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EURO-CARES: A Plan for European Curation of Returned Extraterrestrial Samples

WP6.5: Identification of Innovations

Written by	***Lucy Berthoud*** ***John Bridges*** ***John Holt*** ***Thomas Pottage*** ***Allan Bennett*** ***Andrea Longobardo*** ***Ernesto Palomba*** ***Samuel Frampton***
Verified by	***John Vrublevskis***
Approved by	

Approval evidence is kept within the documentation management system.

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CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
0.1	28/09/16	First issue	LB
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1. INTRODUCTION

1.1 Aims and Objectives

This report is part of the EURO-CARES project – an EU Horizon 2020 funded project to create a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility (ESCF), specifically material returned to Earth from Mars, the Moon or asteroids. Once the Earth Return Capsule (ERC) lands on Earth, it is imperative that it is recovered, handled and transported in a way that maintains the scientific integrity of the samples within. In the case of returned material from Mars, the need for biocontainment will make these steps even more challenging.

This report is one of 6 reports produced in EURO-CARES Work Package 6 (WP6) "Sample Transport" (see Table 1-1). This overarching Work Package is broken down in to 5 smaller Work Packages:

- the preparation for recovery (WP6.1)
- the recovery and initial inspection (WP6.2)
- transport to the Curation Facility (WP6.3)
- impact of Planetary Protection (WP6.4)
- any technological innovations necessary (WP6.5)

Report	Title	Responsible
D6.1	Preparation for Recovery	University of Leicester
D6.2	Recovery and Initial Inspection	Thales Alenia Space UK
D6.3	Transport to Curation Facility	IAPS/INAF
D6.4	Impact of Planetary Protection	Public Health England
D6.5	Identification of Innovations	All

Table 1-1: Summary of Reports delivered for WP6.

1.2 Objectives:

The objective of this report for WP6.5: "Identification of Innovations" is primarily to examine the innovations necessary to prepare for landing, recovery, inspection and transport of the samples.

Specific Objectives of the work will be:

• To determine what innovations have been identified in previous parts of this Work Package and identify the nature of the innovation necessary.
• To assess the criticality of each innovation.
• To determine the current TRL level for each development and propose a timeline for its development in Europe.

As a secondary objective, "non-technical" readiness will be assessed. This assessment will be made because of the entirely novel nature of the European Extra-terrestrial Sample Curation Facility (ESCF) and recognizing that the capability delivered by the ESCF is not due to equipment alone. Important issues of non-technical readiness, e.g. Staff recruitment & training will also be addressed since lack of readiness in this area would have just as much impact as lack of technology readiness.

1.3 Scope

This Work Package builds on the detailed work performed in Work Packages 1, 6.1-6.4 and provides necessary updates on the Mars Sample Return mission designs. The aim of this report is to establish any technology development and new procedures required to develop a roadmap for the implementation of the European Extra-terrestrial Sample Curation Facility (ESCF). Many of these innovations will be linked to the planetary protection aspects of sample transport, as this is the most critical new driver. It does not provide any new engineering or analysis, but serves more as a summary of the critical factors which need prioritisation in future work. The technology development plan is not expected to be accurate to the month, but gives more of an overall idea of the sequence and order of timescales involved.
It is important to identify that some of the innovations necessary are new to researchers worldwide, whilst others are new to European researchers, but have been tackled already by other nations, notably the US and Japan. These distinctions are made clear in the text.

1.4 Approach

A workflow diagram describing the approach used to perform this work is shown in Figure 1-1.
A review of existing literature and some preliminary findings have already been prepared in Work Package 1 (Literature review) Table 1-1. The Work Packages 6.1 to 6.4 in Work Package 6, as specified in Table 1-1, also provide inputs into this Work Package.
These previous Work Packages have identified various elements of their proposals which will involve innovation and these are reviewed in detail. The critical elements are analysed and then a technology development plan is proposed.

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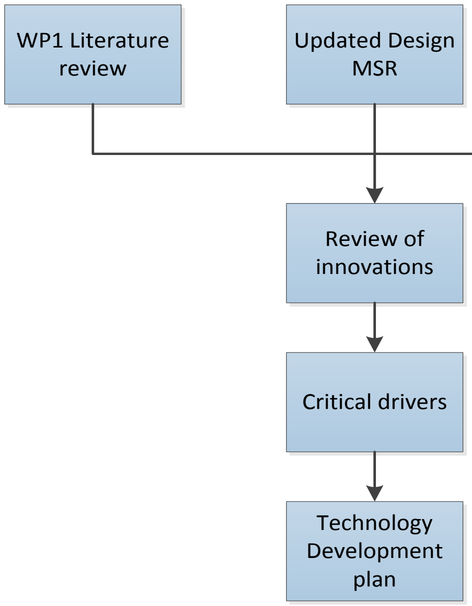

Figure 1-1 : Workflow for WP6.5 Critical Areas for Innovation

1.5 Modified Technology Readiness Levels (TRL)

The approach to TRLs used by the European Space Agency, which is taken to apply in this European project, are defined in ISO standard 16290 (ISO, 2013):
"*Technology Readiness Levels (TRLs) are used to quantify the technology maturity status of an element intended to be used in a mission. Mature technology corresponds to the highest TRL, namely TRL 9, or flight proven elements.*
The TRL scale can be useful in many areas including, but not limited to the following examples:

- *a) For early monitoring of basic or specific technology developments serving a given future mission or a family of future missions;*
- *b) For providing a status on the technical readiness of a future project, as input to the project implementation decision process;*
- *c) In some cases, for monitoring the technology progress throughout development.*

The TRL descriptions are provided in Clause 3 of this International Standard. The achievements that are requested for enabling the TRL assessment at each level are identified in the summary table in Clause 4. The detailed procedure for the TRL assessment is to be defined by the relevant organization or institute in charge of the activity."

The definition of a 'Laboratory Environment' in TRL4 is a 'controlled environment needed for demonstrating the underlying principles and functional performance'. This can be applied to a ground based facility as much as a space-based instrument.

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For TRL6 to TRL9 the word 'system' can also include a curatorial facility, as a facility is also a system which is composed of sub-systems and components.

The definition of a '<u>Relevant Environment</u>' in TRL5 and TRL6 is: 'minimum subset of the operational environment (2.11) that is required to demonstrate critical functions of the element (2.2) performance in its operational environment (2.11)'.

The definition of '<u>Operational environment</u>' in TRL7 is "a set of natural and induced conditions that constrain the element from its design definition to its operation, for example: Natural conditions: weather, climate, ocean conditions, terrain, vegetation, dust, light, radiation, etc. or another example: Induced conditions: electromagnetic interference, heat, vibration, pollution, contamination, etc. "
Natural conditions may apply to some elements of a ground-based facility eg: temporary clean tents and recovery vehicles. But some elements e.g.: sample preparation devices, may require testing in 'environmental chambers' in which the technology can be tested. These environmental chambers shall provide operational conditions of contamination (organic, particulate and biological), relative humidity, temperature, pressure, etc.

