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

WP6.1: Preparation for Recovery

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Approval evidence is kept within the documentation management system.

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CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
1.0	13/07/16	First issue (draft)	JH & JB
2.0	20/07/16	Second issue (including changes recommended by Lucy Berthoud, TAS)	JH & JB

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1. INTRODUCTION

1.1 Aims and Objectives

As part of EuroCares WP6, to propose methods for the recovery of planetary sample return and its transport to a permanent curatorial facility; WP 6.1 is presented here.

Aim: to propose methods of logistics and recovery preparations for a Mars Moon asteroid or other planetary sample delivered to a landing site on the Earth as part of a European sample return mission. Consideration is given to the implication of different landing sites and how their nature will determine the recovery of samples. A focus on Planetary Protection, PP, will also consider the impact of a sample container breach during the entry descent and landing.

Specific Objectives of the work will be:

- Identify local environmental conditions for the proposed sites such that it will inform the logistics of sample recovery.
- Determine what information and procedures are necessary in terms of legislation, permits and local by-laws to facilitate recovery.
- Differentiate between both restricted and unrestricted category V sample return and how this classification may inform an ideal site.
- Discuss the risk and quantify the impact of a compromised sample at landing.

1.2 Scope

This work (WP6.1) considers the general requirements and preparations of a landing site that are necessary in the recovery of a landed component for a European, planetary sample return mission. The scope of this work should be used to inform detailed planning of such a mission and the requirements for transport to a curation facility.

Recovery preparation, the focus of WP 6.1, with respect to mission architecture and the engineering of a return mission, are shown in fig 1-1 and 1-2.

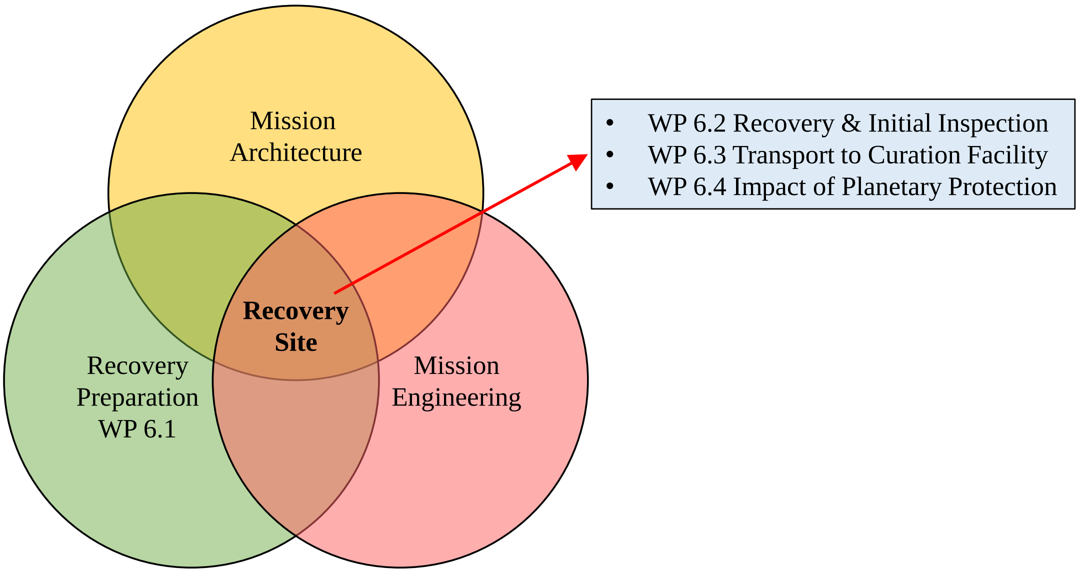

Figure 1-1 Venn Diagram of WP 6.1

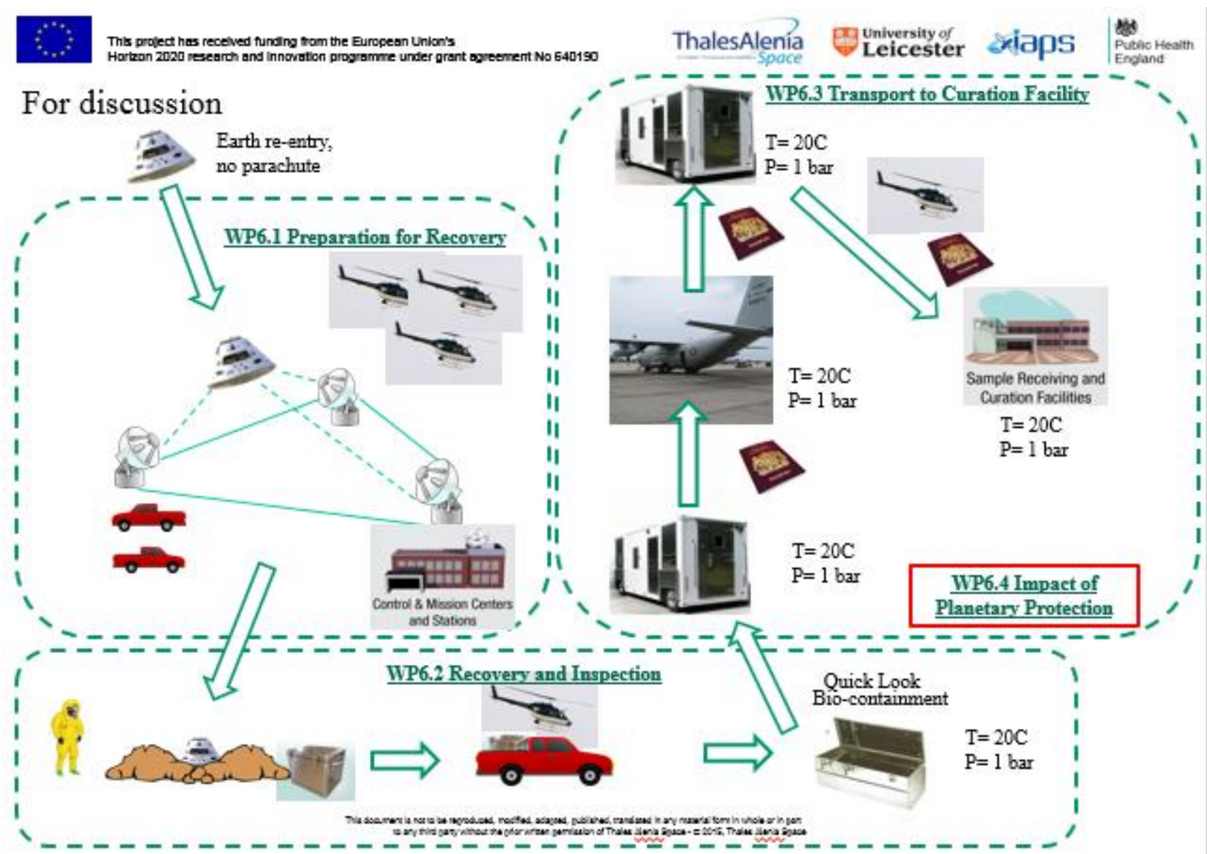

Figure 1-2 Scope of 6.1 within WP6.

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When considering the preparations necessary in selecting a terrestrial landing site for planetary return missions, it becomes clear that both the overarching mission architecture and the engineering of the return spacecraft will have a reciprocating impact.

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2. INTRODUCTION TO LANDING SITES

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

The information presented here will focus on previous sample return missions in terms of the test ranges used and identifies a new European option for consideration.

2.1 Return Mission Site Requirements

A given mission may have specific requirements. For example, a sample must land in a dry area that will maintain an internal sample temperature below the freezing point of water; and one may select a site and time of year to support such a requirement. However, it is possible to focus on general requirements that a return mission may impose on such a facility. In support of the requirements given in §9, the following are proposed.

ID	Requirement Text
Recovery from Landing Site	
FR-110	The latitude and longitude shall be compatible with an Earth return insertion orbit.
	Comment: *Early landing site is necessary in the mission planning.*
FR-120	Test range area shall be of sufficient size that it can accommodate a passive and active landing ellipse with a TBD margin.
	Comment: *Size may depend on a number of early factors, including the re-entry profile.*
FR-130	Airspace in the immediate vicinity of the landing ellipse shall be restricted or controlled
	Comment: *If the range facility do not control the airspace it will be necessary to coordinate landing with civilian air traffic control.*
FR-140	The prevailing wind of the test range shall favour the landing ellipse
	Comment: *Both lower cross winds and upper atmosphere, seasonal jet streams should be considered.*
FR-150	Airspace from the ground shall be unlimited to 100km.
	Comment: *100km is the formal definition of the beginning of 'space'*
FR-160	Immediate ground-space of the landing ellipse shall be restricted.
	Comment: *This is an ideal requirement because it can never be guaranteed.*
FR-170	Immediate ground-space of the landing ellipse shall be unpopulated.
	Comment: *This req refers to people.*

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ID	Requirement Text
FR-180	The geology, landform & local climate of the landing ellipse must limit the risk of a failed landing
	Comment: *Inc natural and manmade.*
FR-190	The test history of the landing ellipse will limit the risk of non-retrieval.
	Comment: *For example, weapons testing or mining.*
FR-200	The test history of the landing ellipse will limit the risk of nuclear, biological or chemical contamination of the landed component and samples.
	Comment: *Both in terms of safety of the recovery personnel and potential contamination of the sample that will impact subsequent analysis.*
FR-210	The test history of the landing ellipse shall minimise the risk of UXO.
	Comment: *Unexploded ordnance may impede the recovery operation and impact safety and cost.*
FR-220	The history of the landing ellipse shall not include "no go" areas that would prohibit recovery of the samples.
	Comment: *Such areas may be biological, chemical, radiological or physical (eg. disused and unstable mines).*

Table 2-1 Landing Site Requirements

In terms of mission infrastructure, it is proposed and recommended that a test range will offer the following logistical infrastructure requirements, as a minimum:

ID	Recommendation Text
Recovery from Landing Site	
REC-01	Pre-selection site inspection to ascertain mission suitability.
	Comment: *Supports selection and training.*
REC-02	Provide a register of known UXO in the landing ellipse.
	Comment: *Supports FR-190 & 210*
REC-03	Provide access to geological surveys of the landing ellipse area.
	Comment: *Some surveys will be proprietary to the land owner and mining rights in the area.*
REC-04	Provide access to local flora and fauna catalogues for the landing ellipse area.
	Comment: *Scientific catalogues are available and should be used in planning recovery operations.*

