EURO-CARES

D7.2 Final Technical Report

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EXECUTIVE SUMMARY

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EURO-CARES (European Curation of Astromaterials Returned from Space) was a multinational, three year project running from January 2015 to December 2017, funded by the European Commission Horizon 2020 programme (Project ID# 640190). The project involved 6 different countries and 14 different institutions. The objective was to roadmap a European Sample Curation Facility (ESCF) that would be suitable for the curation of material returned from the Moon, Mars and asteroids. While there have been previous studies specific to particular missions, countries, or target bodies, this was the first project to bring together scientists and engineers from across Europe to plan a single facility that would fit the needs of European sample return missions over the next decades. We planned the pathway of our returned samples from the landing site and transport to the facility, to their early and preliminary examination and long-term storage.

With this broad remit, we chose keywords for our ESCF: Flexible, Adaptable and Modular, to guide our planning. This would allow the ESCF to adapt to a wide variety of missions with samples of different sizes and forms, from restricted or unrestricted missions. The ESCF would also house a comprehensive suite of relevant analogue samples. Such a facility would be well placed to respond to the requirements of future sample return missions. Each mission or task is linked to a Functional Unit in our ESCF to allow a modular approach to the ESCF building. Much of our work has focused on the planetary protection aspects of restricted missions. Bringing back samples from Mars would require a new generation of curation facility, capable of controlling contamination of the samples so that they remain pristine, and preventing contamination from the sample from reaching the outside environment. Communications and public engagement will also be an essential element of the ESCF and at the heart of its operations.

During the project it has become apparent that there is a need for future innovations to prepare for the ESCF. We strongly recommend that the planetary protection protocols, now more than 15 years old, are updated in accordance with new generation instrumentation and our better understanding of planetary protection requirements. We note that innovations are required to assist with sample transfer, especially for restricted samples, and see scope for the use of robotics in curation to increase accuracy, control contamination and work in a wide range of environments.

We conclude that the ESCF would require a staffing level of 30-50 people and that work to begin on this should start at least 7 years prior to the samples being returned to Earth. The cost of the ESCF would range from 10-20 M€ for an unrestricted facility, to over 100 M€ for a complete ESCF for unrestricted and restricted samples. This is still a minor cost compared that of the total mission. Our next steps will be to seek a route for funding for the development of the ESCF. Large scale projects such as this would be an appropriate project for inclusion in the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap. All future work should be overseen by the European Space Agency to ensure that their mission requirements are met and to reduce duplication of effort.

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ACRONYMS AND ABBREVIATIONS

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AMUF	Analogue/Mock-Up Facility
ASI	Agenzia Spaziale Italiana
ASRS	Automated Storage and Retrieval System
BAP	Biohazard Assessment Protocol
BSL	BioSafety Level
CBM	Centre de Biophysique Moléculaire
CNRS	Centre National de la Recherche Scientifique
COSPAR	COmmittee on SPAce Research
CRPG	Centre de Recherches Pétrographiques et Géochimiques
CT	Computerized Tomography
DLR	Deutsches Zentrum für Luft und Raumfahrt
DWI	Double Walled Isolator.
Dx.x	Deliverable x.x
ERC	Earth Return Capsule
ESA	European Space Agency
TCR	Temporary Clean Room
ESCF	Extra-terrestrial Sample Curation Facility
ESD	Electrostatic Discharge
ESF	European Science Foundation
EURO-CARES	EUROpean Curation of Astromaterials Returned from Exploration of Space
EXA	Exposed to Air
EXD	Exposed to Dust
EXW	Exposed to Water
FFI	Flexible Film Isolators
FFU	Fan Filter Unit
FIB	Focused Ion Beam
FPA	Focal Plane Array
FTIR	Fourier Transform Infrared Spectroscopy
FU	Functional Unit
GC-MS	Gas Chromatography-Mass Spectrometry
HAZOP	HAZard and OPerability study
HEPA	High-Efficiency Particulate Arrestance
HSE	Health and Safety Executive
HVAC	Heating, ventilation and air conditioning
IAPS	Istituto di Astrofisica e Planetologia Spaziali
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INAF	Istituto Nazionale di Astrofisica
IPA	IsoPropyl Alcohol
IR	Infra-Red
ISO	International Organization for Standardization
JAXA	Japan Aerospace eXploration Agency
JSC	Johnson Space Center
LaARF	Lunar and Asteroid Receiving Facility
LC-MS	Liquid Chromatography–Mass Spectrometry
LD	Life Detection
LDS	Life Detection Samples
LEI	University of Leicester

LOPA	Layer Of Protection Analysis
LPF	Laboratory Protection Factor
LSPET	Lunar Sample Preliminary Examination Team
MNHN	Museum National d'Histoire Naturelle, Paris
MOOC	Massive Open Online Course
MS	Mass Spectrometry
MSC	Microbiological Safety Cabinets
MSHARP	Mars Sample Handling And Requirements Panel
MSR	Mars Sample Return
MSRF	Mars Sample Return Facility
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NHM	Natural History Museum, London
NHMW	Naturhistorisches Museum Wien
NIH	National Institutes of Health
NRC	National Research Council
OSIRIS-REX	Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer
OU	Open University
PISA	Dipartimento di Scienze della Terra, Università di Pisa
PBS	Product Breakdown Structure
PE	Preliminary Examination
PES	Preliminary Examination Samples
PHE	Public Health England
PMSCF	Planetary Material Sample Curation Facility
PP	Planetary Protection
PP	Polypropylene
PPE	Personal Protective Equipment
PPL	Planetary Protection Level
PRF	Portable Receiving Facility
PS	Preserved Samples
PTFE	PolyTetraFluoroEthylene
PTS	Polished Thin Section
QLF	Quick Look Facility
REC	Risk of Environmental Contamination
RIC	Risk of Internal Contamination
RM	Remote Manipulation
RRC	Risk of Refrigerant Contamination
SCF	Sample Curation Facility
SEC	Sample Early Characterisation
SEM	Scanning Electron Microscope
SENCK	Senckenberg Gesellschaft für Naturforschung
SIMS	Secondary Ion Mass Spectrometry
SNOM	Scanning Near field Optical Microscope
SRC	Sample Return Canister
SRF	Sample Receiving Facility
STIFF-FLOP	STIFFness controllable Flexible and Learnable manipulator for surgical Operations
SWIFT	Structured What IF Technique
TAS	Thales Alenia Space
TBD	To Be Decided

TEM	Transmission Electron Microscope
TOF-SIMS	Time-of-Flight Secondary Ion Mass Spectrometry
TRL	Technology Readiness Level
TS	Total Sample
ULB	Université Libre de Bruxelles
ULPA	Ultra Low Penetration Air
UP	Utility Plant
UPS	Uninterruptible Power Supply
URS	User Requirements Specification
UXO	Unexploded Ordnance
UV	Ultraviolet
VEC	Verified Environmental Contamination
VIC	Verified Internal Contamination
VRC	Verified Refrigerant Contamination
WHO	World Health Organisation
WP	Work Package

INTRODUCTION

1 INTRODUCTION

1.1 The EURO-CARES Project

EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space; Figure 1.1) was a three year (2015-2017), multinational project, funded under the European Commission's Horizon2020 research programme (Project ID# 640190). The objective of EURO-CARES was to create a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility (ESCF). There have been previous studies, some funded by the European Space Agency, which have typically been either country-specific or mission/target specific. EURO-CARES moved on from these studies to look at what would need to be done to create a European facility that would be suitable for the curation of samples from all possible return missions likely over the next few decades, to the Moon, asteroids, Mars, and other bodies of the Solar System.

Study and long-term curation of extra-terrestrial samples requires keeping samples in as clean an environment as possible to reduce any terrestrial contamination. For samples returned from restricted missions (Mars, Europa, Enceladus) there will be an additional requirement for high level containment to ensure potential biohazards are not released from the facility. The requirements for a combined high containment and ultraclean facility will naturally lead to the development of a highly specialised and unique facility that will require the development of novel scientific and engineering techniques.

Figure 1.1 - The EURO-CARES Logo

The first phase of EURO-CARES was a literature review (January 2015 to June 2015), followed by a technical phase (July 2015 to March 2017), and finally, synthesis (April 2017 to December 2017). One work package, focused on public outreach, was active throughout the project. The work was organized around five distinct technical Work Packages (from WP2 to WP6), led by academic institutions, scientists and engineers from all over Europe:

- Knowledge capture and requirements review (WP1)
- Planetary protection (WP2)
- Facilities and infrastructures (WP3)
- Methods and instruments (WP4)
- Analogue samples (WP5)
- Portable receiving technologies (WP6)
- Synthesis, recommendations and roadmapping (WP7)
- Maximising impact (WP8)
- Management (WP9)

The overall organization of the project is shown in Figure 1.2.

The EURO-CARES website (www.euro-cares.eu) collects all the information and the outcomes of the project. Some general information about the EURO-CARES WPs is presented in the Appendices of this Deliverable.

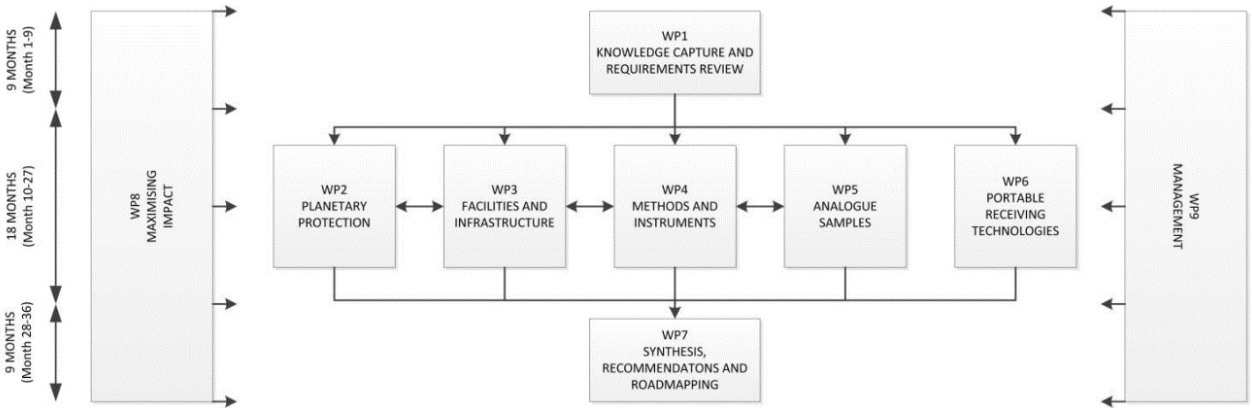


Figure 1.2 - EURO-CARES overall work structure

1.2 Sample Return Missions and Facilities

1.2.1 Overview

The instinct to explore is at the heart of the human condition. In the 21st century, we have the opportunity to explore new worlds by mounting space missions to our Moon, other planets and their moons and to other minor bodies in the Solar System such as asteroids and comets. Visiting these worlds provides much more information than can be gained from observing them remotely, and potentially provides the opportunity to bring pieces of these other worlds back to Earth.

Sample return missions are among the most exciting of space missions, providing both scientifically unique information and an unparalleled mechanism for inspiring the public. Returned samples from spacecraft allow us carry out sophisticated analyses using a wide range of scientific equipment that can enhance remote sensing measurements from spacecraft. Some scientific studies can only be done in laboratories on Earth rather than remotely or with spacecraft. These investigations include precise isotope measurements that allow age dates to be determined or a chemical history to be unravelled. Similarly, detailed measurements of organic material can help us understand whether life has been present elsewhere in the Solar System.

1.2.2 Planetary Protection

One of the most important issues surrounding sample return missions is the requirement for Planetary Protection (PP). This guides the design of a mission, aiming to prevent biological contamination of both the target celestial body and, in the case of sample-return missions, the Earth. 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 the astrobiologically-interesting planets and moons of our Solar System by preventing contamination with terrestrial micro-organism or organics and thus removing the possibility of 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 aspects have been considered, forward PP on samples collected and then returned, and backward PP during transport and curation phases.

COSPAR defines 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. samples from the Moon) or restricted Earth return mission (e.g. 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 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 stored under specific conditions (depending of their origin) so they remain as pristine as possible. At the same time, for restricted missions, the Earth environment must also be protected from potential hazards. Currently, worldwide, no single facility exists that allows containment of restricted materials, as would be required for a sample receiving facility for materials returned from 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, procedures, protocols and instrumentation, sample handling, as well as staff training shall all be adapted to PP requirements.

1.2.3 State of the Art and Future Sample Return Missions

A sample return mission has the goal of collecting and returning samples from an extraterrestrial location to Earth, for analysis in ground-based laboratories. Material brought back may range in size from atoms and molecules (e.g., the Genesis collector assembly exposed to the Solar Wind) to a mixture of loose material ('regolith') and rocks (e.g., the Apollo samples from the Moon). Samples may be obtained in a number of ways, including arrays used for capturing particles of solar wind or cometary debris, impact excavation of regolith, drilling and coring of solid rock, etc.

Samples have been returned by spacecraft from the Moon, an asteroid and a comet, as well as the solar wind. Material from Earth's Moon was collected by robotic and human sample return missions, whilst the comet Wild 2 and the asteroid Itokawa were visited by robotic spacecraft. As well as material returned by spacecraft, we also have a rich harvest of meteorites that have fallen on Earth; whilst these are mostly from asteroids, there is a small but significant fraction from the Moon and from Mars. Table 1.1 shows the list of sample return missions that have already taken place.

Table 1.1 - Overview of past sample return missions

Mission	Year of Sample Return to Earth	Target	Returned Material	Country
Apollo	1969-1972	Moon	382 kg (Rock and regolith)	USA
Luna	1970-1976	Moon	326 g (Rock and regolith)	Russia
Genesis	2004	Solar Wind	Atoms implanted into various media	USA
Stardust	2006	Comet Coma (81P/Wild-2) and Interstellar Grains	Grains implanted into aerogel and impacted into Al foil	USA
Hayabusa	2009	S Class Asteroid (Itokawa)	1500 Grains	Japan

Over the next decade, there are clear opportunities for Europe to lead a sample return mission to the Moon, and to collaborate with other space agencies on sample return missions to asteroids and to Mars and its moons (Phobos and Deimos). ESA, as well as national and other international space agencies, have several

missions under study to these bodies. It is essential that a sample receiving and curation facility is considered as a critical element of the mission architecture and that its planning and design requirements are fully incorporated during the earliest phases of planning for each sample return mission. Previous work has indicated that from site selection to full-readiness for receiving Mars samples takes 8 - 11 years (iMARS, 2008). Table 1.2 shows potential future sample return missions.

Table 1.2 - Future sample return missions

Mission	Year of Sample Return to Earth	Target	Returned Material	Country
Chang'e 5	2018	Moon	2 kg	China
Hayabusa-2	2020	C Class Asteroid (1999 JU3)	tbc grams of regolith	Japan
Luna-Grunt	2020	Moon	Up to 1 kg	Russia
Osiris-Rex	2023	B Class Asteroid (Bennu)	60-2000 g rock fragments	USA
Mars Sample Return	2020s	Mars	500 g	USA/Europe
Mars-Grunt	2020s	Mars	200 g	Russia
CAESAR	2020s	67P/Churyumov-Gerasimenko Comet	100 g	USA
Phootprint	2025	Phobos	tbc grams of regolith	Europe/Russia
Lunar Sample Return	2020s	Moon, S.Pole Aitken Basin	tbc grams of regolith plus potential for core material (rock and ice)	Europe/Russia
MMX	2029	Phobos, Deimos	tbc grams of regolith	Japan

1.2.4 State of the Art in Sample Receiving and Curation Facilities

Curation is defined as:

'The collection, handling, documentation, preparation, storage and preservation (into the indefinite future) of samples and distribution of a sub-fraction of samples for research'.

While dealing with samples returned from space, the purpose of a sample receiving and curation facility is to take delivery of the returned spacecraft, open it up and extract the sealed sample container, open the sample container and recover the samples (rock, dust, headspace gas, etc.) from the sample container, and then to transfer samples to the curation laboratory. If applicable, depending of the origin of the samples, biohazard and life detection tests would also be conducted within the facility.

Sample curation facilities are currently operational at the NASA Johnson Space Centre in Houston, Texas (USA) and at the Planetary Material Sample Curation Facility (PMSCF) of the Japan Aerospace Exploration Agency (JAXA) in Sagamihara (Japan). As previously stated, neither of these facilities meet all the requirements for sample return missions from Mars (i.e. these facilities are not currently capable of handling restricted samples).

While JAXA curates asteroidal grains collected by the Hayabusa mission, the Johnson Space Centre curates several different types of sample:

- Moon rocks and regolith (Apollo)
- Solar wind atoms (Genesis)
- Comet coma dust grains (Stardust)

- Asteroidal grains (Hayabusa)
- Antarctic meteorites (ANSMET)
- Cosmic dust grains (using high flying aircraft)
- Microparticulate matter (impacted on spacecraft)

Before the EURO-CARES project, there were a few studies of similar European curatorial facilities; they were either country-specific (e.g., Counil et al., 2002) or mission/target specific (e.g., for Marco Polo-R; Brucato et al., 2012 and for Mars, Smith et al., 2010). The main objective of EURO-CARES is to move forward from these specific studies, to look at what would be required to create a European facility suitable for the curation of material from potential sample return missions planned over the next few decades to the Moon, asteroids, Mars and a comet.

1.2.4.1 Unrestricted Laboratories

Laboratories for unrestricted samples are cleanrooms designed to eliminate the possibility of contamination of the sample from the terrestrial environment (particulate, organic, microbiological, etc.). The usual approach for the design of a cleanroom is to start with the ISO norm for particulate contamination (relying on filtering the incoming air with high-efficiency filters and keeping the room under positive pressure), and to restrict as much as possible potential contamination from the materials and instruments used in the cleanroom. Any personnel accessing the facility would change into cleanroom clothing, so changing areas must be included in the design, including lockers for storage of outer clothing and belongings. Buffer corridors and increasing levels of cleanliness are used to step up to the cleanest part of the laboratory. This approach is already implemented at NASA JSC and JAXA (Yada et al., 2013).

1.2.4.2 Restricted Laboratories

Laboratories for restricted samples must address two big challenges: keeping the precious samples as pristine as possible (in the same way as for unrestricted samples), whilst also avoiding release of a potential biological or hazardous agent to the environment.

Containment of biological agents is a well-known process, with levels of containment adapted to known pathogens (WHO, 2004). The concept of a containment laboratory is to use successive layers of protection, safe practices of work and engineering controls (primary, secondary and tertiary) to ensure that aerosols of agents are not released to the environment or to workers.

Containment is provided by a high level of redundancy, by access control, barrier minimization and by an approved decontamination methodology; safe practices of work are also required to ensure these measures are used correctly and the worker reduces any possible risk of contamination from the start. For unknown pathogens, it is recommended that the highest level of containment, BSL-4, is adopted, and remains at this level until the samples are proven to be devoid of biohazard, or sterilised using a validated method (Rummel et al., 2002).

Rummel et al. (2002) proposes four planetary protection levels (PPL), combinations of containment and cleanliness conditions (Table 1.3). The levels of cleanliness associated with each PPL are to be determined and should be defined explicitly well in advance of sample return.

Table 1.3 - Anticipated laboratory conditions and PPL categories

PPL-type	Biocontainment	Cleanliness	"Ambient" conditions	Used for
PPL-α	Max. (BSL-4)	Maximum	1atm, inert gas	Incoming container and materials; some preliminary tests; sample bank/storage; some Life Detection
PPL-β	Max. (BSL-4)	Maximum	Earth-like	Life Detection; some physical/chemical; TBD
PPL-γ	Max. (BSL-4)	Moderate	Earth-like	Some Biohazard Assessment Protocol testing; some physical/chemical processing and animal testing
PPL-δ	Strict BSL-3-Ag	Ambient	Earth-like	Some Biohazard Assessment Protocol; post-release tests TBD

1.3 Planning for a European Sample Curation Facility

1.3.1 Main Activities

The European Sample Curation Facility (ESCF) is designed to undertake the activities defined as curation: 'Collection, handling, documentation, preparation, storage and preservation ('into the indefinite future') of samples, and distribution of a sub-fraction of samples for research.'

The main activities to be conducted inside the ESCF are:

- to receive the Earth re-entry capsule;
- to extract the sealed sample container(s) from the spacecraft;
- to extract the sample itself from the container;
- to store the sample(s);
- to characterise and curate 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.

1.3.2 Design Requirements

The ESCF will, ideally, be **flexible**, **adaptable** and **modular** to allow for:

- Samples from a wide variety of missions;
- Samples from different environments;
- Restricted and un-restricted samples.

The proposed set of technical and scientific solutions are designed to provide an adequate level of flexibility to deal with samples returned from unrestricted bodies (**no mission/target specific**), so as to be applicable in different countries of Europe, taking into account different laws and regulations (**not country specific**).

The proposed ESCF is designed to receive the sample return capsule after it lands, to access the containers and the samples, and to curate and store the samples, independently of the parent body and of the mission and of the mission classification (restricted or unrestricted).

Sample receiving and curation areas are separate for restricted and unrestricted samples.

The ESCF includes working space for curators, visiting researchers and staff. Public awareness and communication are part of the functions of the building, to manage in the best way the various stakeholders involved in the ESCF (Cohen, 2002).

The ESCF project plan proposes an integrated design for all functions listed above. The design will be sufficiently modular and flexible so that parts of the building can be added following a long-term building

timeline. To achieve this flexibility, different Functional Units ('FU') units within the ESCF have been defined and integrated into a non-exhaustive list of 'building scenarios', to test the modularity of the facility. A possible, original, architectural design (Häuplik-Meusburger and Lu, 2016) is included in the report.

Several locations could be envisioned for the ESCF, such as a 'remote location' (i.e. relatively far from uninhabited area), an existing research centre, 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 remodelled building(s).

The architectural layout shall encourage a pleasant working environment, meetings and communication between personnel to increase working efficiency and cooperation. Since cleanroom workers (personnel who work on samples) show significantly higher sick leave statistics than other personnel, this requirement shall not be overlooked.

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

The facility is designed 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.

1.3.3 Planetary Protection Requirements

In general terms, the facility will be designed, constructed and operated to prevent the release of biohazardous material and contamination of the samples by the Earth environment. It will also allow the samples to be studied by the international scientific community, either within the facility itself, or in external laboratories, through the 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 state that the probability of a single unsterilized particle of ≥0.1 µm being released from this facility shall be $\leq 1 \times 10^{-6}$ (ESF-ESSC Study Group, 2012).

The measures already employed for high containment facilities demonstrate that most 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, development of new technologies, such as the double walled isolator, robotic manipulation, integration of scientific analytical instruments, etc. is required. There will also be a need for specialized training in working with restricted samples for ESCF staff.

1.3.4 Sample Contamination Requirements

Contamination is defined as molecular, liquid or particulate material that could be adsorbed or absorbed and alter or degrade the characteristics of 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 100 µm size) solid particles.

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 are likely to consist of regolith material with the following principal chemical characteristics:

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

- **Organic compounds**: soluble carbonaceous and insoluble kerogen-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 a subsample.

1.3.5 Scientific Requirements

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

- **Sample Early Characterisation** (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, sample mass, etc. This occurs whilst the sample is still in its canister.
- **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 poses any threat to terrestrial organisms or ecosystems. Since 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.
- **Characterisation** 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. PE activities in the curation facility shall be conducted with little, or no, impact on the physical and chemical properties of the sample.
- **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, chip, 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 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.

1.3.6 Sample Early Characterisation vs Preliminary Examination vs Long-term Allocation

After the opening of the sample return capsule, three or four different phases, of variable extent and amplitude can be distinguished, depending on the restricted or unrestricted nature of the samples

- The first phase is the Sample Early Characterisation (SEC). During this phase basic information will be acquired on the samples with the goal of initial characterisation and documentation (e.g. nature of the samples, granulometry, basic chemistry and heterogeneity). The SEC phase takes place entirely inside the ESCF and is performed by ESCF staff.

- Life Detection and Biohazard Assessment for samples from restricted areas operates in parallel with the SEC phase, and takes place entirely inside the ESCF and is performed by ESCF staff.
- After the SEC period, a Preliminary Examination (PE) period starts with the goal of answering the first and major scientific questions of the mission. During this period samples are prepared and characterised in the ESCF in a similar way to the SEC but once characterised and proved to be free of biohazard (restricted mission), the sample will be distributed to external laboratories for dedicated analyses by scientists to be selected according to mission specific criteria (e.g. large, interdisciplinary groups or small numbers of scientists, restricted to some countries or worldwide). The goal of this period is to benefit from the expertise and instrumentation of world-class experts and specific instrumentation to achieve rapid, high-quality scientific results. The duration of PE is also specific to each mission. As an example, the PE period for the Stardust mission at comet 81/Wild 2 lasted one year, was carried out by appropriately qualified scientists around the world and was very successful in terms of scientific results.
- Once the PE is over, the long-term phase starts. During this phase, samples will be prepared and characterised in the ESCF to be allocated to individual scientists or teams on a proposal basis with the aim to answer second order or new arising questions.

In the specific and simple case of unrestricted samples, the major difference between the phases is mostly administrative and varies in the selection of involved scientists. Sample preparation, characterisation and documentation is expected to be mostly the same in terms of instrumentation and analytical methods.

1.4 Report Structure

The structure of this report traces the chronological order which would be followed for the design and implementation of a European Sample Curation Facility (ESCF). This approach does not reflect the manner in which different aspects of the EURO-CARES project were arranged into separate work packages, but is a logical way of viewing the required inputs now that the project is completed.

Information arising from individual WPs has been collected and harmonized, then reorganized, as shown in Figure 1.3. The coloured boxes represent the main sections of this report and, following the chronological approach taken (indicated by the blue arrow at the top of the figure), are organized as a sequence of operations.

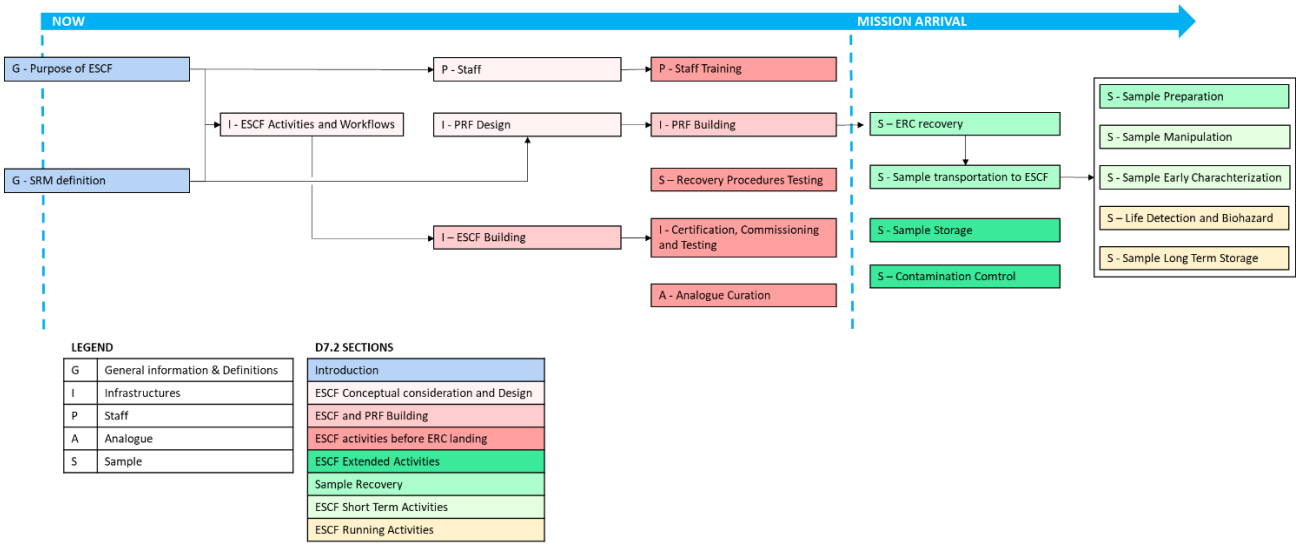


Figure 1.3 - Timeline of activities

The report is laid out as follows:

Chapter 1: **Introduction** (this chapter)

Chapter 2: **Conceptual considerations and design:**
highlights the activities to be performed inside the ESCF, and gives suggestions to be incorporated in the design phase (containment, cleanliness, staffing, siting, etc.).

Chapter 3: **European Sample Curation Facility and Portable Receiving Facility (PRF) Building Design:**
describes Functional Units and how they are linked in different design options. Includes recommendations for a preferred design

Chapter 4: **Activities before landing**:
describes activities to be undertaken prior to sample arrival on Earth, to test operations and processes in the ESCF. Includes discussion of analogue samples

Chapter 5: **Continuous activities:**
describes activities performed throughout the timespan of the project, from the launch of the mission to long-term storage of the samples.

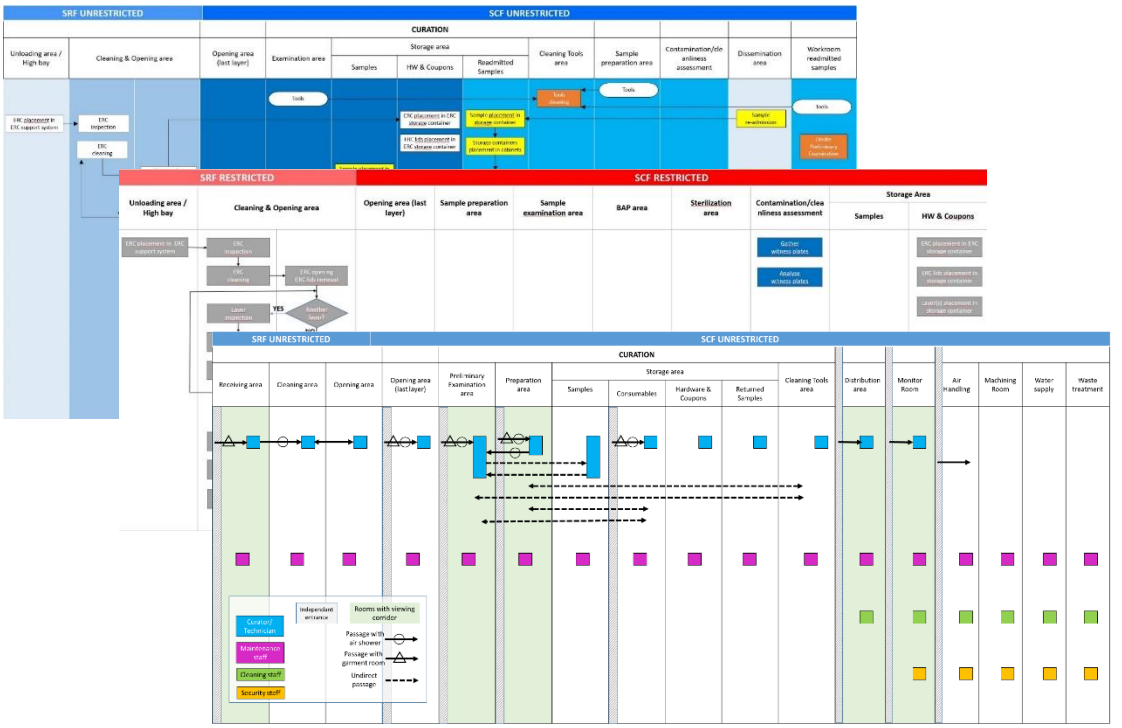
Chapter 6: **Sample recovery**:
describes the activities that surround recovery of the Earth Return Capsule (ERC) and its transportation to the ESCF. Includes recommendations for landing site.

Chapter 7: **Immediate Activities**:
describes the activities that are carried out as soon as the ERC or returned samples are brought to the ESCF.

Chapter 8 **Long-term activities:**
focuses on procedures to be performed after the short-term ones, when the initial transient phase is ended. Includes Public Outreach and Education programmes

Chapter 9 **Recommendations and Next Steps:**

2. CONCEPTUAL CONSIDERATIONS & DESIGN



2 CONCEPTUAL CONSIDERATIONS & DESIGN

2.1 Activities and workflows

The activities that will be undertaken within the ESCF are described in this section in terms of separate activity workflows for samples, procedures and workers.

2.1.1 Samples from Restricted Missions

Figure 2.1 shows the sequence of operations performed inside containment in the ESCF for restricted missions. Operations to be conducted on the samples are indicated, without specifying the exact location in the ESCF where they will take place.

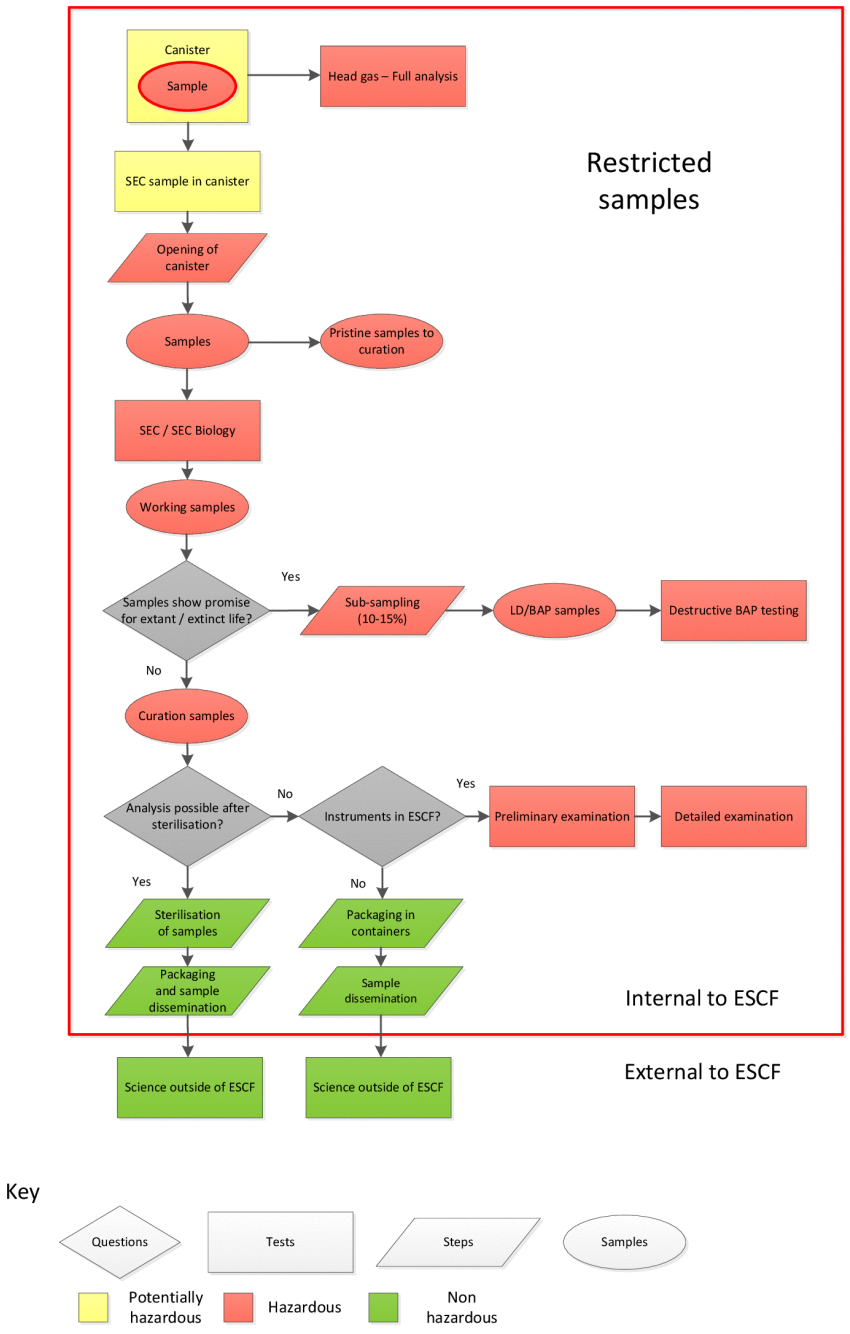


Figure 2.1 - Flow diagram of procedures that will be performed on a restricted sample in the ESCF

As described in the workflow, after the initial sample characterisation has been completed (whilst the sample is still in its canister), the main research question for the samples is to ascertain if there is the presence of extant or extinct life. A predetermined proportion of the sample will be used for LD and BAP. This fraction of the returned sample will be dependent on the amount of returned sample, its type and the techniques that are available at the time. These tests will mostly likely be destructive to the sample or alter it in such a way as to reduce its further scientific value. The initial full sample that is returned by the spacecraft can be described as the Total Amount of Sample (TS) and can be subdivided as:

- Life Detection Samples (LDS), which will be investigated for LD and BAP activities;
- Preliminary Examination Samples (PES), which will be used for Preliminary Examination (PE) analyses.

The TS will also contain a proportion of the sample that will be left unopened and stored in long-term storage. This will be an undefined amount of time and will allow the samples to be examined in the future (potentially for many decades to come) using enhanced or new techniques, these are defined as Preserved Samples (PS).

Therefore:

$$TS = LDS + PES + PS$$

In some cases, the sum of PS and PES should be equal to 0, for example when the total amount is lower than a defined value and all the samples should be analysed.

Rummel et al. (2002) proposed that about 10% of returned sample was a reasonable amount of sample to be used for LD and BAP assessment, the same approach that had been used by De Vincenzi and Bagby (1981). In contrast, MEPAG E2E-iSAG (2011) calculated that a mass of 1.5 g of sample was assumed reasonable to conduct LD and BAP tests, given improvements in instrumentation and detection limits since the previous reports. According to this approach, if TS < 1.5g it would mean that all the sample would be analysed for life. So, TS = LDS and PES + PS = 0.

These suggestions are illustrated in Figure 2.2, where the amount of LDS versus the TS is shown.

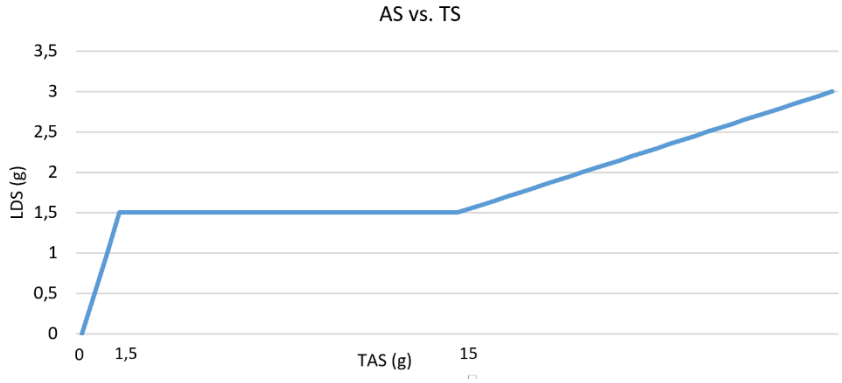


Figure 2.2 - Amount of sample required for LD and BH (LDS) dependent on total amount of sample (TS) returned by space mission

2.1.2 Samples for Unrestricted Missions

Figure 2.3 shows the required sequence of operations inside the ESCF for unrestricted missions. Groups of tests that will be conducted on the samples are indicated, but without specific locations where they will be undertaken. The workflow is generally less complicated than for restricted samples.

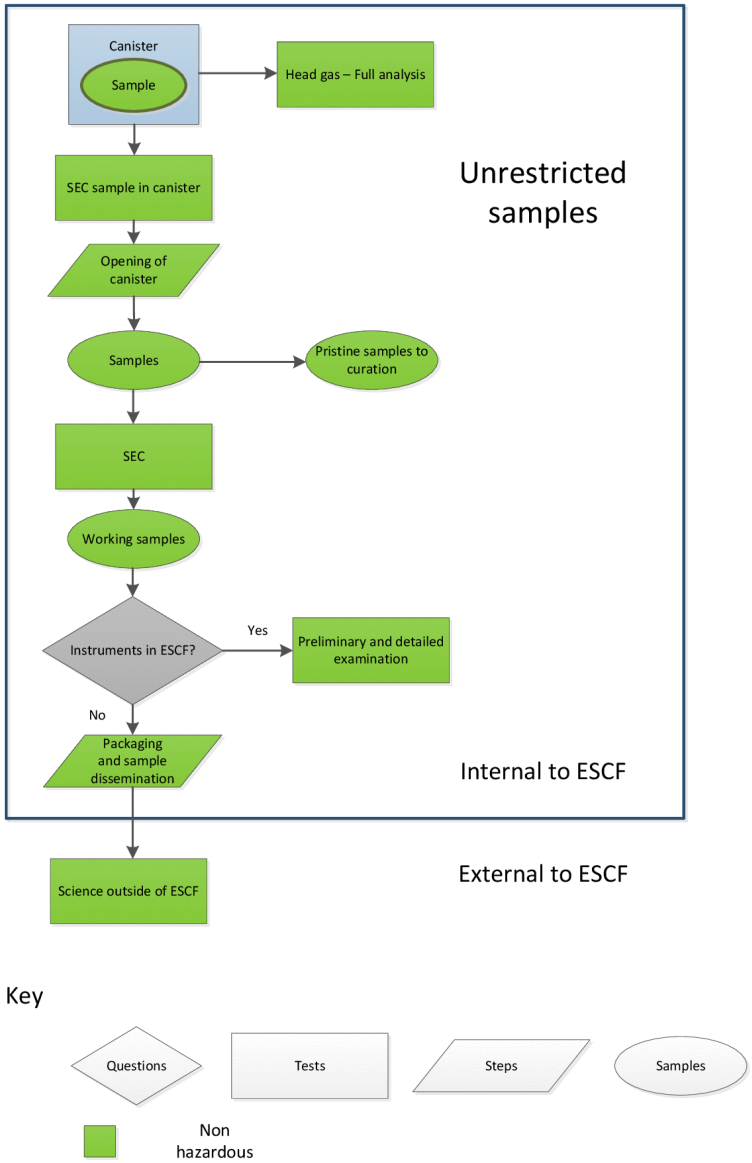


Figure2.3 - Flow diagram of procedures that will be performed on an unrestricted sample in the ESCF

2.1.3 Operations

Figure 2.4 shows an overview of the operations which will be conducted in the unrestricted section of the ESCF, with additional details regarding the specific area in which they should be conducted. The levels of cleanliness that must be maintained have been indicated, this then ties in the connections between each of the areas, including the flow of samples and workers through the facility.

We have distinguished operations where the sample can be left inside the original canister (yellow boxes) and the operations where the sample will need to be taken out of the canister (orange boxes). Similarly, Figure 2.5 shows the operations to be conducted in the restricted section of the ESCF.

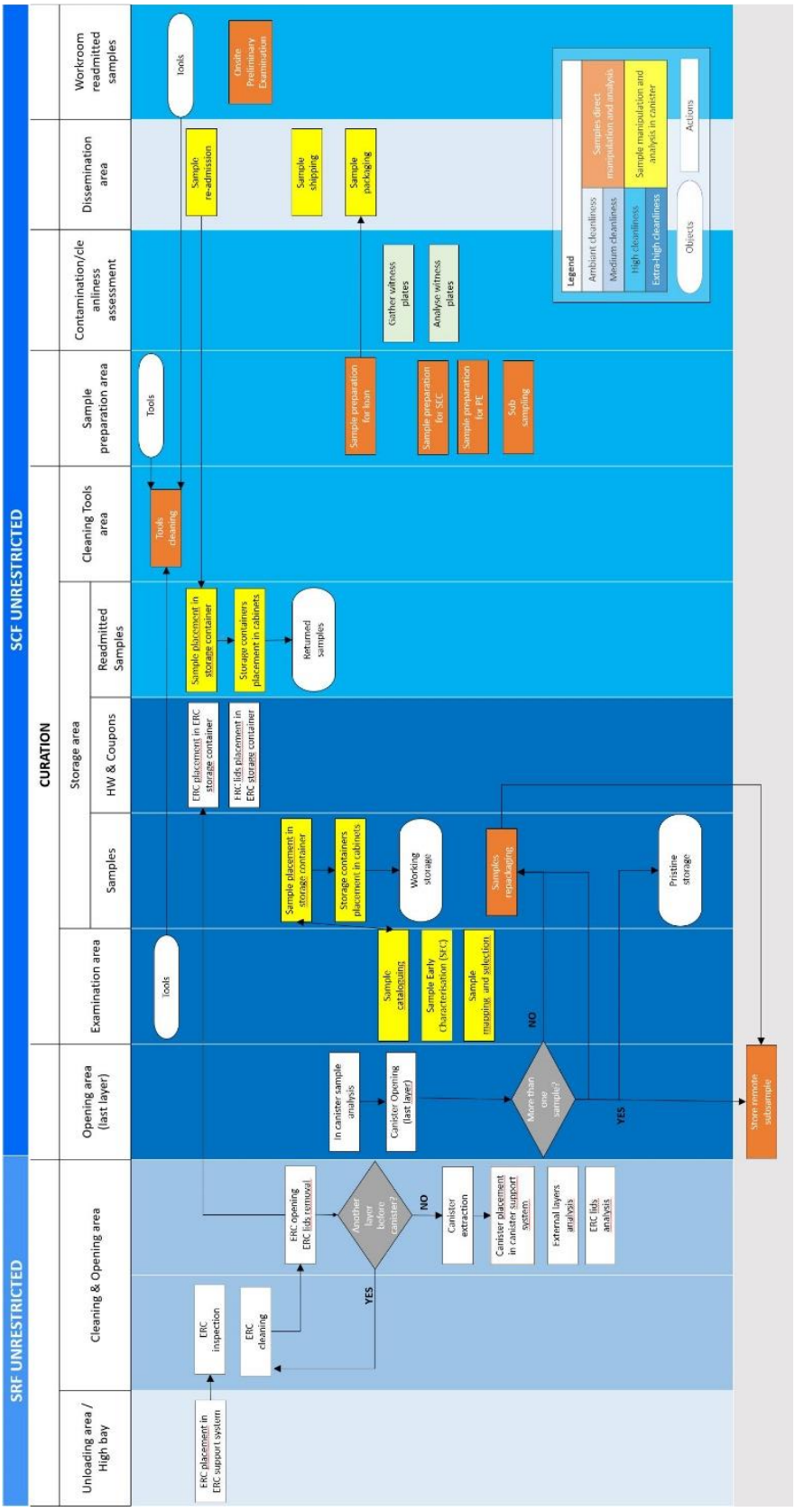


Figure 2.4 - Flow of operations for unrestricted science areas.

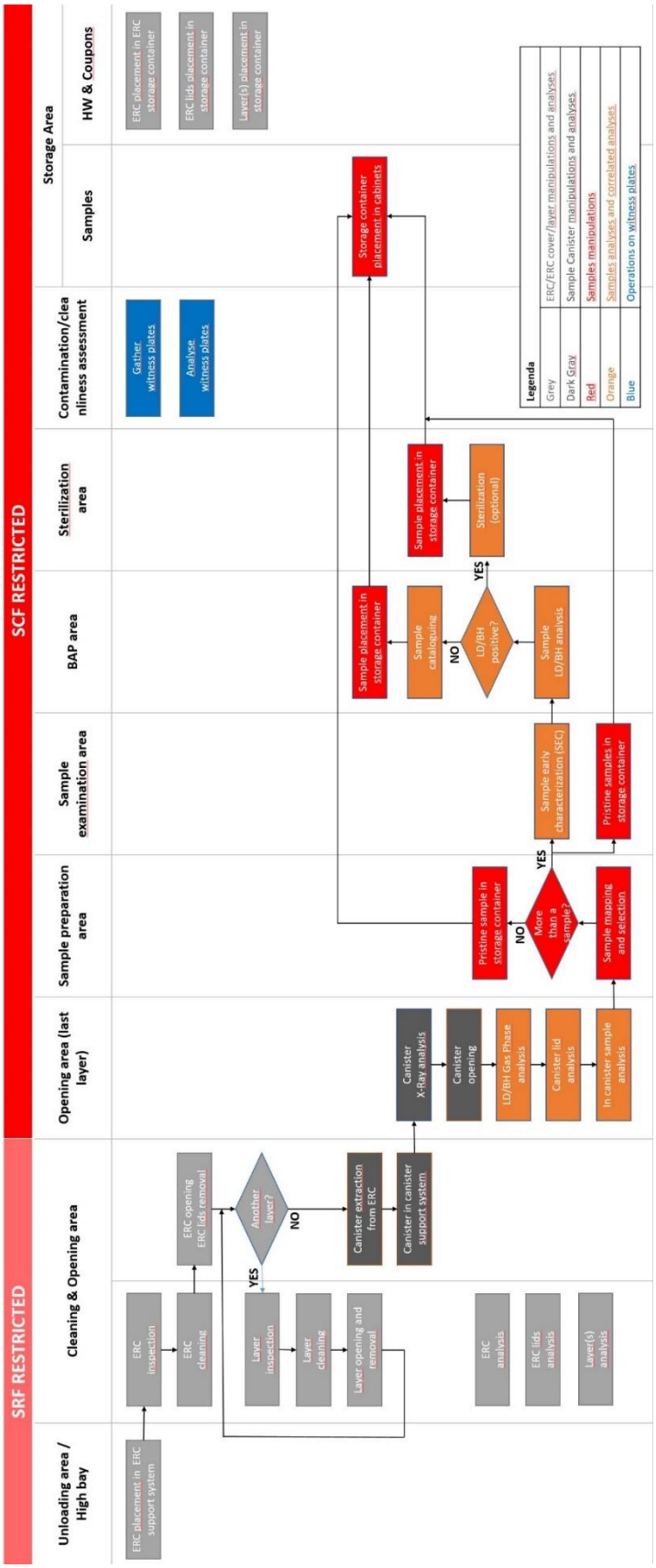


Figure 2.5 - Flow of operations for restricted science areas.