Note that the definition of TRL7 uses 'Operational Environment' instead of 'Space Environment'. This operational environment is represented with prototype testing within an operational facility using standard facility procedures and resources.
It is proposed that until an operational Facility exists, it may be required that a 'TRL6 development facility' be established with full design aspects of the SRF and operated using full SRF procedures, although much smaller in scale and using non-hazardous materials. This would allow technologies to be de-risked well before the establishment of the final (and first) operational SRF.

The only changes necessary to the Technology Readiness Levels are to the "flight" and "flight-proven" words, which are not applicable to ground-based equipment. Modifications will be made to the ISO definitions for space applications to allow for the ground-based nature of the Facility and its equipment. Proposed modifications to the TRLs are compared to the space application TRLs are shown in Table 1-2.

Level	ESCF	ESA Definitions
TRL1	Basic principles observed and reported	Basic principles observed and reported
TRL2	Technology concept and/or application formulated	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function and/or characteristic proof-of-concept	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL4	Component and/or	Component and/or

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	breadboard functional verification in a laboratory environment	breadboard functional verification in a laboratory environment
TRL5	Component and/or breadboard critical function verification in the relevant environment	Component and/or breadboard critical function verification in the relevant environment
TRL6	Model demonstrating critical functions of the element in the relevant environment	Model demonstrating critical functions of the element in the relevant environment
TRL7	Model demonstrating element performance demonstrated in an operational environment	Model demonstrating element performance demonstrated in an operational environment
TRL8	Actual system completed ***and "qualified" through test and demonstration.***	Actual system completed and accepted for **flight**.
TRL9	Actual system ***"qualified"*** through successful ***facility*** operations	Actual system "**flight-proven**" through successful mission operations.

Table 1-2 Comparison between Euro-Cares TRLs and ISO TRLs used for space applications (with differences in concepts highlighted in bold italic text)

This document proposes a development path for technologies identified as critical technology elements. The route to achieving TRL6 requires a *relevant environment* for test purposes. Demonstrating technologies to TRL7 and above requires their deployment in an *operational environment* within the C/D phase of an ESA project. Detailed information on developing the technologies to this level will not be detailed in this document.

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2. INNOVATIONS FOR RESTRICTED MISSIONS

2.1 Restricted Return procedure

2.1.1 Summary

The missions being discussed currently include:

- 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 (moons of Mars)
- Missions to planets other than Mars

The recovery process should be adaptable to all these sample returns and not be limited to Asteroid and Mars missions. For this reason, the scenarios were changed to 'Restricted' and 'Unrestricted'. The definitions of these are:

- 'Restricted' – Category V missions to bodies where there is a possibility of life.
- 'Unrestricted' – other missions.

Analysis of the nominal and non-nominal *unrestricted* missions resulted in the realisation that there was no difference between the recovery process 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 (i.e.: where some kind of breach occurs to the capsule)

2.1.2 Nature of innovation required

The flow of functions for a restricted mission is illustrated in Figure 2-1. 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 bio-containment 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 bio-monitoring system will not be able to be used after landing since it is not designed to survive hard landings.

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 ECSF for analysis.

If the ERC is determined to be damaged or the integrity of the seal is compromised, then the flow is classed as "non-nominal" (see red sections of Figure 2-1) and a temporary tent will be placed over the landing site (more details of this in the WP6.4 report on planetary protection aspects). 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.

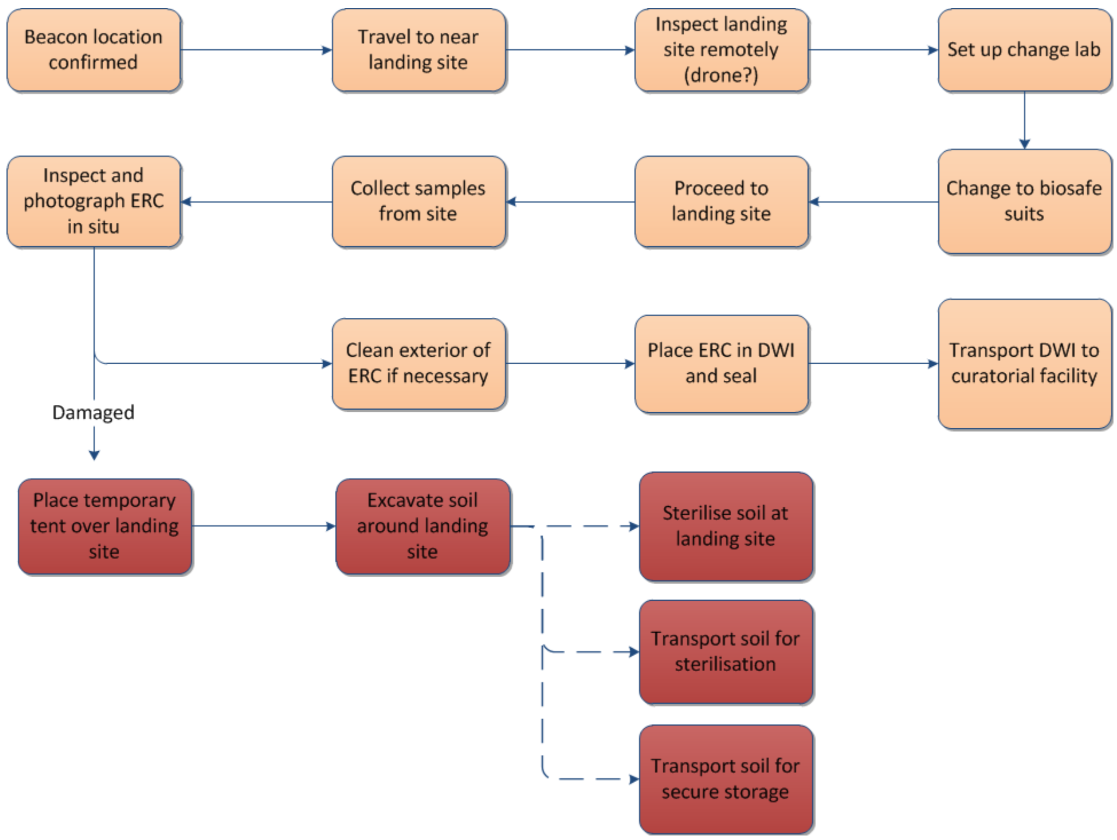

Figure 2-1: Functional flow for a Category V restricted mission (red section describes scenario for non-nominal mission)

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2.1.3 Criticality

This procedure is of the highest criticality to the success of a Mars Sample Return or other Category V restricted mission.

2.1.4 TRL level (non-technical)

This procedure has never been performed, despite considerable experience of unrestricted sample return missions. Although the whole process has not been performed in sequence, every aspect of the flow in fig 2-1 has been done separately and in a representative and relevant way, which places it at TRL 6.

The challenge for a MSR mission will be to test each segment of the functional flow with a flight like prototype (TRL 7) and then show actual system level technology in a qualified final form (TRL 8).

