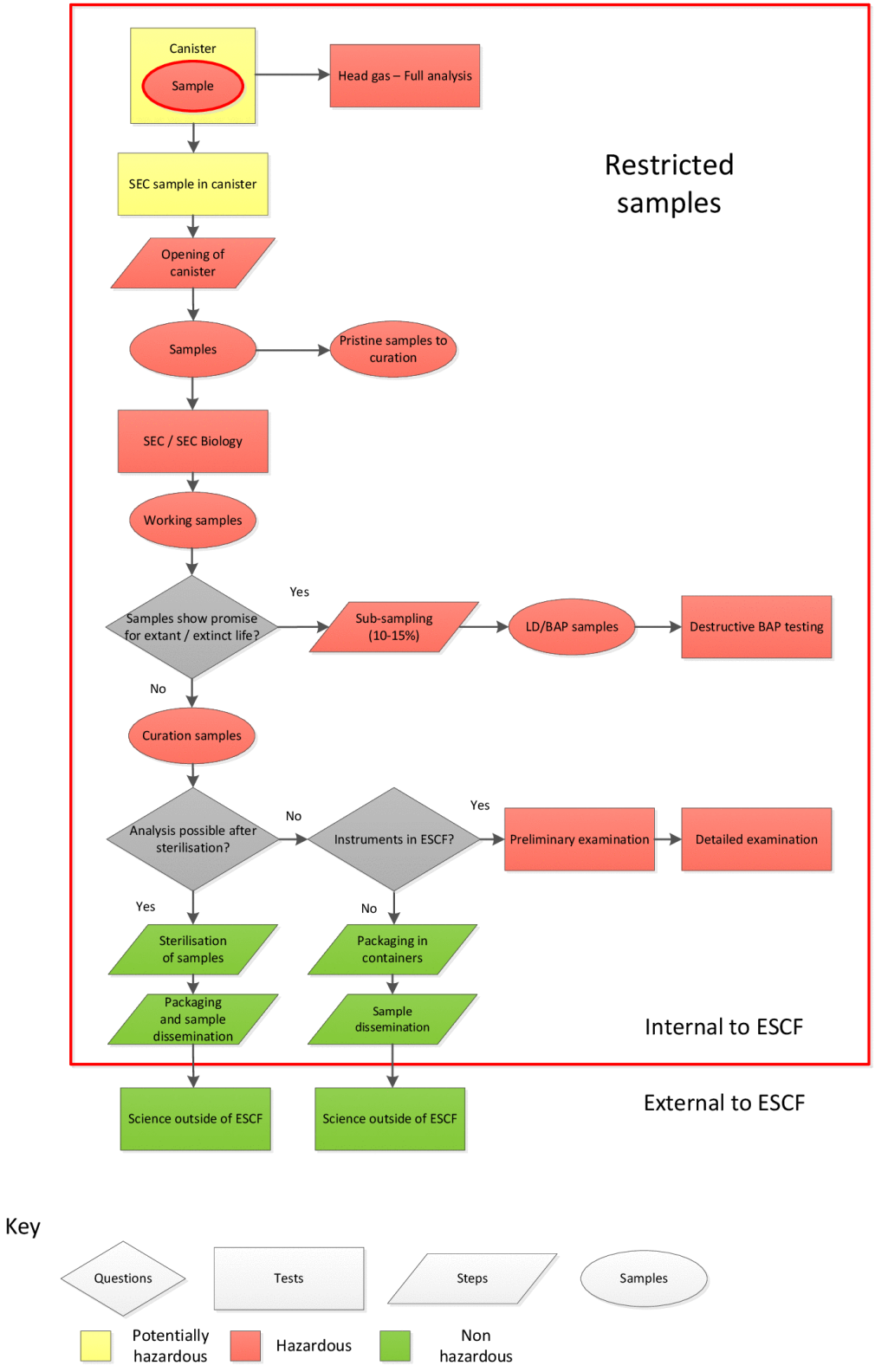

Figure 2. Restricted samples workflow.

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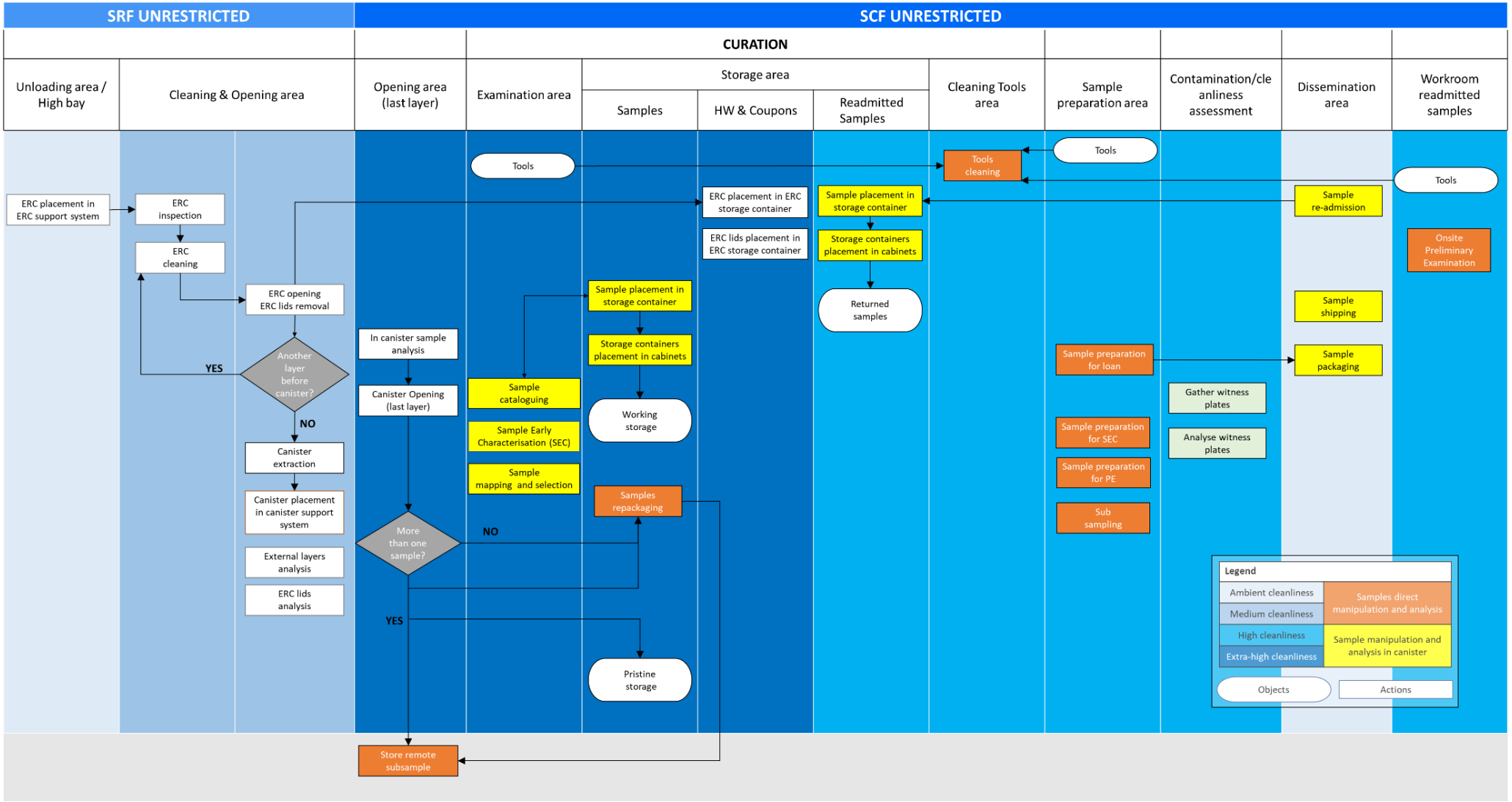

Figure 3. Unrestricted operations workflow. Cleanliness levels are indicated with different shades of blue, so that physical connections between different areas, the flow of workers and the samples, can be discussed. Operations where the sample can be left inside the container (yellow boxes) and the operations where the sample will need to be taken out of the container (orange boxes) have been differentiated.