ID	Recommendation Text
REC-05	Provide a historical overview of biological, chemical and nuclear testing in the ellipse area.
	Comment: *Supports FR-190 & 200*
REC-06	A test range shall provide road or port of access for standard freight carrying vehicles.
	Comment: *The provision of access is both physical and political.*
REC-07	Ideally, accommodation facilities shall be provided.
	Comment: *If physical accommodation is not provided, this infrastructure must be included in the early management of the recovery and the recovery team selected to include appropriate support staff.*
REC-08	Pre-landing training access to the site, possibly including balloon drop testing.
	Comment: *Multiple training exercises in the area is crucial to mitigating the risk of a failed recovery.*
REC-09	Aerial photography (<1 m spatial resolution) should be requested, if not available.
	Comment: *Aerial photography enables localised detailed maps to support both training, identification of hazards and aid rapid recovery.*
REC-10	Fixed or mobile, radar, optical and radio tracking facilities shall be provided.
	Comment: *If not provided, this infrastructure must be included in the early management of the recovery and the recovery team selected to include appropriate support staff. The cost of such infrastructure and training to operate these assets should not be underestimated.*
REC-11	Ideally, multi-terrain recovery vehicles shall be provided.
	Comment: *Specialist vehicles or military support.*
REC-12	Air support (helicopter) shall be provided.
	Comment: *Required for both radio beacon and optical tracking and possibly for recovery.*
REC-13	Subsequent access to the recovery site should be provided.
	Comment: *Enable environmental legacy monitoring to reinforce a clean recovery or effective clean up in the event of a failed landing.*

Table 2-2 Landing Site Recommendations

2.2 Potential landing site candidates

Landing site selection must be included in the initial stages of the mission design because many dictating factors are greatly weighted by the early architectural decisions of the mission; typically mass, cost and the orbital manoeuvres available. Spacecraft like the Apollo Command Module, used an active descent system

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to reduce its return velocity through the atmosphere. An Earth Return Capsule must also dissipate its energy and the technique (active or passive, like aerobraking) will have an impact on the final trajectory (where it can land, safely). Other factors may be more subtle, for example, the decision to adopt a posigrade or retrograde de-orbit may not have a major impact on the additional need for propellant mass; however, because the dissipated heat energy scales quadratically with the difference in velocity, the size and hence the mass of the heat shield, must also be similarly scaled. This in turn has an impact on the range safety requirements and ellipse size.

Sample return missions are not new and NASA have published their "Sample Return Handbook" covering all aspects of such missions [1]. In addition to the landing ellipse requirements in terms of latitude and longitude, another consideration in site selection concerns the accessibility of the site both logistically and politically along with the *in situ* resources necessary to effectively and safely recover such a craft and its components (parachute, heatshield etc).

A major consideration that affects the logistical recovery of a landed component are the local climate, flora and fauna. With regard to World climate, the most widely used quantitative classification is the Wladimir Köppen system, which has been applied to a World atlas [2]. This enables the typical regional climate to be identified. An updated model, based on the Köppen classification uses a 0.1° by 0.1° grid reference for each continent and is freely available to download as a map [3]. See fig 2-1.

In terms of flora and fauna this is somewhat secondary in landing site selection because it does not have a direct impact on the actual landing. However, some flora may be considered as an asset in 'cushioning' a passive lander or a hazard if the landing mechanism is active and should be further investigated. Regarding the local wildlife, this needs to be understood because of its impact on the recovery operation. This includes:

- Necessary vaccinations
- Medical training to manage snake bites (and other dangerous animals)
- Interacting with protected species
- Need for protective weapons and side arms

During early preparations, this information should be requested from the operators of the landing site test range.

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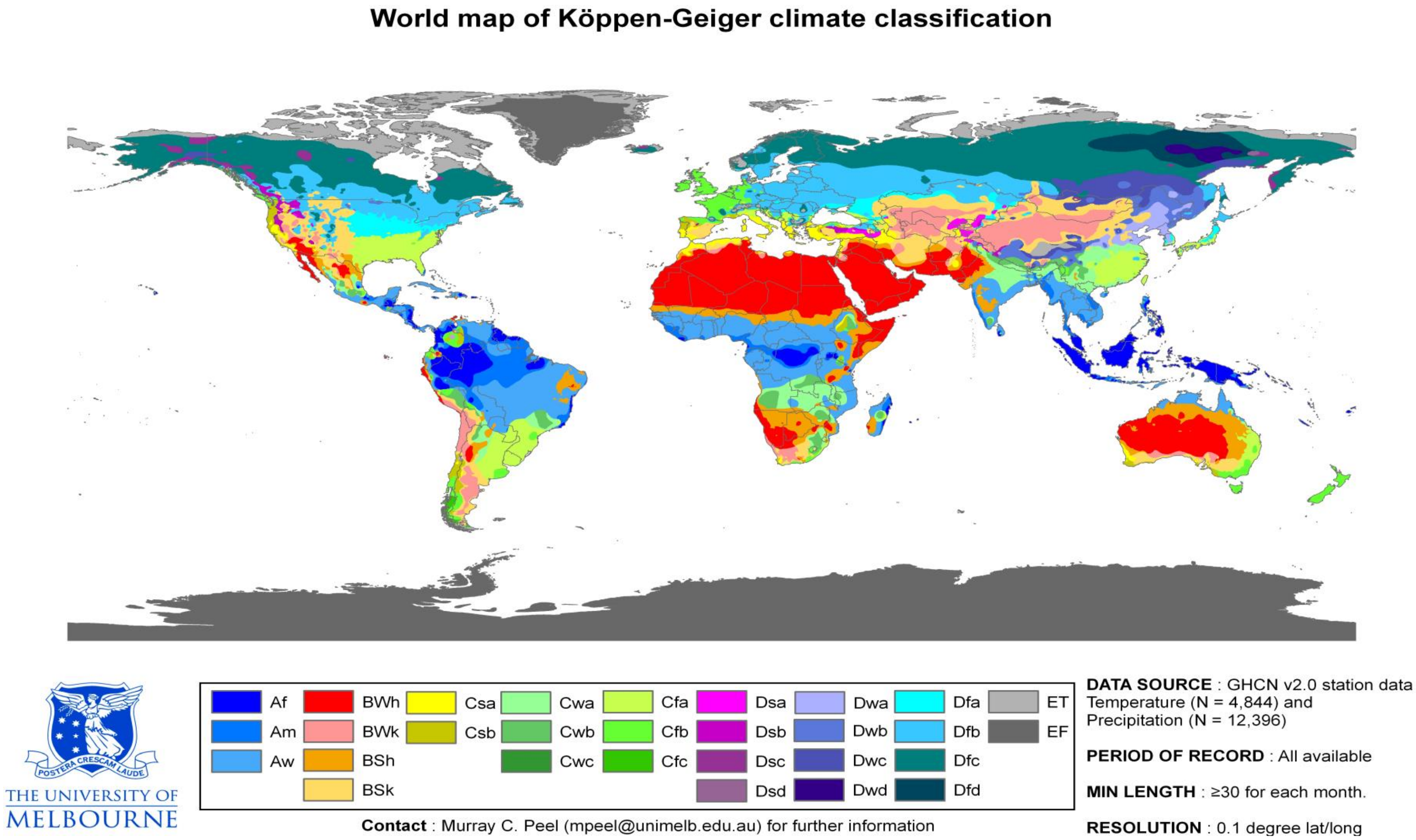

Figure 2-1 Köppen World Classification

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2.2.1 Foreign Participation in NASA Range Operations

The participation of foreign nationals in a NASA led operation (planetary sample return mission) is permitted within the United States of America or at a non US site. However, all foreign participation in any NASA range operation shall require prior coordination with the NASA office of International and Interagency Relations [4], which will be conducted in accordance with NPD 1360.2 [5] and NPD 1050.1 [6].

Six example candidates are presented here for consideration by a future, European led mission.

2.2.2 US – White Sands

The White Sands Missile Range (WSMR) is operated by the United States Military in the State of New Mexico, covering an area of approx. 8,300km^2. Coordinates are: 32°20′08″N, 106°24′21″W. The area has been used extensively for weapons testing and rocket development since the Early 1930's. Of relevance to a future sample return mission is the United States early nuclear testing because of the risk of low level isotope contamination in the area; a potential contamination risk to the samples. In particular, the test detonation of the so-called Trinity device, a plutonium fission weapon developed under the Manhattan project, occurred in July 1945. This resulted in widespread radioactive and chemical contamination of the area, which has now been catalogued by the US Centre for Disease Control in the Final Report of the Los Alamos Historical Document Retrieval and Assessment Project (LAHDRA) [7].

The White Sands area is characterised as a large flat salt basin just North of Lake Lucero and within the WSMR is the site of the White Sands Space Harbor, often associated with the one time Shuttle landing of STS-3 in 1982. Coordinates are: 32°56′35.67″N, 106°25′10.31″W. The prevailing wind is SW to NE and the climate is characterised as arid, with steppe precipitation. A 2012 Geological Inventory Report of the area is available from the US Dept of the Interior, National Park Service and provides a detailed geological catalogue of the location [8].

2.2.3 US – Utah

The Utah Test and Training Range (UTTR) is a Military operated test range in Utah's West desert covering an area of approx. 6,900km^2 and operated by the United States Air Force [9]. Coordinates are: 40°29′39″N, 113°38′12″W, contained within the Great Salt Lake Desert basin and characterised by variable desert terrain, undulating sand dunes and abrupt mountains rising from the desert floor. As a military facility, established in 1940, the range has seen extensive ordinance testing with tens of thousands of munitions dropped in the area. Control facilities for the facility are based at Hill Airforce base. A description of the UTTR facility is published by the Utah Dept. of Environmental Quality [10]. The area is used extensively for the treatment of hazardous waste, explosives and rocket propellants and hosts several inactive hazardous landfill areas, which could lead to risk of contamination of the returned samples.

At the middle latitude the climate is characterised by steppe or semi-desert region with by hot, dry summers, cool springs and autumns, moderately cold winters, and a general lack of precipitation.

The range has been host to NASA return missions, including Genesis (Sept 8th 2004), Stardust (Jan 15th 2006), and the upcoming OSIRIS-REX. UTTR has an extensive infrastructure needed for tracking and has and can easily contain the footprint size of a returned lander. Furthermore, UTTR controls the airspace over the range to an altitude of 17,700 meters and hence may not require complex coordination with US air traffic control.

2.2.4 US – Wallops (NASA)

Operated by the NASA's Goddard Space Flight Centre, the Wallops test range [11] has been considered for previous return missions [1], pg H-2 and does make agency interfacing (civilian) easier. However, Wallops is an ocean range and would have required the SRC to be designed for water landing. Coordinates are: 37°56′19″N 75°27′26″W.