2.1.5 Timeline for development

The Genesis mission investigation board said that 'recovery contingency planning and training were not sufficient to ensure an adequate response to the incident that occurred', i.e.: sample breach on landing (Ryschkewitsch, 2006). For Stardust, recovery personnel trained for 4 days for nominal recovery and for the capsule opening on landing only (due to budgetary constraints), but according to experts, more training would have been helpful, see section 6.5 of WP 6.1). Landing at UTTR requires advance planning by up to 2 years as an example. Suggestions for restricted return have been given a margin of a year over unrestricted return. But it is possible that partial qualification of the process will occur via recovery of an unrestricted mission. In this case the timeline may be relaxed.

Proposed timeline:

T is defined as the landing time of the restricted sample return capsule on the Earth.

Negotiate Landing site location. T-4yrs
Field training and advanced preparation including environmental assessment, planning for clean tent setup, helicopter transport walk through. T-2yrs
Full recovery rehearsals T-1yr

2.2 Selecting a landing site

2.2.1 Summary

In terms of access and transport, it is important to consider requirements that may be imposed by a country on the free movement of material across its borders. For example, WP 6.1 made reference to issues concerning the transport of ITAR restricted items and WP 6.2 discusses the wider issue of international transportation of biological and hazardous substances. WP6.1 also discusses the lessons learned from previous return missions, all of which are CAT V, unrestricted in nature. In this sense, free movement within Europe and the transport of Category V unrestricted samples outside of Europe, is already managed and well defined by international customs law. However, any future Mars Sample Return mission will be an historic first attempt by any space agency to recover category V restricted samples. In terms of its scientific, political and societal impact, such a scientific mission may be akin to the 1960's Apollo programme that still resonates loudly in the 21st century.

Managing public opinion for large projects is crucial to their success and implementing a European led Mars Sample Return mission may require an innovative approach to public relations and a cross disciplinary approach to include the social sciences. For example, a study was undertaken by NASA and SETI (Race & MacGregor, 2000) that looked at the issue of public perceptions for a future sample return mission, undertaken by NASA. This study mainly focussed on a US-led mission, rather than a European project. It concluded that such an endeavour would be a matter of intense public concern and interest. NASA has invested heavily in public relations and cultivated an image that inspires confidence in the agency's capability to manage risk. It is important that such a perception of image can be mirrored within Europe and in the same way that medical developments engage with the public, a mission like MSR should also seek popular opinion from the start. A European study on public perception of Mars Sample Return, would inform our understanding of common perceptions for such an endeavour.

2.2.2 Nature of innovation required

A new approach within WP6.1 was to consider the potential of a European Mars Sample Return recovery at the Esrange Space Centre located in Northern Sweden. Covering a total area of 5,600 km2, the facility is comparable to other test ranges and may be appropriate for such a mission. Section 2.2.8 of WP 6.1 provided a "first look" summary table that highlighted the advantages and disadvantages of six ranges considered . The Esrange facility scored the highest marks in the comparison, although there was some technical uncertainty regarding a passive landing at the range (mostly relating to the flora and weather during the winter months). A detailed study should consider the Esrange facility in relation to a Mars Sample Return mission. ESA's Phobos Sample Return CDF study [2] could be used as a baseline for a passive recovery if the landing model was modified to include a Northern latitude of 67°53′N, 21°04′E.

2.2.3 Criticality

The landing site selection will be one of the most critical decisions in the sample recovery process. To use a European landing site such as Esrange would enable the development of considerable new experience in Europe; building on an existing know-how, capability and facilities. However, it will be necessary to engage early with the mission planning team so that the correct transfer trajectory and aero-shell profile can be implemented for a ballistic landing at a high latitudes. Furthermore, such development of experience would provide Europe with the autonomy to implement other sample return mission that could include Lunar, Phobos, cometary and asteroid samples.

2.2.4 TRL level (non-technical)

TRL levels do not really apply to a process such as the selection of the landing site. Europe has not been through the complex negotiation process necessary for securing and preparing a suitable landing site. Thus, there needs to be sufficient time to achieve this result. This is covered in section 2.1.5.

2.2.5 Landing Site Risk

In terms of risk, section 7.1 of WP 6.1 summarises aspects of a selected landing site (environmental, geological and industrial) that may be seen as detrimental risk factors that are deemed unacceptable to a Cat V restricted return mission. Due to the specialist nature of such a mission it will be necessary to consider, in detail, the individual risks presented by each landing site; a process than must be factored in to the selection time table.

2.3 Decontaminating a landing site

2.3.1 Summary

In the event of a non-nominal landing of the ERC, which includes a breach of containments, there may be a release of sample to the Earth environment. If the mission is designated as restricted return, then there will be a minimum requirement to continually monitor the area to establish if there are any adverse effects from the contamination. Decontamination of the landing area may be deemed necessary after assessment of the release i.e. sample type, mass of sample released and area it has been released into. If the sample has been released over a wide area then it may not be feasible (practically or financially) to decontaminate the landing site. If the contaminated area can be easily identified, in a small area and close to the surface then the contaminated soil can be collected, and transported to an appropriate decontamination facility, if the contamination is over a larger area, but one that is practical to decontaminate, then measures can be implemented. The most appropriate methodologies identified in WP6.4 that would be able to process large volumes of landing site soil would be either incineration or moist heat sterilisation (autoclaving). Large static autoclaves are the most likely to be able to fulfil the requirement to process a large volume of soil, although these would be difficult to transport to the landing site. But as highlighted in WP6.4, the simple containment of the soil and monitoring of the landing site could be an alternative option to soil decontamination.

2.3.2 Nature of innovation required

Please note that this is a description of the equipment which requires developing, not any new technology. In WP6.4, large autoclaves and incinerators are described. These are constructed in a purpose-built facility and are non-mobile as they require a large investment in terms of supply of their utilities (e.g. steam, electricity and fuel). Smaller autoclaves and incinerators are currently available for use in the field, but they have a greatly reduced capacity which makes them unsuitable for large volumes of waste material. Therefore, the production of an autoclave or incinerator with a capacity large enough to contain contaminated soil, in a volume that would

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make its treatment a viable method for decontamination could be developed. This is difficult to identify at present, but large fixed autoclaves can currently process up to 1,000kg/hr, this would equate to approximately 750 litres of top soil, so the internal capacity of the autoclave would need to be increased. Similarly, for incinerators, an increase to the internal capacity of the combustion chamber would be required. This will also allow for greater throughput of the mass of soil. Currently thermal desorption is used to volatilise chemical contaminants from the soil, but longer processing times might be required to ensure decontamination of the soil from biological contamination. There is also a need to ensure the power supply and steam generators for the autoclave will be mobile and can be transported to remote locations where the ERC might land.

2.3.3 Criticality

Whilst the need for decontamination of the landing site after non-nominal landing with sample release would be high, the chance of this occurring will be very low. The ERC will be designed to withstand a hard landing with Earth and there will be multiple layers of containment within it, which will reduce any chance of a sample release on landing. With these ERC design precautions, the likely need for the innovations to provide the capacity for the landing site decontamination is low.

