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

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

WP6.2: Recovery and Inspection of the Sample

Written by	***Lucy Berthoud*** ***Mike Guest*** ***Ysatis McCulloch*** ***Anthony Buckley***
Verified by	***John Vrublevskis***
Approved by	

Approval evidence is kept within the documentation management system.

OPEN

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
0.1	17/02/16	First issue	LB
0.2	23/03/16	Content added	LB
0.4			LB
0.5			MG
0.6	10/06/16	Updated requirements	AB
0.7			
0.8	21/06/16	Product breakdown structure explanations. Requirements comments updated.	AB
0.9			
0.10			
0.11	05/07/16	Restricted/Unrestricted Discussions	AB
0.12	20/07/16	Figure numbers updated	AB
0.13			LB
0.14	25/07/2016	Merge of v0.12 and v0.13. Updated figure numbers.	AB
0.15	26/07/16	Introduction and Conclusions added	LB
0.16	16/08/16	Updates after review comments by JBV (TAS)	JV
0.17	25/08/16	Updates after review comments by MG (TAS), JB (UoL)	LB
1.0	31/08/16	Updates after review comments by WP6 team.	LB

OPEN

© 2016, Thales Alenia Space UK Ltd

TABLE OF CONTENTS

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

OPEN

© 2016, Thales Alenia Space UK Ltd

1. INTRODUCTION

1.1 Aims

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 which means 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). The scope of this overarching Work Package is broken down in to 5 smaller Work Packages to analyse:

- the preparation for recovery (WP6.1),
- the recovery and initial inspection (WP6.2), and
- transport to the Curation Facility (WP6.3)

with consideration of the :

- impact of Planetary Protection (WP6.4), and
- any technological innovations necessary (WP6.5)

Table 1-1 : Summary of Reports delivered for WP 6.

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

1.2 Objectives

The objective of this report for WP6.2 "Recovery and Initial Inspection" is to propose methods for recovery and inspection of Mars, Moon or asteroid samples. This will cover the activities at the time of landing, at the landing site, at any temporary facilities nearby the landing site and

© 2016, Thales Alenia Space UK Ltd

until the capsule is boarded onto the final method of transport which will take it to the receiving facility.

Further objectives of the work will be:

- To find out what procedures have been used by previous missions
- To determine what procedures are necessary for preparation for recovery of the sample
- To assess what tasks and facilities are necessary for recovery and initial inspection of the sample
- To determine how the procedures for recovery to be used will differ in the case of i) Restricted mission samples (which contain the risk of biohazard) and ii) Unrestricted mission samples.

1.3 Scope

The objective of this Work Package is to propose methods for the recovery and inspection of Mars or Lunar/asteroid samples from the landing site to the method of transport to the Curation 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.

Please note that portable receiving facilities for providing biocontainment will be covered in depth in report D6.4 'Impact of Planetary Protection'. Also, the transport container and general handling procedures will be covered in report D6.3 'Transport to Curation Facility'.

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) [RD22]. The design for Mars Sample Return (MSR), which is a driver for the process, is continually being updated so this information is also an input. Six experts from NASA and JAXA were interviewed to provide some lessons learned on the recovery process.

After this, requirements are developed for the infrastructure of the recovery and inspection process. A concept of operations is developed which describes the various phases of the recovery procedure for the entire Work Package 6. Any necessary trade-offs are considered next then the system of is defined in order to clarify what is in the system and what is outside the system. The functions and functional flow for 'restricted Category V' missions (material returned from Mars) and for 'unrestricted Category V missions' (material returned from the Moon or asteroids) is developed and then the different elements of the necessary infrastructure are described in product breakdown structures for both restricted and unrestricted missions.

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

Conclusions are described. From this work and with the results from the other sub-Work Packages in WP6, the critical areas for innovation will be covered in WP6.5.

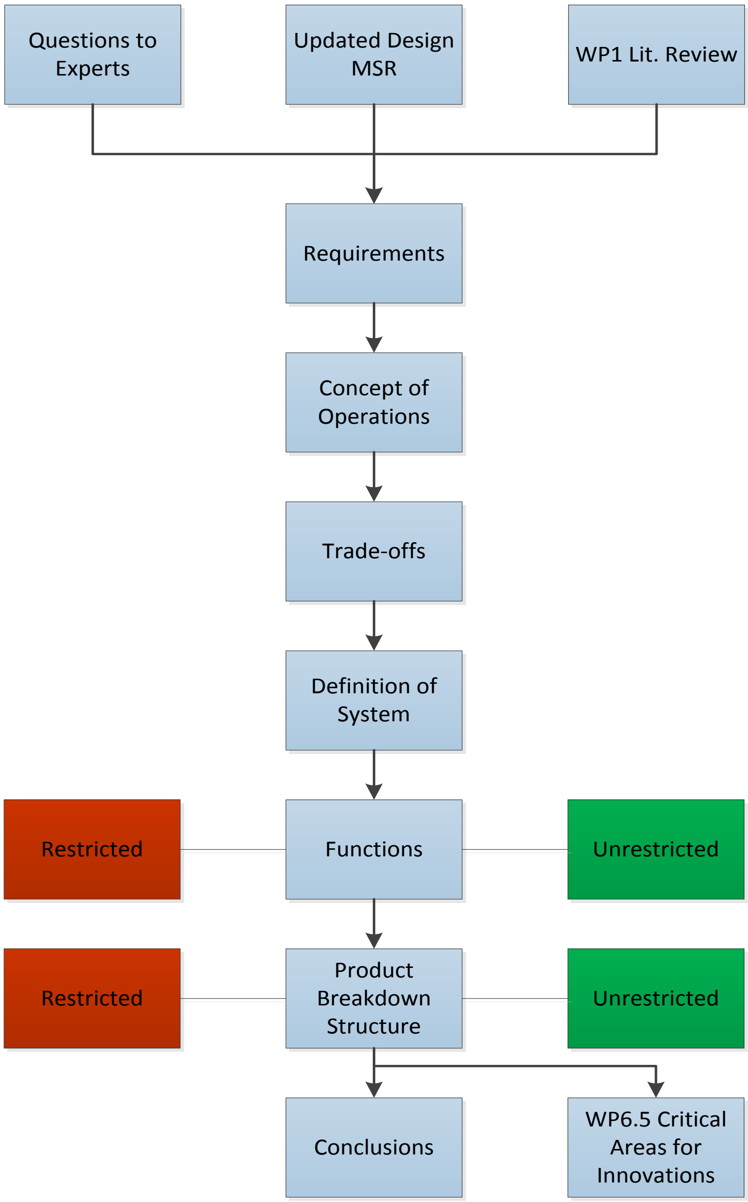

Figure 1-1 : Workflow for WP6.2 Recovery and Inspection

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

2. SUMMARY OF WP1

Work Package 1 section 6 report 'sample transport and recovery' (TAS UK, 2015) [RD22] provided a literature review and an initial investigation of the issues involved in designing the recovery phase of a sample return mission.

2.1 WP1 Mission lessons learned

The Work Package 1 report [RD22] gave an overview and background information on previous sample return missions: Genesis, Stardust, Hayabusa-1 and Osiris-REX. The information is summarised in this section.

2.1.1 Genesis (Recovery and Inspection aspects)

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 and was badly damaged. (Figure 2-1). 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 (JSC) for cleaning, documentation, storage, and allocation. It is believed that all of the collector plates and materials were recovered. The lessons learned for EURO-CARES from this would be:

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

© 2016, Thales Alenia Space UK Ltd

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

Figure 2-1: Genesis capsule recovery (Image credit : NASA)

2.1.2 Stardust (Recovery and Inspection aspects)

The Stardust Sample Return Capsule (SRC) was released from the mother spacecraft, and successfully parachuted to Earth above UTTR in the early morning hours on January 15, 2006 (Figure 2-2). 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 [RD27]). 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, 2010 [RD18]). 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. The samples received a police escort from Houston's Ellington Airport to the curation facility at JSC (Zolensky et al 2008) [RD27].

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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

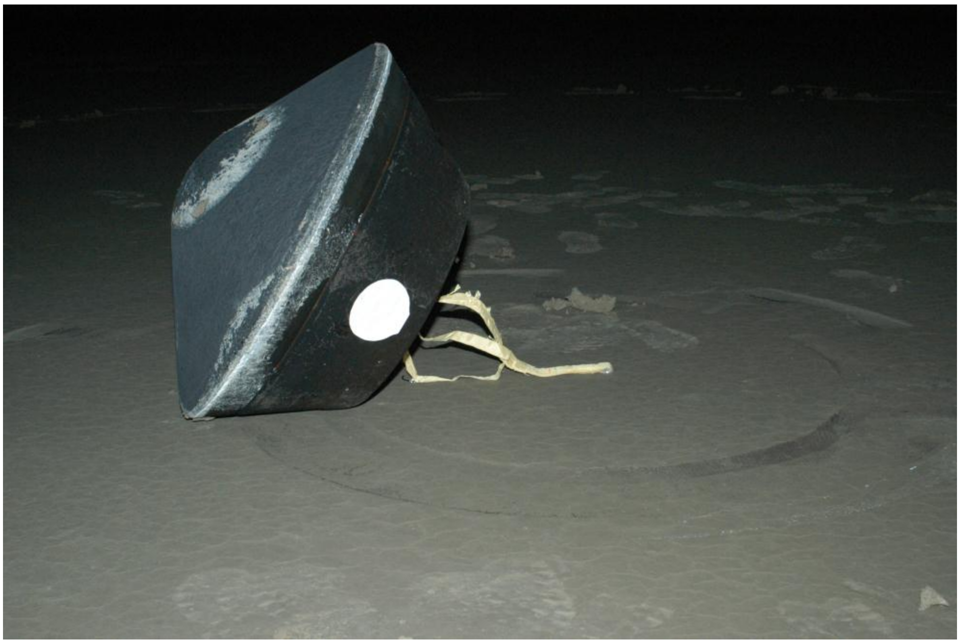

Figure 2-2 (Right) : Stardust sample return capsule at UTTR (Image credit: NASA)

2.1.3 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 due to 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 safing to ensure pyrotechnics and batteries are deactivated.
- Micromanipulation may be necessary to sort particles in the ECSF.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

2.1.4 OSIRIS-REx *(NASA) – Future Mission*

OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) is a NASA mission slated for launch in 2016 to encounter and sample Asteroid (101955) 1999 RQ36 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 similar to that used by the Stardust mission.