2.2.5 Australia – Woomera

Woomera is a small town in Southern Australia but frequently refers to the Woomera Range Complex (WRC) operated by the Royal Australian Air Force. Covering an area of approx. 122,000km^2 the facility has been used extensively for rocketry and weapons testing with extensive UK involvement between 1947 to 1982 during the Anglo-Australia Project, which include nuclear testing at the Maralinga site. Nuclear tests occurred between 1956 and 1963 at approx. coordinates 30°10′S, 131°27′E, 500 km North East of the Woomera Village located at 31°12′0″S 136°49′0″E [12]. The National Archives of Australia (NAA) operate a web based database where historical Commonwealth multi-agency records, about the Maralinga tests, can be accessed [13]. As with the White Sands test range, the potential for isotopic contamination of the samples and subsequent impact on radiometric dating, should be considered when selecting a site.

The WRC is a large facility the size of the UK characterised by a hot arid summer and cooler winters with occasional record lows below zero degrees Celsius. The Australian Government provides monthly climatic statistics at all locations including the Woomera Aerodrome [14]; see: http://www.bom.gov.au/climate/averages/tables/cw_016001_All.shtml.

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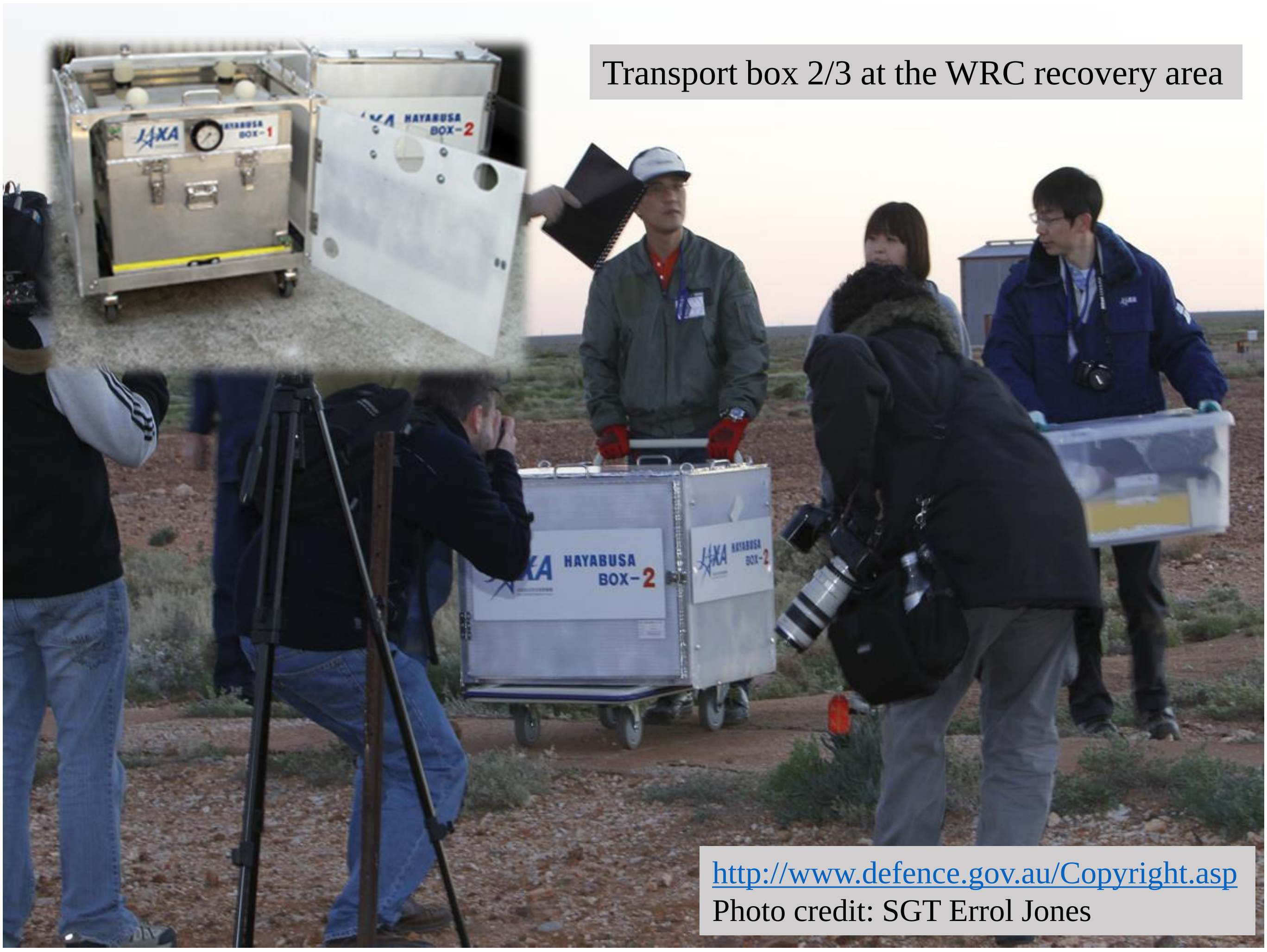
Figure 2-2 WRC

Fig 2-2 is typical of the vast open space area of the WRC prohibited area and the dirt track, from which vehicles are not to deviate except with special permit.

In 2010 the WRC provided landing and recovery support to the JAXA Hayabusa mission on 13th June within the prohibited area of the range. It is understood that soil samples were collected at the time of recovery and a series of specialist transport boxes used to carry the samples to Japan on a charted cargo flight.
See: http://www.mrd-matsuda.co.jp/jaxa.html



Transport box 2/3 at the WRC recovery area

http://www.defence.gov.au/Copyright.asp
Photo credit: SGT Errol Jones

Figure 2-3 Hayabusa at the WRC

Non-defence use of the Woomera prohibited area, as with Hayabusa, is permitted and the Australian Government Dept of Defence managers a Coordination Office for such use. The remit of this office will oversee all non-defence access while preserving local Aboriginal and National interests. Contact details (correct as of June 2016 are presented in table 2-3).

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WPA Coordination Office	**Woomera Test Range**
Department of Defence PO Box 7901 Canberra BC ACT 2610 • Phone: 1300 727 420 • International: +612 6265 4448 • Fax: (02) 6265 5878 • Email: WPACO@defence.gov.au	PO Box 157 Woomera SA 5720 • Phone: Range Operations Office • (08) 8674 3370 • International: +618 8674 3370 • Fax: (08) 8674 3217

Table 2-3 Woomera Contacts

It is worth noting that many people in the community (sample return missions) have expressed a preference to the Woomera range over UTTR citing WRC as being more robust in recovery operations [15].

2.2.6 Kazakhstan - Kazakh steppe

Kazakh steppe is a region of grassland, savanna and shrubland in northern Kazakhstan covering approx. 804,500km^2 with coordinates of longitude and latitude of 50° 00' N, 72° 00' E [geographic.org]. It has a semi-arid continental climate with summer mean temperatures of 23ºC and winter mean temperatures of -15ºC. Average precipitation levels are low at around 327mm per annum, mainly in spring; however, strong winds sweep the plains often from several directions which would have to be taken into consideration for a lander. Droughts are common in summer and snowstorms in winter. The area is sparsely populated with around 3 people per square kilometre with varied amounts of wildlife such as antelopes, deer, wolves, foxes and badgers. These would have to managed in relation to a potential landing site and considerations such as their habitat may need to be considered. The area has few trees, flora consists mainly of grasses and large sandy areas. This site was recently used for the return of British Astronaut Tim Peake from the International Space Station in June 2016.

2.2.7 A European Union Test Range Option

Established in 1966, the Esrange Space Center operates a large test range of 6,100km^2 located in Northern Sweden, above the Arctic Circle at approx. 67°53′N, 21°04′E, with a small mining town, Kiruna, up-range of the main site. Kiruna is served by commercial air access from Stockholm. The climate is characterised as dry snow between November and April with temperatures considered as extremely continental (cold winters, -35ºC and warm summers, 20ºC); with inland water frozen solid in winter.

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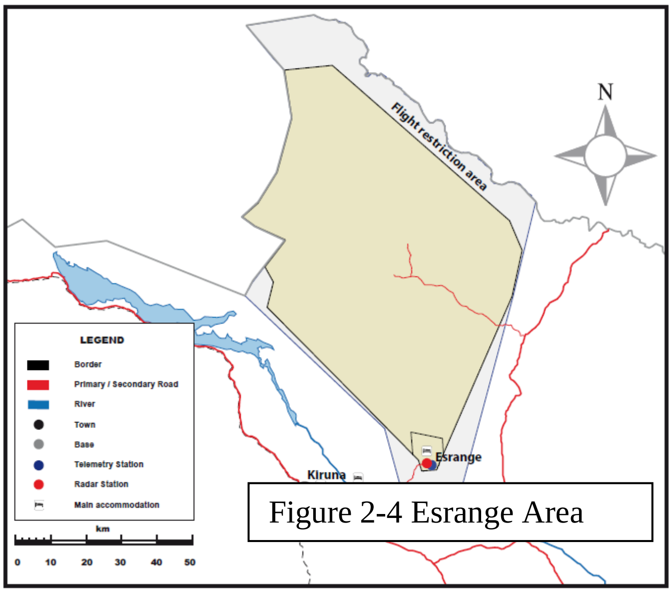

Figure 2-4 Esrange Area

Due to a little known Swedish regulation, the number of people in the area is limited and the actual range remains unpopulated with restricted air space to 100 km. Primarily used for sounding rocket launches, high altitude balloon testing and unmanned air vehicle testing, the range has not been previously considered for recovery of sample return missions. Figure 2-4 shows the test range area [16]. The impact area is located down-range of the main base area in the Swedish tundra region with total a ellipse of 120 km North – South by 75 km East – West [17].

The facility operates a number of sounding rocket launches and balloon missions each year with recovery of payloads established as standard procedure at the range. The land impact area makes Esrange very suitable for various flights, where recovery is necessary. The open landscape allows for smooth payload landing, contributing to a minimum of impact damage [18].

Infrastructure of the range allows for rapid recovery of the landed hardware using helicopter air support, radio beacons and radar; along with experienced staff. Additionally, the long periods of high latitude daylight, 24 hours, in the summer may be an advantage during recovery as may the clean snow during winter months (4 hour daylight in winter). Science buildings, with workshops, may also provide support should a temporary cleanroom need to be established as a "quick look" facility in the case of unrestricted sample return mission. The base is equipped with different tracking systems including L/S-band telemetry antenna, 650 kW C-band radar and a flight trajectory ranging system (provided the return capsule is equipped with an appropriate transceiver (beacon)). The area has an open radio spectrum but recommended beacon frequencies are in the range 240 MHz to 260 MHz with a continuous wave or pulsed modulation at an output power of 0.4 W. Typical beacon frequencies include 240.8, 242.0 and 244.05 MHz.
NB: 121.5 MHz and 243.0 MHz are international emergency frequencies and should not be used.

A down-range station, approx. 25 km North of the launch area, is provided and may serve as a forward operations base in preparation for landing (helicopter access only).

Accommodation:
Domestic facilities are also provided by the range including hotel rooms, located close to the Main Building with a restaurant. Corporate facilities are also provided, including conference rooms with global internet access, telephones and data projectors.