2.1.4 Staff

Figure 2.6, for unrestricted facilities only, shows which physical links should exist between different areas, to allow a smooth path through the ESCF for staff. It can be modified depending on the design of future missions e.g. if there is the use of robotics in the ESCF. The workflows have been developed mainly for curators and technicians, since they will access the facility on a daily basis. Mapping their activities is of the utmost importance to define how the facilities can be interconnected.

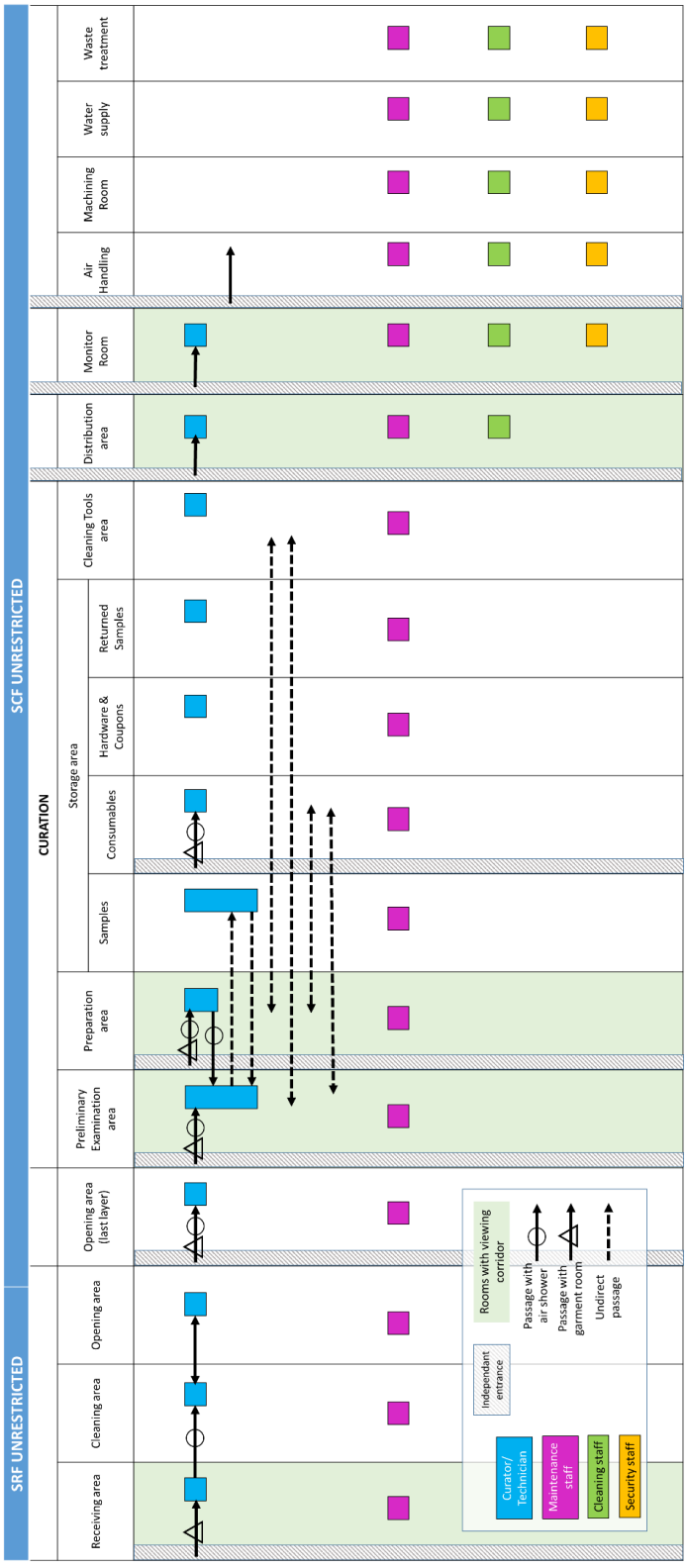


Figure 2.6- Flow of workers in unrestricted science areas

Maintenance staff comprise three categories, with different security clearance and access requirements:

- Cleanroom technicians, cleanroom instruments, daily;
- Facility engineers, technical areas (power supply, air filtration, etc.), daily;
- External companies, in both technical and curation areas, periodic service and maintenance.

Regular cleaning staff will not be granted access to cleanroom and other controlled areas. Cleaning of sensitive areas (such as cleanrooms, containment rooms, etc.) will be performed by the appropriate Curators/Technicians.

Security staff should be granted access to unrestricted areas and in viewing corridors.

2.2 Containment and Cleanliness

2.2.1 Principles of Cleanliness

2.2.1.1 Cleanroom Definition for the ESCF

Cleanrooms are designed to control airborne contamination to a specified level. Therefore, before designing a cleanroom for the ESCF it is necessary to identify what particles will be generated within (and ingress from outside) and to what level the contamination needs to be removed/prevented. Figure 2.7 shows the airborne capacity of particles dependent on their density and size. For particles in the grey zones of the diagram a cleanroom might not be needed, this could be replaced by protective clothing to reduce particle contamination.

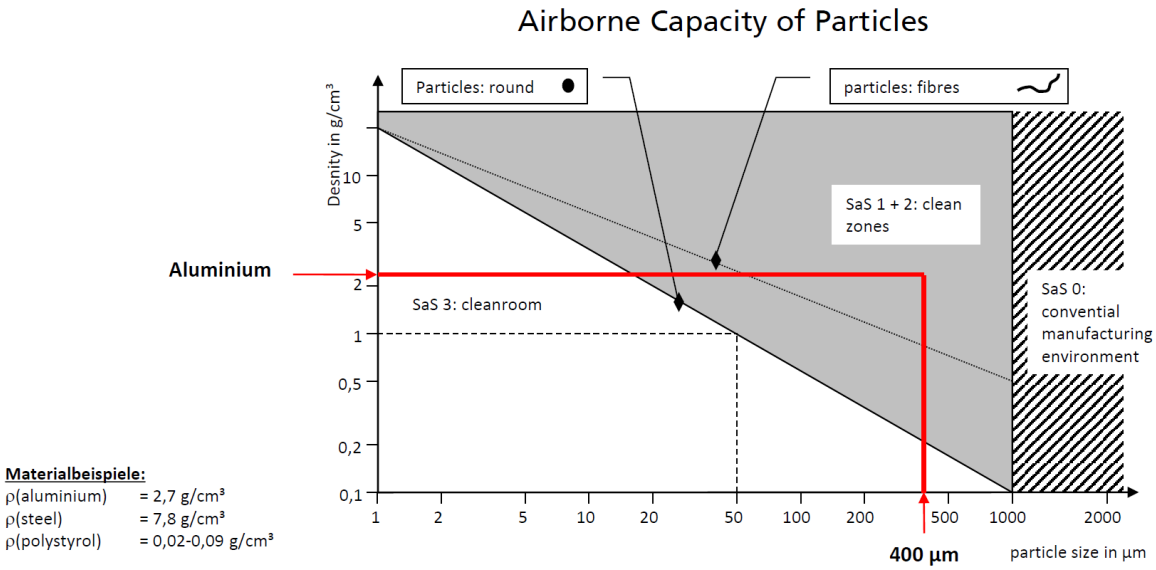


Figure 2.7 - Airborne capacity of particles, depending on size and density. Diagram courtesy of Dr. Udo GOMMEL, Fraunhofer IPA, Department Ultraclean Technologies and Micromanufacturing, Stuttgart, Germany

2.2.1.2 Airflows

There are a number of different airflow patterns that can be used within a cleanroom to remove particles (see Figure 2.8), these are:

- Turbulent or non-directional airflow. This is achieved through partial coverage of the ceiling with Fan Filter Units (FFUs). The cleanliness is achieved by diluting the air within the room with cleaner air. The more air changes per hour (i.e. the faster the diluting happens) the cleaner the cleanroom is. However, cleanliness greater than ISO 5 (in ISO 14644 standard for particles) cannot be achieved with this airflow pattern, and the turbulent air combined with a high air change rate can be disruptive to returned dust samples.

- Laminar, or unidirectional airflow. This is used for higher classes of particulate cleanliness (ISO 5 to ISO 1, ISO 14644 standard classification for particulate contamination allowed). It is achieved primarily by full coverage of the ceiling with FFUs for the inflow of air with the exhaust at the base of the walls creating a down flow of clean air. Raised perforated floors can be used for higher cleanliness and full laminar flow in the whole room. The airspeed is fixed at 0.5m/s, therefore the air change rate for the room will be dependent on the height of the ceiling. Additional precautions must be taken to not disturb the laminar flow (e.g. perforated tables or counter top) while working in the cleanroom.
- Tunnel cleanroom, or 'room in a room': part of the ceiling is fully covered with FFUs (main ceiling) then additional FFUs, this creates a mixture of turbulent areas and laminar flow areas.

We recommend using laminar flow for maximal flexibility.

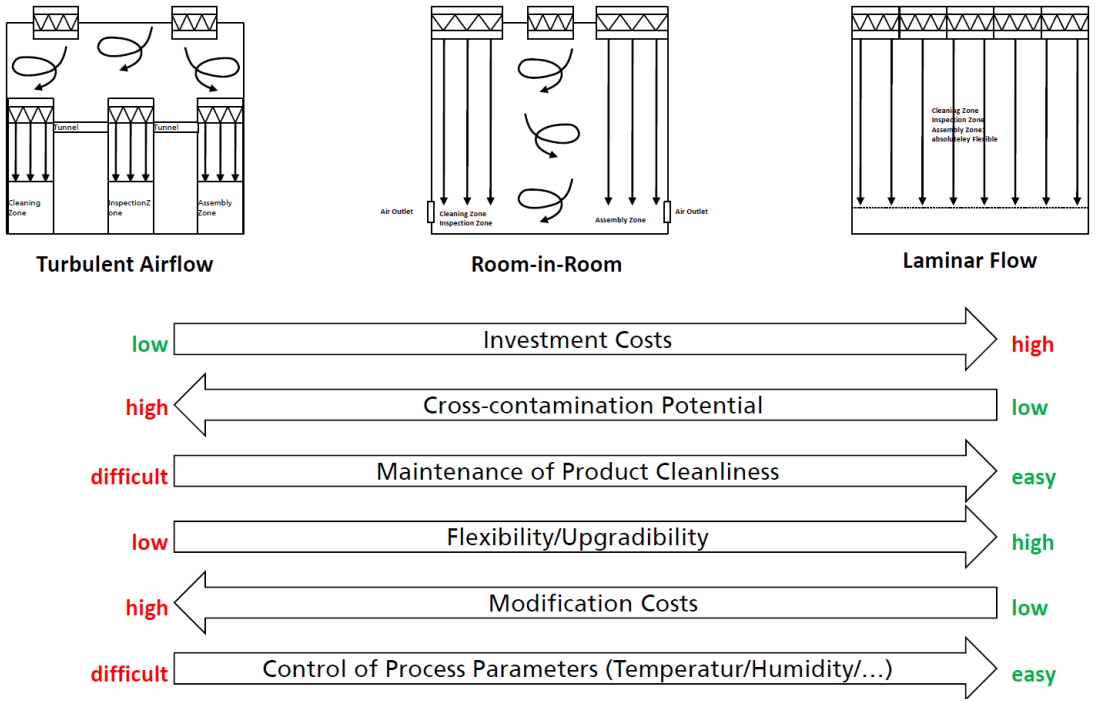


Figure 2.8 - Airflow in a cleanroom. Diagram courtesy of Dr. Udo GOMMEL, Fraunhofer IPA, Department Ultraclean Technologies and Micromanufacturing, Stuttgart, Germany

2.2.1.3 Standards for Cleanrooms

Different standards for cleanrooms exist; these depend on the area of the world that the cleanroom is built in or the commissioning body (Figure 2.9). There will be different considerations for the level of cleanroom needed depending on the type of samples being handled; for unrestricted samples there is a need to remove particulates and organic contaminants, where for restricted samples there is also the need to remove any biological contaminants to avoid forward contamination of the samples.

We recommend the use of the Good Manufacturing Practice (GMP) standards for biological contamination.

2.2.1.4 Air Filtration

For the unrestricted sections of the ESCF, concern is for contamination of the samples by Earth contaminants. Therefore, the primary focus is on the filtration of the inflowing air and not the exhaust air. The exception to this would be when hazardous chemicals are being used or produced as a by-product from a test procedure, then the exhaust air would require filtration to remove the chemical(s) or the procedure would be undertaken within a fume hood. Restricted facilities within the ESCF would require the same controls on the

inlet air, but there is also a requirement to ensure that the probability of unsterilized sample particles of ≥20nm being released is < 1 x 10^{-6} (ESF-ESSC Study Group, 2012).

To achieve particulate cleanliness and biological particle removal, High-Efficiency Particulate Air (HEPA) filtration should be used, and for a higher standard of cleanroom Ultra Low Penetration Air (ULPA) filtration can be used. HEPA and ULPA filters capture airborne particles in a combination of the following three ways depending on the size of the particles:

- Impaction (particles > 1 µm), larger particles will impact onto the filter fibres as opposed to following the air currents around the fibres. The impaction factor will decrease with increasing airflow or greater distance between fibres.
- Interception (< 1 µm), small particles are drawn along the air flow path and contact the outer surface of the fibres and are captured.
- Diffusion (< 0.1 µm), the smallest particles that are in Brownian motion will contact the fibre and will adhere to it. The diffusion capture process increases with low flow rates through the filter.

Generally, once a particle has contacted a fibre, it is attached *via* van der Waals forces and is not released (First, 1998). The size of the particle most likely to penetrate through the filter is approximately 0.3 µm for HEPA filters, and 0.12 µm for ULPA, but it also depends of the velocity of the air passing through the filters. As such the testing of these filters is undertaken with artificially generated particles of that size (in a range around that size).

Standard				Limiting values of each Air Cleanliness Class											
EG-GMP "in operation"	EG-GMP "at rest"	US Fed. Standard 209E*	DIN EN ISO 14644-1	0,1 µm		0,2 µm		0,3 µm		0,5 µm		1,0 µm		5,0 µm	
				pro m³	pro cbf	pro m³	pro cbf	pro m³	pro cbf	pro m³	pro cbf	pro m³	pro cbf	pro m³	pro cbf
			1	10	0,3										
			2	100	3	24	1	10	0,3						
			3	1.000	30	237	7	102	3	35	1				
		1		1.240	35	265	8	106	3	35	1				
			4	10.000	300	2.370	67	1.020	29	352	9,9	83	2		
		10		12.000	340	2.650	75	1.060	29	353	10				
			5	100.000	2.833	23.700	671	10.200	289	3.520	100	832	24		
	A									3.520	100			20	0,6
A										3.520	100			20	0,6
	B									3.520	100			29	0,8
		100				26.500	750	10.600	300	3.530	100				
			6	1.000.000	28.329	237.000	6.710	102.000	2.890	35.200	997	8.320	235	293	8
		1.000								35.300	1.000			247	7
			7							352.000	9.972	83.200	2.357	2.930	83
B										352.000	9.972			2.900	82
	C									352.000	9.972			2.900	82
		10.000								353.000	10.000			2.470	70
			8							3.520.000	99.716	832.000	23.569	29.300	830
C										3.520.000	99.716			29.000	821
	D									3.520.000	99.716			29.000	821
		100.000								3.530.000	100.000			24.700	700
			9							35.200.000	997.167	8.320.000	235.694	293.000	8.300

Figure 2.9 - Different standard for air cleanliness. Diagram courtesy of Fraunhofer IPA

Since a major requirement of the restricted ESCF is its ability to contain particles of 0.1 µm, we recommend using a cascade of filters with ULPA filters for the exhaust air. This approach is currently used in high containment microbiological laboratories worldwide where HEPA filter are used in banks to reduce the likelihood of a particle being released via the aerosol route.

Each type of contamination requires a different type of filter (e.g. active charcoal filters for organics, HEPA and ULPA filters for particles). Filters can be added after one another for the removal of different types of contaminants.

2.2.1.5 Positive Pressure and Cleanroom Design

Positive pressure is a requisite of cleanrooms, and is achieved by having more clean air entering the room than the air being removed. Cleanrooms are designed with successive layers of increasing cleanliness and with a cascade of pressure with the highest positive pressure being the cleanest part of the laboratory. This pressure cascade is designed to limit the movement of particles from an area with a lower pressure to that with a higher pressure (i.e. from dirty to clean).

Transition space for staff must be kept between areas of different cleanliness. These areas can be airlocks, gowning rooms, or air showers and are used to help remove particles from the air and the staff before transition to a cleaner area. Air showers use directional airflow at high velocities to remove larger particles (> 25µm) from staff clothing, and are usually smaller (a few m^2) than airlocks relying only on air filtration. They are also a useful psychological tool to reinforce that cleanliness is extremely important, whilst being an acceptable procedure for staff (see deliverable D3.4). One of the conclusions of this study is that air showers should be used within the facility. We identified two possibilities that may coexist in the ESCF:

- Closed air shower, or closed air tunnel. This type of airlock is integrated in the workers path, to separate cleanliness levels. They can be laminar or turbulent. The latter is faster in use and is preferred in this instance.
- Open air showers are corridors of clean air around facility: These units operate 24 hours a day, continually filtering the air by recirculating it through a HEPA/ULPA filter and creating an 'air curtain.' The idea is that by continuously filtering the air, the chances of having loose particulate material in the facility is reduced.

To summarize, see Figure 2.10.

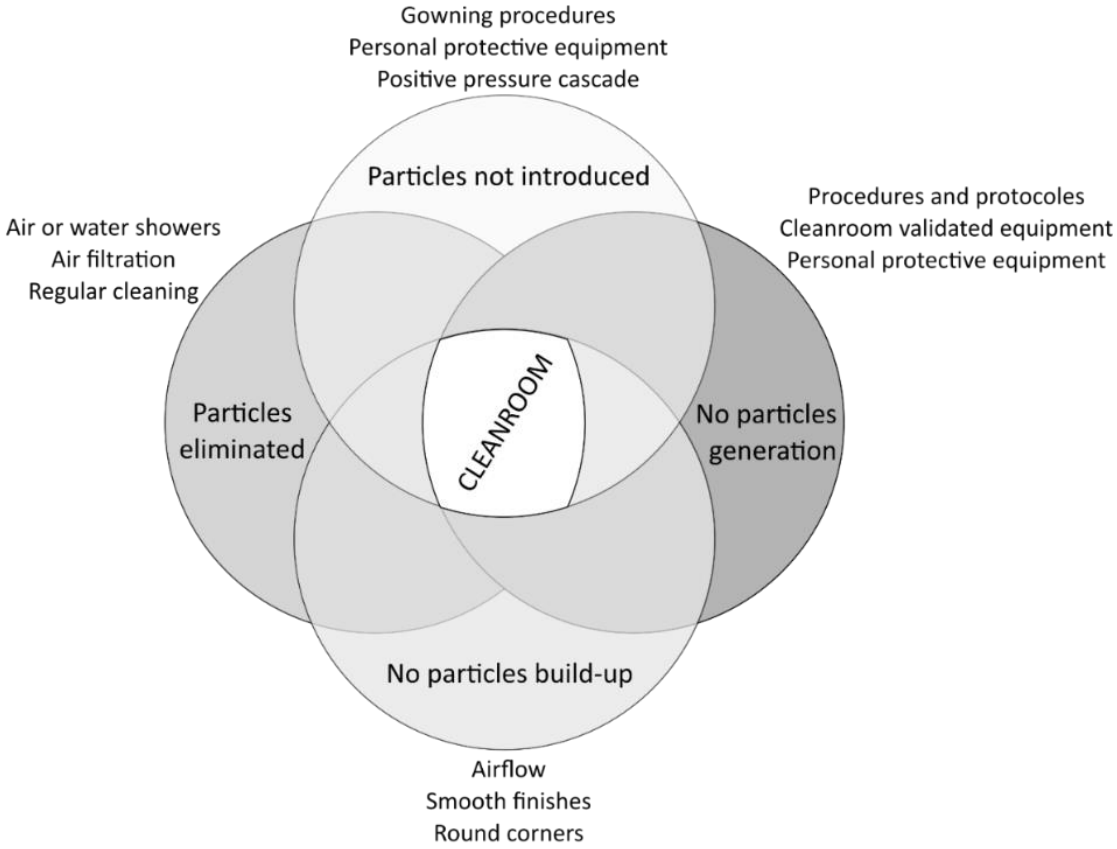


Figure 2.10 - Summary of cleanroom principles and actions to achieve cleanliness

2.2.2 Principles of Containment

This section specifically deals with the issues pertaining to restricted samples.

2.2.2.1 Negative Pressure and Levels of Containment

One of the principles for high containment laboratories is to use a number of layers between the agent being handled and the outside of the facility, conceptually built like 'Russian dolls'. Unlike cleanrooms, the laboratories are kept at negative pressure to the outside, utilising more exhaust air than supply air to create a negative pressure. However, although negative pressure is a requirement for high containment laboratories there are no specific international recommendations for the magnitude of the differentials (e.g. Rogers et al., 2007; Ide, 1979) (see D3.4 for more details).

Containment laboratories have design requirements adapted to the agent being handled, and range from Biosafety Level (BSL) 1 (e.g., non-pathogenic *Escherichia coli*) to BSL-4 (e.g., Ebola virus). Planetary protection measures recommend that the highest level of containment is used for restricted return samples as they may contain unknown biological agents and the Earth's biosphere should be protected from these.

The use of high pressure differentials within the facility needs to be balanced with the operation and functionality of the facility. The facility will need to be designed and built to withstand high pressure differentials. This can add extra cost to the facility in terms of building quality and energy consumption of the facility when in operation. Achieving the desired pressure differentials can be challenging and can be the cause of delays caused by lengthy commissioning periods ensuring the pressure cascades can be achieved and maintained.

2.2.2.2 Containment Types

2.2.2.2.1 Primary containment

Primary containment describes the protective barrier between possibly biohazardous sample and staff.

At the highest level of biological containment, BSL-4, there are two engineering approaches that are generally used for the safe handling of high consequence pathogens (WHO, 2004). These are either:

- Cabinet Line Laboratory. Work is carried out within a series of interconnected class 3 Microbiological Safety Cabinets (MSC) where the worker uses thick rubber gauntlets on the side of the cabinets to manipulate the infectious materials. Samples enter through disinfectant baths (dunk tanks) and waste leaves through a double door autoclave.
- Suited Laboratory. Workers wear a positive pressure suit supplied with breathing air by umbilicals, linked to compressors which are located on the service floor. Within a suited laboratory, class 2 MSC are normally used to confer extra protection to the workers and the samples from contamination during manipulation.

In the case of the ESCF, another engineering approach is being considered, i.e. a 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. If there is a leak from the DWI operating area it will be from the positive pressure compartment which will be filled with filtered gas and so will not contaminate the sample. If there is a leak in the outside of the positive pressure compartment it will just be filtered gas without any biohazard. The possible asphyxiation hazard will be minimised, with enough sensors and emergency procedures in place to avoid a depletion of oxygen around the DWIs.

These three different approaches have a huge impact on the design and operation of the laboratories and are considered further in Section 2.2.3.

2.2.2.2.2 Secondary containment

The next level of containment is the laboratory itself (room, systems, etc.), some aspects of which are: negative pressure, directional airflow, sealability and filtration of extracted air.

2.2.2.3 Air Filtration

The EU Directive 2000/54 requires the air supplying a BSL-4 facility to pass through at least one HEPA filter, and two HEPA filters in series on the extract side, mounted separately. This allows for independent testing and replacement of each filter (HSE, 2009) and provides protection if one of the filters should fail. Once a filter is installed it still requires *in situ* testing to ensure it is operating correctly. To make the testing and replacement of the extract HEPA filters easier they are usually located in the plant room outside of the laboratory. Installed HEPA filters should be regularly tested (rules differ from country to country) to ensure they operate correctly.

An argument could be made that samples should be kept within primary enclosures with their own filters, with decisions about the number of HEPA filters made on a risk assessment basis for each of the enclosures, depending on the procedures and operations that will be undertaken in them and the likely challenge for the filters.

2.2.2.4 Redundancies

As with all systems, some redundancies must be built in. Depending on the equipment, on the risk of failure, and on the danger in the case of failure, redundancies can be of the type 2n, or n+1 (with n being the number of pieces of equipment that might fail, e.g., a HEPA unit).

2.2.3 Sample Handling and Primary Enclosures

2.2.3.1 Unrestricted Samples

Unrestricted samples must be kept in a specific environment, to avoid alteration. Usually, samples are kept in positive pressure gloveboxes, with a constant supply of an inert gas (nitrogen, sometimes argon or helium is used; See deliverable D3.4 and D4.1 for more information).

2.2.3.2 Restricted Samples

In the case of restricted samples, the safety of staff must be ensured, alongside non-contamination of samples. There are three possibilities:

- Cabinet Line Laboratory;
- Suited Laboratory;
- DWI Line Laboratory.

This section details the different laboratory types and how they can be used in the case of a sample return facility.

2.2.3.3 Cabinet line laboratories

Microbiology Safety Cabinets (MSC; Figure 2.11) are typically employed in microbiology laboratories, and use a combination of directional airflow and high air change rates to prevent exposure of workers to any microbial aerosol within the working area of the cabinet. Within Europe, cabinet performance is specified in the European standard EN 12469:2000 for biotechnology performance criteria for microbiological safety cabinets (BSI, 2000).

The MSC type 3 (MSC3) is designed to offer the highest level of protection to the worker and the surrounding environment whilst also protecting the work from particulate and biological contamination (Chosewood and Wilson, 2009).

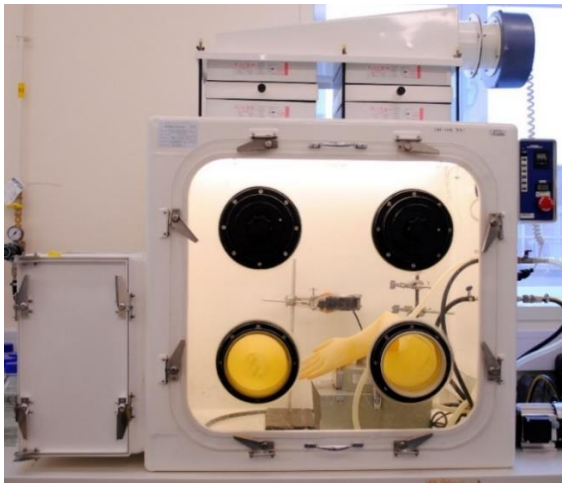


Figure 2.11 - A MSC3 in operation at PHE Porton (UK)

The MSC3 exhibits a very high protection factor when operating correctly and allows the users to work without the necessity for respiratory protection or constraining suits. However, the cabinets can be difficult to work with and restrictive because of the positioning of the glove ports. Their high airflow and turbulent environment is unsuitable for handling materials such as powders.

Cabinet lines are composed of several MSC3 are connected to form a spine. Further MSC3's may be connected onto the spine for manipulation of the samples and to house specialist equipment required for processing, e.g., microscope, balance, etc. The cabinet line spine is used to move the samples along to the necessary cabinet branch where the manipulation/analysis can be performed. Technical details about MSC can be found in EURO-CARES deliverable D3.4.

2.2.3.3.1 Flexible Film Isolators

Flexible Film Isolators (FFI) have been used in the UK for working with risk group 4 agents and infected (small) animals (van der Groen et al., 1980). FFI are thought of as non-standard MSC3, where a metal frame is constructed with a flexible canopy covering it. It increases the flexibility of the work that can be completed within the FFI compared to a MSC2 or 3 because the design can also include a number of half suits on the floor of the isolator allowing operators to be inside, increasing the usable surface area (Figure 2.12).

Modified FFI have been used for the transport and treatment of infected patients with high risk group agents, such as during the recent West African Ebola virus epidemic, where infected workers were transported by plane to specialist treatment facilities and then housed in large isolators during treatment.

Figure 2.12 - A flexible film isolator used BSL-4 at PHE

While classic MSC3 provide a high degree of operator and sample protection, they must be adapted to the procedures and equipment. FFI are a solution that offers more flexibility. They can be incorporated into a cabinet line by future-proofing it with the design of sections where further cabinets can be attached containing additional equipment. This allows the modification of operations performed within it as newer equipment becomes available.

2.2.3.4 Suits

Positive pressure suits are used within most BSL-4 laboratories. With the operator wearing the positive pressure suit specific procedures with the infectious agent will be undertaken in an open-front cabinet to reduce the possibility of release to the wider environment because suits will only help to protect the worker, not the laboratory environment. However, for non-normative processes such as large animal experiments, suits can be used as the main containment system. Positive pressure suits have been used within the nuclear industry with a long history of safe use.

The layout of the laboratory needs to allow movement of a worker in an inflated suit without danger of knocking into any equipment or damaging the suit. Technical details about suits are available in EURO-CARES deliverable D3.4.

2.2.3.5 DWI Line Laboratory

Another possibility is a sequence of DWIs, with full robotic integration for sample manipulation. The concept of one DWI is shown in Figure 2.13.

In the case of DWIs, workers can wear simple lab coats, knowing that the samples are not in contact with external contaminants.

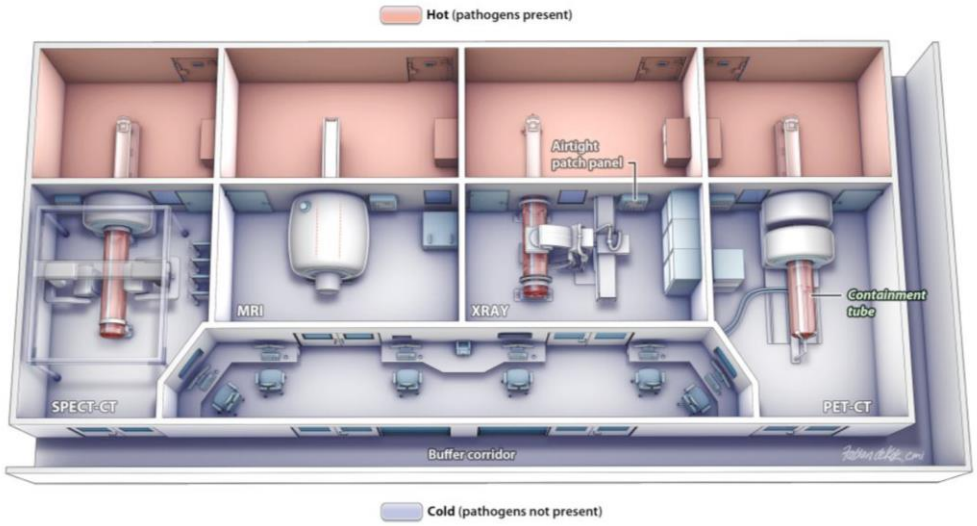


Figure 2.13- Schematic of the imaging suite at the National Institute of Allergy and Infectious Diseases (NIAID) Integrated Research Facility (de Kok-Mercado et al., 2011

2.2.4 Design Solutions for Clean and/or Contained Areas

Some design solutions can be helpful to keep a clean and/or contained environment.

2.2.4.1 Windows and Glass Walls

It is foreseeable that the ESCF will attract a lot of attention from different sources, including media and dignitaries, and that requests to visit it will be numerous. It would be impossible to accommodate visitors inside the working rooms and as such alternative designs or arrangements should be reviewed to increase the facility's visibility. Whenever possible, windows or glass walls should be used to allow a direct line of view

to the working area(s). If a training centre is constructed, then this can be used for tours and educational talks.

2.2.4.2 Instruments Integration

For the curation facilities, we followed the recommendations of D4.2 in trying to keep the largest instruments outside of the cleanrooms and/or contained areas. This system, based on interconnected contained/clean areas and non-contained ones, was nicknamed 'villi', and is shown in Figure 2.14.

The purpose of keeping instruments outside of the working areas is to:

- Minimize particle-emitting and off-gassing sources inside the DWI and laboratory/cleanrooms;
- Limit the need to decontaminate (fragile) instruments (for restricted samples);
- Allow staff to operate some of the instruments without going through donning/doffing of protective clothing, and to work in a more relaxed environment;
- Allow maintenance from outside of the laboratory.

Instrument integration into the facility and laboratories requires development of the instrumentation; such systems have been devised and constructed already, for example instrumentation at high containment facilities at the US Army Research Institute at Fort Detrick.

Figure 2.14 shows a functional layout for the 'villi' solution.

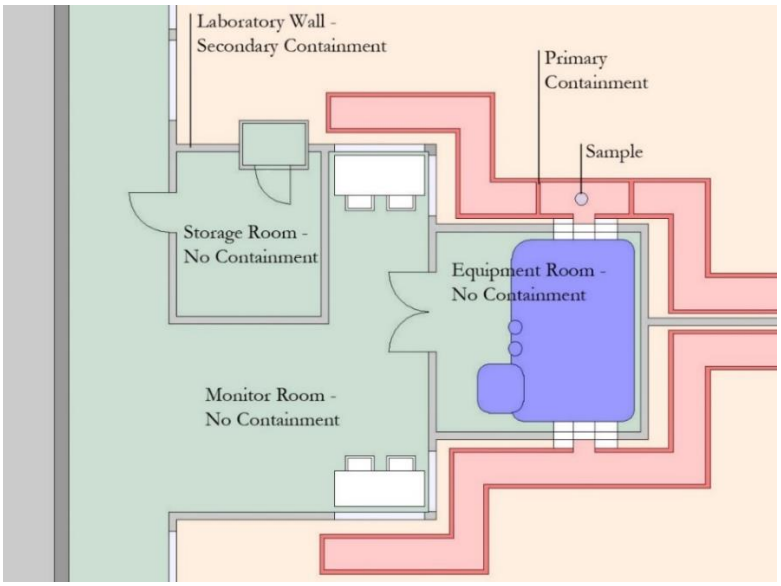


Figure 2.14 Graphic representation of one villus. A villus is composed of a non-contained working room (in green), hosting an instrument (in blue). Samples are kept within the primary containment layer (in red), with secondary containment being the laboratory room. (EURO-CARES deliverable D3.4, 2017)

Each instrument room can be equipped to handle specific requirements, such as low vibrations, electromagnetic field suppression, etc. The construction of the laboratories with the large pieces of equipment external to them will help to reduce their size and lower costs of the facility

2.2.5 Waste Handling and Sterilisation

For unrestricted laboratories and cleanrooms, there is no biological threat to the environment. Liquid waste should be treated only for potentially harmful chemicals. Solid waste having been potentially in contact with samples (disposable tools, gloves, etc.) will be stored and carefully searched for sample particles before disposal with other waste following traditional systems.

2.2.5.1 Solid Waste Decontamination

2.2.5.1.1 Autoclaves

Autoclaves have historically been used to provide an effective method of sterilisation of laboratory waste (Block, 2001). The most effective way of sterilising waste before it can leave a high containment laboratory is through autoclaving. Within a BSL-4 laboratory the autoclave is required to be double-ended, with interlocking doors. The external doors should only be able to be opened once a cycle has been completed to all the parameter set points. This stops unsterilized material from being released from the laboratory.

The European Standard 12347 describes the minimum operating parameters that must be exceeded for a correct autoclave cycle. There are a number of different autoclave cycles that can be used, and these will reflect the waste that is being processed, i.e. high liquid volumes, or highly absorbent loads. Validation of the cycle can be completed using either chemical, physical or biological methods, or a combination of more than one. Spores of the bacteria *Geobacillus stearothermophilus*, are recommended as the biological indicator organism, as these are resistant to moist heat. Chemical indicators that change colour after exposure to the required conditions can be used. Thermocouple recorders can also be used to establish if suitable conditions have been achieved for each cycle.

If the autoclave cycle fails, then the waste inside can be returned to the laboratory and the autoclave repaired. Autoclaving provides a well-established and easily validated methodology to sterilise waste generated in the laboratory, by constant monitoring of physical parameters.

2.2.5.1.2 Incinerators

Incinerators use combustion at high temperatures to reduce the waste within it to non-combustible ash. Incineration is used as the final stage of the solid waste disposal process, where waste is incinerated after autoclaving. As such there are no incinerators housed directly within BSL-4 containment facilities.

The most standardised design of incinerator is the dual chamber incinerator. In this design the waste is fed into the bottom chamber which is operated at a temperature ranging from 870 - 980 °C; The oxygen content within this chamber is also regulated, allowing the control of the oxidation of the waste and fixing of the carbon. Waste gases from this chamber can move to the second chamber, which is above the first one, where extra air is introduced to burn the waste gases from the first chamber. The temperature in the second chamber is higher than in the first one, at >1093 °C (Block, 2001).

Generally, incineration after a validated autoclave cycle is unnecessary as there is little benefit and the incineration process is costly and environmentally unfriendly.

2.2.5.2 Liquid Waste

Most of the liquid waste produced within a BSL-4 facility is from either positive pressure suit decontamination showers or from personal showering. Small volume processes completed in the restricted areas will also be collected in the effluent system. The effluent system must have two HEPA filters in series if it uses atmospheric ventilation to stop any contamination within the gases from being released in the environment (Chosewood and Wilson, 2009).

The effluent treatment system must be completely sealed to prevent any leakage of effluent. The material the effluent treatment equipment is constructed of must be able to withstand any chemicals that are used in the treatment process and also used in the laboratory. Currently the preferred method of treatment for the effluent is heat, produced by steam, this is because it is easier to validate, control and therefore reproduce (WHO, 2004). Other methods can be used such as chemicals or heat and chemicals in combination. After treatment the effluent can be cooled and discharged to the main sewer (HSE, 2009), or if the treatment is chemical then the effluent must be neutralised and/or returned to a neutral pH prior to discharge. The construction of the effluent system should allow for regular inspection of the pipework, with no pipework being hidden from view e.g. by enclosures. Any drains and U-bends incorporated into the system must be

able to be sealed or engineered to prevent drying out to stop any air from the effluent treatment plant from returning to the laboratory. The pipework should be able to be sterilised *in situ* to reduce the need for human intervention during operation.

The effluent system should work on a gravity feed because this removes the need for back up devices in the event of a pump or power source failure. The treatment vessels must be situated in a plant room that is bunded, to contain any leaks or spillages from the treatment vessels. This bunding must be able to hold the capacity of the treatment vessels plus an additional 10% (HSE, 2009). This needs to be demonstrated by filling the bunding with water to this level and then being held over time with no loss. In the case of large facilities that are envisaged to be in continual use, then it may be appropriate to use two processing tanks, as once one reaches the fill level and the treatment is undertaken, the other tank allows the laboratory to continue to operate. The processing tanks should be able to stir their contents continually to maintain homogeneity of the effluent during treatment.

Validation is completed using biological indicators, such as spores of *G. stearothermophilus*. After validation, monitoring of the physical parameters can be completed to determine if the process if effective, prior to release of the treated effluent to drain.

2.3 Security Issues

2.3.1 Overview

Hazards in the case of the ESCF can be classified in three different categories:

- External hazards (natural and non-natural);
- Infrastructure hazards (failure of pumps, filters, etc.);
- Protocol and human-related hazards.

A sample receiving and curation facility will require a number of different approaches to maintaining security. This implies that a security approach should planned for the facility itself, the surrounding environment, the staff, the samples and the information generated from the testing regime. The type of security systems applied inside the ESCF not only depends on regulatory requirements, but also on the mission of the facility. A good security system should, among other things, increase overall safety for laboratory personnel and the public, improve emergency preparedness by assisting with pre-planning, and lower the organisation's liability. There are four integrated domains to consider when improving security of a facility:

- **Architectural**: doors, walls, fences, locks, barriers, controlled roof access, and cables/locks on equipment;
- **Electronic**: access control systems, alarm systems, password protection procedures, and video surveillance systems;
- **Operational**: sign-in sheets or logs, control of keys and access cards, authorisation procedures, background checks, and security guards;
- **Information**: passwords, backup systems, shredding of sensitive information.

2.3.2 Risk Assessment Strategy

All the potential hazards inside the ESCF should be studied and for each of them, a worst-case scenario should be highlighted. The most common method is a Risk Matrix, where hazards are identified and then weighted by their severity of impact, and by the likelihood that they will happen, the combination of impact and likelihood will give the overall risk.

Table 2.1 - Risk Matrix

		Likelihood				
	Provision	**Rare**	**Unlikely**	**Possible**	**Likely**	**Certain**
Impact	Severe	Medium	Medium	High	Extreme	Extreme
	Major	Low	Medium	Medium	High	Extreme
	Moderate	Low	Low	Medium	Medium	High
	Minor	Low	Low	Low	Medium	Medium
	Minimal	Low	Low	Low	Low	Low

Table 2.1 shows the cases where the risk is acceptable (green), where the risk is acceptable with mitigation (yellow) and where the risk is not acceptable (orange and red). Table 2.2 is a catalogue of the types of hazards that may be present.

Accidents in a facility such as the ESCF can impact several different areas, including: the staff, the surrounding environment and population, and the samples themselves. The Risk Matrix should be considered for each of these areas. Where hazards to health may not be the only hazard, but failure in the facility can lead to the loss of scientific importance of the mission, impacting on the financial and reputation aspects of the facility and project staff. Table shows a non-exhaustive list of potential hazards for the ESCF.

The strategy to follow is shown in Figure 2.15.

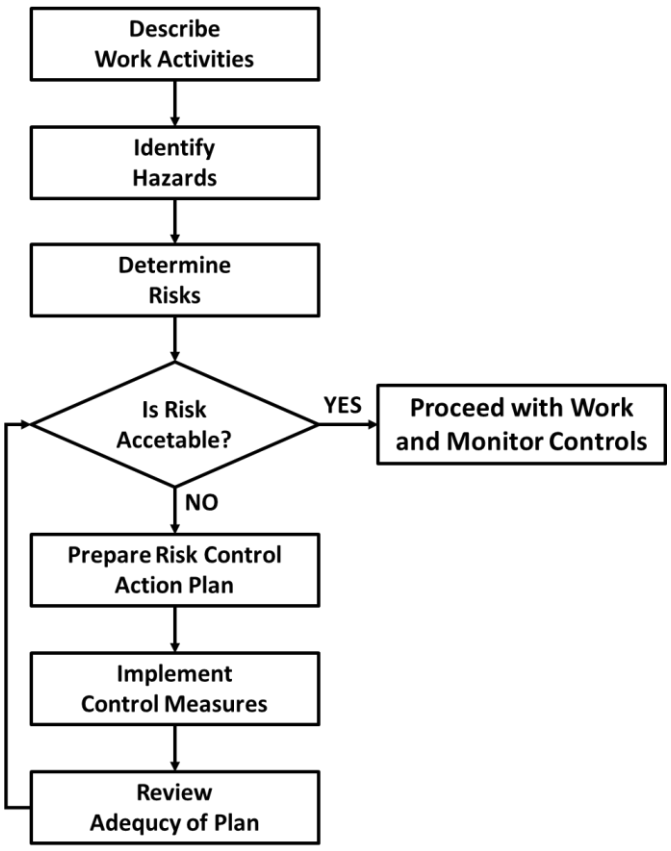


Figure 2.15 - Risk assessment strategy and mitigation. Figure modified from http://www.dartmouth.edu/~ehs/biological/risk.html

Table 2.2 - Potential hazards for the ESCF. Modified after presentation by U. Müller-Doblies, EURO-CARES WP3 Workshop, Vienna, 2016. http://www.euro-cares.eu/files/WP3_Vienna/Presentations/Mueller-Doblies_EUROCARES_WP3_2016_PRESENTATION.pdf

Category	Hazard	Example
Building	Sealability	Leak tightness less than that specified
	Surfaces	Outgassing
	Doors	Leak tightness less than that specified
	Penetrations	Leak through poorly designed penetrations
Laboratories	Emergency procedures	Faulty alarm
	Equipment	Outgassing
	Furniture	Furniture broken
Air	Air Handling Units (AHU)	Failure of AHU
	Ventilation controls	Failure of pressure sensors
	Air filtration	Failure of filters leading to contamination of the samples
Liquid	Effluent treatment	Inefficient decontamination protocol
	Effluent piping	Leakage of pipes
	Flood detection	Failure of flood sensors
Solid	Waste treatment	Inefficient decontamination protocol
	Autoclaves	Fails certification testing; autoclave seals fail.
	Dunk tank	Leakage of tank
	Incinerator	Failure of incinerator
Services	Electricity	Low continuity of power
	Generators	Failure
	Water	Flood
	IT & Telecom	Release of data
	Gasses	Unclean gas
Processes	Documentation	Wrong sample code
	Entry/exit of laboratories	Wrong exit process
	Human factors	Loss of a sample
	Maintenance	Infrequent maintenance
	Change management	Loss of information
	Competency management and Training	Untrained staff
Natural	Earthquake	Barrier break
	Tsunami	Flood
	Tornados	Air flux disrupted
	Wild fire	Contamination by particles
	Floods	Water contaminated
	Air pollution	Risk to samples integrity
	Water pollution	Risk to staff
	Solar storm	Power outage
Non-Natural	Terrorism	Barrier break

A full risk analysis of the facility will be required using one or more of the following methodologies HAZOP (Hazard and Operability Studies), SWIFT (Structured What-If Techniques), LOPA (Layers of Protection Analysis), etc. This will require input from the architects, scientists, biosafety and safety professionals from the project and from external organisations.

The risk analysis will inform the design of the ESCF and will specify requirements for redundancy such as:

- Having dual HVAC systems operating at less than full capacity so that if one fails the other one can take the full load;
- The use of back-up generators or uninterruptible power supply (UPS) to prevent loss of power;
- Back up storage vault for critical samples.

The facility shall be designed to minimise risks related to natural disasters (such as earthquakes, floods, etc.), man-made disasters (such as terrorism, etc.) and other external hazards, such as a fire (this topic is further discussed in EURO-CARES deliverable D3.1).

Security processes will be designed according to the risks associated with the samples, personnel and building (human errors, technical failures, etc.). The indirect interaction between humans and samples (especially for restricted samples) shall be kept to a minimum, for safety and security reasons.

2.3.3 Restricted/Unrestricted Areas Access

One of the main issue of an ESCF is the infrastructural security, which begins at the perimeter of the building and becomes increasingly more stringent moving toward the interior area, where sensitive material, equipment, or technology will be held. This requires that the ECSF layout shall be take a layered approach as shown in Figure 2.16, where the level of security increases with each internal layer.

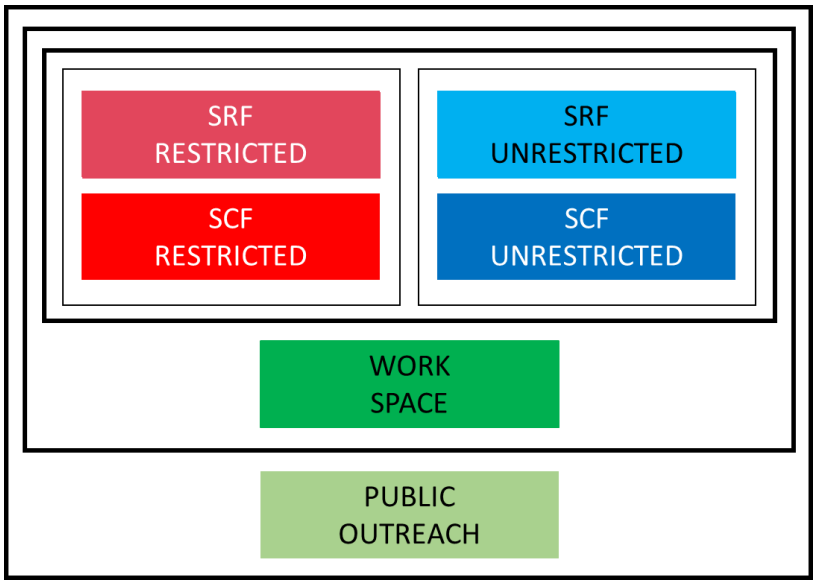


Figure 2.16 - ECSF layout defined as concentric

Following this layered principle, there will be a need to identify access requirements for staff (and visitors/visiting workers) within this facility depending on where they are required to work. To do so, three types of identification tools can be used:

- **What you have**, such as an identification badge;
- **What you know**, such as a code;
- **Who you are**, by using biometric identification (e.g., fingerprints, facial or retinal recognition, etc.).