After a 2-year cruise, Earth atmospheric entry of the ERC will occur in September 2023 [RD6]. Four hours before entry, the SRC will be released from the spacecraft bus, and a divert maneuver 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 Utah Test and Training Range 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 [RD2]. 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 ECSF 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.

2.2 WP1 Recovery and Initial Inspection

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) [RD16].

In this section, the recovery and initial inspection of the sample is covered, with recovery of spacecraft parts, portable laboratories, temporary cleanrooms, the challenges of handling and the public perception of risk examined subsequently.

Table 2-1 : Comparison of recovery techniques from the Genesis, Stardust and Hayabusa missions.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

Mission	Recovery
Genesis	Transport to class 10000 cleanroom at UTTR then on to Curation Lab at JSC
Stardust	As above
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

2.2.1 Portable Laboratories

In addition to past mission operations, existing "portable laboratories" were examined. These mobile biocontainment facilities are used by public health organisations for disease outbreaks, environmental accidents and counter-terrorism. Examples are shown in Figure 2-3. 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 [RD13]). These portable laboratories were thought to be useful for adaptation when recovering Restricted Category V capsules (this has been discussed in WP6.1 and will be covered in more detail in WP6.4).

Figure 2-3 : Germfree Mobile Container Laboratories can be loaded on an aircraft, pulled as a trailer and transported by sea or rail. (Image: © Germfree).

2.3 WP1 Handling

There are a number of potential sources of damage including vibration and shock, and electromagnetic contamination. Additionally contamination such as that introduced by polythene bags used on the Stardust mission must be considered. Teflon is recommended if bags must be used. The orientation of the sample during transit was discussed. The ESF ESSC report (ESF-ESSC Study Group, 2012 [RD8]) discusses perceived risk and public perception of risk. It discusses the hazard vs the risk and the event chain necessary for substantial environmental consequences. In the same report it is suggested that «potential release scenarios are defined and investigated» in order to develop ways to respond. The area of handling has been transferred to WP6.3 Sample Transport.

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

3. LESSONS LEARNED FROM EXPERTS

3.1 Introduction

The previous section 2.1 gives an insight into the value of looking at previous sample return missions in order to learn for the future. In order to pursue this, a number of further questions were asked of experts from each of the missions previously mentioned. This section is the result of interviews and questions posed to these sample recovery experts:

Table 3-1 : Experts consulted for the 'recovery and inspection process' lessons learned

Expert	Affiliation	Mission
Judith Allton	NASA JSC	Genesis
Scott Sandford, Mike Zolensky	NASA JSC	Stardust
Masanao Abe, Hajime Yano	JAXA	Hayabusa 1
Kevin Righter	NASA JSC	OSIRIS REx

Please note: the information contained in the next section does not represent the views of these individuals' organisations, it is merely a collection of opinions gathered for the purposes of this study.

3.2 Contingency Scenarios

Contingency plans help to preserve the mission objectives when difficult circumstances occur. All past missions have analysed a number of contingency scenarios for the landing and recovery. There is a trade-off between thoroughness and financial/ time constraints to be considered in the selection of these scenarios, so it is particularly useful to establish what scenarios were considered for past missions and what actually happened in the recovery. This will help to build and plan future scenarios.

The Genesis mission included the following planning measures:

- Site visits 2 years before the return
- The recovery team had 'proper containers for samples should the need arise (6000+ on hand, more later) in a contingency situation'
- Environmental impact assessment
- Temporary cleanroom in a hangar at UTTR
- Helicopter fly through or dry run
- Full retrieval rehearsals 6 months prior to return

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 [RD17]).

After Genesis, Stardust planned more comprehensively for contingencies and had five main contingency plans based on the following situations:

1. SRC landing outside of landing ellipse

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

2. SRC not being found in a long time
3. SRC landing in water
4. SRC landing in mud (preventing nominal recovery operations)
5. SRC opening upon landing

In the case of the SRC landing in water, there were procedures established detailing how to move the sample while ‘minimising the redistribution of any ingested water and drain the water as best as they could in the field’. ‘The recovery team carried containers to collect all drained liquids since they might contain a sample’. Stardust also had detailed procedures for what would happen if the SRC ruptured upon landing. Recovery team members were ‘trained to search for loose aerogel under night time conditions’. Stardust also had contingencies for additional emergency materials that could be brought in when needed. Recovery personnel trained for 4 days for nominal recovery and scenario 5 only due to budgetary constraints, but according to experts, more training would have been helpful. No account was taken in the training and planning for bad weather and within a few hours of recovery, a snowstorm hit, grounding everything.

The Hayabusa mission returned to Earth in June 2010 at Woomera, Australia. Hayabusa was considered unrestricted in terms of planetary protection, but the Australian Government requested, as a contingency, that biocide be available to deal with a capsule breakage.

Figure 3-1: Hayabusa retrieval at Woomera (image credit: JAXA)

The future OSIRIS-REx sample return is planned to have contingency plans for a breached capsule including the availability of a class 10000 temporary cleanroom for engineers and scientists to work for many weeks after return. Landing at UTTR requires advance planning by up to 2 years, so this has already been negotiated.

3.3 Field Training

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

Field training and advanced preparation for the Genesis mission started 2 years prior to capsule re-entry. This included 'environmental assessment, planning for clean tent set-up, helicopter transport walk-thru etc.' Full mid-air retrieval rehearsals then started 6 months before re-entry. The Stardust mission trained for nominal recovery operations and for the SRC opening upon landing to minimise costs. The Stardust recovery team were lucky as the SRC almost landed outside of the recovery area and landed upside down resulting in limited usefulness of the recovery beacon. The majority of training started 6 months prior to Stardust re-entry and the frequency increased with time. More specialist training was necessary for UTTR to recognise unexploded ordinance and to be able to report it appropriately. Hayabusa was similar to other missions where rehearsal operations were run through many times. Clean rooms were built 2 years before the return and rehearsals were run for a year before the return. OSIRIS- REX is planning training in 2022 and 2023 for recovery operations in Utah, each training period lasting a few days. Lessons learnt from previous missions show that comprehensively rehearsing contingency plans is very important to ensure good preparation and reduce the risk of contamination but also to protect the Earth from extra-terrestrial samples in the case of a restricted Cat V missions.

3.4 Landing Site

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 UTTR, United States and Woomera, Australia. 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.

Figure 3-2 : Woomera after rain

The Stardust capsule and all other NASA sample return missions have landed at UTTR. It took 2 years for Lockheed Martin to get approval from military authorities for landing at UTTR for the

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

Stardust mission. This site has unpredictable weather and unexploded ordnance, so the recovery team had to walk behind range personnel for safety. For Stardust, part of the landing ellipse was in a 'restricted area' due to the presence of restricted weapons and should the capsule have landed in this area they would never have retrieved it. Due to the high military presence at UTTR there is difficulty in getting permission for using cameras.

3.5 Landing Technology

Genesis was the first US mission since the Apollo program to return samples. The parachute failed due to the inversion of G-switch sensors (accelerometers) (Ryschkewitsch, 2006). Hayabusa, Genesis and Stardust all employed active sub-sonic parachute deployment. All designs for sample return capsules have included pyrotechnics as part of the system in order to release the parachutes. However, as soon as the capsule lands, these pyrotechnics need to be deactivated. This is an important safety procedure. Currently the MSR baseline design uses a passive entry and descent aero-shell design, so no pyrotechnics will be present on the MSR return capsule and the battery for the beacon electronics will be designed to withstand a hard landing.

3.6 Environmental Measurements

The ideal weather conditions for sample return are cold and dry. Various measurements need to be taken at the landing site in order to determine what materials the capsule has come into contact with. This would enable scientists the determine if any of the samples have been contaminated. The Stardust mission took photos, soil and air samples at the landing site. It can also be noted that they would have taken samples of vegetation, local water samples or anything else that seemed relevant should the SRC be in close proximity to them, a mission expert said 'If we'd landed on a coyote, we would have sampled it!'

The verification of safe batteries was completed using direct-read sulphur dioxide and acetonitrile detectors and dissipated heat shield gases using an hydrogen cyanide analyser (Barrow et al, 2007 [RD5]). Gas samples were also collected in pre-evacuated metal bottles from near the heat shield of the SRC. This was done so that gases given off by the heat shield could be identified and recognised, should they show up later in sample analysis. The SRC temperature was also measured with an IR gun shortly after the recovery team arrived. Also an SO2 detector was used to confirm the capsule transponder battery had not shorted out.

3.7 Recovery and Inspection

When planning a sample recovery, numerous groups are involved. For UTTR, air force, army, navy, Department of Environment, munitions experts all needed to be consulted. During recovery rehearsals and actual recovery, the team is accompanied at all times by an armed soldier.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

After Genesis re-entry and recovery, "the plan was to get the canister on nitrogen purge ASAP to reverse any inward airflow and to dissipate heat transfer from the heat shield (it takes 10s of minutes to hours for heat to affect the canister contents – called 'heat soak'"). 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.

For Stardust, the Recovery Team were planning to travel to the SRC landing point by helicopter or by 'MATTRACK' (a pickup with wheels replaced by treads). It took a team of spacecraft engineers 2 hours to locate the capsule once it had landed. It was then moved to a class 10,000 (ISO class 7) modular cleanroom located in a facility at UTTR for preliminary processing (Zolensky et al 2008 [RD27]). Here the SRC was separated from the heat shield and back shell (Sandford et al, 2006 [RD18]).