Logistics:
For a European led sample return mission having direct access from Sweden to major air ports, within Europe and a subsequent modern road infrastructure, offers a considerable advantage in terms of freedom of movement and delivery of samples to a curation facility. However, if the UK is to remain a key partner in such a mission it is vital that Brexit negotiations fully represent the scientific needs of the country.

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Contact details of the Esrange Space Centre can be seen in table 2-4.

Esrange Coordination Office

Mattias Abrahamsson
Director of Business Development

Postal address:
P.O Box 4207
SE-171 04 Solna
Sweden

- Phone: +46 980 720 06
- Email: science.services@sscspace.com

Table 2-4 Esrange Contacts

2.2.8 Landing Site Summary

Six landing site examples have been presented here. The following sections, regarding planetary protection and logistics, and the components of WP 6 will inform the decision to choose a site for future European missions. However, a 'first look' summary table, of the above examples, is provided here:

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

Table 2-5 Landing Site Summary Table

A 'traffic light' indicator is used here to show the top level advantages and disadvantages of the example sites.

Red = Disadvantage or difficult
Yellow = Unknown or indifferent
Green = Advantage

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3. CATEGORY V PLANETARY PROTECTION

General discussion

As a guiding principle, planetary protection (PP) is an evolving regulatory framework that responds to our developing understanding of the evolution of life, biological processes and distribution of life in the Universe. The aim of planetary protection is to maintain the pristine biological status of a celestial body when it is made the subject of surface or orbital investigation and exploration; possibly for commercial exploitation in the future. The United Nation's Office of Outer Space Affairs defines the internationally agreed planetary protection guidelines, which are promulgated by The Committee on Space Research, COSPAR, and adopted by both ESA and NASA, along with over 100 countries that have signed up to the treaty. Hence, these requirements will apply to a European sample return mission. The policy was amended on 24th March 2011 and defines five categories of planetary missions, which in turn dictate the planetary protection constraints and requirements that will be imposed on such a mission [19]. For sample return missions, "Category V" will apply; where concern relates primarily to backward protection of the Earth Moon system.

3.1 Category V Unrestricted

Additionally, "Category V" incorporates a further sub category, "unrestricted Earth return" which is defined by a target planet, moon or other celestial body where scientific opinion has deemed that target to have no indigenous life. This category is considered safe if; the preponderance of scientific opinion determines liquid water has never existed on the body, metabolic energy sources are absent, there is a lack of sufficient organic material, the target is subjected to high temperatures (>160 ºC), long exposure to sterilising radiation (specifically relating to terrestrial life forms) or that there has been a natural influx of the target material to Earth [20]. A 1998 US National Research Council report [21] identified the defining framework to be used with current scientific opinion in detailing an Earth return classification.

3.2 Category V Restricted

Planetary protection is concerned with maintaining the pristine biological status of a celestial body in terms of forward contamination and mitigating the risk of backward contamination by the intentional return of a sample, to the terrestrial biosphere.

The Earth return component of a Mars Sample Return (MSR) mission will be categorised as CAT V restricted until such a time as it can be demonstrated that Mars does not or has never harboured indigenous or other extra-Martian biological life processes.

MSR architectures typically contain multiple spacecraft and landed components and each may have a different PP category. For example, in terms of risk to Mars, the outbound orbital phase may adopt category III requirements where bioburden levels, in relation to probability of impact with Mars, are still TBC and will be dictated to the spacecraft by the space agency. Risk mitigation of forward microbial contamination of Mars will likely be implemented by orbital biasing and bioburden reduction techniques during spacecraft assembly and test. By comparison, landed components will be Cat IV, which details 3 sub-categories, depending on location and type of sample returned.

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3.3 Planetary protection and its impact on landing site selection

In terms of impact on the selection of terrestrial landing site and planetary protection, this will be influenced by its restricted / unrestricted classification and the local environment. This is made clear in the following truth table:

Category	Forward Contamination	Backward Contamination
CAT V Restricted	*Concern*	*Major Concern*
CAT V Un-Restricted	*Concern*	*No Concern*

Table 3-1 PP Truth Table

Concern = risk is quantified by the scientific loss
Major Concern = risk is quantified as greater than the scientific or fiscal value of the mission.

The major concern with a CAT V Restricted mission is that an unknown pathogen from a celestial body, could contaminate the terrestrial biosphere; shown in red. While this risk is considered very low, the impact is difficult to quantify and therefore warrants serious consideration in terms of mitigation approaches and preparation management in selecting the site.

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

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

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

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

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

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4. LESSONS LEARNED FROM SPACECRAFT SAMPLE RETURN RECOVERIES

The NASA 2007 Sample Return Primer & Handbook [1] incorporates a lessons learned for the Genesis and Stardust missions.

It is also noted that the missions identified below were all CAT V Unrestricted, active landers and the current architectures for Mars Sample Return (CAT V Restricted) is to implement a passive entry descent and landing system.

4.1 Genesis (landing & recovery perspective)

The Genesis Mishap Report identifies the main cause of the mission failure and section 6.1 of the report makes 12 recommendations to address the systems engineering process failures and management issues of concern [22]. However, upon impact and recovery, it was known that a number of personnel were close to the return canister. This led to a review of the contingency plans initiated to ensure proper procedures had been followed, and to improve plans and procedures, as necessary for future missions [23].

Findings of the review included (pg 7 of the report):

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

4.2 Stardust (landing & recovery perspective)

See section F-1 [1].

A key finding of the Stardust lessons learned team is that a minimum of one additional day should have been included in the two day recovery schedule. Given the complexity of a restricted return mission, requiring seal integrity verification, careful recovery and local context sample collection, it seems likely that five to ten days for recovery will be necessary. The stardust team conducted extensive field testing for both nominal and off-nominal scenarios leading to and operational readiness review. Furthermore, a full end to end balloon drop test was performed, simulating an actual landing [24].

4.3 Hayabusa-1 (landing & recovery perspective)

The Hayabusa mission was the first attempt to send a spacecraft to an asteroid, sample material and return it to the Earth, returning from the asteroid Itokawa. Hayabusa returned to Earth on 13th June 2010 and landed at the Woomera site in Australia. The Earth return capsule was protected by the heat shield whilst the rest of the spacecraft burnt up in the atmosphere as the reaction control functions on the spacecraft had failed during the mission. After landing, the Earth return capsule was retrieved within one hour using the JAXA developed beacon tracking system [25]. The capsule was then packed inside double layer plastic

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bags filled with nitrogen gas to reduce the risk of contamination. The soil at the landing site was also sampled for reference against any contamination. The capsule was placed inside an insulated cargo container and were then transported by plane to the JAXA/ISAS Sagamihara campus on 18th June [26, 27].

4.4 Osiris-REx (landing & recovery perspective)

Osiris-REx is a New Frontiers Program mission planned to launch on 8th September 2016, land and collect samples of the Bennu asteroid and return to the Earth in September 2023; landing at UTTR. Osiris-REx is planned to bring back a sample of mass 60g [28]. The capsule design will be similar to NASA's Stardust spacecraft with samples proposed for delivery to NASA's Johnson Space Centre in Houston.

4.5 Lunar Sample Return and Immediate Quarantine

The main difference between Apollo and future, robotic sample return missions is that safety consideration for the astronaut crew is not a factor. However, human safety at the point of terrestrial landing is. Lessons learned from the Apollo programme proposed the following points, relating specifically to a MSR mission [29].

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

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5. UPDATED DESIGNS FOR MARS SAMPLE RETURN MISSIONS

The analysis of carefully selected and well-documented samples from a well-characterized site will provide the highest science return on investment for understanding Mars in the context of solar system evolution and for addressing the question of whether Mars has ever been an abode of life: 'NASA Decadal Survey Vision and Voyages for Planetary Science in the Decade 2013-2022'.

US and European interest in Mars Sample Return was rekindled in 2008 with the publication of the iMARS report (International Mars Exploration Working Group; iMARS 2008) [30]. This provided an architecture for Mars Sample Return from launch to Sample Receiving Facility on Earth. Subsequently, the 2013 NASA Decadal Survey [31] confirmed the commitment of the science community, and NASA to Mars Sample Return. In Europe there has also been a commitment to Mars exploration – notably Mars Express and ExoMars [32] leading ultimately to sample return. Europe has expressed an interest in sample curation and recently the concept of an ESA Courier mission which could bring an Earth Return Vehicle (ERV) to Mars to get the contained samples from a NASA Mars orbiter and return them to Earth [33].

A more recent iMARS II report [34] has produced an updated architecture for a multinational Mars Sample Return mission (MSR). In order to retrieve drilled samples from Mars (e.g. the Mars2020 mission, though this is not an explicit part of an MSR mission plan) there could be two launches, one to provide a Mars Ascent Vehicle (MAV) and a Mars Fetch Rover to retrieve samples, and a separate Earth launch to provide an orbiter to capture a sample container launched from Mars by the MAV, and return in to Earth. A variant of this architecture would be the ESA Courier mission (in a third separate launch) which would aim to rendezvous with a Mars Orbiter and return the samples to Earth [33, 35]. Thus the exact architecture and number of launches associated with MSR is not certain. Some required elements for any design include a Sample Return Orbiter element of the mission requires a rendezvous sensor suite and a capture mechanism, a bio containment system to break the chain of contact between Mars and Earth, an Earth Re-entry Capsule and a propulsion module [34].
However, the aims of MSR remain to return to Earth a minimum of 500 g of drill core, regolith and an atmospheric sample (iMARS II). This remains a planetary protection Category V, restricted Earth return mission (iMARS II).
Following Earth return, recovery, transportation to a Sample Receiving Facility, science analysis and long term curation will be designed at BSL-4 levels of planetary protection.

5.1 Engineering in Relation to Recovery Site

There are two aspects to the engineering requirements in terms of the landing site:

1. The lander technology itself may be restricted.
2. The engineering technology implemented in the landed component must mitigate the risk of backward contamination (and minimise the forward risk to the sample).

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With regard to restricted technology, one of the biggest 'headaches' in the spacecraft industry is that of ITAR, the international Traffic in Arms Regulations, which controls the export and import movement of defence related components included on the US munitions list. In practical engineering terms, ITAR regulations limit the transfer of information and material pertaining to items included on the US munitions list, to US citizens and those individuals and organisations authorised, by the US Department of State, to handle such material. Within the scope of this work, individuals and organisations may be European or British.

Space technology has been subject to ITAR since 1999 and it is likely that any sample return landed subsystem will contain ITAR restricted components, particularly if there is US and NASA involvement in the design. This does not prevent the use of ITAR components; however, it would be a major factor in selecting a test range, import / export countries during transport and personnel involved with the recovery, if ITAR components are used. For example, an Actel FPGA (field programmable gate array) chip is commonly used in electronic sub-systems and could very likely be used in an Earth return capsule.