For a relatively low level of security (e.g., entering an office), a personal badge and/or a key should suffice. For higher security parts, one or two other types of identification should be added, such as a code to enter a cleanroom, and a biometric identification reader to access the sample storage room (a 'robot-only' option may also be considered). This type of system is very flexible, and can fine tune the access of the various rooms.

Examples of well-designed security levels can be found at most high containment facilities, for example the Public Health Ontario (PHO) facility in Toronto (Canada), or the International Atomic Energy Agency (UN/IAEA) laboratories in Seibersdorf (Austria).

2.4 ESCF Functional Units

2.4.1 Description

The ESCF will have several diverse functions, and is designed to be able to host various types of samples. For the sake of clarity, the ESCF concept is broken down into several areas linked with specific functions. These are the ESCF Functional Units (FUs), shown in Table 2.3. The colour red is used for scientific FUs dealing with potentially biohazardous samples, the colour blue is used for scientific FUs dealing with unrestricted samples, the colour yellow is used for the last scientific FU, which will host only terrestrial samples. The colour green is used for accommodation of people.

The Portable Receiving Facility (PRF) is part of the ESCF but separate from it; the PRF is considered in Chapter 3. A Remote Storage Facility is also a separate building from the ECSF, but is not considered in this report. All the other FUs, Sample Receiving Facility (SRF), Sample Curation Facility (SCF), Analogue/Mock-Up Facility (AMUF), Work Space, and Public Outreach are units to be co-located on a single 'campus'.

Table 2.3 – Functional Units for the ESCF

PRF Unrestricted	PRF Restricted	Assessing, cleaning and/or 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, restaurant, 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.
Remote Storage Unrestricted	Remote Storage Restricted	Storage under dead-mode of a TBD part of the samples. Clean environment. For restricted samples, contained environment.

Red - scientific FUs dealing with potentially biohazardous sample; Blue - scientific FUs dealing with unrestricted samples; Yellow - scientific FU for terrestrial samples; Green - accommodation of people.

In Table 2.4, we examine the relationships between FUs, in term of circulation of staff. Physical links to allow for transfer of personnel were considered: + indicates a necessary link; - indicates a necessary absence of link; () indicates a possible link, if it is deemed beneficial for scientific goals; no marker indicates that the presence or absence of link is scenario dependent.

Table 2.4 - Links matrix for onsite FUs

	SRF Restricted	SCF Restricted	SRF Unrestricted	SCF Unrestricted	Work Space	Public Outreach	AMUF
SRF Restricted		+	()	-	+		
SCF Restricted			-	-	+		
SRF Unrestricted				+	+		
SCF Unrestricted					+		
Work Space							+
Public Outreach							+
AMUF							

+ necessary link; - necessary absence of link; () possible link, if deemed beneficial for scientific goals; no marker indicates that the presence or absence of link is scenario dependent

Restricted FUs and unrestricted were treated separately, for the following main reasons:

- Instruments cannot be shared between restricted and unrestricted samples (Franchi et al., 2016);
- Instruments will need to be modified to fit into villi or DWI;
- Additional facilities will be required for BAP/LD;
- Retrofitting is not sustainable (SEA, 2012).

For both unrestricted and restricted FUs, we joined the SRF and SCF in the functional layout. It is not a strong requirement, but it makes the transfer and opening of the sample canisters easier.

2.4.2 Parts of Each Functional Unit

The first step was to define the functional relationships and adjacency of each room or area of the FUs. To do so, the environment of each room, regarding cleanliness, containment levels (for restricted samples), presence of humans and/or robots, etc. was defined (see Table 2.3). In Table 2.4, we examine the relationships between FUs, in term of circulation of staff. Physical links to allow for transfer of personnel were considered: + indicates a necessary link; - indicates a necessary absence of link; () indicates a possible link, if it is deemed beneficial for scientific goals; no marker indicates that the presence or absence of link is scenario dependent.

TableThe definitions took into account the flows of activities, what samples would be manipulated and what staff would be required.

2.4.2.1 Analogue / Mock-Up Facility (AMUF)

This FU should be built before the other scientific FUs, and has several purposes:

- Testing of protocols and instruments, using analogue samples;
- Storing a sufficient collection of analogue samples;
- Training and vetting of staff;
- Development of containment solutions and equipment for the restricted facility;
- Participating to the public outreach program;
- Testing of materials and building techniques, before applying those to the other scientific FUs.

This FU has been designed to be smaller in comparison to the other FUs, as a ‘sandbox’ allowing curators, researchers, engineers, technicians and contractors to test and validate protocols, equipment and materials before using them on the precious returned samples. The analogue/mock-up facility features notably a

gowning suite (replica from the one for restricted FUs), a 'villi system', a storage room, a replica of an examination room and a smaller room to be used for material testing. The AMUF will not receive the Earth Return Capsule (ERC), so we did not include a high-bay.

2.4.2.2 Returned Sample Laboratories: General Design Decisions

At the interface of SRF and SCF, there is a Material Airlock coupled with a Dirty Tool room. These rooms are used as an airlock for reception of the ERC or the sample canister. They are also an area for instruments and tools that need maintenance or calibration out of the laboratories, when such tasks would otherwise disturb the operation, cleanliness and/or containment of the laboratory if carried out inside. The rooms are also used for the removal of decommissioned instruments. The area must be accessible by corridor from the laboratories in the FU.

The Vault is located next to the Preliminary Examination Room so the samples can be accessed and stored with limited transportation, reducing time and resources required to access them.

Doors for entering rooms are sized depending on what is required to pass through them; either people (single door) or instruments (double doors). In general, doors open contrary to the air flow and have an automatic closing mechanism.

2.4.2.3 Receiving Facility

Receiving facilities (Unrestricted and Restricted SRF) include a high-bay, able to accommodate a truck and potentially cranes if the transport case and ERC are too heavy to be moved manually. A fully enclosed unloading dock has been chosen as part of the SRF for cleanliness/containment and security reasons.

The ERC goes through a cleaning and opening room, and then the sample canister is introduced in the SCF. Layers of the ERC are also introduced in the SCF, to be curated in a dedicated storage room.

The level of containment, as well as transfer mechanisms from one room to the other, is dependent on whether the samples are restricted or unrestricted.

2.4.2.4 Unrestricted Sample Curation Facility Functional Layout

The Unrestricted SCF is split into two sub-sections; one extremely clean part for pristine and analogue samples, and a section for returned samples, spare hardware storage and preparation of samples to be disseminated to external laboratories.

Work on samples should be conducted in positive-pressure gloveboxes filled with an inert gas (see D1.3 and D3.1). Staff entrance is possible through a gowning suite adapted to the level of cleanliness.

The receiving area for samples is shared with the general receiving area (for instruments, consumables, maintenance needs, etc.).

Flow of samples and staff is usually through doors, with the occasional use of an air shower. Table 2.5 allocates a numerical value to different processes that are carried out within the FU within the ESCF, so that different aspects of the use of the FU can be evaluated.

Table 2.5 - Parameters for the Unrestricted SRF and SCF. Frequency: 1 = every day; 3 = very week; 9 = rarely. Cleanliness level: 1 = ambient; 2 = medium; 3 = clean; 4 = ultra-clean. People vs Robots: 1 = people only; 2 = Robots only; 3 = both possible. Light blue indicates high cleanliness areas, dark blue indicates lower level cleanliness areas, and green indicates no cleanliness level.

	Areas	Frequency of use	Cleanliness level	People vs. Robots	Air shower to enter	Changing room
SRF						
#01	Receiving area	9	1	1	N	Y
#02	Opening/Cleaning area (cycle)	9	3	3	Y	Y
#03	Material Airlock	9	2	1	N	N
SCF						
	High Cleanliness Curation					
#04	Preliminary Examination area	1	4	3	Y	Y
#05	Vault (Samples)	3	4	3	Y	Y
	Medium Cleanliness Curation					
#06	Sample preparation	3	3	3	Y	Y
#07	Contamination/Cleanliness Assessment	3	3	1	Y	Y
#08	Work room readmit. samples	3	3	2	Y	Y
#09	Cleaning tools area	1	3	3	Y	Y
#10	Storage area (readmit. samples)	9	3	3	Y	Y
#11	Storage area (HW & Coupons)	9	4	3	Y	Y
#12	Storage rooms (consumables)	1	3	3	Y	Y
#13	Dirty Tool room	9	2	1	N	Y
#14	ISO 5 Corridor	1	3	1	Y	Y
#15	ISO Airlock	3	3	1	Y	Y
	Outside of cleanroom					
#16	Instrument alcove	1	1	1	N	N
#17	Monitor room	1	1	1	N	N
#18	Distribution/Packaging room	3	1	3	Y	Y
#19	Buffer corridor	1	1	1	N	N
#20	ISO 4 Changing room	1	1	1	N	N
#21	ISO 5 Changing room	1	1	1	N	N

2.4.2.5 Restricted Laboratory Functional Layout

In this laboratory, the main design driver was the way the samples are handled.

A large part of the facility is designed to host several interconnected DWIs. Since a DWI provides primary containment and a physical barrier from sample to laboratory, staff can access the laboratory where it is positioned using only a rear fastening gown over disposable clothing (Table 2.6). As the DWI will have robotic manipulators within, staff will not be required to directly interact with it in the laboratory because the manipulators will be controlled remotely. However, in non-nominal situations, such as emergency procedures or maintenance of the DWI then it may be necessary to have airtight suits for workers to use, or some form of access to the inside of the isolator using gauntlets or haptic systems.

Table 2.6 - Parameters for the Restricted SRF and SCF. Frequency: 1 = every day; 3 = very week; 9 = rarely. Cleanliness level: 1 = ambient; 2 = medium; 3 = clean; 4 = ultra-clean. Containment Level: x = none; m = medium; h= high. People vs Robots: 1 = people only; 2 = Robots only; 3 = both possible. Yellow indicates medium containment levels, or gradual containment levels, Orange indicates the highest containment level

	Areas	Frequency of use	Cleanliness level	Containment Level	People vs. Robots	Air shower to enter	Changing room	Decon. Shower (exit)
SRF								
#01	Receiving area	9	1	m	3	N	Y	N
#02	Opening/ Cleaning area (cycle)	9	3	h	3	Y	Y	Y
#03	Material Airlock	9	2	m	3	Y	Y	Y
SCF								
	Contained curation							
#04	Examination area	1	4	h	2	Y	Y	N
#05	Vault (Samples)	3	3	h	2	Y	Y	N
#06	Contamination/Cleanliness Assessment	3	4	h	3	Y	Y	Y
#07	Storage Area (HW & Coupons)	9	3	m	3	Y	Y	Y
#08	Tool room/Dirty Room	9	2	h	1	Y	Y	Y
#09	Material Airlock	9	2	h	1	Y	Y	Y
#10	Corridor	1	3	h	1	Y	Y	N
	Non-contained rooms							
#11	Instrument alcove	1	1	x	1	N	N	N
#12	Monitor room	1	1	x	1	N	N	N
#13	Storage rooms (consumables)	1	2	n	3	N	N	N
#14	Storage rooms (general)	1	2	n	3	N	N	N
#15	Sterilisation area	9	3	h	3	Y	Y	Y
#16	Changing room	1	2	n	1	N	N	Y
#17	Suit changing rooms	1	2	m	1	N	N	Y
#18	Corridors	1	1	n	1	N	N	N
#19	Bathrooms	1	1	n	1	N	N	N
#20	Janitor room	1	1	n	1	N	N	N

Another part of the restricted SCF is designed to use either MSC3 as primary containment, or positive pressure suits. Staff entrance for this part is through a changing facility, whether using a suit or not, where staff will be required to don protective clothing before entering the restricted area.

A material airlock with decontamination capacities between those two parts allows for flows of instruments and staff if needed. This airlock, by completely isolating both parts of the laboratory, allows for a complete shut-down of one part (for maintenance or emergency) without impacting the other part.

2.4.3 Sizing of Functional Units

Sizes of rooms have been defined according to the activities conducted inside (Tables 2.7 to 2.10). FU sizing has been completed on information known on current technology, it would be envisaged that future technology development would lead to a change in the sizes used in the ESCF. Specific areas have been custom sized (and are described below), while more common parts of a laboratory (gowning, changing rooms, air shower, etc.) have been sized according to our visits to existing facilities, and interactions with the designers at Merrick and Company. Sizes indicated are minimum sizes. When the functional layouts were defined, the sizes may have changed to a certain extent.

2.4.3.1 Analogue / Mock-Up Facility

Table 2.7 - Sizing for the Analogue / Mock-Up Facility. Dimensions are in meters.

	Areas	Length (m)	Width (m)	Height (m)
#01	Test room	9	10	8
#02	Instrument alcove	5	5	4
#03	Monitor room	4	4	4
#04	Suit suite	…	…	…
#05	Material suitability room	4	4	4
#06	Storage room	5	5	4

2.4.3.2 Unrestricted Laboratory

Requirements are summarised in Table 2.8. The SRF needs to accommodate a transportation vehicle for the transport packaging used to safely house the ERC for transfer from landing site to SRF and should be high enough to accommodate, for example, a temporary cleanroom or a crane. Owing to the unrestricted nature of the sample there is no issue of biohazard so the same docking station can be used for instruments and pieces of equipment.

Opening/Cleaning area should be large enough for relatively large return capsules.

Preliminary Examination Areas are the largest rooms in the unrestricted SCF, and are planned to accommodate up to 20 gloveboxes.

Sample Preparation and Contamination/Cleanliness Assessment areas are wide enough to allow two working stations (or counters) on opposite ends and a wide enough for two people to stand in between.

Dirty Tool rooms are scaled so that large pieces of equipment can go through for maintenance and cleaning purposes.

Instrument Alcoves are designed with large machinery in mind, where they will be designed according to the pieces of equipment they will house (see deliverable D4.2). But to future proof the FU, alcoves can be made larger than necessary to accommodate equipment at later stages. Some large pieces of equipment will require stabilisers while others may need a Faraday cage. Monitor Rooms are large enough for observation windows and desks to be accommodated inside.

Table 2.8 Sizing for the Unrestricted SRF and SCF. Dimensions are in meters. Light blue indicates high cleanliness areas, dark blue indicates lower level cleanliness areas, and green indicates no cleanliness level.

	Areas	Length	Width	Height	Iterations
SRF					
#01	Receiving area	10	13	8	1
#02	Opening/ Cleaning area (cycle)	5	8	4	1
#03	Material Airlock	4	5	4	1
SCF					
	Contained curation				
#04	Preliminary Examination area	9	10	4	2
#05	Vault (Samples)	6	6	4	1
	Medium Cleanliness Curation				
#06	Sample preparation	4	4	4	1
#07	Contamination/Cleanliness Assessment	4	4	4	1
#08	Work room readmitted samples	3,5	7	4	1
#09	Cleaning tools area	3,5	3,5	4	2
#10	Storage Area (readmitt. Samples)	4	5	4	1
#11	Storage Area (HW & Coupons)	4	4	4	1
#12	Storage rooms (consumables)	3	3	4	3
#13	Dirty Tool room	7	10	4	1
#14	ISO 5 Corridor	…	…	…	…
#15	ISO Airlock	…	…	…	1
	Outside of cleanroom				
#16	Instrument alcove	5	5	4	2
#17	Monitor room	4	2	4	4
#18	Distribution/Packaging room	7	7	4	1
#19	Buffer corridor	…	…	…	…
#20	ISO 4 Changing room	…	…	…	1
#21	ISO 5 Changing room	…	…	…	1

2.4.3.3 Restricted Laboratory

Requirements are summarised in Table 2.9. Similar to the unrestricted facility, the SRF for restricted samples needs to accommodate a transportation vehicle delivering the transport container with the ERC inside. However, the facility design will include another docking station for pieces of equipment, when containment measures are not necessary, allowing for quicker access to the facility.

The opening/cleaning area should be large enough to accommodate any ERC, with a pass-box large enough between the docking station and the opening/cleaning area. This space should be modifiable in order to allow for the return of any ERC shape/design in future missions.

Preliminary Examination Areas are the largest rooms in the restricted SCF, and are planned to accommodate up to 20 gloveboxes or DWIs.

Dirty Tool rooms are large enough for the big equipment to fit through for maintenance and cleaning purposes. It will also be necessary to include a sterilisation chamber/room to ensure no unsterilized material is transferred out of the facility.

Instrument Alcoves are designed with large machinery in mind and they will be considered with the equipment they will house. Some large equipment will require stabilizers while others may need a Faraday cage. Monitor Rooms are large enough for observation windows and desks. In the case of restricted samples, the containment cascade must be maintained to ensure no unsterilized material is released to the environment.

Sterilisation of the samples and waste will be undertaken in the high containment laboratories. Primarily through energy sterilisation methods that will need to be validated. A sterilisation area adjoining the laboratories may also be necessary, this will be used to remove equipment from the laboratory. This area will be equipped with the equipment necessary for the validated sterilisation process e.g. gamma irradiation, dry heat, but have airlocks either end to ensure unsterilized particles are not released from the room.

2.4.3.4 Work Space

Requirements are summarised in Table 2.10. Areas have been designed to be of a size that is adequate to fulfil their intended purpose (and considering the total number of employees that is foreseen for the ESCF; cf. D3.1 and below) but also will allow for flexibility if instrumentation needs change or further work is required and the laboratory can then be adapted. For instance, in this case (Table 2.10) we account for a large bathroom unit that accommodates over 40 persons with male, female and disabled access bathrooms. If the design needs a larger area, then it might be wiser to have multiple smaller bathrooms.

For the most part, the working areas consist of shared offices with multiple meeting rooms ideally located in between them to favour interactions between employees. Single offices are considered for the administrative staff and curators. The Server room is narrow and long but this takes into account the consideration of multiple server racks in a side by side configuration. Its location, if possible not next to an exterior wall, will need to be as far as possible from potential sources of interference (i.e. from power plants or lifts, etc.). An Archive Room is also included to allow the storage of hard copies of documentation (i.e. based on different visits of similar facilities and curation expertise, hard copies will still be used in the next decades even if increasingly digital files are generated). It is also a narrow, 'corridor-like' room, so the documents can be stored in cupboards or archive cabinets with drawers. It will need to be ensured that the environmental conditions are maintained at a level that will not lead to damage of the media over an extended period. A large 'Mission Control' room (roughly over 100 m^2) is designed for scientific committee works or emergencies meetings. It can also be used for press conference or other purposes yet to be defined according to needs.

Table 2.9 - Sizing for the Restricted SRF and SCF. Dimensions are in meters. Colours show the level of containment, from none (white) to high (red).

	Areas	Length	Width	Height	Iterations
SRF					
#01	Receiving area	10	13	8	2
#02	Opening/ Cleaning area (cycle)	5	8	4	1
#03	Material Airlock	4	5	4	1
SCF					
	Contained curation				
#04	Examination area	9	10	4	3
#05	Vault (Samples)	4	5	4	1
#06	Contamination/Cleanliness Assessment	4	4	4	1
#07	Storage Area (HW & Coupons)	4	4	4	1
#08	Tool room/Dirty Room	7	5	4	1
#09	Material Airlock	3	4	4	1
#10	Corridor	…	…	…	…
	Non-contained rooms				
#11	Instrument alcove	5	5	4	5
#12	Monitor room	4	2	4	4
#13	Storage rooms (consumables)	3	4	4	7
#14	Storage rooms (general)	3	4	4	1
#15	Sterilisation area	5	6	4	1
#16	Changing room	…	…	…	1
#17	Suit changing rooms	…	…	…	1
#18	Corridors	…	…	…	…
#19	Bathrooms	…	…	…	2
#20	Janitor room	…	…	…	1

Table 2.10 - Sizing for the Work Space. Dimensions are in meters.

	Areas	Length	Width	Height	Iterations
Workers					
#01	Security booth	2	3	4	2
#02	Entrance desk	5	4	4	2
#03	Entrance hall	10	15	4	1
#04	Meeting rooms	14	10	4	3
#05	Guest offices	5	5	4	2
#06	Single offices	3	3	4	5
#07	Shared offices	4	3	4	7
#08	Administration rooms	3	4	4	5
#09	"Mission control" room	12	8	4	1
#10	Archive room (papers)	16	4	4	1
#11	Server room	10	4	4	1
#12	Security camera room	5	5	4	1
#13	Social rooms	4	5	4	2
#14	Cafeteria	20	8	4	1
#15	Toilets/Bathrooms	8,5	5	4	1

2.5 ESCF Siting

2.5.1 Siting Requirements

This project is a desk-based study and as so no specific site has been chosen; this section summarises the characteristics that must be considered when choosing the final location for the ESCF.

The siting of the facility depends on the following overarching factors:

- Site constraints:
  - Topographical
  - National regulations;
- Possibility of international/European/multinational politics;
- Funding phases.

Since the ESCF is primarily designed to receive the ERC, and secondarily for access of collaborating external researchers and visiting officials (potentially a wider audience due to the Public Outreach program), it is recommended that the facility is positioned somewhere that is easily accessible. This involves choosing a site with good existing transportation networks (roads, airport, train station), or to have the option to create the necessary infrastructure (although this will be significant additional cost and so could be a major issue).

When dealing with restricted returned samples, it is recommended to have a medical facility nearby with the capability of handling patients infected with unknown biohazards, or the provision of a quarantine facility at the facility.

Although the design and subsequent operation is a multinational effort, the construction would usually be carried out by local contractors. Since the ESCF facility will be bespoke and require specialist construction in some areas, contractors from other countries may be required for certain phases of construction and will need to travel to the country.

Natural and manmade hazards for the ESCF site are to be considered (see the section 'Safety and Risk Assessment').

Whilst there will be a high political impact on where the ESCF will be constructed a detailed trade-off was not undertaken within this project comparing the impact for the ESCF housed on one site or with FUs separated over several sites/countries. Scenarios have previously been presented in D3.1.

2.5.2 Siting Parameters

2.5.2.1 Required Height for the Laboratories

The spacing between the floors of the ESCF will be dependent on the layout of the laboratory and the associated plant material, services required and the effluent treatment system. The height of the laboratory itself will be dependent on the equipment in it, the heat load given off by the equipment and the required parameters for the negative pressure/air flow in the laboratory (i.e. a large volume will require a more powerful HVAC system to be able to maintain the set parameters) (Franchi et al., 2016). Each FU has different requirements, hence different heights (Figure 2.17). A comprehensive design of the ESCF must take into account these space requirements.

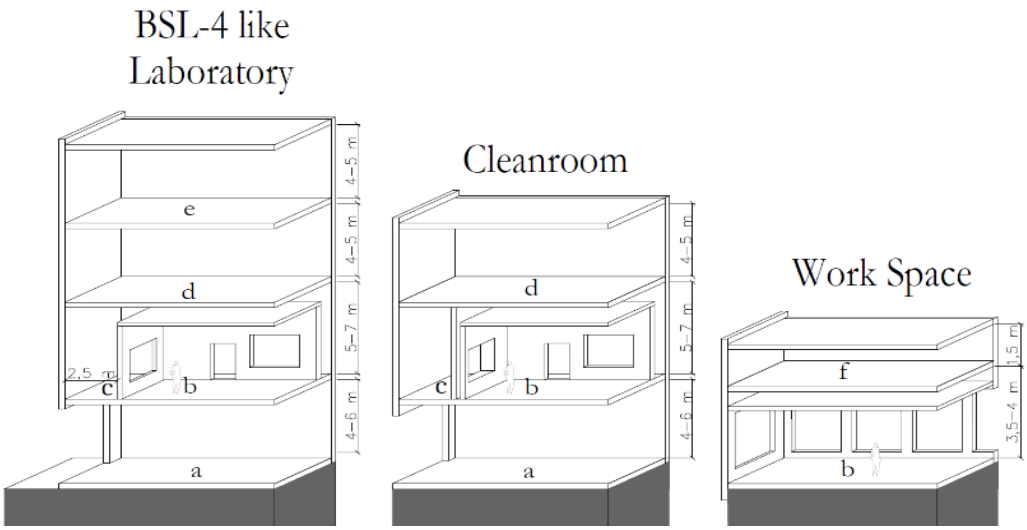


Figure 2.17 - Required heights for FUs. A BSL-4 like laboratory will be used for all restricted FUs. Cleanroom design will be used for all unrestricted FUs. (a) Effluent systems and waste treatment; (b) Working space; (c) Buffer corridor; (d) Air filtering systems

Restricted (BSL-4 like) laboratories require the most space above and below, usually two floors above and one floor below large enough to accommodate waste treatment (waste tanks). In general, liquids are kept below the laboratory floor, while air handling systems are kept above it. The machinery itself typically does not require a height of several meters, but it will impact the maintenance and servicing if staff cannot easily access this floor.

Unrestricted Laboratories have less need regarding waste and effluent treatment systems, and have also a more limited heating, ventilation and air conditioning (HVAC) system. All the different cleanrooms can be located on one floor, with a system of 'grey area' surrounding them, housing the machinery. However, a dedicated floor for the machinery will help with the maintenance and servicing without causing

contamination. Leaving the outside walls of the cleanrooms 'free' would also allow space for better integration of the instruments and possibilities for public outreach, by using see-through windows.

The third block in Figure 2.17, shows a standard office level with a false ceiling, included for comparison purposes to the scientific FUs.

2.5.2.2 Position of Ground

Each floor must be easily accessible to accommodate ingress of new equipment, egress of decommissioned instruments and of waste. This is extremely important for the areas that support the laboratories, such as the effluent treatment and air handling floors, but also for the receiving areas for the lab supplies and consumables. Figure shows several possibilities, by using goods lifts and by using the position of the ground relatively to the building. The facility configuration in this figure is a BSL-4 like configuration.

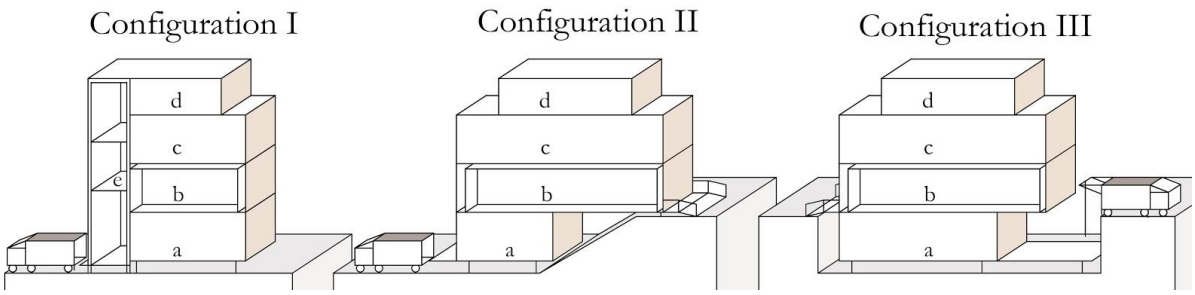


Figure 2.18- Placement of ground level. (a) Effluent systems and waste treatment; (b) Laboratory level; (c) Air filters and machinery I; (d) Air filters and machinery II; (e) Goods lift

In configuration I, the entire building is above ground level and a goods lift is used to service each floor. The lift must have the capacity to carry any piece of equipment needed in the facility (including any possible machinery in the future). Movement of large lifts can also create a 'piston effect' where airflows around the facility can be affected. The use of large lifts needs to be considered when designing the air handling of the building. In this configuration, the laboratory itself is on the second floor, hence being less accessible in case of unauthorised security access of the building. Issues can arise with this configuration if there is a breakdown of the lift meaning no equipment or supplies can be transported between floors unless they can be manually carried by the stairwell.

In configuration II, a sloped terrain is used (or built) to allow an access to different floors from the ground level. The concept could be artificially generated by building a ramp around the building, allowing a road access to each of the main levels. This design would mean that heavy equipment could be moved into the building on pallet trucks without the need for a lift between floors, providing easier access for larger items. This solution could increase the cost of the infrastructure and may also generate for example unwanted vibrations.

In configuration III, the effluent systems and waste treatment floor is below ground and can be reached through an opening on the side of that area, whilst offering ground floor access for the laboratory level. Access to the lower level is somewhat more complex than in the other two configurations, and a goods lift is still required for upper levels. The lower level of the facility would need to be designed to withstand flood water entering from the ground or run off areas outside.

2.5.3 Materials Requirements

The materials that could be used for containers, tools or gloves (everything that could be in close or direct contact with the samples) are discussed in this section. Building materials (walls, floors, paint, etc.) are not considered here because they would be dependent on what would be identified in the design phase of the

project and would have to adhere to the local building regulation of the nation where the facility would be built.

In general, materials with a low rate of particle production, a low rate of outgassing and a simple composition (meaning they can be measured easily in contamination instances) are favoured. A review of both metallic and plastic materials is given below.

2.5.3.1 Metallic Materials

Metallic alloys should be preferred to other rigid materials such as carbon fibre and other carbon compounds (e.g. SiC, TiC) because of their lower outgassing rate (at least one order of magnitude less; Craig Jr, 1980).

The following properties should be considered in the selection of the metallic alloys:

- *Outgassing rate.* A low outgassing rate is needed in order to minimize the risk of forward contamination.
- *Rigidity and resistance to breakage.* This has to be considered only in case of transport outside the ESCF in order to withstand to shocks (i.e. it is not a fundamental property for containers that remain inside the ESCF). Although there will need to be a level of rigidity for materials used in the construction of equipment in order to allow them to function e.g. cabinet wall materials.
- *Thermal conductivity.* This should be taken into account in case the samples need to be maintained at a reduced temperature and hence thermal insulation from the container is required.
- *Cost.* This is something to be considered if two or more materials have similar properties.
- *Electromagnetic properties*. Electrostatic and/or magnetic charging can alter the properties of the samples, or make the manipulation of small-sized particles difficult. On the contrary, some materials can shield the samples from magnetic fields.

We do not consider density in this trade-off analysis, since the amount of samples to be transported is expected to be low (in the order of some grams) and hence the containers' size is also expected to be relatively small. Therefore, container/box mass is not critical, contrary to boxes aimed at transporting entry and return capsules (whose masses can be in the order of 10^2 kg), for which density is crucial for materials' selection (Longobardo et al., 2016). A summary of the considered properties is given in Table 2.11.

Table 2.11 - Physical properties, thermal properties (Patrick, 1973; Edelmann, 1992; Koyatzu et al., 1996; Huttel, 2014; Moshey, 1982) and costs of metal alloys (derived from an analysis of the current market prices).

Alloy	Outgassing rate (10^{-6}torr l s^{-1} cm^{-2})	Young's modulus (GPa)	Thermal conductivity (W/(m. K))	Cost (€/kg)
Stainless steel	0.05	195-215	16-24	1.3-1.5
Aluminum	0.6	70-80	230	1.5-1.7
Magnesium	1	40-45	120	1.6-1.8
Titanium	0.1-0.3	85-130	6	43079
Copper	0.7	120-150	400	4-4.5

Outgassing rate and cost are the only criteria taken into consideration for transport of samples inside the ESCF, if there is no requirement for low-temperature storage. For both criteria, stainless steel is the most appropriate material. Young's modulus (i.e. resistance to being deformed elastically during a mechanical stress) should also be taken into account for materials used in the transport containers used externally to the facility; stainless steel is again the most suitable alloy because it has the highest rigidity.

If the samples must be kept cold, titanium may be more appropriate than stainless steel because it has better thermal insulation properties. However, its greater outgassing rate (one order of magnitude larger than stainless steel) and cost (~7 times more than stainless steel at current market price) might preclude its use. A combination of two (or more) alloys could also be considered but should be avoided as the number of materials used should be kept as low as possible to allow for detection in contamination identification.

2.5.3.2 Plastic Materials

According to WHO requirements for packaging, plastic materials should have a good mechanical resistance and a low permeability to avoid escape of pressure or material. In addition, a low outgassing rate is a fundamental property, since it minimises the risk of contamination to the samples. Plastics should be chemically inert as well, to avoid any reactions with the samples, or with chemicals used during analyses.

Longobardo et al. (2016) describes that the polymers with the lowest outgassing rates are Polyurethane (or Adiprene, polyether or polyester di-isocyanate copolymer), Teflon (tetrafluoroethylene polymer), KEL-F (or Neoflon, chlorotrifluoroethylene copolymer) and Perfluoroelastomer (or Kalrez, tetrafluoroethylene-perfluoromethylvinyl ether copolymer).

The following trade-off has been performed on these four materials and is based on:

- Wear/abrasion resistance;
- Water permeability (water resistance is a necessary property);
- Nitrogen permeability (since the containers can be filled with nitrogen);
- CO_2 permeability (since CO_2 might be released from Martian samples or used as the atmosphere to mimic Mars during sample handling);
- Linear coefficient of thermal expansion (this should be low in order to minimise the risk of permeability increase due to thermal expansion of the plastic material);
- Cost.

Table 2.12 summarises the properties of the four polymers.

Table 2.12 - 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). Costs have been derived from an analysis of the current market prices

	Wear/abrasion resistence	**Water permeability (10^8scmm s^{-1} cm^{-2} cm atm^{-1})**	**Nitrogen permeabil. (10^8scmm s^{-1} cm^{-2} cm atm^{-1})**	**CO_2 permeability (10^8scmm s^{-1} cm^{-2} cm atm^{-1})**	**Linear coefficient of thermal expansion (10^5 $°C^{-1}$)**	**Cost (€/kg)**
Polyurethane	Excellent	260-9500	0.4-0.11	11232	42064	0.3-0.4
Teflon	Excellent	27	0.14	0.12	42952	43952
Neoflon	Very Good	0.5	0.004-0.03	0.02-1	42920	20-60
Kalrez	Excellent	40	0.05-0.3	5.8-6.0	23	3000-5000

Polyurethane is not suitable due to its high levels of permeability. Kalrez has overall good mechanical and thermal properties, but it is extremely costly compared to the other polymers.

Teflon and Neoflon (KEL-F) are potentially the materials if material cost is a high priority. Linear coefficients of thermal expansion are similar between Teflon and Neoflon; Neoflon has a lower permeability to water, nitrogen and CO_2, but also a lower resistance to abrasion and is at least three times more expensive than Teflon. Therefore, for the plastic bags in which the sample containers would be placed, Neoflon is more suited because the samples' insulation is the most important issue and abrasion has a low probability with the bag being secured in the transport container to stop it from becoming damaged. Alternatively, for covering the

internal walls of the sample containers Teflon should be used because it is less expensive than Neoflon and thermal insulation would be provided by the external layers (i.e. the transport container).

2.6 Portable Receiving Facility (PRF) Design

Previous recovery missions have not needed a portable facility that can be placed over the respective ERC and the immediate area. This would only be considered necessary if the mission is Category V, restricted. In this case, if the landing is nominal and there is no risk that the containment has been compromised, then the ERC can be retrieved and packaged into the transport container. If there are adverse weather conditions, rain or high winds, then covering the ERC landing site can aid the packaging into the transport container by protecting the workers and the equipment from damage. If there has been a non-nominal landing and a loss of containment, then a mobile facility placed over the impact site will also help to limit any spread of sample material if there has been a breach of containment from the ERC through wind dispersal or precipitation. A covering over the site will aid the process of dealing with sample release in the immediate vicinity of the impact site, but if the sample release was wider than the area the covering can be deployed over then contamination risks being spread with environmental conditions.

2.7 Staff

2.7.1 PRF Staff

Several factors can be used to decide on the selection of staff required for the initial inspection, recovery and transport of the samples to the ESCF. It would be envisaged that whilst there would be overlap between each of these activities there would also be differences and as such this would reflect in the makeup of potentially different the teams being used. This would require a decision at high level whether a person or persons would be involved in more than one of the aspects of the collection and transportation elements. Staff would ideally be selected on their ability for working with the technology needed for each stage of the recovery (Barrow et al. 2007). Staff with specialist knowledge of the construction of the ERC would be required for the initial inspection and potential identification of any variances from the nominal landing process.

Throughout the landing process it would be necessary to have a multifunctional team available for different purposes. This team must be fully trained and competent to fulfil the following functions:

- Recovery (including initial inspection);
- Transportation.

And if required:

- Environmental sampling;
- Decontamination.

It would be prudent to have expert leads in each of the above fields within the team. Whilst a number of scenarios would be used in training exercises, it would be unlikely that every scenario would be covered and therefore experience in the field would be required for the staff.

Selection of staff may depend on the chosen PPE required at the landing site. Certain physical attributes might be required and others selected against. If there is a suspected containment breach then it may be deemed necessary for all personnel accessing the site to wear high level PPE, such as a positively pressurised air fed suit. Conditions in these suits can be hot, and physically demanding and reduce visual and communication ability, so staff members might need a medical test and physical fitness assessment before they can be selected for the team.

A key attribute that should be sought in staff is the ability to work in teams. It will be required to work using a ‘buddy’ system where one person will undertake a task that will be watched, checked and documented by

another. This will be extremely important for tasks that require records being taken and notes being documented. For example, during the process of taking environmental samples the two-person team will work together with one person taking the sample and the buddy documenting the procedure, by recording the exact location, sample type, conditions and taking photographs. Another example would be for a complex protocol the buddy can assist the operator by providing details of the protocol steps and any tools that might be required, and therefore making it easier for the operator to focus on performing the necessary steps.

The number of trained individuals would be determined during the mission design process. It would advisable to have a number of staff members trained in more than one role so they can replace any individuals that maybe not able to complete their task.

Figure 2.19 shows an estimate of the number of staff and staff structure in planning a recovery operation.

2.7.2 ESCF Staff

During the initial phase of characterisation, experience shows that there is intense pressure to obtain results quickly, and fatigue within science teams and technical staff is likely to be an issue. One member of the Lunar Sample Preliminary Examination Team (LSPET) described being in a 'daze of exhaustion' after three weeks of analysing Apollo 11 samples (Taylor, 1994). In a curation setting, especially for Mars samples, fatigue could further lead to breaches in protocol that could undermine both scientific and public confidence. Accordingly, considerable attention should 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 after a sample return mission.

As the sample return missions and the curation of the samples are projects spanning decades, a mix of experienced workers and of younger technicians, engineers and scientists would be beneficial. In general, studies have shown that variety in staff regarding age, gender, disciplinary field or country of origin makes work more competitive.

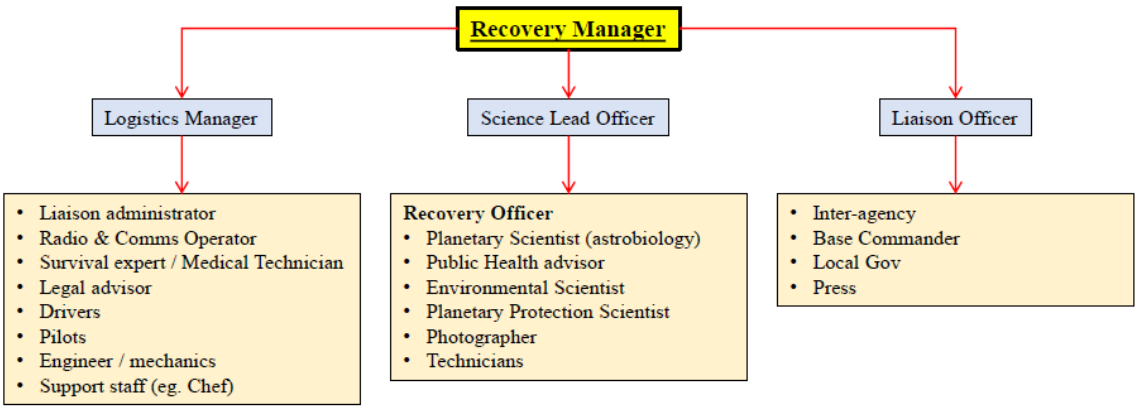


Figure 2.19 - Personnel for recovery process

Figure 2.20 shows the hierarchy of staff expected to work in the facility with their respective function(s), including an estimate of the minimum number needed for the ESCF to operate. The number of employees is highly dependent of the state of the ESCF (FUs built, mission arriving or already curated, etc.).

The following list considers an integrated approach for the facility. But if the design concept is broken down to different units, there might be replicas needed such as separate staff working on unrestricted and restricted missions.

The list was first compiled based on expertise of the WP3 team members, some input from the WP4 and then completed using other various sources, including personal working at JSC (NASA) and JAXA.

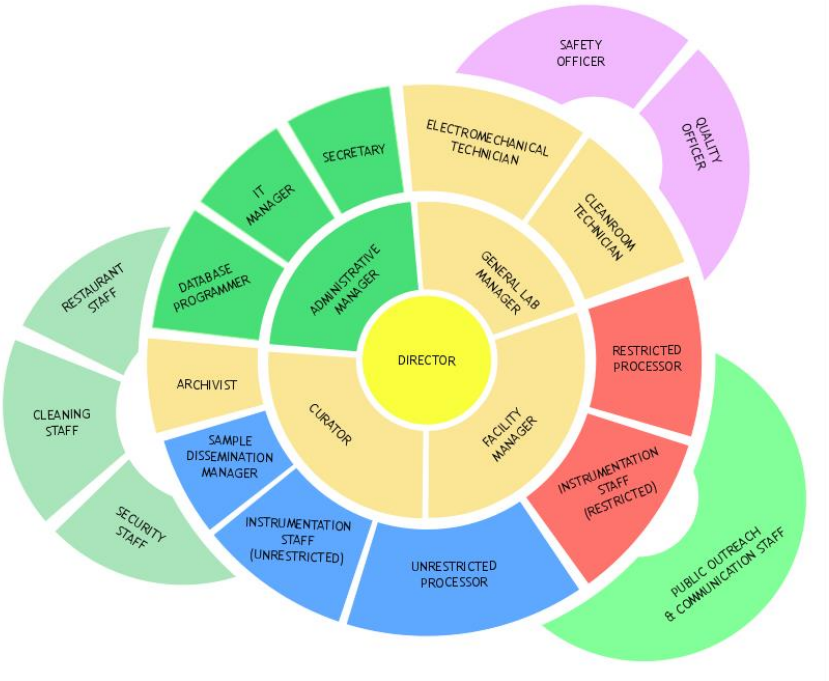


Figure 2.20 - Proposed organigram of the ESCF

2.7.2.1 Administrative Staff

The administrative staff do not deal directly with the samples and are required whether the facility is hosting unrestricted or restricted samples.

Director of the facility: Directs and manages all the facility operations. 1 full time person.

Administrative manager & Secretary: In charge of the business planning, finances, human resources, etc. Supports staff, handles personnel issues and assists with various other administrative tasks. 2 full time persons.

Quality officer: Writes and reviews operating procedures in collaboration with science staff. Carries out quality audits. Interacts with external quality auditors. 1 full time person.

Safety officer: Provides safety advice, risk assessments and planned maintenance schedules for the facility. Carries out safety audits. Interacts with regulators. 1 full time person.

IT manager: Handles the day-to-day computer and network related issues. 1-2 full time person(s). Can be outsourced to an external company. If the facility is included in an already existing institution, there is no need of a dedicated worker.

Database manager/programmer: In charge of the database software (to develop, manage and maintain database(s) and the general website of the facility). 1-2 full time person(s).

Public outreach & Communication staff: Organises the activities of the Public outreach unit, promote the ESCF through communication media. Liaise with local associations and authorities for ensuring open communication. 1-2 full-time person(s).

Security staff: In charge of the security of the site and its assets. 4-6 full time persons. Can be outsourced to an external company. If the facility is included in an already existing institution, the number of dedicated workers could be reduced if they already operate at the required level.

Restaurant staff: Applicable if catering is on site. Deals with the operation of the restaurant. 4-5 full time persons. If the facility is included in an already existing institution, no need for dedicated workers.

Cleaning staff: In charge of the cleaning of the non-restricted areas (i.e. non-cleanroom parts) of the facility. 1 full time person. Can be outsourced to an external company. If the facility is included in an already existing institution, no need of a dedicated worker.

2.7.2.2 Science Staff for General Functions

Science staff deal with samples and maintenance of the facility.

Curator: Responsible for the curation of the samples. In charge of the handling, documentation, preparation, preservation and distribution/allocation of the samples. Also assumes managerial roles, supervises personnel and is involved in education and public outreach. The same person can be curator for multiple collections. 1 per mission and/or set of samples, full time.

General (laboratory) supervisor/manager: Provides oversight of day-to-day technical and scientific functions of the facility. 1 full time person.

Facility manager/engineer: Responsible for ensuring that the building operates correctly and is correctly maintained. May be responsible for contracting out servicing and maintenance (i.e. filter testing, room air flow validation, autoclaves, primary containment, equipment testing, etc.). 1 full time person (?).

Archivist: Tracks the records associated with samples (loans, publications, etc.). Can be associated with the sample dissemination manager, at first. 1 full time person (?).

Cleanroom technician: Responsible for keeping the laboratories clean, cleaning the tools, helping with organization in the laboratories, etc. and of the training of facility staff and visiting researchers. 1-2 full time person(s).

Electromechanical technician: Fixes and maintains things in the laboratories (lights, microscopes, heat-sealers, etc.) and of the major infrastructure systems that supply the laboratories (i.e. air-handlers, liquid and gaseous N systems, UPW systems, etc.). Only light works, considering there will be full maintenance once or twice a year done by an external company. Can also build small custom things for the cleanrooms. 1-2 full time person(s).

2.7.2.3 Science Staff for Unrestricted Samples

Sample dissemination manager: Responsible for dissemination of the samples to external science laboratories (and to education institutions). Deals with loan agreements, contracts, shipping and receiving of the samples, education & public outreach, etc. 1 full time person.

Unrestricted processor: Performs the preliminary examination on sample containers and samples. Prepares samples for dissemination, according to requests. Processors are cross-trained to be able to work on several collections and several techniques. Training is performed with analogue samples. Unrestricted processors cannot work on potentially biohazardous samples, since it requires a specific and demanding training. 2 full time persons (to be increased with time and multiplication of the samples/collections).

Instrumentation staff: WP4 (Instruments and Methods) plans a suit of 13 instruments in total to perform the SEC on unrestricted samples (see D4.2). To properly run these instruments, a minimum of 9 (full time) persons is envisaged by the WP4 team.

2.7.2.4 Science Staff for Restricted Samples

Restricted processor: Specially trained scientists/technician/engineer to handle restricted samples. Work on samples in the BSL-4 part, on life detection (including BAP). Must work in pairs and for a limited time inside the laboratory. 2-4 full time person(s). In the case where a robotic approach is preferred, workload will be reduced.

Instrumentation staff: WP4 (Instruments and Methods) plans a suite of 13 instruments in total to perform the SEC on restricted samples (D4.2), independently of Life Detection and Biohazard Assessment Protocol. To properly run these instruments, a minimum of 9 (full time) persons is envisaged by the WP4 team. LD and BAP will require additional instruments (see WP2 deliverables), and hence additional staff.

In total, we estimate between 30 and 50 staff independently on the choice of scientific FUs (unrestricted or restricted).

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.

2.8 Internal Communications

There should always be a method of communicating directly between the different units of the ESCF. Inside the laboratories communication will be *via* a hands-free telephone, which removes the potential for contamination of the worker's face or person when handling the telephone. Person to person communication within a cabinet line laboratory can be achieved easily but a different system will be required when the operators are working in positive pressure suits as these can be noisy and difficult to communicate in, even when two workers are standing together. In these instances, radio communication systems are employed with push to talk microphones. This allows easy communication to others in the laboratory or outside the laboratory. One security issue with radio usage is that people external to the facility could intercept the communications within it. This can be overcome by using a secure frequency and encrypted radios.

An ESCF communication plan is mandatory: laboratory personnel should be aware of the plan and should know what to expect and what is expected of them.

Following the concentric infrastructural security approach, there is a requirement for a highly level of redundancy for the communication devices used, so in an emergency there are several different ways of communicating. This applies to both the internal communications systems (between each facility unit) and the external ones (from the facility to the outside and vice-versa).

The ESCF should be then considered as a net, where each unit is a node. If no unexpected incident occurs nside the facility, the communication net is shown in Figure 2.21.

It should be noted that, for graphical reasons, not all the connections are showed in the Figure : communications is possible 'across' a unit, when it has two or more connections (i.e. SRF restricted unit can directly communicate with the work space unit).

In this case the work space unit acts as an information collector, connected to all the other ESCF units and to the outside.

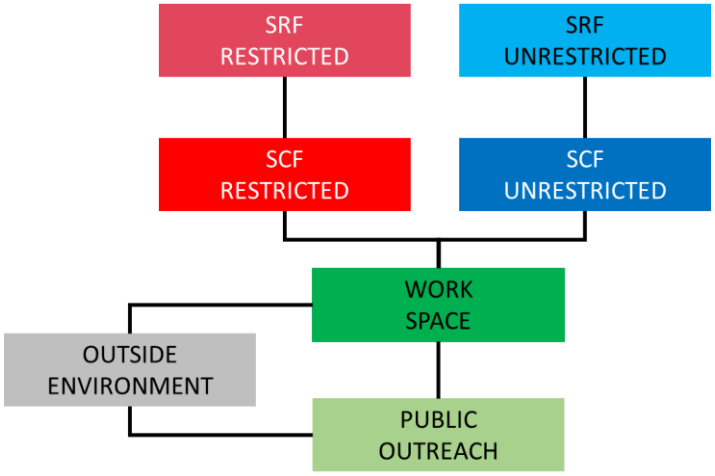


Figure 2.21 - ESCF communication net

If an emergency affects the facility (i.e. some regular means of communication may be compromised: telephones may not work, a power loss may affect access to computers, etc.), all the units are connected to each other and to the outside. Figure 2.22 shows the communication net in case of emergency. This is particularly important in case of security issues when, depending on the circumstances, some connections may fail.