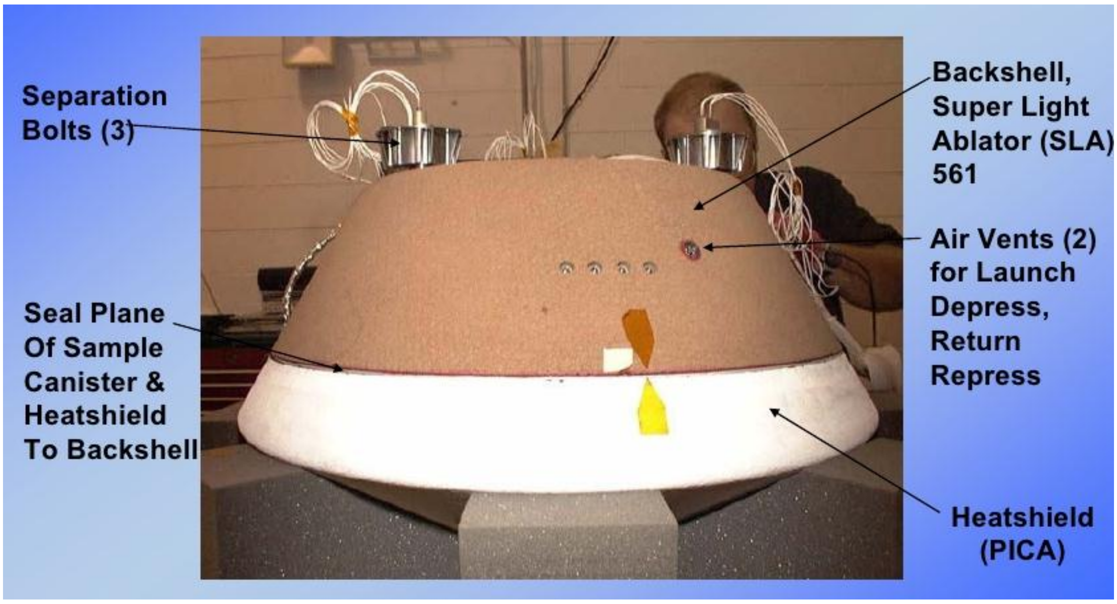

Figure 3-3: Stardust SRC. Image credit: NASA

The science canister was removed and secured in a clean transport container in this facility. The samples were then flown from UTTR to Houston's Ellington Airport in a National Guard C-130 military cargo aircraft where a police escort was provided for the journey to JSC.

The ERC was placed into a polyethylene bag for several hours causing the outgassing from the bag to contaminate the aerogel capture media with organic molecules (Sandford et al., 2006, 2010 [RD18]). 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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

Figure 3-4 : Hayabusa transportation box. Image Credit : NASA

During Hayabusa re-entry at Woomera, four ground teams located the re-entry capsule by optical observation and a radio beacon. Hayabusa took 16 hours before it was recovered. There are fewer radars and cameras at Woomera than at UTTR although this was not necessarily the reason it took longer to get to the landing site. Once the capsule had been located, a helicopter was dispatched and the GPS position of the capsule was recorded. After initial inspection the pyros (for parachute) were made safe at the landing site. Gas masks and a Geiger counter were used to approach the capsule initially. Following safing of the batteries, the capsule was placed into a container with a nitrogen atmosphere, for transportation to the Quick Look Facility (QLF) nearby. The container was put inside a cargo container which had air suspension to keep the capsule below 1.5G shock during transportation (Matsuda, 2015). After being processed in the QLF, a chartered plane was used to fly the samples to Japan where JAXA had built and equipped a specialist laboratory in Sagamihara. This laboratory was equipped 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.

3.8 Cleanrooms

The Genesis spacecraft parts were collected together in a temporary cleanroom in an aircraft hangar at the UTTR site. This class 10000 cleanroom was where thousands of spacecraft components and collector fragments were catalogued and packaged. These were then transported to the Genesis Curation Laboratory at JSC for cleaning, documentation, storage, and allocation. It is believed that all of the collector materials were recovered. Genesis, Stardust and Hayabusa have all used temporary cleanroom facilities near to the landing site in order to disassemble the capsule and prepare it for shipment to a sample return facility. Such tasks have included:

- Safe pyros

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

- 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 (in case of Stardust)
- Cleaning of canister (Stardust)
- Placing canister and spacecraft hardware in containers (Stardust and Hayabusa)
- Security (Hayabusa)

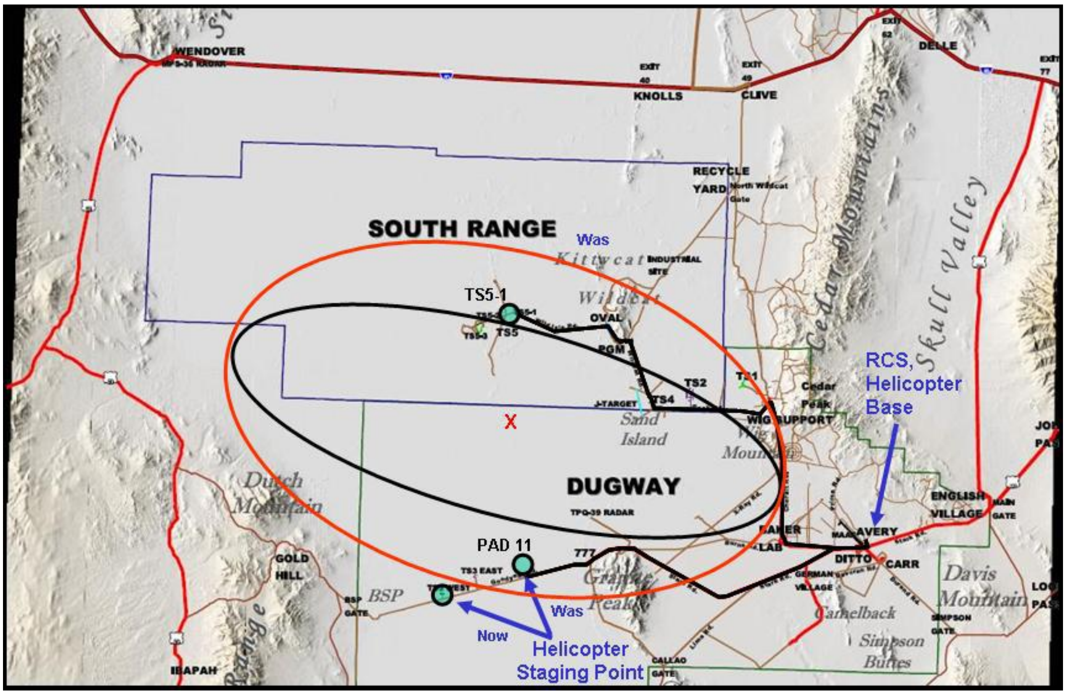

Figure 3-5: Stardust recovery ellipse at UTTR (Barrow et al, 2007, 2007 [RD5])

The temporary cleanroom was set up in a hangar 30km from the centre of the landing ellipse at UTTR, 2 weeks before the Stardust return (Zolensky at al, 2008 [RD27]). After recovery, the capsule was placed into a polyethylene bag at the landing site which was then removed an hour later in the cleanroom (see Figure 3-5). Outgassing products from this bag were later detected in the aerogel.

For Stardust, the capsule was opened in the cleanroom and sample canister removed. The sample canister was then 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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

Figure 3-6: Stardust and its bag. Image Credit: NASA

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 in order to monitor contamination with terrestrial materials. After the Hayabusa-1 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 safing 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 [RD1]). Setting up a cleanroom at the landing site is something that would need to be explored further as Lockheed said it would have been too expensive for Stardust.

3.9 Recommendations

The lessons learned from past missions can be used to create recommendations for ECSF 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:

1. Start landing site negotiations more than 2 years in advance of planned landing.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

2. Liaise with local governments and military to understand all regulatory aspects of a landing site, including cultural.
3. Plan for recovery in all areas of the landing ellipse.
4. 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.
5. All recovery personnel to be equipped with protection suits, clean tools, bags, containers to secure loose samples if necessary.
6. Make environmental measurements at the landing site using photography, taking soil, liquid, air and vegetation (if any) samples.
7. A temporary cleanroom is useful.
8. Container/s for fractured components should be available.
9. Cataloguing the many different fractured segments may be necessary from the point of landing
10. Use Teflon bagging (if necessary).
11. Provide containers for environment samples, spacecraft hardware as well as sample container.
12. Use an interim cleanroom for contingency scenarios and security.
13. Use N_2 purge for transport container for unrestricted missions.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

3.10 Summary of sample return capsule mass and size ranges

In order to design a recovery process which can be adapted to Mars, asteroid and lunar missions, it was considered useful to produce a summary of sample mass, capsule size and capsule mass for previous sample return missions (see Table 3-2). The capsule size and mass will affect the recovery handling procedures and equipment including transport options such as helicopters and trucks, ground support equipment such as cradles to support the capsule in transit and the necessity for lifting equipment at the site and at any temporary cleanrooms.

The mass of the sample chamber itself is critical as it affects the size of the Earth return capsule and size of the transport container and size of the sample return facility. The argument for mass and size is important in appreciating what services might be deployed at the recovery site. For example, a field-deployable BSL-4 shipping container could provide a biocontainment facility to transport a restricted return capsule (see report D6.1 for more details). Such a facility would need to be designed for these sizes. Also, any transport container (see D6.3 report) will need to be able to accommodate these sizes.

Table 3-1 : Sample and capsule details for previous sample return missions.

(Missions in grey have not yet been launched)

Mission	Sample mass (g)	Capsule size (m dia)	Capsule mass (kg)
Genesis	$2x10^{-5}$	1.5	191
Stardust	10^{-3}	0.8	46
Hayabusa-1	10^{-5}	0.04	18
Luna 16, 20, 24	101,55,170	N/A	40
Osiris Rex	60	0.8	50
Marco Polo*	2000	0.9	33
Chang'e 5	2000	2.5	600
Fobos Grunt	160	?	11
Phobos Sample Return	100	0.8	31
Mars Sample Return	500	1.5	100

*Capsule designed but never built and launched

The Chang'e 5 lunar sample return capsule will not be included in the generalisations as it is is a statistical outlier and future mission, however it is worth noting as it may change the paradigm if used for other missions. So, with the exception of Chang'e, from the table, it can be deduced that:

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

© 2016, Thales Alenia Space UK Ltd

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

These values will be included in the design drivers in the selection of ECSF infrastructure.

4. UPDATED DESIGNS FOR MARS SAMPLE RETURN MISSIONS

4.1 Earth Return Capsule Updates

Work progresses rapidly on the Mars Sample Return mission so the design is constantly evolving. Since the publication of WP6.1, more information has come to light.

The basic return capsule structure philosophy is one of 'breaking the chain of contact' between Earth and Mars. Therefore, samples are often double sealed with a further tertiary group seal of the canisters. Current designs for MSR capsule include a monitoring system for leak detection (see section 4.2).

Development of titanium and stainless steel alloy sample tubes (container where the actual sample is held) is under way with current designs achieving 10^{-7} atm-cc/sec He and presumed internal sample gas pressures being equivalent to local Mars atmospheric; approx. 6 mbar (Younse et al. 2014 [RD24]). Planetary protection requirements to monitor the integrity of sample seals has, to some extent, been relaxed in favour of incorporating, "…elaborate steps to guarantee that the sample canister is sealed at every stage of the journey." (Farmer et al. 2009 [RD10]).