2.3.4 TRL level

If a mobile incinerator was needed (it is not currently baselined), the TRL level for a large mobile autoclave or incinerator that can be deployed to a landing site would be 8 or 9 (as the equipment already exists and just needs to be scaled).However, this equipment would need to be designed and developed.

2.3.5 Timeline for development

Restricted mission
Identification and procurement of small scale autoclave/incinerator T– 43 months
Demonstration of practicality and sterilisation of landing site soil T– 39 months
Design of large scale mobile autoclave/incinerator T– 30 months
Construction of large scale mobile autoclave/incinerator T– 21 months
Demonstration and validation of large scale autoclave/incinerator at landing site T – 9 months

2.4 Portable covering of the landing site

2.4.1 Summary

Portable coverings can be used to protect the Earth return capsule (ERC) and the landing site from terrestrial contamination if there has been a non-nominal landing and a breach in the containment layers. Initial detection of loss of containment could be provided by sensors on board the capsule which would lead to the impact site being covered with a portable covering. If

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containment loss was only detected during initial inspection of the capsule then a portable covering may be deemed necessary to reduce any sample loss from environmental factors (wind, precipitation, etc.) and to protect the returned sample from Earth contamination through the same environmental factors. If the landing was catastrophic and components of the capsule and the sample were scattered over a large area (i.e. >100m^2) then a portable covering would not be effective and a future environmental monitoring regimen might be applicable.

2.4.2 Nature of innovation required

At present, there are a number of designs that are commercially available and already used in other areas, as previously discussed in WP6.4 The Impact of Planetary Protection, including forensic tents and hospitals. These tents can be designed and built to cover a large area, as can be seen from Figure 2-2 below. They are weather proof and can be erected quickly by a small team.

Figure 2-2. An inflatable structure used by Medicins Sans Frontieres for a hospital after an earthquake in Haiti. Image credit www.doctorswithoutborders.org

Innovations that could be considered are: a) An ante room for entrance to the portable covering to provide a further barrier for sample contamination or release. This would create a barrier from the external environment to the internal space. It would allow workers to don and doff any necessary personal protective equipment required for contacting the ERC; b) The use of a fan unit to introduce a positive/negative pressure cascade compared to the pressure outside of the portable covering. This would help to maintain the integrity of the sample or the environment. Maintaining the sample integrity would occur by introducing filtered air into the portable covering creating a positive pressure inside which would decrease any Earth contaminants from entering. By using a fan unit to draw air out of the portable covering (and passing the air through a filter) this would stop any released sample from contacting the Earth environment.

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2.4.3 Criticality

The need for a portable covering over the impact site would be determined by the environmental factors of the landing site, the capsule impact and the timescale for the retrieval of the capsule.

If there is a threat of adverse environmental factors that will affect the ERC or there is a containment breach in the ERC then a portable cover can be erected over the ERC. Whilst this item might not be required with a nominal landing it should be available and potentially taken to the impact site to be deployed if containment loss is discovered on inspection of the ERC. Therefore, its design and deployment can be seen as critical for the mission because the loss or contamination of the returned sample could cause a failure of the mission.

2.4.4 TRL level

Currently tents that could be used or developed for covering the impact site are commercially available and already used in other areas at a TRL level of 9, where they have been demonstrated for use in a relevant environment, such as covering outdoor crime scenes to prevent contamination or being used as hospital wards.

The development of a portable covering to be used for covering the ERC's impact site would need to be investigated. At present the existing portable covering structures could be tested for their suitability for the mission. This would be achieved by testing during training missions.

2.4.5 Timeline for development

Restricted mission:
Identification of suitable portable coverings for use: T– 11 months
Procurement of suitable portable coverings for demonstration/testing in an operational environment: T- 9 months
Demonstration/testing of portable coverings in an operational environment: T-6 months

2.5 Staff training

2.5.1 Summary

Using appropriately designed and tested protocols, staff will be able to collect and handle the ERC to ensure no damage occurs to it or there is no contamination to the sample from Earth, or vice versa. Previously, staff have been trained for the collection and transport of unrestricted return missions e.g. Stardust, Genesis and Hayabusa-1, therefore protocols and training used for these missions can be built upon for future missions. Training will need to be modified for each specific mission as the parameters will be different for each mission.

2.5.2 Nature of innovation required

Training will need to be given to staff for a number of different scenarios. Whilst there could be an almost unlimited number of variables that can be used in training, it would be prudent to focus on those which are most likely to occur or have occurred on previous missions. Then lessons learnt from these previous missions can be employed and the training enhanced. Training can be broken down into that which is applicable for both unrestricted and restricted missions, and training which is applicable only to restricted missions.

Innovations required for both restricted and unrestricted mission training would be:

- Detailed training plans
- Training records
- Competency assessments

Innovations required for restricted missions would be:

- Inclusion of appropriate Personal Protective Equipment (PPE) and its use for ERC collection, environmental sample collection and decontamination of the landing site.
- Training in more than one area of the collection process i.e. engineering to determine if the containment in the ERC has failed, sample collection for the environmental samples of the landing site, packaging and transport of the ERC.
- Requirements of a multi-team response, for example if there was a breach in containment then other teams may be required, e.g. to erect the portable covering for the impact site.

Training scenarios can be devised and used for the assessment of the staff selected to determine their suitability and competence. Problem solving skills can be identified during this phase and teams selected for those individuals that work together the best. Training areas can be broken down further for example recovery procedures for:

- Nominal landing
- Collection of the ERC after containment loss detected by sensors
- Collection of the ERC after containment loss found on collection

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- Collection of the ERC from water
- Collection of the ERC from mud
- Testing and demonstration of the transport of personnel and equipment to remote areas of the landing site in adverse weather conditions

2.5.3 Criticality

The training that would need to be identified and developed for the collection of the ERC is of a high criticality.

2.5.4 TRL level (non-technical)

Currently the TRL for unrestricted return missions is 9 if taken in the worldwide context. Restricted missions will be lower at TRL 7, as the concepts have been demonstrated in other environments e.g.: for outbreak containment.

2.5.5 Timeline for development

Restricted mission
Identification of the training needs could begin immediately using existing training for unrestricted missions. This could be adapted to the mission specific parameters (i.e. landing capsule design and landing site geography) when more details are known.
Development of specific scenarios for the recovery team to practice on, T- 18 months.
Practice and assessment on the scenarios developed T-12 months.

2.6 BioContainer for transport

2.6.1 Summary

The following layered structure for the transportation box for restricted samples (from internal to external layer) is proposed:

- A primary receptacle, generally the Earth Return Capsule (ERC)
- Absorbent material surrounding the primary.
- A secondary package, consisting of a plastic bag, preferably made in Neoflon (or KEL-F, perfluoromethylvinyl ether copolymer). Neoflon has a lower outgassing rate than Teflon, but, has a lower water, nitrogen and CO2 permeability. This guarantees a better sample insulation, which is important in the case of restricted samples.

- An outer package, with the following characteristics:
  - In most general case, made of stainless steel due to its low outgassing properties. If mass issues arise, titanium alloys could be a better choice. If both mass and cost issues arise, aluminium alloys would represent the best trade-off.