ITAR components, used in the Earth Return Capsule, ERC, component, will be managed by the mission product assurance plan and implemented through all stages of the mission product life cycle, including the return phase. This may impact selection of the test range (with regard to its location *wrt* prohibited states) and the transport of the ERC to the curation facility. Furthermore, shipment must not be undertaken by vessels, couriers or other means of conveyance by parties owned or operated by, or leased to or from any prohibited state. As an example of countries currently excluded by ITAR, but not exclusive, include; China, Cuba, Iran, North Korea, Sudan, Syria, Cote d'Ivoire, DRC, Eritrea, Iraq, Lebanon, Liberia, Somalia and countries that the US Secretary of State deems to have supported terrorism [36].

In terms of the engineering requirements, *wrt* the landing site, local and national jurisdiction will dictate what can and cannot be returned, both hardware and samples alike. With the exception of ITAR controlled components, it seems unlikely that hazardous (in terms of ERC engineering materials) or radioactive components will be included. What is more, current MSR architectures favour a completely passive landing scenario [37, 38] and therefore no pyrotechnic elements will feature.

When it comes to the entry descent and landing phase there are two broad phases that may result in accidental release of the sample ref [39]:

1. Break up during re-entry
2. Seal compromise at landing

It has been reported that a micro meteorite could damage a sample container during the return transfer orbit to Earth [39] and this may result in burning up in the upper atmosphere (depending on whether or not the heat shield is damaged) or contamination at the landing site. Break up during re-entry may be caused by an incorrect orbital insertion manoeuvre (causing the ERC to tumble and break up in the upper atmosphere), a design flaw or sabotage before launch. Seal compromise may similarly be caused by an orbital error (resulting in a higher impact energy) or a design flaw in the containment sub-system (the seals or sealing mechanism). The imposition of engineering requirements during mission preparation may provide a means of managing some risks in terms of exposing the landing site to the unknown hazard of restricted planetary samples.

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The detection of biohazard and toxic chemical compounds has been widely reported in the recorded literature including techniques and protocols that will be used in the assessment and monitoring of a returned Mars sample, particularly at a sample receiving facility. However, consideration is rarely given to the monitoring of hazards at the point of impact / landing for the Earth Return Capsule (ERC) and then the initial transport of samples to the curation facility; perhaps because of the unique nature of missions like Mars Sample Return. Mass spectroscopy is widely used to detect hazardous chemicals of a fluid in the ppb range and may be implemented in an ERC transport container. However, a major problem with the direct detection of biological activity is the acquisition of a sufficient sample quantity above the sensitivity of a particular technique, which is further compounded by the unknown nature of potential extra-terrestrial biology. Typically, very low molecular weight of a biological sample contained inside a complex rock matrix must be processed such that the target analyte can be identified; the complexity of which is the very reason for returning samples to a dedicated and sophisticated laboratory. This poses a potential problem for the detection and monitoring of biohazards during the retrieval and initial transport of the Mars sample containing capsule because it will not be possible or at the very least, extremely difficult, to perform any *in situ* processing of the precious samples. This very complexity may place an engineering requirement, *wrt* the test range, on the ERC to demonstrate risk mitigation in terms of a compromised landing.

There have been a number of MSR mission architectures based on the COSPAR PP requirements [19, 40] and detailed, in terms of systems engineering, by the major space agencies [20, 41]. A draft protocol for the detection of possible biohazards of MSR samples has been written by NASA [42] and will be reviewed as part of this work. The basic return capsule structure is described here [43], where the philosophy is one of 'breaking the chain of contact' between Earth and Mars. Therefore, samples must be individually double sealed with a further tertiary group seal of the canisters. A minimum of three seals are required to ensure both sample integrity and risk mitigation of backward contamination from a returned sample containing vessel. New insights regarding the design of sample containment exceed this requirement and have further integrated an early PP requirement for leak detection [44] and a novel wireless interface that further mitigates the risk of containment loss [45]. A recent review [46] of developments in PP technology highlighted several approaches in terms of forward contamination, some of which are applicable to backward contamination controls. However, these developments do not consider the complex issues of biohazard detection at the point of impact / landing of the Earth Return Capsule.

NASA's Mars2020 mission is currently being designed as the first stage of a MSR mission where a subsequent retrieval lander / spacecraft will collect its cached samples, hopefully in the mid to late 2020's. (Obj C of the Mars2020 SDT Report). For this reason, estimates of sample size are based on these mission requirements. Section 6.2.3.1 of the SDT defines a total sample mass of 500g divided over approximately 31 individual samples, which gives a sample mass of between 15 to 16g. It is also assumed that a sample may contain rock core, regolith, ice, atmospheric gas and potentially sample off-gas. Development of titanium and stainless steel alloy sample tubes (container where the actual sample is held) is underway with current designs [47] achieving 10^{-7} atm-cc/sec He and presumed internal sample gas pressures being equivalent to local Mars atmospheric; approx. 6 mbar. The cache canister (containing the 31 individual, sealed sample tubes) will be collected from the carousel by a subsequent mission and secured inside a biocontainment system, as described in concept [45]. 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" [48]. The current mission architecture does not appear to include a means of monitoring the integrity of seals on the sample tubes;

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however, this could be implemented by way of monitoring pressure decay of the Earth return biocontainment system, the ERC.

The current surface habitability of Mars may not support the survival and proliferation of carbon based life. However, the surface of Mars may support pre-biotic chemistry, preserve some biosignatures of extinct life and be habitable to hibernating / dormant forms of life. This suggests that any potential pathogenic organism is likely to exist in small localised niche colonies where the conditions conducive to Martian life are met. For example, terrestrial anaerobic microbes can form colonies of the order of tens of microns across [49]. Any biological organism that has evolved to survive in the harsh environment of the Mars near surface will exhibit ultra-slow anaerobic metabolic characteristics and therefore are unlikely to interact with terrestrial cells in an oxygen rich atmosphere, which by comparison, represent a hostile and extreme environment. This does not however preclude the pathogenic potential of Martian microbes, which could produce small quantities of toxins, therefore representing an indirect risk if a sample tube is breached [50]. (As a terrestrial example, see: Clostridium Botulinum, a bacteria that can produce heat-resistant endospores, often found in soil. Clostridium Tetani and Bacillus Anthracis, which can both form an endosporic bacterium). With living cells high molecular weight enables molecular identification or even DNA sequencing with processers such as PCR, but only if the microscopic colonies are accessible and processed from within the returned rock samples. Extinct cells will not have intact structure and will have been subject to unknown chemical modification and may only exhibit morphological signatures for very ancient specimens. This point is raised because any subsequent failsafe monitoring technique or contingency protocol should also seek to preserve such potential fragile biosignatures.

In terms of analysing the pathogenic risk exhibited by a potential Martian organism and the biohazard detection technologies realistically available at the Earth returned landing site, it will be necessary to consider in detail the following:

- Sample size
- Largest potential colony size & estimate of colony molecular weight
- Modes of microbial motility and pathogen release

This will support identification of biohazard technology appropriate for monitoring a MSR capsule at the point of returned impact / landing and inform the necessary preparations required for recovery. (NB: Biohazard detection and the impact of planetary protection detail are discussed in WP 2 and WP 6.4). However, Martian biology remains an unknown variable and any attempt to quantify a direct detection method will include considerable uncertainty and perhaps, an unacceptable risk. Thus, a third option, with regard to indirect biohazard detection should be considered as part of the spacecraft engineering.

As described above, planetary requirements demand either the monitoring of seal integrity or elaborate steps to mitigate the risk of containment breach throughout the return journey, particularly the complete terrestrial component of that journey. The ESF-ESSC study group [39] concurs that, containment of particles larger than a given size is an appropriate constraint to be considered when designing a MSR mission. They further assert that the current particle size of 0.2 µm is no longer valid and recommend a new value of 0.05 µm. The capability to monitor seal integrity of the biocontainment system, as discussed here [45], may "…kill two birds with the one stone." It provides the capability to monitor seal integrity and thus quantify the risk of particulate passage (potential biological contamination) through a leak path during at all stages of the journey.

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A leak rate is defined as the pressure volume (pV) throughput of a gas via a small leak path such that in stable thermal conditions the pressure difference either side of that path will equalise over time. In its simplest form, this is expressed as:

$$Q_1 = V\frac{\Delta p}{\Delta t} \qquad \text{Eqn 1}$$

where Q_1 is the leak rate, p is the pressure and t is time.

The monitoring technique described, shows that approximately 200 mbar of Ar will be used to determine the pressure decay of a known volume (the inner-vessel chamber). Variants of such a Bio-containment system may have multiple chambers, different sample tube quantities, different pressures and so on; however, the basic principle adopted offers configuration versatility to monitor seals. For example, implementing a pressurisation just prior to its Earth landing may be used to assess seal integrity and containment of potential pathogens during descent, landing and transport to a curatorial facility. Figure 1 shows such a theoretical timeline.

t_0 = initiation of pressurisation
t_1 = impact of Earth return capsule
t_2 = equalisation of pressure (if one or more sample tube seals failed)

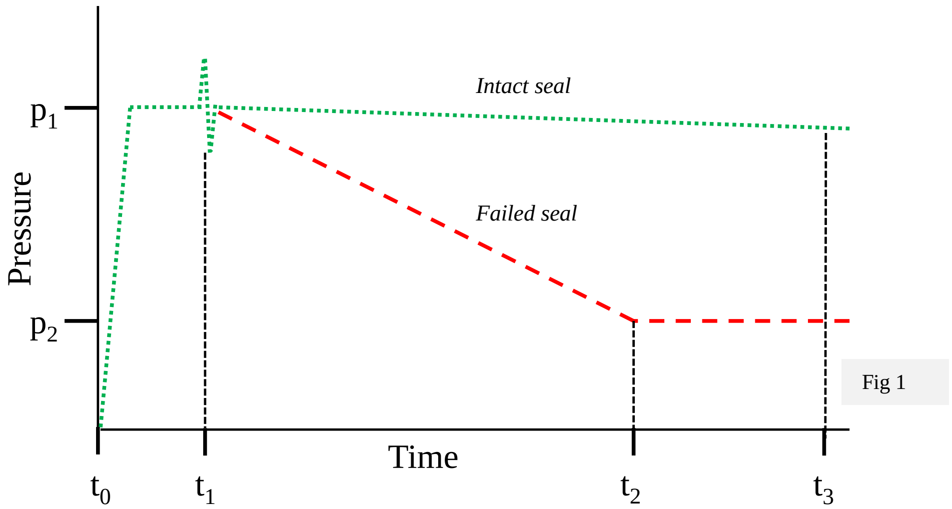

Figure 5-1 Leak Rate

At time index 0 the pressure p_1 is initiated and stabilised to approx. 200 mbar before the descent phase. Time index 1 indicates the point of impact and a fluctuation in pressure reading caused by rapid elastic deformation of the vessel. At t_1 it is assumed there will be one of two basic scenarios; i) all seals remain intact, ii) one or more seals of a sample tube are compromised to some lesser or greater degree (determined by the rate of change of pressure from t_1 to t_2 (red line)). Over a period of hours or a few days, between t_1 and t_2, it is assumed that the ERC will be stationary and managed according to its status at the point of landing / impact and that there will be some small pressure decay if all seals remain intact. But, if an internal seal is damaged by the EDL sequence, a larger pressure decay would be observed, indicating the movement of gas from the pressurised bio-container in to the sample tubes (approx. 6 mbar). Furthermore, the rate of

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decay may be used to indicate the severity of leak and may indicate the physical dimensions of such a leak to inform the management of recovery. Sense *et al* describe a system whereby data telemetry is wirelessly enabled between the internal pressure and temperature sensors and the external electronics within the ERC. It is conceivable that modification of this electronic system could be used such that management of recovery and transport of the bio-container to a curation facility would utilise this telemetry to monitor seal integrity and indirectly monitor the biohazard status.