As of March 2016, the MSR mission ('Mars2020) appears to be baselining an 'adaptive caching' approach (Farley, 2016 [RD9]). This involves collecting the samples directly into sample tubes, hermetically sealing the samples in the tubes then caching them directly (ie: 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. The sample and caching system Preliminary Design Review will be held on 19-20 October 2016.

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 is a biocontainer (BC). Inside the Biocontainer is a Sample Container (SC) and inside this 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 (BC) (see Figure 4-1 : Returned Sample Material Types and the containing hardware, (see [RD9] [RD19] & [RD24]) showing approximate size & weight of returned Sample Material & containing hardware).
Figure 4-1 and Figure 4-2) 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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

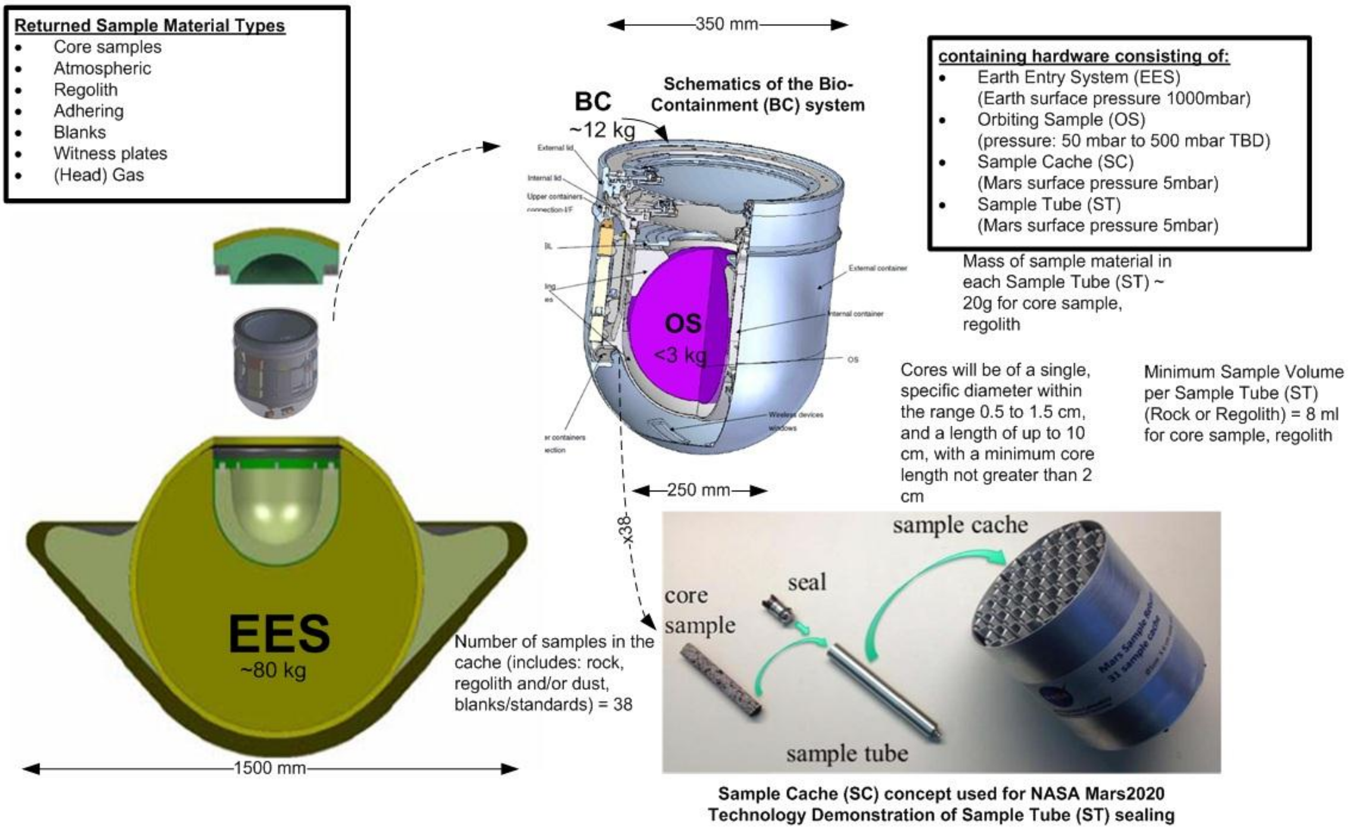

Figure 4-1 : Returned Sample Material Types and the containing hardware, (see [RD9] [RD19] & [RD24]) showing approximate size & weight of returned Sample Material & containing hardware).

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

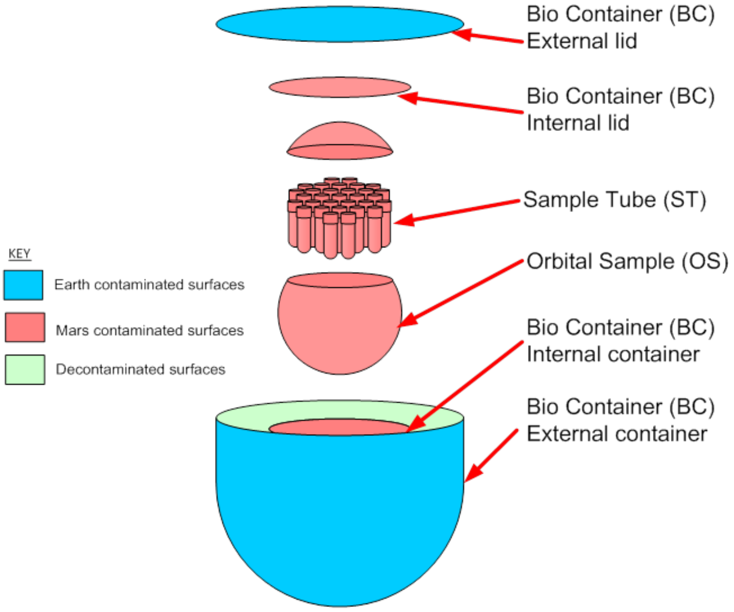

Figure 4-2 Biocontainer showing orbital sample and sample tubes within. Colour scheme shows Earth contaminated (blue) and Mars contaminated (red) surface

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

4.2 Biocontainer Monitoring

The Mars Sample Return biocontainer 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 intervessels chamber and chamber containing the samples is then monitored by reading the pressure and temperature from the Pressure /Temperature 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 Martian material. This is that the probability of contamination by a particle > 20nm in size shall be less than $1x10^{-6}$. This is the critical requirement all space segment designs are trying to meet. So by implication, in order to establish that there is no breach, the biomonitoring system would need to prove that the likelihood of contamination by a particle > 20nm in size is less than $1x10^{-6}$.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.

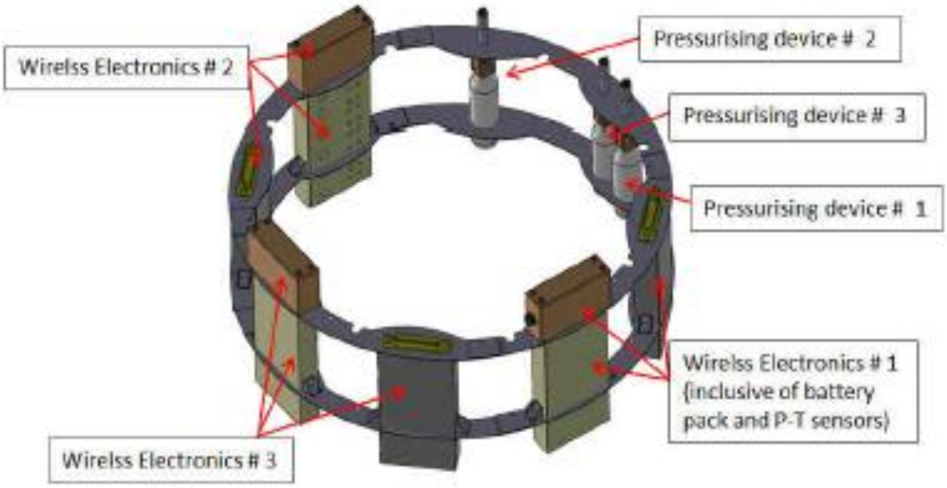

Figure 4-3 Monitoring system for biocontainer

4.3 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 reentry (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. These issues are treated in more detail in other Work Packages (WP3 and WP4) in the EURO-CARES project.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

5. RECOVERY AND INITIAL INSPECTION

5.1 Introduction

In this section, the recovery and initial inspection of the sample will be covered, with recovery of spacecraft parts, portable laboratories, the challenges of handling and the public perception of risk examined subsequently.

5.2 Requirements for Recovery and Initial Inspection

5.2.1 Introduction

The following are a set of proposed requirements for the recovery and initial inspection equipment and processes. Whilst the word 'infrastructure' is used to describe the equipment and processes involved in the recovery and inspection processes, please note that the infrastructure is solution–independent, ie: the infrastructure may comprise a set of equipment and procedures or may include large parts of infrastructure such as a cleanroom. Requirements will cover:

- Function (what it needs to do)
- Performance (to what standard it must perform to satisfy its function)
- Design (aspects of design that are predetermined by the function and performance)

The designations for the different categories of requirements are:

FR = Facility Recovery
FL = Facility Landing site
FI = Facility Infrastructure
FD = Facility Distribution
FO = Facility Operation

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

Table 5-1 List of requirements relevant to Recovery procedures

ID	Requirement Text
Recovery from Landing Site	
FR-10	The recovery team shall be able to recover all returned hardware from the landing site.
	Comment: No equipment shall be left at the landing site
FR-20	The recovery operation shall be adaptable to different mass and volumes of return capsule.
	Comment: The generic recovery operations should be able to handle equipment from a broad range of possible missions (up to a TDB limit)
FR-30	The recovery operation shall be adaptable to restricted and unrestricted category sample capsules.
	Comment: The recovery operation will be designed for Mars, Asteroid, Moon and other sample return missions and should therefore be adaptable to all possible recovery scenarios.
FR-40	The recovery operation shall plan for multiple contingency scenarios (TBD).
	Comment: A nominal situation should be considered as the baseline scenario with certain contingency scenarios (TBD) considered to ensure that all contingency equipment and personnel are available immediately once the hardware is located.
FR-50	Planning for non-nominal recovery shall not compromise nominal recovery
	Comment: Having the necessary contingency plans should not have a negative impact on any nominal recovery procedures. The recovery team should be adaptable for recovery in both nominal and non-nominal situations.
FR-60	The handling of the sample shall not introduce vibrations or shocks that could damage or destroy the sample (levels TBD).
	Comment: The sample should be handled with care in order to preserve the structure and integrity of the sample. There should be specific procedures outlining the correct methods for handling the samples.
FR-70	The capsule shall be placed within a transport container within TBD hours of landing (mission dependent)
	Comment: This could be further broken down into specific phases. Entry to location. Location to team on site. Team on site to placement within transport container
FR-80	Recovery operations shall conform to the laws and regulations of the country in which the hardware lands.
	Comment: Any religious or cultural circumstances at the recovery site should also be taken into account.
FR-90	For restricted sample return, the landing area shall be decontaminated by methods agreed with public health experts.
	Comment: Restricted missions will have the landing area decontaminated to reduce the risk of contamination by extra-terrestrial material.