- Insulated and cushioned internal walls. Polymers commonly used for cushioning (e.g. polystyrene, polyethylene, polyurethane, polypropylene) have both a good mechanical resistance and a low outgassing rate,
- Wheels and mechanical supports for handling
- Filled with an inert gas, namely pure nitrogen
- Equipped with a pressure and a temperature sensor and valves for pressure control. Pressure of temperature inside the box depends on the mission requirements.
- An overpacking, consisting of a standard ISO container, including a laboratory to control the environment inside the box. Section 5.2 of WP 6.1 recommends the use of Intermodal Cor-Ten steel transport containers, commonly used for the international transportation of goods. The key advantage of such containers is a worldwide common interface to multiple transport modes including road (truck), rail, air and shipping with port infrastructure (ie. cranes) designed specifically to handle such containers without unloading the contents. In relation to Mars Sample Return recovery, ISO containers have been used for numerous scientific applications with modifications (e.g. cryogenic, gas and specialist internal environmental control) to meet the requirements of specialist research projects that has a mobile requirement to their infrastructure.

The following operations would be performed during the transport of the container:

- Real-time pressure monitoring and control
- Real-time temperature monitor
- Real-time contamination monitor

The following instrumentation for contamination is proposed:

- For ground transport: Thermal Desorption Tubes (TDT)
- For air transport:
  - Gas-Chromatograph Mass Spectrometer, if measurement sensitivity is the main requirement
  - Piezoelectric Crystal Microbalances (PCM), if it is needed to reduce the overall mass and/or costs (since the GCMS mass is 20-50 kg, whereas PCM's weight is less than 1 kg, including electronics)

The contamination after arrival can be retrieved by means of witness plates placed inside the box.
The schematic structure of the transportation box is shown in Figure 2-3. All details can be found in TN6.3.

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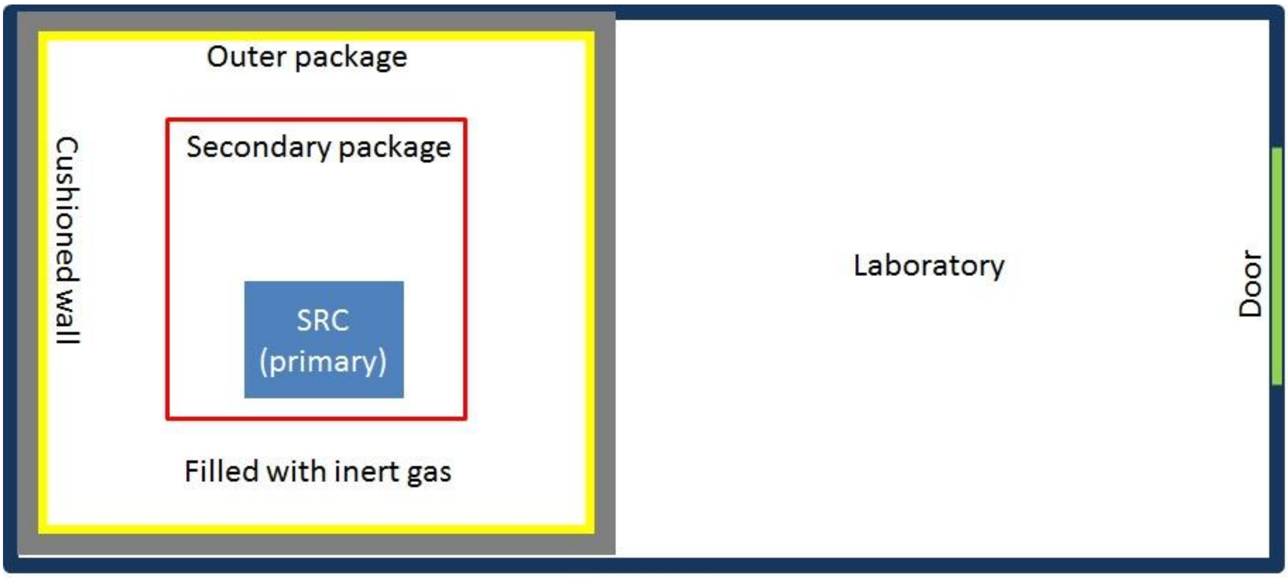

Figure 2-3 Schematic view of transportation box structure for restricted mission.

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.

2.6.2 Nature of innovation required

The basic concept proposed here is based on existing technology referenced in WP 6.1. There are two distinct technologies involved in transportation:

1. ISO container - which is a mode of transport containerisation that supports the transport box with specialist facilities (e.g. power, gas, laboratory etc.)
2. A specialist transport box for the probe and its samples

The main innovation is in the coupling of different materials/techniques (in particular instrumentation or laboratory (to control environmental parameters of the box) inside the ISO container).). The ISO technology is well established, see WP 6.1. The transport box should be designed to use any mode of transport that meet its requirements. The instrumentation should be able to monitor the environment inside the box according to the mission's requirement. The ISO container is a box that has the flexibility to house all manner of facilities. Laboratories and specialist instrumentation that has been accommodated many times inside an ISO contain as highlighted in WP 6.1.

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2.6.3 Criticality

The world has a lack of experience in restricted sample return missions. However, Europe has a lot of relevant experience in handling specialist samples from Ice and geological samples and the UK's experience in sub-glacial lake drilling.
Other criticalities may arise due to:

- Materials outgassing
- Regulations and rules of the country hosting the landing site
- Connecting the instrumentation with the ISO container

In the proposed basic design in TN6.3, we have discussed how to overcome these criticalities in the most general case, giving also different options, which can be applied to specific mission requirements.
However, a more detailed trade-off analysis should be performed once the sample requirements are identified and the landing and SRC recovery operations are determined.

2.6.4 TRL level

The technology for a Mars Sample Return (MSR) ISO container already exists; A collaborative project between academia, space industry and specialist shipping industry, should consider the use of a bespoke MSR ISO container facility and report on its feasibility, technical risk and anticipated cost.
This is the first time that a transportation box for restricted samples has been designed. At this stage, we have identified the technology concept of the transportation box at TRL 2.

2.6.5 Timeline for development

The activities for the development of a transportation box for a restricted mission should start at least 4 years before the planned scenario. A suggested timeline follows:

- T - 48 months for trade-off analyses
- T - 44 months for detailed design
- T - 32 months for manufacture (including ISO container and instrumentation development) and testing at sub-system level
- T - 16 months for testing at system level

This timeline is more extended than an unrestricted mission due to the low TRL level of the design in this kind of mission. It also takes into account possible unexpected criticalities (e.g. design can be changed if test failure occurs or a more intense testing activity may be needed).

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3. INNOVATIONS FOR UNRESTRICTED MISSIONS

3.1 Unrestricted Return Procedure

3.1.1 Summary

The procedure proposed for unrestricted missions for the ESCF is based upon tried and tested procedures already established for the Genesis, Stardust, Hayabusa and OSIRIS-REX missions. Lessons learned have been described in TN6.2 of this project. Thus, the proposed procedure requires no genuine innovations, however, most of this procedure would be new to Europe and all procedures would take a significant time to develop.