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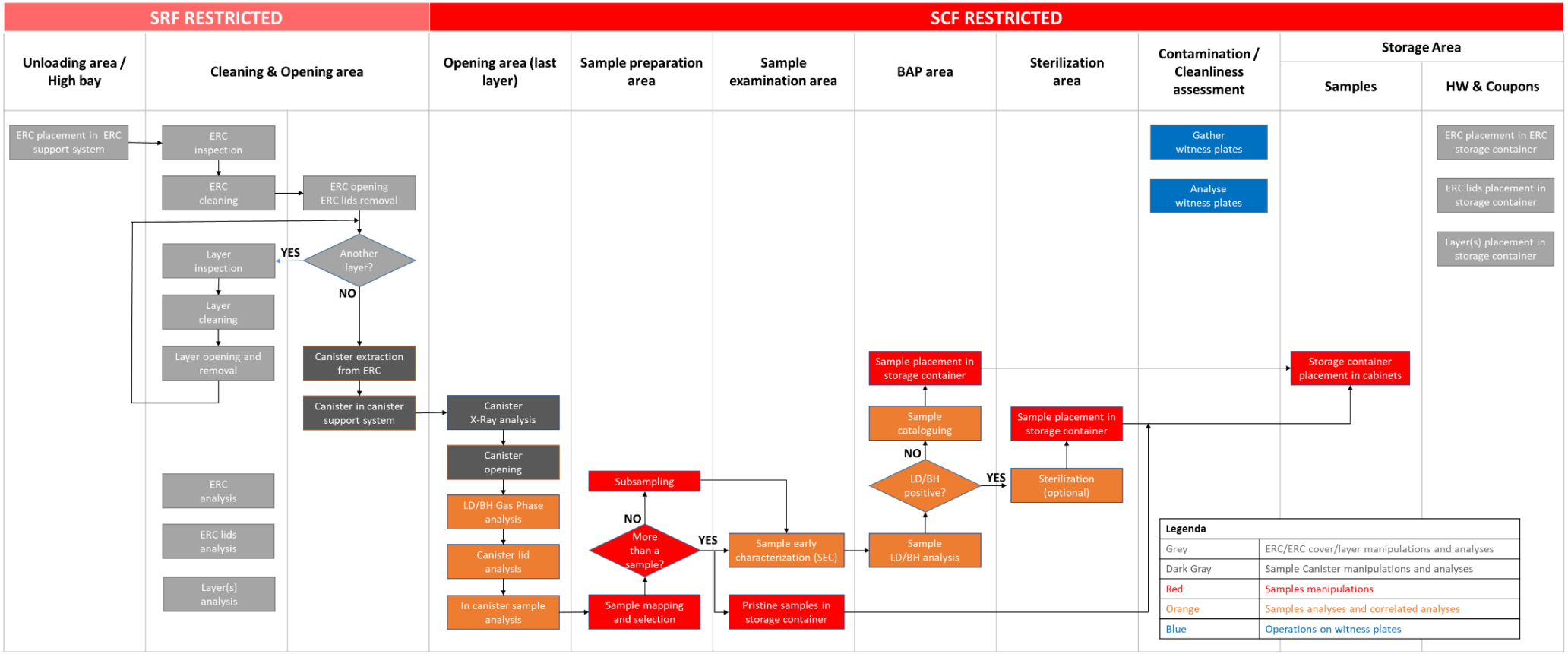

Figure 4. Restricted operations workflow.

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5 Keypoints on sample recovery and transport to the ESCF

5.1 Selection of landing site

Landing sites are often military test ranges due to their remote location, large area and operational support. For restricted Category V sample return missions, six potential landing sites have been considered: White Sands missile range, Wallops test range, Utah Training and Test Range, Kazakhstan, Woomera Range Complex and Esrange Space Center, Sweden.

Recommendations:

- Start landing site negotiations more than 2 years in advance of planned landing and liaise with local governments and military to understand all regulatory aspects of a landing site, including cultural aspects.
- The landing site shall be chosen to reduce the risk of extreme adverse weather and allow the easiest access to the Earth Return Capsule (ERC) after landing. In addition it shall be as far as possible away from population centers.

5.2 Collection of the capsule and preliminary site sampling

Prior to EURO-CARES, there had been little information regarding the complexities of recovery available, particularly for a Category V restricted mission such as Mars Sample Return. This work has looked at recovery from the landing site, planetary protection requirements, and transportation from the landing site. This has included consideration of recovery infrastructure, training of personnel and preserving the integrity of the sample.

Recommendation: Prepare for ERC landing contingency scenarios: Plan and train for the following non-nominal contingency scenarios for the landing: ERC landing outside of landing ellipse, ERC not being found within the defined timescale, ERC landing in water, ERC landing in mud (preventing nominal recovery operations), ERC opening upon landing, night landing, extreme weather conditions such as flood/snow/high winds.

The meteorological conditions over the landing site will need to be assessed before, during and after landing. This will allow for projections of sample release if there has been a breach in containment of the ERC. The necessity of taking environmental samples from the landing site was highlighted, but analysis and interpretation of the results could be difficult to achieve, especially if there has been a small release over a wide area. Environmental sampling could help to determine if there has been Earth contamination of the sample on landing.

Recommendations:

- Collect samples of all substrate types (soil, rock, air, water, etc.) at predefined time points from the landing site. Sampling shall continue after the landing of the ERC. For a restricted mission, samples will be stored and only analyzed if there is a possibility of containment breach of the ERC or life is found in the samples to help determine if there is either backwards and/or forward contamination.
- Conduct trade off to determine the best selection of resources for the collection of the ERC. This would identify if any robotic systems are available for use or mechanical aids that may be required depending on the size of the ERC and need for heavy lifting. Humans shall be included in the collection team on site to assist if there are any unforeseen difficulties.

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- **Temporary cleanroom and containers:** A temporary cleanroom, or a temporary tent shall be installed near or at the landing site so that safing, cleaning, collection and security for the ERC can be provided.
- Containers shall be provided for all components of the ERC and samples including in the case that it fractures into many components.

5.3 Sample return capsule and transport container

5.3.1 ERC

Sample return capsule dimensions have been defined using previous and proposed missions as:

- sample mass range: μg to 500 g
- capsule size range: 0.04 to 1.5 m diameter
- capsule mass range: 18-190 kg

5.3.2 Transportation container for the sample

The basic design of the transportation box is based on WHO guidelines for transporting potentially hazardous samples. The influence of environment conditions of different landing sites on design of transportation box has been analyzed. Materials of transportation boxes have been selected in order to minimize contamination to transported extraterrestrial samples, caused by terrestrial environment and container itself. Other key issues to select the most suitable materials for transportation boxes concern density, rigidity and costs. Pressure, temperature and air quality inside the box could be monitored during the transport and the instrumentation suitable to this end has been identified. Requirements for each kind of transport (via ground, ship and air) have been identified.

Recommendation: Triple packaging shall be used for restricted mission samples. An ISO container is recommended for monitoring the environment inside the box. In the case of unrestricted samples, triple packaging is not strictly required, but is preferred. Teflon and Neoflon are recommended for secondary packaging.