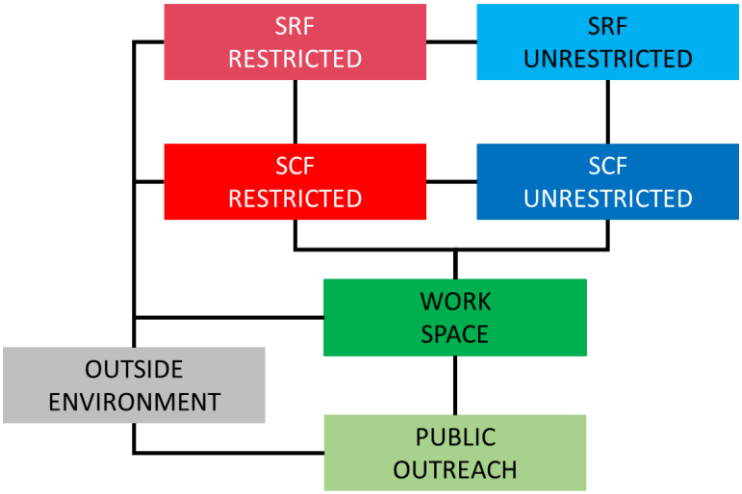
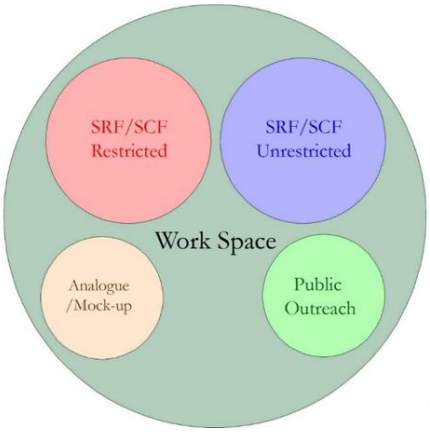
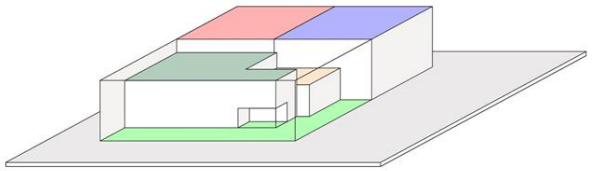


Figure 2.22 - ESCF emergency communication net

Redundant systems are mandatory in case of unexpected incidents when an emergency affects the ESCF or the surrounding environment. In these cases, telephone systems may quickly become overloaded, and local or institutional police, security, or public safety officials may receive a number of calls that their network cannot cope with. Text messaging, e-mail, and the internet can be the primary redundant means of communication. Self-powered devices are also mandatory in case of extremely serious incidents. If an incident has caught the attention of the media, the institution's press officer must be involved in any conversations with reporters. Media inquiries should go through the person or group that is used to working with the media, because it is very easy for facts or issues to be misconstrued or presented in an inflammatory manner. All involved should be instructed to forward calls and interviewers to the media relations group. When an incident command system has been instituted, a press officer will be appointed. All inquiries and statements go through this individual or group.

3. ESCF AND PORTABLE RECEIVING FACILITY BUILDING DESIGN





3 EUROPEAN SAMPLE CURATION FACILITY AND PORTABLE RECEIVING FACILITY (PRF) BUILDING DESIGN

3.1 Timeline of Building

Combinations of Functional Units (FU) are considered in ways that deliver the most efficient use of resources and space, whilst providing the necessary scientific benefit to the projects handled within the facility. The facility should be built with the idea of future-proofing, to ensure the minimum amount of work is required in the future. Although any specific combination of units should make sense structurally, technically and architecturally, some scenarios are more likely than others and are discussed below.

The most probable phasing is:

Step 1: Analogue/Mock-Up Facility (AMUF) and offices, to test building services, sample protocols and staff training;

Step 2: Either Restricted Laboratories or Unrestricted Laboratories, with extension of offices unit (if necessary);

Step 3: The other scientific laboratories, with extension of the offices unit.

Public Outreach should be considered from the beginning.

Extension of scientific FUs is not considered here.

We identify the main steps of the project, with an estimated time required for each step (Space Studies Board, 2002; NIH, 2016; personal communication Merrick and Co.). In between each step, there will certainly be added time for reviews by external experts or by the funding agency. Since it is currently unclear where and how the ESCF will be built, these intermediate steps might vary.

Development of new technologies: for the restricted sample facility there will be requirements for the development of new technologies to produce a facility that meets the cleanliness and containment requirements while allowing achievement of scientific objectives. These developments may include double-walled isolators (DWI) and novel methods of incorporating scientific equipment into a DWI.

Pre-design phase: this phase is to identify and document factors that will impact the project. We recommend an integrated pre-design phase, with an assembly of all the stakeholders involved in the project: users (PIs, technical staff, etc.), architects and engineers, safety officers, commissioning agents and an executive committee. Depending on the mission planned, this phase should focus on protocols for the AMUF, and for one of the scientific laboratories (12 - 24 months). The outputs of this design phase should be white papers regarding:

- Scientific objectives;
- Ergonomics and staff well-being;
- Staffing;
- Budget;
- Master planning;
- Biocontainment strategy;
- Safety and security;
- Sample Early Characterisation Protocols;
- Life Detection Protocols.

Out of this process should come a user requirements specification document (URS) which can be given to designers and architects for them to provide detailed designs.

Design phase: incorporating the requirements defined earlier room by room (with technical information), the design aims at delivering plans that can be used for building the facility. This phase is composed of the Concept Designed Phase, and of the Detailed Design Phase. Based on the detailed design, contractors can be contacted for price estimations (up to 24 months).

Construction phase: the construction phase will be dependent on the type of facility i.e. restricted or unrestricted. The possible timelines for this are +12 months depending on the construction materials to be used and the complexity of the design.

Certification and Commissioning: this phase aims at troubleshooting and testing all building parts and laboratory mechanisms: Heating, ventilation and air conditioning (HVAC), pumps, redundancy systems, etc. (12 - 24 months depending on complexity).

Procedures and protocols testing phase: all procedures should be rehearsed with a trained staff. If required mock ups can be constructed to assess the practicalities of the procedures. If deemed necessary, procedures will be adapted (6 - 12 months).

The minimum time required to build the first steps of the ESCF would be around 7 years; this must be completed prior to the return of samples.

3.2 PRF at Landing Site

A tent can be erected within a short space of time to provide cover over the landing site, should this be required for planetary protection purposes. Tents and portable facilities are used in a number of other fields to protect their occupants or the material within. Inflatable structures (Figure 3.1) can be bespoke made to the user requirements and are currently used in a number of situations to protect the occupants and material inside, such as disaster management and military applications (field hospitals). They can be easily and quickly inflated using a generator to power the fan, and have multiple anchor points to affix them to the ground.

Figure 3.1 - An inflatable structure used by Medicins Sans Frontieres for a hospital after an earthquake in Haiti. Image credit www.doctorswithoutborders.org

These tents are provided flat packed and can be erected within a short space of time to provide cover over the landing site. The use of the tents in their current sectors where protection of the contents and floor area are critical, show that they are currently at a high technology readiness level (TRL). This would mean that

they would exhibit a technology maturation level of TRL 5/6 for the space industry, with the capacity to increase rapidly to a mission ready TRL.

After use of the tent or other portable facility they can easily be disassembled and either cleaned and repackaged for future use or packaged and then transported for disposal/incineration depending on what is determine as the most appropriate course of action. Continuing to cover the impact site will allow for more considerations to be undertaken regarding the future of the impact site if a breach of containment has occurred.

3.3 ESCF Building

3.3.1 Flexibility

Flexibility is one of the most important concepts to be considered for project such as the ESCF. We developed this concept at several levels, with the requirement of future extensions and expansion. Each core function of the ESCF is linked to a Functional Unit (FU).

- 'Campus' scale: units should be linked in a way that allows the efficient flow of personnel and materials. Any specific combination of units should make sense structurally, technically and architecturally. *This flexibility is important, especially since the funding and building status is not yet fixed, to allow for different working scenarios. It can also be a way to (quickly) adapt to a change of mission architecture, or to the failure of a mission.*
- 'FU' scale: one unit should be easily adaptable for future developments and expansion of activities and utilities (mechanical, electrical, etc.). *In most of the similar facilities (such as at NASA JSC and JAXA), non-scientific rooms (usually work spaces or public outreach spaces) are retrofitted after some time to accommodate new missions or science goals. It usually results in less appropriate laboratories (i.e. not as much functionality as if they had been planned as laboratories from the start), and also the well-being of workers.*
- 'Room' scale: some rooms should allow for easy restructuring or change of the activity to be conducted inside. *It should be stated here that a given laboratory will need to be completed at least 7 years before the return of the samples. Consequently, without knowledge of the exact nature of the samples or the condition of the sample inside the containers (see NASA's Genesis sample-return mission), the laboratory should be easily adaptable (i.e. by adding new instruments that were not originally planned).*

3.3.1.1 Flexibility on Campus Scale

The concept of flexibility was constantly kept in mind while designing siting scenarios. However, the flexibility will heavily depend on the location, and on the size of the available space.

3.3.1.2 Flexibility on FU Scale

While designing the functional layouts for scientific FUs, we tried to follow three requirements: allow easy and efficient staff flow, allow access by truck (with an access ideally far from the staff entrance) and keep expansion possibilities for the future.

The staff flow was mostly enabled by a buffer corridor surrounding the laboratories - and incidentally fulfilling the requirements on cleanliness and containment successive layers. The staff entrance to the buffer corridor should be kept close to the office portion of the complex, in order not to increase the route to the laboratories.

The future expansion was enabled by dedicating one or two sides of the unit for the said expansion. These fixed sides are adding more constraints on the siting plans.

The laboratories have at least one side reserved for the sample transportation (with a high bay) which should have a road leading to the outside of the complex.

Given all these considerations, adjacency or not of FUs might be heavily constrained, and it will at the end largely influence the final design of the ESCF in its entirety. Figure 3.2 is a schematic representation of these three requirements.

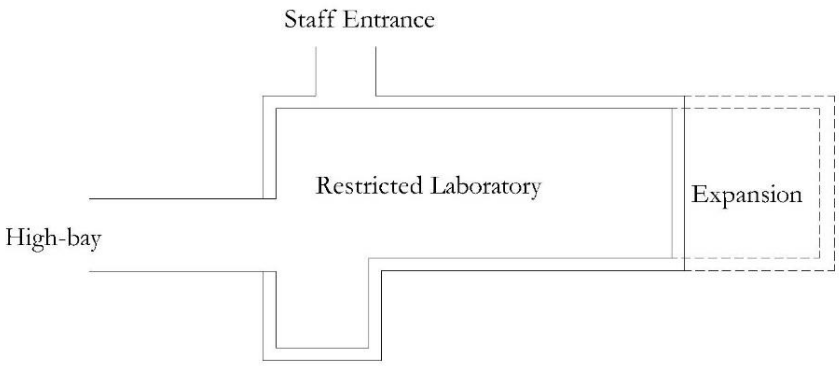


***Figure 3.2** - Schematic representation of access and expansion possibilities for a laboratory, in the case of the restricted SRF/SCF*

Security aspects also factor in the consideration of the design of the ESCF. Higher security risk units/buildings can be covered physically by larger, less security demanding units/buildings. The connections will need to reflect these considerations. Restricted FUs for example should not have direct connections with the public outreach program.

3.3.1.3 Flexibility on Room Scale

Interior design of laboratories can be used to increase flexibility with cleanrooms panels separating areas, movable furniture, etc.

3.3.2 Siting Scenarios

Based on the requirements presented in Chapter 2, we are proposing different possible approaches for building the entire ESCF to fulfil the 'Campus' scale flexibility requirement. We then reflect on each approach regarding flexibility, security, costs and other parameters as summarized in Table 3.1.

These approaches are all generated over a unique site, however, the entire concept is made so that if one FU is not built, it does not impact on the other FUs. Each different approach (Figure 3.3 to 3.7) is presented with a conceptual diagram on the left and a schematic interpretation on the right (to allow better visualisation).

To accommodate such a campus, a dedicated Utility Plant (UP) must be planned, providing power, water, steam and anything necessary to the operation of the FUs. In emergency cases, single functions should be able to work independently. It is also imperative to allow shut down protocols to be effective in certain time frames. UP is not shown in the diagrams below, for clarity reasons.

Orientation relative to the external surroundings is also important as to how to connect the functions to each other and to the outside world, be it roads for transportation or blocked directions for security reasons (against man-made disasters). The terrain itself and the degree of elevation and slope might require some changes depending of the design.

3.3.2.1 Approach 1 - Single Building (Figure 3.3)

The FUs are stacked next to one another in a very classical way and hidden under a regular façade.

This method does not allow for easy expansion and the entire complex should be planned at the same time. This might allow, however, for certain plumbing and effluent systems to be shared (if there is no containment

requirements), hence reducing the total costs. Outer walls are kept to a minimum, reducing the costs as well. Scientific FUs are better protected from outer threats.

Public and office spaces are close to each other and the laboratories and they allow for visitors to have a very close view at the researcher's activities, which may be good for the complex if public outreach is a significant activity.

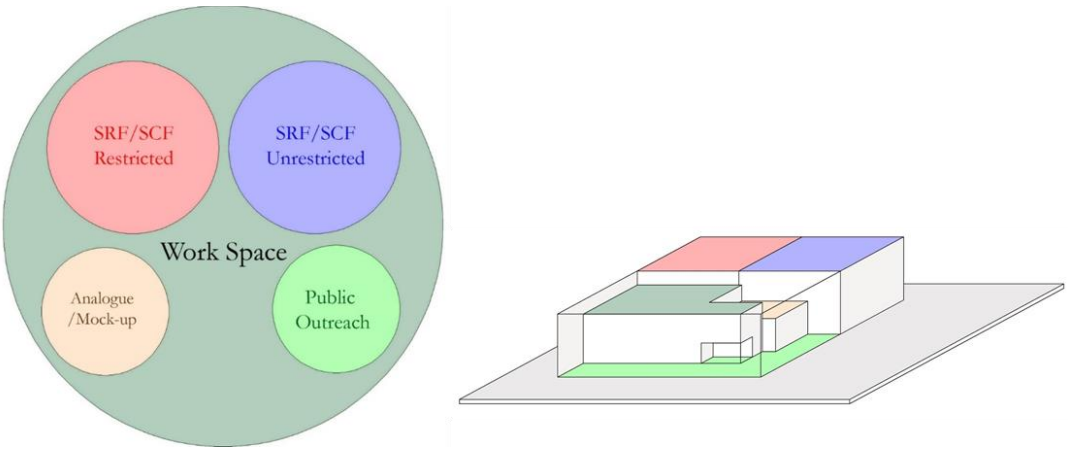


Figure 3.3 - Single building approach

3.3.2.2 Approach 2 – Puzzle (Figure 3.4)

Functions are partially separated and one FU (in this instance the work space for the staff) connects the separated functions with each other. The shape this central FU can take is highly flexible.

Flexibility and adaptability are high for the entire complex, as well as for each FU, with several outward and vertical expansion possibilities.

Scientific FUs can be placed away from the entrance of the site (for example to lower the risk of terrorist attacks).

Because of the expanse of external walls, the construction costs will be high. The restricted facility will not be as secure.

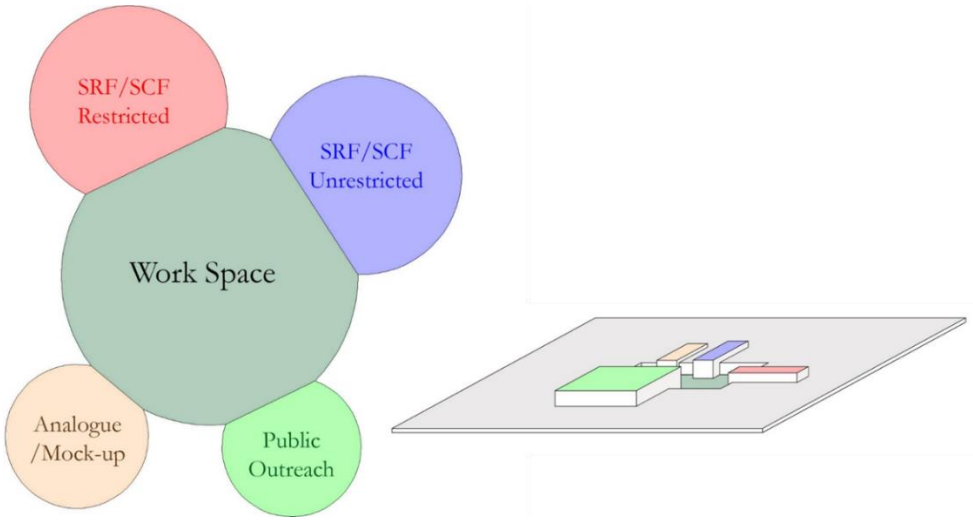


Figure 3.4 - Puzzle approach

3.3.2.3 Approach 3 – Bridges (Figure 3.5)

The FUs are independent blocks that are positioned to allow for future expansion. This layout is the same as Scott Base (Antarctica, NZ).

Several bridges or corridors are used to connect the FUs together. This configuration allows for great independence of each unit but puts them further away from each other which results in greater distance for the staff to move around. The cost of such a configuration would be relatively high compared to other approaches as, each FU would effectively be a single unit for security and utility purposes.

This approach has the advantage of being highly flexible and great for modular design for an incremental build of the complex. Again, a costly design with security implications.

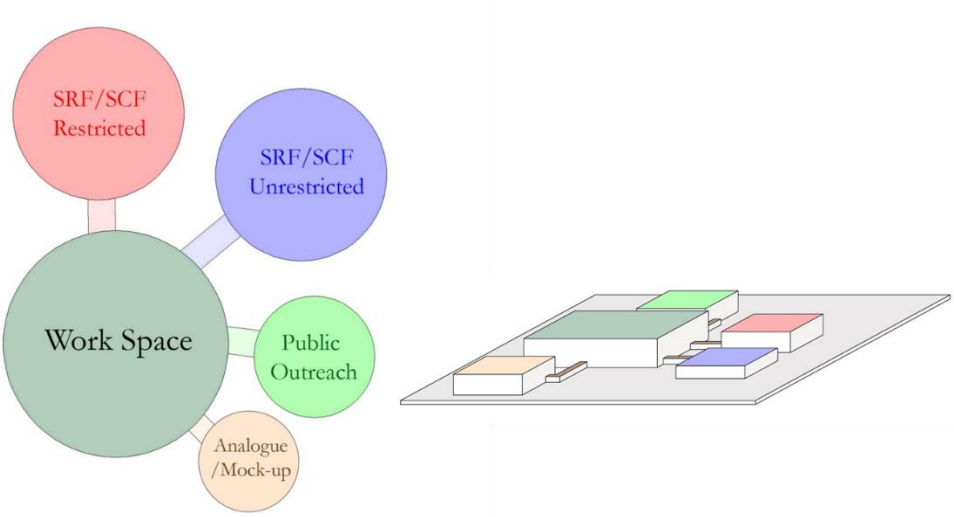


Figure 3.5 - Bridges approach

3.3.2.4 Approach 4 - Docking Station (Figure 3.6)

In this configuration the central work space overhangs the other FUs. This allows for researcher flow to be seamless from office space to laboratory area while allowing expansion to the sides. External sides of the laboratories are reserved for transportation and stores purposes. Please note that on the diagram that the functions not only border each other but intersect, unlike in the 'Single Building' approach.

This configuration offers great versatility whilst offering a small footprint of the campus.

The laboratories are partially exposed (to aerial threats), but the more restricted parts could be flipped to the side where they are merging with the office portion, to offer an extra level of security concerning non-natural threats.

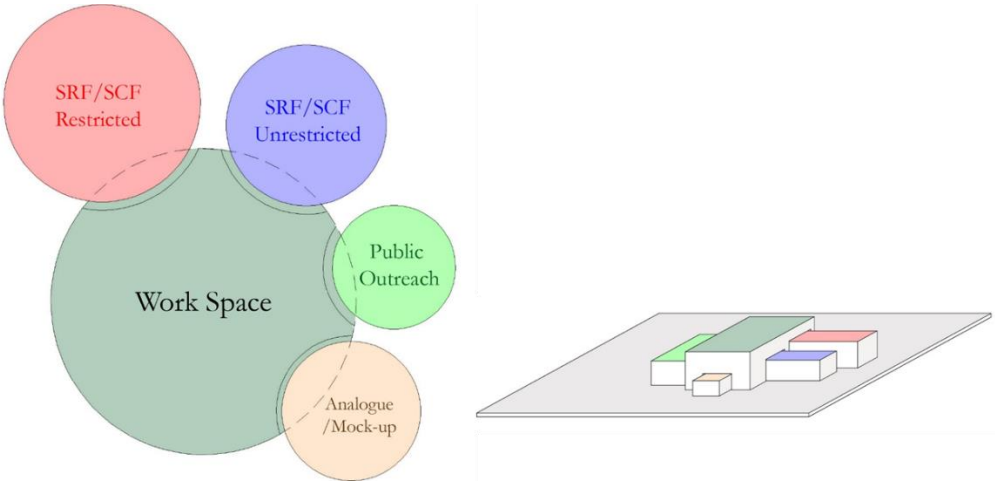


Figure 3.6 - Docking Station approach

3.3.2.5 Approach 5 - Shell (Figure 3.7)

Each function is laid on the site and the entire site is covered with a shell. FUs are placed far from each other so they can be expanded as needed in the future. This configuration offers the most versatility as the shell protects the whole complex despite everything being separated.

The downside of this approach would be the initial cost and estimation of the covered site portion with the shell. A certain margin would have to be calculated and the blocks would be placed giving them enough room to expand in future. In a different scenario (shell I) this shell could be between the functions instead of covering the entire site.

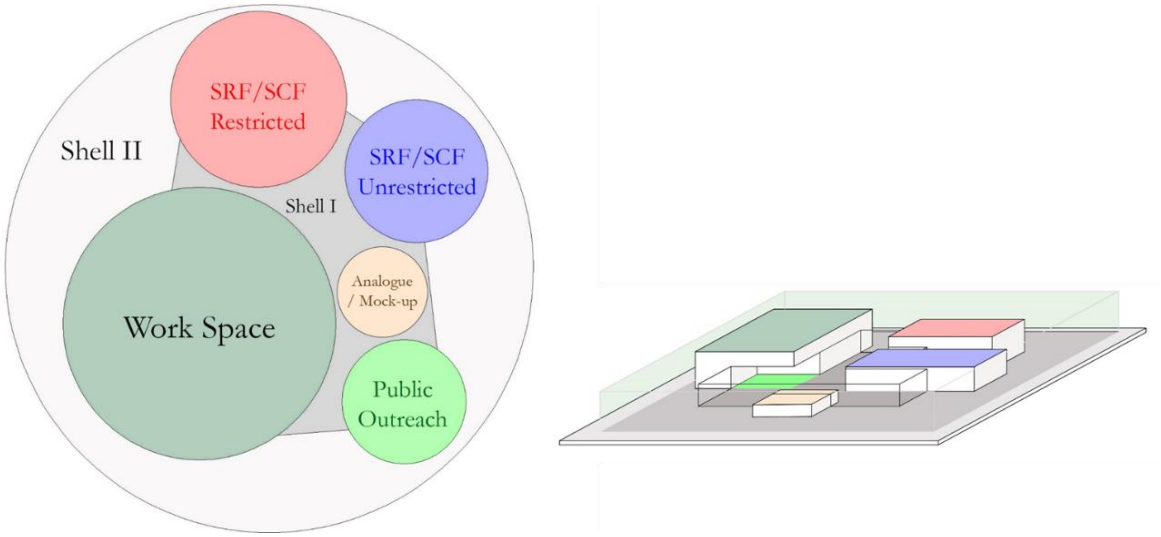


Figure 3.7 - Shell approach

Table 3.1 - Trade-off between the different siting approaches. '+' indicates that the approach ranks positively for the criterion, '=' indicates that the approach is neutral, and '-'indicates that the approach is at a disadvantage for the criterion

Approach	"Campus" flexibility	Security	Economics	"FU" flexibility
1 - Single building	-	=	+	-
2 - Puzzle	=	-	=	=
3 - Bridges	+	-	=	+
4 - Docking station	=	+	+	=
5 - Shell	+	+	-	+

3.3.2.6 Recommendations

From this trade-off, the Docking station approach seems to be the best choice, especially with a high focus on security for external risks, and various innovative possibilities for Public Outreach. However, this approach needs to plan and design the whole structure well ahead of the time it will be operational.

Our second choice would be either the Bridges approach, or the Shell approach.

3.3.3 Scientific FUs Layouts

Figures 3.8 to 3.10 are proposed designs for the scientific FU: the AMUF and the SCF for unrestricted and restricted samples

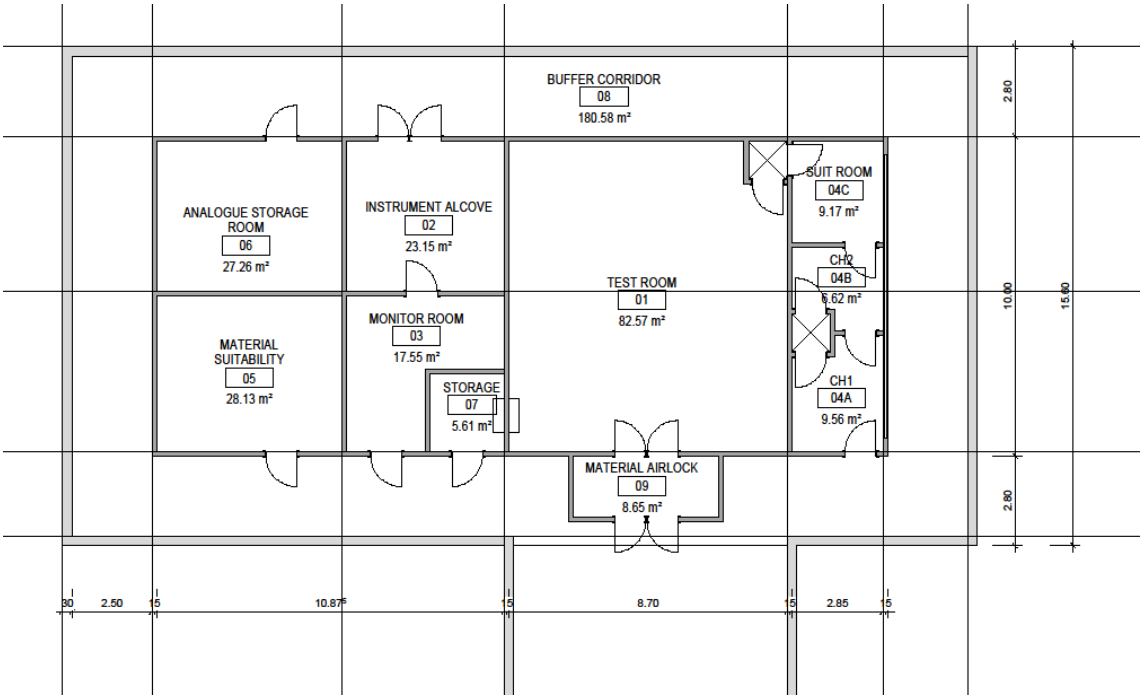


Figure 3.8 - Analogue/Mock-Up Facility function layout.

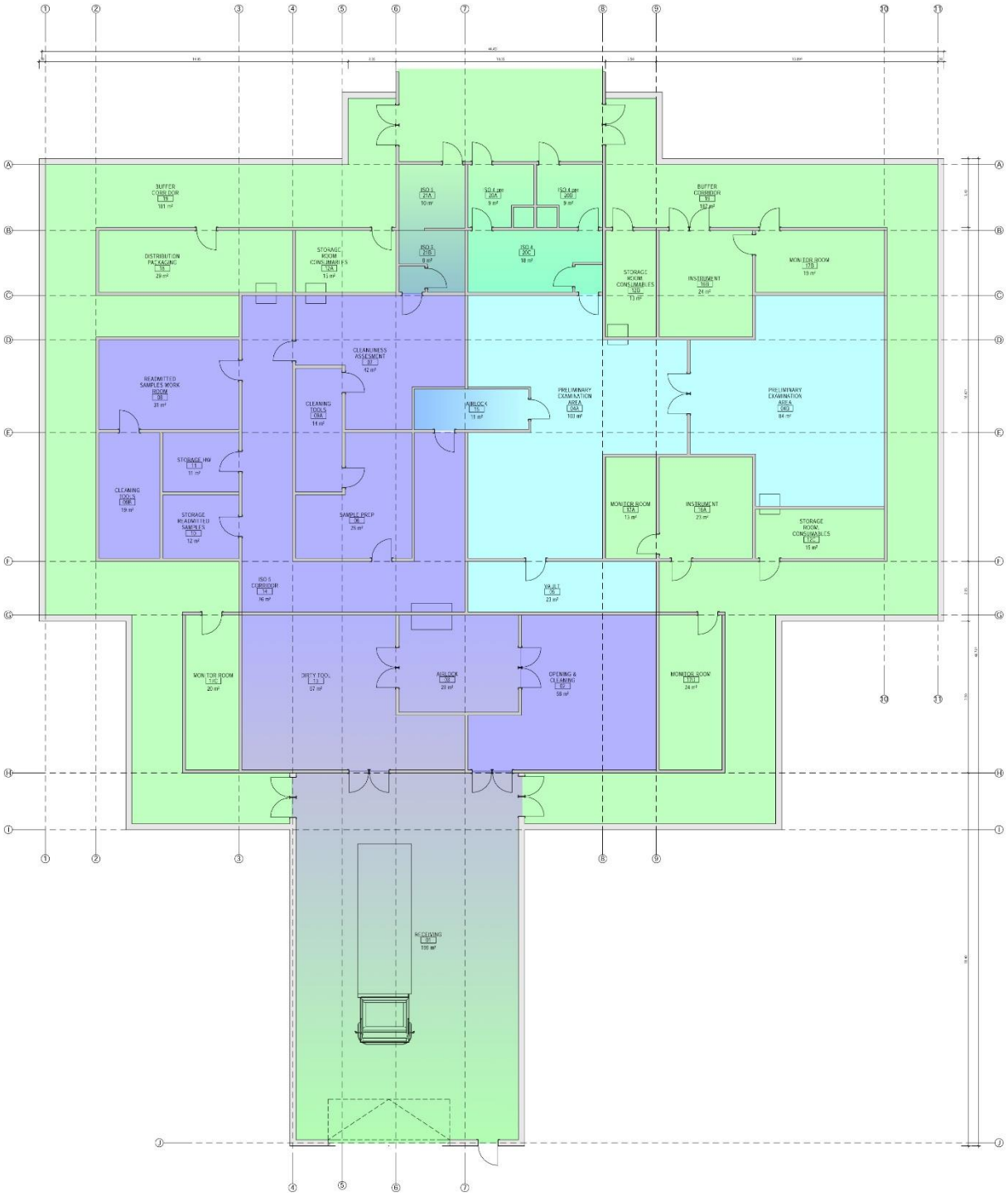


Figure 3.9 - Unrestricted SRF and SCF functional layout. Colours indicate the levels of cleanliness from green (ambient) to light blue (high level of cleanliness).

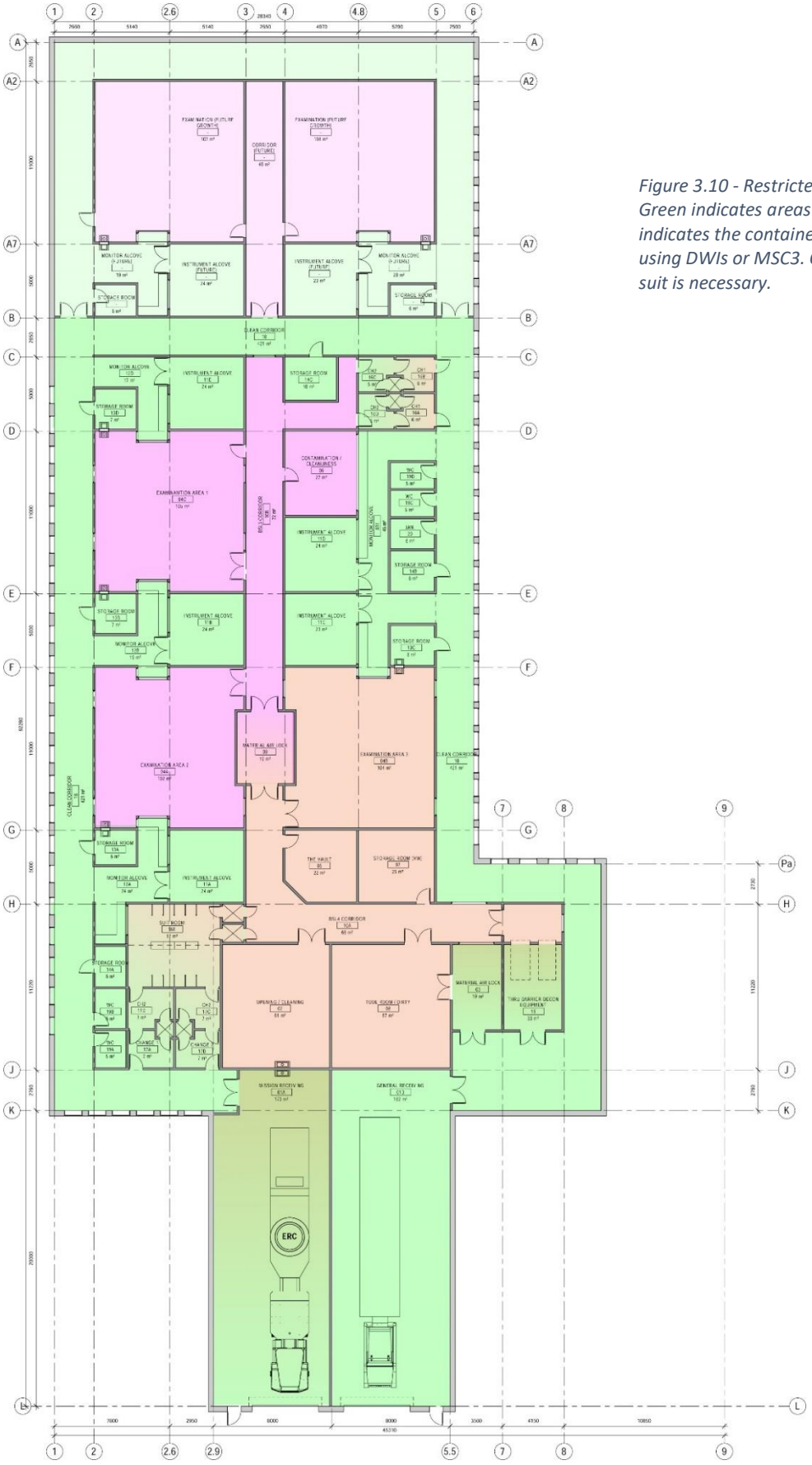


Figure 3.10 - Restricted SRF and SCF functional layout. Green indicates areas that are not contained. Pink indicates the contained areas where work is conducted using DWIs or MSC3. Orange indicates areas where a suit is necessary.

3.3.4 Location Requirements

As stated clearly in the proposal, the ESCF should be built in Europe. European and local (when a country is chosen) legislation should then prevail for the design and building. It should be easily accessible (not too far from an airport and a train station), but not too close to a city centre, to limit potential 'Not in my backyard' opposition.

A location with limited natural hazards is to be favoured: it is possible to build a facility to resist floods, hurricanes, earthquakes, etc., but it will involve additional costs. On top of that, natural disasters can involve shut-down of the facility for length of time.

It is highly recommended that the facility is constructed in a country where BSL-4 laboratories are already well established (such as in France, Germany, Italy, Sweden, and the UK) and also in a country involved in space programs, which is the case of a large number of European countries.

The host country should be ready to support the implementation of such a facility.

3.3.5 Cost and cost drivers

Cost for such a facility will depend on the units being built and on the activities inside. Based on literature, and on data gathered from the architects we collaborated with, the building costs would range from 10-20 M€ for an unrestricted facility, to over 100 M€ for a complete ESCF for unrestricted and restricted samples. However, a lot of parameters can drive the costs up and down.

As standards for construction are more and more harmonized at the European scale (i.e., Eurocodes; http://eurocodes.jrc.ec.europa.eu/), national standards are just another aspect that should be considered but from one to another European country it will not impact so much the final costs of the construction.

If the facility is to be constructed in an "isolated area", all aspects, including the means of access (roads), electric power system, security aspects, etc., will have to be designed and constructed specifically. This would significantly increase the costs.

Sustainability of local/national specialist subcontractors (for cleanrooms, instrumentations, etc.) is a very important aspect that should be considered. If builders and specialists must come from another country, whether for the initial building phase, of for maintenance, it will increase the costs.

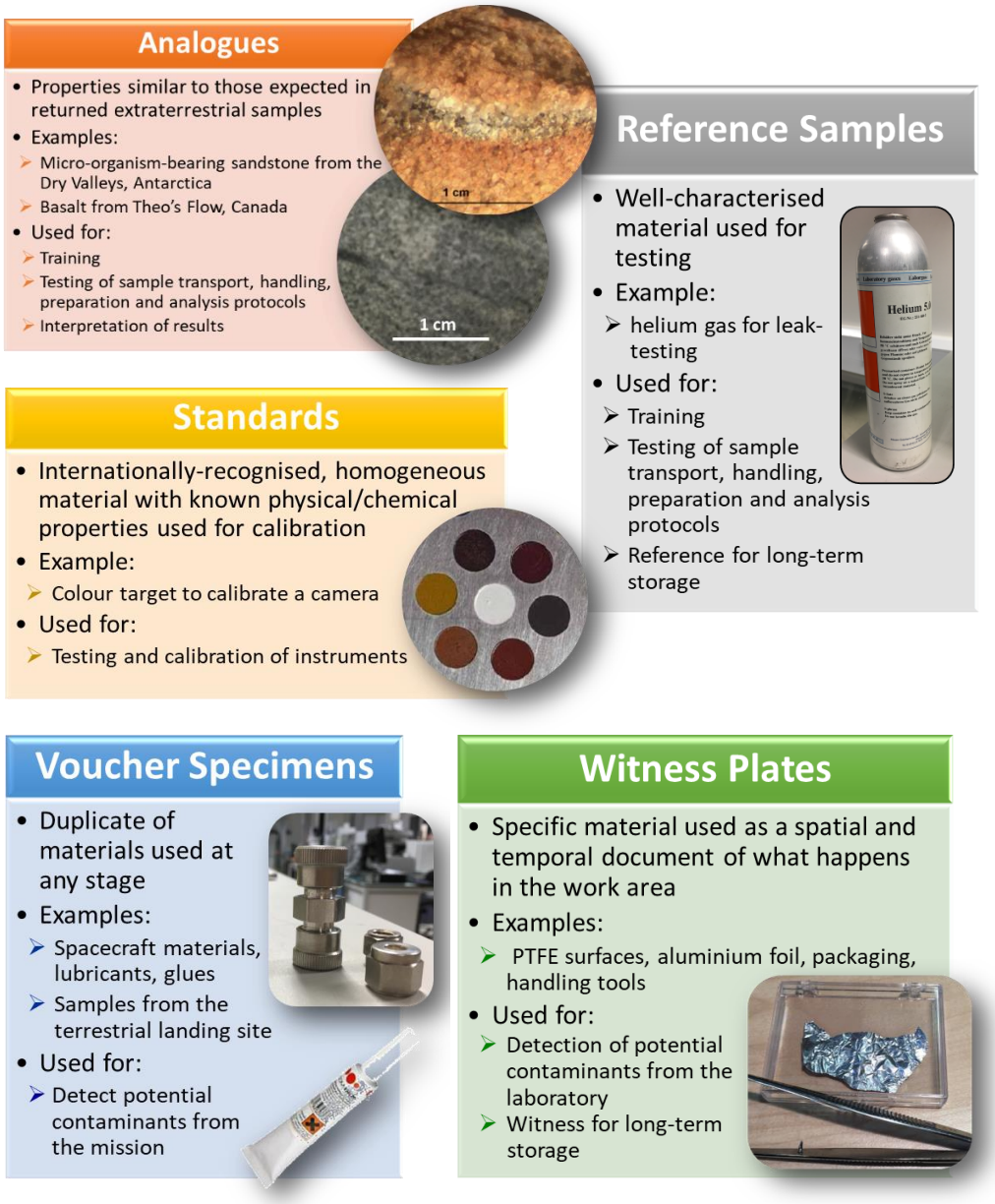
For regular staff, differences in (highly skilled) labour costs from one to another country should also considered.

We recommend that the cleanrooms are built under a laminar flow regime. It will involve a higher cost at the beginning, but will avoid having high costs for cleaning and renovating in case of a retrofitting, or of a change in activity.

We recommend keeping the cleanroom and contained areas as small as possible. Even though the initial costs for adapting through-barrier installation of instruments should be considered, they will be lower than those for building large areas of cleanrooms, and/or of contained laboratories.

Instruments can rapidly increase costs, especially if large and/or complex equipment is needed. We recommend keeping the instrument suite as minimal as possible.

4. ACTIVITIES BEFORE LANDING



Two of the main activities that take place in a SCF prior to return of samples are extensive staff training, and testing of sample handling and analysis protocols. For these activities, a comprehensive library of different types of analogue materials is required

4 ACTIVITIES BEFORE LANDING

4.1 Staff training

4.1.1 PRF Staff Training

Training is paramount to the success of any complex endeavour and the recovery of samples from a multi-billion Euro mission is no exception. Launch campaigns are practiced and drilled repeatedly until there is collective confidence in the ability of the team to safely execute the actual launch. Recovery of a restricted sample may not be as complex as a launch, but it is also not without problems and challenges. For this reason, and because of the potential risk of sample exposure, training must engender the same level of collective confidence in the team that will effect recovery. Procedures can reduce the risk of things going wrong, but training and practice identifies the unknown areas that cause failures.

Staff recruited for the team roles will ideally have previously worked in a similar environment. This helps to identify staff members that have the appropriate skills and the required aptitude for the tasks. For the ERC collection teams, several practice recovery missions simulating a variety of scenarios should be undertaken. This would be started with desk based exercises, progressing to field exercises, then a full recovery mission of a dummy ERC. Training in this way can be used as part of the team selection process, observing the individual's performance before selection of the final teams and improving working protocols. As with working in any team environment, one of the key characteristics required is the ability to work effectively when under pressure. Pressures that could be exerted during training are:

- Time, it may be that there is a stringent window of time during which the capsule needs to be recovered and any containment breaches identified
- Deviation from the mission plan, this could be simulated by a non-nominal landing
- Environmental conditions, recovery exercises could be completed using staged conditions (e.g. high winds).

The use of training activities increases the competency of the worker over a number of different scenarios. This will in turn give the worker translational skills, which can be applied to even wider scenarios which may happen and have not been able to be trained for. Increasing the competency of the workers will also have the positive effect of decreasing the risks of a recovery mission, reducing the potential spread of contamination from a non-nominal landing and decreasing the potential contamination effects to Earth from sample release.

Training recommendations:

- Implement Key Personnel early in the mission
- Include independent expert assessment at all stages of the training
- Key and critical roles should have shadow redundancy
- Document and video collective training
- Identify analogue sites for outdoor training
- Train for both day and night recovery
- Include balloon drop test training

4.1.2 ESCF Staff Training

For the same reasons as described above, staff training for characterisation and curation activities must start before the samples are brought back. The Analogue and Mock-Up Facility, the first functional unit we recommend being built, is designed to enable the team to train and troubleshoot instruments and procedures.

4.2 Analogue Curation Activities

4.2.1 Overview

Analogue samples are of great importance in space exploration as they may be used for many purposes. The basic functions and purposes of analogue materials, with special emphasis on sample return missions, are:

- to test and calibrate payload and sample preparation systems for *in situ* missions before launch;
- to help interpretation of data acquired in situ during missions, and to carry out laboratory experiments;
- to identify analogue samples crucial for evaluating and defining the protocols necessary to accomplish safe and sustainable handling of extra-terrestrial materials;
- to test and calibrate instruments and sample preparation protocols in a curation facility;
- to define the protocols necessary to accomplish safe and sustainable handling and analysis of extra-terrestrial materials;
- to evaluate specific short-term and long-term storage conditions during curation of extra-terrestrial materials.

According to the previous list, analogue samples are necessary in a curatorial facility for testing sample handling, storage and preparation techniques, and to train workers. Furthermore, they can be used to test instrumentation within the facility, if necessary. Thus, to ensure that the curation facility is ready to work on the samples which are expected to be returned to Earth, it is essential that a well- defined list of analogue samples be ready well before the ERC landing.

4.2.2 Use and Storage of Analogues

Analogues will be used for the following activities inside the ESCF:

Sample handling – It requires samples with different physical or geotechnical properties (porosity, yield strength, compressive strength, density, temperature, cohesivity), electrical and magnetic properties, different size distributions and different states of matter (solid/liquid/gas). Analogues to be tested should be different according to the samples expected from different missions:

- for Mars, an homogenous basalt, mudstone or a coarse-grained sediment and soil, etc.
- for asteroids, meteoritic material, loose regolith-like material, and dust, etc.
- for the Moon, lunar samples, lunar regolith and icy samples, etc.

Sample transport – Curation relies on the movement of the returned samples within the facility and for shipment out of it. It will be necessary to practice with empty containers and appropriate analogue samples (cores, fragments, dust, etc.). Testing of analogue samples exhibiting different physical, chemical and technical properties will be necessary.

Sample preparation - Science and curation will determine the need for dedicated sample preparation, e.g. petrographic sections, powder aliquots, grain separation, dissolution, etc. Depending on the techniques and instruments used, sample preparation may involve procedures such as cutting, polishing, powdering, splitting, chemical/heat extraction, or microtome and FIB sectioning. All analogue types exhibiting relevant physical/chemical properties will be appropriate to optimise these procedures, in particular to minimise the loss of material.

Training of science and curation teams and science laboratory quality assessment - A particular issue shall be making sure that the external facilities can handle/analyse allocated returned samples in an appropriate manner. ISAS/JAXA made a blind test of laboratories interested in analysing the Hayabusa samples (Kushiro et al., 2003). Such activities would use reference analogue materials.

Long-term storage – needs to be tested using witness plates, hardware samples, voucher and reference materials (including, if necessary, frozen materials).

Analogue, reference, standard, and voucher specimens need to be isolated from each other and temporally and/or spatially isolated from extra-terrestrial samples while, at the same time, being accessible. In the case of restricted Earth-return samples (e.g. from Mars or Europa), analogue samples should strictly not share space with the extra-terrestrial samples either temporally and/or spatially. It will be important to produce protocols for keeping the analogues samples temporally and/or spatially isolated from the returned extra-terrestrial samples. This does not necessarily mean that they need not to be in the same room. With respect to witness plates, those in use actively need to be in close proximity to the returned extra-terrestrial samples, while the past plates need to be stored elsewhere. This could be within the facility as a voucher specimen or outside. Since planetary protection aspects need to be addressed from the beginning of the curation activities, contamination assessment and control plans should be emplaced during mission planning and development.

It should be taken into account that many sets of analogues having different purposes would coexist inside the ESCF: a set of analogue materials for training in non-sterile conditions, a set for training in sterile conditions, a set available for public outreach.

4.2.3 Types of Analogue

Regardless of the type of mission, five different types of analogue samples shall be included in the ESCF collection and are listed in Table 4.1. See also image at the start of the chapter.

Table 4.1 - Types of analogue samples to be considered for a ESCF

Type of samples	Definition	Interest and Objective
Analogue	Sample having properties similar to those expected in returned extraterrestrial samples (e.g. a piece of basalt).	Testing and preparing for sample transport, handling, preparation and anlysis protocols. Useful for interpretation.
Reference Sample	Well characterised material used for testing (e.g. helium gas to test the absence of leaks in a canister).	Testing and training for sample transport, handling, preparation and analysis protocols. Reference for long-term storage.
Standard	Internationally recognised, homogeneous material with known physical/chemical properties used for calibration (e.g. a colour target to calibrate a camera).	Testing and calibrating the instruments.
Voucher Specimen	Duplicate of materials used at any stage (e.g. spacecraft materials, lubricants, glues and samples from the terrestrial landing site).	Detecting potential contaminants from mission hardware and during re-entry.
Witness Plate	Defined materials used as a spatial and temporal document of what happens in the work area (e.g. PTFE surface).	Detecting potential contaminants from the laboratory. Witness for long-term storage.