3.1.2 Procedures

The flow of functions for an unrestricted mission is illustrated in Figure . 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 as necessary as pyrotechnics may need to be safed and toxic gases may be emitted by heat shield. The personnel will then need to determine if there is any damage to the ERC 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 N2 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.

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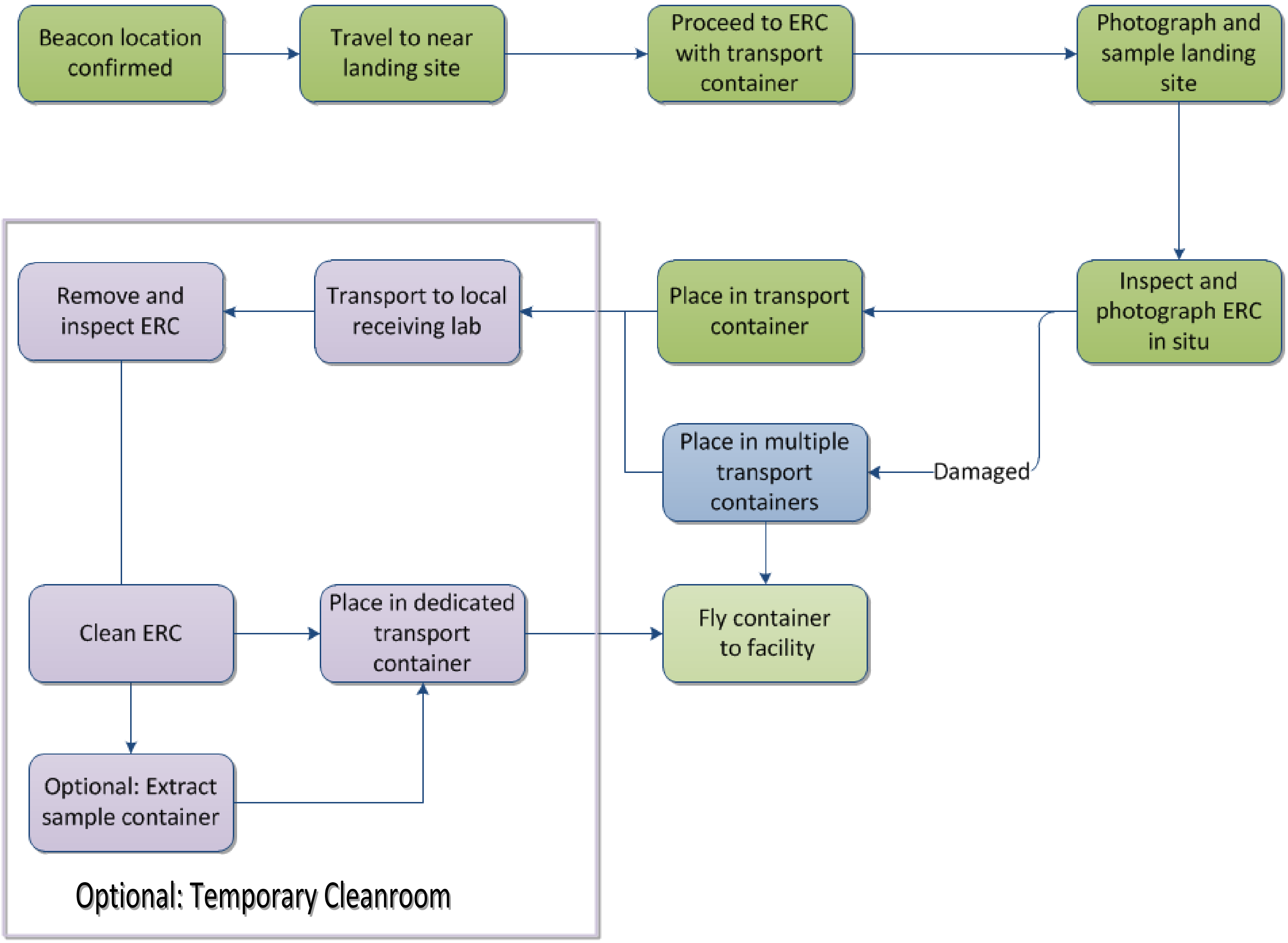

Figure 3-1 Functional flow for unrestricted missions

3.1.3 Procedures Criticality

All parts of the procedure are important, but it is suggested that those requiring practice/rehearsals due to their complexity and importance are:

- Locating and confirming the location of the ERC (i.e.: Beacon location confirmed)
- Any non-nominal landings
- Placing the ERC in the transport container (possibly involving handling equipment)
- Extracting the sample container if necessary

It is to be noted that in nominal landing conditions, extracting the sample container will occur (and be rehearsed) in the ESCF, so the same procedures will apply. Non-nominal landings will also require rehearsal.

3.1.4 Procedures TRL level

All the unrestricted return procedures would be at level 9 as they have already been tested by NASA and JAXA.

3.1.5 Procedures Timeline for development

Lessons learnt from previous missions show that comprehensively rehearsing contingency plans is very important to ensure good preparation. Further margins may be necessary if a new landing site is proposed.

Proposed timeline:
Negotiate Landing site location. T-3yrs
Field training and advanced preparation including environmental assessment, planning for clean tent setup, helicopter transport walk through. T-2yrs
Full recovery rehearsals T-1yr
Temporary cleanroom construction T-6months
Temporary cleanroom installation T-3months

4. DEVELOPMENT ROADMAP

4.1 Current plans for Mars Sample Return missions

The mission architecture that is used for this study is the International Mars Architecture for the Return of Samples (iMARS). This was established in 2006 by the major space agencies (see Figure 4-1), who were already cooperating in the framework of the International Mars Exploration Working Group (IMEWG). The objective of iMARS is to ensure that the science return for the Mars Sample Return mission is maximised.

The first iMARS report was released in 2008 (iMars WG, 2008) and the second iMARS report, addressing a baseline implementation approach for MSR with identification of critical challenges and opportunities, was released in March 2017.