For the outer packaging, stainless steel is the lowest outgassing material, but aluminium alloy is a lightweight alternative. Nitrogen is recommended as a purge gas due to its larger availability and lower cost. The transportation box shall have the possibility to measure the pressure of the inert atmosphere inside the outer package, the temperature inside the box and to control the air quality in the box. For contamination control instrumentation, Thermal Desorption Tubes are recommended for ground transport and GCMS for air transport.

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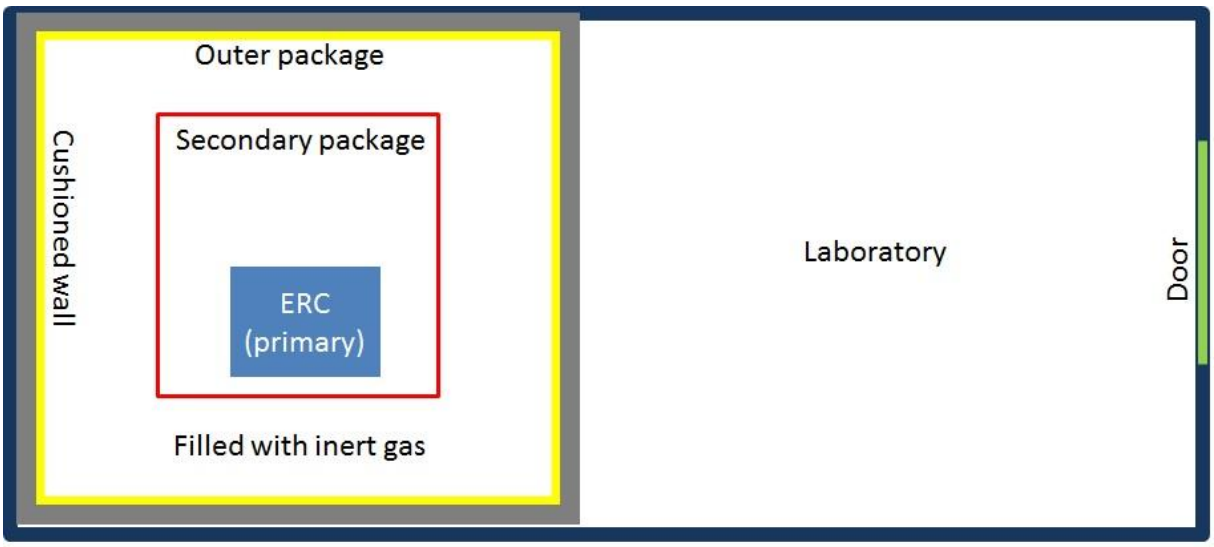

Figure 5. Schematic view of transportation box structure for restricted mission. The ERC is enclosed in a secondary package (Neoflon bag), in turn enclosed in the outer package (metallic alloy), having cushioned walls and filled with an inert gas. The ISO container includes both the triple package and instrumentation for controlling contamination, environment and motion.

5.4 Specificities of restricted missions

5.4.1 Biocontainment of the ERC for restricted mission

The potential release of returned sample material to Earth can only occur from a failure in the containment of the ERC i.e. non-nominal landing.

Recommendations:

- Design and build the biocontainer and ERC to withstand any impact forces that could occur during transit or landing.
- **Restricted Mission Infrastructure:** The recovery infrastructure may need to be single use, if there is a chance of contamination by a non-nominal restricted mission. It will need to be under a mission-appropriate level of security with restricted access.

5.4.2 Decontamination of the landing site

Decontamination of the landing site would only be considered if a breach in the ERC containment had been determined. Decontamination of soil to remove all viable microorganisms is very difficult and would be extremely costly, especially as the contaminated area would be difficult to determine. The decontamination process is easier for water, but contamination can spread over a wider area/volume making it almost impossible to contain and complete.

Recommendation: In the case of a non-nominal restricted mission, environmental monitoring of the site shall be undertaken and if the area was small enough, soil could be removed and incinerated.

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5.5 Restricted and Unrestricted Mission scenarios

Three mission scenarios (unrestricted mission, figure 6, nominal restricted mission and non-nominal restricted mission, figure 7) are proposed and functional flows of each scenario are shown.

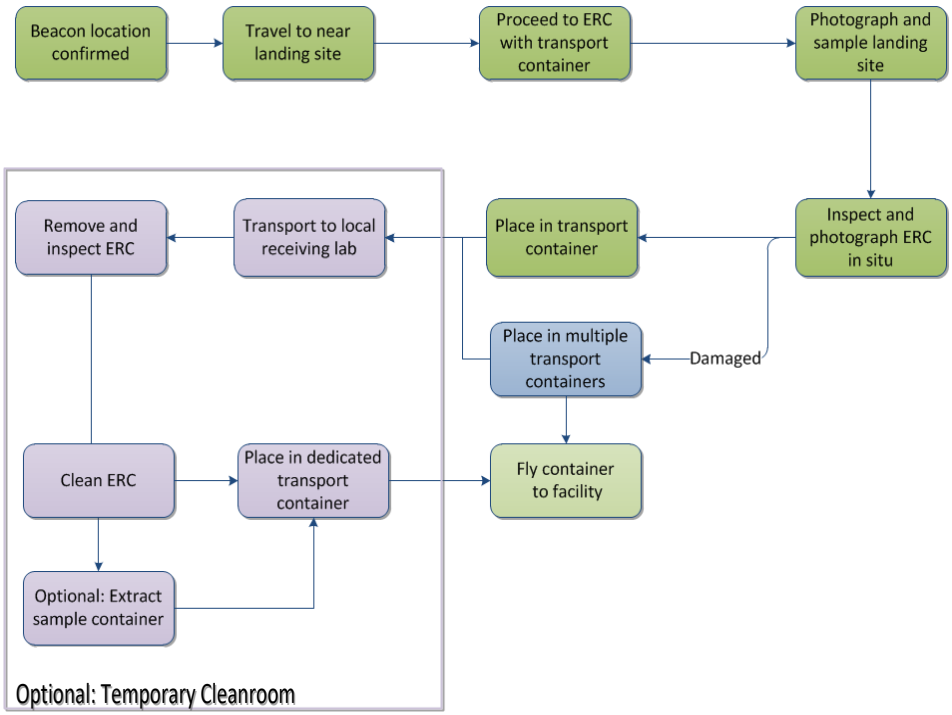

Figure 6. Functional flow for unrestricted missions

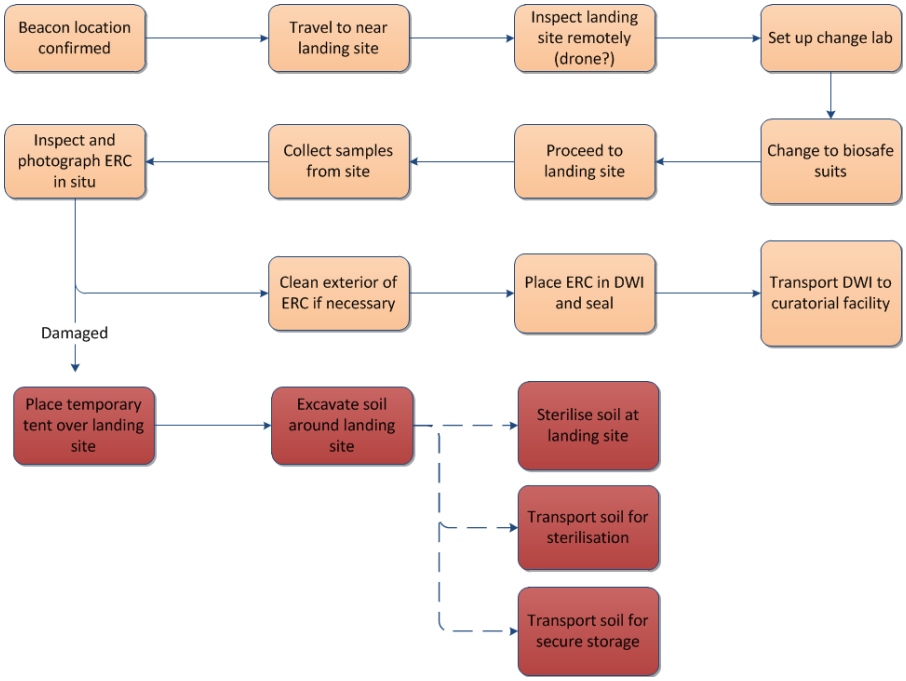

Figure 7. Functional flow for a Category V restricted mission (red section describes scenario for non-nominal mission)

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6 Keypoints on sample curation

6.1 Staff

The number of employees is highly dependent on the state of the ESCF (functional units built, mission arriving or already curated, etc.).