© 2016, Thales Alenia Space UK Ltd

ID	Requirement Text
FR-100	The recovery operations shall conform to ESA Planetary Protection Requirements Category V for Earth return missions.
	Comment: The recovery operation will follow either redistricted or unrestricted earth return regulations set out in Category V of ESA's planetary protection requirements.
Transportation from Landing site	
FL-10	The transport container shall guarantee good insulation from the atmosphere, particulate and molecular matter whilst also avoiding organic contamination and preserving the integrity of the capsule.
FL-20	The capsule shall be contained within an ultrapure nitrogen atmosphere in the transport container.
	Comment: The transport container will be filled with N2 in order to prevent terrestrial contamination.
FL-30	The transport container shall protect the samples from any expected (TBC) mechanical shock and vibration experienced during transportation to the recovery facility.
	Comment: Air suspension may be used to absorb any shock during transportation thus retaining the integrity of the sample.
FL-40	Transport of the capsule within the transport container shall only be permitted after approval by the Recovery team leader.
	Comment: This will keep the chain of command clear.
FL-50	The safety and security of the samples shall be the responsibility of the Recovery team leader.
	Comment: This clarifies responsibilities.
FL-60	The transport container shall be able to withstand a temperature range of (TBD) degC.
	Comment: A wide range of temperatures during transportation may affect the integrity of the sample and therefore the container shall be able to insulate the sample.
Recovery Infrastructure	
FI-10	The recovery infrastructure shall be able to receive spacecraft capsules with dimensions of up to TBD m and mass of TBD kg.
	Comment: There must be sufficient room to store, work and examine samples.
FI-20	The recovery infrastructure shall contain the sample until it is safe for release.
	Comment: No samples will be released to the scientific community until they have been decontaminated and it has been determined that there is no biohazard risk present.
FI-30	The recovery infrastructure shall contain any restricted return samples to a biosafety level defined by Biohazard experts.
	Comment: Biocontamination experts will define the appropriate level of biosafety based on the category of mission and the mission status.

© 2016, Thales Alenia Space UK Ltd

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

ID	Requirement Text
FI-40	The probability that a single unsterilized particle of 0.2 microns in diameter or greater shall be inadvertently released into the Earth environment shall be less than 1x10e-6. (TBC).
	Comment: There should be an very low probability that a potentially hazardous particle is released into the Earth environment.
FI-50	The recovery infrastructure shall consider all parts of all elements inside the transport container as either A. Earth Contaminated, B. Extra-terrestrial Contaminated, C. Earth and Extra-terrestrial Contaminated or D. Decontaminated.
	Comment: The spacecraft parts and sample container will be categorised as above when put in to the transport container.
Preserve the Integrity of the Sample	
FC-10	The recovery infrastructure shall limit contamination of the samples by organic compounds (TBD levels)
FC-20	The recovery infrastructure shall limit contamination of the samples by inorganic compounds (TBD levels)
FC-30	The recovery infrastructure shall limit contamination of the samples by biological material (TBD levels).
	Comment: These are the standard biohazard requirements for missions requiring Planetary Protection.
FC-40	The recovery infrastructure shall maintain an environment with a temperature range of TBD, that will prevent degradation of the sample.
	Comment: This temperature range will take account of the physical state of the samples, the temperature range limits of the sample capsule and the requirements for the analysis at the ECSF.
FC-50	The recovery infrastructure shall maintain an environment with a pressure level of TBD, that will prevent degradation of the sample.
	Comment: This pressure level will be decided based on the pressure history of the sample capsule and the pressure requirements for the analysis at the Sample Receiving facility.
Operation of the Recovery Infrastructure	
FO-10	The recovery infrastructure will be operational TBD months before samples are returned to Earth.
	Comment: This will enable thorough testing of equipment and rehearsal practice before the samples return to Earth.
FO-20	The recovery infrastructure shall have an operational lifetime of TBD years after the samples have been returned to Earth.
	Comment: The recovery infrastructure will be used for other scientific analysis and possibly other future sample return missions.
FO-30	The recovery infrastructure shall develop and implement procedures for monitoring the health and safety of the personnel and the environment in and around the facility.

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

ID	Requirement Text
	Comment: These will become particularly critical in the case of the restricted return mission.
FO-40	The recovery infrastructure shall develop and implement procedures for the security of the recovery operation and the samples.
	Comment: The recovery infrastructure will be under a mission-appropriate level of security with restricted access.

5.3 Concept of operation for recovery and inspection

5.3.1 Introduction

The concept of operation describes the different phases of the recovery procedure. For a general overview, Figure 5-1 shows the overall 'concept of operations'. This covers the four parts of Work Package 6:

WP6.1 Preparation for recovery
WP6.2 Recovery and inspection
WP6.3 Transport to ECSF
WP6.4 Impact of planetary protection

The figure shows the flow of the samples through the process. On approach to the landing ellipse, the capsule 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 capsule in the air. Helicopters will also be used for visual tracking during its descent. Land vehicles can then be used for recovery of the capsule 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 'safed'.

Landing site environmental samples will be taken and atmospheric conditions recorded. The capsule will most likely be taken in a land vehicle to a temporary 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 ECSF 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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

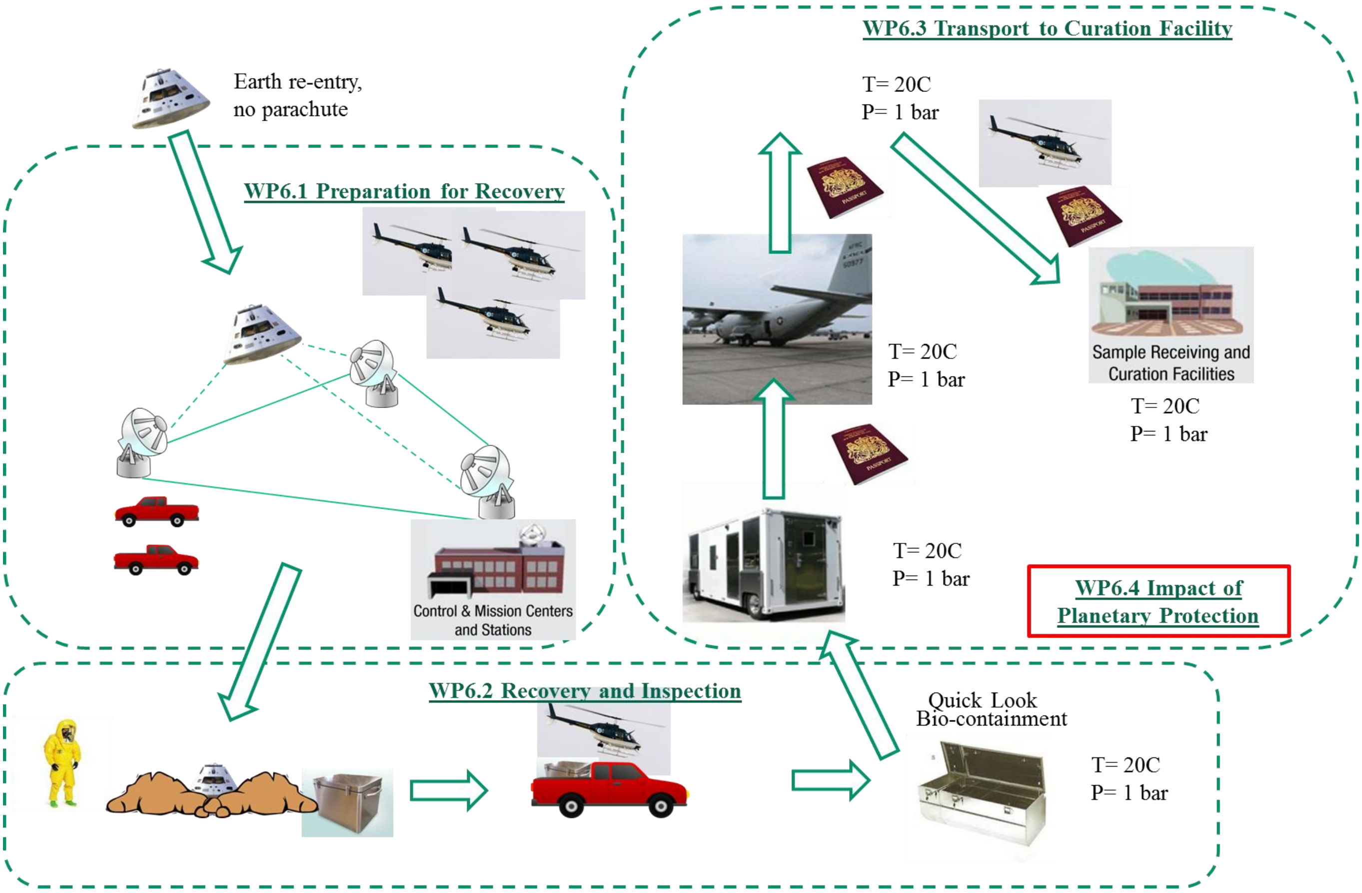

Figure 5-1 : Initial concept of operations for recovery procedure.