Figure 4-1 International Mars Architecture for the Return Samples (Smith, Haltigin, 2016)

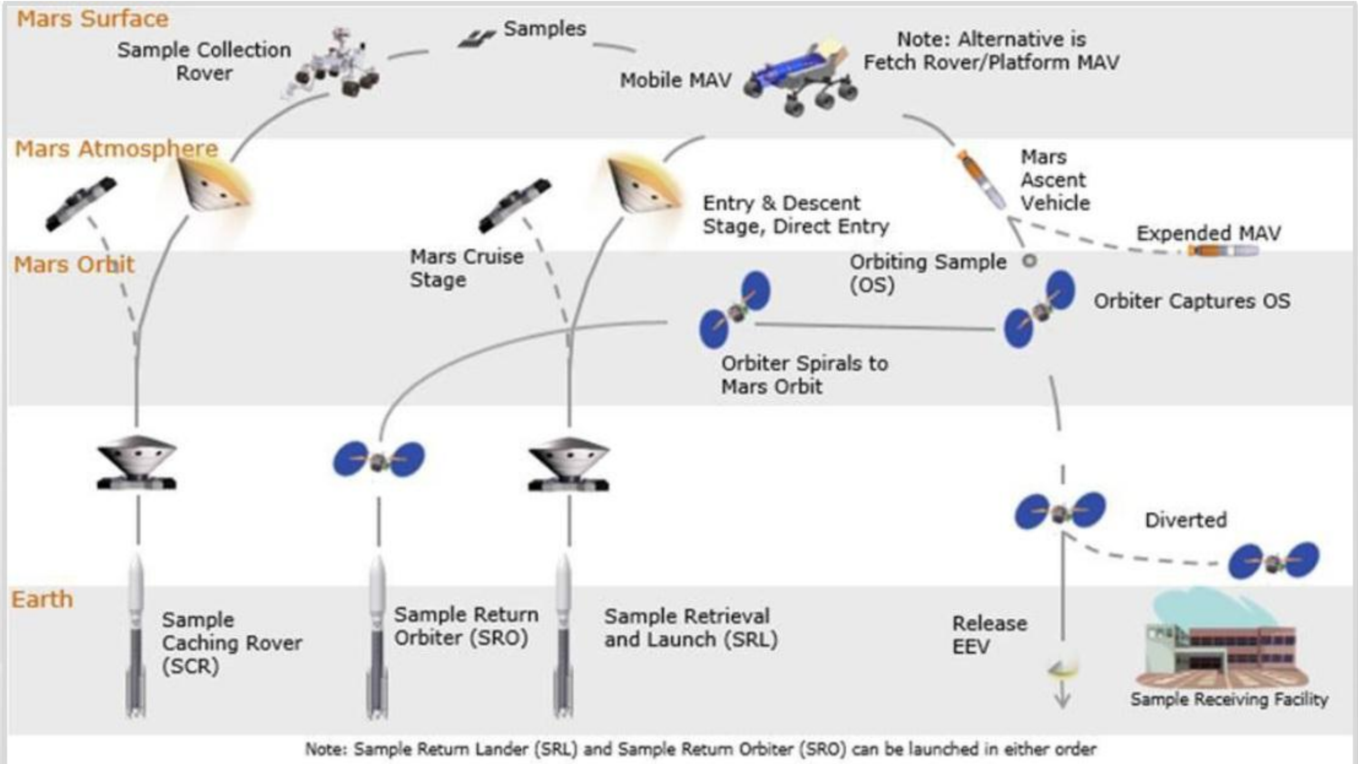

Figure 4-2 Overview of iMARS2 Reference Architecture mission elements (3+1) (Smith, Haltigin, 2016)

4.1.1 iMARS2 Flight Hardware

Four mission options are offered by iMars2 ranging from a single launch to four launches (Smith, Haltigin, 2016). Currently, the "3+1" launch option 'is considered the reference architecture for the MSR mission. This consists of 3 launches. This mission is expected to require:

1. A Sample Caching Rover (SCR) launched in JUL-2020 (currently known as NASA Mars2020), comprising:
   - Mars Descent Module
   - Sample Caching Rover with Sample Tubes (STs*)
2. Sample Return Orbiter (SRO) launched in SEP-2024, comprising:
   - Sample Return Orbiter with Bio-Container (BC*)
   - Earth Entry Vehicle (EEV*)
3. Sample Retrieval and Launch (SRL) – Rover launched in NOV-2028, comprising:
   - Earth/Mars transfer stage
   - Mobile Mars Ascent Vehicle (MAV) with Orbiting Sample (OS*)

Note that the elements of flight hardware returned to Earth, which will be handled by the Remote Manipulation (RM) system in the Mars Sample Receiving Facility are marked '*'. In

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addition to the identification of the elements of a reference architecture for the Mars Sample Return mission (Figure 4-2), a notional campaign timeline has been developed for a sample return in September 2031 (Figure 4-3). This also gives a timeline for the development of a Mars Returned Sample Handling Facility which shows build commencing in 2025 and a landing of the ERC in Sept 2031.
So, the latest that an ESCF could be operational is by this date. However, it would be desirable to use the facility for other sample return missions and these could also provide valuable training for the challenge of a restricted mission.

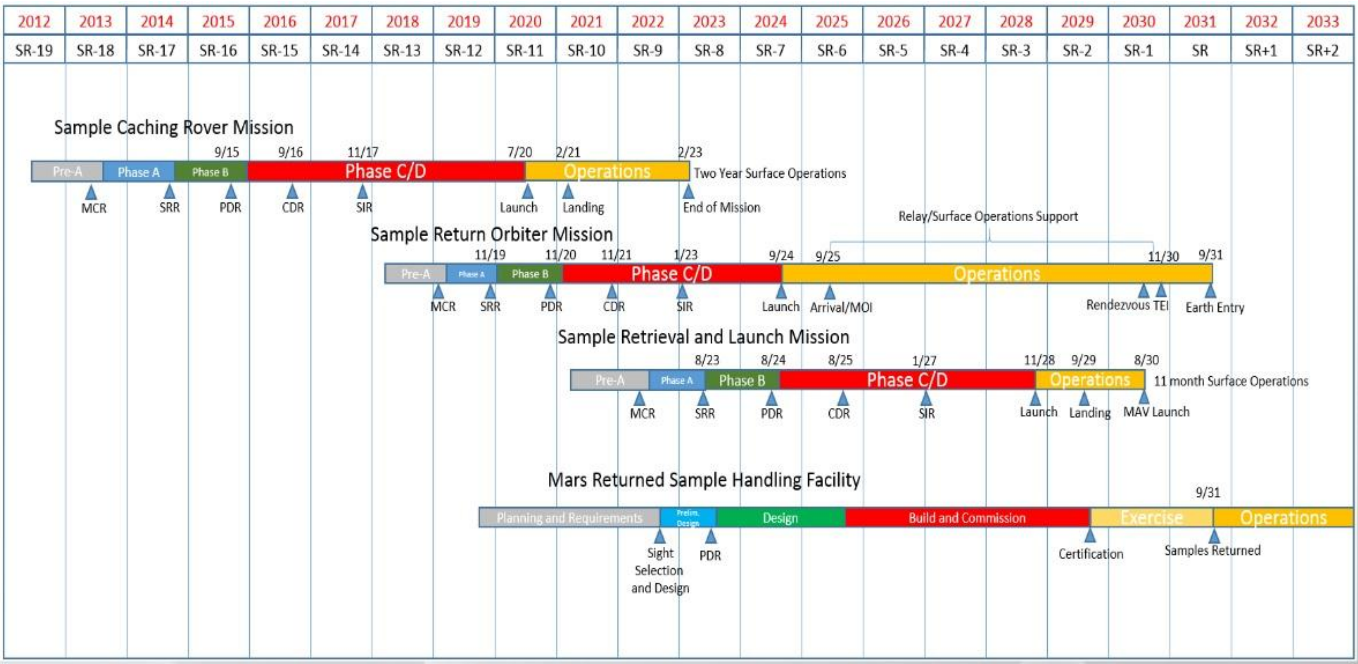

Figure 4-3 Mars Sample Return Campaign Timeline (3+1 option) (Smith, Haltigin, 2016)

4.2 ROADMAP

Roadmaps relate developments to timelines. The proposed development plan is approximate, but identifies the timescales over which the innovations identified could be demonstrated.