Additional mitigation mechanisms could be engineered within the ERC that would enable limited "self-sterilisation" of the samples, in the event that orbital control of the spacecraft or return capability was lost. Discrete, addressable heaters could be integrated with the sample tube (eg. small, flexible Kapton heaters as used on spacecraft), such that a single tube may be heated by command. And thereby offer limited sterilisation of a sample in the event that a particular sample seal or canister is compromised. In terms of spacecraft component sterilisation, bioburden is defined with respect to the number of aerobic microorganism that survive a heat shock of 80 ºC for 900 seconds [19] and the aim of "self-sterilisation" should meet this requirement as a minimum. However, the samples would still be considered CAT V restricted and this technique is proposed only as a means of reducing the risk.

In summary, this section has discussed the risk of exposing a landing site in terms of the basic engineering associated with current MSR mission architectures and spacecraft systems that could be implemented as a means of limiting the risk of sample exposure to the landing site.

Effect	Top-level Cause	Impact	Mitigation
Break up during descent	Micro-meteoroid Orbital error Design flaw	Area exposure	*In situ heat sterilisation
Ground exposure	Micro-meteoroid Orbital error Design flaw	Point contact exposure	**In situ sterilisation. ***Leak monitoring
NB: This table does not identify post exposure incident management as this will be explored in subsequent sections.			

Table 5-1 Risk Summary Table

* It is assumed that spacecraft tele-commanding would be used to activate sterilising heaters in the event that a compromised entry and descent is expected.

** Transit leak monitoring would identify a seal breach before entry descent and landing and spacecraft tele-commanding would be used to sterilise a single or group sample.

*** The ability to read sample chamber leak rate telemetry on the ground allows the risk of sample exposure to be quantified. For example, if the leak rate is below a set threshold, the mean dimensions of a leak path can be estimated in relation to the max acceptable particle size value

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5.2 Recommended Logistical Considerations

With regard to preparation of landing site selection it is necessary to additionally consider not just the recovery (covered in WP6.2) and the transport (covered in WP6.3) but how recovery and transport assets are delivered to the landing site. The nature of the landing site and its environmental conditions will dictate recovery operations and it is therefore proposed that a common logistical infrastructure is considered as part of landing site preparation.

Intermodal Cor-Ten steel transport containers offer a potential cost effective and durable solution to the transport of materials and products, making them a consideration when planning the recovery of a sample return mission. 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. Standard lengths are 6 m and 12 m with a typical height of 2.6 m. A High Cube option is available at 2.9 m and often used for specialist applications; for example, active refrigeration units and containers with integrated diesel power generation units. Preparation of the landing site should enable access of such containers with appropriate multi terrain vehicles.

In addition to the transport of commodities and goods, Intermodal containers (also known as ISO Containers) have been modified for numerous specialist operations because of their availability and the common interface provided on the 8 corners of their steel construction. For example, the US Ice Core Project transports scientifically valuable ice cores in a specialist refrigeration ISO Container from Antarctica to a curation and analysis facility, NICL, in Lakewood Colorado.

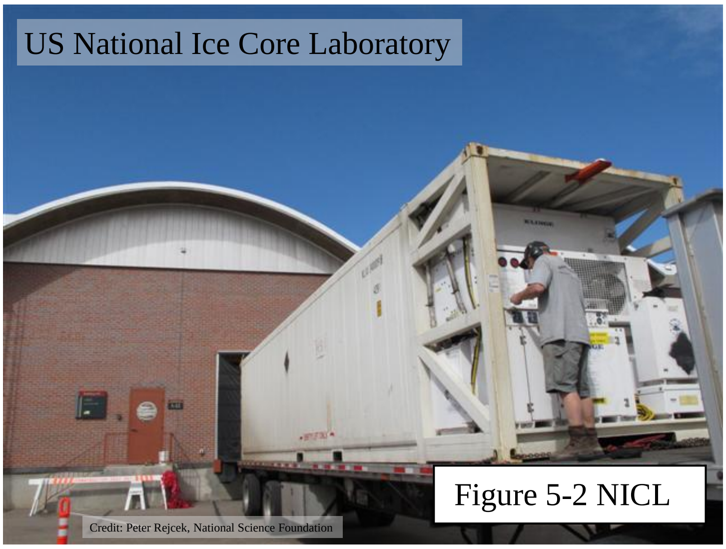

Figure 5-2 NICL

It is conceivable that such a specialist transport facility might be implemented in the recovery of a Mars Sample Return mission (or other), where a power plant is used to control and condition the internal container environment and any associated monitoring equipment. One half of the container (perhaps reinforced to provide enhanced impact resistance) may be used to accommodate an active / passive vibration isolation fixture for the transport box and the second half for basic laboratory / environmental monitoring.

A basic configuration is proposed in fig 5-3 where access is provided at one end for the SRC containment shipping box and a sealing plate that is bolted to a welded frame on the inside of the container walls. Double elastomer seals provide another layer of isolation where the shipping box section could be maintained clean (by the plant) with a closed circuit HEPA filtered nitrogen gas circulation system. Double lining in that section may be implemented to provide additional thermal isolation or external fire retardation. Accelerometers on the vibration isolation fixture should be logged along with other housekeeping sensors like relative humidity, oxygen content and temperature. Furthermore, the closed circuit gas filtration system may include sampling to a GCMS (to

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provide time resolved contamination monitoring) or thermal desorption tubes to provide total organic contamination, if used for the entire journey.

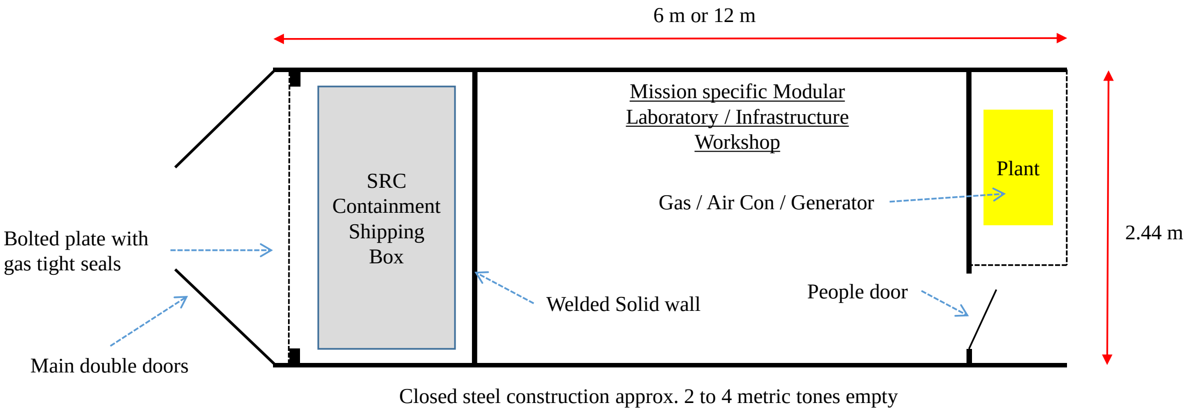

Figure 5-3 Proposed ISO Container

As an example, the image below shows an example of a specially modified Iso Container that has been specified by the University of Leicester for deployment in Polar Regions. In terms of size (6 m), it is not dissimilar to he proposed solution presented here and shows the key components to be modified in preparation for a sample recovery. Namely, modified container access, correct customs labelling and a lined interior. (In the example shown here the interior is wood lined, but could equally be stainless steel or other depending on design requirements).

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Figure 5-4 University of Leicester Special ISO Container

5.2.1 Preparation for Transport

As discussed above, ISO Containers provide a multimodal interface that enables cross platform transportation and port handling. European and US military services, with their respective logistical Corp's, are both expert in the transport of ISO Containers and the operation of multi terrain vehicles that carry such containers. For example, the UK Army, Royal Logistics Corp, operate the Demountable Rack Offload & Pickup System, DROPS, which is able to carry a standard 20' (6 m) container at a total weight of 15,000kg.

NB: this transport system is now being replaced with the MAN SX family of high mobility off road tactical trucks manufactured by Rheinmetall MAN Military Vehicles that also accommodate 6 m ISO Containers.

The delivery of specialist facilities, based on the standard multimodal ISO Container, could be implemented by either off road tactical trucks or helicopter and then collected when loaded. It is likely that sea shipping will not be used in the movement of precious planetary samples (because the container cannot be accompanied on the ship) and a minimum of two driving staff will be required to accompany the ISO Container either by road or air freight for the complete journey. A further advantage of the ISO Container, particularly if military transport assets are used, is its compatibility with several airframes. These include

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the Lockheed Martin C-130, the Boeing C-17 Globemaster and Airbus A400M ATLAS, the latter two operated by the RAF.

Figure 5-5 shows an example of a standard ISO Container inside a Boeing Globemaster III.

Figure 5-5 ISO Container inside a C-17A

5.2.2 Logistical Components of Recovery

Common components of any recovery are:

- A safe area for a landing ellipse.
- Basic infrastructure to the area (eg. port, radar, communications and accommodation)
- Traversable terrain

The diagram below shows how such a range might be configured with a base of operations up-range of the landing ellipse and an area, lateral to the mid-range, where a forward operations base, FOB, may be deployed in readiness for recovery. Preparations for any planetary return should consider early in the

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mission planning the basic infrastructure necessary for recovery and the entry / exit ports to enable logistical transport within the legal confines of the country operating the test range and permits to transport through neighbouring countries (consideration of ITAR and the movement of potentially hazardous material).