The most important analogue samples are analogues *per se* that occur naturally. The minimum list of natural analogues considered to be available within the curation facility includes solids (rocks, minerals and ices) as well as gases and liquids. The latter two should be provided on demand if considered necessary. Minerals identified as necessary analogues include rock-forming minerals such as olivine and pyroxenes, metal (Fe-Ni alloys), magnetite, hematite, calcite, dolomite, gypsum, anhydrite, perchlorates, sulphides, smectites, serpentine, silica polymorphs, as well as ices.

As a sample return mission is defined, the science team should make recommendations on suitable analogues, reference samples, and standards to be held by the curation facility (Table 4.2). These will include

gases and liquids, as well as manufactured analogue samples. Gases and liquids could be provided on a short term whenever they are necessary.

The provision of terrestrial landing site samples (from the touch down site) would be necessary in case of doubtful analysis, even if normally this type of contamination is not expected (e.g. non-nominal landing). For the same reason, mission related hardware that comes into contact with the return samples should be kept as voucher specimens within the ESCF.

The total amount of sample analogue mass will depend on mission objective and analogue types. It means that the suggested masses will be driven by mission architecture and the target body of interest, as well as the defined science requirements, and availability. For natural analogues, we suggest the following amount, approximately:

- 40 kg of terrestrial analogues (rocks);
- 1 kg minerals;
- 1 kg meteorites.

Table 4.2 – A library of planetary analogues should include the following:

Rocks	Minerals	Gases	Simulants
Primitive basalt	Olivine	$^{13}CO_2$	Regolith/soil
Anorthosite	Pyroxene	$^{13}CH_4$	Soil mixtures (e.g. with perchlorate, ice)
Dolerite	Plagioclase		Icy/dusty mixtures
Tuff	Metal (Fe-Ni alloys)		Doped samples (biological)
Suevite	Sulphides (troilite; pyrrhotite)		Doped samples (organic)
Mudstone	Iron oxides (Magnetite; Hemetite)		Shape (e.g. drill core)
Sandstone	Jarosite		Physical properties (e.g. density, hardness, etc.)
Lunar Regolith	Silica (amorphous/opal)		
Chondrite (Carbonaceous; Ordinary)	Carbonates (Calcite; Dolomite)		
Achondrite (HED from Vesta; Iron)	Sulphates (Gypsum; anhydrite)		
	Perchlorates		
	Clays (Mg-Smectites; Serpentine)		
	Ices		

4.2.4 Analogue Database

The analogue database should be embedded, as a database sub-section, in the main ESCF samples database. Each analogue sample included should be characterised with specific information, provided in the form of a spreadsheet specifically developed for this purpose. These spreadsheets can be consulted via the online database: http://www.euro-cares.eu/wp5/database/index.php.

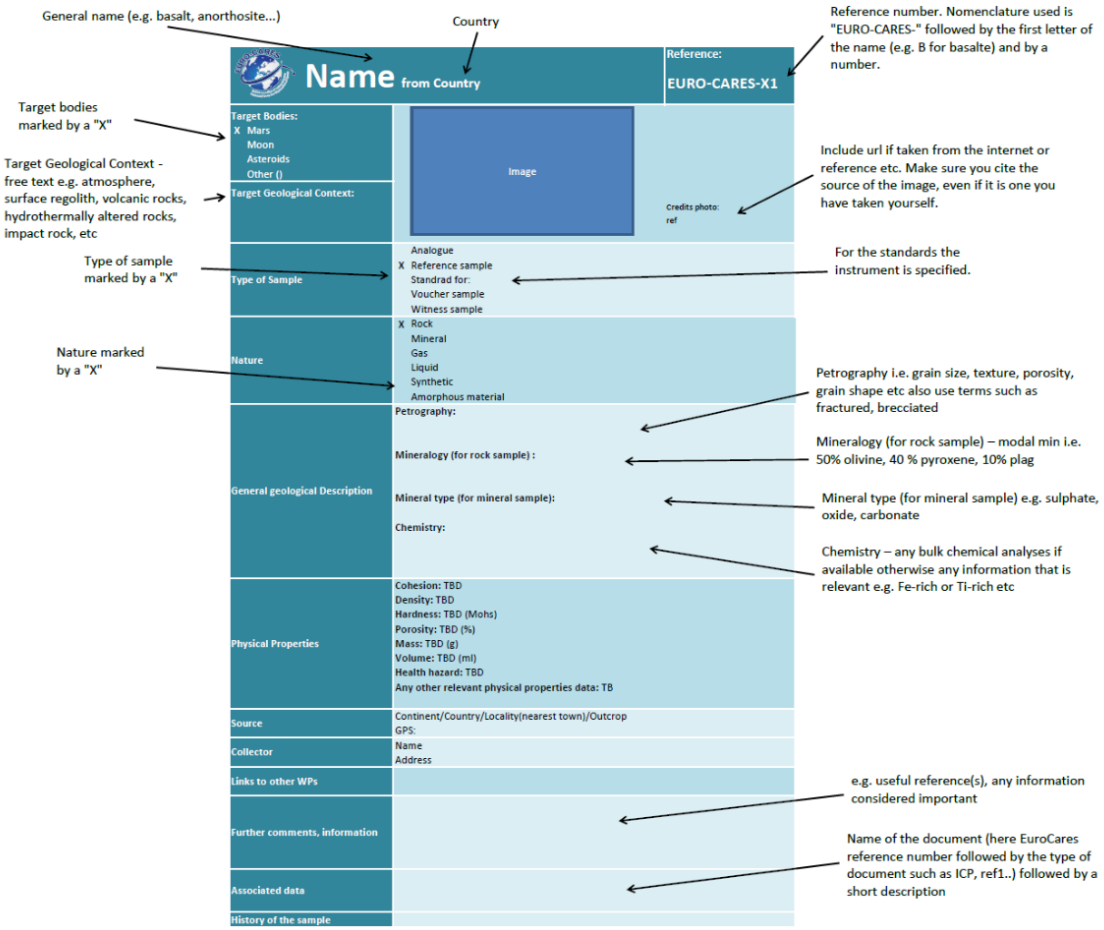


Figure 4.1 - Analogue spreadsheet

An example of the spreadsheet page is shown in Figure 4.1. Each spreadsheet contains information about:

- Name and provenance of the analogue sample;
- A EURO-CARES code number;
- Target extra-terrestrial body for which it is an analogue sample (specific mission, if relevant);
- Target body geological context;
- Type of analogue sample and curation facility storage;
- Analogue's state of matter;
- General geological description (petrography, mineralogy, chemistry, etc.);
- Physical properties (density, hardness/compressive strength, porosity, tenacity, cleavage, fracture, electrical properties, magnetic properties, thermal behaviour, etc.);
- Potential health risks;
- Source of the analogue sample;
- Other information;
- Associated data;
- History of the sample.

An online form provides multiple options for searching the database assisting the selection of an appropriate analogue sample (Figure 4.2).

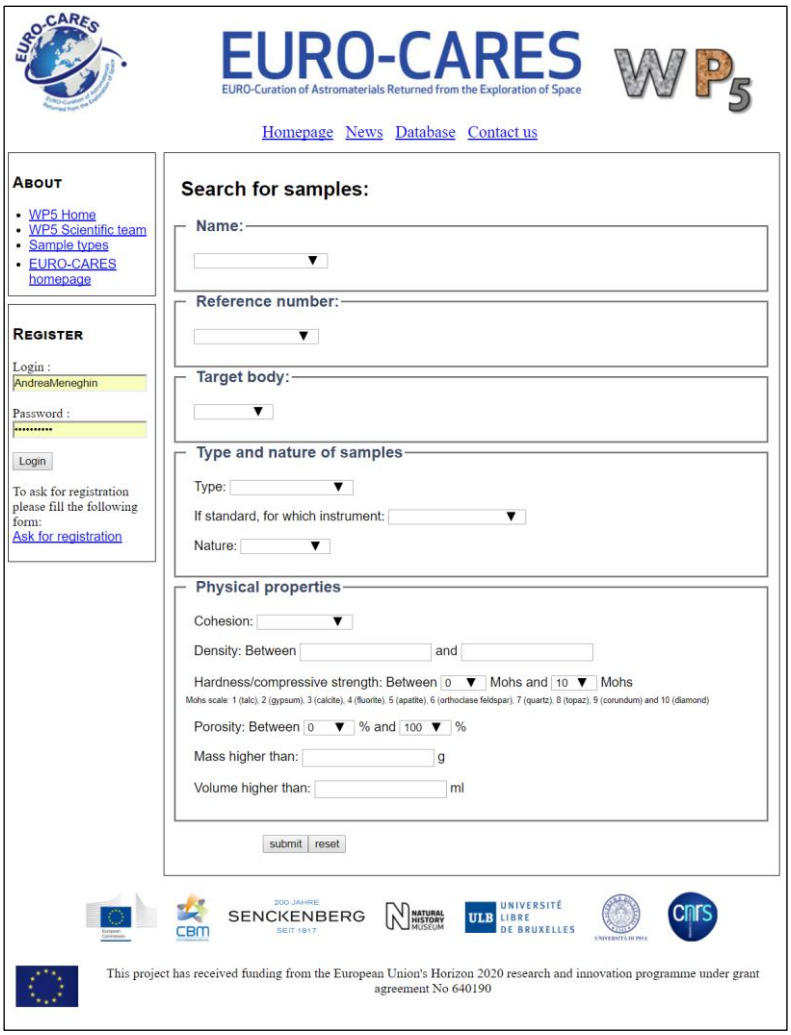


Figure 4.2 - Analogue selection on line form

4.3 Recovery Procedure Testing

As part of the training process prior to ERC return, but after selection of the teams to be used in the recovery phase of the sample return mission, a selection of scenarios can then be devised using existing knowledge or risk analysis of the mission. Training will begin with desk-based studies to identify protocols and equipment that can be used. The definition of mission parameters will allow for the identification of specific equipment that will be needed for the recovery phase of the mission, or at least be designed and tested prior to ERC landing. The definition or parameters such as ERC size, design and mass can lead to bespoke lifting equipment being required to place it into the secondary layer of containment before transport to the ESCF. Training will be undertaken with any new items of equipment again against a range of scenarios to ensure there is a high level of competence with any mission scenario.

4.4 Sample Databasing

Sample cataloguing will begin as soon as the samples are removed from their containers. This cataloguing will serve as the permanent record for each sample and will include various types of information and data. The cataloguing system will need to follow a standard and methodical approach. Such methodologies are currently used in many international institutions such as museums and national laboratories and many electronic cataloguing and database solutions are available. Curatorial procedures/workflows should be incorporated into the cataloguing system. Sample cataloguing will be a regular and constant part of the curatorial tasks during preliminary examination and well into the future.

A main purpose of curation is to catalogue the samples, to:

- Make them available to the science community for in-depth research;
- Make them partially available to the public for display in museums and other outreach activities;
- Keep constant track of the location of the samples;
- Keep constant track of the analyses and subsampling activities.

The software will act as a logbook to track and document all the actions performed on the (sub)-samples inside the ESCF and in external laboratories.

The sample categories of the database will be:

- Pristine samples (within original containers);
- Work samples;
- Aliquots and preparations for staff training, sample classification, and subsample for allocation to external laboratories;
- Allocated and returned aliquots and preparations;
- Analogues, references samples, and standards;
- Hardware and pieces of the spacecraft as voucher specimens;
- Voucher specimens and witness plates.

Datasets linked to each sample will include:

- Identification (e.g. labelling, origin, imaging, state of matter, mass);
- Pictures of *in situ* sampling and of next stages of the samples;
- Paths in and out of the ESCF;
- Conditions (T, P, etc.) from the sampling site to the arrival in the SCF;
- Classification (e.g. structural, compositional);
- Preparation (e.g. type of preparation/mount, preparation/mount description and imaging);
- Location (e.g. sample container/location in the facility);
- Allocation (e.g. requested samples, location outside the curation facility, research purposes and methods duration of the loan/donation, expected results);
- Documentation (e.g. internal/external data and reports, scientific publications);
- Public (selected data online, e.g. sample description and availability for research).

All the above information will be obtained and documented during the following procedures/actions:

- Cataloguing (identification, location);
- Classification (to be meant as preliminary/basic classification);
- Pre-delivery (preparation and allocation);
- Post-delivery (check of returned samples for research, storage).

Efficient data collection and storage in the various laboratories of the facility will make use of state-of-the-art electronic devices (e.g. internet, wireless audio-video recorders, bar-coded samples, subsamples and preparations, etc.) enabling unambiguous link of data sets to samples.

As with any IT system, care will be taken for the security of the system, during internal use as well as in those circumstances external users can access the database, e.g. external scientists providing or searching for information.

5. CONTINUOUS ACTIVITIES

Correct cleanroom clothing must be worn to minimize contamination, even before the samples are returned

5 CONTINUOUS ACTIVITIES

This chapter covers activities performed during the entire timespan of the project, from the launch of the mission to long-term storage of the samples

5.1 Cleaning of Laboratories and Tools

In cleanrooms, the main process to ensure cleanliness is by the filtration of the inlet air.

Additional cleanliness protocols can be undertaken, by sweeping the laboratory's surfaces with IPA wipes or with ultra-pure water, on a regular basis.

A specific vacuum cleaner (e.g. http://biobubble.com/products/hepa-vacuum/) could be used, especially for changing rooms.

5.1.1 Tools

To avoid sample cross-contamination, all curatorial equipment (sample handling and preparation tools, containers, etc.) should be able to be thoroughly cleaned after each operation of the sample processing work flow. In the situation where equipment cannot be cleaned to the required levels, then it would be necessary to replace with new equipment. Depending on the type of equipment it may be possible that only the part(s) in direct contact with the samples would require replacement rather than the entire equipment. These issues can be identified during the testing and verification process for the sample handling, manipulation and preparation equipment and informed decisions can be made then.

Cleaning procedures for production cleaning routinely use the following methods:

- Cleaning with IPA wipes;
- Ultrasonic and megasonic baths of UPW, with or without surfactant;
- Rinsing with UPW;
- Drying in an oven, under inert atmosphere or not.

New tools and equipment must be degreased and cleaned initially, with a specific procedure including extra steps, such as mild acid cleaning.

These procedures are efficient for particulate cleaning.

For restricted samples, or organic-rich unrestricted samples, it will be necessary to clean organically as well. Organics are usually cleaned using solvents where the target molecule will dissolve. If the cleaning process is done in an area that was built to be organic-free, it is recommended to clean organically first, then for particles, as it is easier to have organic-free UPW, rather than particles-free solvents.

For thermostable materials, a good solution is to clean for particles, then enclose the tools in a stainless steel box (e.g. http://www.wagner-steriset.de/en/the-steriset-system/sterisets-concept/) and bring it to a temperature high enough to completely oxidize organic matter, while flushing the box with inert gas to remove the by-products. Thermolabile materials will be treated chemically, either gaseous or liquid.

Innovative methods of cleaning must be tested to see if they are applicable to the ESCF needs. For example, CO_2 snow cleaning is a very promising technique, both for particles and organics (e.g. https://www.fraunhofer.de/en/press/research-news/2012/october/deep-cleaning-with-carbon-dioxide.html).

If the tool cannot be cleaned and/or decontaminated then single use tools should be procured for the facility.

5.1.2 Rooms

The surfaces of the laboratory and rooms will initially be treated using a liquid disinfectant to remove gross contamination. After this step in the decontamination process a gaseous application of a decontamination chemical will be used. For this process there is a range of techniques and technologies that are available for use, e.g. formaldehyde, chlorine dioxide and hydrogen peroxide (Beswick et al., 2011). More details on these processes are found in the D2.3 'Sterilization and Cleaning' of the EURO-CARES project.

5.1.3 Showers for Suited Workers

On exit from a restricted facility the exterior surfaces of the suit must be decontaminated before it can be removed. The shower will be at a positive pressure to the laboratory but at a lower pressure to the changing area to create a flow of air into the laboratory away from the areas where PPE is not necessary.

At present there is no defined guidance for the type of chemical that should be used in the decontamination shower or the cycle parameters in a BSL-4 laboratory (Klaponski, 2011). In the case of the ESCF, considering unknown biological agents, decontamination procedures will need to be chosen by a panel of experts and extensively tested. Impact on the suit must be considered (for more technical details, see EURO-CARES deliverable D3.4).

Redundancies are built into the shower set-up where a gravity fed tank of chemical disinfectant is always available so the suits can be decontaminated in the event of a power loss. This emergency tank needs to be large enough to wash and decontaminate the maximum number of suits that will be in the laboratory at any one time.

In the restricted parts of the ESCF using cabinet line of suits, the operators will be required to also pass through a personal shower before leaving the laboratory. In the case of a DWI line, no shower is needed.

5.2 Protection/Outfit of Workers

In the case of unrestricted samples, workers' safety from biological agents is not an issue. The only concerns are to protect the samples from external contamination. We recommend the use of positive-pressure gloveboxes kept under an inert atmosphere.

5.2.1 Cleanroom Garments

Cleanroom garments are adapted to the level of cleanliness and must be cleaned and packed accordingly. A study has been published considering the effect of particle contamination reduction with usage of cleanroom garments, versus garments and additional undergarments. The study showed a reduction of nearly 50% in biological contaminants (skin flakes, hairs, etc.) when cleanroom style undergarments were used (Moschner, 2002).

However, a complete change can be straining for the workers and expensive. The use of clean room undergarments should be addressed depending on the procedures that will be completed, if a further reduction in particulates is required for a process then undergarments can be worn.

5.2.2 Minimizing the Sources of Contaminants

As discussed, instruments deemed to be prone to produce contaminants (particles or outgassing), will be kept outside of the cleanrooms.

5.2.3 Restricted Labs

5.2.3.1 Workers Attire

Within both cabinet line and suited restricted laboratory, safe operating procedures include that the workers must remove their own clothes prior to entry into the laboratory (Hilliard et al., 2007). Within the cabinet

line laboratory, disposable underwear is worn under operating theatre style scrubs, which are then covered by a rear fastening gown (solid front). The clothing worn in a suited laboratory will depend on the operator's preference. Within both laboratory types, the only personal item that can be worn are glasses knowing that on exit they must be washed in the personal shower with the worker. On exiting the laboratory, the clothing will be removed and either disposed of via incineration or sterilised using an autoclave, if reusable.

5.2.3.2 Gloves

The main interface between the worker and the infectious material being handled in a restricted facility is either gauntlets in a cabinet line laboratory or gloves on a positive pressure suit. Before entering the laboratory, the worker will always put on a set of personal gloves. The gloves attached to positive pressure suits will be made of neoprene or heavy-duty household cleaning gloves, where the gauntlets on the cabinet line are generally made of rubber, although other materials with better disinfectant compatibility are now available. Therefore, in each laboratory there are two layers of protections between the potential contamination and the worker's hands.

Biological laboratory gloves are usually manufactured from either latex or nitrile and are useful for a secondary barrier if used correctly (Mansdorf, 1987). Staff must still be trained in good laboratory practice, since any contamination on the exterior of the gloves can be transferred, e.g., to the worker's face, if they are not made aware of the hazard.

Gloves can be affected by the disinfectants used for decontaminating a laboratory, leading to permeation and penetration of the gloves by the infectious agent. Several studies have been undertaken to identify the chemical agents that can permeate gloves, and European standards have been produced e.g. BS EN 374-2:2014 Protective gloves against dangerous chemicals and microorganisms, determination of resistance to penetration. Alcohols can penetrate a range of glove materials, one study showed that alcohol was detected within the gloves tested after 10 minutes exposure (latex, nitrile, and a synthetic polymer) (Baumann et al., 2000).

Perhaps one of the major criteria for selection of gloves is worker dexterity. Different materials can affect the dexterity of the worker. In a comparison between latex and nitrile gloves there was a slight decrease in fine dexterity movements when workers used nitrile gloves, but during gross dexterity testing no difference was detected (Sawyer and Bennett, 2006). The dexterity of the worker is further decreased when a secondary layer of glove is worn (increasingly so with the thickness of the second layer, i.e. rubber gauntlets).

These points show that there are several options for use for glove materials in the facility, for both primary and secondary barriers. Careful consideration needs to be given as to what processes will be undertaken and then the most appropriate gloves can be chosen for this process. For example, if chemical cleaning is used the glove material will need to be tested against the chemical to determine if they are compatible. Whilst a material might provide excellent dexterity, if they are prone to breakage or become easily permeable, then an alternative option might need to be used that decreases dexterity but provides more protection.

For the removal of the samples from the Earth return capsule (ERC), workers could wear positive pressure suits to protect themselves from any sample contamination if there had been a non-nominal landing and ERC containment failure, since cleanliness is less of an issue.

5.3 Sample Storage

5.3.1 Restricted Samples

Curation and storage principles are similar to those for unrestricted samples when it comes to SEC/PE and storage, but sample containers will be required to be held in more secure facilities both in terms of biosafety and security principles. However, the dissemination activities are not as straightforward as for unrestricted samples. Potentially biohazardous samples cannot leave the ESCF without either being proven to be free of

biohazards or sterilised using a validated method, as such the containers for the restricted samples must be constructed like those identified in D6.3 (Longobardo et al., 2016), i.e. a two- or three-layered package.

The requirements of the sample container strictly depend on the analyses planned for the sample. Current practice (e.g., this is the procedure used for Stardust samples) is that researchers who require a sample also provide the sample container to the Curation Facility. For internal ESCF sample transport, the container should be composed of a sample container, a container protection and metallic walls (possibly internally Teflon-coated) aimed at insulating the samples. This can be modified to reflect the type of sample (e.g. regolith, rock, gas, ice, liquid).

When the sample is transported inside the ESCF, the pressure system (coupled with collector protection) is optional (since the internal environment is controlled) but is mandatory when the transportation occurs outside the ESCF. Figure 5.1 (right) shows a basic design for a sample container.

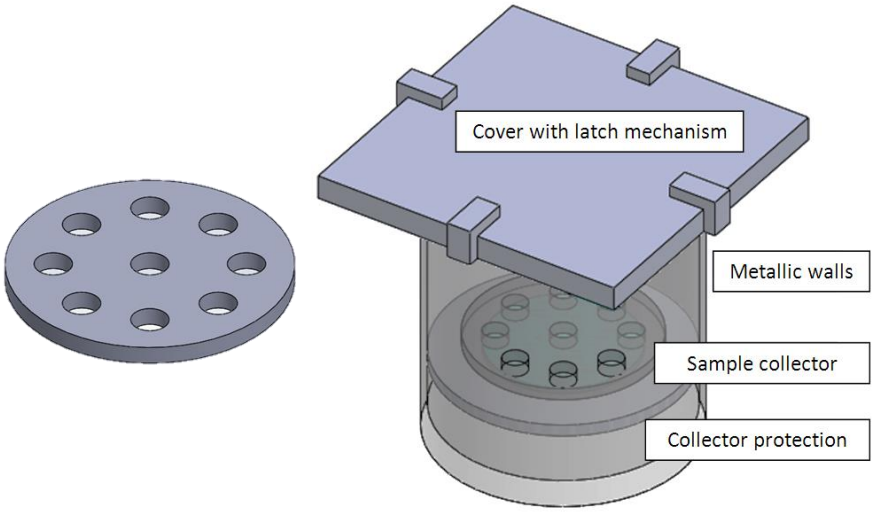


Figure 5.1 - Left: Sample collector ('racket' model). Right: Basic design of a sample container. Depending on the study to be performed, a window of transparent material should be added in order to allow optical analyses of the sample(s).

The sample container would be the innermost layer of the double or triple packaging.

The additional layers aim to:

- Protect the sample(s) from forward contamination;
- Protect the container from vibrations/shocks during (ground/air) transportation.

The container should be housed in a rigid and cushioned box. The box material should have low outgassing rate, to avoid contamination in case of container damage/breakage during the transportation. When samples need to be preserved at low temperatures, a low thermal conductivity material should be used to minimize heat exchange with the external environment. Low temperature inside the box would be guaranteed by a cooling system, involving liquid nitrogen or a refrigeration plant. A trade-off among metallic materials is covered in Section 2.5.3.1.

To reduce forward contamination, the outer metallic layer should be filled with an inert atmosphere of nitrogen or argon gas. Trade-off analysis performed in D6.3 shows that nitrogen would be preferable because of its lower cost and its higher reactivity and thermal conductivity are not critical for transport of extraterrestrial samples.

During the transportation phase, box pressure should be monitored in real-time: indeed, pressure change may be ascribed to box leakage or forward contamination. It should be possible to perform a further

contamination evaluation after the arrival of the box to its destination, by placing one or more witness plates inside the box.

Additional precautions must be adopted for transport of restricted samples, i.e.:

- The sample container should be surrounded by an absorbent material to prevent a risk of fluid leakage (e.g. phase transition in Martian samples).
- A layer consisting in a bag of non-outgassing plastic material must be added between the sample container and the metallic box. Whereas the double packaging (container + metallic box) reduces the risk of forward contamination, the risk of backward contamination arises for restricted samples and a safer packaging must be adopted in this case. According to World Health Organization (WHO) guidelines (WHO, 2015), this triple packaging (container + plastic bag + metallic box) is mandatory for samples which may host life forms. It failed only in 106 cases out of 4.92 million (0.002%), hence this packaging can be considered safe (WHO, 2015).
- A real-time monitoring of the pressure inside the box during the transport could be necessary. D6.3 shows different instrumentation/techniques that could be used for this purpose.

5.4 Contamination Knowledge and Control

Contamination control and contamination knowledge is a critical aspect of the sample curation process and includes monitoring of the clean room environment, all cleaning and handling protocols that may impact the samples, and provides a record of key contamination markers that the samples are exposed to during processing and storage.

Contamination can occur in various forms (particulate, organic, abiotic or biotic, etc.), and from various origins, as shown in Figure 5.2.

Figure 5.2 - Main sources of contaminants in a cleanroom.

The simple storage of the samples in the curation facility can result in some level of modification and/or contamination, as the storage environment almost always differs from that where the samples are collected, and the samples will undoubtedly be in physical contact with some form of storage container. In that respect different storage and/or handling conditions may be required to avoid contamination of the samples (e.g. storage or manipulation under inert gases vs. vacuum, as inert gases may introduce contamination for noble gas analyses, (Yada et al. 2013).

However, it is likely that manipulation and processing of the samples has the potential to lead to more significant modification and contamination and, therefore, a suitable compromise is required to provide the optimum balance of level of information against the preservation of sample material. The environment within the curation facility will be designed to minimize the addition of terrestrial contamination to the samples. This will require complex, high specification systems controlling the air/gases the samples are exposed to, as well as particulate matter, volatile organics, and biological organisms. In addition to a forward approach aiming at minimizing the contamination from the beginning, we describe here a suite of instruments estimated to be necessary to evaluate the contamination the samples could be exposed to including real time monitoring and off-line analysis of representative samples or witness plates. Measurements should 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. Frequent measurements are required to verify that samples are not exposed to unacceptable levels of contamination and that cleaning and handling procedures are meeting specification. As contamination cannot be guaranteed to be zero, such measurements and witness plates will also provide knowledge about what contamination the samples are exposed to during their residence and processing in the facility. This will provide invaluable help in the interpretation of contamination sensitive measurements performed on allocated samples.

Contrary to the sample preparation and characterisation procedures already described, and recommended to be kept as simple as possible, control systems require highly specific analyses involving, for instance, trace gas analysers and particle monitors, as well as mass spectrometers to identify organic contaminants. In addition, sample handling/processing is potentially a particularly hazardous time for the samples in terms of exposure to contaminants, so these phases require careful monitoring using clean analogue samples and witness plates. However, it is important to remember that the environment of spacecraft assembly, as well as sample storage, needs also to be controlled and monitored for contamination. Contamination control thus needs to be planned well ahead the sample return and to continue for as long as samples are available and stored. Witness plates exposed during spacecraft assembly and representative materials and pieces from the collector and the spacecraft will be analysed similarly to the witness plates and analogues during sample handling.

Here we focus on the instrumentation required for contamination control and the analytical methods required to investigate most aspects of possible contamination, including highly specific techniques (Table 5.1).

Particle counters are required to monitor particle abundances in real time within the clean environments and residual gas analysers to monitor the abundance of trace gases and volatile organics in the clean sample handling and storage areas. These instruments are required with high frequency and will be an integral part of curation facility operations.

The other instruments are all required to assess the level and nature of the contamination at regular intervals (using witness plates to record contamination around key functions/samples, Figure 5.3) and for monitoring

the efficiency of cleaning protocols and handling procedures. The frequency and complexity of these measurements will be sample and/or mission specific. Samples/missions with high cleanliness demands will require frequent access with rapid turn-around time for results and it is therefore important for these instruments to be located on site within the curation facility.

As these instruments are not involved in the analysis of returned samples there is no need for such instruments to be in the main clean environment areas. However, to ensure that detection limits are compatible with the contamination levels expected in the cleanest areas, dedicated clean rooms with protected sample transfer mechanisms are required. For less demanding sample cleanliness requirements the frequency of use of these may be relatively limited and therefore these analyses could be performed off-site under contract. As the planned sample curation facility is expected to host multiple mission with a range of requirements it is assumed that all these instruments would be within the curation facility.

Table 5.1 - 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	Surface contamination in situ
Elemental Analysis-MS	C, N abundance
Residual Gas Analysis-MS	Continuous environment monitoring
Particle Counters	Continuous environment monitoring
Optical microscopes	Particle counting and size distribution on witness plates
Analytical SEM	Identification + chemical characterization of contaminant particles

To facilitate the maintenance of instrumentation involved in contamination control a small chemistry lab is required for some aspects of cleaning and preparing parts of the system, particularly important for those instruments with vacuum systems, where high levels of cleanliness are required for all components inside the vacuum systems. If the instrumentation is located within a clean room environment, then this chemistry laboratory should also be situated in a comparable environment.

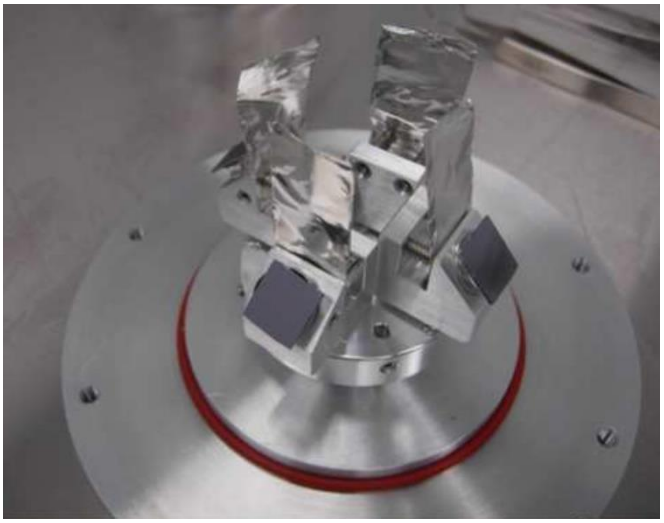


Figure 5.3 - Witness plate assembly used to monitor the environment around the assembly of the OSIRIS-Rex spacecraft (Dworkin et al., submitted to Space Science Review (2017), http://arxiv.org/abs/1704.02517

ICP-MS: a dedicated small chemistry laboratory is required for sample preparation. This should be located immediately adjacent to the ICP-MS instrument lab. This chemistry lab must be a high level clean room (Class 100, with careful attention to materials – usually low VOC, metals) to minimise contamination of the samples (primarily witness plates).

Gas chromatography/liquid chromatography mass spectrometry: a dedicated sample preparation chemistry laboratory will be required. The prep lab will need to be of a high clean room level (Class 100) to minimize sample contamination. The lab is primarily required for solvent extraction of witness plates and concentration of rinses and extracts prior to analyses.

6. SAMPLE RECOVERY

Transporting the Stardust Earth Return Capsule to a Sample Receiving Facility at Dugway, Utah. Image courtesy NASA

6 SAMPLE RECOVERY

6.1 Overview

This chapter deals with the methods for the recovery of sample return capsules and their transport to a permanent curatorial facility. The Earth Return Capsule from a sample return mission will be targeted at a specific landing point on the Earth with uncertainties in re-entry conditions resulting in a 'landing ellipse', possibly a considerable distance from the sample return facility. Before the capsule arrives, considerable preparations for the recovery need to be made. Once the capsule has landed, an assessment of the state of the spacecraft will lead to the execution of a pre-determined recovery procedure. The sample will then be transported to a Curation Facility using a safe and secure method of transport. When considering the recovery preparations for planetary return missions, the mission architecture and the design of the return spacecraft will have a significant impact. There is a distinction to be made between unrestricted missions and restricted missions as the latter will need planetary protection considerations. Mars Sample Return missions fall under the category of restricted missions. The recovery of sample return capsules for restricted missions will be different to that for unrestricted missions – both are shown in Figure 6.1.

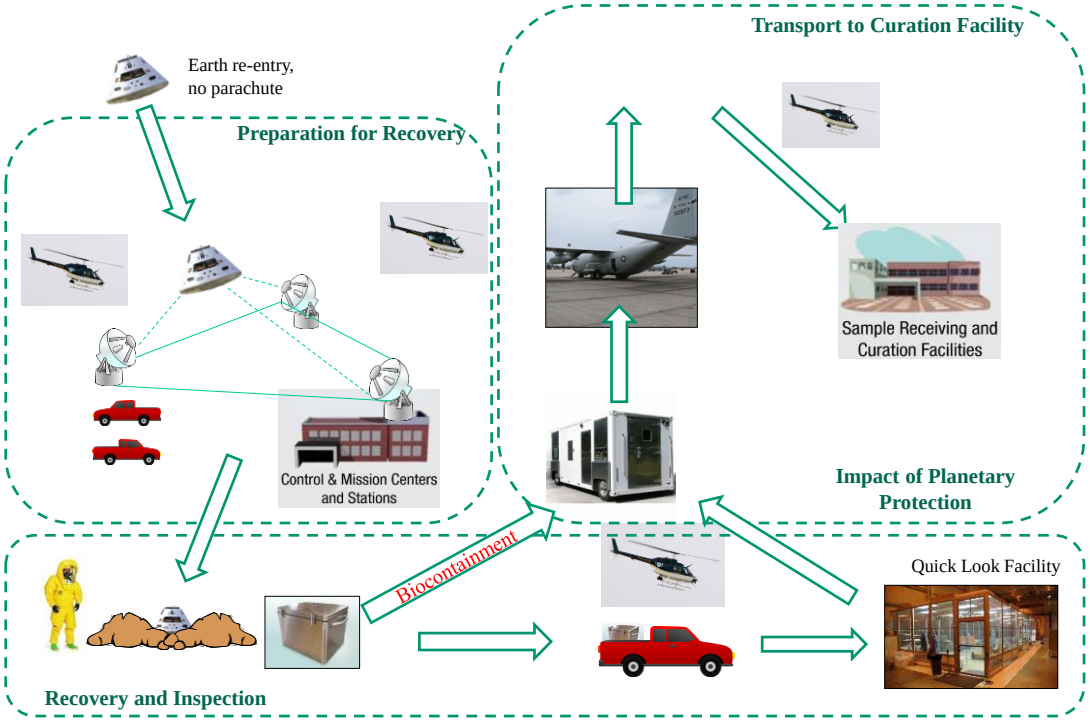


Figure 6.1 - Simplified sample return recovery procedure, incorporating options for restricted (biocontainment) and unrestricted missions (quick look facility)

American and European interest in Mars Sample Return was rekindled in 2008 with the publication of the iMARS report (International Mars Exploration Working Group; iMARS 2008)

An iMARS II report (Smith et al., 2016) produced an updated architecture for a multinational Mars Sample Return mission (MSR). To retrieve drilled samples from Mars (e.g., the Mars2020 mission, though this is not an explicit part of an MSR mission plan) there could be two launches, one to provide a Mars Ascent Vehicle (MAV) and a Mars Fetch Rover to retrieve samples, and a separate Earth launch to provide an orbiter to capture a sample container launched from Mars by the MAV, and return in to Earth. A variant of this architecture would be the ESA Courier mission (in a third separate launch) which would aim to rendezvous with a Mars Orbiter and return the samples to Earth. Thus, the exact architecture and number of launches

associated with MSR is not certain. Some required elements for any design include a Sample Return Orbiter element of the mission. This requires a rendezvous sensor suite and a capture mechanism, a bio containment system to break the chain of contact between Mars and Earth, an Earth Return Capsule (ERC) and a propulsion module (Smith et al., 2016)

6.2 Earth Return Capsule Landing Strategies

6.2.1 Nominal Landing

A nominal landing of the ERC would see the descent and landing of the capsule according to the mission design. This would mean that there would be no release of sample material from the capsule through failed containment and therefore no potential for life transmission to Earth. The operators would then be able to follow normal protocols for the collection of the ERC, its handling and transport to the sample return facility.

There are several different landing approaches that can be used in returning samples to Earth via an ERC. The ERC can be designed to use an active descent system that uses a parachute/s to slow its velocity before impact with Earth in the designated landing ellipse. This approach has previously been used for a number of return missions, such as Stardust.

6.2.2 Non-Nominal Landing

A non-nominal landing is where one or more aspects of the landing procedure did not happen according to protocol. This could range from the ERC landing outside of the determined landing zone, coming to rest in the wrong orientation after landing (as was seen with the Stardust mission), Failure of the parachute or deployment system could lead to a 'ballistic' landing at a velocity that may cause failure or destruction of the ERC containment. This was witnessed during the Genesis mission in 2004 where the drogue parachute failed to deploy after an accelerometer had been installed incorrectly and the ERC was only slowed down by its own air resistance, leading to a ballistic impact which the capsule was not designed to withstand, Figure 6.2. Damage to a restricted mission ERC from could cause a loss of containment and sample release to the Earth's atmosphere. This would present a serious problem in terms of contamination of the immediate area with the returned samples and more widespread contamination from environmental factors (e.g. wind), if particles were small enough to be dispersed. This type of landing will require extra procedures to be put in place to handle any potential release of extra-terrestrial sample into the Earth's biosphere, or conversely, Earth contamination of the returned samples. A non-nominal landing will potentially expose Earth to the collected sample in the ERC and/or the sample to Earth contamination (both biological and chemical) decreasing the scientific merit of the mission.

Current Mars sample return missions have planned to use an ERC which is able of withstanding a hard landing (as previously mentioned). This will involve using several layers within the ERC to provide protective containment to the sample containers. Whilst the ERC will be designed to withstand hard impact and provide a nominal landing, plans will be made for every eventuality, including a non-nominal landing.

During the Stardust mission, in 2006, after successful deceleration with a parachute, the ERC rotated onto its side on contact with Earth and partially obscured the tracking devices which led to an extended period before the capsule was found and retrieved. If this was the case for time critical samples then the delay in retrieving the capsule could cause degradation in the samples. Furthermore, if there was a failure in the containment of the capsule then there would be a potentially greater release and dispersal of sample material.

Figure 6.2 - Genesis capsule, 2004, after impact with the ground. Credit NASA

6.2.3 Lesson Learned from Spacecraft Sample Return Recoveries

Experience from the recovery of sample return missions to date show the importance of examining the entire sample handling and containment chain, including 'landing site characteristics, ground recovery and transport to ground facilities, not just the quarantine or containment laboratory' (NRC, 2009).

To summarise, in Table 6.1 there is a list of recovery techniques used for Genesis, Stardust and Hayabusa Mission and the expected plan for OSIRIS-Rex mission.

Table 6.1- Comparison of recovery techniques from different Missions

Mission	Recovery
Genesis	Transport to class 10000 cleanroom at UTTR then on to Curation Lab at JSC
Stardust	Transport to class 10000 cleanroom at UTTR then on to Curation Lab at JSC
Hayabusa	Transport to temporary cleanroom at Woomera and flown to Curation facility at Sagamihara
OSIRIS-Rex	Staging area at UTTR to prepare for transport to JSC Space Exposed Hardware cleanroom

In the following paragraphs there is a list of possible lessons learnt from the missions mentioned in Table 6.1.

6.2.3.1 Genesis

The Genesis Return Capsule, bearing the science canister with collected solar wind samples, returned to Earth in 2004. Following a flawless, on-target re-entry the parachutes failed to deploy due to a set of incorrectly oriented deceleration sensors. The spacecraft impacted the landing site, in the US Air Force Utah Test and Training Range (UTTR), at a speed above 86 m s^{-1} and was badly damaged. Most of the fragile collectors were fractured and all were contaminated on the surface by debris from the spacecraft and the landing site. A dedicated team of spacecraft engineers and curators immediately went to work to recover the broken spacecraft and move it to a temporary cleanroom at UTTR, where they painstakingly packaged and catalogued thousands of spacecraft parts and collector fragments. These were transported to the Genesis Curation Laboratory at NASA Johnson Space Center for cleaning, documentation, storage, and allocation. It

is believed that all the collector plates and materials were recovered. The lessons learned for EURO-CARES from these unrestricted missions would be:

- A temporary cleanroom is very useful for unrestricted missions;
- Container/s for fractured components should be available;
- Cataloguing the many different fractured segments may be necessary from the point of landing.

The Genesis Mishap Report identifies the main cause of the mission failure and section 6.1 of the report makes 12 recommendations to address the systems engineering process failures and management issues of concern (NASA, 2005).

Findings of the review included:

- A shortcoming of the Genesis preparation was the minimal amount of coordinated training for recovery;
- 'Safety first' was not an adequate part of the whole management approach;
- There was no single document defining the contingency plan and associated operations;
- There were no training exercises for the various contingency situations;
- Personnel on the scene were not equipped with proper communication capabilities; consequently, intentions were confused and conflicting.

6.2.3.2 Stardust

The Stardust Sample Return Capsule (SRC) was released from the mother spacecraft, and successfully parachuted to Earth above UTTR. However, an issue during the recovery was that the SRC landed upside down, which hampered the correct operation of the recovery beacon. Once on the ground, the Stardust SRC was recovered by a team of curators and spacecraft engineers within 2 hours, and was moved to a class 10,000 (ISO class 7) modular cleanroom located in a facility close to the landing site within UTTR for preliminary processing (Zolensky et al., 2008). The science canister was removed and secured in a clean transport container in this facility. The SRC was placed into a polyethylene bag for several hours, and outgassing from this bag contaminated the aerogel capture media with several organic molecules (Sandford et al., 2006). Following the preliminary processing, the SRC was placed into a dry nitrogen environment and flown to the Stardust Laboratory at JSC in a specially chartered plane. The Stardust Science Team used a class 100 (ISO class 5) cleanroom at JSC for preliminary examination and curation of the returned samples. Logistics associated with receiving these samples required careful planning and coordination with JSC Receiving, Security, Safety, Quality Assurance, Photography, and Curation teams. The samples received a police escort from Houston's Ellington Airport to the curation facility at JSC (Zolensky et al., 2008).

The lessons learned from this for EURO-CARES would be:

- Avoid polythene bags and use Teflon ones instead (if necessary);
- Contingency planning is vital and is time and money well spent.

A key finding of the Stardust lessons learned team is that a minimum of one additional day should have been included in the two-day recovery schedule. Given the complexity of a restricted return mission, requiring seal integrity verification, careful recovery and local context sample collection, it seems likely that five to ten days for recovery will be necessary. The Stardust team conducted extensive field testing for both nominal and off-nominal scenarios leading to and operational readiness review. Furthermore, a full end-to-end balloon drop test was performed, simulating an actual landing (Sandford et al., 2006).

6.2.3.3 Hayabusa-1

Following a series of propulsion, communication, and control failures, the spacecraft successfully returned to Earth in June 2010. The return capsule was predicted to land in a 20 km by 200 km area in the Woomera

Prohibited Area, South Australia. Four ground teams were stationed around this area and located the re-entry capsule by optical observation and a radio beacon. Then a team on board a helicopter was dispatched. They located the capsule and recorded its position with GPS. Following operations ensuring that the pyrobolts and batteries used with EDL were safe and disconnected, the capsule was placed into a container with a nitrogen atmosphere, for transportation, initially to a temporary facility in South Australia. JAXA built and equipped a main laboratory in Sagamihara, Japan to carry out the external cleaning and de-integration of the recovered spacecraft, sample extraction and preliminary examination, and sample curation for the Hayabusa mission.

The returned hardware was planned to include one sample of ~100 g, but because of the failure of the sampling system, only ~1500 grains of asteroid material were recovered. These are still immensely valuable scientifically, and were recovered from the sample container on an individual basis. Contingency facility operations were needed where micromanipulation was used to sort genuine asteroid particles from contamination particles.

The lessons learned for EURO-CARES would be:

- The capsule may require de-arming to ensure pyrotechnics and batteries are deactivated;
- Micromanipulation may be necessary to sort particles in the ESCF.

6.2.3.4 OSIRIS-Rex

OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) is a NASA mission launched in 2016 to encounter and sample Asteroid (101955) 1999 RQ36 (known now as Bennu) and return ~60g of asteroid sample back to Earth. The sampling is based on a 'touch-and-go' method that will retrieve sample directly off the surface in a single collector and return it to Earth in a return capsule like that used by the Stardust mission.

After a 2-year cruise, Earth atmospheric entry of the ERC will occur in September 2023 (Beshore et al., 2015). Four hours before entry, the SRC will be released from the spacecraft bus, and a divert manoeuvre will be executed to place the spacecraft into a heliocentric orbit. The SRC will enter Earth's atmosphere at more than 12 km/s, slowed first by a drogue and then a main parachute, and will soft land at the US Air Force's UTTR, west of Salt Lake City.
The SRC is tracked with UTTR range radars to within ~10 m of the landing location. Once landed, the SRC is recovered and transported to a staging area at UTTR to prepare for transport to JSC. Air samples are taken at both landing site and staging area to test for ERC outgassing. In addition, relevant soil samples will be taken from the landing site, as well as samples of any other materials the ERC may have come into contact with during landing and recovery. The canister is removed from the ERC and all hardware is transported to the JSC Space Exposed Hardware cleanroom, where the sample canister will be opened in the dedicated OSIRIS-REx ESCF at JSC. Curators will have 6 months to complete an inventory of the returned sample, after which time, investigators from around the world may apply for material and witnesses using an established astromaterials loan request.

Lessons learned for EURO-CARES would be:

- The ERC heat shield may emit contaminating gases;
- Analysis of ERC outgassing at the landing site and later will be necessary.

6.2.3.5 Lunar Sample Return and Immediate Quarantine

The main difference between Apollo and future, robotic sample return missions is that safety consideration for the astronaut crew is not a factor. However, human safety at the point of terrestrial landing is. Lessons learned from the Apollo programme proposed the following points, relating specifically to a MSR mission (Allton et al. 1998):

- Initiate planetary protection and sample preservation planning early in the mission design;
- Place responsibility for back contamination and sample preservation at high management levels;
- Allow time for proper implementation of back contamination and sample preservation requirements;
- Devise a technical plan to minimize conflicts in protocols for quarantine vs sample examination and preservation;
- Reduce magnitude, and thus cost, of quarantine and curation operations by careful pacing and careful planning of what to do in quarantine mode and what not to do in quarantine mode;
- Conduct necessary scientific and technical research.

6.2.3.6 Overall Lessons Learned

The lessons learned from past missions can be used to create recommendations for ESCF recovery operations. Please note that these recommendations do not represent the views of the experts consulted, they have been constructed by the authors of this study.

Recommendations:

- Start landing site negotiations more than 2 years in advance of planned landing;
- Liaise with local governments and military to understand all regulatory aspects of a landing site, including cultural;
- Plan for recovery in all areas of the landing ellipse;
- Plan and train for: SRC landing outside of landing ellipse, SRC not being found in a long time, SRC landing in water, SRC landing in mud (preventing nominal recovery operations), SRC opening upon landing, night landing, extreme weather conditions such as flood/snow;
- All recovery personnel to be equipped with protection suits, clean tools, bags, containers to secure loose samples if necessary;
- Make environmental measurements at the landing site using photography, taking soil, liquid, air and vegetation (if any) samples;
- A temporary cleanroom is useful, but more relevant for unrestricted missions
- Container/s for fractured components should be available;
- Cataloguing the many different fractured segments may be necessary from the point of landing
- Use Teflon bagging (if necessary);
- Provide containers for environment samples and spacecraft hardware;
- Use N_2 purge for transport container for unrestricted missions.

6.3 Landing Site

Generally, a landing site is an area identified for the controlled arrival of an aerial vehicle. Sites for sample return missions tend to be isolated and remote areas with low or zero population, which often equates to limited infrastructure and the need for specialist access. Such environments also make ideal civilian and military test ranges because of the inherent security and safety provided by the location. As such, test ranges with their specialist infrastructure make potential good landing facilities when considering a return space mission.

There are limited options in terms of landing sites worldwide and many factors to consider such as security of the site, accessibility, and political issues. The only two sites that have been used for previous sample return missions are Utah Test and Training Range, United States and Woomera, Australia. In both cases, there were specific issues to solve prior to their use.