Initially the team agreed an approach to divide all possible missions into a more limited number of general scenarios:

1. Mars Sample Return nominal, ie: everything performs without any problems occurring,
2. Mars Sample Return non-nominal, ie: some kind of problem occurs which will affect the containment
3. Asteroid Nominal, ie: everything performs without any problems occurring
4. Asteroid Non-nominal, ie: some kind of problem occurs which will affect the containment

This is illustrated in Figure 5-2. However, it was soon realised that, with the breadth of mission possible, the categories of scenarios may need to be refined. 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 other planets than Mars

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

The recovery process should be adaptable to all these sample returns and not be limited to Asteroid and Mars missions. So 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 (ie: where some kind of breach occurs to the capsule)

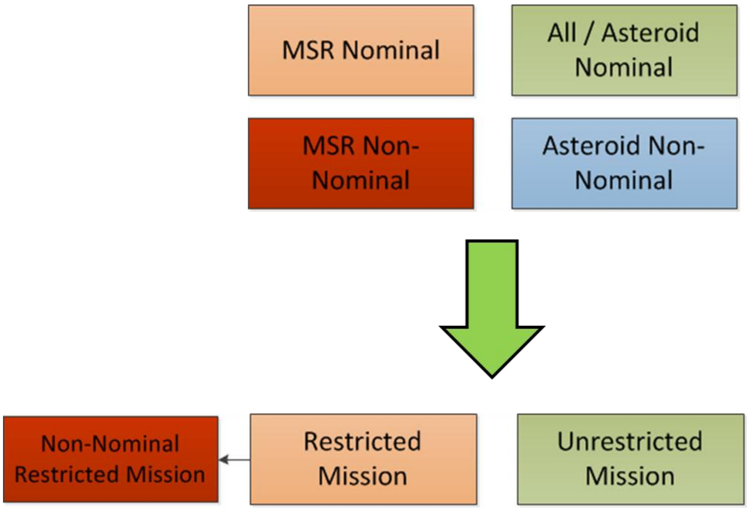

Figure 5-2 : How the initial scenarios evolved into two main scenarios

The following sections treat the functions required for each of these scenarios in more detail.

5.3.2 Restricted mission Flow

The flow of functions for a restricted mission is illustrated in Figure 5-3. 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

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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 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 5-3) 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.

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.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

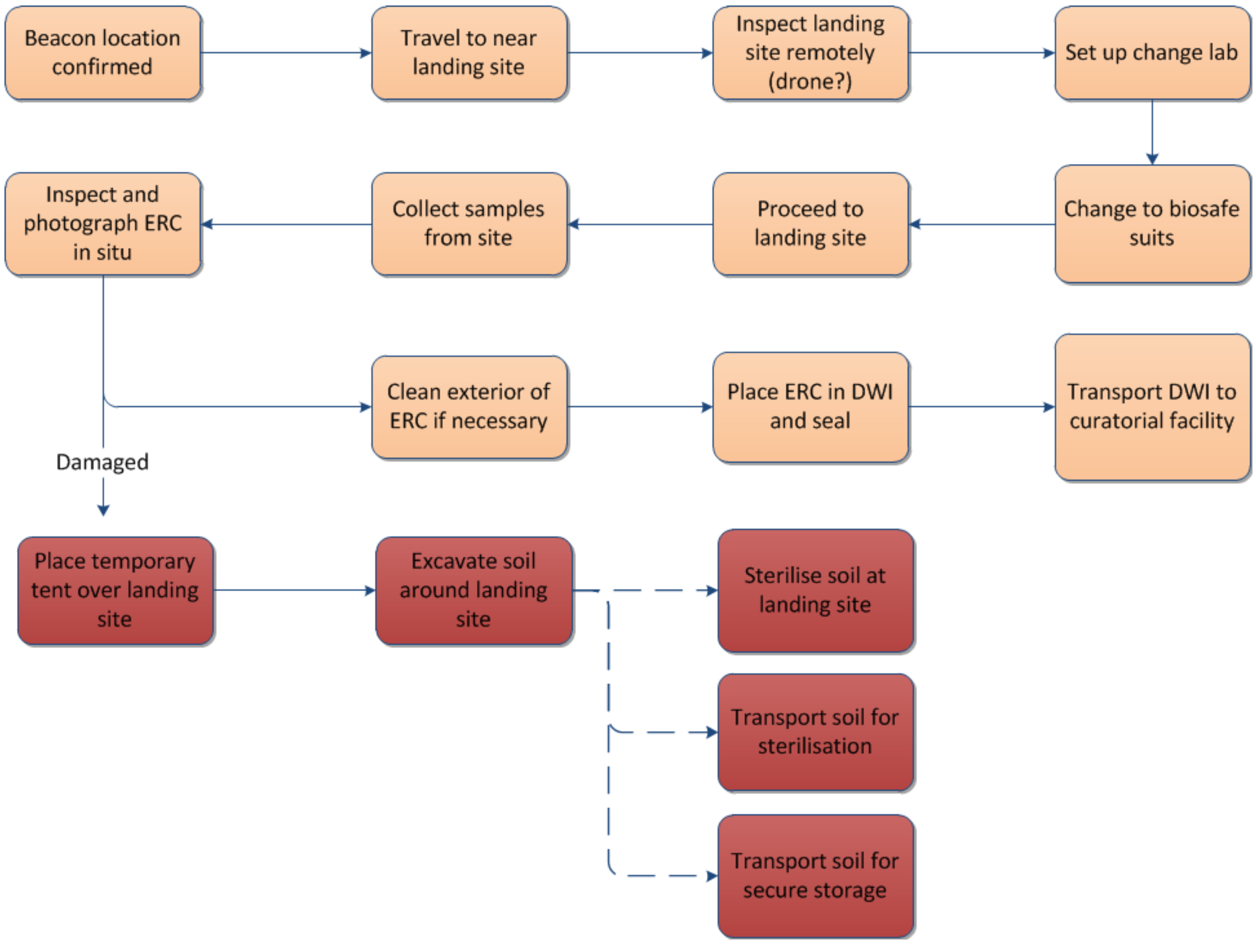

Figure 5-3 : Functional flow for a Category V restricted mission (red section describes scenario for non-nominal mission)

5.3.3 Unrestricted missions

The flow of functions for a restricted mission is illustrated in Figure 5-4. 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 safed 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 ECSF 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 ECSF. The container will be purged with N2 gas to

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

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

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 ECSF.

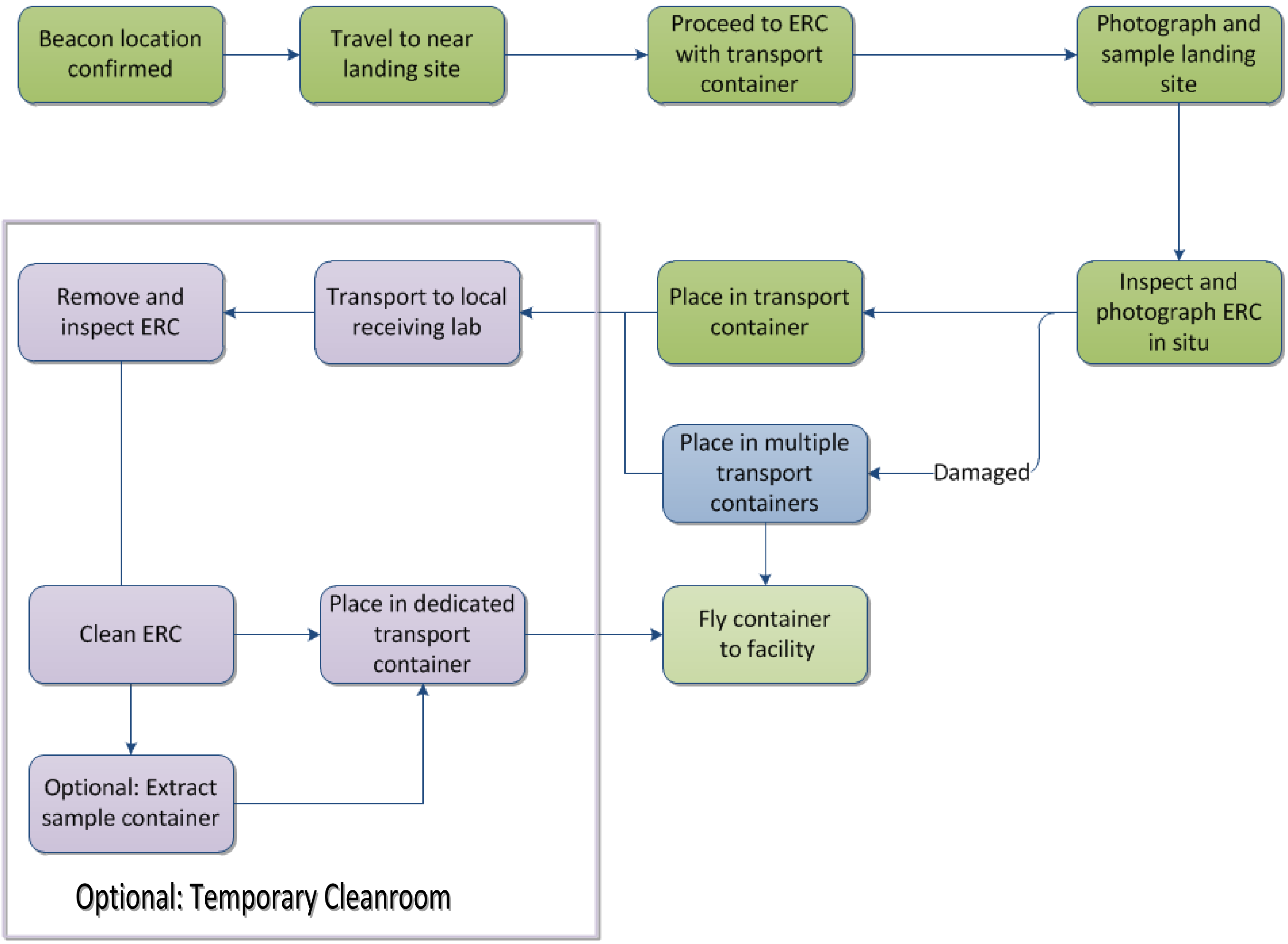

Figure 5-4 : Functional flow for unrestricted missions

5.4 Trade off for Temporary Cleanroom

5.4.1 Introduction

The idea of a temporary cleanroom, also known as 'Quick Look Facilty', has been mentioned several times in the course of this report. This section seeks to decide by means of trade-off whether this idea is a useful one or not in the context of the design of an ECSF.

Initially it is necessary to define the meaning of 'temporary cleanroom'. This is taken to mean a modular cleanroom which is installed inside another building (typically a military building on the site of a test range /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

© 2016, Thales Alenia Space UK Ltd

from the existing building to power the fans. The cleanroom can be installed in a day or two and removed just as easily.