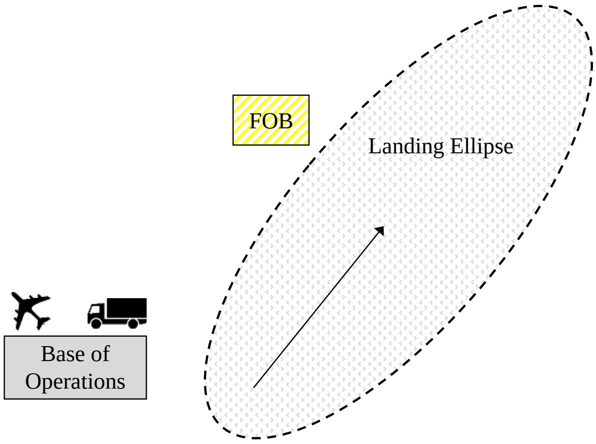

Figure 5-6 Basic Range

An estimated model timeline for recovery operations is given in table 5-2, to illustrate how a recovery might be executed. The detail of such a recovery is beyond the scope of this work, but it highlights the key areas (**BOLD Green**) where preparation of recovery should be considered.

Times are estimated and may vary depending on the actual landing site selected.

Est Time line	Activity	Notes
T - 50 days	Transport ISO by road	The **specialist ISO Container** is **transported by road** / air (**2 drivers**).
T - 10 days	Deliver ISO	The ISO Container is **delivered** by road to the range **operating base.**
T - 5 days	Load ISO	**Load** the ISO Container on to the **multi terrain vehicle** or prepare for **helicopter** lift to the **forward operating area**.
T - 5 days	Move ISO	Move the ISO Container on to the multi terrain vehicle or fly by helicopter to the forward operating area with **necessary staff** and **prepare for recovery** (test **infrastructure** and monitor **weather** reports).
T - 0 days	Landing	**Track** landing with **radar, radio beacon and air assets**
T + 0 days	Tracking	Deploy immediate **assessment team** (**Land Rover type vehicle**)
T + 1 hour	Recovery Preparation	Move ISO Container on the multi terrain vehicle **to landing site cordon** and off-load Container.
T + 2 hour	Recovery Assessment	**Assess** lander and context.
T + 5 hour	Recovery Isolation 1	**Make safe** any lander components and **recover** to the **Containment shipping box**.
T + 7 hour	Recovery Isolation 2	Recover Containment Shipping Box to the ISO Container, secure to **anti vibration** fixture and **seal** compartment.
T + 10 hour	Recovery Context	**Collect local context samples** (soil, flora, air samples etc) and **verify containment.**
T + 24 hour	Recovery Move	Load ISP Container on to multi terrain vehicle or prepare for helicopter lift to the rear echelon operating base.
T + 1 day plus	Transport	It is assumed that the ISO Container with contents will be **shipped by road or air.**

Table 5-2 Estimated Recovery Timeline, Category V mission.

In terms of preparation related to landing site selection, areas that should be included in mission recovery planning are; management / command, logistical and scientific. Personnel and functions highlighted in this table are proposed in the following section.

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5.2.2.1 Personnel

In any critical operation whether it be military, manned space mission or civilian, a command structure is critical to ensure success and within that structure, responsibility is apportioned to appropriately trained people. Key personnel are likely to be:

Key Personnel	Function
Recovery Manager	Overall responsibility. Must answer directly to the leading space agency
Logistical Manager	Oversee all transport training and communications
Scientific Lead Officer	Oversee recovery and advise on scientific impact. Represents the scientific interests of the mission.
Recovery Officer	Responsible to the Science lead for all recovery operations. Represents the safety interests of the immediate recovery.
Liaison Officer	Interface to Base Commander, local public and press.

Table 5-3 Recovery Key Personnel

The following planogram is used as a first order estimate of the number of staff and staff structure necessary in planning a recovery operation.

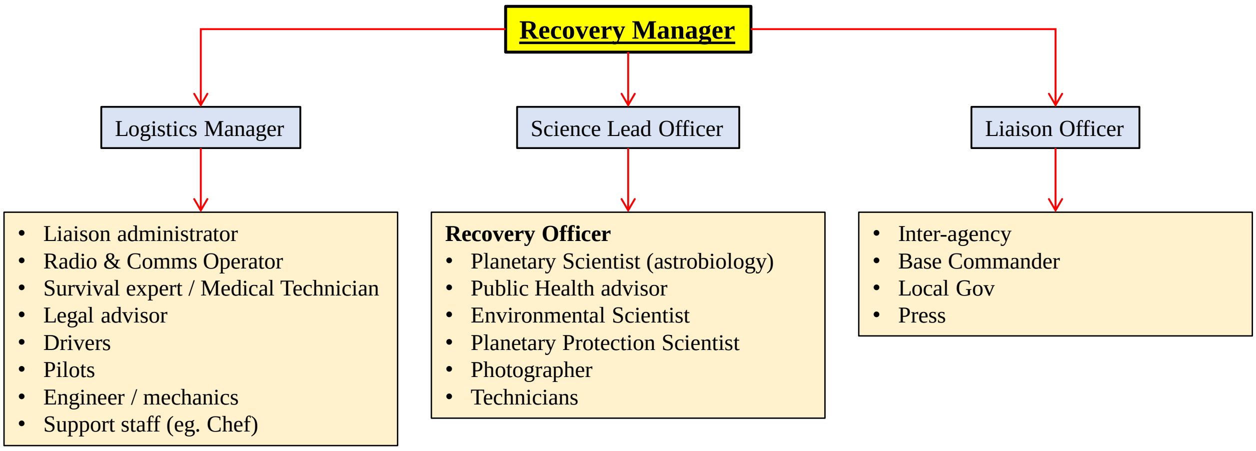

Figure 5-7 Basic Personnel Planogram

6. LANDING SITE CONSIDERATIONS

The following is a list of considerations that should be investigated as part of a detailed landing site selection process.

6.1 Legal Documents

Legal documents include initial applications and all permits that relate to use of the range site, people, hardware, shipping (including special permits to move potentially hazardous material and local samples), ITAR paperwork and declared materials / components, risk assessments and passports / visas. It is also

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advised that during preparation of recovery, key individuals are identified early in the programme and all relevant legal documentation is managed with due consideration of time as some permits may require in excess of a year to complete.

6.1.1 Visas

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

6.1.1.1 US Visas:

The information presented here is *wrt* a British citizen; other nationalities will have specific visa requirements and this must be considered during landing site selection and planning.
Passports must be electronic (ePassport), in date for the duration of the proposed visit and for a post 6 month period. British citizens may travel to the US under the "Visa Waiver Programme". However, some exceptions may result in complicated customs arrangements or denied access to the country. See below for examples of denied access (others may apply):

- A British passport that describes an individual's nationality as something other than 'British Citizen'.
- Have dual nationality with certain countries, including; Iran, Iraq, Sudan or Syria.
- Have travelled to certain countries (since March 2011). For example, Iran, Iraq, Sudan, Libya, Somalia or Yemen
- Arrested for certain crimes even if it didn't result in a criminal conviction.
- Denied access in the past.
- Have previously overstayed under the terms of the waiver programme.
- Carry certain serious communicable illnesses.

Background checks may be implemented before travel.

Further advice should be sought from the US Embassy and with NASA's office of International and Interagency Relations.

6.1.1.2 Australia Visas:

The information presented here is wrt a British citizen; other nationalities will have specific visa requirements and this must be considered during landing site selection. eVisitor visas are available directly from the Department of Immigration & Border Protection and specialist visas should be referred to the Australian High Commission in London.

Because of the nature of the visit, to a Government administered area, it is advisable to seek further advice from Department of Defence WPA Coordination Office.

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6.1.2 Permits (inc. equipment)

Test ranges tend to be military establishments and it is advised that permits are sought in relation to photography and sample collection. Illicit photography could result in transport complications and at worst, the entire sample cache being impounded. Because photography is critical to the science it is advised that a dedicated photographic technician be assigned to the recovery team.

Permits should be discussed with NASA's office of International and Interagency Relations, Australia's WPA Coordination Office and the Esrange Space Center.

6.1.3 Local By-laws

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

6.1.4 Alien access

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

6.1.5 Local Legalities in Relation to containment Loss

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

6.2 Public Opinion

Planetary protection concerns are ultimately driven by expert scientific opinion and a careful quantified assessment of the risks involved. However, there are many examples of how a partially media informed and somewhat vigilant public can have an effect on a decision that goes against the preponderance of expert opinion. So much so, that a project, no matter how valuable to science, may be stopped in its tracks [51, 52]. Brexit is very much a recent example of how public opinion can change direction; in this case, that of an entire country. Public perception of risk and actual risk are very often "worlds" apart and the negative impact of public opinion and mistrust of science should not be underestimated when planning a sample return mission and the country where that sample should be recovered.

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6.3 Local Environment

The local environment has been briefly covered in the suggested ranges presented by this report. However, in addition to the advantages for different sites, described above, the Genesis and Stardust experiences show how safety is now known to be paramount in any recovery. Controlled, unpopulated ground space allowed Stardust to safely return the capsule while meeting range safety requirements [1]. Other environmental conditions should be considered and included in a wider engineering risk assessment of the test range. These may include:

i. Annual climate
ii. Typical weather
iii. Typical surface conditions (snow covered, ice or wet / dry surface)
iv. Prevailing winds and the annual position of the jet streams
v. Average visibility
vi. Local topography
vii. Water basins, lakes, rivers, seasonal water routes
viii. Ground Water
ix. Flood risk
x. Seismic activity
xi. Typical surface features (lose sand, bogs, mud pools, ragged geology, and boulder size distribution)
xii. Subsurface features (caves, sink holes, mines and geological faults)
xiii. Vehicle access (helicopter or multi-terrain truck)
xiv. Air access
xv. Other local activities (weapons testing, waste processing / disposal)
xvi. Flora (grassland, shrubbery or trees)
xvii. Fauna (local wildlife, particularly dangerous animals (bears, snakes, large cats, mosquitos))

6.3.1 Local Hazards

i. Chemical / Toxic waste from legacy testing
ii. Radioactive contamination (low level and may represent a risk to the samples)
iii. Land Mines
iv. Mine Shafts
v. Unexploded ordinance

6.3.2 Inbound / Outbound Freight Ports

Because test ranges are generally military facilities, inbound and outbound air freight is possible. The location of the landing site will have a considerable impact on the logistics of sample movement to a European curation facility. Runway length for UTTR, White Sands, Woomera and Sweden are sufficient for large aircraft like the Globemaster and ATLAS.

6.3.3 Military Ports

The use of military ports is recommended where possible because they are familiar with the safe handling of unusual and / or hazardous items. They also afford greater security.

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6.3.4 Local Security

Because test ranges are remote and often operated by military establishment the local personnel will have some level of security clearance and background checking. Security tends to fall in to several areas:

- Security and safety of personnel involved in the recovery.
- Security and safety of the recovered samples immediately following recovery.
- Security and safety of the recovered samples during transport to the curation facility.