The suggested timelines of development presented in section 2 are summarised in chronological order in Table 4-1. This provides a timeline for restricted missions only as this is where the vast majority of the innovations are necessary. T is defined as the ERC landing date.

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Restricted Mission

Timeline	Actions
T-48 Months	• Trade off analysis/ detailed design of Transport box. • Identification & procurement of small scale autoclave/incinerator • Negotiate Landing Site location • Demonstration of practicality and sterilisation of landing site soil. • Identification of training needs.
T-36 Months	• Manufacturing of Transport box • Design of large scale mobile autoclave/incinerator
T-24 Months	• Field training of staff • Construction of large scale autoclave/incinerator • Development of specific scenarios for recovery practice. • Testing of Transport box at system level
T-12 Months	• Practice and assessment of scenarios developed • Identification of suitable portable coverings for use • Full recovery rehearsal
T-09 Months	• Demonstration and validation of large scale autoclave/incinerator • Procurement of suitable portable coverings
T-06 Months	• Demonstration and testing of portable covering in operational environment

Table 4-1: Suggested Timeline of Events for Restricted Mission

Figure 4-4 below summarises the timeline of developments with respect to the ERC landing date 'T' and the x axis representing time until this date (for example, point 50 on this graph indicates 50 months before T, or T-50 months). This chart assumes no delays from other areas of the project.

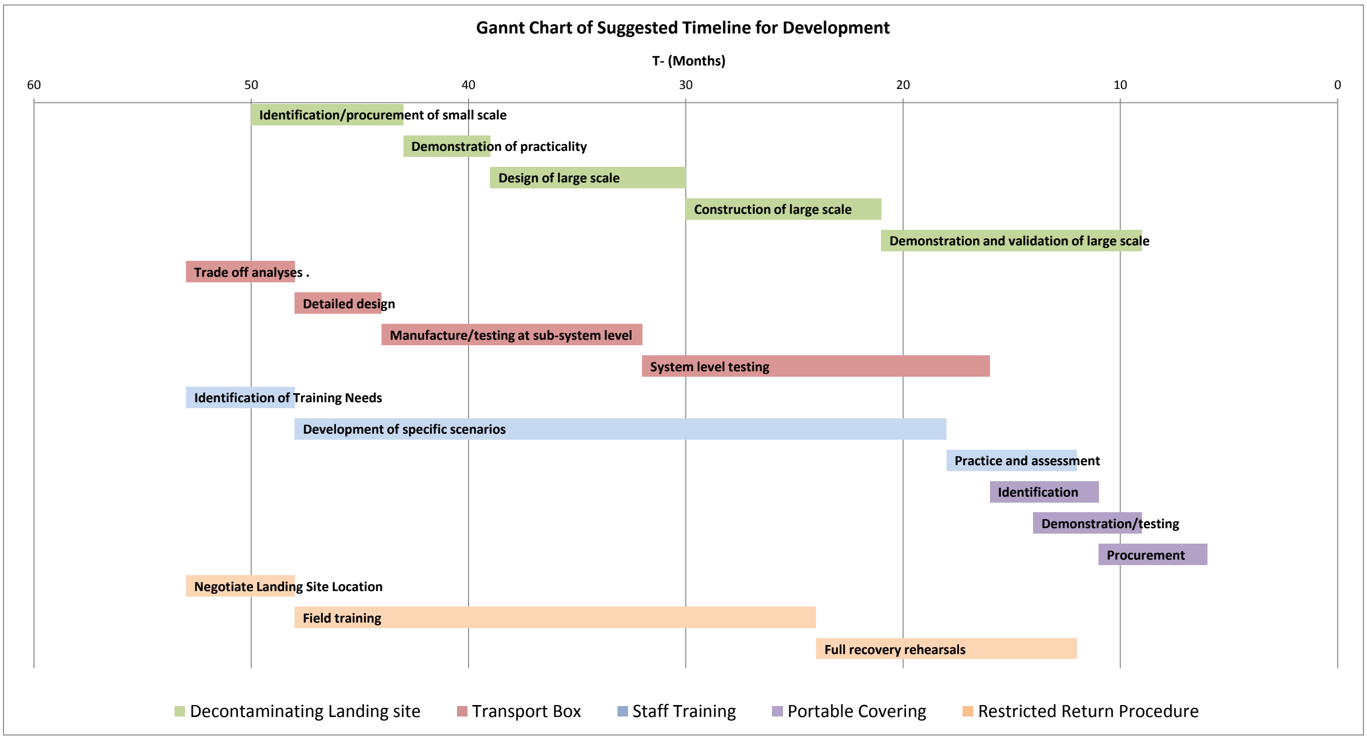

Figure 4-4 Gantt Chart of Developments Required for Restricted Mission

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5. CONCLUSIONS

The innovations necessary to this Work Package have now been identified and their nature has been described. Innovations for the World cover the restricted return procedure, the decontamination of a landing site, the portable covering of the landing site, the training of staff for a biocontainment recovery, an autoclave/incinerator, the ISO biocontainer and the transport box. In the case of Europe, the innovations include the selection of the landing site, if it is European, and the unrestricted return procedure (as this has not been carried out in Europe yet).

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

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

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

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

OPEN

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6. REFERENCES

iMars Working Group (2008) "Preliminary Planning for an International Mars Sample Return Mission Report of the International Mars Architecture for the Return of Samples (iMARS) Working Group", June 1, 2008. https://mepag.jpl.nasa.gov/reports/iMARS_FinalReport.pdf. Accessed 29/03/17.

ISO 16290 (2013) "Space systems – Definition of the Technology Readiness Levels (TRLs) and their criteria assessment ".https://www.iso.org/obp/ui/#iso:std:iso:16290:ed-1:v1:en accessed on 29/03/17

MEPAG (2017)

Race, M.S. and MacGregor D.G. (2000) "Integrating public perspectives in sample return planning", Advances in Space Research, 2000, Elsevier.

Ryschkewitsch, M. et al (2006). "*Genesis Mishap Investigation Board Report, Volume I*" (.PDF). NASA 13 June 2006. Retrieved 2010-05-01.

Smith, C. Haltigin, T and iMARS Phase II WG, (2016) "International Mars Architecture for the Return of Samples (iMARS) Phase II: Findings and Recommendations" https://mepag.jpl.nasa.gov/meeting/2016-03/13_iMARS-FinalPresentation_MEPAG_2016-03-02_FINAL.pdf. Accessed 29/03/2017. Note: PRE-DECISIONAL FOR DISCUSSION PURPOSES ONLY

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