5.4.2 *Trade-off*

Temporary cleanrooms of 10000 class have been used in all the previous missions that have been examined in section 3 of this report. In the past these operations have included:

- Safe pyrotechnics
- Disconnect batteries
- Removal of electronics
- Disconnect power sharing circuit to beacon (Hayabusa)
- Back shell removed from heat shield (Stardust)
- Collecting up of spacecraft components, cataloguing and placing in containers (Genesis)
- Opening of sample return capsule to extract canister (in case of Stardust)
- Cleaning of canister (Stardust)
- Placing spacecraft hardware in containers (all missions)
- Security (Hayabusa)

Figure 5-5: Genesis Temporary Cleanroom at UTTR

(Image credit: NASA)

The trade-off is covered in table 5-2 where the pros and cons of providing a temporary cleanroom are discussed. The table is applicable to all unrestricted missions. Further discussion is needed with respect to any restricted missions, where the need for biocontainment means

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

that a temporary cleanroom is not suitable and the sample capsule should be transported directly to the sample return facility.

Table 5-2 Advantages and Disadvantages of a temporary cleanroom for unrestricted missions

	Temporary Cleanroom	**Fly capsule directly to Curation facility**
Pros	• Flexibility if situation is non-nominal • Possible to safe spacecraft by disconnecting pyrotechnics, batteries, avionics in a clean environment. • Possible to clean outside of capsule • Collect parts of spacecraft if damaged (eg: Genesis) • Possible to remove canister from return capsule in clean environment. • Provide security for capsule.	• 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.	• Risk: if situation is non-nominal, then it may not be possible to accommodate all scenarios by operations at landing site. • Nitrogen purge needs to be installed as soon as possible.

Overall, it is apparent that there are many benefits to having this facility available, 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.

5.5 Definition of System

It is standard practice when architecting 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 objects and agencies. For the recovery and inspection Work Package WP6.2, the system was defined by the dashed boundary, as shown in Figure 5-6.

The recovery and inspection system has as an input the Earth Return Capsule and various functions including organisation and management of the entire process (covered in WP3), political, ethical, legal and social aspects of establishing the recovery procedure (covered in

© 2016, Thales Alenia Space UK Ltd

WP6.1). Whilst the transport container is an integral part of the recovery procedure, as it is covered in WP6.4, it is defined as outside with the system.

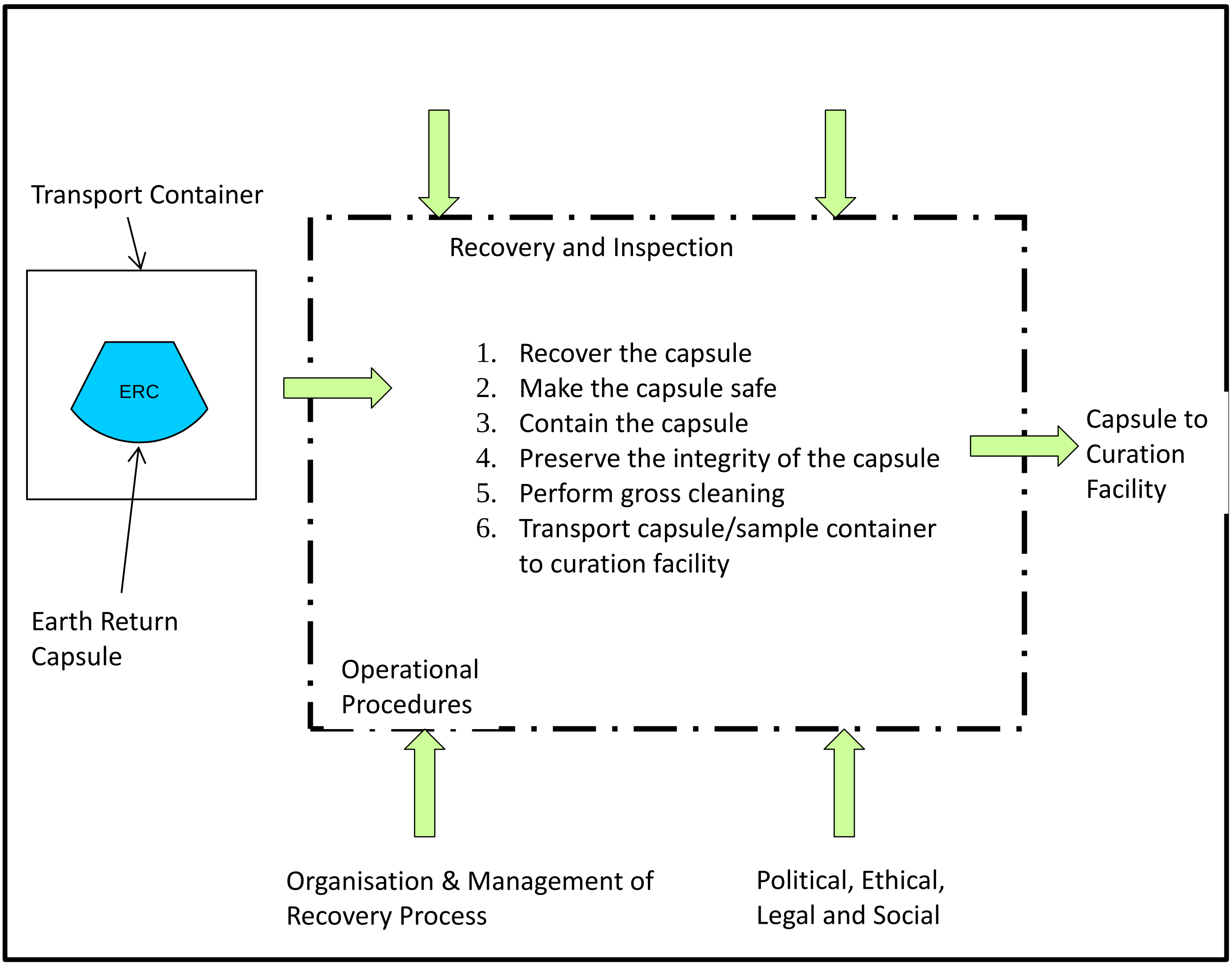

Figure 5-6: Definition of system (dashed line marks system boundary, green arrows indicate interfaces to external factors).

The capsule and its component parts eventually need to be transported to the ECSF which is covered in WP3 of this study, so this is also defined as outside the system. The functions of the system are contained within the system boundary.

Once a system boundary has been defined, a product breakdown structure can be produced. This is covered in the next section.

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

5.6 Product Breakdown structures

A product breakdown structure 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 5-7 describes 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 Table 5-3.

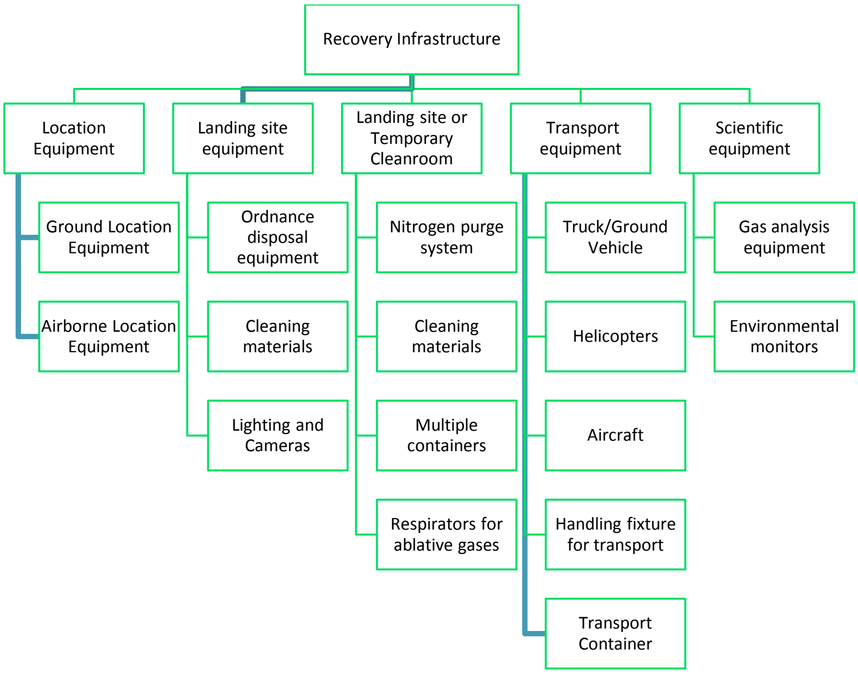

Figure 5-7: Product Breakdown structure of the infrastructure needed for unrestricted missions

Table 5-3 : 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.

© 2016, Thales Alenia Space UK Ltd

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

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 the event and the capsule's location.
Landing Site or Temporary Cleanroom	
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/Landrover	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.

© 2016, Thales Alenia Space UK Ltd

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

Figure 5-8 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 5-4.

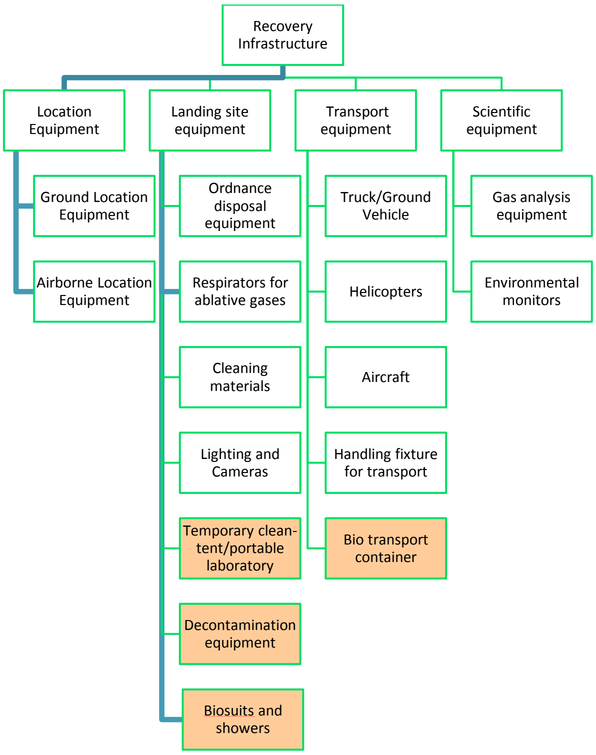

Figure 5-8: Product Breakdown structure of the infrastructure needed for restricted missions.

Table 5-4: Rationale for additional equipment for restricted missions

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

OPEN

	contamination such as CO_2 snow blasting may be used for gross cleaning.
Biosuits and showers	All recovery personnel to use an appropriate level of biological contamination protection (more detail given in D6.4).
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 level. The container will be purged with N_2 gas to reduce moisture and help retain the integrity of the samples.