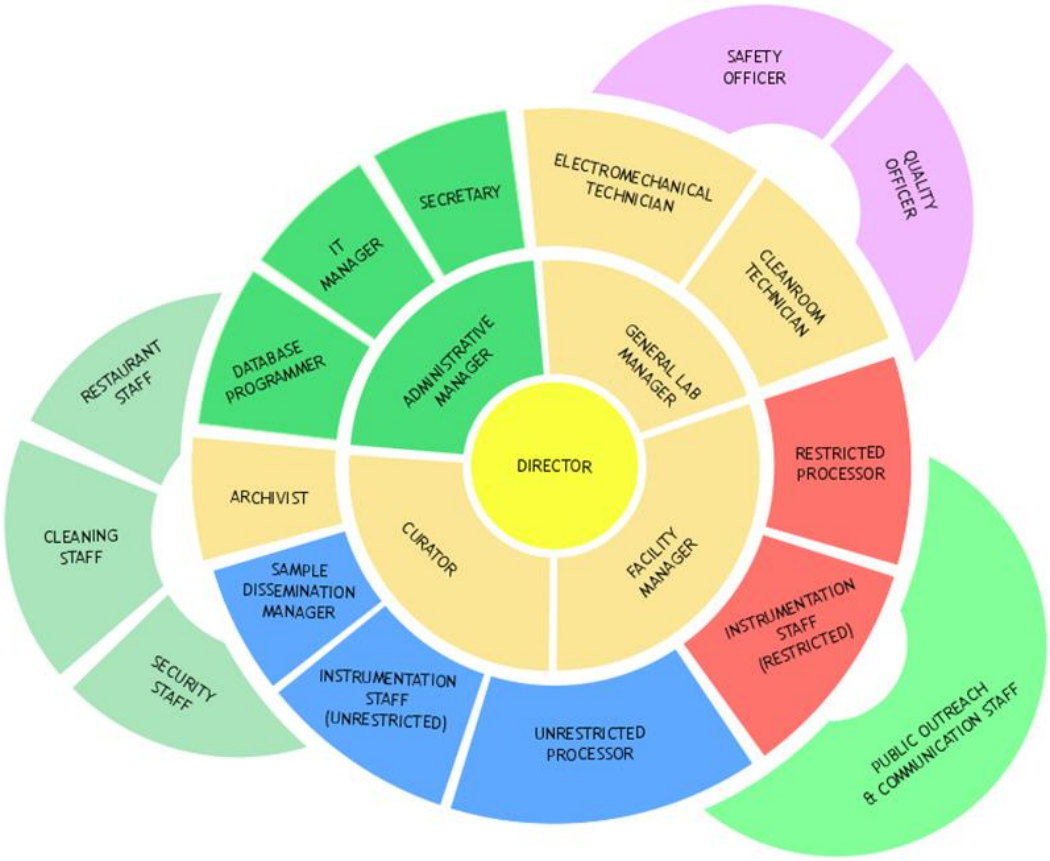

Figure 8. Proposed organigram of the ESCF.

In total, there is the need of between 30 and 50 staff to run the ESCF.

An increased number of personnel will be required at each mission arrival. These personnel may be a combination of permanent staff and visiting or contractual staff. Experience from previous sample return missions shows that there is intense pressure to obtain results quickly, and fatigue within science teams and technical staff is likely to be an issue. Accordingly, considerable attention shall be paid to developing plans for mitigating fatigue issues – for example, by having extensive training and a program of rotating staff, especially during the first few weeks to months before a sample return mission (for the recovery team) and after (for the ESCF team).

Recommendation: Health surveillance and blood banking shall occur during and after the collection and handling of the ERC, and during work at the facility. This applies in the case of a non-nominal restricted mission, and for work on restricted samples.

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6.2 BSL-4 hybrid laboratory and principles of high containment

BioSafety Level 4 (BSL-4) laboratories provide the highest level of biological containment. Containment is achieved through successive layers of protection. Primary containment is the primary enclosure containing the pathogenic agent and protecting the workers in the immediate laboratory environment. Secondary containment is the use of the laboratory design, construction, engineering controls to protect the environment and other operators of the facility. Examples of secondary containment are the use of ventilation to create negative pressure and inflow of air, and the sealability of the laboratory structure itself.

Three possibilities for sample enclosures are considered. These approaches are not interchangeable, and shall be adapted to the work being carried out.

- Class-3 Microbiological Safety Cabinets (MSC), which can be linked in a line. Cabinets are kept at negative pressure where the worker uses gauntlets on the side of the cabinets to manipulate the infectious materials.
- Suited laboratory. Workers wear a positive pressure suit supplied with breathing air by umbilicals. Suits can be used with open-front MSC to confer extra protection to the worker and the samples from contamination during manipulation.
- Double-Walled Isolator (DWI), being the primary and secondary containment. This isolator is operated at negative pressure with all penetrations or seals being surrounded by an outer compartment at positive pressure. This solution requires robotic system for sample manipulation, since there is no opening for gloves.

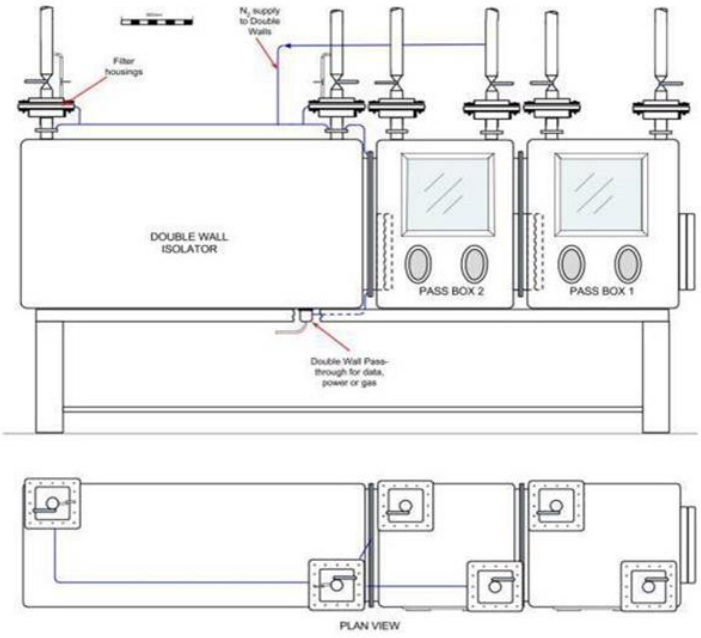

Figure 11. DWI preliminary concept design from Vrublevskis et al. (2016), http://euro-cares.eu/files/WP3_Vienna/Presentations/Vrublevskis_EUROCARES_WP3_2016_WIsystems_PRESENTATION.pdf

Figure 9. A cabinet line laboratory

Figure 10. Operators within a suited high containment laboratory

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7 Keypoints on infrastructure and design

7.1 Functional units of the ESCF

From the point of view of infrastructure and instrumentation, it is recommended to keep restricted and unrestricted facilities distinct.