Sample return, particularly from Mars, will generate huge public and media interest and this should be a consideration in the selection of a landing site. A site that is remote and difficult to travel to will discourage many (probably most) interested onlookers from traveling there. Also, restricted test range access, guarded by military personnel with firearms, offers a further layer of security to protect both the recovery team and the public, in the event that a sample container is compromised.

The security of samples during transport is covered by WP 6.3.

6.3.5 Local Facilities

There is a balance between total project sufficiency and utilising local facilities. This is important for both training events in the area and the actual recovery. Both of which may require some personnel to be at the site for several weeks. Because of the remote nature of such sites the very basic commodities for human survival must be considered; food, fresh water and accommodation. For this reason, it is likely that a landing site will be an established range facility with modern accommodation (hotel type with all modern amenities) and medical capabilities. However, a forward operation base may require group accommodation of five or more people and provisions for survival in a remote desert, arid, hot or cold climate will need to be assessed.

6.4 Political Spectrum

Political alliances and their impact on inter-agency relations in multiple countries should be a forward looking factor in preparations for a lander recovery. Return mission planning is typically ten to twenty years from beginning to actual samples back on Earth and recent years has shown the rapid pace of change in the political spectrum across Europe, Russia, China and the UK. The impact of such changes might have a bearing on the free movement of expert people during the project and crucially at the point of lander recovery.

Additionally, the traditional models of space projects and agency collaboration has seen equally rapid change with countries like India very successfully entering the "Mars Club" and China pursuing its sample return ambitions, currently with Lunar exploration, but with firm intentions to go to Mars [15]. Given the cost of planetary exploration it seems likely that NASA will begin to work more closely with China and European ambitions for sample return may need to consider a landing site in China. Similarly, we are seeing commercial exploration of space becoming a daily facet of the space industry and recent activity by SpaceX to develop their "Red Dragon" programme to facilitate a Mars Sample Return mission. Although SpaceX is American, their commercial interests are financial, and this will reflect their choice of a sample recovery.

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6.5 Training Requirements for Recovery

Training is paramount to the success of any complex endeavour and the recovery of samples from a multi-billion euro mission is no exception. Launch campaigns are practiced and drilled repeatedly until there is collective confidence in the ability of the team to safely execute the actual launch. Recovery of a restricted sample may not be as complex as a launch; however, it is not a routine unrestricted sample recovery either. For this reason, and because of the potential risk of sample exposure, training must engender the same level of collective confidence in the team that will effect recovery. Procedures reduces the risk of things going wrong, but training and practice identifies the unknown areas that cause failure.

A key recommendation from previous return missions is that recovery operations and procedures must be contained within a single document (book) so that everyone involved has the same information in a single source. Furthermore, this document must contain all relevant and pertinent information such that it is not necessary to consult other documents during recovery operations.

Another key criticism of the Genesis failure was a lack of command and coordination on the ground with a lack of training that left individuals in the recovery team unsure of contingency procedures (what to do in an emergency).

Figure 5-7, Basic Personnel Planogram, proposes a basic personnel and role structure with departmental heads (Logistics Manager, Science Lead Officer, Recovery Officer and Liaison Officer) overseen by a single 'Recovery Manager 'appointed by and directly responsible to the space agency. The numbers of staff will be dictated by the size of the mission where a complex restricted MSR will require more time and staff to effect recovery. Training falls in to 3 basic categories.

I. Individual training
II. Collective / sub-group training
III. All-Up Collective training

6.5.1 Individual training

Individual training will be specific to a particular trade or speciality. For example, the radio and comms operator will train on the equipment used to track the capsule beacon or the mechanic on how to use and fix specialist lifting frames.

Training facilities will include laboratories/workshops and at analogue training sites around Europe.

6.5.2 Collective / sub-group training

It is inevitable that there will be some training cross-over and key/critical roles must include shadow redundancy personnel. Because of the systematic approach to recovery, teams will train in hand over procedures. For example, a planetary protection scientist may perform a final check on the integrity of sample seals and then hand over to the mechanical engineer who will orchestrate lifting the capsule into the Shipping Containment Box (see fig 5.3 and table 5.2). Training will necessarily include hand over interfaces and practice will occur at both laboratories/workshops and analogue training sites around Europe.

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6.5.3 All-Up Collective training

Preparation for recovery operations must include multiple mandatory training, both at analogue sites and the actual landing site selected. It is essential that communication works from end to end in the time line for both nominal and non-nominal scenarios practiced. In particular, MSR represents a considerable investment in science, unmatched by previous sample return missions, and it is therefore crucial that any failure is not the result of bad training.

6.5.4 Training Recommendations

A. Implement Key Personnel early in the mission
B. Include independent expert assessment at all stages of the training
C. Key and critical roles should have shadow redundancy
D. Document and video All-up Collective training
E. Identify analogue sites for outdoor training
F. Train for both day and night recovery
G. Include balloon drop test training

7. RISKS

A detailed risk analysis is out of the scope of this study and the detailed technical data for the MSR mission is not yet available so the following presents a discussion of the areas of greatest risk.

7.1 Identification of Risk

The discussion of WP 6.1 has presented a number of factors that must be considered in planning a future, European led, sample return mission. In terms of risks we have identified environmental, geological and industrial factors that may be used in assessment of the landing site recovery, particularly for a restricted mission. The consequence of sample release at the recovery site is difficult to quantify; however, it is possible to consider a worst case scenario, where a pathogen renders an area unusable for a period of time. Data is available to quantify the impact of this outcome and the example used to illustrate this is Woomera, Australia.

According to the iMINCO mining group the extraction of copper and gold, already underway, and other ore in the prohibited area of Woomera is worth in excess of $35 billion to the economy over the next ten years [53, 54]. See also: http://iminco.net/1-trillion-mining-future-at-woomera-site/
Additionally the WRC administers an extensive portfolio of civilian and defence test facilities worth hundreds of millions of dollars with companies like BAE systems who are currently using the range to test the new £200 million Taranis UAV system.
See: http://www.defensenews.com/story/defense/air-space/strike/2015/06/01/britain-conduct-further-flight-tests-taranis-ucav-mod-bae-fcas-sdsr/28305861/

The operation of test rang facilities is costly and defence business in particular, has a substantial dollar value attached to it. In preparation of a recovery site, for a restricted sample return mission, the business case will be a major factor imposed on the mission overhead.

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Space engineering is always plagued with issues of cost and mass, which leads to accepted risk in the design of a mission. For example, MSR will be a multi-billion dollar programme with several tons of hardware delivered to Mars and only a small fraction returned to the Earth. Given the risk associated with an unknown and potentially pathogenic restricted sample, should it not be recommended that greater mass resources be afforded the Earth Return Capsule and if technical risk in the hardware is accepted that this be assigned earlier in the mission chain. Furthermore, in terms of systems engineering and predicting risk with probability analysis there is a difference between manned and unmanned missions and the level of accepted risk. Although CAT V missions, for the foreseeable future, are not manned, and therefore represent no risk of loss of human crew life, there is a potential risk to human life if a return sample is exposed to the environment as a result of failure in the entry descent and landing. For this reason should the design of a restricted CAT V Earth return capsule not be afforded the same level of systems engineering risk mitigation and safety margins as components designed for human space flight?

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8. CONCLUSION

There are a number of sites around the world that could be used for a sample return lander recovery and to cover them all in detail is far beyond the scope of this work. However, those selected in this discussion have shed light on the preparations necessary when considering a return mission, from a European perspective. With MSR in mind, the community often focusses on mission architecture or the technology for the hardware design and the difficulty in landing on Mars. It seems that there is very little recorded literature regarding the complexities of recovery, particularly for a CAT V restricted mission. With the exception of the Apollo programme, sample return has been unrestricted, with the recovery of samples exploiting active lander technology. This has proven difficult and the NASA investigation into the crash landing of Genesis, highlighted a lack of resources and failures in the systems engineering as the major contributing cause. Mars Sample Return and others like Europa will be a future goal of ESA, but will be considerably more costly (perhaps by a factor of 10) and because of the planetary protection constraints in sample containment and concern with regard to backward contamination, the technical challenges will be far greater. This has a direct and considerable impact on the selection of a landing recovery site because of the risk associated with sample release into the local ecosystem. The potential risk is low, but the potential detrimental impact on the local environment, public health and commercial interests are considerable, in a worst case scenario.

WP 6.1 has considered six potential terrestrial landing sites in relation to CAT V return missions and for restricted samples, proposes new technology to be considered both in terms of the Earth return vehicle and the development of logistical technology from the recovery site.

Figure 1-1 shows how consideration of the mission architecture and engineering has a bearing on the preparation and selection of an appropriate landing site. Furthermore, it provides a baseline from which recovery and initial inspection (WP 6.2) can be detailed and the design of a specialist transport container (WP 6.3) proposed; all within the confines of planetary protection (WP 6.4) protecting the scientific value of returned samples.

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9. ASSUMPTIONS AND REQUIREMENTS

9.1 Assumptions

In order to move to WP6, certain assumptions need to be made about the requirements of the sample capsule and landing, including:

9.1.1 Landing Site Requirements

The following EuroCares requirements are assumed for WP 6.1.

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 facility 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 assume the sample seal is not compromised
	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.
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

ID	Requirement Text
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 with a non-nominal landing, the landing area shall be decontaminated by methods agreed with public health experts.
	Comment: Restricted missions with a non-nominal landing will have the landing area decontaminated to reduce the risk of contamination by extra-terrestrial material.
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 isolation from the Earth 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 purged 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 might need input from the Planetary Protection officers around the world.
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.

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ID	Requirement Text
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 sterilised or it has been determined that there is no biohazard risk.
FI-30	The recovery infrastructure shall contain any restricted return samples to a biosafety level defined by Biohazard experts.
	Comment: Biosafety experts will define the appropriate level of biosafety based on the category of mission and the mission status.
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 a 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 Earth contamination of the samples
FC-20	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 Sample Receiving facility.
FC-30	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.

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ID	Requirement Text
	Comment: This will enable thorough testing of equipment and training before the samples return to Earth.
FO-20	The recovery infrastructure for an unrestricted mission shall have an operational lifetime of TBD years after the samples have been returned to Earth.
	Comment: The recovery infrastructure may be used for other scientific analysis and varioussample return missions.
FO-30	The recovery infrastructure for a restricted mission shall have an operational lifetime of TBD years after the samples have been returned to Earth.
	Comment: The recovery infrastructure may be single use if there is a chance of contamination with a non-nominal mission or if life is found.
FO-40	For restricted return, 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.
FO-50	The recovery infrastructure shall develop and implement procedures for the security of the facility and the samples.
	Comment: The recovery infrastructure will be under a mission-appropriate level of security with restricted access.

Table 9-1 EuroCares WP Requirements

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