5.7 Innovations report

WP6.5 is an innovations report to establish any technology development and new procedures which will be required in order to contribute towards 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. Most other aspects of sample return have been covered by other missions and much can be learned from them. It should be pointed out that all aspects of a sample return mission are new to Europe and so new European procedures will need to be adapted from the existing NASA and JAXA ones, with their advice.

The proposed contents list for the innovations report will be as follows:

1. Introduction, Scope and Aims (TAS)
2. Key signature of life (UoLeicester)
3. ISO container (UoLeicester and INAF)
4. Double Walled Isolator design (UoLeicester)
5. Biocontainment aspects of recovery (PHE)
6. Tent over landing site (PHE)
7. Decontaminating a landing site (PHE)
8. Transport container (INAF)
9. Restricted mission recovery procedure (TAS and PHE)
10. Conclusions (TAS)

© 2016, Thales Alenia Space UK Ltd

6. CONCLUSIONS

This report forms 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). This report has described the work in Work Package 6.2: 'Recovery and Inspection of the Sample', which is a subsection of the wider Work Package 6: 'Sample Transport'. The aim of the work was to propose methods for recovery and transport of Mars, Moon or asteroid samples from a landing site to the method of transport.

A review of existing literature and some preliminary findings were prepared in Work Package 1. A Mars Sample Return (MSR) mission would provide the most demanding mission constraints, and so the latest information about developments with this project has been included here. In order to benefit from the experience of previous missions such as Genesis, Stardust and Hayabusa, six experts from NASA and JAXA were interviewed to provide some lessons learned on the recovery process. From this, a list of recommendations was developed.

Some of the work in this report describes tasks which were performed for the benefit of the whole Work Package 6, for example: a survey of the masses and sizes of previous sample return capsules was performed in order to work out the size of the transport container and any transport vehicles, also a concept of operations was developed to describe the various phases of the WP6 sample transport procedure, this was to enable the boundary line to be drawn between the different sub parts of the Work Package 6.

A list of requirements were developed for the recovery process. The system for the WP6.2 recovery and inspection process was defined in terms of boundaries and interfaces. the functions of the recovery and inspection infrastructure and functional flow for restricted and unrestricted missions have been developed. The different elements of the necessary infrastructure have been described in product breakdown structures for both restricted and unrestricted missions. A trade-off as to the advisability of installing a temporary cleanroom (eg: in a hangar) near to the landing site was considered and established to be of significant advantage. The critical areas for innovation are established to be those aspects of the sample transport which require significant planetary protection input, including: the portable biocontainer, a protective tent over the capsule landing site, how to decontaminate a landing site and restricted mission recovery procedures. The results of Work Packages 6.1-6.4 will provide the foundation for a more detailed discussion of this in WP6.5 'Critical areas for Innovation'.

© 2016, Thales Alenia Space UK Ltd
Template 83230326-DOC-TAS-EN/003

7. REFERENCE DOCUMENTS

[RD1] Abe M. et al (2011) '*Recovery, Transportation And Acceptance To The Curation Facility Of The Hayabusa Re-Entry Capsule'*. 42nd Lunar and Planetary Science Conference, 2011.

[RD2] Ajluni T., Everett D., Linn T., Mink R., Willcockson W. and Wood j. (2015) *'OSIRIS-REx, returning the asteroid sample'*. Aerospace Conference, IEEE, 2015: p.13.

[RD3] Allen C. et al. (2011) '*Curating NASA's extraterrestrial samples – Past, present and future*.' Chemie der Erde 71,1–20

[RD4] Backes, P., et al., *Demonstration of Autonomous Coring and Caching for a Mars Sample Return Campaign Concept.* Aerospace Conference, IEEE, 2012: pp.1-10.

[RD5] Barrow K. et al (2007) "*Sample Return Primer and Handbook*", JPL report No. JPL D-37294

[RD6] Beshore E., Lauretta D., Boynton W., Shinohara C., Sutter B., Everett D., Gal-Edd J., Mink R., Moreau M. and Dworkin J. (2015) *"The OSIRIS-REx Asteroid Sample Return Mission"*. Aerospace Conference, IEEE, 2015: p.7.

[RD7] Bridges J. and Guest M. (2011) '*Planetary Protection and Mars Sample Return'*, Proc I MechE Vol 225, Part G :J. Aerospace Engineering.

[RD8] 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.

[RD9] Farley, 2016, "Mars 2020 Project Update for Planetary Science Subcommittee", http://science.nasa.gov/media/medialibrary/2015/11/03/Mars2020_PSS_Farley_Tahu.pdf

[RD10] Farmer, J., et al., *Assessment of Planetary Protection Requirements for Mars Sample Return Missions*. Space Studies Board, National Research Council, National Academy Press, Washington, DC, 2009: p. 80.

[RD11] Frick, A., et al., (2014) *Overview of current capabilities and research and technology developments for planetary protection*. Advances in Space Research, 2014. 54(2): p. 221-240.

[RD12] Germfree (2015) http://www.germfree.com/product-lines/mobile-laboratories/airc-130-transportable/airc-130-transportable/ accessed on 10/3/15.

[RD13] Grolla A. et al. (2011) '*The use of a mobile laboratory unit in support of patient management and epidemiological surveillance during the 2005 Marburg Outbreak in Angola'*. PLoS Negl Trop Dis 5: e1183. doi:10.1371/journal.pntd. 0001183.

[RD14] Hayabusa Sample Investigator's Guidebook, A policy document for curation, handling and allocation of Hayabusa samples.

[RD15] Jenniskens, P., et al., *Preparing for hyperseed MAC: An observing campaign to monitor the entry of the Genesis Sample Return Capsule.* Earth Moon and Planets, 2005. **95**(1-4): p. 339-360.

[RD16] National Research Council (2009) *Assessment of Planetary Protection Requirements for Mars Sample Return Missions*. Washington, DC: The National Academies Press, http://www.nap.edu/catalog/12576.html).

[RD17] Ryschkewitsch, M. et al (2006). "*Genesis Mishap Investigation Board Report, Volume I*" (.PDF). NASA 13 June 2006. Retrieved 2010-05-01.

[RD18] Sandford S. et al. '*The Recovery Of The Stardust Sample Return Capsule'*, Lunar and Planetary Science XXXVII (2006).

OPEN

© 2016, Thales Alenia Space UK Ltd

[RD19] S. Senese et al. (2012) *Design, breadboarding and testing of a Bio-Containment system for Mars Sample Return mission*, IAC63, Naples, 2012

[RD20] Sims, M.R., D.C. Cullen, and J.M.C. Holt, *Development status of the life marker chip instrument for ExoMars.* Planetary and Space Science, 2012.

[RD21] Stoecker K. and Woelfel R., 2014 'Deployment of the European Mobile laboratory during the 2014 Ebola outbreak in Guinea', CSCM Conf.

[RD22] TAS-UK, 2015 "*WP1 Literature Review for WP6: Sample Transport/Portable Receiving Technologies*", TAU-1792-WP1-TN-0002, Issue 1, dated 17/02/15.

[RD23] Yano, H. (2014). JAXA Report on Hayabusa-2, Procyon, and International Collaboration Sample Return Working Group. NASA Advisory Council Planetary Protection Subcommittee May 2014.

[RD24] Younse, P., et al., *Sample Sealing Approaches for Mars Sample Return Caching.* 2012 IEEE Aerospace Conference, 2012.

[RD25] Zacny, K., et al. *SAC architecture for the 2018 Mars Sample Return mission*. in *Aerospace Conference, 2011 IEEE*. 2011.

[RD26] Zolensky M., Sandford S. (2011) "*Lessons learned from 3 recent sample return missions"*. http://www.lpi.usra.edu/meetings/sssr2011/presentations/zolensky.pdf. Accessed 21/04/2015.

[RD27] Zolensky, M. et al. (2008). Curation, Spacecraft Recovery and Preliminary Examination for the Stardust Mission: A Perspective From the Sample return facility. MAPS, 43, 1-2, 5-21.

© 2016, Thales Alenia Space UK Ltd

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

APPENDIX A: STARDUST RECOVERY TIMELINE

G - 5 min	Helicopters begin vectoring towards capsule under range control, from above and upwind of the capsule
G - 0	Capsule landing determined by tracking; location of site provided to recovery team and recovery command system. First helicopter begins vectoring toward capsule location, with others following behind
G + 10 min	First helicopter arrives at capsule - On-scene commander and safety expert debark, helicopter lifts off to provide overhead lighting - Initial unexploded ordnance assessment complete - safe approach route to capsule defined - Initial capsule safety assessment complete - Landing locations for other helicopters determined and marked
G + 15 min	Second helicopter arrives and lands. Additional recovery team members cleared to proceed to capsule
G + 20 min	Capsule safety inspection completed - Capsule's structural integrity assessed - Capsule vents cleared of any obstructions, material bagged - Sulphur dioxide, acetonitrile, hydrogen cyanide, carbon monoxide monitored at capsule - Safety keep-out zones (if any) marked with flags - Gas samples collected from vicinity of capsule's back-shell vents - Tape placed over both back-shell vents - Recovery team briefed on condition of capsule and approach route

© 2016, Thales Alenia Space UK Ltd

Template 83230326-DOC-TAS-EN/003

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

G + 30 min	Capsule field processing complete
	- Photos taken to document capsule's condition
	- Gas samples collected from vicinity of capsule
	- Three persons lift capsule, one person removes debris, material bagged
	- Capsule double-bagged with sulfur dioxide monitor
	- Capsule secured in handling fixture
	- Soil samples collected from impact and recovery sites
G + 45 min	Overhead helicopter lands
	- Capsule handling fixture secured in helicopter for transport
G + 75 min	Helicopter returns to air field with capsule
G + 90 min	Capsule manually transferred from helicopter to ground vehicle
G + 110 min	Ground transport vehicle arrives outside entrance to Building 1012
	- Capsule transferred from vehicle to a point just outside entrance to building
	- Wearing half mask respirator, safety expert removes double bags from capsule
	- Any additional external debris removed and bagged
	- Building door opened; capsule transferred inside and placed on cleanroom holding fixture
G + 120 min	Capsule transferred into cleanroom
	- Photos taken
G + 130 min	Capsule processing begins
	- 6 bolts and parachute canister removed
	- 2 cables disconnected

END OF DOCUMENT

© 2016, Thales Alenia Space UK Ltd