To allow flexibility of the ESCF (in term of timeline and/or location) and to design some possible different layouts, a list of independent "high-level" Functional Units (FU), each fulfilling a unique function, was defined. Working space and public outreach have been kept separated, again to allow modularity and flexibility.

Portable Receiving Facility (PRF) and Remote Storage (RS) are not to be built on the site of the ESCF, contrary to the Sample Receiving Facility (SRF), the Sample Curation Facility (SCF), the Analogue and Mock-Up Facility (AMUF) and the accommodation units.

Table 1. FU for the ESCF. Red is used for scientific FUs dealing with potentially biohazardous samples. Blue is used for scientific FUs dealing with unrestricted samples. Yellow is used for the last scientific FU, which will host only terrestrial samples. Green is used for accommodation of people.

PRF Unrestricted	PRF Restricted	Assessing, cleaning and packaging the spacecraft on the landing site. Delivery of the spacecraft to SRF.
SRF Unrestricted	SRF Restricted	Receiving the sample container, cleaning and opening of the outer layers and delivery of the unopened sample canisters to the curation facility. Clean environment. For restricted samples, containment environment required.
SCF Unrestricted	SCF Restricted	Receiving of the sample canister, accessing the samples. Preliminary Examination (sample and hardware) and Sample Early Characterisation, Curation and Dissemination. For restricted samples, Life Detection and Biohazard Assessment Protocol. Ultra-clean environment. For restricted samples, high containment environment required.
Work Space		Support space for workers (offices, meeting rooms, social rooms, etc.).
Public Outreach		Space accessible to the public (different categories of public, TBD) to promote the activities of the ESCF.
AMUF		Personnel training, instruments and protocols testing on analogue samples. Material testing for cleanliness and containment suitability.
RS Unrestricted	RS Restricted	Storage under static atmosphere of a TBD part of the samples. Clean environment. For restricted samples, contained environment.

The combination of FUs shall be considered to present the most efficient use of resources and space, whilst providing the necessary scientific benefit to the projects handled within the facility. The facility shall also be built with the idea of future proofing to ensure the minimum amount of work is required in the future. Although any meaningful combination of units, at any time, shall make sense structurally, technically and architecturally, some scenarios are more likely than others and are discussed below.

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The proposed sequence of build is:

- Step 1/ AMUF laboratory with enough offices, to test protocols and to train staff.
- Step 2/ Either Restricted Laboratories or Unrestricted Laboratories, with extension of offices unit (if necessary).
- Step 3/ The other scientific laboratories, with extension of offices unit.

Public Outreach shall be considered from the beginning.

7.2 Flexibility

Flexibility is seen as one of the most important concept to be considered for such an ESCF. We developed this concept at several levels, with the requirement of future extensions and expansion. Each core function of the ESCF shall be inked to a specific functional unit. These units shall be linked in different ways:

- "Campus" scale: units shall be linked in a way that allows the efficient flow of personnel and materials. Any meaningful combination of units, at any time, shall make sense structurally, technically and architecturally. This flexibility is important as long as the funding and building status is not better defined, to allow for different working scenarios. It can also be a way to adapt to a change of mission politics, or to the failure of a mission.
- "FU" scale: one unit shall be easily adaptable for future developments and expansion of activities and utilities (mechanical, electrical, etc.). In most of the similar facilities, non-scientific rooms (i.e. usually work spaces or public outreach spaces) are retrofitted after some time to accommodate new missions or science goals. It lessens the functionality and reduces the well-being of workers.
- "Room" scale: some rooms shall allow for easy restructuring or change of the activity to be conducted inside. It shall be stated here that a given laboratory will need to be completed years before the return of the samples. Consequently, without knowledge of the exact nature of the samples or of the condition of the sample inside the containers (see e.g. NASA's Genesis sample return mission), the laboratory shall be easily adaptable (e.g. by adding new instruments that were not originally planned for).

7.3 ESCF Site layouts

Onsite FUs (all excluding PRF and remote storage) can be arranged following various designs (see Fig. 12). A trade-off does not permit to identify the best solution easily.

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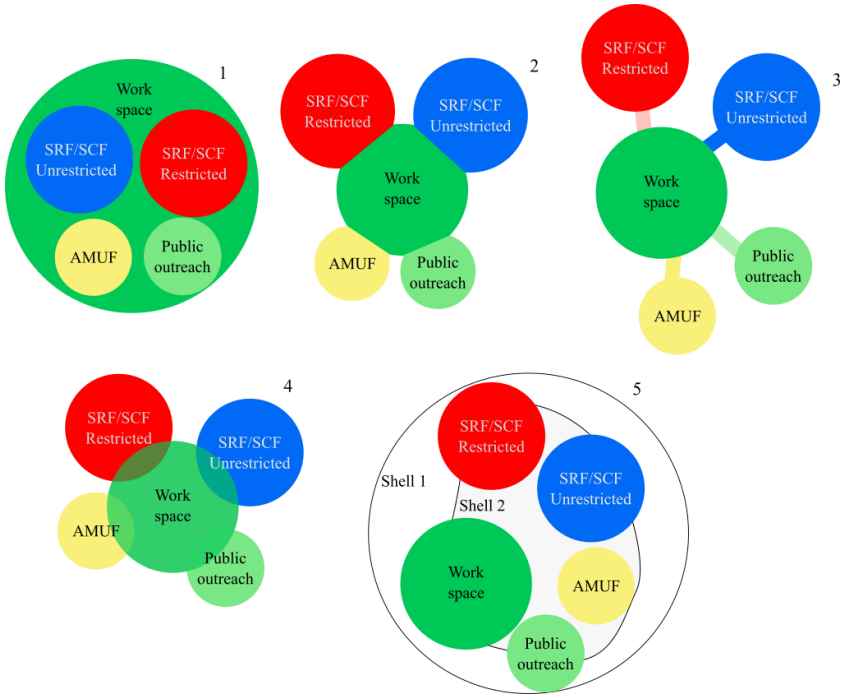

Figure 12. Design approaches for all onsite FUs. 1/- Single building, 2/ Puzzle, 3/ Bridges, 4/ Docking station, and 5/ Shell.

7.4 Scientific units' functional layout

Taking into account the workflows and the design requirements, functional layouts were produced for the AMUF and for the unrestricted and restricted SCF/SRF.

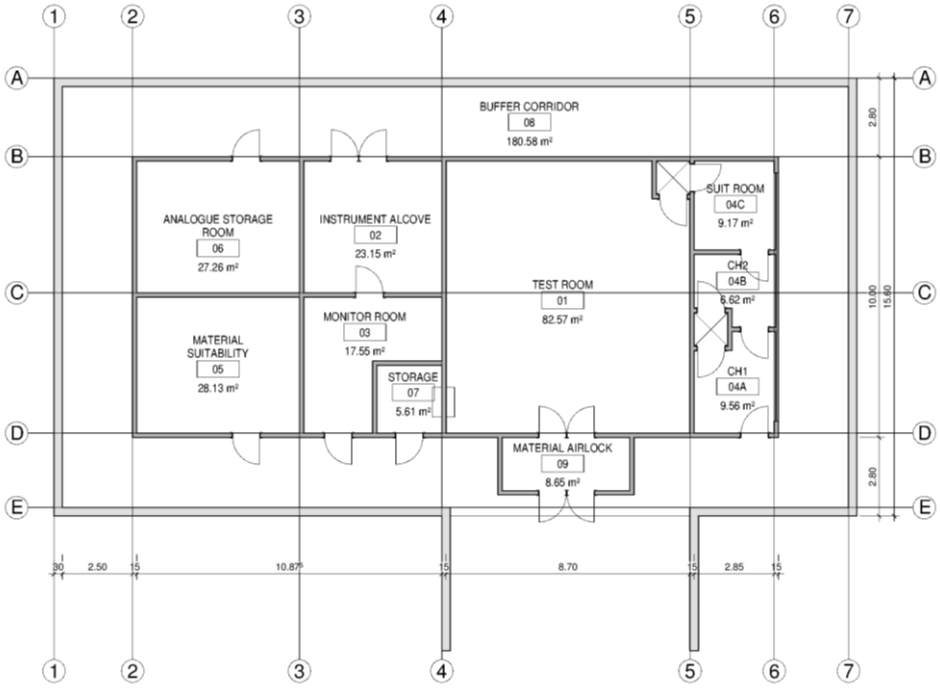

Figure 13. Analogue/Mock-Up Facility function layout.