The NASA Stardust and Genesis missions landed at UTTR, and it is also planned for Osiris Rex to land there. It took 2 years for Lockheed Martin to get approval from military authorities for landing at UTTR

for the Stardust mission. This site has unpredictable weather and unexploded ordnance. For Stardust, part of the landing ellipse was in a 'restricted area' because of the presence of restricted weapons and the recovery would have been slower should it have landed here.

At Woomera, during the recovery of the Hayabusa capsule, two aboriginal clan members had to travel in a helicopter with the recovery team because, depending on where the ERC landed, there could have been cultural/religious implications.

A given mission may have specific requirements. For example, a sample must land in a dry area that will maintain an internal sample temperature below the freezing point of water; and one may select a site and time of year to support such a requirement. However, it is possible to focus on general requirements that a return mission may impose. The main ones are the following:

- The latitude and longitude shall be compatible with an Earth return insertion orbit;
- Test range area shall be of sufficient size that it can accommodate a passive and active landing ellipse with a TBD margin;
- Airspace in the immediate vicinity of the landing ellipse shall be restricted or controlled
- The prevailing wind of the test range shall favour the landing ellipse
- Airspace from the ground shall be unlimited to 100km;
- Immediate ground-space of the landing ellipse shall be restricted;
- Immediate ground-space of the landing ellipse shall be unpopulated;
- The geology, landform & local climate of the landing ellipse must limit the risk of a failed landing;
- The test history of the landing ellipse will limit the risk of non-retrieval;
- The test history of the landing ellipse will limit the risk of nuclear, biological or chemical contamination of the landed component and samples;
- The selected landing ellipse shall minimise the risk of UXO.

6.3.1 Landing Site Candidates

Landing site selection must be included in the initial stages of the mission design because many dictating factors are greatly weighted by the early architectural decisions of the mission; typically: mass, cost and the orbital manoeuvres available. Spacecraft like the Apollo Command Module, used an active descent system to reduce its return velocity through the atmosphere. An Earth Return Capsule must also dissipate its energy and the technique (active or passive, like aerobraking) will have an impact on the final trajectory (where it can land, safely). Other factors may be more subtle, for example, the decision to adopt a posigrade or retrograde de-orbit may not have a major impact on the additional need for propellant mass; however, because the dissipated heat energy scales quadratically with the difference in velocity, the size and hence the mass of the heat shield, must also be similarly scaled. This in turn has an impact on the range safety requirements and ellipse size.

Sample return missions are not new and NASA has published its 'Sample Return Handbook' covering all aspects of such missions (Barrow et al, 2007). In addition to the landing ellipse requirements in terms of latitude and longitude, another consideration in site selection concerns the accessibility of the site both logistically and politically along with the *in situ* resources necessary to effectively and safely recover such a craft and its components (parachute, heatshield, etc.).

Landing sites selected for the future European sample return mission could be:

- White Sands Area (WSA), USA;
- Utah Test and Training Range (UTTR) USA;
- Wallops, USA;
- Woomera Range Complex (WRC), AUS;
- Kazakh steppe, KZ;

- Esrange Space Centre, SWE.

These are the conditions for landing in an ideal scenario:

- The sample would be landed in a dry area;
- The sample would be landed in day time;
- The sample would be landed not in winter (due to the risk of rain, snow and floods);
- The internal temperature of the sample would be below the water freezing point;
- The sample must not be contaminated by dust.

The characteristics of the main potential terrestrial landing sites are given in Table 6.2; six have been selected for further study in the context of a ESCF. Table 6.3 summarises findings from a preliminary examination of the main planetary protection and logistics issues for the six sites, to help in decision-making for a landing site for future European missions. A 'traffic light' indicator is used here to show the top-level advantages and disadvantages of the example sites.

- Red = Disadvantages or difficult;
- Yellow = Unknown or indifferent;
- Green = Advantage.

Six potential sample recovery landing sites have been considered in this work and it has been shown that the mission architecture and engineering of the ERC has a bearing on the preparation and selection of an appropriate landing site. It is expected that a US NASA-led sample return mission will adopt the use of the UTTR facility, as has been the case with previous and current missions, such as Osiris-Rex; with non-US citizens required to liaise through NASA's International Office. However, future missions could be led by a variety of agencies (e.g., China), or even commercial entities like SpaceX, with ESA as a partner. Flexibility is therefore key, and this is indicated by several options in Table 6.3. A European test range facility, which could be developed for this type of sample recovery, would be an attractive option. The Esrange Space Centre in Sweden is a viable option with the potential to provide Europe with a landing site for future CAT V missions, such as MSR. It is recommended that this European capability is explored and expertise developed further, as sample return mission architectures are refined.

Table 6.2 - Environmental characteristics of possible landing site

Region/Area	Av. Temperature Range (°C)	Dust/Snow Storm	Av. monthly Precipitation (mm)	Biological Contamination	Unexploded Ordnance	Population
White Sands Area	-6 to +36	Yes	21 - 97	Yes	Yes	No
Utah Test and Training Range	-3 to +32	Rare	1 - 80	Yes	Yes	No
Wallops	-2 to +27	Rare	73 - 106	-	No	-
Woomera Range Complex	6 to +35	No	13 - 20	-	Yes	No
Kazakh Steppe	-18 to +26	Yes	18 - 41	No	No	No
Esrange Space Centre	-12 to +15	Yes	25 - 180	-	No	No
Siberia	-25 to +17	Yes	14 - 72	No	No	3 km^{-2}
Vidsel Test Range	-18 to +22	Rare	14 - 58	No	Yes	No
Siziwang Banner Area	-15 to +20	Yes	5 - 60	-	Yes	< 3 km^{-2}

Table 6.3 - Landing site summary table

Provision	White Sand Area	Utah Test and Training Range	Wallops	Woomera Range Complex	Kazakh Steppe	Esrange Space Centre
Nationality	US	US	US	Commonwealth	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 Liason	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

6.3.2 Planetary Protection and its Impact in Landing Site Selection

In terms of impact on the selection of terrestrial landing site and planetary protection, its restricted/unrestricted classification and the local environment will influence this. The major concern with a Category V Restricted mission is that an unknown pathogen from a celestial body could contaminate the terrestrial biosphere. While this risk is considered very low, the impact is difficult to quantify and therefore warrants serious consideration in terms of mitigation approaches and preparation management in selecting the site.

Forward contamination (an unwanted substance added in an uncontrolled quantity to the sample) is similarly a concern. However, this can be quantified by the total cost of the mission, assuming a total loss. With regard to preparation, it is possible to manage and limit forward contamination, at the point of landing, if a pre- and post-landing inventory of the area is catalogued.

In broad terms, landing site contamination can be considered as:

- Biological (pollen, microbial & small multi-cellular organisms);
- Organic;
- Inorganic;
- Isotopic (natural and industrial / legacy nuclear testing (e.g. plutonium and tritium));
- Particulate (e.g. pollen, dust, salts, industrial or spacecraft debris);
- Gaseous (particularly oxygen);
- Liquid (water).

This broad definition of contamination should be used to inform the type of landing site monitoring and context sample collection. It also informs the necessary preparation in obtaining permits or special negotiations to remove samples from some sites.

Beyond the issue of contamination, temperature is also a major factor because of its effect on the rate of chemical reactions between the sample and its container or the sample and localised contamination, in the event that a sample container is breached.

6.3.3 Landing Site Consideration

6.3.3.1 Legal Documents

Legal documents include initial applications and all permits that relate to use of the range site, people, hardware, shipping (including special permits to move potentially hazardous material and local samples), ITAR paperwork and declared materials/components, risk assessments and passports / visas. It is also advised that during preparation of recovery, key individuals are identified early in the programme and all relevant legal documentation is managed with due consideration of time as some permits may require in excess of a year to complete.

6.3.3.2 Visas

Travel visas to both the US and Australia may be required. Some visas will be conditional on certain vaccinations where individuals have travelled to 'at risk' countries (i.ie. countries with endemic Yellow Fever, in the case of Australia).

6.3.3.3 Permits

Test ranges tend to be military establishments and it is advised that permits are sought in relation to photography and sample collection. Illicit photography could result in transport complications and at worst, the entire sample cache being impounded. Because photography is critical to the science it is advised that a dedicated photographic technician be assigned to the recovery team. Permits should be discussed with NASA's office of International and Interagency Relations, Australia's WPA Coordination Office and the Esrange Space Center, Sweden.

6.3.3.4 Local By-laws

The relevant agencies can advise on local by-laws and jurisdiction that may apply to visitors to military property. Within Australia, the Government Law Reform Commission recognises Aboriginal customary laws and traditions relating to land and special religious sites. Some areas of Woomera are considered as special sites and this should further be researched as part of initial assessment and negotiation with the WPA Coordination Office.

6.3.3.5 Alien Access

Particularly within the USA, some foreign nationals will not be permitted visas to work on a sample return mission. Furthermore, while some aliens will be permitted access to the US only very limited access to military facilities will be granted.

6.3.3.6 Local Legalities in Relation to Containment Loss

The risk of an extra-terrestrial pathogen must be quantified and a full risk assessment carried out to determine how such risks might be limited and the effects of a worst case scenario. For example (and not including the value of tourism), the mining rights to parts of Woomera are estimated to be worth some 35 billion dollars over the next ten years; with industrial contracts from BAE Systems to test drone aircraft and a recent multi-million dollar contract for facility upgrades to test performance of the F-35 Joint Strike Fighter, it seems likely that the Australian Government will want to consider assurances that a Mars Sample Return mission does not represent any risk to their business interests.

6.4 Earth Return Capsule (ERC)

6.4.1 Risk Mitigation of Return Mission

There are several factors that can be used to reduce the risks from the returned sample in the case that there is a breach of containment (backward PP).

6.4.1.1 Capsule Design

Sample return mission design will use an ERC designed for hard landing on Earth. The ERC will not use a parachute for slowing descent, instead a descent aero-shell design will be incorporated. This design and the numerous containment layers surrounding the sample tubes will reduce the likelihood that any containment breach will happen and therefore release of sample to the Earth biosphere. It is envisaged that numerous tests will be completed prior to mission launch to demonstrate the ability of the ERC to withstand this hard landing into the several different surface types it might encounter at the chosen landing site. A hard landing could result in a transient of hundreds of g. The sample biocontainer, which is within the ERC, has a design requirement to be able to withstand approximately 50g of acceleration and it may be assumed that anything within the sample container may also be submitted to this acceleration. There may also be a test method engineered into the ERC to show that containment has not been breached in the descent to earth and impact.

6.4.1.2 Impact Forces with Earth

As the envisaged return missions will utilise hard landing of the ERC, then this will potentially reduce the viable population of any lifeform in the return samples from the impact of the ERC with Earth. Impacting organisms at high velocities into a solid semi solid surface will cause pressure waves and heat that could inactivate certain organisms within them (SterLim, Feasibility studies and tests to determine the sterilisation limits for sample return planetary protection measures, in response to ESA call RFQ/3-14132/14/NL/HB).

6.4.1.3 Sample Composition

Of the samples returned during a Mars Sample return mission, most will be rock cores and small rocks mixed with regolith. These are likely to be a mixture of sedimentary, hydrothermal and igneous in origin (e.g. iMars, 2008). Microorganisms can survive the formation of some rocks, particularly sedimentary and evaporites. Expedition have recovered samples of DNA that were 250 million years old as far down as 1.2 km underground. Water can aid the penetration of bacteria into basalt by carrying the cells through pores if the size is adequate to allow passage. In contrast, sedimentary and hydrothermal samples may have micro-organisms as an intrinsic part of their formation associated with the presence of water.

6.4.1.4 Exposure to Earth's Atmosphere

It is likely that the terrestrial environment may be toxic for any microorganisms coming from an extraterrestrial environment. Organisms that thrive in a high carbon dioxide and low oxygen environment (capnophiles) may find high levels of oxygen toxic, like many capnophiles found in environments on Earth (George, 1979). If containment were to break on the ERC and Earth atmosphere were to contact the sample, then the level of oxygen could kill any organism present, eliminating any potential risk from backwards contamination. It should be noted though that some organisms are capable of aerobic respiration and fermentation, so can survive in either oxygen- or carbon dioxide-rich atmospheres (Gregory and Fridovich, 1974). This entire reasoning assumes that pathogenicity of Earth's biosphere is limited to an active prokaryotic-type organism. But there are also spores or non-living macromolecules/prions that could have a toxic effect on terrestrial life.

6.4.1.5 Decontamination of the Landing Site

The ERC may be engineered to have sensors within it to detect if there has been a loss of containment and release of sample (e.g. pressure sensors). This will allow the retrieval teams to identify early in the recovery phase if measures are needed to decontaminate the landing site (or a wider area). Decontamination of the

landing site will help to reduce the risk from a small-scale contamination event limiting further spread of any potential extraterrestrial lifeform.

6.4.1.6 Biocontainment of Earth Return Capsule

Currently, the MSR mission appears to be baselining an 'adaptive caching' approach (Farley, 2016). This involves collecting the samples directly into sample tubes, hermetically sealing the samples in the tubes then caching them directly (e.g. no intermediate canister will be used) on the Mars rover for transport to an appropriate location. Sample tubes and blanks will be picked up from the Mars surface for return to Earth at a later date. As a consequence, the current MSR mission scenario has an Earth Return Capsule (ERC) which performs a hard landing at a sparsely occupied location on Earth. Inside the ERC (Figure 6.3) is a Biocontainer (BC). Inside the Biocontainer there is a Sample Container (SC) and inside this there are the Sample Tubes (ST). The exact amount of sample and number of sample tubes is subject to change.

The outside of the hardware down as far as the biocontainer is considered to be Earth contaminated during landing and so high-level contamination protection is, in theory, not needed. However, if the Earth Return Capsule is breached or damaged in some way, contingency measures may need to be in place.

The sample tubes (ST) will be exposed to several different pressures during the course of the mission. The initial pressure within the ST represent the atmospheric pressure found on the celestial body, such as Mars. Then when the sample container is in space, this external pressure will be reduced in comparison to the ST pressure. Then on entry into the Earth's atmosphere, the external pressure will be higher, thus the ST will be at negative pressure to the Earth. The most recent design of sample tube is currently being pressure tested to investigate the most appropriate tube and seal material. These need to provide a low leak rate for the tubes whilst also having minimal off-gassing that might taint the sample with chemicals. The design of the biocontainer (Figure 6.4) may accommodate a monitoring system to identify any breach in containment. These will measure the pressure within the biocontainer and will transmit the information to mission control and/or the recovery team, so containment can be assessed during the landing process. A measurement in the level of pressure change from that which is expected will help determine the size of the breach in containment.

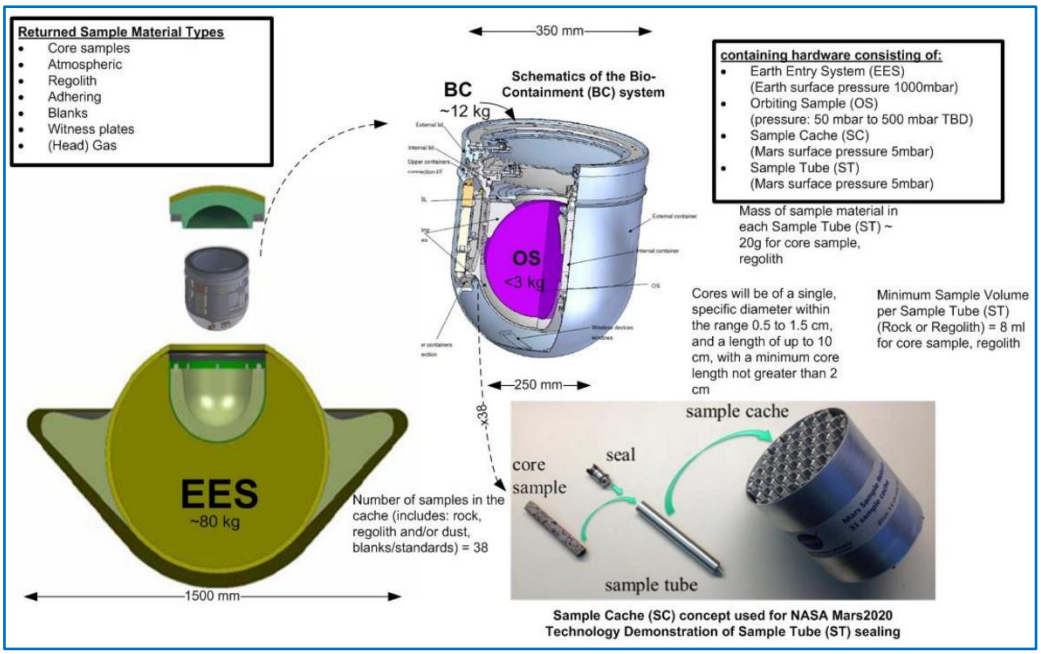


Figure 6.3 - Returned sample material types and container hardware. Credit (TAS, 2016)

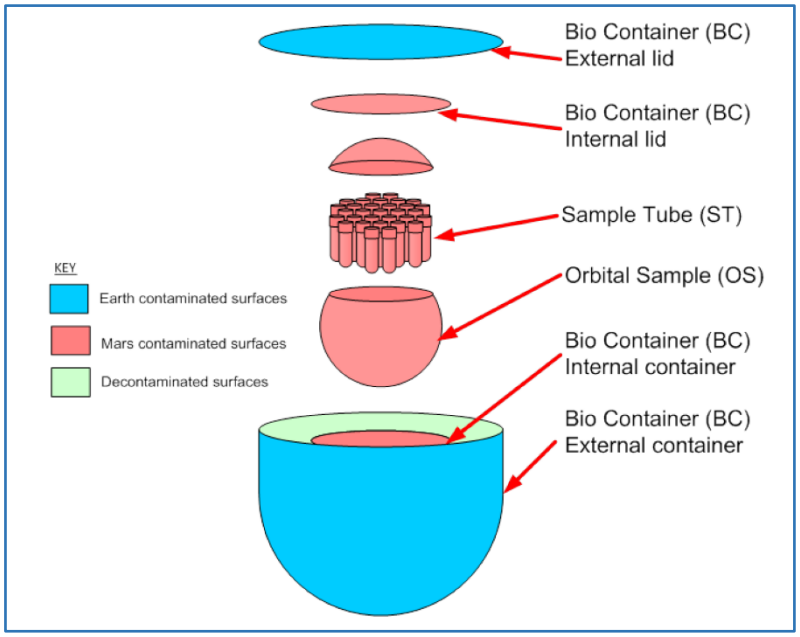


Figure 6.4- Biocontainer showing orbital sample and sample tubes within. Colour scheme shows Earth contaminated (blue) and Mars contaminated (red) surface

6.4.1.7 Biocontainer Monitoring

The Mars Sample Return biocontainer (Figure 6.4) will use a monitoring system to detect a breach. The monitoring system is a pressure/temperature based system that will monitor a defined pressure within a well-known volume. Once pressurised, the environment and status of the inter-vessels chamber and chamber containing the samples is then monitored by reading the pressure and temperature from the transducers. The data collected is then transferred to the capsule *via* wireless data transmission.

There is an overall requirement on the end-to-end probability of contamination of the Earth with returned samples. This is that the probability of contamination by a particle ≥ 0.1 µm in size shall be less or equal to 1×10^{-6}. This is the critical requirement all space segment designs are trying to meet. By implication, to establish that there is no breach, the biomonitoring system would need to prove that the likelihood of contamination by a particle > 20 nm in size is less than 1×10^{-6} (ESF-ESSC Study Group, 2012). This is very challenging technically, and may be difficult to establish, so it may be necessary to assume that there is a breach from a Planetary Protection point of view. On the other hand, thorough engineering validation and testing could be used to confer protection, whereas the public perception of risk may prevent the mission going ahead if there is an assumption of a breach.

6.4.1.8 Temperature of the Samples

Consideration needs to be given to the temperature of the capsule during recovery. The capsule will undergo the possible extreme temperatures of re-entry (although protected by an ablative heat shield) and then land in a hot desert. It has been assumed here that rather than undergo repeated melt-freeze cycles, it would be preferable scientifically that the samples temperature be kept within room temperature range. If cold storage is required, then a subset of the samples could be sent to the vault storage facility which will have cold storage capacity.

6.5 ERC recovery and initial inspection

6.5.1 Concept of Operations

It is standard practice when designing a system to define what is in the system and what is outside the system. This helps to define what the boundary of the system is and where it interfaces with external factors. The recovery and inspection system described in this work is influenced by external factors, including the Earth Return Capsule (which is designed by an industrial team and is not part of the ESCF infrastructure) and the organisation and management of the process as well as political, ethical, legal and social aspects of the recovery procedure. Whilst the transport container is an integral part of the recovery procedure, it is defined as outside the system. The capsule and its component parts eventually need to be transported to the ESCF, so this is also defined as outside the system. The functions of the system are contained within the system boundary (dashed in Figure 6.5).

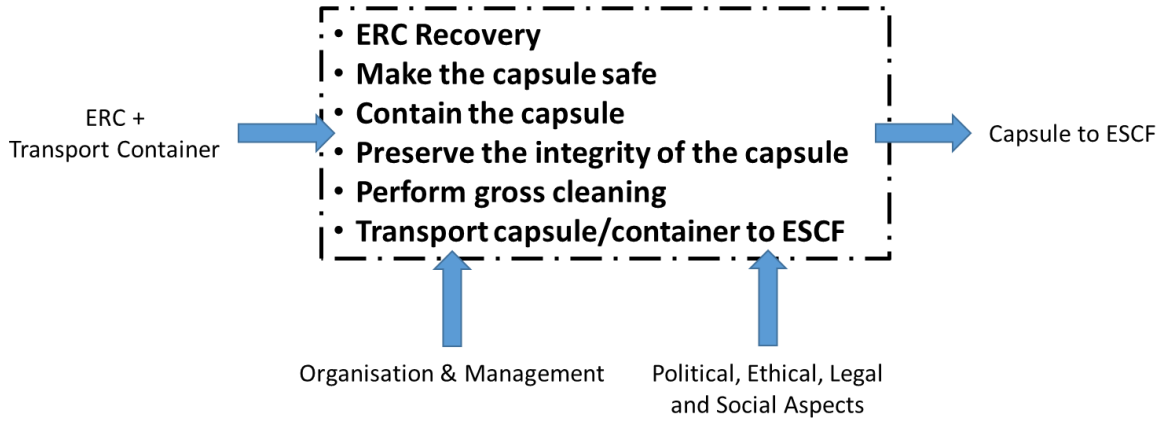


Figure 6.5 - Definition of system (dashed line is the system boundary, blue arrows are interfaces to external factors)

The concept of operation describes the different phases of the recovery procedure. For a general overview, Figure 6.6 shows the overall 'concept of operations'.

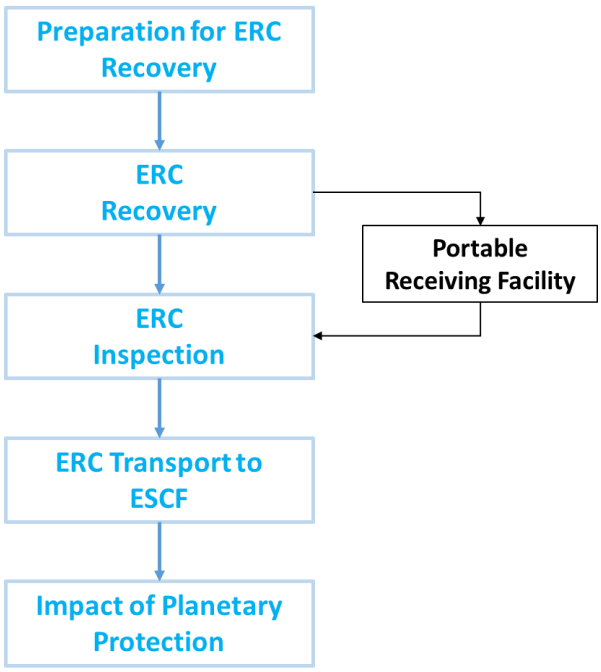


Figure 6.6 - ERC Recovery and inspection concept of operations

On approach to the landing ellipse, the ERC will emit signals via an onboard beacon. This beacon can be used by the onsite radar and reconnaissance facilities to establish the location of the ERC in the air. Cameras and radars will be used for visual tracking during the descent. Land vehicles and helicopters can then be used for recovery of the ERC and will travel to the location provided. If the mission is a restricted one, then biohazard and planetary protection measures will be put into place and all personnel will don appropriate biosafety equipment before approaching the capsule. If the mission is unrestricted, then a careful approach may still be needed to render the capsule safe, as any capsules with pyrotechnics onboard (to release the parachute) or batteries (to power the radio beacon) pose a threat to recovery personnel and these need to be de-armed.

Landing site environmental samples will be collected, and atmospheric conditions recorded. The capsule will most likely be taken in a land vehicle to a portable receiving facility close to the landing ellipse where a preliminary examination takes place. Here the capsule is cleaned, and in some cases the capsule may be opened to remove the sample canister/container. The sample canister/container will be placed carefully into a transport container. This container is then transported to the ESCF by aircraft. The aircraft is likely to be a military aircraft due to restrictions on commercial flights carrying N_2 purged containers. Once the receiving/curation facility has received the samples, analysis can take place. The recovery process should be adaptable to all the possible sample returns:

- Mars missions;
- Missions to other Category V restricted bodies such as Titan, Enceladus and Europa;
- Lunar missions;
- Asteroid missions;
- Missions to other Moons, such as Phobos and Deimos.

The different recovery options could be summarized in two possible scenarios:

- Restricted: sample return missions to bodies where there is a possibility of life;
- Unrestricted: other sample return missions.

Analysis of the nominal and non-nominal unrestricted missions resulted in the realisation that there was no difference between the recovery processes planning for these, so they were merged into one unrestricted mission.

Upon analysis of the restricted mission scenarios, it was realised that there was a smaller subset of functions, which were necessary in the case of the non-nominal scenario, where some kind of breach occurs to the capsule.

6.5.2 Restricted Missions

The flow of functions for a restricted mission is illustrated in Figure 6.7. For a Category V restricted mission, onsite radars and reconnaissance facilities will be used to locate the capsule's recovery beacon and determine its position. Recovery personnel will then travel to a safe distance from the landing site. The landing site will be inspected for any breach or hazards (possibly using a drone) before any recovery personnel approach the capsule. The site will be secured by appropriate personnel. Personnel will change into appropriate biocontainment suits before proceeding to the landing site (this can be done in most dry and light conditions, otherwise a change lab may need to be set up in the vicinity of the landing site). Environmental samples will be taken from the landing site including soil and atmospheric gases. Heat shield gases from the ERC will be measured. The ERC will be inspected and photographed to document its position. Information about the integrity of the seal will be available up to landing but the biomonitoring system will not be able to be used after landing since it is not designed to survive the hard landing.

If the ERC is determined to be in a 'nominal' condition (i.e., the seal is intact and no fractures are apparent) the exterior of the ERC may be cleaned using a gross cleaning method. The type of cleaning method will

depend on the physical state and quantity of Earth contamination and condition of the capsule's outer surface. The flow follows the orange boxes. The ERC will then be placed into an appropriate transport container to prevent any contamination and transported to the ESCF for analysis.

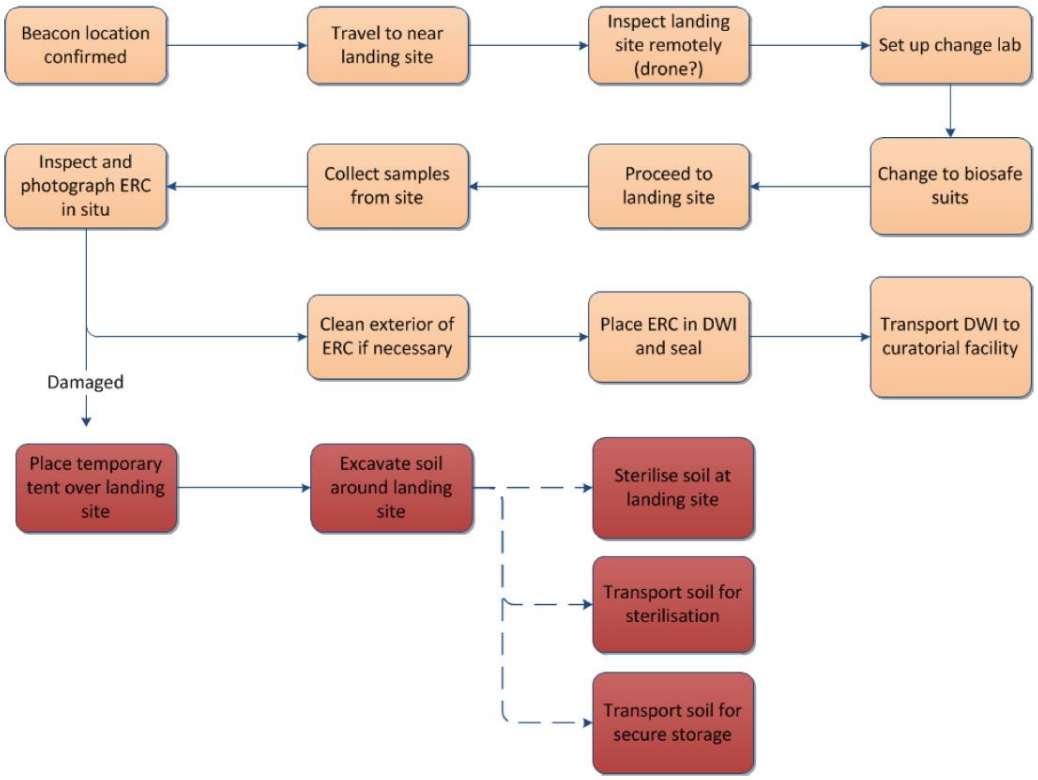


Figure 6.7 - Functional flow for a Category V restricted mission (red section describes scenario for non-nominal mission)

If the ERC is determined to be damaged or the integrity of the seal is compromised, then the flow is classed as 'non-nominal' (red sections of Figure) and a temporary tent will be placed over the landing site. It may be necessary to deactivate any pyrotechnics (although for instance the current Mars Sample Return design does not include pyrotechnics) disconnect the battery and remove parts of the electronics. The soil surrounding the landing site will be excavated and one of three methods of sterilisation will take place to help protect the earth from extra-terrestrial contamination: the soil will either be sterilised at the landing site; transported elsewhere for sterilisation; or transported for secure storage for later analysis.

It could be argued, that as if it is not possible to determine if the seal has broken on landing, the operations should treat the ERC as compromised and as a 'non-nominal' scenario. This is the 'safety first' approach, but could be regarded as challenging from a public perception of risk point of view, as the public may question why it might be necessary to, say, decontaminate the area after an apparently perfect landing and recovery.

6.5.3 Unrestricted Missions

The flow of functions for an unrestricted mission is illustrated in Figure 6.8. For unrestricted missions, landing site radar and reconnaissance facilities will be used to locate the capsule's recovery beacon and determine its position. Recovery personnel will then travel to the landing site and don protective clothing if necessary (i.e. if pyrotechnics need to be de-armed and if toxic gases are being emitted by heat shield). The ERC transport container also will be transported to the landing site. The ERC will be inspected and photographed to determine if there is any damage and to document its position. The ERC will then be placed into the transport container. If the capsule is damaged, there are two possibilities: either the containers will be transported by aircraft straight to the ESCF or the parts may be transported to a nearby cleanroom for cleaning and sorting. For a nominal landing, the transport containers may be transported to a temporary

cleanroom in a hangar close to the landing ellipse where the ERC will be removed and inspected. Gross cleaning will be performed on the outside of ERC. A transport container will then be used to fly the container to the ESCF. The container will be purged with N_2 gas to help remove any moisture that could compromise the samples and reduce oxidation. In some cases, the sample container may be removed and sent separately to the spacecraft hardware or it may be left inside the ERC until opening at the ESCF.

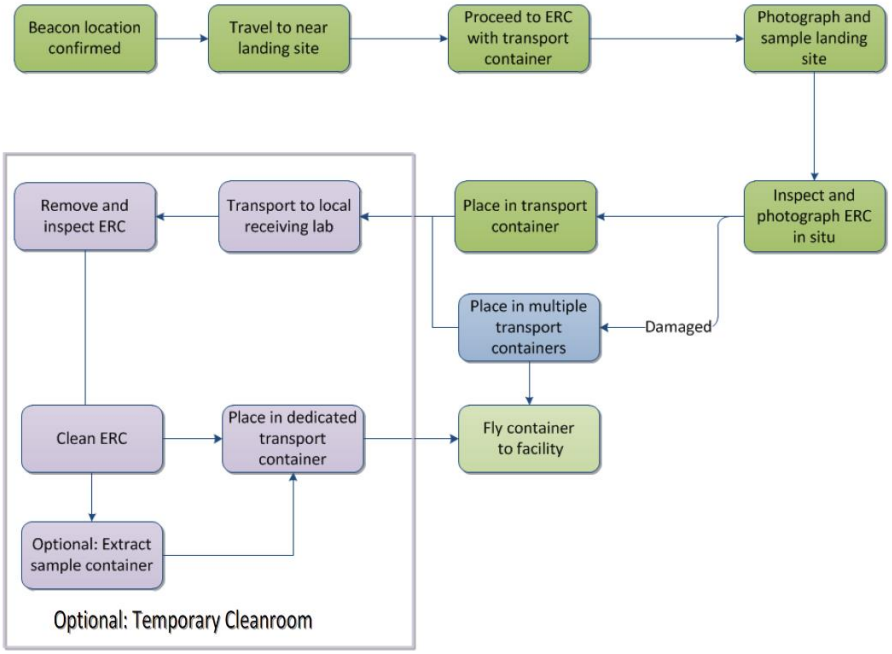


Figure 6.8 - Functional flow for an unrestricted mission

6.5.4 Product Breakdown Structure

A product breakdown structure (PBS) is a tool that details the physical components of a particular product, or system, under consideration. The formal PBS comes in the form of a hierarchy. It begins with the final product at the top of the hierarchy followed by the sub-categorized elements of the product. Figure 6.9 illustrates the infrastructure needed for unrestricted missions.

The five main components are location equipment, landing site equipment, a temporary cleanroom (as discussed previously this can be optional), transport equipment and scientific equipment. The latter could be necessary for use either at the landing site or in the temporary cleanrooms. Explanations for each type of equipment is given in Figure 6.9 and Table 6.4.

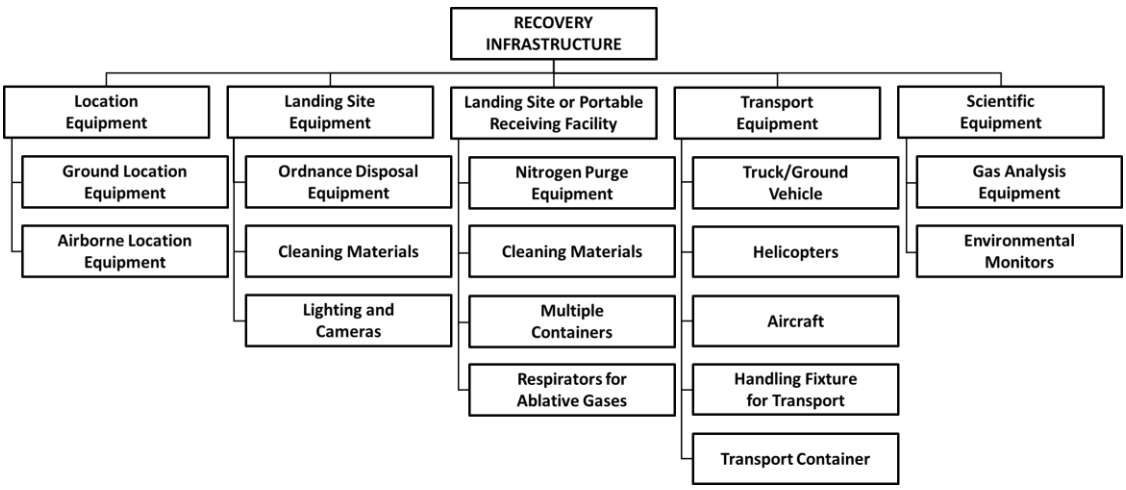


Figure 6.9 - Product Breakdown structure of the infrastructure needed for unrestricted missions

Table 6.4 - Rationale for unrestricted mission equipment

Location Equipment	
Ground Location Equipment	Ground location equipment is required so that the capsule can be located by the Truck/Ground Vehicle.
Airborne Location Equipment	Airborne location equipment is required so that the capsule can be located by the Helicopters/Aircraft.
Landing Site Equipment	
Ordnance Disposal Equipment	Landing sites such as UTTR have problems with unexploded ordnance. An explosive ordnance disposal (EOD) assessment may need to be carried out prior to approaching the capsule.
Cleaning Materials	Gross' cleaning may be performed on the capsule at the landing site. This may require suction cleaning equipment, wipes, a power spray and/or brushes. Cleaning methods employing chemicals or solvents will be avoided due to the risk of contamination or corrosion.
Lighting and Cameras	External floodlights can be used to light up the landing area to enable a good visual assessment of the capsule at night as well as photography for the recording
Landing Site or Portable Receiving Facility	
Nitrogen Purge System	The transport container will have a N2 purge system installed. This will remove any moisture that could compromise the samples and reduce oxidation.
Cleaning materials	A 'fine' cleaning method will be employed for cleaning the outside of the capsule, such as suction, wipes or brushes, to help remove any gross terrestrial contamination.
Multiple Containers	Multiple containers of different sizes will be in supply for contingency situations such as a fractured capsule. (This was particularly important during Genesis recovery).
Respirators for Ablative Gases	At the landing site, half mask respirators should be worn as a minimum for protection against any potentially harmful gases such as Sulphur dioxide being emitted from the capsule.
Transport Equipment	
Truck/Ground Vehicle	Specialist vehicles, such as a MATTRACK (a pickup with wheels replaced by treads) may be used to enable easy travel across rough terrain.
Helicopters	Helicopters can be used to track the capsule during its decent through the atmosphere and used to transport the capsule to an interim facility on the edge of the landing ellipse. Also helicopters give quick access to landing site.
Aircraft	Military aircraft can be used to transfer the container holding the sample from the temporary cleanroom at the landing site to the curation facilities.
Handling Fixture for Transport	After the capsules integrity as been determined, it will be lifted onto a handling fixture for easy transportation to the cleanroom. Using a handling fixture will help reduce any shocks or vibrations that could damage the samples.
Scientific Equipment	
Gas Analysis Equipment	Heat shield gases can be verified using a hydrogen cyanide analyser. Direct-read sulphur dioxide and acetonitrile detectors can be used to verify safe batteries.
Environmental Monitors	Meteorological instruments will be used to record the weather at the landing site at the time of recovery. Weather prediction services will be used to monitor weather conditions.

Figure 6.10 describes the infrastructure needed for restricted missions. The five main components are once again: location and landing site equipment, a temporary/landing site cleanroom (as discussed previously this can be optional), transport equipment and scientific equipment necessary for use at the landing site. Explanations or rationale for each type of equipment is given in Table 6.5.

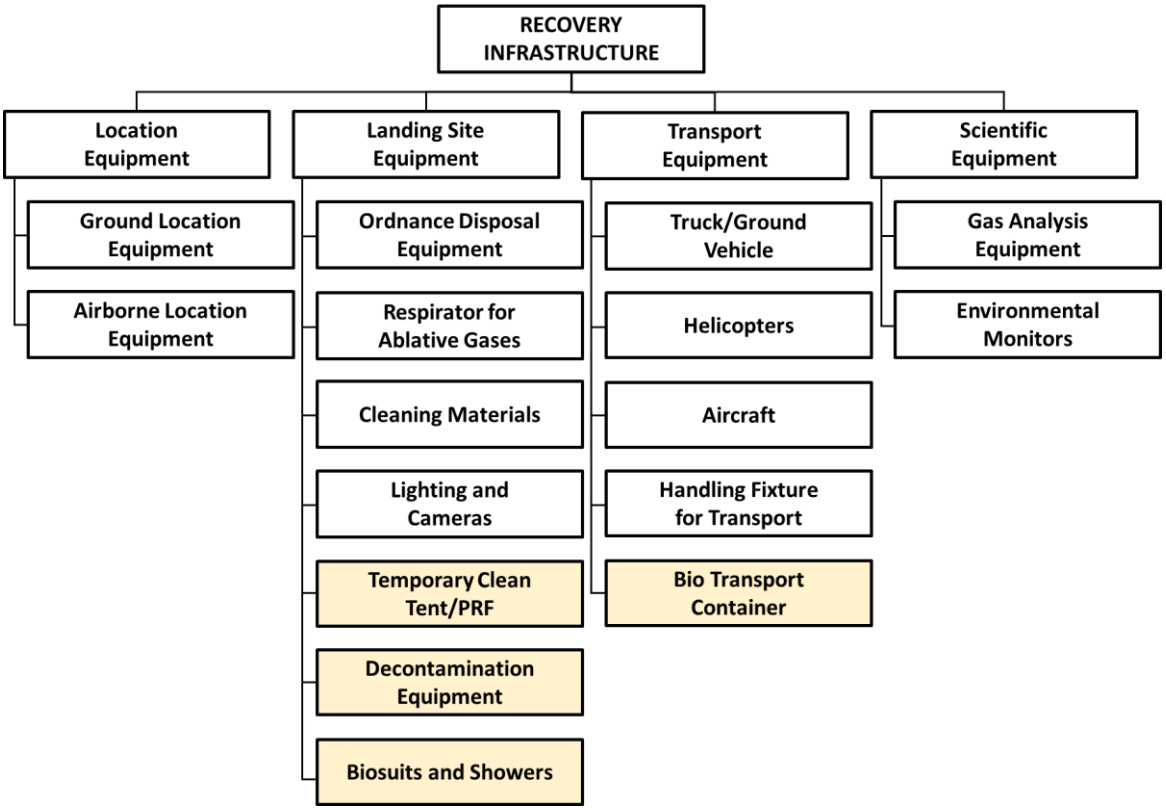


Figure 6.10 - Product Breakdown structure of the infrastructure needed for restricted missions

Table 6.5 - Rationale for additional equipment needed for restricted mission

Landing Site Equipment	
Temporary Clean Tent	A temporary clean-tent can be set up at the landing site while preliminary examination of the capsule is carried out and checks are made to verify the integrity of the capsules seal. This can be mounted over the landing point and can minimise any potential airborne dispersal of contamination or from precipitation /animals over the site. It will also allow for environmental sampling of the landing site.
Decontamination Equipment	Biocides will be used on the outside of the capsule to de-contaminate it and reduce the risk of possible hazardous extra-terrestrial substances affecting the Earth's environment. Cleaning methods suitable for organic contamination such as CO2 snow blasting may be used for gross cleaning.
Biosuits and Showers	All recovery personnel to use an appropriate level of biological contamination protection.
Transport Equipment	
Bio Transport Container	A bio transport container will be used to transport the bio container holding the samples. Each surface within this container will have a designated contamination

6.6 Temporary Cleanroom

A temporary cleanroom is a cleanroom which is installed inside another building (typically a military building on the site of a test range or landing site) to provide a clean area for various operations to be carried out on the landed capsule. Modular cleanrooms can be installed for a short time and can use power from the existing building to power the fans/lighting/equipment.

6.6.1 Previous Experiences

Genesis, Stardust and Hayabusa have all used portable receiving facilities, a temporary cleanroom facility near to the landing site to disassemble the capsule and prepare it for shipment to a sample return facility. Such tasks have included:

- Safe pyros;
- Disconnect batteries;
- Removal of electronics;
- Disconnect power-sharing circuit to beacon (Hayabusa);
- Back shell removed from heat shield;
- Opening of sample return capsule to extract canister (Stardust);
- Cleaning of canister (Stardust);
- Placing canister and spacecraft hardware in containers (Stardust and Hayabusa);
- Security (Hayabusa).

For Stardust, a temporary cleanroom was set up in a hangar 30 km from the centre of the landing ellipse at UTTR, 2 weeks before the capsule return (Zolensky et al, 2008). After recovery, the capsule was placed into a polyethylene bag at the landing site which was then removed an hour later in the cleanroom. Outgassing products from this bag were later detected in the aerogel. The capsule was then opened in the cleanroom and sample canister removed and placed in a container purged with grade G nitrogen gas and transported to JSC. It is not possible to fly a purged container on a commercial flight and therefore a C-130 military cargo aircraft was used. The container was transferred to a vehicle followed by a police escort to the sample return facility at JSC.

The Hayabusa mission used a similar method where the sample was double sealed in the transportation box with N_2 purged gas to avoid terrestrial contamination. The temperature and humidity were also monitored throughout the transportation of the Hayabusa sample as well as putting contamination coupons into the transportation box to monitor contamination with terrestrial materials. After the Hayabusa landing and recovery, the capsule was packed into a double layer of plastic bags filled with pure nitrogen gas and then inside an initial/temporary transportation box. The recovery capsule was then transported to the WPA Instrument Building where the recovery team and Quick Look Facility (QLF) were installed. One day was spent de-arming the explosive devices and the battery in the capsule. The next day was spent on the removal of contaminants adhering to the capsule and the packing the capsule into another clean transportation box for internal transport. For Stardust, the heatshield, backshell and sample containers each had a specially designed box for transportation to the Sample return facility at JSC. The surface cleaning of the capsule and packing operation were both executed in the temporary cleanroom at the QLF installed in the building (Abe et al, 2011).

In addition to what has been done for previous missions, existing ‘portable laboratories’ are also employed in other science fields. Mobile biocontainment facilities are used by public health organisations for disease outbreaks, environmental accidents and counter-terrorism. A team who set up an on-site portable laboratory for a Marburg virus outbreak in Angola reported that the greatest challenge was the lack of consistent electrical power, this necessitated portable generators and battery backup systems for thermocyclers and the storage of samples at freezing temperatures was not possible (Grolla and Jones, 2011). These portable laboratories were thought to be useful for adaptation when recovering Restricted Category V capsules (this has been discussed in EURO-CARES deliverable D6.1 and will be covered in more detail in EURO-CARES deliverable D6.4).

6.6.2 Use of a Temporary Cleanroom

Table 6. summarises the pros and cons of providing a temporary cleanroom at the landing site. The table is applicable to all unrestricted missions. Further discussion is needed for a restricted mission, where the need for biocontainment means that a temporary cleanroom is unsuitable and the sample capsule should be transported directly to the sample return facility.

Table 6.6 - Advantages and disadvantages of a PRF in an unrestricted mission

	Portable Receiving Facility	**Fly Directly to ESCF**
PROS	Flexibility if situation is non-nominal Provide security for capsule. Possible to clean outside of capsule Collect parts of spacecraft if damaged (e.g. Genesis) Possible to remove canister from return capsule in clean environment Possible to safe spacecraft by disconnecting pyrotechnics, batteries, avionics in a clean environment	Quick Low cost No possibility of further contamination by new agents Safing and cleaning might be done at the landing site
CONS	Cost of cleanroom Pre-planning necessary Presence of cleanroom undesirable for military Not suitable for restricted missions	Nitrogen purge needs to be installed as soon as possible if non-nominal, it may not be possible to accommodate all scenarios by operations at landing site

Overall, it is apparent that there are many benefits to having a PRF, particularly for non-nominal scenarios, and few disadvantages. If the budget is available and the space can be made free in a building in or near the landing site, then the recommendation would be to provide such a facility, but note that it is not necessary for restricted missions.

6.7 Sample Transportation to ESCF

6.7.1 State of the Art

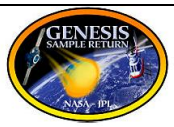
This work considered containers and transportation boxes of various size and shapes, from the Apollo Missions up to Hayabusa1 Mission (Figure 6.11 to 6.13). A list of completed and planned SRM's is shown in Table 6.7, with landing sites, means of transport used to move the sample from the landing site to a Temporary Clean Room (TCR) (if present), the transportation box and any contamination at the landing site (from impact with the ground or from the environment).

Figure 6.11 - 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 the Woomera Prohibited Area.

Figure 6.12 - Left: The Stardust capsule where it landed at the UTTR; Right: the Stardust capsule wrapped in double plastic bags and transported to the PRF by the recovery team

Figure 6.13 -Left and centre: the transportation boxes used for the Hayabusa 1. The N_2 valve 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 2nd May 2014).