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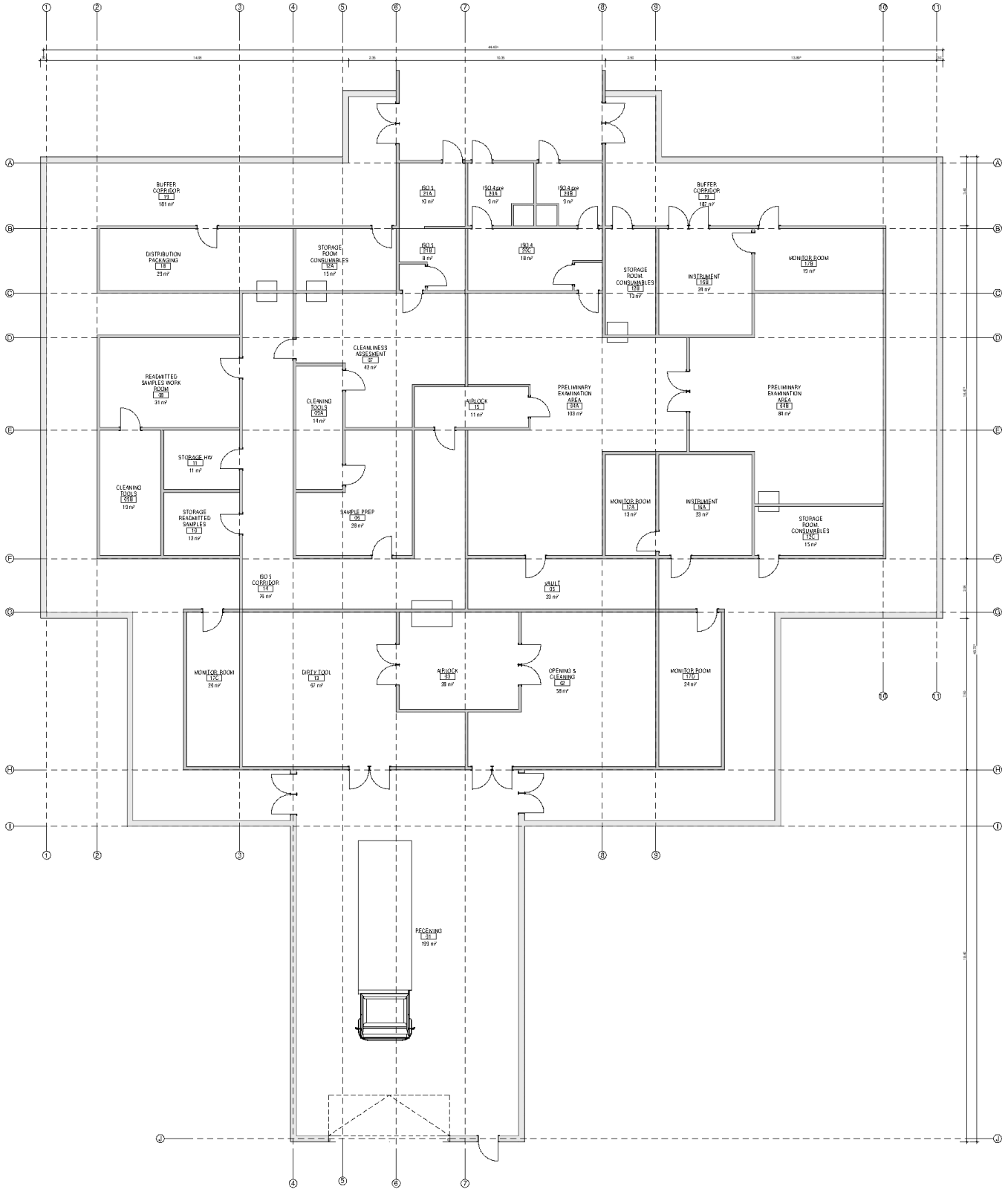

Figure 14. Unrestricted SRF and SCF functional layout.

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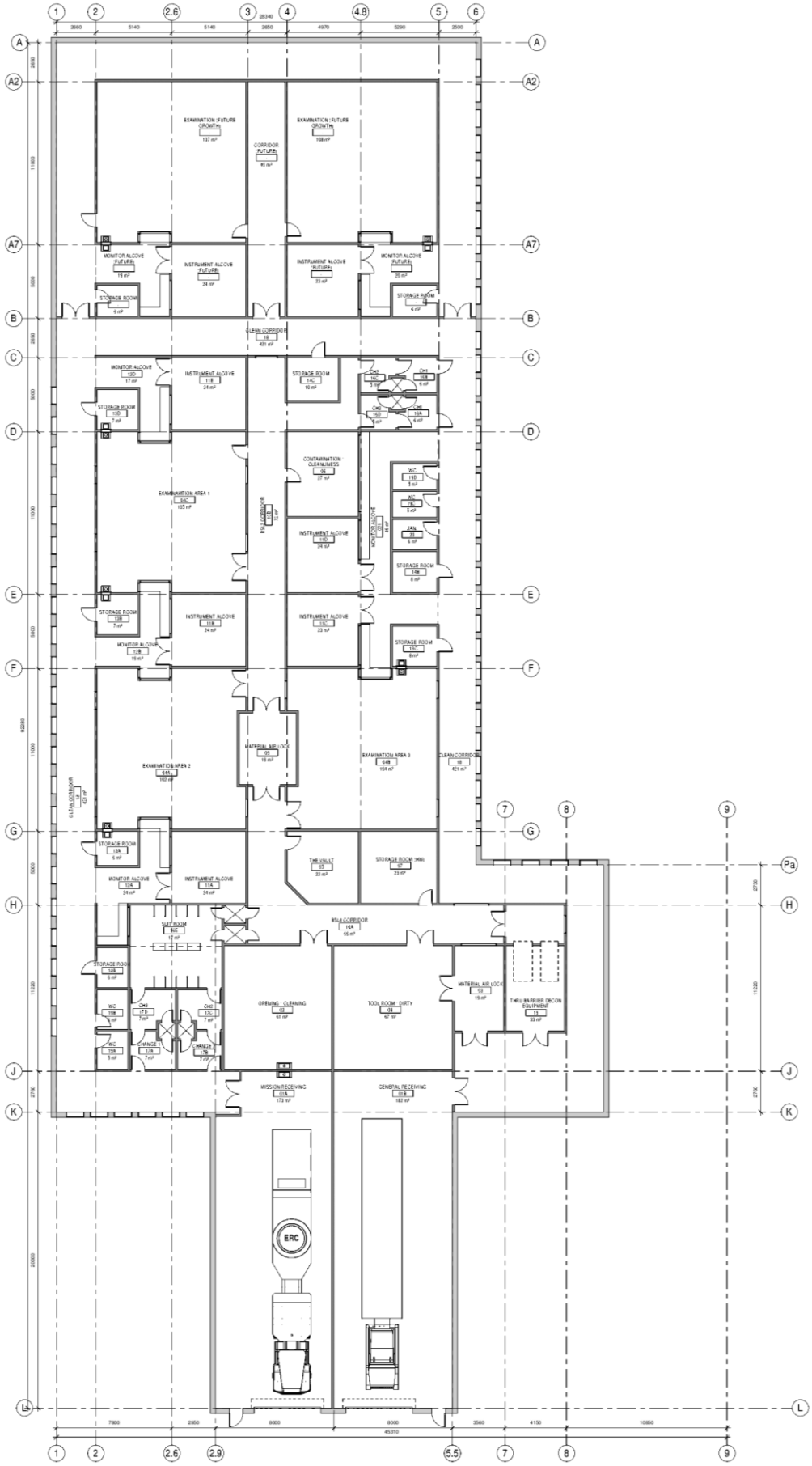

Figure 15. Restricted SRF and SCF functional layout.