Table 6.7 - 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

SRM	Landing Site	Mean of transport	TCR	Transportation Box	Contam.	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	Yes	Particles
 STARDUST (NASA)	UTTR Area (USA)	Helicopter	Yes	Special- designed containers	No	Particles
 HAYABUSA-1 (JAXA)	WPA (AUS)	Helicopter	Yes	Designed transportation box	No	Particles
 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)

6.7.2 Regulatory Issues

This section will focus on the regulatory issues concerning the packaging and transport of extraterrestrial samples, either potentially hazardous or not. The regulations described here are based on the World Health Organization (WHO) directives about the transport of hazardous/infectious samples. 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. According to World Health Organisation regulations, the system of packaging hazardous samples must be based on three layers of packaging:

Primary receptacle. This is the inner layer that contains the sample material. It must be watertight and leak-proof and contain the samples. Moreover, it should be encapsulated with enough absorbent material to absorb all the fluid in case of leakage and/or breakage of the receptacle. The primary receptacle should 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. This packaging can also contain more primary receptacles (i.e. one for each suite of samples): in this instant more absorbant material is required to match the liquid that could be in the sample containers. Contact between primary receptacles should be avoided by including enough cushioned material: this is mandatory if primary is made of fragile materials.

Outer package. The external layer is required to be rigid and sufficiently cushioned to withstand an impact. It can consist of a drum or a box. 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 a temperature range from -55°C to 40°C.

6.7.3 BioContainer for Transport

It is conceivable that such a specialist transport facility might be implemented in the recovery of a Mars Sample Return mission (or other), where a power plant is used to control and condition the internal container environment and any associated monitoring equipment. One half of the container (perhaps reinforced to provide enhanced impact resistance) may be used to accommodate an active/passive vibration isolation fixture for the transport box and the second half for basic laboratory/environmental monitoring. A basic configuration is proposed in Figure 6.14 where access is provided at one end for the SRC containment shipping box and a sealing plate that is bolted to a welded frame on the inside of the container walls. Double elastomer seals provide another layer of isolation where the shipping box section could be maintained clean (by the plant) with a closed circuit HEPA filtered nitrogen gas circulation system. Double lining in that section may be implemented to provide additional thermal isolation or external fire retardation. Accelerometers on the vibration isolation fixture should be logged along with other housekeeping sensors like relative humidity, oxygen content and temperature.

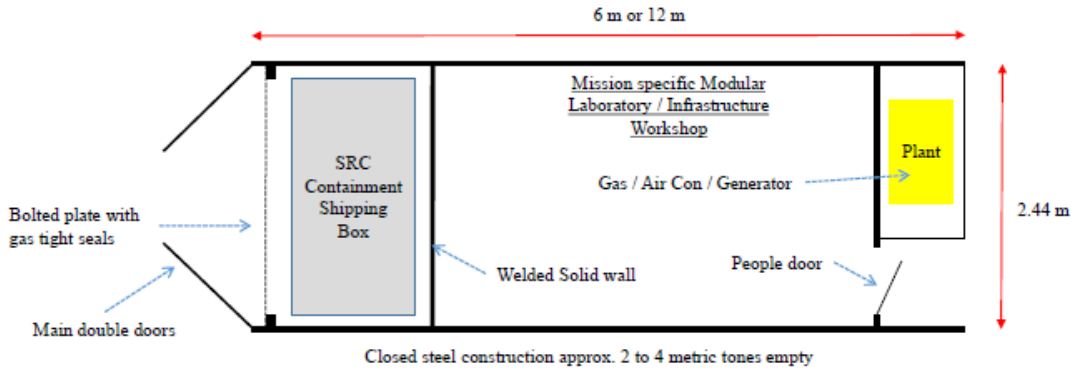


Figure 6.14 - Proposed ISO container

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). For restricted missions, the requirement would be stricter and hence the (at least) triple packaging required by WHO guidelines must be applied.

The following section will outline a basic design for the transportation boxes for unrestricted and restricted samples. Each design considers a non-nominal scenario (i.e., ERC damage). The ERC can be classified as:

- Small, mass < 20 kg;
- Medium, mass between 20 kg and 50 kg;
- Large, mass between 50 kg and 100 kg .

6.7.3.1 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.

If the SRC is broken (non-nominal scenario) and hence samples are at risk of exposure, 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 have:

- A pressure sensor with regulator (to ensure constant atmospheric pressure);
- A temperature sensor (to monitor the possible temperature variations induced from external environment);
- An entrance for gaseous N_2 for a controlled atmospheric environment.

The mechanical design comprises:

- An insulated internal wall;
- Cushioned internal walls, to avoid internal collisions or shifting;
- External walls to withstand collisions;
- Four wheels, to simplify the outer movement (TBD);
- Interfaces such as attachment/lifting points to pallets, trolleys, trucks and dollys, to move the box
- Mechanical supports (e.g. pads) in order to avoid mechanical stress.

The outer configuration (Figure 6.15) is a single section with several pads to limit mechanical stress, an inert gas entrance (blue), a gate valve for inert gas removal (black) during the analysis procedure, micro-connectors for external temperature monitoring (light blue) and pressure monitoring (green). Some pads (light yellow) 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.

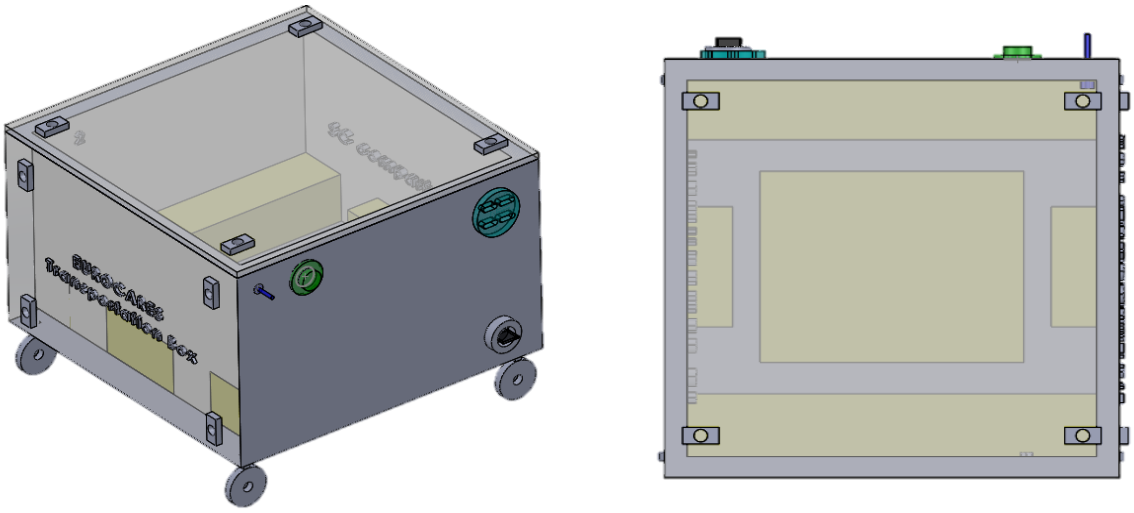


Figure 6.15 - Left. Outer package configuration. The four valves on the lateral wall are devoted to inert gas (nitrogen or argon) entry (grey), pressure monitoring (green), temperature monitor (light blue) and pressure control (black). Right. Top view, the internal pads (light yellow) are shown

A view of the schematic structure of the transportation box for unrestricted samples is shown in Figure 6.16.

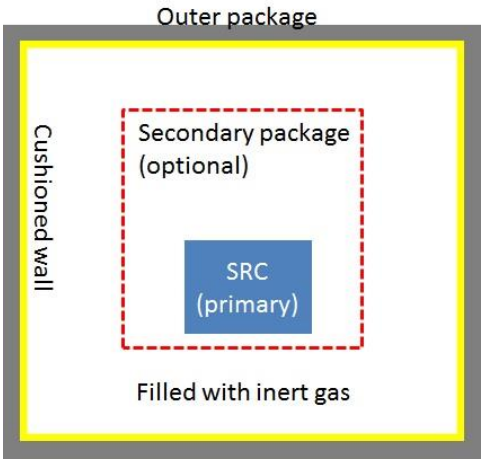


Figure 6.16 - Schematic view of transportation box structure for unrestricted mission. The primary (SRC) is enclosed in the outer package (metallic alloy), having cushioned walls and filled with nitrogen, argon or helium). The secondary package (plastic bag) may be needed only in a non-nominal scenario and only if the plastic material has an outgassing rate lower than the metallic alloy

6.7.3.2 Restricted Return

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. The outer characteristics are the same as unrestricted case and will be not repeated here. But pressure regimes become important in the restricted case.

The outer is then enclosed in an ISO container (overpackaging), which also contains instrumentation for contamination and environmental control inside the outer, as well as to accelerometers to measure the box motion.

The ISO container used in restricted scenario would include the following characteristics:

- mechanical stops to fix the outer wheels on the container surface
- an insulated material between the internal and external walls to isolate the internal environment

The configuration and schematic view of the transportation box for restricted samples are shown in Figure 6.17 and Figure 6.18, respectively.

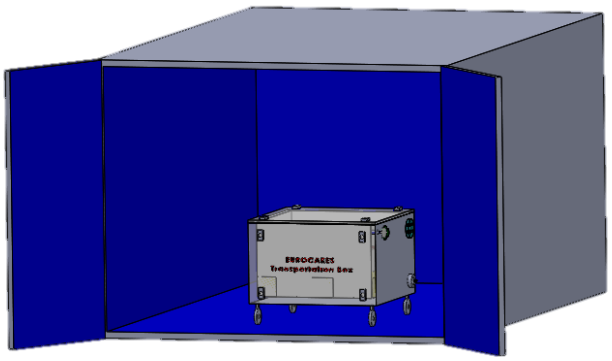


Figure 6.17 - Configuration of the transportation box outer (grey) enclosed in the ISO container (blue) for restricted missions

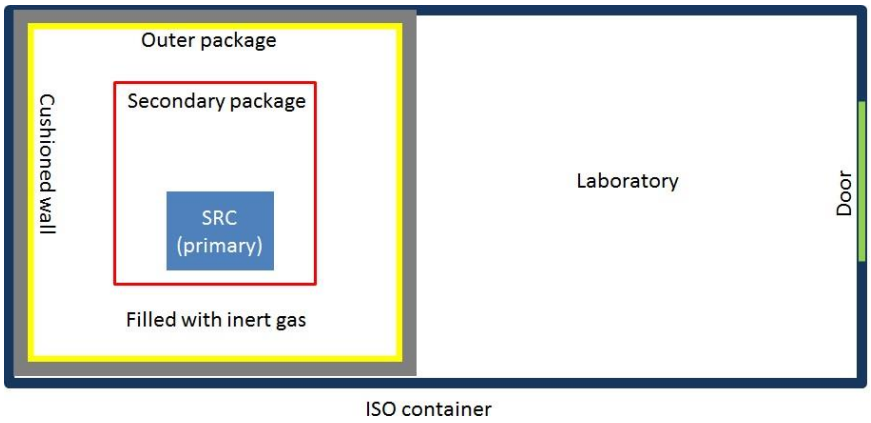


Figure 6.18 - Schematic view of transportation box structure for restricted mission. The primary (SRC) is enclosed in a secondary package (plastic bag), in turn enclosed in the outer package (metallic alloy), having cushioned walls and filled with an inert gas (preferably nitrogen). The ISO container includes both the triple package and instrumentation for controlling contamination, environment and motion

6.7.4 Labelling and Documentation

The secondary package should be labelled with a specimen record, including an itemized list of contents. The outer package and the possible overpackaging should 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 of hazard;
- 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.

The documentation related to transported packages include:

- A Declaration for Dangerous Goods - 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 contents should be located between the secondary and the outer package.

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 6.8.

Table 6.8 - Labelling marks according to the WHO guidelines (first column) and proposed adaptation to Sample Return Missions (second column), with relative examples (third column)

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	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, Caloris Planitia, 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

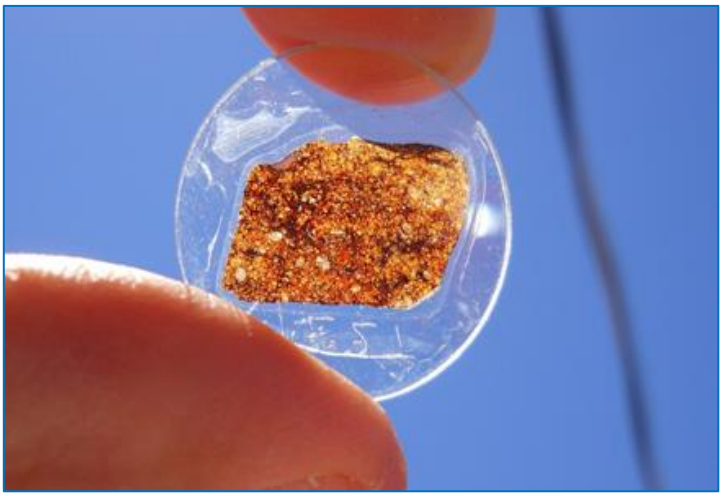
6.8 Conclusions

Chapter 6 has covered methods for the recovery and transport of Mars, Lunar and asteroid samples from a sample return landing site to a permanent curatorial facility. ERC landing strategies were described first, followed by a review of previous sample return recoveries for the Genesis, Stardust, Hayabusa-1 and Apollo missions, with input from experts involved in the recoveries. Lessons learned were extracted from the past missions; plans for the future recovery of OSIRIS-REx were also considered. Landing sites examined in detail included UTTR, White Sands and Wallops in the US, Woomera in Australia, Kazahkstan, and Esrange in Sweden. Comparison of the sites concluded that whilst US missions may favour UTTR, because of its use in previous missions, the Esrange Space Centre in Sweden is a viable alternative with the potential to provide

Europe with a recovery option to support future CAT V missions, like Mars Sample Return. It is therefore recommended that this European capability is explored, and expertise developed further, as sample return mission architectures are refined.

The most recent information on current designs for Mars Sample Return missions has also been collected and presented. Preparation for recovery has looked at Mars sample sizes, masses and forms, i.e., rock, regolith, ice, brine and gas. Issues covered have been integrity of the seal on the collection chamber, chamber integrity monitoring and special measures for biohazards. Ground recovery of intact and non-intact samples and the possibility of a temporary cleanroom were discussed. To deliver the samples safely, it is necessary to prevent them from coming in to contact with terrestrial contaminants during transportation. A packaging container suitable to transport the ERC from landing site to SCF has been discussed, together with a discussion of customs and regulations, security, labelling and documentation for transport.

7. IMMEDIATE ACTIVITIES



7 IMMEDIATE ACTIVITIES

7.1 Refining of the Analogue Collection

The main activities based on the use of analogue samples will take place from the beginning of mission planning to well before ERC landing to ensure that the ESCF is ready to work on the extraterrestrial samples (see chapter 4). As a sample return mission becomes increasingly defined, the science team can make recommendations regarding appropriate analogues, reference samples, and standards to be used in the curation facility. The analogue collections are likely to be continually refined and augmented.

By the time the ERC lands, the curation facility should be ready to work on the extra-terrestrial samples. All aspects of planetary protection must have been addressed, and contamination assessment and control plans in place. Sample handling procedures would have been tested and protocols for sample handling, storage and preparation techniques established. Instrumentation within the facility should be in place and fully-commissioned with the requisite standard and calibration materials available. There should be a full staff complement of trained workers conversant with the work flow protocols.

After first examination of the returned sample, the library of analogue materials should be checked to ensure that appropriate analogues are on hand and evaluated. It may become important from a curation and/or science point of view to select natural or manufactured analogues exhibiting physical/chemical properties more relevant to the actual samples. Following on from this, it may become necessary to re-optimise the predefined procedures and handling protocols. Expand the list of analogue samples will also increase the amount of storage space required for the analogues.

7.2 Sample Preparation

The primary function of the sample curation facility is to preserve returned samples in a pristine condition, and a second high-priority function is to provide samples to the scientific community. Critical steps are thus to provide a detailed catalogue of the samples and sub-samples of specific samples with minimum loss and modification.

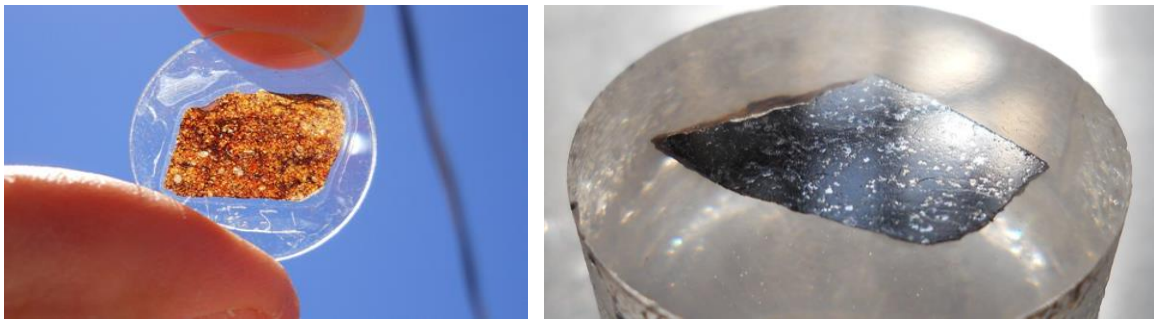


Figure 7.1 – Left: Polished thin section of a meteorite. Polished wafers of samples (typically 30 µm thick) are glued to glass disks. Right: Polished block of meteorite. A sample of material is mounted in a resin block, which is then ground and polished on one surface. The prepared surfaces have a high quality finish that is necessary for a wide range of microscopy and analytical techniques. Images courtesy of Wooddell

Cataloguing involves building a database that allows for the identification and record of each sub-sample that includes basic information such as written description, photo-documentation (potentially at multiple scales and in 3D) and sample mass. Cataloguing cannot be separated from the sample preparation, as every step of sample modification requires documentation and recording for identification and verification of the most appropriate samples to meet the requirements of approved sample requests. If specific sample preparation is required (e.g., polished sections (Figure 7.1), microtome section), it is important to document the sample

before, during and after any modification. The instrumentation required for documentation and cataloguing are summarized in Table 7.1.

Table 7.1 - Instruments for Cataloguing/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)

Dedicated laboratories are required to support the operation of the instrumentation involved in sample processing and characterisation.

If a large collection of rock samples is collected, a dedicated sample prep lab will be required for preparation of polished thin sections and polished blocks. An extensive suite of tools and facilities are required (Table 7.2). Thin section preparation is a process that creates large quantities of dust, so careful consideration of where this activity is located relative to other areas of the ESCF is required. Care must also be taken in designing the layout of the preparation area and during its use, to eliminate cross contamination of samples. In a facility with multiple collections, separate sample preparation laboratories may be more appropriate.

The location of the sample preparation area should be outside any cleanroom environment because of the potential for dust to be generated. This is particularly sensible when applied to large samples. However, when sample mass is very limited and/or particles are very small (e.g. Stardust, Hayabusa) then sample preparation in clean environments is more important, and because of the reduced sample mass being processed, more viable. In such a scenario, specialist high-precision sample preparation equipment such as the Leica EM TXP Target Surfacing System for cutting, grinding and polishing could be installed in individual, clean glove boxes.

Table 7.2 - Instruments/Equipment for Sample Preparation

Instrument	Comments
Sputter coaters	C and noble metal for SEM
Microtome	Primarily for small sample sizes
Ion Micromills	Primarily for small sample sizes
Micromanipulators	Electro-static tips, micro-tweezers for diff sizes
Integrated prep 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 PTS

By their very nature, each of these instruments/tools creates debris that is incompatible with operation in the cleanest environments that the samples are exposed to. Dedicated clean areas optimised for these systems are required to minimize avoidable contamination (some contamination and/or modification is unavoidable). Fully integrated systems exist which provide end-to-end advanced sample preparation (e.g. Leica EM TXP; Figure 7.2) that are ideally suited to preparation of small, precious samples with remote/semi-autonomous operation and therefore compatible with clean bench operation. Further development to integrate with existing instrument transfer systems would ensure that a comprehensive integrated sample transfer system could provide protected preparation, transfer and analysis of all samples.

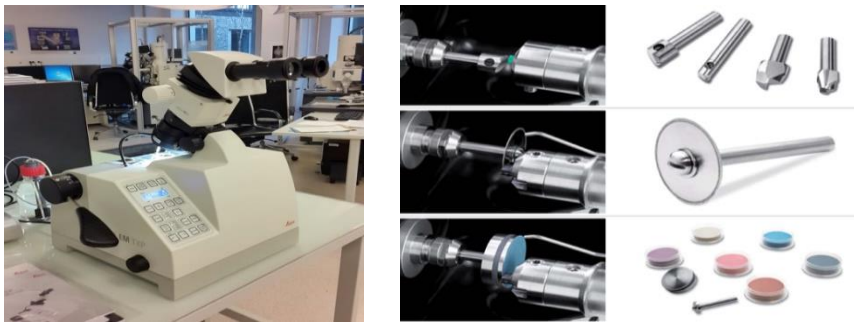


Figure 7.2 - Left: Leica EM TXP sample preparation system for polished mounts. Right: tools used for milling, cutting and polishing

7.3 Sample Manipulation

7.3.1 Micro-Manipulation

Sample handling and manipulation systems will have to be capable of handling samples of different shapes and sizes and personnel operating those systems will have to be trained to deal with different types of material. The use of analogue materials will be very helpful because technologies/equipment can be tested prior to being validated for use in the facility and personnel can also be trained using these materials. During sample handling and manipulation there will be close collaboration between the curation personnel who will be carrying out these operations and the scientists that will participate in the Preliminary Examination. Sample handling and preparation will be a regular occurrence (happening on a daily basis) during the Preliminary Examination phase and shortly after as the samples will be of great interest to the scientific community. However, over time it is anticipated that the requests for new samples will gradually diminish with the reuse of samples that have already been prepared for earlier investigations e.g. polished sections of samples. It will be important that the skills honed by personnel during the early stages are maintained and also passed onto new personnel through time. This could also be achieved through regular training on analogue samples.

Manipulation without physical contact reduces contamination of samples as low as possible and protects the workers for restricted return samples. Table .3 shows a few possibilities for contactless manipulation.

Table 7.3 - Techniques of contactless manipulation

Technique	Notes	Ref	Pro	Cons
Optical tweezers	Atomic scale up to 100 µm	S.K. Joshi, WP3 workshop	No direct contact, no opening container	Not good with metal Heating of the particle
Tractor beams	Objects up to mm	S.K. Joshi, WP3 workshop	No heating	Needs dense atmosphere
Optical levitation	Objects up to kg	S.K. Joshi, WP3 workshop		Unstable, needs high energy
Electrostatic forces	Hayabusa samples	JAXA SCF		

7.3.2 Robotics and Humans

In deliverable D3.3, an extended discussion on the advantages and disadvantages of robots compared to humans was presented together with the possible improvement of the functional requirements of the ESCF robots may allow. From our previous discussion it was clear that it will not be robots or humans but robots and humans. The idea is to use robots (including automatic tools, robotic manipulation, artificial intelligence) to conduct the repetitive and fine manipulation tasks. For example, a robotic manipulation would sort and catalogue small particles/grains, especially in the case of regolith samples (this technology already exists, Micro Support Co. microsupport.co.jp/en/).

The following information presented was obtained from meetings and discussions with several robotics experts, high-containment experts, curators of collections and a variety of colleagues from different fields and expertise. Information extracted from the WP3 Workshop, from previous EURO-CARES deliverables and publications, as well as from unpublished reports were also used.

We first identified all the main tasks that could possibly be undertaken in the case of unrestricted samples using robots and robotic systems in the facility. These tasks are also to be conducted with the restricted samples. A questionnaire was prepared and circulated to experts on the use of robotics in scientific facilities, follow up discussion were held with the experts. The results from the survey and discussions are summarised below.

This section will not define which areas will have robotics in the ESCF, but to evaluate what procedures can be undertaken (or not) with robotics and how this can be completed. However, it should be noted that the use of robots and/or humans will have direct implications on the design of the facility and, thus, their usage should be discussed as early as possible in the planning and design process.

In total, we have identified five main tasks and applications for which the use of robotic systems would be appropriate:

- Opening of the sample container;
- Extraction of the sample(s) from the container;
- (Micro-)Manipulation of the sample(s);
- Transfer of the sample in the scientific instrument (for SEC/PE);
- Re-packaging and transfer of the samples to the storage room.

Some of these tasks are highly dependent on several factors and parameters that were unknown or not defined at the time this report was compiled, e.g. sample material, size of samples, etc. In some cases, the applicability of the use of a robot can be greatly affected by these factors and parameters. For example, for the (micro-) manipulation of the samples, without previous knowledge of their size how diverse and non-homogeneous they will be, their properties, etc. it is difficult to define how suitable robotic systems will be.

7.3.2.1 Different Types of Robots and their Suitability for Different Tasks

We have distinguished three different types of robot:

- Fully autonomous robot (i.e. capable of self-adaptation to the situation);
- Autonomous robot programmed for a specific task (object and path planned in advance or at the time of carrying out the operation, based on the specificity of the task to be conducted);
- Tele-operated robot (i.e. remotely controlled by a human operator) and cobots (collaborative robots).

Table 7.4 summarizes the suitability of the different types of robots for undertaking different tasks.

From the results of our survey, it appears that the most difficult task to be conducted by robots is the (micro) manipulation of samples due to the number of uncertainties on the nature, size (range and homogeneity), properties, etc. of the samples to be manipulated. However, the use of cobots is currently likely to be the best available solution. It involves direct physical interaction between a human and the machine, 'hand in hand'. An example can be seen at www.percipio-robotics.com/index.php/en/ and new developments are very encouraging (Lu, 2016).

The transfer of the sample in the scientific instrument for SEC/PE (if the samples are fixed/mounted on a specific holder) was felt to be a task that would be suitable for robots as would be the opening of the sample container and the transfer of the samples to the storage room. In the case of the transfer of the samples to the storage room, an automated storage and retrieval system (ASRS) was thought to be the best solution. ASRS are commonly used in many industrial sectors such as pharmaceuticals (e.g. BoxPicker™ Automated Pharmacy Storage System), warehousing and libraries, etc. (Figure .3). The advantages in using such a system are numerous, including accuracy (tracks permanently the position of the samples and records all the movements and eliminates human errors), security (as humans do not have access to the storage area), possibility of working in extreme environments (such as at cold temperatures and gases), time saving and allows efficient use of storage space.

Table 7.4- Suitability of the different types of robots to operate different types of tasks (based on a questionnaire). '0' in case the robot is 'not suitable', '1' in case it is 'quite suitable' (or suitable under specific conditions), and '2' in case it is 'suitable'. It is to be noted that in some cases, specific conditions can drastically change the suitability of one type of robot; in such a case some text is added

Task	Fully autonomous robot	Autonomous robot programmed for a specific task	Teleoperated robot and Cobot
Opening of the sample container	2	1-2	0 (or 1 in case it does not go as planned)
Extraction of the sample(s) from the container	0	0	1
(Micro)-manipulation of the sample(s)	0	0	1-2
Transfer of the sample in the scientific instrument	0-2 (0 in case the sample is not fixed on/in a specific holder)	0-2 (0 in case the sample is not fixed on/in a specific holder)	1-2
Transfer of the samples to the storage room	2 (automated storage and retrieval system)	1 if automated system and retrieval system not used)	0

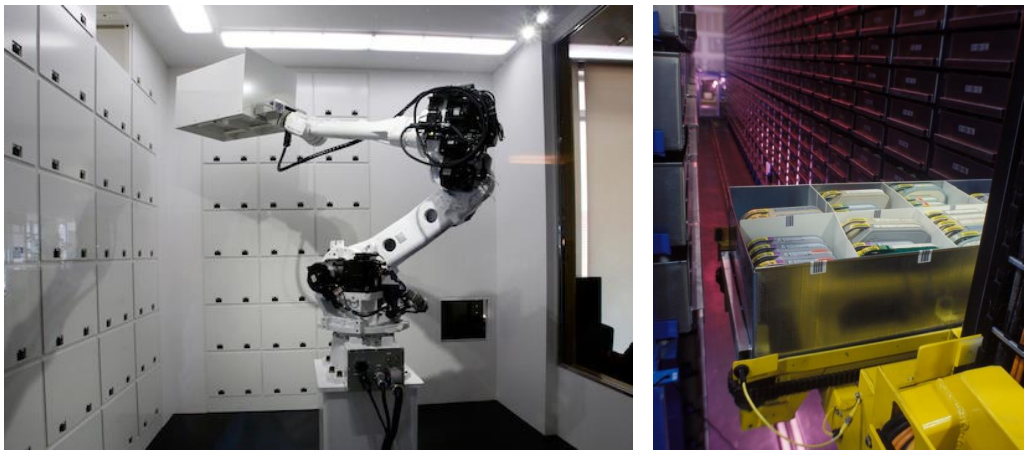


Figure 7.3 - Examples of automated storage and retrieval systems (sources: left, Public domain; right, Wikimedia commons).

7.3.2.2 Challenges and Solutions

Robots and robotic systems would need to operate in a clean environment without shedding of particles from motors or joints. At present there are robots working in cleanrooms that were developed specifically to

meet the requirements of clean environments (typically used by semiconductor companies; Mathia, 2010), such as:

- https://www.robots.com/applications/cleanroom
- http://www.staubli.com/en/robotics/6-axis-scara-industrial-robot/specialized-robot/cleanroom-semiconductor-robot/
- http://www.kuka-robotics.com/taiwan/en/products/industrial_robots/special/clean_room_robots/

In most of these cases, appropriate coatings have been developed to encase robots for working in clean environments. These coating materials can contain any leakage and be decontaminated. However, these coating materials were developed to limit particulate contamination but not molecular contamination. Certain coatings and lubricants may off-gas and produce molecular contamination with the sample environment. Cleaning can also be challenging (Saito et al., 2017) and more research is needed to provide an adequate system. To summarize, some solutions to adapt robots to the work environment inside the ESCF already exist but still an assessment on whether they are inorganically and/or organically clean enough needs to be conducted. Cleaning protocols would also need to be defined and assessed but again this would depend on the location of the robot and the process it is required to complete.

In recent years, alternative (lighter) materials have been developed for the construction of robots (i.e. robots are generally constructed with aluminium, steel or titanium) including different types of composite materials and plastics. As the joints and motors are the main sources of contamination (i.e. friction creates particle contamination, lubrication used off gases), one solution is to keep them partially outside of the working environment. The use of non-conventional robots may also be a solution, such as 'soft robots' (i.e. robots characterised by non-conventional structures, constructed with soft and deformable materials like silicone, rubber, plastic, etc.). In general, soft robots are continuous deformable structures that do not have joints and have no motors on board. Such robots have several advantages over traditional rigid robots. Their deformable structures allow them to adapt to the environment; this could allow for example grasping and manipulation of samples with unknown/undefined properties (such as size or even consistency). However, they may be less suitable for high precision tasks. Shen (2016) discusses that most soft robots are currently only at the prototype stage, but future developments should be highly considered for use in the ESCF. A good example of a recent and successful development is STIFF-FLOP (STIFFness controllable Flexible and Learn-able Manipulator for surgical OPerations; www.stiff-flop.eu/index.php/en/). More information on soft robots can be found here: http://softrobotics.org/.

Apart from the contamination risk from moving parts and lubricants, one of the issues of the robot is the gripper. Research is needed to develop suitable grippers for both efficiency and of non-contamination (knowing that this task is complicated to some extent by the unknown nature of the samples and their properties). Currently, several different physical effects are used to guarantee a stable grasp between a gripper and the object. There are four general categories of robot gripper (Monkman et al., 2007), namely:

- Impactive (such as jaws or claws; physical grasping of the sample, not very suitable in the case of small samples);
- Ingressive (such as needles or pins; physically penetrates a sample, not suitable in our case);
- Astrictive (suction forces are applied to the sample surface; whether by vacuum, magneto- or electroadhesion);
- Contigutive (requires direct contact for adhesion to take place; use of a glue, surface tension or freezing).

The purpose of this report is not to review all different types of robot grippers, this is something that would need to be completed during the design and planning phases of the ESCF.

7.3.2.3 Current Usage of Robotics in Curation Facilities

Currently robotic systems are not generally used at the NASA Johnson Space Centre curation facility in Houston (USA) with the exception of a semi-automated micro-manipulator which is used for picking small cosmic dust grains (it is currently not done in a cabinet environment but rather on a laminar flow bench). However, for Mars 2020, the plan is to drill onsite rock samples to make them conform to shape and size to be handled robotically. Past experiences of the use of robotics is limited to very few experiments such as the use of a robotic manipulator (i.e. a small robotic arm) in an advanced curation glove box (Bell et al., 2013).

At the Planetary Material Sample Curation Facility (PMSCF) of the Japan Aerospace Exploration Agency (JAXA) in Sagamihara (Japan), micromanipulators are used for handling very small particles. They consist of a specially designed electrostatically controlled micromanipulation system which is operating in an ultra-pure nitrogen environment (Yada et al., 2014). The group also constructed an electrostatically controlled micromanipulation system composed of commercial based instruments which could be used both in a clean booth of an electron microscope room and also in a glove box filled with nitrogen. Theoretical information on electrostatic particle manipulation has previously been documented by Saito et al. (2007).

7.3.2.4 Robots Needed

Containment and cleanliness are required for successful curation of restricted samples. Three possible methods to simultaneously maintain both requirements were presented in a Space Studies Board report (2002) and in Rummel et al. (2002) (Figure 7.4).

Knowing that conventional isolators are prone to leakage and that both principles, of 'protecting the outside from the inside' using negative pressure and 'protecting the inside from the outside' using positive pressure are not usually used together in one place, two main solutions (that we are aware of) are presented, a 'double-walled glovebox' (Beaty et al., 2009; 'FLAD team project') and a DWI system (e.g. Vrublevskis et al., 2016).

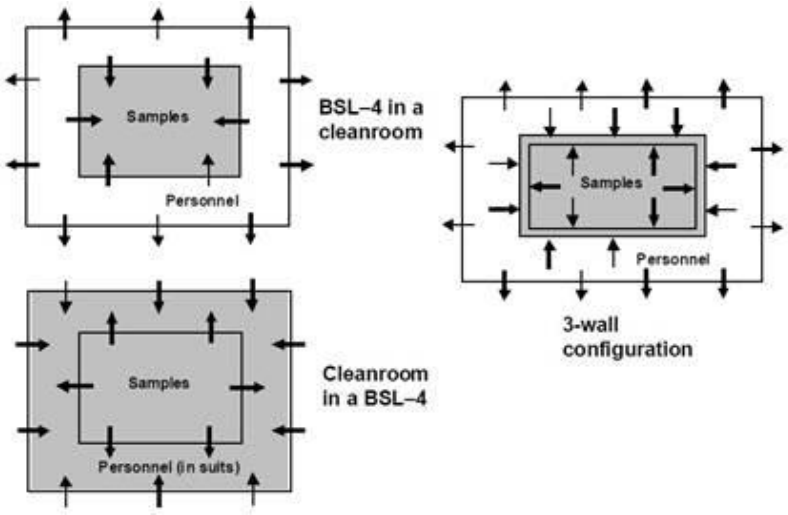


Figure 7.4 - Different options to simultaneously maintain both containment and cleanliness (modified from Space Studies Board, 2002). Arrows show gas flow (via leakage) caused by pressure differentials in the spaces shown

The 'double-walled glovebox' consists of a glovebox linked to a double-walled Class III Biological Safety Cabinet with reduced pressure between the walls (Figure). In Beaty et al. (2009) it is presented as a concept with more work to be conducted before validation. Recently, in 2016, a somewhat more detailed concept was presented by J.S. Ellis, all the details can be seen on pages 27 to 31 of the presentation that was given in the framework of the WP3 meeting by Ellis, see here:

http://www.euro-cares.eu/files/WP3_Vienna/Presentations/Ellis_EUROCARES_WP3_2016_PRESENTATION.pdf.

Even though this concept is interesting, it is not only very challenging, but the gloves cannot always guarantee the 'double walls' principle (i.e. the biocontainment requirements are not adhered) and contamination issues due to the use of gloves would have to be seriously considered.

The DWI system is based on the principle that containment and cleanliness is maintained by the pressure regime, using filtered dry inert gas (Figure 7.5, 7.6). With this 'box within box' principle, the only way samples can be handled is with remote manipulation and thus the use of robotic systems is mandatory. For this reason, the DWI must be capable of housing a robotic manipulation system (see previous section on the different types of robotic systems that were suggested for unrestricted samples and associated discussion) and interfacing with a range of analytical instrumentation. Interfaces need to be available to pass the samples into and out of the isolator. The DWI system does not require high airflows, which is important especially in case of fragile, dust (like), samples that would possibly be manipulated within this system (i.e. we do not want (parts of) the sample to end-up in the HEPA filters).

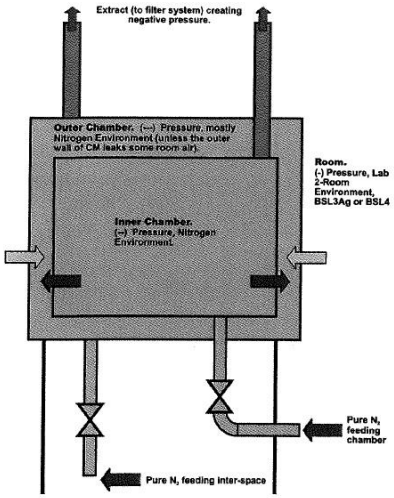


Figure 7.5 - Conceptual double-walled Class III Biological Safety Cabinet (Beaty et al., 2009)

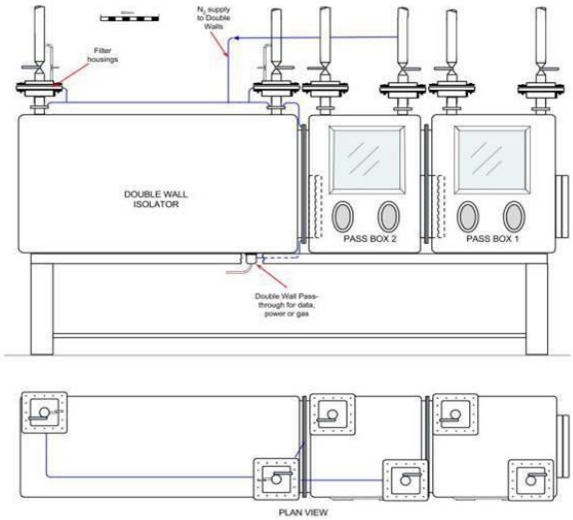


Figure 7.6 - DWI preliminary concept design from Vrublevskis et al. (2016). More details can be seen in the presentation that was given in the framework of the WP3 meeting by Vrublevskis et al., see here: http://euro-cares.eu/files/WP3_Vienna/Presentations/Vrublevskis_EUROCARES_WP3_2016_WIsystems_PRESENTATION.pdf

Research work is currently in progress on this type of DWI system but for the moment it seems to be the only viable method that can be used for most of the SEC and PE. For further examination, later stage of LD and

BAP, where cleanliness of the samples is not so much an issue, a MS3 cabinet commonly used in BSL-4 could then be used.

7.3.2.5 Current Use of Robotics in Contained Environment

The use of robotic systems to handle pathogenic agents has been proposed as a way to increase the safety of BSL-4 facilities by reducing potential operator exposure. Robotic systems are widely used in microbiology laboratories (for diagnostic procedures) and in biotechnology/pharmaceuticals (for high throughput screening of antimicrobial compounds). However, because of high capital costs and economics they are only used when the sample throughput is very high. Because of the low incidence of highly pathogenic agents within humans and the additional capital burden of containment measures, and knowing that the conducted work is rather individual, robotic systems have until now not been used to any extent at high containment. Nevertheless, robotic systems have been considered for use in BSL-4 facilities as it would allow to separate any operator from the process. In that respect, a system is being developed in a European laboratory in which antiviral compounds screening is carried out using a robotic process line within a metal isolator. This device is currently being evaluated at BSL-2 but has been designed to operate at BSL-4 if required. For use in high containment systems any robotic system will have to withstand liquid and gaseous disinfection to prevent cross contamination of samples and allow servicing and maintenance.

7.3.2.6 Use of Robotics in Clean and Contained Environment

A few studies on handling and (remote) (micro-)manipulation systems for restricted samples have been completed or are currently in progress, such as for example Stewart (2010), Nelson and Mani (2011), and Vrublevskis et al. (2016). However, on the basis of these studies, no physical system has so far been produced and tested.

Several studies on facilities to receive, contain and curate restricted samples, called for the use of robotics. An example is in Beaty et al. (2009) where robots are either used for the entire spectrum of tasks to be conducted within the SRF, such as for the preparation, analysis, transfer of the samples, etc. or for only a subset of these tasks. As already mentioned in the case of the unrestricted samples, the use of robotic systems has direct implications on the concept of the facility, and, thus, the extent of their usage, which is mandatory in the case of restricted samples, should be properly considered in the first steps of the concept design.

7.4 Sample Early Characterisation - Unrestricted Samples

In addition to the sample preparation and cataloguing described in Section 7.2, the SEC phase aims to provide sufficient characterisation of the samples to allow identification of the most appropriate ones for scientific requirements. This covers a wide range of measurements, addressing multiple aspects of the preliminary determination of the structure, mineralogy and organic inventory of the samples. The level of detail acquired is relatively limited as more detailed measurements of this type would be very time-consuming, requiring extensive interpretation and expertise. The expectation is that such activity would be undertaken by the scientific community on allocated samples during the Preliminary Examination (PE) period or during the extended long-term allocation phase. Characterisation activities in the curation facility should be conducted with little, or no, impact on the physical and chemical nature of the sample.

7.4.1 Instruments

The details of the cataloguing, characterisation, sample preparation and the most critical specific contamination types and levels are all mission-defined and unique to each mission or sample source, although for most large, rocky types of samples there is likely high levels of commonality. As such there is a broad suite of key instruments that can deliver all key documents, information and measurements. These instruments were identified and described in D4.2. Incorporating on-going visits to instrument manufacturers (see above), an updated version of the instrument requirements for an unrestricted sample curation facility

is summarised here. All the main instruments here (Table 7.5) are compatible with operation inside clean rooms or even inert gas clean glove boxes with either remote automated operation or through-wall operation.

Table 7.5- Instruments for Sample Characterisation

Instrument	**Comments**
FTIR microscope	Spectral imaging detectors for 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	Micron-scale selection of areas for TEM study
Analytical TEM	Nm to micron scale analyses
Optical microscopy	High resolution

The FTIR and Raman microscopes can operate through clean environment walls, or possibly within clean environments without significantly compromising sample purity. X-ray instruments and analytical SEM are not compatible with highest specification clean room environments, although sample chambers could be interfaced to clean environments directly with the instrument primarily outside the cleanest area. Alternatively, samples could be transferred under sealed controlled inert gas or vacuum conditions from clean environments to sample chambers (e.g. Figure 7.7).

Figure 7.7 - Sample transfer system produced by microscope manufacturer Leica (left) The samples can be loaded into transfer system under clean, inert atmosphere or vacuum conditions. The sample transfer device can then be attached to a compatible docking chamber attached to various compatible instruments and the sample transferred without exposure to unwanted contamination

The FIB and TEM systems are only really required for samples with the smallest particle sizes. The nature of the analyses and the effects on samples negate any requirement for such samples to be operated in clean environments, although integrated sample transfer systems compatible with the analytical SEM would help minimise sample contamination and modification.

7.5 Sample Early Characterisation - Restricted Samples

Restricted samples have a requirement for cataloguing and examination to the same degree or greater than for unrestricted samples. However there are additional challenges from the requirement to operate in a contained laboratory. This can hinder or prevent the operation of instruments that are routinely used for geological characterisation.

7.5.1 Instruments

The recommended instrumentation for characterising samples are listed in section 39 above. As a first step we look at whether these instruments are suitable for use in a contained area.

Cataloguing tools such as balances and optical microscopes can be operated in a contained environment. Likewise FTIR and Raman microscopes can be operated in a range of environments and would be suitable for characterisation inside a contained environment. X-ray instruments and analytical SEM are an important aspect of preliminary characterisation but would require modification to be used in a biocontainment area to ensure they are safely vented, etc.

The FIB and TEM systems are only really required for samples with the smallest particle sizes. The nature of the analyses and the effects on samples negate any requirement for such samples to be operated in clean environments, although integrated sample transfer systems compatible with the analytical SEM would help minimise sample contamination and modification. The nature of the characterisation using FIB and TEM are unrelated to biodetection and therefore sub samples can be sterilised and removed from the contained area prior to such analysis.

Once a sample has been characterised optically, sub-samples can be selected for biohazard assessment and life detection. Samples that have been through the process of preliminary characterisation using all the techniques above can also be then sub-sampled for these important measurements.

8. LONG-TERM ACTIVITIES

8 LONG-TERM ACTIVITIES

8.1 Samples Preparation for Delivery and Retrieval during PE - Unrestricted samples

The methods and instrumentation required for the preparation, delivery and retrieval of unrestricted samples during the Preliminary Examination period, as well as during the long-term allocation period is essentially the same as that described for the Sample Early Characterisation. Given that the unrestricted nature of the sample is already established and that a first characterisation of the samples has already been achieved during the SEC period, two cases can be considered after the initial cataloguing:

(1) the sample is prepared, and a preliminary characterisation carried out, to fulfil the needs and requests of external scientists. This is a continuation of the work undertaken in the SEC period.
(2) An alternative approach is to minimize the amount of experimental work carried out within the facility. In this case, sample handling can be restricted to sample preparation and minimal documentation (optical imaging, weighing); additional analyses are undertaken by the applicant. For instance, if SEC has revealed that all samples are chondritic in chemical composition (in the case of an asteroid sample return mission), it is possible to allocate an unknown sample and leave it to the applicant to check more detailed properties and classification. This approach allows the ESCF to be faster and more efficient in sample allocation.

The sample preparation and cataloguing methods that are listed for the SEC period are given again here for simplicity (Tables 8.1 and 8.2).

Table 8.1 – Instruments/equipment for sample preparation

Instrument	**Comments**
Sputter coaters	C and noble metal for SEM
Microtome	Primarily for small sample sizes
Ion Micromills	Primarily for small sample sizes
Micromanipulators	Electro-static tips, micro-tweezers for diff sizes
Integrated prep 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 PTS

Table 8.2 - Instruments for Cataloguing/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)

8.2 Preliminary Examination - Restricted Samples

Preliminary Examination (PE) is a 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 perform further analyses, within or outside of the ESCF. Characterisation activities in the curation facility should be conducted with little, or no, impact on the physical and chemical properties of the sample.

8.2.1 The Issue of Sample Sterilization

A prerequisite of the PP guidelines (COSPAR, 2002) is that restricted samples cannot be allocated to external laboratories if there is a risk of the samples being biohazards. If a restricted sample must leave the ESCF, and in the absence of an adequate sealed container, then the sample must be sterilised first. Returned samples will be primarily composed of cored rock samples and regolith. If the sample has a high porosity, which is the case for regolith, organisms might use pores and fissures as a microenvironment. This may only be determined through microscopic analysis of the rock, meaning it will need to be considered as contaminated internally until proven otherwise. Sterilisation of these rock and regolith samples will only be achieved by using an energy-based technology that can penetrate to their interior, such as heat or radiation. Validation will need to be undertaken to ensure that the appropriate parameters are met for effective sterilisation without altering the physical or chemical properties of the sample material and influencing future testing. More details on these methods are included in the D2.3 'Sterilisation and Cleaning' of the EURO-CARES project (Leuko et al., 2017).

8.3 Life Detection & Biohazard Assessment

Life Detection (LD) and Biohazard Assessment Protocol (BAP) are wide range of techniques to investigate the presence of life and biohazard in returned samples, for restricted missions. 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 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.

8.3.1 Instruments

Before defining a list of instruments for LD and BAP, a list of potential biosignatures has been produced, with their occurrence and relevance to LD and BAP. This list includes:

- Morphological biosignature: size of single cell/targets, numbers of single bacteria/targets, population size (colonies)
- Chemical: composition: chirality, organic molecules

- Biochemical: DNA, RNA, organic pigments, proteins
- Isotopic: Isotopes, isotopologues, isotopomers
- Mineralogical: Elemental analysis, structure

The list of instruments (Table 8.3) has been chosen to cover the largest spectrum of biosignatures. It should be noted that more traditional techniques such as organism direct culture, cell culture and animal models can be used, but these will most likely only be used if signs of life are determined using the instruments and techniques below.

A key question is to determine if current instrumentation capabilities in microbiology and clean room facilities used for life detection are appropriate for an extra-terrestrial sample curation facility, and to what extent they need to be adapted.

Table 8.3 - Instrument for life detection and biohazard assessment protocol

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
Fluorescent in-situ hybridization (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
13C-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 Outreach

8.4.1 Science and Communications

Running parallel with the sample curation and analysis activities would be a programme of outreach, education and training. Whilst some of the programme is focused on activities at the Curation Facility (Section 8.4.2), there will also be a significant resource available for download from the ESCF website (Section 8.4.3).

8.4.2 Public Outreach Unit

The Public Outreach (PO) unit is an integral part of the ESCF, with a mission of education and entertainment for people of all ages and abilities. The function and activities are modelled on analogous centres associated with scientific facilities, rather than on institutions whose primary aim is outreach. So the remit of the PO unit is similar to that of the Visitor Centres at the Royal Observatory Greenwich, Jodrell Bank and CERN, rather than of a national museum.

The PO unit will be on the ground floor, with separate, step-free, access from the facility itself. All displays will be produced with consideration for visitors with restricted mobility, impaired vision or reduced hearing. It is also anticipated that the centre will be available to host conferences and workshops – as well as weddings and other celebratory events.

The Public Gallery: this will be open at weekends and school holidays for the general public, and also during term time for school visits. It will comprise informative displays about the origin and evolution of the Solar System, and the importance of studying returned samples. There will be hands-on displays focusing on the work of the ESCF, including opportunities for dressing in cleanroom clothes, manipulation of material in a glove box, etc. There will be links to the Virtual Microscope and Virtual Field trip, allowing visitors to access these resources from the PO unit.

Lecture Theatre: as well as for use by school groups, the theatre will be available as a venue for conferences and workshops, as well as to host special events, such as film nights, or public lectures.

Tours: throughout term time, there will be tours of the ESCF, bookable in advance for school groups. During school holidays, at weekends and for special events, there will regular, time-tabled tours.

Cafeteria & Gift Shop: self-explanatory. The premises should be licensed for the sale and consumption of alcohol. There will be outdoor and indoor picnic areas, suitable for school students and families to eat their own food.

8.4.3 Education

Educational resources have been described in the reports from WP8 and are summarized in Figure 8.1. The resources are divided into pre- and post-age 16, plus leisure learners. There are five separate resource packs for the pre-age 16 school students, based around the theme of ‘Living and Working on the Moon’ (Figure 8.2). Material for the older students and leisure learners is around the theme of ‘Space on Earth’, and is mainly a MOOC (Massive Open Online Course, Figure 8.3).

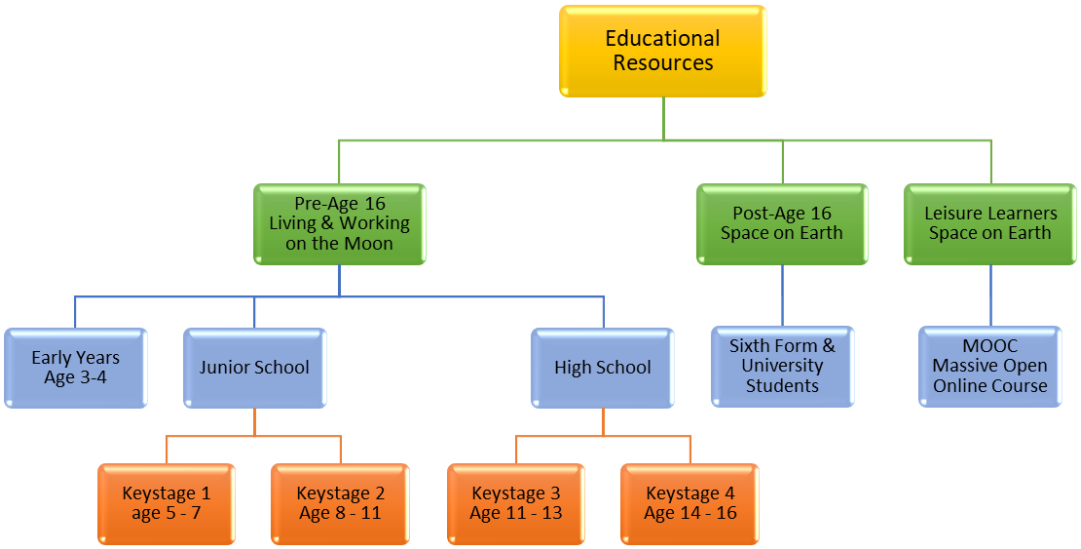


Figure 8.1 - Educational resources

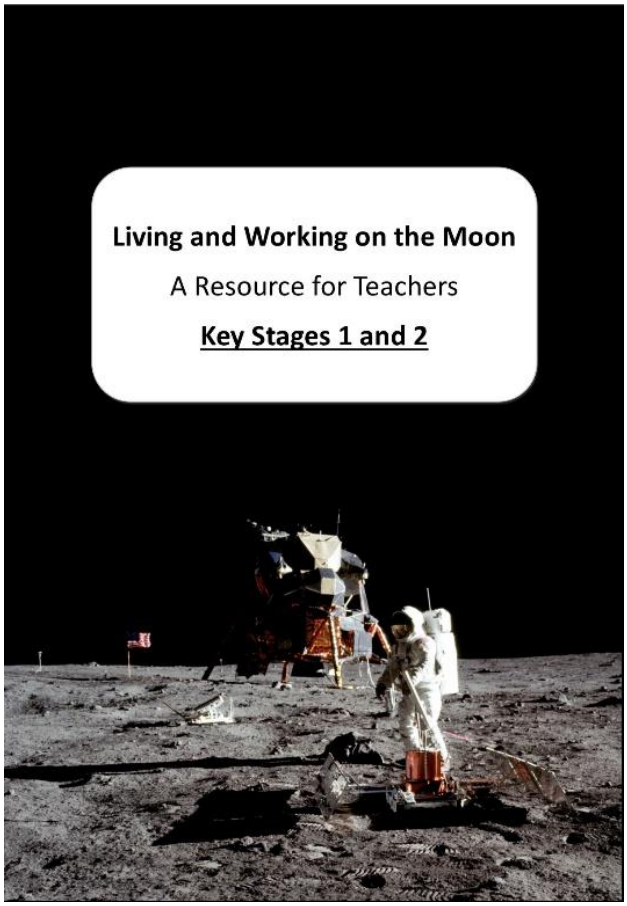


Figure 8.2 - An example of resource pack for school students

Figure 8.3 - An example of MOOC for students

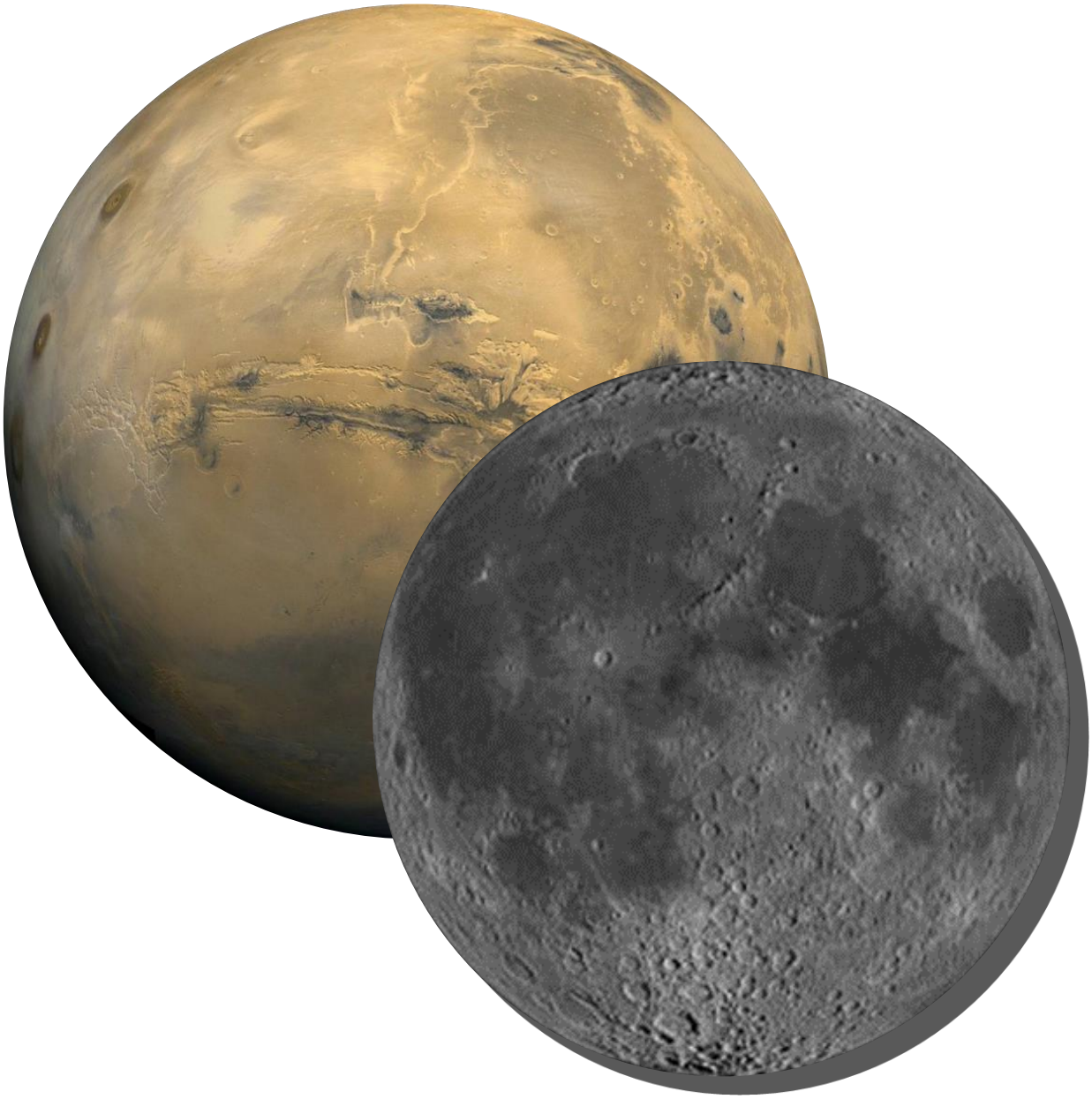
8.4.4 Training

Curation of extraterrestrial materials is a specialized field and requires a breadth of skills, including:

- Sample manipulation (manual and semi-autonomous);
- Planetary Protection;
- Documentation;
- Data management.

To ensure that there are sufficient staff within Europe to operate the ESCF, it will be necessary to develop a course in sample curation. This will include the different requirements for samples from Mars, Moon, asteroids and cometary dust. The course would be aimed at postgraduates and final year undergraduates, and could be accredited for continued personal development (CPD) training purposes as well as towards a Masters-level qualification. International participants would be invited to help build the course, and it would be relevant to subject areas beyond planetary sciences (e.g. medical, nuclear, etc.).

RECOMMENDATIONS AND NEXT STEPS



RECOMMENDATIONS

Europe has curated samples of extraterrestrial material for over 200 years, ever since first recognition that stones falling from the sky were valuable objects for scientific investigation. Europe has an extremely strong and internationally-recognised community of scientists and engineers that specialise in study of extraterrestrial materials and their terrestrial analogues, and in handling and containment of biologically-sensitive material. The combination of skills and knowledge ensures that Europe is strongly placed to curate samples collected by the next generation of sample return missions, including material from asteroids, the Moon, Mars and other restricted targets.

In this document, we have outlined the steps required for the preparation and building of a European Sample Curation Facility, the receipt of collected material, and its characterisation and curation. We have prepared a series of outreach and educational resources to engage and inform a variety of audiences about the project, seeking to inspire students to continue the study of STEM subjects for the future benefit of the European Community.

We do not make recommendations about the location of the facility. That decision is dependent on considerations beyond the scientific and technical, and was not part of our mandate. The facility is likely to cost from €10 - 20M for a basic curation facility for unrestricted samples, to > €100M for a bespoke facility for Mars Sample Return. These costs will need to be included in the cost of the mission, either through space agency budgets or from elsewhere. To put this into context, current sample return missions to asteroids (e.g. Hayabusa 2 and OSIRIS-Rex) are costed in the 100s of millions of Euros and a Mars Sample Return mission campaign is likely to cost billions of Euros. Hence the cost of any curation facility will make up a very small part of the overall budget of these exploration missions. In addition, we expect that the facility can be used for all future sample return missions with European involvement, and so the burden on a single mission or funding agency is diminished.

We have the following recommendations:

1. There is an **urgent** need to update the Planetary Protection Protocols. The most recent published protocol for assessing Mars samples for potential hazards was issued in 2002[1]; (although other teams have considered some of the relevant issues[2]) and whilst the philosophical approach and many of the broad concepts are still valid, our scientific knowledge and analytical capabilities have changed significantly in the last decade. **We strongly recommend a cross-European effort with significant international participation to update the Planetary Protection protocols**, utilising the significant expertise in the life and Earth sciences as well as analytical instrumentation innovation that exists within Europe.
2. Funding for a European Sample Curation Facility must be budgeted. Given we anticipate that the required time to build an ESCF is a minimum of 7 years, and perhaps longer in view of the administrative barriers that must be overcome, it is essential that a funding line for an ESFC is identified as soon as possible. **We strongly recommend that a European Sample Curation Facility becomes part of the ESFRI roadmap** (European Strategy Forum on Research Infrastructures; http://www.esfri.eu/). This then provides a route for funding.
3. Appropriate training of staff working in the facility is critical. The amount of time required should not be underestimated and is a major part of the 7 year (minimum) facility development time. We also have a need to promote links between European researchers and combine efforts around Europe to take advantage of complementary skill sets and expertise and to avoid duplication of work or knowledge gaps. **We strongly recommend that a training programme for curators is established**. This could be through the EC's Marie Skłodowska-Curie actions program, although it would be advantageous to widen the focus beyond Europe, to draw on international expertise.

[1] A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth (2002). Rummel J. D et al. NASA/CP-2002-211842

[2] For example, Kminek et al., 2014, http://dx.doi.org/10.1016/j.lssr.2014.05.001

4. There are several complementary activities involving terrestrial analogues in Europe that have a direct link to curation facility development. ESA are funding the development of a collection of terrestrial analogues and associated curation facility for technology development activities[3]. CNES have funded the ISAR Collection which is a collection of analogues useful for testing scientific payload[4] and the European Union are funding the PTAL project, which is designed to develop a collection of analogues and associated database of spectral analogues[5]. **We recommend that a well-defined and fully characterised suite of analogue materials is assembled for the ESCF before the arrival of material returned from space.**
5. As the major European space agency, ESA should be a leading stakeholder in the curation effort, enabling technological development and scientific studies to oversee work undertaken and to develop products that match their future space mission requirements. Individual national space agencies also have their own priorities and bilateral agreements with other space-faring nations. **We recommend that this report[6] is sent to ESA's Directors plus the Directors of other space agencies, as an information and awareness-raising exercise**.
6. We considered various building designs in terms of separate functional units, each one with its own purpose, such as curatorial space, communications, analogue samples etc. This maximises flexibility and allows for growth of the facility as more missions are returned to Earth. **We recommend that the building that houses the ESCF is built as a series of modules, to maximize flexibility.**
7. We considered six potential landing sites, and the strengths and weaknesses of each in terms of weather, accessibility and population. From our work, the best site for landing a European sample return mission appears to be the Esrange Space Center, Sweden. However, specific considerations for each individual mission may favour another site. **We recommend that a more detailed evaluation of the Esrange Space Center's feasibility as a landing site is undertaken**.
8. Early characterisation of the samples returned must be undertaken in the ESCF as part of curatorial best practice, and in view of the requirements for handling restricted samples. However, to the extent possible given potential planetary protection constraints, **we recommend that detailed examination of returned samples is undertaken by specialists outside the ESFC**. This enables the broader science community to engage in the missions and is more cost effective, as it negates the need for multiple large laboratories.
9. Engagement with the public and with decision makers is essential for the ongoing support of the facility. Methods for outreach, education and communication with the public should be at the heart of the ESCF. **We recommend continuation of a public awareness programme based on the resources that we have developed** (outlined in the 'Next Steps' section).

As well as specific recommendations, we have also recognised a series of innovations that are required:

1. Robotics. New generation curation facilities would be greatly aided by the use of robotics. Robotic instrumentation can perform tasks such as sample movement and manipulation to great accuracy, and can work in a variety of conditions, including, for example, very cold environments or in nitrogen or noble gases atmospheres. We recommend the development of sample manipulation robotics, using robots already available in industry as a starting point. However, issues such as potential contamination by moving parts and lubricants need to be addressed.
2. Detailed design of the transport container for restricted missions. One of the biggest challenges of working with restricted samples is to break the chain of contact between Earth and Mars. A requirement[7] for restricted samples is that the probability of contamination to Earth by a particle ≥ 0.1 µm in size shall be less or equal to $1x10^{-6}$.To meet this requirement, we have considered suitable designs for containers and these now need to be further developed.

[3] http://www.nhm.ac.uk/our-science/our-work/origins-evolution-and-futures/esa-exploration-sample-analogue-collection-curation-facility.html
[4] http://www.isar.cnrs-orleans.fr/isar/
[5] http://www.mn.uio.no/geo/english/research/projects/ptal/
[6] The EURO-CARES brochure was prepared with this objective in mind
[7] ESF-ESSC Study Group (2012), 'Mars Sample Return backward contamination – Strategic advice and requirements', Report from the ESF-ESSC Study Group on MSR Planetary Protection Requirements. ISBN: 978-2-918428-67-1.

NEXT STEPS

The requirement for a European Sample Curation Facility will grow as the number of proposed sample return missions increases: at the beginning of 2018, two sample return missions to asteroids were in progress (USA, Japan), two separate lunar sample return missions were at planning stage (ESA-Russia; China) and a USA-led comet nucleus sample return mission was in the selection process. An international Mars Sample Return programme was also in the planning stages, based on material selected and cached by the Mars 2020 mission.

For European scientists to take full advantage of such opportunities, it is essential that a sample curation facility be built in Europe. Information about the ESCF must remain on the political agenda and in the public consciousness.

The next steps that EURO-CARES will take are based on a communications strategy aimed at four communities:

Political and Funding bodies
Major funding decisions are taken at national and international levels. A large-scale project such as the ESCF cannot be funded by a single nation. Although the Facility might reasonably be expected to fall within the remit of the European Space Agency, its brief goes beyond that of ESA. It is important for continued planning of an ESCF that the correct mechanism is found to enable its establishment. The **European Strategy Forum on Research Infrastructures** (ESFRI; http://www.esfri.eu/) is the body within the EC that advises on development of research infrastructures in Europe. It keeps a forward look – on decadal timescales - at what facilities might be required within Europe, and maintains a roadmap for funding and development of the facilities. **A key next step for EURO-CARES is to submit a proposal for an ESCF for consideration by ESFRI**.

The Academic Community
It is important to keep the wider academic community informed about the findings of the Euro-CARES project. This will ensure that our recommendations are incorporated into future discussions and proposals, and are widely disseminated beyond Europe. We have already made presentations about an ESCF at major international conferences. **A key next step for EURO-CARES is to publish its findings in a Special Edition of the peer-reviewed journal *Planetary and Space Sciences***

Students
We will build on our European student community (school and university), through the learning resources that we have developed, to engage the next generation of scientists and engineers with the excitement of research on extraterrestrial materials. We will use social media to build up an international network of students enthused by space research and exploration. **A key next step for EURO-CARES is to produce translations of our resources into French, German, Spanish and Italian.** We aim to accomplish this through continued engagement with the Horizon 2020 programme, *via* the EuroPlanet portal.

The General Public
Non-specialists are an important audience with whom to engage, because as tax-payers, voters, and consumers and producers of news media, they are significant in influencing opinion formers and funding bodies. **A key next step for EURO-CARES is to use local and national media to publicise the advantages of a European Sample Curation Facility**. We aim to accomplish this through lectures to the general public and articles in non-specialist and special-interest magazines.

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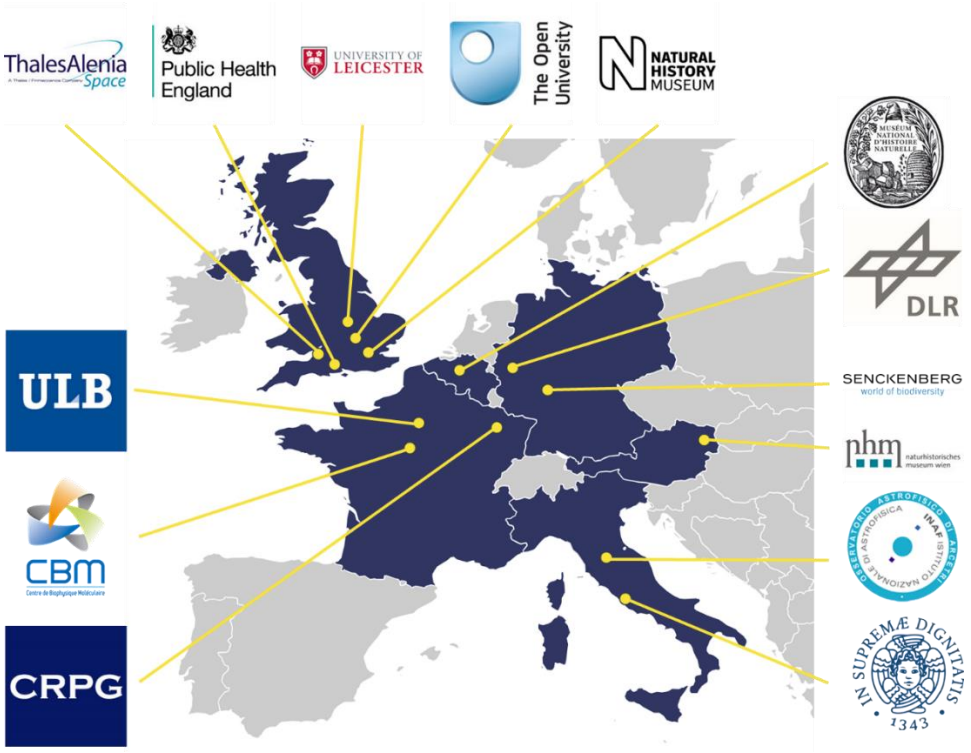
APPENDICES

APPENDICES

THE EURO-CARES TEAM

Institutions



Centre de Biophysique Moléculaire, Orléans, France (CBM)

The Centre de Biophysique Moléculaire (CBM) is one of the largest chemistry institutes in France. The Exobiology Group of the CBM is specialised in prebiotic chemistry, specifically the origin of the building blocks of critical molecules for the origin of life, micropaleontology and the search for life on Mars. Space experiments using various types of support documented the fate of prebiotic molecules, such as amino acids and peptides, both in space and after simulated impact on Earth. Research in the group importantly includes the geological context for the origin of life and life on other planets, looking at aspects such as the formation and early habitability of the Earth (and Mars), early ecosystems and the oldest traces of life, as well as the nature of and formation of signatures of life. The Exobiology Group collaborates closely with other researchers on the CNRS campus in Orléans in the space laboratory 'Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E)' and the geology laboratory 'Institut des Sciences de la Terre d'Orléans (ISTO)'. The enlarged group comprises researchers, technicians, postdocs, and doctoral students involved in different aspects of research related to the early Earth, Mars and the appearance and early evolution of life. The Exobiology group has access to a vast array of analytical instrumentation between the different laboratories and the University of Orléans.

Centre de Recherches Pétrographiques et Géochimiques, Nancy, France (CRPG)

The Centre de Recherches Pétrographiques and Géochimiques (CRPG) is a research laboratory for Earth and Planetary Sciences, it specializes in geochemistry and petrology and is recognized for its expertise in the study of meteorites and cosmochemistry in general. Hosting two CNRS national facilities, the SARM (rock chemical analyses) and the Ion Probe laboratory, CRPG also deploys large experimental and analytical infrastructures composed of high-temperature experimental laboratory (able to synthesize chondrule- and CAI-like materials), a department of secondary electron microscopy, two chemistry laboratories and several mass spectrometers (Ion probe, TIMS, ICP-MS, stable isotopes, noble gas isotopes). Thus, CRPG is particularly well equipped to tackle challenging analyses like those on extra-terrestrial materials. Notably, CRPG has probed samples returned by most sample-return space missions launched so far, including Apollo, Lunar, Stardust and Genesis. Major discoveries in cosmochemistry have been made over the past two decades at CRPG

including the nitrogen isotopic composition of solar wind, oxygen isotopic composition of the Sun, circumstellar carbonate condensation, the finding of differentiated planetesimals in the precursor materials of chondrules, and chondrule formation by interaction with the ambient gas.

CRPG organizes its scientific policy around four research departments, which work in close partnership with the CNRS (French public institution of scientific research) and other French research institutes (INRA, IRD, etc.).

Deutsches Zentrum für Luft und Raumfahrt, Cologne, Germany (DLR)

The Deutsches Zentrum für Luft (DLR) is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

Within DLR the Institute of Aerospace Medicine (DLR-ME) is the only research institution that primarily deals with life science research concerning space flight, exploration, aviation and traffic. The research activities of DLR-ME are focused on medical, biological and physical research (e.g. development of countermeasures to protect humans from the effects of weightlessness, research under microgravity conditions and space microbiological aspects). Projects concerning research on viability and adaptability of microorganisms to extreme environmental conditions as they occur in space or on other planets like Mars are accomplished in the research group 'Astrobiology' of the Radiation Biology Department. Furthermore, the bioburden of spacecraft, spacecraft assembly facilities and confined habitats (e.g. space/research stations) is routinely monitored according the COSPAR Planetary Protection guidelines in order to prevent forward and backward contamination of our solar bodies and of Earth due to human exploration/robotic missions on behalf of ESA.

National Institute for Astrophysics, Italy (INAF)

National Institute for Astrophysics (INAF) is the main Italian research institute for the study of the Universe. It promotes, implements and coordinates research, nationally and internationally, in the fields of astronomy and astrophysics. It designs and develops innovative technologies and state-of-the-art instrumentation for the study and exploration of the Cosmos.

For the activities relative to EURO-CARES, the two Institutes Astrophysical Observatory of Arcetri, Firenze and Institute for Space Astrophysics and Planetology (IAPS), Rome, are among the largest INAF institutes in Italy with numerous scientific staff and technology groups.

INAF - Astrophysical Observatory of Arcetri is the leading Institute for astrobiology studies for the search of signs of life in the Solar System and prebiotic chemistry. The group has significant experience in sample return mission studies from primitive asteroids, Moon, and Mars, being also the leader of Sample Curation Facility study for ESA Marco Polo-R study mission. The Astrophysical Observatory of Arcetri is the reference centre in Italy for planetary protection activities. The group collaborates with ASI, Universities, other INAF Institutes and industries (Thales-Alenia Italy, Leonardo SpA, Kayser Italy, etc.) for planetary protection tasks and procedures and it is involved in policy revision in collaboration with ESA and NASA working group.

IAPS-INAF has a strong experience in the study of planetary analogues and extra-terrestrial materials as well as in the design and the development of space instrumentation for planetary exploration.

University of Leicester, Leicester, UK (LEI)

The Space Research Centre of University of Leicester (LEI) houses the Space Project and Instrument Group of the Department of Physics and Astronomy at the University of Leicester. The Centre has the role of carrying out the space research programme of the University in collaboration with other members of the Department and College. The main activities of the Space Research Centre are in the areas of instrumentation and missions for space science, planetary science (meteorites, sample return, planetary surfaces), earth observation science, technology transfer and exploitation, undergraduate and postgraduate education, and public outreach. The planetary science includes the analysis of Martian and asteroidal meteorites, Comet

Wild2 samples and the analysis of the Martian surface using CRISM, near IR analysis and HiRISE imagery. The Mars Science Laboratory work includes the study and selection of Mars landing sites and terrestrial analogue sites informed buy our new understanding of clay-bearing sites revealed by this mission.

Muséum National d'Histoire Naturelle, Paris, France (MNHN)

The Muséum National d'Histoire Naturelle (MNHN) is one of the world's major natural history institutions and contributes to the knowledge and conservation of biodiversity and geodiversity through research, higher education, training, and conservation of reference collections, as well as providing expertise to the French and European government for environmental policies. Its research topics cover biology, earth sciences and human sciences. In addition, a series of other laboratories are devoted to ecology, biophysics and biochemistry, chemistry of natural substances, physical oceanography and comparative physiology. Together, they represent a research complex that enables multi-disciplinary research to be undertaken.

Its staff is composed of almost 2,000 people. Recognized as a centre of excellence due to its publications and international prizes awarded to its scientists, the Museum organizes its scientific policy around seven research departments, which work in close partnership with the CNRS (French public institution of scientific research) and other French research institutes (INRA, IRD, etc).

The collections of the MNHN are, quantitatively and qualitatively, in the top three in the world. They comprise an estimated 70 million specimens and house approximately 835,000 primary types and reference specimens of natural history.

The scientists working at the institution possess expert knowledge in a vast array of zoological, botanical and geological disciplines. In many cases, they are world-leading experts in their fields and/or represent unique or rare expertise in Europe. In addition to international research collaboration at the individual level, MNHN plays important international roles. It is heavily involved in the numerous European programs and projects related to biodiversity.

The national meteorite collection supplies the French and international community with meteorite samples.

Natural History Museum, London, UK (NHM)

The Natural History Museum (NHM) is an international leader in the scientific study of the natural universe. NHM has a history of curating diverse objects that spans several centuries, including over 200 years of meteorite curation. NHM also host a state-of-the-art suite of analytical facilities including imaging in 2D and 3D, micro-chemical and micro-mineralogical analysis.

NHM has a strong track-record in European Commission-funded research and training. The planetary sciences team at NHM are particularly active. As an established leader of the global meteoritical community, NHM have traditionally published the Catalogue of Meteorites, the internationally definitive listing of known meteorites, and are ex officio members of the Meteorite Nomenclature Committee. NHM also perform a critical role in providing extra-terrestrial material to the research community.

In partnership with Imperial College's Department of Earth Sciences and Engineering, NHM is part of the Impact and Astromaterials Research Centre (IARC), a multi-disciplinary group of planetary scientists benefiting from the synergies of shared expertise and facilities.

There is a dedicated grant administration team at NHM who assist grant holders in the delivery of the project including contractual and financial management and reporting.

Naturhistorisches Museum Wien, Vienna, Austria (NHMW)

The Natural History Museum Vienna (NHMW) is one of the largest, oldest, and most noteworthy natural history museums in the world and a centre of competence for scientific questions of fundamental importance. NHMW hosts several reference (scientific) collections, including the world's oldest meteorite collection, of which a large number of specimens is shown in the Meteorite Hall, the world's largest meteorite display. NHMW not only has a long history of curating rare and precious objects, it is also one of the largest non-university research institutions in Austria. In the seven research departments of the NHMW, more than 60 scientists are performing basic research in various fields of geosciences, biosciences and human sciences,

including the study of the composition of the Earth and the origins of the universe as well as the development and proliferation of primitive plants and animals, biodiversity and genetics. The world-leading experts in their fields of the NHMW work in close partnership with other Austrian and international research institutions.

NHMW possess a state-of-the-art laboratory of molecular systematics and new electron microscopy facilities. In relation to the present proposal, the 'meteorite' team at the NHMW have a particular expertise in curation, including the preparation and loan of meteorite samples, and the study of extra-terrestrial material.

Open University, Milton Keynes, UK (OU)

The Open University (OU) is a world-leading provider of distance learning higher education, with over two hundred and forty thousand UK and international students enrolled. The OU continues to play a leading role in public outreach nationally, with a formal agreement with the BBC to provide academic leadership/input to a large portfolio of high profile television and radio programmes and is the lead organisation for FutureLearn – a platform for Massive Open Online Courses (MOOCS) involving 22 leading UK universities, plus other institutions and international universities.

One of the largest and highest profile areas is Planetary and Space Sciences. The team works across a wide range of planetary and space projects from the analysis of meteorites and other extra-terrestrial samples, through to the development and exploitation of spaceflight instrumentation. The team are involved in many European multi-national projects, including ESA Technology contracts and EU consortia and networks. Staff are involved in all currently planned ESA, NASA and JAXA planetary missions. Planetary and Space Sciences is located in recently built bespoke laboratory complex, housing specialised laboratories and clean rooms facilities with state of the art analytical, testing and simulation facilities. Core areas of expertise in the sample analysis area includes the study of light elements and their organic and mineral forms.

Public Health England, Salisbury, UK (PHE)

Public Health England (PHE) is an executive agency of the UK Department of Health. Its mission is to protect and improve the nation's health and to address inequalities. The Microbiological Services Porton part of PHE is an international leader in the safe handling and containment of highly pathogenic agents. This involves the development and use of containment equipment, cabinets, isolators and BSL4 cabinet lines and knowledge of filtration and decontamination processes. The Biosafety Unit of MS has recently been active in a number of planetary protection activities funded by the European Space Agency.

Dipartimento di Scienze della Terra, Università di Pisa, Italy (PISA)

The Dipartimento di Scienze della Terra of Pisa University (PISA) is historically and currently the leading Earth Science Department in Italy, for the quality of research, education and placement (data from the national agency ANVUR). The staff is involved in several research fields at the national and international level, from geophysics to georesources, from environmental geology to geological hazard, from geotechnologies and geomaterials to extra-terrestrial materials. On a political level, PISA is one the reference Earth Science Department for the National Guard. PISA is the headquarter of the national project for the search for meteorites in Antarctica within the Italian 'Programma Nazionale delle Ricerche in Antartide (PNRA)'. Through this project, PISA has access to the PNRA meteorite and micrometeorite collections, which are amongst the most important Antarctic meteorite and micrometeorite collections in the world and to the state of the art PNRA analytical facilities.

Senckenberg Gesellschaft für Naturforschung, Frankfurt am Main, Germany (SENCK)

The Senckenberg Gesellschaft für Naturforschung (SENCK) is a non-profit civil society, founded by Frankfurt citizens in 1817. It is based at six institutes located at 11 sites in seven of Germany's federal states and maintains three public museums. Senckenberg is an institute of the Leibniz association. It has the mission to perform natural history research, to maintain and develop natural history collections, to communicate the results of its research to the public through its museums, exhibitions and publications, and to educate in the fields of natural history research and scientific collection management. The natural history collections, encompassing about 38.5 million units, are the largest in Germany and rank highly among museums in the world. They represent a key component of Senckenberg's research infrastructure and are available to the

global scientific community. Senckenberg has a successful record in acquiring third-party funding among which are several EU funded projects.

The meteorite research group at Senckenberg has close scientific connections to cosmochemistry groups in other German universities, (e.g., JWG University in Frankfurt, Leibniz University in Hannover) as well as the Max Planck Institute for Chemistry in Mainz. Although a small group, it is well connected within the international research community studying solar system materials and has developed an active profile in publication and acquiring third party funding. It curates one of the largest and most important meteorite collections in Germany and provides extra-terrestrial materials to the international research community. Senckenberg has a state-of-the-art suite of analytical facilities including CT analyses and mass spectrometry for age dating and analyses of stable isotopes.

Thales Alenia Space UK, Bristol, UK (TAS)

Thales Alenia Space (TAS) is a UK-based company, whose staff have gained their space Engineering experience on key ESA, Earth Observation (EO) and science programmes such as Rosetta, Envisat, Planck, Earthcare and BepiColombo. They have extensive experience of managing partnerships with industrial and academic/research organisations.

TAS staff have led ESA studies on both Mars and Lunar Sample Return Facility design. They have many years of experience in planetary protection and cleaning technologies. They are currently designing a biohazard container suitable for a returned Mars sample for the European Space Agency. They have provided expertise to Mars Sample Return orbiter, lander, and sample vessel biocontainer studies.

Université Libre de Bruxelles, Brussels, Belgium (ULB)

The Université Libre de Bruxelles (ULB) is a multicultural institution at the heart of Europe. It is a comprehensive university in all disciplines and study cycles (BA, MA, PhD) and is the second in size in Belgium French-speaking community. It is also a major research centre is recognized by the academic community the world over. ULB is a foundation member of a network of major universities from different European capitals 'UNICA' and is involved in international programs for research and development and for mobility.

In particular, the Laboratoire G-Time (Geochemistry: Tracing with Isotopes, Minerals and Elements) has a long tradition in isotope geochemistry, starting in the 60's. After being a pioneer in having the first Belgian MC-ICP-MS in 2001, the Laboratoire G-Time still has a present-day recognized strong expertise in isotope geochemistry. With several clean laboratories and several mass spectrometers, the laboratory is an ideal place for performing isotope geochemistry and cosmochemistry.

At the Belgian scale, an important partnership has been set up between the Université Libre de Bruxelles, the Vrije Universiteit Brussels and the Royal Belgian Institute for Natural Sciences for collecting meteorites in Antarctica and their subsequent curation. For this, ULB is closely collaborating with the National Institute for Polar Research (Tokyo, Japan). Several Antarctic campaigns have been achieved, that collected more than 1,000 meteorites.

Team Members

The EURO-CARES project team worked in six different European countries and represented 14 different institutions. The unrivalled expertise of the individual team members was very varied and covered many different scientific and engineering fields that are applicable to curating samples returned from Solar System exploration missions. All Members are additionally involved in WP1 and WP9.

Centre de Biophysique Moléculaire, Orléans, France (CBM)
Dr. Frances Westall (Leader of WP5)
Dr. Frédéric Foucher (WP5)

Centre de Recherches Pétrographiques et Géochimiques, Nancy, France (CRPG)
Dr. Yves Marrocchi (WP4)

Deutsches Zentrum für Luft und Raumfahrt, Cologne, Germany (DLR)
Dr. Petra Rettberg (Deputy of WP2)
Dr. Stefan Leuko (WP2)

National Institute for Astrophysics, Italy (INAF)
Dr. John Robert Brucato (Leader WP2 & WP7; WP3 & WP4)
Dr. Ernesto Palomba (WP3, WP4 & WP6)
Prof. Alessandra Rotundi (WP2)
Dr. Andrea Meneghin (WP2, WP3 & WP4)
Dr. Andrea Longobardo (WP3, WP4 & WP6)

University of Leicester, Leicester, UK (LEI)
Prof. Dr. John Bridges (WP2, WP5)
Dr. John Holt (WP6)

Muséum National d'Histoire Naturelle, Paris, France (MNHN)
Dr. Jérôme Aléon (Leader of WP4)
Prof. Matthieu Gounelle (Deputy of WP4)

Natural History Museum, London, UK (NHM)
Prof. Sara Russell (Project coordinator; WP4)
Dr. Caroline Smith (Project co-coordinator; Leader of WP1; Co-Leader of WP7; WP3)

Naturhistorisches Museum Wien, Vienna, Austria (NHMW)
Dr. Ludovic Ferrière (Leader of WP3)
Dr. Aurore Hutzler (WP3)

Open University, Milton Keynes, UK (OU)
Prof. Monica Grady (Leader of WP8)
Dr. Ian Franchi (Deputy in WP4)
Dr. Ben Dryer (Web manager; WP8)

Public Health England, Salisbury, UK (PHE)
Mr. Allan Bennett (Deputy of WP3; WP2 & WP6)
Mr. Thomas Pottage (WP2, WP3 & WP6)

Dipartimento di Scienze della Terra, Università di Pisa, Italy (PISA)
Prof. Luigi Folco (WP3 & WP5)
Dr. Maurizio Gemelli (WP3 & WP5)

Senckenberg Gesellschaft für Naturforschung, Frankfurt, Germany (SENCK)
Dr. Jutta Zipfel (Deputy of WP1 & Deputy of WP5)

Thales Alenia Space UK, Bristol, UK (TAS)
Dr. Lucy Berthoud (Leader of WP6)
Dr. John Vrublevskis (Deputy of WP6)
Dr. Mike Guest (WP6)

Université Libre de Bruxelles, Brussels, Belgium (ULB)
Dr. Vinciane Debaille (WP3 & WP5)

EURO-CARES WORK PACKAGE DESCRIPTIONS

WP1 - Knowledge Capture and Requirements Review

WP1 identified the current state of the art knowledge in the subject areas for all the technical work packages (from WP2 to WP6). This WP was undertaken at the start of the project to form the foundation for the other WPs. In this WP there was close engagement with scientists from outside Europe, involved in curating samples from previous sample return space missions, such as Apollo, Stardust, Genesis and Hayabusa and liased with the Osiris-Rex mission curation team, to keep up to date with the best practice in the field. There was also engagement with scientists from Europe, the United States and Japan who curate meteorites and micrometeorites collected from cold and hot deserts and interplanetary dust particles collected in the (upper) atmosphere. In addition the status, mission architecture and science objectives of potential sample return missions to asteroids, the Moon and Mars was reviewed.

WP1 published the following deliverables, available through the EURO-CARES web site:

- D1.1 - Mission Overview and Timeline Document;
- D1.2 - Preliminary Requirements - Planetary Protection;
- D1.3 - Preliminary Requirements - Facilities and Infrastructure;
- D1.4 - Preliminary Requirements - Methods and Instruments;
- D1.5 - Preliminary Requirements - Analogue Samples;
- D1.6 - Preliminary Requirements - Portable Receiving Technologies;
- D1.7 - List of Provisional Requirements;
- D1.8 - Workshop Report and Recommendations;
- D1.9 - Consolidated Requirements Document.

WP2 - Planetary Protection

Stringent requirements regarding Planetary Protection (PP) and *in situ* biological and organic molecule contamination control are recognized as a major factor in spacecraft hardware design and also in the design of facilities for the curation of the returned samples. In particular, Mars Sample Return missions are classified as 'restricted Earth return' and will require extensive PP measures. In addition to fulfilling all the forward contamination control requirements for the mission, there will be a variety of measures aimed at avoiding back contamination of Earth. Within WP2, we recommended techniques and procedures for life detection. Existing techniques were critically examined for potential incorporation into the ESCF.

Within the activities of the WP2, techniques to select the portion of returned restricted samples to be analysed for the presence of pathogens and infective substances were investigated and defined. An interactive approach was followed, to define the selection processes of restricted samples for sterilization and early distribution to the science community.

Technical requirements for structure, environments, waste handling, security, and communication were produced. Particular emphasis was given to the definition of processing requirements in terms of number of operations and amount of flow through the facility's sub-units designed for sample transfer.

WP2 published the following deliverables, available through the EURO-CARES web site:

- D2.1 - Bioload Assessment;
- D2.2 - Biohazard and Biosecurity;
- D2.3 – Sterilisation;
- D2.4 - Sample Transfer;
- D2.5 - Facility Requirements;
- D2.6 - WP2 Summary report.

WP3 - Facilities and Infrastructures

The first objective of WP3 was to define the requirements for the state of the art facilities required to receive, contain and curate extra-terrestrial samples and guarantee terrestrial planetary protection. All these aspects were considered to accomplish the second objective of WP3, which was to cover all the aspects of designing an ESCF: from the design of the building to the storage and curation of the samples. Knowing that the primary function of the curation facility is to contain the samples, all the specificities of the samples, including their origin in the Solar System (e.g. from Mars, the Moon, and/or from asteroids, or other bodies) their size, their shape, etc., were considered, as briefly described in the following list.

Building design: The ESCF infrastructure was designed to prevent sample contamination and alteration for all samples, and to prevent potential biohazards from restricted samples (input from WP2). The facility was composed of sub-units dedicated to specific operations such as cleaning, biohazard assessment, curation, storage, etc. The facility was designed to be highly adaptable, to follow instrumentation development, and to allow the addition of new sub-units.

Storage of the samples: Long-term curation of samples is challenging, especially because their pristine nature needs to be preserved. With restricted samples some specific planetary protection constraints will also have to be taken into consideration which may impact on sample contamination. The facility was designed to meet controlled pressure, temperature, and atmospheric environmental constraints, depending on the samples requirements.

Curation: This mainly consists of the handling, documentation, preparation, preservation and allocation of limited amount of sample for research. All these aspects were studied and included in the design of the ESCF.

WP3 published the following deliverables, available through the EURO-CARES web site:

- D3.1 - Preliminary Conceptual Design;
- D3.2 - Workshop Report;
- D3.3 - Advanced Design and Technology Identification;
- D3.4 - WP3 Summary report.

WP4 - Methods and Instruments

The objective of WP4 was to understand the most valuable analyses to be performed within the ESCF whilst ensuring minimal contamination, minimal damage to the sample and rapid distribution of samples to the scientific community. In addition, it looked at instruments required for cleaning. As the facility may be space-limited (the facility cannot be infinitely large) and time-limited (initial characterisation should be fairly quick to ensure rapid dissemination of samples to selected researchers). However for restricted samples characterisation will need to be more extensive and take longer to ensure that the sample is free of biohazardous material. The objectives of WP4 were to determine the types of analyses that are necessary for preliminary examination and curation, the types of analyses that may be carried out on 'pristine' samples within sample containers and those that would require samples to be removed from their containers. Another key issue was to determine if destructive analyses were required and the assessment of the risks versus opportunities of carrying out of such analyses within the facility.

WP4 published the following deliverables, available through the EURO-CARES web site:

- D4.1 - Report on Instrumentation;
- D4.2 - Space agency visits;
- D4.3 - Workshop WP4 report;
- D4.4 - Industry visits;
- D4.5 - WP4 Summary report;

WP5 - Analogue Samples

The WP5 identified the characteristics of analogue materials to represent a full range of sample return missions and produced a catalogue of suitable analogue samples that are available or obtainable, including artificial and manufactured analogues.

Analogue samples are critical for instrument testing during the design and construction of robotic exploration spacecraft and for a first level of readiness in the event of returned samples. This will help the success of sample return missions starting from collection to careful sample curation and long-term storage, in order to ensure availability for decades of future scientific analyses. These are essential aspects of an ESCF for all types of samples, with respect to receiving potential Moon, Mars, asteroidal or even cometary samples. Analogue samples, either natural or manufactured, are necessary for testing all the steps of sample processing in a curatorial facility (sample handling, storage, preparation, analysis and planetary protection measures). Furthermore, under the term 'analogue samples' are included voucher specimens to test for potential sources of mission related contaminants (e.g. bits of hardware, terrestrial rocks and soils from the ERC landing site, etc.).

Workshops were organized with a representative number of experts in order to:

- Determine the characteristics of the kinds of samples needed in a curatorial facility for returned extra-terrestrial materials;
- Prepare a catalogue of available and obtainable analogue samples with recommendations as to the kinds of samples that need to be produced artificially.

WP5 published the following deliverables, available through the EURO-CARES web site:

- D5.1 - Interim Report - Required Analogue Characteristics;
- D5.2 - Interim Report - Appropriate Analogues;
- D5.3 - Interim Conclusions;
- D5.4 - WP5 Final Report.

A shortlist of analogues can be found on the EURO-CARES website, at the following link:

http://www.euro-cares.eu/wp5/database/index.php

WP6 - Portable Receiving Technologies

The objective of WP6 was to propose methods for the recovery and transport of samples from the landing site to the ESCF. These methods are of the utmost importance to break the chain of contact between Earth and extra-terrestrial matter. The Earth re-entry capsule from a sample return mission is targeted at a specific landing ellipse on Earth, possibly at considerable distance from the curatorial facility. Once the capsule has landed, an assessment of the state of the spacecraft lead to a recommended recovery procedure. A portable receiving facility may be used to inspect, document and package the sample container. It will then be transported to the ESCF using a safe and secure method. Methods for the transport of samples from the ESCF to the outside institutions were also be studied, to insure security and non-contamination of the samples.

WP6 published the following deliverables, available through the EURO-CARES web site:

- D6.1 - Report on Recovery Preparation;
- D6.2 - Report on Initial Inspection;
- D6.3 - Report on Transport;
- D6.4 - Report on Planetary Protection;
- D6.5 - Report on Required Innovations.

WP7 - Synthesis, Recommendations and Roadmapping

The concept of WP7 was to synthesise all the work undertaken in the technical WPs (from WP2 to WP6), and to strengthen the looped feedback between WPs. Findings and recommendations, including inputs from the workshop organized by WP7, provide a roadmap of how we can realise an ESCF.

WP7 published the following deliverables, available through the EURO-CARES web site:

- D7.1 - Synthesis report;
- D7.2 - Final Report (current report).

WP8 - Maximising Impact

The objective of WP8 was to communicate effectively with all stakeholders, to gain maximum impact from the project. The following methods were used:

Website: to publicise the project and news about the findings. The site act as a portal through which visitors can reach public areas of the site. There is also a password-protected area for participants, who will use the site as a centre for exchange of information and a repository for documents, results, etc.

Social Media: to update the stakeholders with news about the progress of the project.

Formal Media: links with print and broadcast journalism were maintained through the participant institutions' press and media offices by producing press briefings as and when appropriate to apprise the media on the progress of the project and its highlights.

Educational materials: for both formal and informal learning opportunities, prepared for students of school age and undergraduate level. Formal learning includes material linked to the Key Stages of the different National Curricula of the participants. Informal learning includes preparation of a MOOC, offered to the open education resource providers.

Outreach: preparation of materials for various audience (e.g. a talk/demonstration package for schools and the general public, a brochure for opinion-formers detailing the new technologies and opportunities arising from space missions in general and sample return missions in particular, a virtual exhibition of sample curation, which may become a physical exhibition for display at the different participant institutions).

WP8 produced the following outcomes:

- D8.1 - Website Framework;
- D8.2 - Website Live;
- D8.3 - Twitter and Facebook
- D8.4 - Web Forum;
- D8.5 - Press Briefings;
- D8.6 - Educational Material – Schools;
- D8.7 - Educational Material – Universities;
- D8.8 - MOOC;
- D8.9 - Outreach Package;
- D8.10 - Brochure;
- D8.11 - Virtual Exhibit.