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8 Keypoints on analytical work

In the case of unrestricted samples, the consensus is to keep SEC to a minimum, and to encourage PE and then scientific investigations by allocating samples to external laboratories.

In the case of restricted samples, the allocation is limited because of planetary protection requirements. Samples can be sent to external laboratories only if efficiently sterilized, or in specific sealed containers.

Instruments in italic are optional.

8.1 Sample characterization and analysis

Table 2. Instruments for cataloguing and documentation	
Instrument	**Comments**
Low magnification microscopes	Multiple microscopes required
High magnification microscopes	Petrographic and materials
3D imaging/shape profiler	Technology development
High precision balances	Multiple required, large mass range
Scanning near field optical microscope (SNOM)	*Only for small samples (≤few micron particle size)*

Table 3. Instruments for Sample Early Characterisation (SEC)	
Instrument	**Comments**
FTIR microscope	Spectral imaging detectors, rapid high resolution
Laser Raman microscope	UV resonance Raman useful for organic analyses
X-ray CT (sample)	Separate X-ray CT for sample container
Micro X-ray diffraction	May be superseded by spectral X-ray CT advances
Analytical SEM	Multi-detector environmental SEM for insulators
Focused ion beam SEM	*Only for small samples?*
Analytical TEM	*Only for small samples?*

8.2 Sample preparation

Samples have to be prepared for characterization and further analysis, whether within the ESCF or for external loan.

Table 4. Instruments for sample preparation	
Instrument	**Comments**
Sputter coaters	C & noble metals for SEM
Microtome	Primarily for small sample sizes
Ion Micromills	Primarily for small sample sizes
Micromanipulators	Electro-static tips, micro-tweezers for different sizes
Integrated preparation systems	High precision cut, grind and polish system
High precision saws	Diamond wheel (band saw for large samples)?
Grind and polish systems	Automated high precision systems for thin sections

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8.3 LD and BAP for restricted samples

A list of potential biosignatures has been produced, with their occurrence and relevance to LD and BAP. Instruments below have been chosen to cover the largest spectrum of biosignature testing. A key question is to determine if current instrumentation capability in microbiology and clean room facilities used for life detection is appropriate for an extra-terrestrial sample curation facility, and to which extent it shall be adapted. More traditional techniques such as organism direct culture, cell culture and animal models can be used. These last techniques will most likely only be used if signs of life are determined using the instruments and techniques below.

Table 5. Instruments for life detection and biohazard assessment protocols

Instrument	Comments
Optical microscopy	Morphological biosignatures
Electron microscopy - SEM	Morphological biosignatures
Gas chromatography–mass spectrometer (GC-MS)	Chemical biosignatures
Liquid chromatography–mass spectrometer (LC-MS)	Chemical biosignatures
Mass spectrometer, matrix-assisted laser desorption/ionization (MALDI)-Time Of Flight (TOF)	Chemical biosignatures
Fluorescence microscope	Chemical biosignatures
Raman spectrometer	Chemical biosignatures
High Performance Liquid Chromatograph (HPLC)	Chemical biosignatures
Polymerase Chain Reaction (PCR)	Biochemical biosignatures
Enzyme-linked immunosorbent assays (ELISA)	Biochemical biosignatures
Fluorescenct in-situ hybradization (FISH)	Biochemical biosignatures
Sequencing	Biochemical biosignatures
Chromatography	Biochemical biosignatures
Protein microarray / Marker Chip	Biochemical biosignatures
Secondary ion mass spectrometer (SIMS)	Isotopic biosignatures
Isotope Ratio Mass Spectrometer (IRMS)	Isotopic biosignatures
^{13}C-Nuclear Magnetic Resonance (NMR) spectrometer	Isotopic biosignatures
SEM-EDX	Mineralogical biosignatures
X-Ray Fluorescence (XRF) spectrometer	Mineralogical biosignatures
X-Ray CT	Mineralogical biosignatures
X-Ray Diffraction (XRD) spectrometer	Mineralogical biosignatures

8.4 Contamination control

Table 6. Instruments for contamination control and contamination knowledge

Instrument	Comments
Time Of Flight-SIMS	Surface contamination in situ
Gas Chromatography-MS	Chemical characterization
Liquid Chromatography-MS	Chemical characterization
ICP-MS	Elemental abundances
X-ray Photoelectron Spectroscopy	In situ surface contamination
Elemental Analysis-MS	C, N abundance
Residual Gas Analysis-MS	Continuous environment monitoring
Particle Counters	Continuous environment monitoring

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Optical microscopes	particle counting and size distribution on witness plates
Analytical SEM	idem + chemical characterization of contaminant particles

8.5 Analogue samples

Analogue samples (sensu lato, s.l.) are necessary in a curatorial facility for testing sample handling, storage and preparation techniques, and also to train workers. They are also a useful tool for public outreach activities.

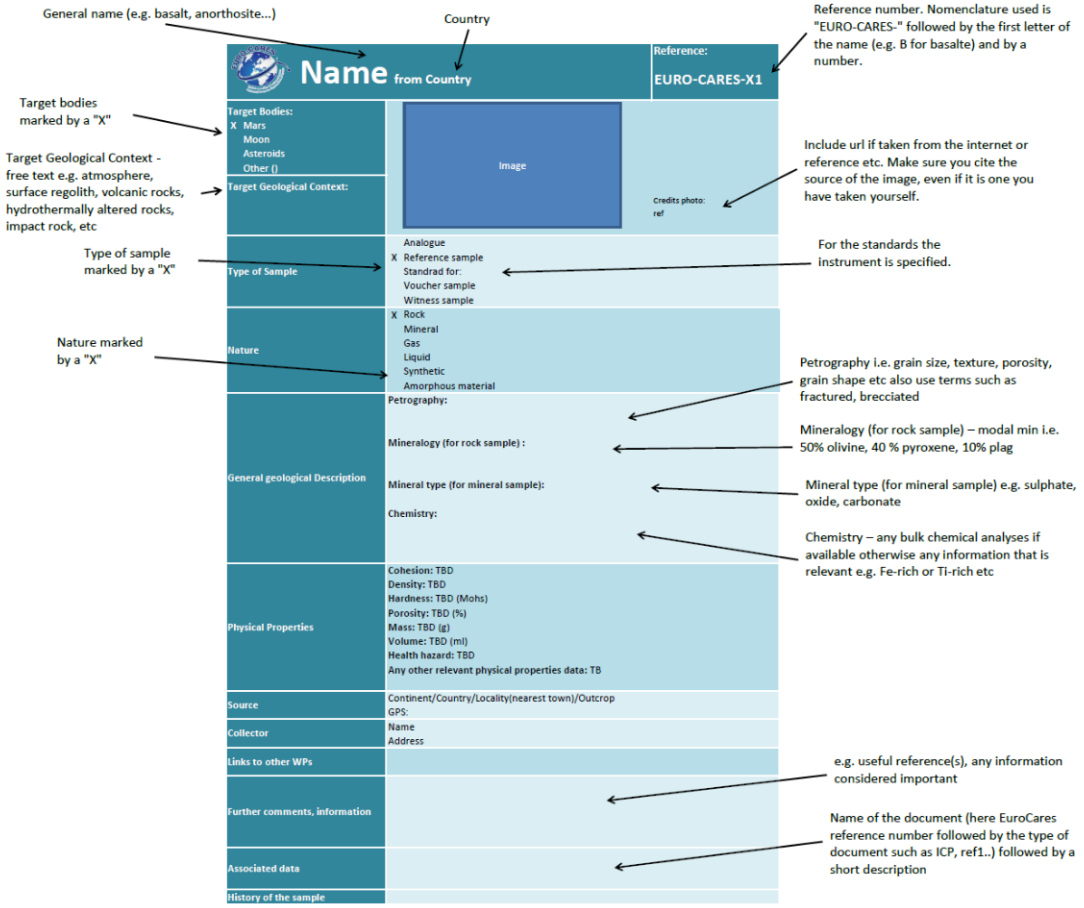

Figure 16. Example of a spreadsheet of the analogue database.

We distinguish five different types of analogue samples (s.l.), namely analogues (sensu stricto, s.s.), witness plate, voucher specimen, reference sample, and standards.

- **Analogues (s.s.)** are materials that have one or more physical or chemical properties similar to returned extraterrestrial samples.
- **Reference samples** are well characterized materials with known physical/chemical properties used for testing of the whole process or part of it. They may not necessarily be the same materials as the analogues defined above.
- **Standards** are internationally recognized, homogeneous materials with known physical/chemical properties that are used for calibration (e.g. silicon for Raman spectrometry). They can also be used as reference samples in certain circumstances. They may be made of natural materials but are often produced artificially.

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- **Voucher specimens** are a duplicate of materials used at any stage during sample acquisition, storage, transport, treatment etc., e.g. space craft materials (including solar panels), lubricants, glues, gloves, saws, drills, etc.
- **Witness plates** are defined materials left in an area where work is being done or assessed for e.g. biological, particulate, chemical, and/or organic contamination. They are spatial and temporal document of what happens in the work area.

A shortlist of analogues (s.l.) can be found on the EURO-CARES website: http://www.euro-cares.eu/wp5/database/database2.php

8.6 Integration of instruments within the facility

Instruments shall be compatible with operation inside clean rooms. Each instrument shall be assessed for contaminants, for materials (and whether it is necessary to replace some parts with authorized materials), and for how it can be used within a glovebox or a DWI, inside of the laboratory space, or if it shall be kept outside of the clean and/or contained space (i.e. using through-barrier technologies). Principle of the latter is presented below (see Fig. 18).

Recommendation: follow up on through-barrier technologies, and study adaptation of the various instruments to be used in the ECSF.

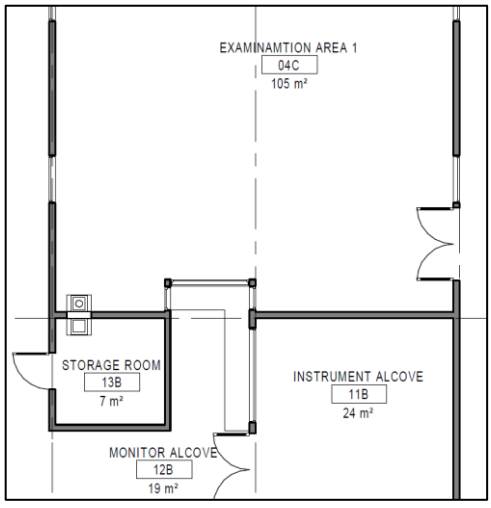

Figure 17. Close-up on the functional layout of the restricted SCF.

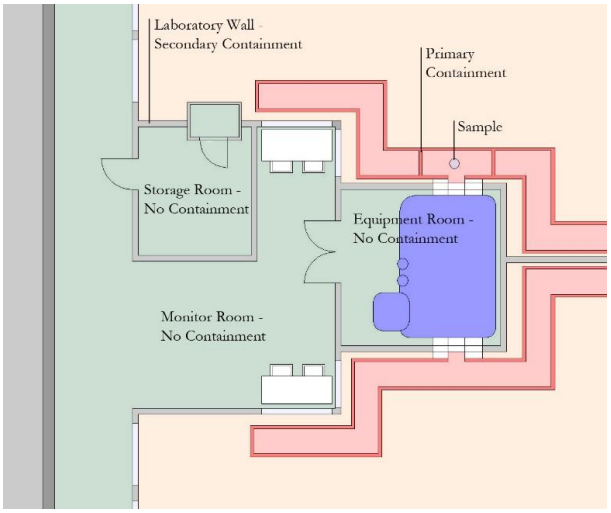

Figure 18. Scheme of a villus, using through barrier-technology to keep instruments outside of the laboratory.

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9 Innovations

9.1 Sample recovery

Innovations cover the restricted return procedure, the decontamination of a landing site, the portable covering of the landing site, the training of staff for a biocontainment recovery, an autoclave/incinerator, the ISO biocontainer and the transport box.

The criticality of each development has been examined and the most critical procedures and components are:

- The landing site selection
- The regulations for the host country
- The detailed design of the transport box
- The design of the transport ISO container
- The staff training and rehearsal time
- The selection of non-outgassing materials for the transport box.

Most of the concepts are at a low readiness level in Europe, but they are not substantial technical challenges. Many have already been demonstrated by other agencies. The challenge is to prepare all equipment and procedures to a suitable timeline. The initial activities would be:

- Performing trade-off analysis/ detailed design of transport box.
- Identification & procurement of an autoclave/incinerator
- Negotiate landing site location
- Demonstration of practicality and sterilisation of landing site soil.
- Identification of training needs.

9.2 Curation

Robotic systems continue to evolve at an incredible speed, now allowing things to be done that would not have been even envisioned a few years ago. Investigating further the use of robotics is recommended, especially cobots (collaborative robots) and haptic feedback devices for restricted sample handling.

Optical tweezers and others laser-based manipulation techniques shall be further studied and tested.

9.3 Analytical work

Through-barrier technologies shall be adapted to instruments non-suitable for cleanroom environment, or that could not sustain decontamination processes in-between samples.

A comprehensive updated draft for test and protocols on restricted samples shall be proposed.

"Non-destructive" analyses shall be reviewed to assess the impact on sample properties. Analyses could then be ordered in time.

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10 Conclusion

This deliverable is an interim technical report which summarizes the work of the EURO-CARES technical work packages.

For each different aspect of the design of a European Extra-terrestrial Sample Curation Facility (samples recovery and transportation, samples curation, infrastructure and design, samples examination, planetary protection, analogues), only the main key points and recommendations have been here presented, to keep the document as short and readable as possible. For more details, the readers are invited to see the several technical deliverables, available on EURO-CARES web site (http://euro-cares.eu/reports).

Since currently, no single facility exists, worldwide, that allows the containment required for samples returned from COSPAR Category V Restricted bodies and since it is impossible to completely foresee all the actual risk factor, the challenge has been to identify the whole set of infrastructures, procedures, protocols and instrumentation, to manipulate and store the samples. At the same time the proposed set of technical and scientific solutions has been designed in order to provide an adequate level of flexibility to deal with samples also returning from unrestricted bodies (no mission centered), so as to be applied in different countries of Europe, taking into account of the different laws and regulations (no country centered).

The final technical report of EURO-CARES Project (D7.2, due on month 36, December 2017), will give a fully comprehensive description of all the aspects studied during the 3-year project.

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